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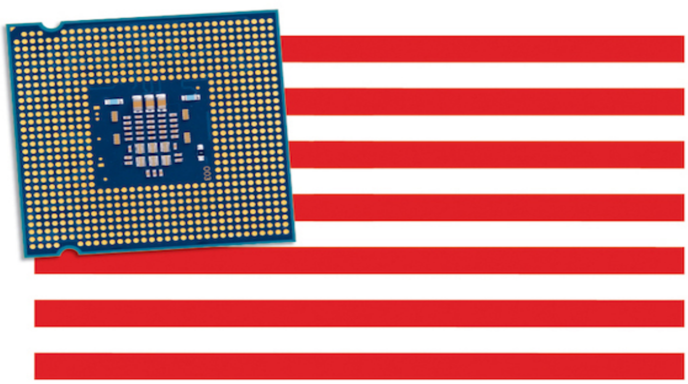
—PAUL KENNEDY, bestselling author of *The Rise and Fall of the Great Powers*

CHIP WAR



THE FIGHT FOR THE WORLD'S MOST CRITICAL TECHNOLOGY

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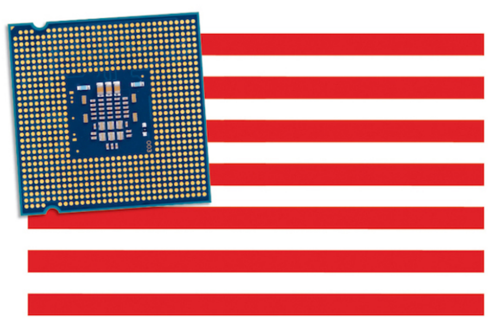

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More Praise for CHIP WAR

"One of the most important books I've read in years—engrossing, beautifully written. Miller shows that, for all its manifest flaws and failures, the American capitalist system has repeatedly outperformed other systems and in the process has done much to bolster the security of democracy."

—Robert Kagan, senior fellow, The Brookings Institution, columnist for *The Washington Post* , and author of *The Jungle Grows Back: America and Our Imperiled World*

"If you care about technology, or America's future prosperity, or its continuing security, this is a book you have to read."

"這是我數年來閱讀過最重要的書之一——引人入勝，寫得美妙動人。米勒表明，盡管美國資本主義體制存在著明顯的缺陷和失敗，但它已在多次表現中超越其他體制，並在此過程中為民主鞏固了安全基礎。" —— 羅伯特•卡根，布魯金斯學會高級研究員，華盛頓郵報專欄作家，著有《叢林復興：美國與我們身陷危機的世界》 "如果你關心技術、美國未來的繁榮，或者它持續的安全，這是一本必讀之書。"

—Lawrence H. Summers, 71st U.S. Secretary of the Treasury and Charles W. Eliot University Professor at Harvard University

"Outstanding. Miller's history of the chip covers all angles: technological, financial, and especially political…. The go-to reference on one of the most important industries today."

—Dan Wang, technology analyst at Gavekal Dragonomics

“The battle for supremacy in semiconductors is one of the most important stories in geopolitics, national security, and economic prosperity. But it’s also been one of the least well understood. Thankfully, we now have *Chip War* to give us a clear view and sharp read on this essential subject.”

「極好的。米勒有關晶片的歷史涵蓋了所有角度：技術、財政，尤其是政治……成為當今最重要產業的必參參考。」 ——勞倫斯·H·莎莫斯（Lawrence H. Summers），第71任美國財政部長，哈佛大學查爾斯·W·艾略特大學教授 「半導體霸權的鬥爭是地緣政治、國家安全和經濟繁榮中最重要的故事之一。但它也是最不被理解的故事之一。幸好，現在有了《芯片戰爭》，讓我們對這個重要的主題有了清晰的看法和深入的了解。」 ——王丹，嘉實龍洲經濟研究有限公司科技分析師

—Andrew McAfee, coauthor of *The Second Machine Age* and author of *The Geek Way* and *More from Less*

—安德魯·麥卡菲(Andrew McAfee)，《第二次機器時代》的共同作者，以及《The Geek Way》和《More from Less》的作者。

CHIP WAR

THE FIGHT FOR THE WORLD'S MOST CRITICAL TECHNOLOGY

CHRIS MILLER

SCRIBNER
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To Liya

給Liya

Cast of Characters

Morris Chang : Founder of Taiwan Semiconductor Manufacturing Company (TSMC), the world’s most important chipmaker; previously, a senior executive at Texas Instruments.

Andy Grove : Former president and CEO of Intel during the 1980s and 1990s; notorious for his aggressive style and success in reviving Intel; author of *Only the Paranoid Survive* .

Pat Haggerty : Chairman of Texas Instruments; led the company as it specialized in building microelectronics, including for the U.S. military.

Jack Kilby : Co-inventor of the integrated circuit, in 1958; longtime Texas Instruments employee; winner of the Nobel Prize.

張忠謀：台灣積體電路製造公司（TSMC）創辦人，全球最重要的晶片製造商；曾是得克薩斯儀器公司的高級執行官。 安迪·格羅夫：在80年代和90年代擔任英特爾總裁和CEO；以他的積極風格和振興英特爾的成功而聞名；著有《只有偏執狂才能生存》一書。 派特·哈格蒂：德州儀器公司主席；帶領該公司專注於建立微電子技術，包括為美國軍方開發技術。 傑克·基爾比：集成電路的共同發明人，於1958年；長期在德州儀器公司工作；諾貝爾獎得主。

Jay Lathrop : Co-inventor of photolithography, the process of patterning transistors using specialized chemicals and light; formerly of Texas Instruments.

Carver Mead : Professor at the California Institute of Technology (Caltech); advisor to Fairchild Semiconductor and Intel; visionary thinker about the future of technology.

Gordon Moore : Cofounder of Fairchild Semiconductor and Intel; creator in 1965 of “Moore’s Law,” which predicted that the computing power on each chip would double every couple of years.

Jay Lathrop：光刻技術共同發明人，利用特殊化學物質和光線來定型晶體管；曾任職於德州儀器公司。 Carver Mead：加州理工學院教授；Fairchild Semiconductor和Intel的顧問；對未來技術的發展有著富有遠見的思考者。 Gordon Moore：Fairchild Semiconductor和Intel的共同創始人；1965年創造了“摩爾定律”，預測每兩年晶片的計算能力將翻倍。

Akio Morita : Cofounder of Sony; coauthor of *The Japan That Can Say No* ; represented Japanese business on the world stage during the 1970s and 1980s.

Robert Noyce : Cofounder of Fairchild Semiconductor and Intel; co-inventor of the integrated circuit in 1959; known as the “Mayor of Silicon Valley”; first leader of Sematech.

William Perry : Pentagon official from 1977–1981 and later Secretary of Defense from 1994 to 1997 who advocated using chips to produce precision-strike weapons.

Jerry Sanders : Founder and CEO of AMD; Silicon Valley’s most flamboyant salesman; an aggressive critic of what he saw as unfair Japanese trade practices in the 1980s.

盛田昭夫：索尼的联合创始人，合著了《可以说不的日本》，在20世纪70年代和80年代代表日本企业走上世界舞台。 罗伯特·诺伊斯：费尔柴尔德半导体和英特尔的联合创始人，1959年集成电路的共同发明人，被称为“硅谷市长”，Sematech的第一位负责人。 威廉·佩里：1977年至1981年间的五角大楼官员，后来成为1994年至1997年的国防部长，主张使用芯片制造精确打击武器。 杰里·桑德斯：AMD的创始人和CEO，硅谷最张扬的推销员，对他所认为的不公平的日本贸易行为进行了积极的批评。

Charlie Sporck : Drove the offshoring of chip assembly while leading manufacturing operations at Fairchild Semiconductor; later CEO of National Semiconductor.

Ren Zhengfei : Founder of Huawei, China’s telecom and chip-design giant; his daughter Meng Wanzhou was arrested in Canada in 2018 on charges of violating U.S. law and trying to evade U.S. sanctions.

Charlie Sporck：在领导費查爾德半導體的製造業務時推動了芯片組裝的海外外包；后来成為國家半導體的CEO。 任正非：華為創始人，中國的電信和芯片設計巨頭；他的女兒孟晚舟因被指違反美國法律和試圖逃避美國制裁，在2018年被加拿大逮捕。

Glossary

Arm :
a UK company that licenses to chip designers use of an instruction set architecture—a set of basic rules governing how a given chip operates. The Arm architecture is dominant in mobile devices and is slowly winning market share in PCs and data centers.

Chip (also "integrated circuit" or “semiconductor”) :
a small piece of semiconducting material, usually silicon, with millions or billions of microscopic transistors carved into it.

CPU :
central processing unit; a type of “general-purpose” chip that is the workhorse of computing in PCs, phones, and data centers.

DRAM :
dynamic random access memory; one of two main types of memory chip, which is used to store data temporarily.

EDA :
electronic design automation; specialized software used to design how millions or billions of transistors will be arrayed on a chip and to simulate their operation.

FinFET :
a new 3D transistor structure first implemented in the early 2010s to better control transistor operation as transistors’ size shrank to nanometric-scale.

GPU :
graphics processing unit; a chip that is capable of parallel processing, making it useful for graphics and for artificial intelligence applications.

Logic chip :
a chip that processes data.

Memory chip :
a chip that remembers data.

NAND :
also called “flash,” the second major type of memory chip, used for longer-term data storage.

Photolithography :

also known as “lithography”; the process of shining light or ultraviolet light through patterned masks: the light then interacts with photoresist chemicals to carve patterns on silicon wafers.

RISC-V :

an open-source architecture growing in popularity because it is free to use, unlike Arm and x86. The development of RISC-V was partially funded by the U.S. government but now is popular in China because it is not subject to U.S. export controls.

Silicon wafer :

a circular piece of ultra-pure silicon, usually eight or twelve inches in diameter, out of which chips are carved.

Transistor :

a tiny electric “switch” that turns on (creating a 1) or off (0), producing the 1s and 0s that undergird all digital computing.

x86 :

an instruction set architecture that is dominant in PCs and data centers. Intel and AMD are the two main firms producing such chips.

Introduction

T he destroyer USS *Mustin* slipped into the northern end of the Taiwan Strait on August 18, 2020, its five-inch gun pointed southward as it began a solo mission to sail through the Strait and reaffirm that these international waters were *not* controlled by China—at least not yet. A stiff southwestern breeze whipped across the deck as it steamed south. High clouds cast shadows on the water that seemed to stretch all the way to the great port cities of Fuzhou, Xiamen, Hong Kong, and the other harbors that dot the South China coast. To the east, the island of Taiwan rose in the distance, a broad, densely settled coastal plain giving way to tall peaks hidden in clouds. Aboard ship, a sailor wearing a navy baseball cap and a surgical mask lifted his binoculars and scanned the horizon. The waters were filled with commercial freighters shipping goods from Asia's factories to consumers around the world.

2020年8月18日，驱逐舰“穆斯廷”号滑入台湾海峡北端，其5英寸炮口指向南方，开始独自一人的任务，穿过海峡并重新确认这片国际水域还未受到中国的控制-至少现在还没有。一股强劲的西南风在船甲板上呼啸而过。高高的云朵在水面上投下阴影，似乎一直延伸到福州、厦门、香港和其他点缀在中国南海岸线上的港口。向东，台湾岛在远处升起，一片广阔而密集的沿海平原让位于云雾中隐藏的高峰。在船上，一名戴着海军棒球帽和口罩的水兵举起他的望远镜扫视地平线。水域中满是商业货船运送着来自亚洲工厂的商品到世界各地的消费者。

On board the USS *Mustin* , a row of sailors sat in a dark room in front of an array of brightly colored screens on which were displayed data from planes, drones, ships, and satellites tracking movement across the Indo-Pacific. Atop the *Mustin* 's bridge, a radar array fed into the ship's computers. On deck ninety-six launch cells stood ready, each capable of firing missiles that could precisely strike planes, ships, or submarines dozens or even hundreds of miles away. During the crises of the Cold War, the U.S. military had used threats of brute nuclear force to defend Taiwan. Today, it relies on microelectronics and precision strikes.

在美國Mustin號驅逐艦上，一排水手坐在一個黑暗的房間裡，面前是一排亮麗的屏幕，顯示著來自飛機、無人機、船隻和衛星的數據，追蹤著整個印度-太平洋區域的移動情況。在Mustin號的船橋上，一個雷達系統輸入到船上的電腦中。甲板上有九十六個發射槽，每個槽都能發射導彈，可以精準地打擊數十甚至數百英里以外的飛機、船隻或潛艇。在冷戰的危機中，美國軍方曾威脅使用核武力保護台灣。今天，它們依賴微電子技術和精確打擊。

As the USS *Mustin* sailed through the Strait, bristling with computerized weaponry, the People's Liberation Army announced a retaliatory series of live-fire exercises around Taiwan, practicing what one Beijing-controlled newspaper called a " reunification-by-force operation." But on this particular day, China's leaders worried less about the U.S. Navy and more about an obscure U.S. Commerce Department regulation called the Entity List, which limits the transfer of American technology abroad. Previously, the Entity List had primarily been used to prevent sales of military systems like missile parts or nuclear materials. Now, though, the U.S. government was dramatically tightening the rules governing computer chips, which had become ubiquitous in both military systems and consumer goods.

當美國海軍航艦「穆斯汀號」駛經洛杉磯岬海峽時，滿載電腦化武器，解放軍宣布在台灣周圍進行了一系列報復性實彈演習，練習了一個由北京控制的報紙所稱的「以武力收復台灣」。然而，在這一天裡，中國的領導人更擔心一項名為「實體清單」的美國商務部規定，限制美國技術在海外轉移。之前，實體清單主要被用於防止出售像是導彈部件或核材料這樣的軍事系統。現在，美國政府正大幅收緊對電腦芯片的規定，這些產品已經成為軍事系統和消費品的無所不在的元件。

The target was Huawei, China's tech giant, which sells smartphones, telecom equipment, cloud computing services, and other advanced technologies. The U.S. feared that Huawei's products were now priced so attractively, partly owing to Chinese government subsidies, that they'd shortly form the backbone of next-generation telecom networks. America's dominance of the world's tech infrastructure would be undermined. China's geopolitical clout would grow. To counter this threat, the U.S. barred Huawei from buying advanced computer chips made with U.S. technology.

目標是中國科技巨頭華為，該公司銷售智能手機、電信設備、雲計算服務和其他先進技術。美國擔心，由於中國政府的補貼，華為的產品現在具有非常高的價值，很快就會成為下一代電信網絡的支柱。這將破壞美國在全球科技基礎設施中的主導地位，增強中國的地緣政治影響力。為了應對這一威脅，美國禁止華為購買使用美國技術製造的先進電腦芯片。

Soon, the company’s global expansion ground to a halt. Entire product lines became impossible to produce. Revenue slumped. A corporate giant faced technological asphyxiation. Huawei discovered that, like all other Chinese companies, it was fatally dependent on foreigners to make the chips upon which all modern electronics depend.

The United States *still* has a stranglehold on the silicon chips that gave Silicon Valley its name, though its position has weakened dangerously. China now spends more money each year importing chips than it spends on oil. These semiconductors are plugged into all manner of devices, from smartphones to refrigerators, that China consumes at home or exports worldwide. Armchair strategists theorize about China’s “Malacca Dilemma”—a reference to the main shipping channel between the Pacific and Indian Oceans—and the country’s ability to access supplies of oil and other commodities amid a crisis. Beijing, however, is more worried about a blockade measured in bytes rather than barrels. China is devoting its best minds and billions of dollars to developing its own semiconductor technology in a bid to free itself from America’s chip choke.

公司的全球擴張很快就停滯不前。整條產品線變得無法生產，收入暴跌。一個企業巨頭面臨著技術窒息的局面。華為發現，像所有其他中國公司一樣，它在所有現代電子產品依賴的芯片上是致命依賴外國人。 美國仍然掌握著賦予硅谷其名的矽晶片的控制權，但其地位已經危險的削弱。中國現在每年在進口晶片上的支出比在石油上的支出還要高。這些半導體被插入了各種設備中，從智能手機到冰箱，這些設備在中國本土消費或出口全球。沙發戰略家們理論化地想象著中國的“馬六甲困境”，這是指太平洋和印度洋之間的主要航道，以及該國在危機中獲取石油和其他商品供應的能力。然而，北京更擔心的是以位元組計量的封鎖。中國正在投入其最優秀的人才和數十億美元的資金，以發展自己的半導體技術，以期擺脫美國的晶片壓制。

If Beijing succeeds, it will remake the global economy and reset the balance of military power. World War II was decided by steel and aluminum, and followed shortly thereafter by the Cold War, which was defined by atomic weapons. The rivalry between the United States and China may well be determined by computing power. Strategists in Beijing and Washington now realize that all advanced tech—from machine learning to missile systems, from automated vehicles to armed drones—requires cutting-edge chips, known more formally as semiconductors or integrated circuits. A tiny number of companies control their production.

如果北京成功了，它将改变全球经济格局和重新平衡军事力量。第二次世界大战的胜负由钢铁和铝决定，随后的冷战则由原子武器定义。美国和中国之间的竞争可能很可能取决于计算能力。北京和华盛顿的战略家现在意识到，所有高级技术——从机器学习到导弹系统，从自动化车辆到武装无人机——都需要尖端芯片，更正式地称为半导体或集成电路。少数公司控制着它们的生产。

We rarely think about chips, yet they've created the modern world. The fate of nations has turned on their ability to harness computing power. Globalization as we know it wouldn't exist without the trade in semiconductors and the electronic products they make possible. America's military primacy stems largely from its ability to apply chips to military uses. Asia's tremendous rise over the past half century has been built on a foundation of silicon as its growing economies have come to specialize in fabricating chips and assembling the computers and smartphones that these integrated circuits make possible.

我们很少想到芯片，但它们创造了现代世界。国家的命运取决于他们利用计算能力的能力。如今的全球化离不开半导体贸易和它们可制造的电子产品。美国军事主导地位主要源于其将芯片应用于军事用途的能力。亚洲在过去半个世纪里的巨大崛起是建立在硅基础上的，随着其日益增长的经济体特化于制造芯片并组装这些集成电路所能实现的计算机和智能手机。

At the core of computing is the need for many millions of 1s and 0s. The entire digital universe consists of these two numbers. Every button on your iPhone, every email, photograph, and YouTube video—all of these are coded, ultimately, in vast strings of 1s and 0s. But these numbers don't actually exist. They're expressions of electrical currents, which are either on (1) or off (0). A chip is a grid of millions or billions of *transistors* , tiny electrical switches that flip on and off to process these digits, to remember them, and to convert real world sensations like images, sound, and radio waves into millions and millions of 1s and 0s.

計算機核心需要的是數以百萬計的1和0。整個數字宇宙由這兩個數字組成。你iPhone上的每個按鈕、每個電子郵件、每張照片和YouTube視頻最終都是以大量的1和0代碼編寫。但是這些數字並不存在，它們是由電流表達出來的，電流要麼開（1），要麼關（0）。晶片是由數百萬或數十億個晶體管組成的網格，這些微小的電子開關可以翻轉，以處理這些數字，記憶它們，並將圖像、聲音和無線電波等真實世界的感覺轉換為數百萬甚至數以百萬計的1和0。

As the USS *Mustin* sailed southward, factories and assembly facilities on both sides of the Strait were churning out components for the iPhone 12, which was only two months away from its October 2020 launch. Around a quarter of the chip industry's revenue comes from phones; much of the price of a new phone pays for the semiconductors inside. For the past decade, each generation of iPhone has been powered by one of the world's most advanced processor chips. In total, it takes over a dozen semiconductors to make a smartphone work, with different chips managing the battery, Bluetooth, Wi-Fi, cellular network connections, audio, the camera, and more.

當 USS Mustin 向南航行時，海峽雙方的工廠和裝配設施正在生產 iPhone 12 的組件，該產品在 2020 年 10 月才推出。近四分之一的晶片行業收入來自手機，新手機的價格大部分用於支付其內部的半導體。在過去的十年中，每一代 iPhone 都由世界上最先進的處理器晶片之一帶動。總體而言，製作智能手機需要超過一打半導體，不同芯片可以管理電池、藍牙、Wi-Fi、蜂窩網絡連接、音頻、攝像頭等。

Apple makes precisely *none* of these chips. It buys most off-the-shelf: memory chips from Japan's Kioxia, radio frequency chips from California's Skyworks, audio chips from Cirrus Logic, based in Austin, Texas. Apple designs in-house the ultra-complex processors that run an iPhone's operating system. But the Cupertino, California, colossus can't manufacture these chips. Nor can any company in the United States, Europe, Japan, or China. Today, Apple's most advanced processors—which are arguably the world's most advanced semiconductors—can only be produced by a single company in a single building, the most expensive factory in human history, which on the morning of August 18, 2020, was only a couple dozen miles off the USS *Mustin* 's starboard bow.

蘋果公司完全沒有製造這些芯片。它們大部分都是從現成的產品中購買：從日本的Kioxia購買內存芯片，從加利福尼亞州的Skyworks購買射頻芯片，從德克薩斯州奧斯汀的Cirrus Logic公司購買音頻芯片。蘋果公司設計內部運行iPhone操作系統的超複雜處理器。但是，這家總部位於加利福尼亞州庫比蒂諾的巨頭無法製造這些芯片。美國、歐洲、日本或中國的任何公司都無法生產蘋果最先進的處理器，這些處理器可說是世界上最先進的半導體，只有一家位於一座最昂貴的工廠中的公司能夠生產，這家工廠在2020年8月18日上午離美國尤斯汀號舷側只有幾十英里遠。

Fabricating and miniaturizing semiconductors has been the greatest engineering challenge of our time. Today, no firm fabricates chips with more precision than the Taiwan Semiconductor Manufacturing Company, better known as TSMC. In 2020, as the world lurched between lockdowns driven by a virus whose diameter measured around one hundred nanometers—billionths of a meter—TSMC's most advanced facility, Fab 18, was carving microscopic mazes of tiny transistors, etching shapes smaller than half the size of a coronavirus, a hundredth the size of a mitochondria. TSMC replicated this process at a scale previously unparalleled in human history. Apple sold over 100 million iPhone 12s, each powered by an A14 processor chip with 11.8 billion tiny transistors carved into its silicon. In a matter of months, in other words, for just one of the dozen chips in an iPhone, TSMC's Fab 18 fabricated well over 1 quintillion transistors—that is, a number with eighteen zeros behind it. Last year, the chip industry produced more transistors than the combined quantity of all goods produced by all other companies, in all other industries, in all human history. Nothing else comes close.

制造和微型化半导体一直是我们时代最伟大的工程挑战。今天，没有一家公司比台湾半导体制造公司（也称为TSMC）更精确地制造芯

片。在2020年，当世界在由直径约为一百纳米（亿分之一米）的病毒驱动的封锁中摇摆不定时，TSMC的最先进设施Fab 18正在刻划微小晶体管的迷宫，蚀刻出比冠状病毒小一半、线粒体的百分之一还要小的形状。TSMC以前所未有的规模复制了这个过程。苹果公司销售了超过1亿部配备A14处理器芯片的iPhone 12，其硅中雕刻了118亿个微小的晶体管。换句话说，在几个月的时间里，单个iPhone中十几个芯片中的一个，TSMC的Fab 18制造了超过1千万亿个晶体管，即一个有18个零的数字。去年，芯片行业生产的晶体管数量超过了所有其他公司在所有其他行业中生产的所有货物的总量，在人类历史上没有任何其他东西能够接近这个数字。

It was only sixty years ago that the number of transistors on a cutting-edge chip wasn’t 11.8 billion, but 4. In 1961, south of San Francisco, a small firm called Fairchild Semiconductor announced a new product called the Micrologic, a silicon chip with four transistors embedded in it. Soon the company devised ways to put a dozen transistors on a chip, then a hundred. Fairchild cofounder Gordon Moore noticed in 1965 that the number of components that could be fit on each chip was doubling annually as engineers learned to fabricate ever smaller transistors. This prediction—that the computing power of chips would grow exponentially—came to be called “Moore’s Law” and led Moore to predict the invention of devices that in 1965 seemed impossibly futuristic, like an “electronic wristwatch,” “home computers,” and even “personal portable communications equipment.” Looking forward from 1965, Moore predicted a decade of exponential growth—but this staggering rate of progress has continued for over half a century. In 1970, the second company Moore founded, Intel, unveiled a memory chip that could remember 1,024 pieces of information (“bits”). It cost around $20, roughly two cents per bit. Today, $20 can buy a thumb drive that can remember well over a billion bits.

只有六十年前，尖端芯片上的晶体管数量不是118亿个，而是4个。1961年，在旧金山以南的一个名为费卡半导体的小公司宣布了一款名为Micrologic的新产品，这是一个嵌入了4个晶体管的硅片。很快，该公司想出了方法，在芯片上放置十几个晶体管，然后是一百个。费卡半导体的联合创始人戈登·摩尔注意到，在工程师学会制造越来越小的晶体管后，每个芯片上可以容纳的组件数量每年翻倍。这个预测——芯片的计算能力将呈指数增长——被称为“摩尔定律”，并导致摩尔预

测了在1965年看起来难以想象的设备的发明，比如“电子手表”、“家庭电脑”甚至“个人便携通讯设备”。从1965年开始展望，摩尔预测了十年的指数增长，但这种惊人的进步速度已经延续了半个多世纪。1970年，摩尔创立的第二家公司英特尔推出了一款可以记住1024个信息（“位”）的存储芯片。它的成本约为20美元，每个比特约为两美分。今天，20美元可以购买一个可以记住超过10亿位的闪存盘。

When we think of Silicon Valley today, our minds conjure social networks and software companies rather than the material after which the valley was named. Yet the internet, the cloud, social media, and the entire digital world only exist because engineers have learned to control the most minute movement of electrons as they race across slabs of silicon. “Big tech” wouldn’t exist if the cost of processing and remembering 1s and 0s hadn’t fallen by a billionfold in the past half century.

This incredible ascent is partly thanks to brilliant scientists and Nobel Prize−winning physicists. But not every invention creates a successful startup, and not every startup sparks a new industry that transforms the world. Semiconductors spread across society because companies devised new techniques to manufacture them by the millions, because hard-charging managers relentlessly drove down their cost, and because creative entrepreneurs imagined new ways to use them. The making of Moore’s Law is as much a story of manufacturing experts, supply chain specialists, and marketing managers as it is about physicists or electrical engineers.

當今人們提到硅谷時，腦海中浮現出的是社交網路和軟體公司，而不是這個山谷得名材料。然而，互聯網、雲端、社交媒體和整個數位世界之所以存在，僅是因為工程師學會控制電子在矽晶片上快速移動的微小經驗。過去半世紀，1和0的處理和記憶成本降低了十億倍，因此"大型科技"不存在也是無法想像的。 這種驚人的躍升部分要歸功於優秀的科學家和諾貝爾獎得主。但並不是每個發明都會創建一個成功的新創公司，也不是每個新創公司都能引發一個轉化世界的新產業。半導體在社會中得以普及，是因為公司發明了以百萬計生產它們的新技術，因為積極進取的管理人員不斷降低生產成本，以及創意企業家想像了新的使用方式。摩爾定律的制定與制造專家、供應鏈專家和行銷經理一樣，與物理學家或電氣工程師一樣重要的角色。

The towns to the south of San Francisco—which weren't called Silicon Valley until the 1970s—were the epicenter of this revolution because they combined scientific expertise, manufacturing know-how, and visionary business thinking. California had plenty of engineers trained in aviation or radio industries who'd graduated from Stanford or Berkeley, each of which was flush with defense dollars as the U.S. military sought to solidify its technological advantage. California's culture mattered just as much as any economic structure, however. The people who left America's East Coast, Europe, and Asia to build the chip industry often cited a sense of boundless opportunity in their decision to move to Silicon Valley. For the world's smartest engineers and most creative entrepreneurs, there was simply no more exciting place to be.

三藩市以南城镇被认为是这场变革的中心，直到20世纪70年代才被称为硅谷，因为它们结合了科学专业知识、制造技能和有远见的商业思维。加州有许多在航空或无线电工业受过培训的工程师，他们毕业于斯坦福或伯克利大学，这两所大学都拥有国防资金，因为美国军方寻求巩固其技术优势。然而，加州的文化和其经济结构同样重要。离开美国东海岸、欧洲和亚洲的人们来到硅谷建立芯片行业，往往都是因为他们在这里感受到了无限的机会。对于全球最聪明的工程师和最具创造力的企业家来说，没有比这里更令人兴奋的地方了。

Once the chip industry took shape, it proved impossible to dislodge from Silicon Valley. Today's semiconductor supply chain requires components from many cities and countries, but almost every chip made still has a Silicon Valley connection or is produced with tools designed and built in California. America's vast reserve of scientific expertise, nurtured by government research funding and strengthened by the ability to poach the best scientists from other countries, has provided the core knowledge driving technological advances forward. The country's network of venture capital firms and its stock markets have provided the startup capital new firms need to grow—and have ruthlessly forced out failing companies. Meanwhile, the world's largest consumer market in the U.S. has driven the growth that's funded decades of R&D on new types of chips.

一旦芯片行业成形，就不可能从硅谷撤离。今天的半导体供应链需要来自许多城市和国家的组件，但几乎每个芯片仍然具有硅谷的联系，

或者是用在加利福尼亚州设计和制造的工具生产出来的。美国广泛的科学专业知识储备，得到政府研究资金培养的，同时也因为能够从其他国家招揽最佳科学家而得以加强，为推动技术进步提供了核心知识。该国的风险投资公司网络和其股票市场，为创业企业提供新的成长所需资本，并无情地淘汰失败的公司。与此同时，美国拥有世界上最大的消费市场，促进了资金支持几十年的新型芯片的研发。

Other countries have found it impossible to keep up on their own but have succeeded when they’ve deeply integrated themselves into Silicon Valley’s supply chains. Europe has isolated islands of semiconductor expertise, notably in producing the machine tools needed to make chips and in designing chip architectures. Asian governments, in Taiwan, South Korea, and Japan, have elbowed their way into the chip industry by subsidizing firms, funding training programs, keeping their exchange rates undervalued, and imposing tariffs on imported chips. This strategy has yielded certain capabilities that no other countries can replicate—but they’ve achieved what they have in partnership with Silicon Valley, continuing to rely fundamentally on U.S. tools, software, and customers. Meanwhile, America’s most successful chip firms have built supply chains that stretch across the world, driving down costs and producing the expertise that has made Moore’s Law possible.

其他國家發現自己獨立無法跟上，但是當他們深度整合矽谷供應鏈時，就能成功。歐洲在半導體專業方面有孤立的島嶼，特別是在生產電晶體所需的機床和設計晶片架構方面。亞洲政府（臺灣、韓國和日本）通過補貼企業、資助培訓計劃、保持低估的匯率以及對進口晶片徵收關稅的方式，進入了晶片行業。這種策略帶來了某些其他國家無法複製的能力，但他們實現的成果都是和矽谷的夥伴關係密不可分，仍然基本上依賴美國的工具、軟體和客戶。與此同時，美國最成功的晶片公司已經建立了遍布全球的供應鏈，降低成本，並產生了讓摩爾定律成為可能的專業知識。

Today, thanks to Moore’s Law, semiconductors are embedded in every device that requires computing power—and in the age of the Internet of Things, this means pretty much *every* device. Even hundred-year-old products like automobiles now often include a thousand dollars worth of chips. Most of the world’s GDP is produced with devices that rely on semiconductors. For a product that didn't exist seventy-five years ago, this is an extraordinary ascent.

As the USS *Mustin* steamed southward in August 2020, the world was just beginning to reckon with our reliance on semiconductors—and our dependence on Taiwan, which fabricates the chips that produce a third of the new computing power we use each year. Taiwan's TSMC builds almost all the world's most advanced processor chips. When COVID slammed into the world in 2020, it disrupted the chip industry, too. Some factories were temporarily shuttered. Purchases of chips for autos slumped. Demand for PC and data center chips spiked higher, as much of the world prepared to work from home. Then, over 2021, a series of accidents—a fire in a Japanese semiconductor facility; ice storms in Texas, a center of U.S. chipmaking; and a new round of COVID lockdowns in Malaysia, where many chips are assembled and tested—intensified these disruptions. Suddenly, many industries far from Silicon Valley faced debilitating chip shortages. Big carmakers from Toyota to General Motors had to shut factories for weeks because they couldn't acquire the semiconductors they needed. Shortages of even the simplest chips caused factory closures on the opposite side of the world. It seemed like a perfect image of globalization gone wrong.

今天，由于摩尔定律的作用，半导体嵌入了需要计算能力的每个设备中，并且在物联网时代，这几乎意味着每个设备。即使是百年历史的产品，如汽车，现在通常包括价值一千美元的芯片。世界上大多数的 GDP 是通过依赖半导体的设备生产的。对于一个七十五年前不存在的产品，这是一个非凡的上升。 当 USS Mustin 在 2020 年 8 月向南航行时，世界刚刚开始认识到我们对半导体的依赖以及对台湾的依赖，后者生产了每年我们使用的新计算能力的三分之一的芯片。台湾台积电几乎制造了所有世界上最先进的处理器芯片。当 COVID 在 2020 年冲击全球时，它也打乱了芯片行业。一些工厂暂时关闭。汽车芯片的购买量下降。PC 和数据中心芯片的需求大幅增加，因为全世界许多人准备在家工作。然后，在 2021 年，一系列事故 - 在日本半导体工厂的火灾；德克萨斯州的冰雪暴，这是美国芯片制造中心；以及马来西亚的新一轮 COVID 封锁，这里汇集了许多芯片制造和测试 - 加剧了这些打扰。突然间，许多远离硅谷的行业面临着令人残疾的芯片短缺。从丰田到通用汽车等大型汽车制造商都不得不关闭工厂数周，因为他们无

法获得所需的半导体。甚至连最简单的芯片短缺也导致另一端的工厂关闭。这似乎是全球化走错路的完美形象。

Political leaders in the U.S., Europe, and Japan hadn't thought much about semiconductors in decades. Like the rest of us, they thought "tech" meant search engines or social media, not silicon wafers. When Joe Biden and Angela Merkel asked why their country's car factories were shuttered, the answer was shrouded behind semiconductor supply chains of bewildering complexity. A typical chip might be designed with blueprints from the Japanese-owned, UK-based company called Arm, by a team of engineers in California and Israel, using design software from the United States. When a design is complete, it's sent to a facility in Taiwan, which buys ultra-pure silicon wafers and specialized gases from Japan. The design is carved into silicon using some of the world's most precise machinery, which can etch, deposit, and measure layers of materials a few atoms thick. These tools are produced primarily by five companies, one Dutch, one Japanese, and three Californian, without which advanced chips are basically impossible to make. Then the chip is packaged and tested, often in Southeast Asia, before being sent to China for assembly into a phone or computer.

美國、歐洲和日本的政治領袖幾十年來沒有怎麼想過半導體。跟我們大家一樣，他們認為「科技」是指搜索引擎或社交媒體，而不是矽晶片。當喬·拜登和安格拉·默克爾問起為什麼他們國家的汽車工廠要關閉時，答案被半導體供應鏈的貿然複雜性掩蓋了起來。一個典型的芯片可能是由位於英國的日本公司Arm的藍圖設計的，由加利福尼亞和以色列的一個工程師團隊，使用來自美國的設計軟件。當一個設計完成後，它被發送到台灣的一個工廠，該工廠從日本購買超級純淨的矽晶圓和專門的氣體。使用一些世界上最精確的機器進行刻蝕，沉積和測量幾個原子薄的材料層，把設計刻在矽晶上。這些工具主要由五家公司生產，其中一家荷蘭公司，一家日本公司，三家加利福尼亞公司，沒有這些公司，先進的芯片基本上無法製造。然後芯片被封裝並測試，通常在東南亞進行，然後被發送到中國進行手機或電腦的裝配。

If any one of the steps in the semiconductor production process is interrupted, the world's supply of new computing power is imperiled. In the age of AI, it's often said that data is the new oil. Yet the real limitation we face isn't the availability of data but of processing power. There's a finite number of semiconductors that can store and process data. Producing them is mind-bogglingly complex and horrendously expensive. Unlike oil, which can be bought from many countries, our production of computing power depends fundamentally on a series of choke points: tools, chemicals, and software that often are produced by a handful of companies—and sometimes only by one. No other facet of the economy is so dependent on so few firms. Chips from Taiwan provide 37 percent of the world's new computing power each year. Two Korean companies produce 44 percent of the world's memory chips. The Dutch company ASML builds 100 percent of the world's extreme ultraviolet lithography machines, without which cutting-edge chips are simply impossible to make. OPEC's 40 percent share of world oil production looks unimpressive by comparison.

如果半導體生產過程中的任何一個步驟被中斷，新的計算能力供應量將會受到威脅。在人工智能時代，人們常說數據是新的石油。但我們面臨的真正限制並不是數據的可用性，而是處理能力。有限的半導體器件可以存儲和處理數據。生產它們是極其複雜且極其昂貴的。不同於可以從許多國家購買的石油，我們的計算能力生產基礎上依賴一系列瓶頸點：工具、化學品和軟件通常由少數幾家公司生產，有時甚至只有一家公司。經濟的其他方面沒有任何一個方面如此依賴如此少的企業。台灣的芯片每年提供全世界37％的新計算能力。兩家韓國公司生產全球44％的存儲器芯片。荷蘭公司ASML制造全球100％的極紫外線光刻機器，沒有這些機器，無法製造頂級芯片。 石油輸出國組織（OPEC）在全球石油生產中佔有40％的份額相比看起來並不令人印象深刻。

The global network of companies that annually produces a trillion chips at nanometer scale is a triumph of efficiency. It's also a staggering vulnerability. The disruptions of the pandemic provide just a glimpse of what a single well-placed earthquake could do to the global economy. Taiwan sits atop a fault line that as recently as 1999 produced an earthquake measuring 7.3 on the Richter scale. Thankfully, this only knocked chip production offline for a couple of days. But it's only a matter of time before a stronger quake strikes Taiwan. A devastating quake could also hit Japan, an earthquake-prone country that produces 17 percent of the world's chips, or Silicon Valley, which today produces few chips but builds crucial chipmaking machinery in facilities sitting atop the San Andreas Fault.

每年以纳米尺度生产千亿个芯片的全球公司网络是效率的胜利，也是一种惊人的脆弱性。大流行病的干扰仅仅展示了一旦单一的地震位置得当，就可以对全球经济造成什么影响。台湾位于一个地震断层线上，而在1999年，那里曾经发生7.3级的地震。谢天谢地，这仅仅使芯片生产停了几天。但是，更强的地震肯定会来临。毁灭性的地震也可能袭击日本以及东京，它们是一个地震多发国家，也生产全球17%的芯片，或者硅谷，它现在几乎不生产芯片，但在坐落于圣安德烈亚斯断层线上的设施中建造关键的芯片制造机器。

Yet the seismic shift that most imperils semiconductor supply today isn’t the crash of tectonic plates but the clash of great powers. As China and the United States struggle for supremacy, both Washington and Beijing are fixated on controlling the future of computing—and, to a frightening degree, that future is dependent on a small island that Beijing considers a renegade province and America has committed to defend by force.

The interconnections between the chip industries in the U.S., China, and Taiwan are dizzyingly complex. There’s no better illustration of this than the individual who founded TSMC, a company that until 2020 counted America’s Apple and China’s Huawei as its two biggest customers. Morris Chang was born in mainland China; grew up in World War II−era Hong Kong; was educated at Harvard, MIT, and Stanford; helped build America’s early chip industry while working for Texas Instruments in Dallas; held a top secret U.S. security clearance to develop electronics for the American military; and made Taiwan the epicenter of world semiconductor manufacturing. Some foreign policy strategists in Beijing and Washington dream of decoupling the two countries’ tech sectors, but the ultra-efficient international network of chip designers, chemical suppliers, and machine-tool makers that people like Chang helped build can’t be easily unwound.

然而，最危及半导体供应的地震性转变不是地壳板块的碰撞，而是大国的冲突。由于中国和美国争夺霸权，华盛顿和北京都着眼于控制计算的未来，而这个未来在很大程度上依赖于一个被北京视为叛逆省份，而美国已经承诺用武力保护的小岛。 美国、中国和台湾之间芯片

产业之间的相互联系错综复杂。没有比创立TSMC的个人更好的说明了这一点，直到2020年，苹果和华为是该公司的两个最大客户。张忠谋出生于中国大陆，在二战期间成长于香港，接受了哈佛、麻省理工和斯坦福的教育，帮助建立了美国早期的芯片产业，曾在达拉斯的德克萨斯仪器公司工作，获得美国军方秘密安全许可证开发电子设备，并使台湾成为世界半导体制造的中心。一些北京和华盛顿的外交策略家梦想着解开两国科技部门的纽带，但像张忠谋这样的人帮助建立的超高效的国际芯片设计师、化学品供应商和机床制造商网络无法轻易解除。

Unless, of course, something explodes. Beijing has pointedly refused to rule out the prospect that it might invade Taiwan to “reunify” it with the mainland. But it wouldn’t take anything as dramatic as an amphibious assault to send semiconductor-induced shock waves careening through the global economy. Even a partial blockade by Chinese forces would trigger devastating disruptions. A single missile strike on TSMC’s most advanced chip fabrication facility could easily cause hundreds of billions of dollars of damage once delays to the production of phones, data centers, autos, telecom networks, and other technology are added up.

當然，除非發生爆炸。北京堅定地拒絕排除可能侵略台灣與大陸“統一”的前景。但就算不需要開展兩棲攻勢，半封鎖也會在全球經濟中引起毀滅性的震盪。中國軍隊對台灣最先進的晶片製造設施發起一次單一導彈打擊，只要將產生的影響放入手機、數據中心、汽車、電信網絡和其他技術的生產延遲中，很容易造成數千億美元的損失。

Holding the global economy hostage to one of the world’s most dangerous political disputes might seem like an error of historic proportions. However, the concentration of advanced chip manufacturing in Taiwan, South Korea, and elsewhere in East Asia isn’t an accident. A series of deliberate decisions by government officials and corporate executives created the far-flung supply chains we rely on today. Asia’s vast pool of cheap labor attracted chipmakers looking for low-cost factory workers. The region’s governments and corporations used offshored chip assembly facilities to learn about, and eventually domesticate, more advanced technologies. Washington’s foreign policy strategists embraced complex semiconductor supply chains as a tool to bind Asia to an American-led world. Capitalism’s inexorable demand for economic efficiency drove a constant push for cost cuts and corporate consolidation. The steady tempo of technological innovation that underwrote Moore's Law required ever more complex materials, machinery, and processes that could only be supplied or funded via global markets. And our gargantuan demand for computing power only continues to grow.

將全球經濟人質化為世界上最危險的政治糾紛之一可能看起來像是一個歷史級錯誤。然而，台灣、南韓和其他東亞地區對先進晶片製造的集中並非意外。一系列由政府官員和企業高層做出的有意決策創造了我們今天所依賴的遍及全球的供應鏈。亞洲龐大的廉價勞動力吸引了尋找低成本工廠工人的晶片製造商。該地區的政府和企業利用離岸晶片裝配設施來學習更先進技術，並最終實現國內化。華盛頓的外交政策戰略家將複雜的半導體供應鏈視為約束亞洲走向美國主導世界的工具。資本主義的經濟效率驅動了對成本削減和企業合併的不斷推動。為Moore定律提供基礎的技術創新的穩定節奏需要更複雜的材料、機器和過程，這些只能通過全球市場提供或資助。而我們對計算能力龐大的需求只不斷增加。

Drawing on research in historical archives on three continents, from Taipei to Moscow, and over a hundred interviews with scientists, engineers, CEOs, and government officials, this book contends that semiconductors have defined the world we live in, determining the shape of international politics, the structure of the world economy, and the balance of military power. Yet this most modern of devices has a complex and contested history. Its development has been shaped not only by corporations and consumers but also by ambitious governments and the imperatives of war. To understand how our world came to be defined by quintillions of transistors and a tiny number of irreplaceable companies, we must begin by looking back to the origins of the silicon age.

藉由對三大洲歷史檔案的研究以及對科學家、工程師、CEO和政府官員的一百多次訪問，本書認為半導體已經所創造的世界，決定了國際政治的格局、世界經濟的結構以及軍事力量的平衡。然而，這個最現代的裝置有複雜而受爭議的歷史。它的發展不僅受到企業和消費者的影響，也受到野心勃勃的政府和戰爭的必備條件的影響。為了理解我

們的世界是如何被數十億個晶體管和少數不可替代的公司所定義的，我們必須回溯矽的起源。

PART I COLD WAR CHIPS

CHAPTER 1 From Steel to Silicon

J apanese soldiers described World War II as a "typhoon of steel." It certainly felt that way to Akio Morita, a studious young engineer from a family of prosperous sake merchants. Morita only barely avoided the front lines by getting assigned to a Japanese navy engineering lab. But the typhoon of steel crashed through Morita's homeland, too, as American B-29 Superfortress bombers pummeled Japan's cities, destroying much of Tokyo and other urban centers. Adding to the devastation, an American blockade created widespread hunger and drove the country toward desperate measures. Morita's brothers were being trained as kamikaze pilots when the war ended.

日本士兵形容第二次世界大戰為「鋼鐵颱風」。對於一個來自富裕清酒商家庭的好學青年工程師森田章夫來說，事實上也是這樣。森田只是因為被指派到日本海軍工程實驗室才勉強避免了前線。但是鋼鐵颱風也席捲了森田的祖國，美國的B-29超級堡壘轟炸機狂轟日本的城市，摧毀了東京和其他城市的大部分。加之美國的封鎖引發了普遍的飢餓，並迫使該國走向絕望的措施。當戰爭結束時，森田的兄弟們正在接受特攻飛行員的培訓。

Across the East China Sea, Morris Chang's childhood was punctuated by the sound of gunfire and air-raid sirens warning of imminent attack. Chang spent his teenage years fleeing the Japanese armies that swept across China, moving to Guangzhou; the British colony of Hong Kong; China's wartime capital of Chongqing; and then back to Shanghai after the Japanese were defeated. Even then, the war didn't really end, because Communist guerillas relaunched their struggle against the Chinese government. Soon Mao Zedong's forces were marching on Shanghai. Morris Chang was once again a refugee, forced to flee to Hong Kong for the second time.

橫跨東海，張忠謀的童年被槍聲和空襲警報所打斷，提醒即將發生的攻擊。張忠謀的青少年時期充滿了逃亡日本軍隊的經歷，從廣州移居到英國殖民地香港，再到中國的戰時首都重慶，最後日本投降後回到上海。即使如此，戰爭也沒有真正結束，因為共產黨游擊隊重新發起

了反抗中國政府的斗爭。不久之後，毛澤東的軍隊就進軍上海。張忠謀再一次成為了難民，被迫第二次逃離香港。

Budapest was on the opposite side of the world, but Andy Grove lived through the same typhoon of steel that swept across Asia. Andy (or Andras Grof, as he was then known) survived multiple invasions of Budapest. Hungary's far-right government treated Jews like the Groves as second-class citizens, but when war broke out in Europe, his father was nevertheless drafted and sent to fight alongside Hungary's Nazi allies against the Soviet Union, where he was reported missing in action at Stalingrad. Then, in 1944, the Nazis invaded Hungary, their ostensible ally, sending tank columns rolling through Budapest and announcing plans to ship Jews like Grove to industrial-scale death camps. Still a child, Grove heard the thud of artillery again months later as Red Army troops marched into Hungary's capital, "liberating" the country, raping Grove's mother, and installing a brutal puppet regime in the Nazis' place.

布達佩斯位於地球的另一端，但安迪·格羅夫同樣經歷了席捲亞洲的鋼鐵颱風。安迪（當時名為安德拉什·格羅夫）在布達佩斯經歷了多次入侵。匈牙利的極右政府將像格羅夫這樣的猶太人視為二等公民，但在歐洲爆發戰爭時，他的父親仍然被徵召入伍，與匈牙利的納粹盟友一起對抗蘇聯，在斯大林格勒失蹤。然後，在1944年，納粹入侵了匈牙利，他們暴露了盟友的真面目，讓坦克車穿過布達佩斯，並宣布計劃將像格羅夫這樣的猶太人運往工業化的死亡集中營。作為一個孩子，格羅夫在幾個月後再次聽到了榴彈炮的聲響，當時蘇聯軍隊走進匈牙利的首都，“解放”了該國，強暴了格羅夫的母親，並在納粹的地位上安裝了一個殘暴的傀儡政權。

Endless tank columns; waves of airplanes; thousands of tons of bombs dropped from the skies; convoys of ships delivering trucks, combat vehicles, petroleum products, locomotives, rail cars, artillery, ammunition, coal, and steel—World War II was a conflict of industrial attrition. The United States wanted it that way: an industrial war was a struggle America would win. In Washington, the economists at the War Production Board measured success in terms of copper and iron, rubber and oil, aluminum and tin as America converted manufacturing might into military power.

无尽的坦克车队；数不清的飞机浪潮；数千吨来自天空的炸弹；船队运输卡车、战斗车辆、石油制品、机车、铁路车辆、火炮、弹药、煤炭和钢材——第二次世界大战是一场工业消耗战。美国希望如此：临战时期，美国将赢得一场工业战。在华盛顿，战争生产委员会的经济学家们将成功定义为铜和铁、橡胶和石油、铝和锡的数量，因为美国把制造业的实力转化为了军事力量。

The United States built more tanks than all the Axis powers combined, more ships, more planes, and twice the Axis production of artillery and machine guns. Convoys of industrial goods streamed from American ports across the Atlantic and Pacific Oceans, supplying Britain, the Soviet Union, China, and other allies with key materiel. The war was waged by soldiers at Stalingrad and sailors at Midway. But the fighting power was produced by America's Kaiser shipyards and the assembly lines at River Rouge.

In 1945, radio broadcasts across the world announced that the war was finally over. Outside of Tokyo, Akio Morita, the young engineer, donned his full uniform to hear Emperor Hirohito's surrender address, though he listened to the speech alone rather than in the company of other naval officers, so he wouldn't be pressured to commit ritual suicide. Across the East China Sea, Morris Chang celebrated the war's end and Japan's defeat with a prompt return to a leisurely teenaged life of tennis, movies, and card games with friends. In Hungary, Andy Grove and his mother slowly crept out of their bomb shelter, though they suffered as much during the Soviet occupation as during the war itself.

美國建造的坦克數量比所有軸心國家總和還多，船隻、飛機以及火砲和機槍的生產量則是軸心國家的兩倍。工業貨物的船隊從美國港口開往大西洋和太平洋，為英國、蘇聯、中國和其他盟國提供關鍵物資。戰爭由在斯大林格勒的士兵和在中途島的水手發動，但戰鬥力的產生來自美國的凱撒造船廠和里弗魯奧格萊斯裝配線。 1945年，世界各地的廣播宣告戰爭終於結束了。在東京外，年輕的工程師森田恭雄身著全副制服聆聽了廣播中的裕仁天皇的投降演說，但他獨自聆聽演講，而不是和其他海軍軍官在一起，以免受到迫使落實儀式自殺的壓力。在東中國海對岸，張忠謀以快速返回輕鬆的青少年生活–打網球、看電影和和朋友玩撲克等方式來慶祝戰爭的結束和日本的失敗。 在匈牙

利，安迪·格羅夫和他的母親慢慢爬出他們的防空洞，盡管在蘇聯佔領期間他們所受的折磨不亞於戰爭本身。

World War II’s outcome was determined by industrial output, but it was clear already that new technologies were transforming military power. The great powers had manufactured planes and tanks by the thousands, but they’d also built research labs that developed new devices like rockets and radars. The two atomic bombs that destroyed Hiroshima and Nagasaki brought forth much speculation that a nascent Atomic Age might replace an era defined by coal and steel.

Morris Chang and Andy Grove were schoolboys in 1945, too young to have thought seriously about technology or politics. Akio Morita, however, was in his early twenties and had spent the final months of the war developing heat-seeking missiles. Japan was far from fielding workable guided missiles, but the project gave Morita a glimpse of the future. It was becoming possible to envision wars won not by riveters on assembly lines but by weapons that could identify targets and maneuver themselves automatically. The idea seemed like science fiction, but Morita was vaguely aware of new developments in electronic computation that might make it possible for machines to “think” by solving math problems like adding, multiplying, or finding a square root.

二战的结局取决于工业产出，但很明显，新技术正在改变军事力量。各大强国生产了成千上万架飞机和坦克，但他们也建立了研究实验室，开发了新的设备，如火箭和雷达。摧毁广岛和长崎的两颗原子弹引发了许多猜测，认为一个初生的原子时代可能会取代以煤和钢为标志的时代。 莫里斯·张和安迪·格罗夫是1945年的学童，太年轻了，无法认真思考科技或政治。然而，盛田昭夫已经二十多岁了，在战争的最后几个月里，他一直在研发热导弹。日本远未能装备可行的制导导弹，但这个项目让盛田看到了未来。现在可以设想，战争的胜利不再取决于装配线上的铆工，而是能够自动识别目标和机动的武器。这个想法似乎像科幻小说，但盛田隐约意识到，电子计算方面的新进展可能使机器通过解决像加、乘或找平方根等数学问题来“思考”成为可能。

Of course, the idea of using devices to compute wasn't new. People have flipped their fingers up and down since Homo sapiens first learned to count. The ancient Babylonians invented the abacus to manipulate large numbers, and for centuries people multiplied and divided by moving wooden beads back and forth across these wooden grids. During the late 1800s and early 1900s, the growth of big bureaucracies in government and business required armies of human "computers," office workers armed with pen, paper, and occasionally simple mechanical calculators—gearboxes that could add, subtract, multiply, divide, and calculate basic square roots.

当然，使用设备进行计算的想法并不新鲜。自智人学会计数以来，人们就一直在用手指翻转计算。古巴比伦人发明了算盘来处理大数目，几个世纪以来，人们通过在这些木制网格上来回移动木珠来进行乘除运算。在19世纪末和20世纪初，政府和商业大型官僚机构的发展需要大量的"计算人员"，这些办公室工作人员手持笔、纸或者简单的机械计算器——齿轮用来加、减、乘、除和计算基本的平方根。

These living, breathing computers could tabulate payrolls, track sales, collect census results, and sift through the data on fires and droughts that were needed to price insurance policies. During the Great Depression, America's Works Progress Administration, looking to employ jobless office workers, set up the Mathematical Tables Project. Several hundred human "computers" sat at rows of desks in a Manhattan office building and tabulated logarithms and exponential functions. The project published twenty-eight volumes of the results of complex functions, with titles such as *Tables of Reciprocals of the Integers from 100,000 Through 200,009* , presenting 201 pages covered in tables of numbers.

這些有生命、能呼吸的電腦可以計算薪資、追踪銷售額、收集人口普查結果，並篩選出有用於保險公司制定保險政策的火災和乾旱數據。在大蕭條期間，美國的 Works Progress Administration 為了聘用失業的辦公室工人，建立了數學表項目。數百個人類"計算機"坐在曼哈頓辦公樓的一排排桌子上，計算對數和指數函數。該項目發表了二十八個複雜函數的結果，其中包括Table of Reciprocals of the Integers from 100,000 Through 200,009等標題，呈現了201頁數表。

Organized groups of human calculators showed the promise of computation, but also the limits of using brains to compute. Even when brains were enhanced by using mechanical calculators, humans worked slowly. A person looking to use the results of the Mathematical Tables Project had to flip through the pages of one of the twenty-eight volumes to find the result of a specific logarithm or exponent. The more calculations that were needed, the more pages had to be flipped through.

Meanwhile, the demand for calculations kept growing. Even before World War II, money was flowing into projects to produce more capable mechanical computers, but the war accelerated the hunt for computing power. Several countries' air forces developed mechanical bombsights to help aviators hit their targets. Bomber crews entered the wind speed and altitude by turning knobs, which moved metal levers that adjusted glass mirrors. These knobs and levers "computed" altitudes and angles more exactly than any pilot could, focusing the sight as the plane homed in on its target. However, the limitations were obvious. Such bombsights only considered a few inputs and provided a single output: when to drop the bomb. In perfect test conditions, America's bombsights were more accurate than pilots' guesswork. When deployed in the skies above Germany, though, only 20 percent of American bombs fell within one thousand feet of their target. The war was decided by the quantity of bombs dropped and artillery shells fired, not by the knobs on the mechanical computers that tried and usually failed to guide them.

有组织的人类计算机团队展示了计算的前景，同时也揭示了使用大脑计算的局限性。即使通过使用机械计算器来增强大脑的能力，人们处理任务的速度依然很慢。想要使用数学表格项目的结果，人们必须翻阅二十八卷书中的一页来找到特定对数或指数的结果。需要计算的量越多，要翻阅的书页也就越多。 与此同时，对计算的需求不断增长。在二战之前，资金流向了更具备能力的机械计算机项目，但战争加速了对计算能力的追求。几个国家的空军都开发出机械炸弹准星，以帮助飞行员命中目标。轰炸机机组人员通过转动旋钮输入风速和高度，这些旋钮又移动调整玻璃镜子的金属杆。这些旋钮和杆子“计算”出更加精确的高度和角度，使飞机将准星对准目标。然而，显而易见的局限性是，这样的炸弹准星只考虑了少量的输入，并提供了一个简单的输出：何时投弹。在完美的测试条件下，美国的炸弹准星比飞行员瞎

猜更加准确。然而，在投入使用时，只有20％的美国炸弹在距目标一千英尺内投中。在战争中，决定胜败的是投掷的炸弹和火炮弹药的数量，而不是机械计算机上的旋钮，它们试图，但通常失败地指导炸弹落点。

More accuracy required more calculations. Engineers eventually began replacing mechanical gears in early computers with electrical charges. Early electric computers used the vacuum tube, a lightbulb-like metal filament enclosed in glass. The electric current running through the tube could be switched on and off, performing a function not unlike an abacus bead moving back and forth across a wooden rod. A tube turned on was coded as a 1 while a vacuum tube turned off was a 0. These two digits could produce any number using a system of binary counting—and therefore could theoretically execute many types of computation.

需要更准确的计算就需要更多的计算。工程师们最终开始用电荷替代早期计算机中的机械齿轮。早期的电子计算机使用了真空管，一种类似灯泡的金属丝封装在玻璃内。通过真空管传输的电流可以开关控制，就像算盘珠子在木棒上来回滑动一样。打开的管就代表是1，而关闭的真空管则是0。利用这两个数字可以使用二进制计数系统得出任何数字，从而理论上可以执行很多类型的计算。

Moreover, vacuum tubes made it possible for these digital computers to be reprogrammed. Mechanical gears such as those in a bombsight could only perform a single type of calculation because each knob was physically attached to levers and gears. The beads on an abacus were constrained by the rods on which they moved back and forth. However, the connections between vacuum tubes could be reorganized, enabling the computer to run different calculations.

This was a leap forward in computing—or it would have been, if not for the moths. Because vacuum tubes glowed like lightbulbs, they attracted insects, requiring regular “debugging” by their engineers. Also like lightbulbs, vacuum tubes often burned out. A state-of-the-art computer called ENIAC, built for the U.S. Army at the University of Pennsylvania in 1945 to calculate artillery trajectories, had eighteen thousand vacuum tubes. On average, one tube malfunctioned every two days, bringing the entire machine to a halt and sending technicians scrambling to find and replace the broken part. ENIAC could multiply hundreds of numbers per second, faster than any mathematician. Yet it took up an entire room because each of its eighteen thousand tubes was the size of a fist. Clearly, vacuum tube technology was too cumbersome, too slow, and too unreliable. So long as computers were moth-ridden monstrosities, they'd only be useful for niche applications like code breaking, unless scientists could find a smaller, faster, cheaper switch.

此外，真空管使得这些数字计算机可以被重新编程。如炸弹瞄准器中的机械齿轮只能执行一种计算类型，因为每个旋钮都与杠杆和齿轮物理上相连。算盘上的珠子受到它们前后移动的杆子的限制。然而，真空管之间的连接可以被重新组织，使计算机能够运行不同的计算。 这是计算机界的一次飞跃，但存在一个问题：虫害问题。由于真空管发出的光线如同灯泡，所以会吸引昆虫，需要工程师定期进行"调试"。并且，与灯泡相似，真空管也经常会烧坏。为美国陆军在宾夕法尼亚大学于1945年构建的联合国艺术学院打击导弹与制导弹道计算机ENIAC来说，就有一万八千个真空管。平均每隔两天就会有一个真空管失效，从而导致整个机器停止运转，技术人员会分散寻找并更换损坏的部件。虽然ENIAC可以每秒乘以数百个数字，比任何数学家都要快，但它却需要一个整个房间的空间，因为它的一万八千个管子都是拳头大小。很显然，真空管技术过于笨重、过于缓慢、过于不可靠。除非科学家能够找到一个更小、更快、更便宜的开关，否则计算机将只适用于像破解代码等特定应用领域。

CHAPTER 2 The Switch

W illiam Shockley had long assumed that if a better “switch” was to be found, it would be with the help of a type of material called semiconductors. Shockley, who’d been born in London to a globe-trotting mining engineer, had grown up amid the fruit trees of the sleepy California town of Palo Alto. An only child, he was utterly convinced of his superiority over anyone around him—and he let everyone know it. He went to college at Caltech, in Southern California, before completing a PhD in physics at MIT and starting work at Bell Labs in New Jersey, which at the time was one of the world’s leading centers of science and engineering. All his colleagues found Shockley obnoxious, but they also admitted he was a brilliant theoretical physicist. His intuition was so accurate that one of Shockley’s coworkers said it was as if he could actually *see* electrons as they zipped across metals or bonded atoms together.

威廉·肖克利长期以来认为，如果要找到更好的“开关”，那就一定要借助一种名为半导体的材料。肖克利在伦敦出生，他的父亲是一名环球旅行的采矿工程师。肖克利在加利福尼亚州宁静的帕洛阿尔托小镇的果树中长大。作为独生子，他完全相信自己比周围任何人都优越，并且让每个人都知道。他在南加州理工学院上了大学，然后在麻省理工学院取得物理学博士学位，并开始在新泽西州的贝尔实验室工作。当时，贝尔实验室是世界上最重要的科学和工程研究中心之一。肖克利的所有同事都认为他很讨厌，但他们也承认他是一位卓越的理论物理学家。他的直觉是如此准确，以至于肖克利的一位同事说，好像他可以看到电子在金属或结合原子时的运动。

Semiconductors, Shockley’s area of specialization, are a unique class of materials. Most materials either let electric current flow freely (like copper wires) or block current (like glass). Semiconductors are different. On their own, semiconductor materials like silicon and germanium are like glass, conducting hardly any electricity at all. But when certain materials are added and an electric field is applied, current can begin to flow. Adding phosphorous or antimony to semiconducting materials like silicon or germanium, for example, lets a negative current flow.

半導體是肖克利專業領域中獨特的材料類別。大多數材料要麼能自由地傳導電流（例如銅線），要麼阻止電流傳導（例如玻璃）。而半導體不同。半導體材料像矽和鍺本身與玻璃一樣，幾乎不傳導電流。但是當加入某些材料並施加電場時，電流就可以開始流動。例如，將磷或銻添加到像矽或鍺這樣的半導體材料中，就能讓負電流流動。

“Doping” semiconductor materials with other elements presented an opportunity for new types of devices that could create and control electric currents. However, mastering the flow of electrons across semiconductor materials like silicon or germanium was a distant dream so long as their electrical properties remained mysterious and unexplained. Until the late 1940s, despite all the physics brainpower accumulated at Bell Labs, no one could explain why slabs of semiconductor materials acted in such puzzling ways.

将其他元素“掺杂”在半导体材料中为创建和控制电流的新型设备提供了机会。然而，只要硅或锗等半导体材料的电学特性仍然神秘和不可解释，就无法掌握电子在半导体材料上的流动。直到20世纪40年代晚期，在贝尔实验室积累的所有物理学智慧下，没有人能够解释为什么半导体材料的厚片表现出如此令人困惑的方式。

In 1945, Shockley first theorized what he called a “solid state valve,” sketching in his notebook a piece of silicon attached to a ninety-volt battery. He hypothesized that placing a piece of semiconductor material like silicon in the presence of an electric field could attract “free electrons” stored inside to cluster near the edge of the semiconductor. If enough electrons were attracted by the electric field, the edge of the semiconductor would be transformed into a conductive material, like a metal, which always has large numbers of free electrons. If so, an electric current could begin flowing through a material that previously conducted no electricity at all. Shockley soon built such a device, expecting that applying and removing an electric field on top of the piece of silicon could make it function like a valve, opening and closing the flow of electrons across the silicon. When he ran this experiment, however, he was unable to detect a result. “Nothing measurable,” he explained. “Quite mysterious.” In fact, the simple instruments of the 1940s were too imprecise to measure the tiny current that was flowing.

1945年，蕭克利首次提出了他所謂的“固態閥”理論，他在筆記本上描繪了一塊連接在90伏特電池上的矽塊。他假設在電場的作用下，將像矽這樣的半導體材料放置在其中，可以吸引儲存在內部的“自由電子”聚集在半導體邊緣附近。如果電場吸引了足夠的電子，半導體邊緣就會變成導電材料，就像金屬一樣，總是有大量的自由電子。如果是這樣，一個之前根本不導電的材料中就可以開始通電流。蕭克利很快就建造了這樣的裝置，期望在矽塊上施加和移除電場可以使它像閥門一樣運作，開啟和關閉矽上的電子流動。然而，他進行這個實驗時，發現無法測量結果。他解釋道：“完全沒有可測量的東西。相當神秘。”事實上，1940年代的簡單儀器太不精確了，無法測量極小的電流。

Two years later, two of Shockley's colleagues at Bell Labs devised a similar experiment on a different type of device. Where Shockley was proud and obnoxious, his colleagues Walter Brattain, a brilliant experimental physicist from a cattle ranch in rural Washington, and John Bardeen, a Princeton-trained scientist who'd later become the only person to win two Nobel Prizes in physics, were modest and mild-mannered. Inspired by Shockley's theorizing, Brattain and Bardeen built a device that applied two gold filaments, each attached by wires to a power source and to a piece of metal, to a block of germanium, with each filament touching the germanium less than a millimeter apart from the other. On the afternoon of December 16, 1947, at Bell Labs' headquarters, Bardeen and Brattain switched on the power and were able to control the current surging across the germanium. Shockley's theories about semiconductor materials had been proven correct.

两年后，贝尔实验室的 Shockley 的两位同事在另一个类型的设备上设计了类似的实验。Shockley 自夸自大，而他的同事沃尔特·布拉坦是一位来自华盛顿州乡村牧场的出色的实验物理学家，约翰·巴丁则是普林斯顿训练有素的科学家，后来成为唯一获得两次诺贝尔物理学奖的人。受 Shockley 理论的启发，布拉坦和巴丁建造了一种设备，将两个金丝丝绸，每个金丝丝绸通过导线连接到电源和金属块，接触小于一毫米的锗块，并将两个金丝丝绸交错，绕成结。1947年12月16日下午，在贝尔实验室的总部，巴丁和布拉坦打开电源，并能够控制横跨锗的电流。Shockley 对半导体材料的理论得到了证明。

AT&T, which owned Bell Labs, was in the business of telephones, not computers, and saw this device—soon christened a “transistor”—as useful primarily for its ability to amplify signals that transmitted phone calls across its vast network. Because transistors could amplify currents, it was soon realized, they would be useful in devices such as hearing aids and radios, replacing less reliable vacuum tubes, which were also used for signal amplification. Bell Labs soon began arranging patent applications for this new device.

AT＆T擁有貝爾實驗室，經營的是電話業務，而不是電腦業務，因此認為這種裝置 - 很快被命名為“晶體管” - 主要是因為它可以放大在其龐大的網絡傳輸電話呼叫的信號而有用的。由於晶體管可以放大電流，因此很快就意識到，它們將在設備中非常有用，例如助聽器和收音機，取代不太可靠的真空管，這些真空管也用於信號放大。貝爾實驗室很快開始為這種新設備安排專利申請。

Shockley was furious that his colleagues had discovered an experiment to prove his theories, and he was committed to outdoing them. He locked himself in a Chicago hotel room for two weeks over Christmas and began imagining different transistor structures, based on his unparalleled understanding of semiconductor physics. By January 1948, he’d conceptualized a new type of transistor, made up of three chunks of semiconductor material. The outer two chunks would have a surplus of electrons; the piece sandwiched between them would have a deficit. If a tiny current was applied to the middle layer in the sandwich, it set a much larger current flowing across the entire device. This conversion of a small current into a large one was the same amplification process that Brattain and Bardeen’s transistor had demonstrated. But Shockley began to perceive other uses, along the lines of the “solid state valve” he’d previously theorized. He could turn the larger current on and off by manipulating the small current applied to the middle of this transistor sandwich. On, off. On, off. Shockley had designed a switch.

蕭克利感到憤怒，因為他的同事們發現了一個實驗證明他理論的方法，他決心要做得更好。他在聖誕節期間鎖在芝加哥一個旅館房間里兩個星期，開始想像不同的晶體管結構，基於他對半導體物理學無與倫比的理解。到1948年1月，他構想了一種新類型的晶體管，由三塊半

導體材料組成。外圍兩個塊體具有多餘的電子，夾在它們之間的那塊體具有赤字。如果向夾心層施加微小電流，就會在整個器件上流動更大的電流。這種由小電流轉化為大電流的過程就是布拉丁和巴丁的晶體管演示的放大過程。但是蕭克利開始感知到其他用途，沿著他之前理論化的“固態閥門”方向。他可以通過操作施加到這個晶體管夾心的小電流來開關更大的電流，開，關，開，關。蕭克利設計了一個開關。

When Bell Labs held a press conference in June 1948 to announce that its scientists had invented the transistor, it wasn't easy to understand why these wired blocks of germanium merited a special announcement. The *New York Times* buried the story on page 46. *Time* magazine did better, reporting the invention under the headline "Little Brain Cell." Yet even Shockley, who never underestimated his own importance, couldn't have imagined that soon thousands, millions, and billions of these transistors would be employed at microscopic scale to replace human brains in the task of computing.

當貝爾實驗室於1948年6月舉行新聞發布會，宣佈其科學家發明了晶體管時，人們很難理解這些有線的鍺塊為什麼值得特別宣布。紐約時報將該故事埋在第46頁。《時代雜誌》做得更好，報導了發明，標題為“小腦細胞”。然而，即使是永遠不低估自己重要性的肖克利，也不可能想象到很快成千上萬、成百萬、成十億這樣的晶體管將以微觀比例取代人腦在計算任務上的作用。

CHAPTER 3 Noyce, Kilby, and the Integrated Circuit

T he transistor could only replace vacuum tubes if it could be simplified and sold at scale. Theorizing and inventing transistors was simply the first step; now, the challenge was to manufacture them by the thousands. Brattain and Bardeen had little interest in business or mass production. They were researchers at heart, and after winning the Nobel, they continued their careers teaching and experimenting. Shockley's ambitions, by contrast, only grew. He wanted not only to be famous but also to be rich. He told friends he dreamed of seeing his name not only in academic publications like the *Physical Review* but in the *Wall Street Journal* , too. In 1955, he established Shockley Semiconductor in the San Francisco suburb of Mountain View, California, just down the street from Palo Alto, where his aging mother still lived.

只有当晶体管可以变得更简化并大规模销售时，它才能取代真空管。理论化和发明晶体管只是第一步；现在的挑战是将晶体管量产。布拉丁和巴丁对商业或批量生产并不感兴趣。他们本质上是研究者，获得诺贝尔奖后，他们继续从事教学和实验。相比之下，肖克利的野心只增不减。他不仅想成名，而且想变得富有。他告诉朋友，他梦想看到自己的名字不仅出现在《物理评论》等学术出版物中，也出现在《华尔街日报》上。1955年，他在加利福尼亚州山景城市成立了肖克利半导体公司，就在帕洛阿尔托街的拐角处，他的年迈母亲还住在那里。

Shockley planned to build the world's best transistors, which was possible because AT&T, the owner of Bell Labs and of the transistor patent, offered to license the device to other companies for $25,000, a bargain for the most cutting-edge electronics technology. Shockley assumed that there'd be a market for transistors, at least for replacing vacuum tubes in existing electronics. The potential size of the transistor market, though, was unclear. Everyone agreed transistors were a clever piece of technology based on the most advanced physics, but transistors would take off only if they did something better than vacuum tubes or could be produced more cheaply. Shockley would soon win the Nobel Prize for his theorizing about semiconductors, but the question of how to make transistors practical and useful was an engineering dilemma, not a matter of theoretical physics.

謝克利計劃建造世界上最好的晶體管，這是可能的，因為AT＆T是貝爾實驗室和晶體管專利的所有者，他們提供了以2.5萬美元的折扣向其他公司授權使用此裝置，這對於最先進的電子技術來說是有利的。 謝克利假定晶體管市場至少會替換現有電子產品中的真空管。然而，晶體管市場的潛在規模還不清楚。 每個人都認為，晶體管是一種基於最先進物理的巧妙技術，但只有當它們比真空管表現更好或可以更便宜地生產時，晶體管才會起飛。 謝克利很快就會因為關於半導體的理論而獲得諾貝爾獎，但如何使晶體管實用並有用是一個工程問題，而不是理論物理問題。

Transistors soon began to be used in place of vacuum tubes in computers, but the wiring between thousands of transistors created a jungle of complexity. Jack Kilby, an engineer at Texas Instruments, spent the summer of 1958 in his Texas lab fixated on finding a way to simplify the complexity created by all the wires that systems with transistors required. Kilby was soft-spoken, collegial, curious, and quietly brilliant. “He was never demanding,” one colleague remembered. “You knew what he wanted to have happen and you tried your darndest to make it happen.” Another colleague, who relished regular barbecue lunches with Kilby, said he was “as sweet a guy as you’d ever want to meet.”

晶體管很快便被用來取代電子管，但數千個晶體管間的連線創建了一個複雜的迷宮。德州儀器公司的工程師傑克·基爾比(Jack Kilby)在1958年的夏天，一心希望找到簡化使用晶體管系統中所有連線複雜度的方法。基爾比說話輕聲細語、合作、好奇和靜靜地聰明。一位同事回憶說：“他從不強求什麼，你知道他想要什麼，就試圖盡力讓它發生。”另一位同事喜歡和基爾比一起午餐烤肉，說他“是你想見到的那樣甜蜜的人”。

Kilby was one of the first people outside Bell Labs to use a transistor, after his first employer, Milwaukee-based Centralab, licensed the technology from AT&T. In 1958, Kilby left Centralab to work in the transistor unit of Texas Instruments. Based in Dallas, TI had been founded to produce equipment using seismic waves to help oilmen decide where to drill. During World War

II, the company had been drafted by the U.S. Navy to build sonar devices to track enemy submarines. After the war, TI executives realized this electronics expertise could be useful in other military systems, too, so they hired engineers like Kilby to build them.

基尔比是AT&T技术被Centralab授权后第一批使用晶体管技术的人之一。1958年，基尔比从Centralab离职，加入了得克萨斯仪器公司的晶体管团队。TI总部位于达拉斯，早在成立之初，该公司就生产使用地震波帮助石油工人决定钻井位置的设备。第二次世界大战期间，该公司被美国海军征用来建造声纳设备，以跟踪敌人的潜艇。战后，TI的高管意识到这种电子专业知识也可以用于其他军事系统，因此他们聘请像基尔比这样的工程师来建造这些系统。

Kilby arrived in Dallas around the company’s July holiday period, yet he’d accumulated no vacation time so he was left alone in the lab for a couple of weeks. With time to tinker, he wondered how to reduce the number of wires that were needed to string different transistors together. Rather than use a separate piece of silicon or germanium to build each transistor, he thought of assembling multiple components on the same piece of semiconductor material. When his colleagues returned from summer vacation, they realized that Kilby’s idea was revolutionary. Multiple transistors could be built into a single slab of silicon or germanium. Kilby called his invention an “integrated circuit,” but it became known colloquially as a “chip,” because each integrated circuit was made from a piece of silicon “chipped” off a circular silicon wafer.

基爾比在公司七月假期期間抵達達拉斯，然而他沒有積累假期時間，所以他獨自待在實驗室裡幾個星期。有了時間可以 tink，他想知道如何減少需要串聯不同晶體管的電線數量。他想到不是使用獨立的矽或鍺來建造每個晶體管，而是想在同一塊半導體材料上組裝多個元件。當他的同事們從暑假回來時，他們意識到基爾比的想法是革命性的。多個晶體管可以建造成單片矽或鍺。基爾比稱他的發明為「集成電路」，但因為每個集成電路都是從圓形矽晶圓上「削下」一片矽製成的，所以它以俚語成為「芯片」。

About a year earlier, in Palo Alto, California, a group of eight engineers employed by William Shockley’s semiconductor lab had told their Nobel

Prize-winning boss that they were quitting. Shockley had a knack for spotting talent, but he was an awful manager. He thrived on controversy and created a toxic atmosphere that alienated the bright young engineers he'd assembled. So these eight engineers left Shockley Semiconductor and decided to found their own company, Fairchild Semiconductor, with seed funding from an East Coast millionaire.

大約一年前，在加州帕洛阿爾托，一群在威廉·肖克利半導體實驗室工作的八名工程師告訴他們獲得諾貝爾獎的老闆，他們要離職。肖克利有一種發現才華的本領，但他是一個糟糕的管理者。他喜歡引起爭議並創造了一種有毒氛圍，讓他聘用的那些年輕有為的工程師感到疏遠。因此，這八名工程師離開肖克利半導體公司，決定創立自己的公司Fairchild Semiconductor，獲得一個來自東海岸的百萬富翁的種子基金。

The eight defectors from Shockley's lab are widely credited with founding Silicon Valley. One of the eight, Eugene Kleiner, would go on to found Kleiner Perkins, one of the world's most powerful venture capital firms. Gordon Moore, who went on to run Fairchild's R&D process, would later coin the concept of Moore's Law to describe the exponential growth in computing power. Most important was Bob Noyce, the leader of the "traitorous eight," who had a charismatic, visionary enthusiasm for microelectronics and an intuitive sense of which technical advances were needed to make transistors tiny, cheap, and reliable. Matching new inventions with commercial opportunities was exactly what a startup like Fairchild needed to succeed—and what the chip industry needed to take off.

被認為是創立矽谷的八位背叛者中，尤金·克萊納是其中之一，他創辦了克萊納帕金斯，這是世界上最強大的風險投資公司之一。 高登·摩爾轉而運營費爾徹爾德的研發過程，後來提出了摩爾定律的概念，以描述計算能力的指數增長。 最重要的是，鮑勃·诺伊斯是"背叛的八人"中的領袖，他對微電子學充滿魅力和願景，對使晶體管變小，廉價和可靠的技術進步有直觀的感覺。 將新發明與商業機會匹配正是像費尔柴尔德這樣的創業公司所需要的成功方式 - 也是芯片行業起飛所需要的方式。

By the time Fairchild was founded, the science of transistors was broadly clear, but manufacturing them reliably was an extraordinary challenge. The first commercialized transistors were made of a block of germanium with different materials layered on top in the shape of a mesa from the Arizona desert. These layers were fabricated by covering a portion of the germanium with a drop of black wax, using a chemical to etch off the germanium that wasn't covered with wax, and then removing the wax, creating mesa shapes atop the germanium.

費爾柴德成立時，晶體管技術已經相對成熟，但可靠地製造晶體管卻是一個極大的挑戰。最早商業化的晶體管是由一塊由德州阿利桑那沙漠中的不同材料層疊而成的鍺製成，被刻成了「台地形狀」。這些層狀物是通過在鍺的部分位置放上一滴黑色蠟來製造的，之後使用一種化學物質來腐蝕沒有被蠟覆蓋的鍺，然後再刪除蠟，這樣就在鍺上面形成了台地形狀。

A downside of the mesa structure was that it allowed impurities like dust or other particles to become lodged on the transistor, reacting with the materials on the its surface. Noyce's colleague Jean Hoerni, a Swiss physicist and avid mountaineer, realized the mesas weren't necessary if the entire transistor could be built into, rather than on top of, the germanium. He devised a method of fabricating all the parts of a transistor by depositing a layer of protective silicon dioxide on top of a slab of silicon, then etching holes where needed and depositing additional materials. This method of depositing protective layers avoided exposing materials to air and impurities that could cause defects. It was a major advance in reliability.

Mesa結構的缺點是它允許像灰塵或其他微粒這樣的雜質附著在晶體管上，與其表面的材料反應。諾伊斯的同事Jean Hoerni，一位瑞士物理學家和熱愛登山者，意識到如果整個晶體管可以內置而不是放置在鍺上，那麼mesa就不是必需的。他設計了一種方法，通過在矽石板上鍍一層保護性的二氧化矽，然後在需要的地方刻孔並鍍覆其他材料來製造晶體管的所有部件。這種鍍覆保護層的方法避免了暴露材料於空氣和可能引起缺陷的雜質中。這是可靠性的一個重大進步。

Several months later, Noyce realized Hoerni's "planar method" could be used to produce multiple transistors on the same piece of silicon. Where

Kilby, unbeknownst to Noyce, had produced a mesa transistor on a germanium base and then connected it with wires, Noyce used Hoerni's planar process to build multiple transistors on the same chip. Because the planar process covered the transistor with an insulating layer of silicon dioxide, Noyce could put "wires" directly on the chip by depositing lines of metal on top of it, conducting electricity between the chip's transistors. Like Kilby, Noyce had produced an integrated circuit: multiple electric components on a single piece of semiconductor material. However, Noyce's version had no freestanding wires at all. The transistors were built into a single block of material. Soon, the "integrated circuits" that Kilby and Noyce had developed would become known as "semiconductors" or, more simply, "chips."

几个月后，诺伊斯意识到霍尔尼的"平面方法"可以用于在同一块硅上生产多个晶体管。在他不知情的情况下，基尔比在锗基础上生产了一种台阶晶体管，然后用电线连接它，而诺伊斯则使用了霍尔尼的平面工艺，在同一芯片上建造了多个晶体管。由于平面工艺在晶体管上覆盖了一层绝缘的二氧化硅，诺伊斯可以将"电线"直接放在芯片上，通过在其上方沉积金属线来导电芯片的晶体管之间。像基尔比一样，诺伊斯也生产出了一种集成电路：在单片半导体材料上的多个电力组件。然而，诺伊斯的版本根本没有独立的电线。晶体管被建造成一个单一的材料块。不久之后，基尔比和诺伊斯开发出的"集成电路"将被称为"半导体器件"，或更简单地称为"芯片"。

Noyce, Moore, and their colleagues at Fairchild Semiconductor knew their integrated circuits would be vastly more reliable than the maze of wires that other electronic devices relied on. It seemed far easier to miniaturize Fairchild's "planar" design than standard mesa transistors. Smaller circuits, meanwhile, would require less electricity to work. Noyce and Moore began to realize that miniaturization and electric efficiency were a powerful combination: smaller transistors and reduced power consumption would create new use cases for their integrated circuits. At the outset, however, Noyce's integrated circuit cost fifty times as much to make as a simpler device with separate components wired together. Everyone agreed Noyce's invention was clever, even brilliant. All it needed was a market.

Noyce、Moore以及Fairchild Semiconductor的同事們早就知道它們的積體電路比其他電子設備所依賴的一堆電線要可靠得多。Fairchild的「平面」設計似乎比標準的積體電路更容易微縮。同時，更小的電路需要更少的電力來運作。Noyce和Moore開始意識到微縮和電能效率是一個強大的組合: 更小的晶體管和降低的電力消耗將為他們的積體電路創造新的應用場景。然而，一開始Noyce的積體電路制造成本是一個由單獨元件有線連接而成的簡單設備的50倍。每個人都同意Noyce的發明是聰明，甚至是卓越的。它所需要的是一個市場。

CHAPTER 4 Liftoff

T hree days after Noyce and Moore founded Fairchild Semiconductor, at 8:55 p.m., the answer to the question of who would pay for integrated circuits hurtled over their heads through California's nighttime sky. Sputnik, the world's first satellite, launched by the Soviet Union, orbited the earth from west to east at a speed of eighteen thousand miles per hour. "Russ 'Moon' Circling Globe," declared the headline in the *San Francisco Chronicle* , reflecting Americans' fears that this satellite gave the Russians a strategic advantage. Four years later, the Soviet Union followed Sputnik with another shock when cosmonaut Yuri Gagarin became the first person in space.

諾伊斯和摩爾創立費爾柴爾德半導體公司三天後的晚上8點55分，第一顆人造衛星"斯普特尼克"從加州夜空疾馳而過，同時也揭開了誰將支付集成電路的問題。這顆蘇聯發射的衛星以每小時一萬八千英里的速度從西往東環繞地球。旧金山纪事报的標題"莫斯科"月亮"环球"反映了美國人對這顆衛星給予蘇聯戰略優勢的擔憂。四年後，蘇聯太空人尤里·加加林成為第一個進入太空的人，再次給世界帶來震撼。

Across America, the Soviet space program caused a crisis of confidence. Control of the cosmos would have serious military ramifications. The U.S. thought it was the world's science superpower, but now it seemed to have fallen behind. Washington launched a crash program to catch up with the Soviets' rocket and missile programs, and President John F. Kennedy declared the U.S. would send a man to the moon. Bob Noyce suddenly had a market for his integrated circuits: rockets.

The first big order for Noyce's chips came from NASA, which in the 1960s had a vast budget to send astronauts to the moon. As America set its sights on a lunar landing, engineers at the MIT Instrumentation Lab were tasked by NASA to design the guidance computer for the Apollo spacecraft, a device that was certain to be one of the most complicated computers ever made. Everyone agreed transistor-based computers were far better than the vacuum-tube equivalents that had cracked codes and calculated artillery trajectories during World War II. But could any of these devices really guide a spacecraft to the moon? One MIT engineer calculated that to meet the needs of the Apollo mission, a computer would need to be the size of a refrigerator and would consume more electricity than the entire Apollo spacecraft was expected to produce.

在美国，苏联的航天计划引起了信心危机。掌控太空将产生严重的军事后果。美国认为自己是世界上最强大的科学超级大国，但现在似乎已经落后了。华盛顿启动了一个紧急计划，以赶上苏联的火箭和导弹计划，总统约翰·肯尼迪宣布美国将派人登上月球。鲍勃·诺伊斯突然有了一个市场，他的集成电路被用于火箭。 诺伊斯芯片的第一个大订单来自NASA，在20世纪60年代，NASA拥有广阔的预算，用于将宇航员送上月球。当美国把目光投向月球登陆时，麻省理工学院的工程师们受NASA委托设计阿波罗宇宙飞船的制导计算机，这是一个肯定是有史以来最复杂的计算机设备。每个人都同意，与在第二次世界大战期间破解密码和计算炮弹弹道的电子管相比，基于晶体管的计算机要好得多。但任何这些设备都能真正将宇宙飞船引导到月球上吗？麻省理工学院的一名工程师计算出，为了满足阿波罗使命的需求，计算机需要像一台冰箱那么大，而且消耗的电力将超过预计生产的整个阿波罗宇宙飞船的电力消耗。

MIT’s Instrumentation Lab had received its first integrated circuit, produced by Texas Instruments, in 1959, just a year after Jack Kilby had invented it, buying sixty-four of these chips for a price of $1,000 to test them as part of a U.S. Navy missile program. The MIT team ended up not using chips in that missile but found the idea of integrated circuits intriguing. Around the same time, Fairchild began marketing its own “Micrologic” chips. “Go out and buy large quantities of those things,” one MIT engineer ordered a colleague in January 1962, “ to see if they are real.”

MIT的儀器實驗室在1959年收到了由德州儀器公司生產的第一塊集成電路，僅僅在Jack Kilby發明這種技術一年後，購買了64個這些芯片，價值1000美元，用於美國海軍的導彈計劃測試。 MIT團隊最終沒有在該導彈中使用芯片，但認為集成電路的概念非常有趣。大約在同一時間，費爾柴德公司開始銷售自己的“微型邏輯”芯片。 "去買大量的那些芯片，"一位MIT工程師在1962年1月吩咐同事，“看看它們是否真實可行。"

Fairchild was a brand-new company, run by a group of thirty-year-old engineers with no track record, but their chips were reliable and arrived on time. By November 1962, Charles Stark Draper, the famed engineer who ran the MIT lab, had decided to bet on Fairchild chips for the Apollo program, calculating that a computer using Noyce's integrated circuits would be one-third smaller and lighter than a computer based on discrete transistors. It would use less electricity, too. The computer that eventually took Apollo 11 to the moon weighed seventy pounds and took up about one cubic foot of space, a thousand times less than the University of Pennsylvania's ENIAC computer that had calculated artillery trajectories during World War II.

費爾柴爾德是一家全新的公司，由一群沒有任何紀錄的三十多歲工程師運營，但它們的晶片可靠且準時到貨。到了1962年11月，擁有麻省理工學院實驗室的著名工程師查爾斯·斯塔克·德拉珀（Charles Stark Draper）已決定將賭注押在費爾柴爾德晶片上，以用諾伊斯的集成電路為基礎的計算機要比基於離散晶體管的計算機小三分之一且更輕。它也會使用更少的電力。最終將阿波羅11號送上月球的計算機重70磅，佔用約一立方英尺的空間，比二戰期間在宾夕法尼亚大学计算炮彈弹道的ENIAC計算機輕了一千倍。

MIT considered the Apollo guidance computer one of its proudest accomplishments, but Bob Noyce knew that it was his chips that made the Apollo computer tick. By 1964, Noyce bragged, the integrated circuits in Apollo computers had run for 19 million hours with only two failures, one of which was caused by physical damage when a computer was being moved. Chip sales to the Apollo program transformed Fairchild from a small startup into a firm with one thousand employees. Sales ballooned from $500,000 in 1958 to $21 million two years later.

MIT認為阿波羅控制電腦是其最驕傲的成就之一，但鮑伯·諾伊斯知道，是他的晶片讓阿波羅電腦開始運轉。到1964年，諾伊斯自豪地說，阿波羅計算機中的集成電路已連續運行了1900萬小時，只出現了兩次故障，其中一次是由於計算機在移動時受到物理損壞造成的。阿波羅計劃對晶片的銷售使費爾德成為擁有一千名員工的公司，銷售額從1958年的50萬美元增至兩年後的2100萬美元。

As Noyce ramped up production for NASA, he slashed prices for other customers. An integrated circuit that sold for $120 in December 1961 was discounted to $15 by next October. NASA's trust in integrated circuits to guide astronauts to the moon was an important stamp of approval. Fairchild's Micrologic chips were no longer an untested technology; they were used in the most unforgiving and rugged environment: outer space.

This was good news for Jack Kilby and Texas Instruments, even though their chips played only a small role in the Apollo program. At TI headquarters in Dallas, Kilby and TI president Pat Haggerty were looking for a big customer for their own integrated circuits. Haggerty was the son of a railroad telegrapher from small-town South Dakota who'd trained as an electrical engineer and worked on electronics for the U.S. Navy during World War II. Since the day he arrived at Texas Instruments in 1951, Haggerty had focused on selling electronic systems to the military.

隨著諾伊斯為NASA增加生產，他也為其他客戶削減了價格。1961年12月銷售120美元的集成電路到了翌年10月已經被折價至15美元。NASA對集成電路的信任，以指導宇航員登月，是一個重要的認可。費爾德的Micrologic晶片不再是未經測試的技術，而是在最嚴苛和艱苦的環境：外太空中被使用。 這對傑克·基爾比和德州儀器公司來說是個好消息，即使他們的芯片在阿波羅計劃中只扮演了一個小角色。在德克薩斯儀器公司的總部，基爾比和TI總裁帕特·哈格蒂正在尋找他們自己的集成電路的大客戶。哈格蒂是來自南達科他州小鎮的鐵路電報員之子，在第二次世界大戰期間接受電氣工程訓練，並參與了美國海軍的電子工作。從1951年到德州儀器公司以來，哈格蒂一直專注於向軍隊銷售電子系統。

Haggerty intuitively understood that Jack Kilby's integrated circuit could eventually be plugged into every piece of electronics the U.S. military used. A captivating public speaker, when he preached to Texas Instruments employees about the future of electronics, Haggerty was remembered by one TI veteran as "like a messiah speaking from the mountaintop. He seemed like he could predict everything." As the U.S. and the Soviet Union lurched between nuclear standoffs in the early 1960s—first over control of divided Berlin, then during the Cuban Missile Crisis—Haggerty had no better customer than the Pentagon. Just months after Kilby created the integrated circuit, Haggerty briefed Defense Department staff on Kilby's invention. The next year, the Air Force Avionics Lab agreed to sponsor TI's chip research. Several small contracts for military devices followed. But Haggerty was looking for a big fish.

哈格蒂直觉地了解到杰克·基尔比的集成电路最终可能会插入美国军方使用的每一件电子设备中。他是一个吸引人的公众演讲家，当他向德州仪器公司员工传授有关未来电子技术的知识时，被一位TI老兵称为"像从山顶传教的救世主。他似乎能预测一切。" 早在1960年代初，当美国和苏联在核危机中摇摆不定时，首先是关于控制分裂的柏林，然后是古巴导弹危机，哈格蒂没有比五角大楼更好的客户了。基尔比发明集成电路仅几个月后，哈格蒂向国防部工作人员介绍了这一发明。次年，空军航空电子实验室同意赞助TI进行芯片研究。接着，进行了几项军用装置的小型合同。但哈格蒂正在寻找一条大鱼。

In fall 1962, the Air Force began looking for a new computer to guide its Minuteman II missile, which was designed to hurl nuclear warheads through space before striking the Soviet Union. The first version of the Minuteman had just entered service, but it was so heavy it could barely hit Moscow from launch sites scattered across the American West. Its onboard guidance computer was a hulking monstrosity, based on discrete transistors, with the targeting program fed into the guidance computer via Mylar tape with holes punched in it.

在1962年秋季，空軍開始尋找一台新的電腦來引導Minuteman II導彈，該導彈旨在在撞擊蘇聯之前將核彈頭投射到太空中。第一版Minuteman剛剛投入使用，但它太重了，將發射地點分散在美國西部，只能勉強命中莫斯科。它的機上引導電腦是一個龐大的怪物，基於離散晶體管，將目標程序通過打孔的Mylar帶輸入到引導電腦中。

Haggerty promised the Air Force that a computer using Kilby's integrated circuits could perform twice the computations with half the weight. He envisioned a computer that used twenty-two different types of integrated circuits. In his mind's eye, 95 percent of the computer's functions would be conducted by integrated circuits carved into silicon, which together weighed 2.2 ounces. The remaining 5 percent of the computer hardware, which TI's engineers couldn't yet figure out how to put on a chip, weighed 36 pounds.

“It was just a matter of size and weight,” explained one the engineers designing the computer, Bob Nease, regarding the decision to use integrated circuits. “ There was really not much of a choice.”

海格提向空军承诺，使用基尔比的集成电路制造的计算机能够以一半的重量执行两倍的计算。他设想使用二十二种不同类型的集成电路制造计算机。在他的脑海中，95%的计算机功能将由刻在硅上的集成电路完成，重量总共为2.2盎司。TI的工程师无法想象如何将剩余的5%计算机硬件放在芯片上，其重量为36磅。正在设计计算机的工程师之一鲍勃·尼斯解释说：“这只是一个尺寸和重量的问题。实际上没有太多选择。”

Winning the Minuteman II contract transformed TI’s chip business. TI’s integrated circuit sales had previously been measured in the dozens, but the firm was soon selling them by the thousands amid fear of an American “missile gap” with the Soviet Union. Within a year, TI’s shipments to the Air Force accounted for 60 percent of all dollars spent buying chips to date. By the end of 1964, Texas Instruments had supplied one hundred thousand integrated circuits to the Minuteman program. By 1965, 20 percent of all integrated circuits sold that year went to the Minuteman program. Pat Haggerty’s bet on selling chips to the military was paying off. The only question was whether TI could learn how to mass-produce them.

赢得Minuteman II合同改變了TI的芯片業務。 TI之前的集成電路銷售數量過去被稱為幾十個，但很快由於對美國與蘇聯之間的“飛彈差距”的恐懼，該公司開始以千計的規模銷售它們。一年內，TI向空軍的出貨佔迄今為止所有芯片支出的60％。到1964年底，德克薩斯儀器已經向Minuteman計劃提供了十萬個集成電路。到1965年，當年銷售的所有集成電路中有20％用於Minuteman計劃。 Pat Haggerty對向軍方出售芯片的押注正在付出。唯一的問題是TI是否能夠學會大規模生產它們。

CHAPTER 5 Mortars and Mass Production

J ay Lathrop pulled into Texas Instruments' parking lot for his first day of work on September 1, 1958, just as Jack Kilby's fateful summer spent tinkering in TI's labs was coming to a close. After graduating from MIT, where he'd overlapped with Bob Noyce, Lathrop had worked at a U.S. government lab where he was tasked with devising a proximity fuse that would enable an 81mm mortar shell to detonate automatically above its target. Like engineers at Fairchild, he was struggling with mesa-shaped transistors, which were proving difficult to miniaturize. Existing manufacturing processes involved placing specially shaped globs of wax on certain portions of the semiconductor material, then washing away the uncovered portions using specialized chemicals. Making smaller transistors required smaller globs of wax, but keeping these globs in the correct shape proved challenging.

杰伊·拉斯罗普（Jay Lathrop）于1958年9月1日首次来到德克萨斯仪器（Texas Instruments）的停车场上班，恰好就在杰克·基尔比（Jack Kilby）在TI实验室里度过富有命运的夏季结束之际。在毕业于麻省理工学院并与鲍勃·诺伊斯（Bob Noyce）并肩的时期后，拉斯罗普曾在一家美国政府实验室工作，他的任务是设计一种接近引信，使81毫米迫击炮弹能够在其目标上方自动引爆。就像Fairchild的工程师一样，他正在为平台形晶体管而苦苦挣扎，这些晶体管证明是难以微型化的。现有的制造工艺涉及将特殊形状的蜡块放置在半导体材料的某些部分上，然后使用专用化学品洗掉未覆盖的部分。制造更小的晶体管需要更小的蜡块，但是保持这些蜡块的正确形状却很具有挑战性。

While looking through a microscope at one of their transistors, Lathrop and his assistant, chemist James Nall, had an idea: a microscope lens could take something small and make it look bigger. If they turned the microscope upside down, its lens would take something big and make it look smaller. Could they use a lens to take a big pattern and "print" it onto germanium, thereby making miniature mesas on their blocks of germanium? Kodak, the camera company, sold chemicals called photoresists, which reacted when exposed to light.

拉索普和他的助手，化学家詹姆斯·纳尔，在检查他们的晶体管时，有了一个想法：显微镜镜头可以将小物体变大看。如果他们将显微镜倒过来，它的镜头将可以将大物体变小。他们能否使用镜头将大图案“印刷”到锗上，在其锗块上制造微型台地？相机公司柯达销售称为光敏树脂的化学品，这些化学品暴露在光线下会产生反应。

Lathrop covered a block of germanium with one of Kodak’s photoresist chemicals that would disappear if exposed to light. Next, he turned his microscope upside down, covering the lens with a pattern so that light would only pass through a rectangle-shaped area. Light entered the pattern, shined in a rectangle shape through the lens, and was shrunk in size by the upside-down microscope as it focused onto the photoresist-coated germanium, with the rays of light creating a perfectly shaped, miniature version of the rectangular pattern. Where light struck the layer of photoresist, the chemical structure was altered, allowing it to be washed away, leaving a tiny rectangular hole, far smaller and more accurately shaped than any glob of wax could have been. Soon Lathrop discovered he could print “wires,” too, by adding an ultra-thin layer of aluminum to connect the germanium with an external power source.

拉斯罗普用柯达的光致抗蚀剂覆盖一块锗，这种化学物质会因暴露在光线下而消失。接下来，他把显微镜倒过来，覆盖镜头的图案使光线只通过矩形区域。光线穿过图案，通过镜头成为矩形形状，倒转的显微镜将它缩小并聚焦在涂有光致抗蚀剂的锗上，光线在其上形成了一个完美的迷你版本的矩形图案。光线照射到光致抗蚀剂层的地方，其化学结构被改变，可以被洗去，留下了一个微小的矩形孔，比任何蜡块粘涂出来的形状都小得多且更准确。很快，拉斯罗普发现他还可以通过在锗上添加一层超薄的铝连接外部电源来打印“电线”。

Lathrop called the process photolithography—printing with light. He produced transistors much smaller than had previously been possible, measuring only a tenth of an inch in diameter, with features as small as 0.0005 inches in height. Photolithography made it possible to imagine mass-producing tiny transistors. Lathrop applied for a patent on the technique in 1957. With the Army band playing, the military gave him a medal for his work and a $25,000 cash bonus, which he used to buy his family a Nash Rambler station wagon.

拉思羅普稱這個過程為光刻技術 - 利用光印刷。他生產了比以前可行的更小的晶體管，直徑僅有十分之一英寸，高度可達0.0005英寸。光刻技術使得大量生產微小的晶體管成為可能。拉思羅普於1957年申請了這項技術的專利。在軍樂隊演奏的儀式中，軍方頒發了獎章和2.5萬美元的現金獎金，他用這筆錢買了一輛納什拉姆勞特旅行車給家人。

Pat Haggerty and Jack Kilby immediately realized Lathrop’s photolithography process was worth a lot more than the $25,000 prize the Army had given him. The Minuteman II missile program needed thousands of integrated circuits. The Apollo spacecraft needed tens of thousands more. Haggerty and Kilby realized that light rays and photoresists could solve the mass-production problem, mechanizing and miniaturizing chipmaking in a way that soldering wires together by hand could not.

Implementing Lathrop’s lithography process at Texas Instruments required new materials and new processes. Kodak’s photoresist chemicals were insufficiently pure for mass production, so TI bought its own centrifuges and reprocessed the chemicals that Kodak supplied. Lathrop took trains across the country in search of “masks” that could be used to project precise patterns of light onto photoresist-covered slabs of semiconductor material to carve circuits. He eventually concluded that no existing mask company had sufficient precision, so TI decided to make masks itself, too. The slabs of silicon that Kilby’s integrated circuits required had to be ultra-pure, beyond what any company sold. TI therefore also began producing its own silicon wafers.

帕特·哈格蒂和杰克·基尔比很快意识到拉思罗普的光刻过程的价值远远超过军队给予他的2.5万美元奖金。Minuteman II导弹计划需要数千个集成电路。阿波罗飞船需要数万个。哈格蒂和基尔比认识到，光线和光阻剂可以解决量产问题，将芯片制造机械化和微型化，这是手工焊接电线所不能做到的。 在德州仪器实施拉思罗普的光刻工艺需要新材料和新工艺。柯达的光阻化学品不够纯净以供量产，因此TI购买了自己的离心机并重新处理柯达供应的化学品。拉思罗普乘火车跨越全国寻找可以用于将精确光图案投射在覆盖有光阻的半导体片上雕刻电路的“掩模”。 他最终得出结论，没有任何现有的掩模公司有足够的精度，因此TI决定也自己制造掩模。基尔比的集成电路所需的硅片必须

超级纯净，超过任何公司销售的。因此，TI也开始生产自己的硅晶片。

Mass production works when everything is standardized. General Motors plugged many of the same car parts into all the Chevrolets that rolled off its assembly lines. When it came to semiconductors, companies like TI lacked the tools to know whether all the components of their integrated circuits were the same. Chemicals had impurities that at the time were impossible to test. Variation in temperature and pressure caused unexpected chemical reactions. The masks through which light was projected could be contaminated by particles of dust. A single impurity could ruin an entire production run. The only method of improvement was trial and error, with TI organizing thousands of experiments to assess the impact of different temperatures, chemical combinations, and production processes. Jack Kilby spent each Saturday pacing TI's hallways and checking on his engineers' experiments.

當一切標準化時，大規模生產才能進行。通用汽車在裝配線上插入許多相同的汽車零件，製造出所有的雪佛蘭汽車。對於半導體，TI等公司缺乏工具來確定他們集成電路的所有零件是否相同。當時的化學品中存在無法檢測的雜質。溫度和壓力變化會引起意想不到的化學反應。用來投射光線的口罩可能會被塵埃顆粒污染。一個純度較低的微粒會破壞整個生產過程。唯一的改善方法是通過試錯法，TI會組織數千個實驗來評估不同溫度，化學物質組合和生產過程的影響。傑克•基爾比（Jack Kilby）每個星期六都在TI的大廳裡踱步，檢查他的工程師們的實驗。

TI production engineer Mary Anne Potter spent months running round-the-clock tests. The first woman to earn a physics degree from Texas Tech, Potter was hired at TI to scale up chip production for the Minuteman missile. She often worked the night shift, from 11 p.m. until 8 a.m., to make sure experiments were progressing according to plan. Gathering data took days of experimentation. Then she ran regressions on the data, using her slide rule to calculate exponents and square roots, plot the results on a graph, and then interpret them—doing it all by hand. It was a slow, laborious, painful process, relying on human "computers" to crunch numbers. Yet trial and error was the only method Texas Instruments had.

德州仪器的生产工程师玛丽·安妮·波特花费数月时间进行全天候测试。作为德克萨斯理工大学物理学学位的第一位女性毕业生，波特被聘用来扩大Minuteman导弹的芯片生产规模。她经常工作到晚上11点到早上8点的夜班，以确保实验按计划进行。收集数据需要数天的实验。然后，她使用滑尺计算指数和平方根，将结果绘制在图表上，然后手动解释数据。这是一种缓慢、费力、痛苦的过程，依赖于人类“计算机”来计算数字。然而，试错是德州仪器唯一的方法。

Morris Chang arrived at TI in 1958, the same year as Jay Lathrop, and was put in charge of a production line of transistors. Nearly a decade had passed since Chang fled Shanghai to escape the advancing Communist armies, first to Hong Kong and then to Boston, having won admission to Harvard, where he was the only Chinese student in the freshman class. After a year spent studying Shakespeare, Chang began to worry about his career prospects. “There were Chinese-American laundry people, there were Chinese-American restaurant people,” he recalled. “The only really serious… middle class profession that a Chinese American could pursue in the early fifties was technical.” Mechanical engineering seemed safer than English literature, Chang decided, so he transferred to MIT.

張忠謀於1958年來到德州儀器公司，與Jay Lathrop同年加入，被安排負責晶體管生產線。此時，從上海逃脫前進的共產軍隊已經十年了，張忠謀當時先逃到香港，再通過入學哈佛獲得入境證，成為該年級中唯一的華裔學生。在研究了一年莎士比亞之後，張忠謀開始擔心自己的職業前途。他回憶道：“當時華裔美國人還是做洗衣店和餐廳生意的居多，而在五十年代初，他們唯一真正可行的中產階級職業就是技術人員。”張忠謀決定轉學到麻省理工學院，認為機械工程比英國文學更有前途。

After graduating, Chang was hired by Sylvania, a big electronics firm with facilities outside of Boston. He was tasked with improving Sylvania’s manufacturing “yield”—the share of transistors that actually worked. Chang spent his days tinkering with Sylvania’s production processes and his evenings studying Shockley’s *Electrons and Holes in Semiconductors* , the bible of early semiconductor electronics. After three years at Sylvania, Chang received a job offer from TI, and moved to Dallas, Texas—“cowboy country,” he remembered, and a land of “95-cent steaks.” He was tasked with running a production line of transistors to be used in IBM computers, a type of transistor so unreliable that TI's yield was close to zero, he recalled. Almost all had manufacturing imperfections that caused circuits to short or to malfunction; they had to be tossed out.

畢業後，張被雇用到席爾瓦尼亞，一家設於波士頓外的大型電子公司。他的任務是提高席爾瓦尼亞的制造"產出率"-實際工作的晶體管的份額。張花費他的時間在席爾瓦尼亞的生產過程上做修整，晚上則研究著薩克利的《半導體中的電子與空穴》，這是早期半導體電子學的聖經。在席爾瓦尼亞待了三年後，張收到了從得克薩斯儀器公司的工作邀請，並移居至達拉斯，德克薩斯州-他記得那是"牛仔之地"，也是"95美分牛排"的國土。他的任務是運營晶體管的生產線，這類晶體管非常不可靠，TI的產出率接近於零，他回憶說，幾乎所有的制造缺陷都會導致電路短路或故障，它們必須被丟棄。

A master bridge player, Chang approached manufacturing as methodically as he played his favorite card game. Upon arriving at TI, he began systematically tweaking the temperature and pressure at which different chemicals were combined, to determine which combinations worked best, applying his intuition to the data in a way that amazed and intimidated his colleagues. "You had to be careful when you worked with him," remembered one colleague. "He sat there and puffed on his pipe and looked at you through the smoke." The Texans who worked for him thought he was "like a Buddha." Behind the tobacco smoke was a brain second to none. "He knew enough about solid-state physics to lord it over anyone," one colleague recalled. He had a reputation for being a tough boss. "Morris was so bad for beating up on people," one subordinate recalled. "If you hadn't ever been chewed out by Morris, you hadn't been at TI." Chang's methods produced results, though. Within months, the yield on his production line of transistors jumped to 25 percent. Executives from IBM, America's biggest tech company, came to Dallas to study his methods. Soon he was placed in charge of TI's entire integrated circuit business.

張先生是一位高超的橋牌玩家，他把製造工作看做是他最喜愛的紙牌遊戲一樣有方法論。他到達德州儀器公司後，開始系統地調整不同化學物質的溫度和壓力，以確定哪些組合效果最佳，並憑藉自己的直覺對數據進行分析，使同事們驚訝和畏懼。"當你和他一起工作時，你必

須小心，”一位同事回憶說。“他坐在那裡抽著煙斗，透過煙霧看著你。”他的德州下屬認為他像是“一位佛陀”。在煙霧背後是一個傑出的大腦。“他對固態物理學的了解足以讓他壓倒任何人，”一位同事回憶說。他以嚴厲的老板聞名。“莫里斯對人批評非常嚴厲，”一名下屬回憶說。“如果你沒有被莫里斯批評過，那就沒有在德州儀器工作過。”張先生的方法帶來了成果。不到幾個月，他的晶體管生產線產量就提高到了25%。美國最大的科技公司IBM的高管們來到達拉斯研究他的方法。很快，他負責了德州儀器整個集成電路業務。

Like Chang, Noyce and Moore saw no limits to the growth of the chip industry so long as they could figure out mass production. Noyce realized his MIT classmate Jay Lathrop, with whom he’d hiked New Hampshire’s mountains while in graduate school, had discovered a technique that could transform transistor manufacturing. Noyce acted swiftly to hire Lathrop’s lab partner, chemist James Nall, to develop photolithography at Fairchild. “Unless we could make it work,” Noyce reasoned, “we did not have a company.”

It was up to production engineers like Andy Grove to improve Fairchild’s manufacturing process. After fleeing Hungary’s Communist government in 1956 and arriving in New York as a refugee, Grove had worked his way into a PhD program at Berkeley. He’d written Fairchild in 1962 to ask for a job interview but was told to try again later: “We like our young men to interview with us when they have finished interviewing with everybody else,” the rejection letter explained. Grove found Fairchild’s rejection letter “condescendingly disgusting,” he recalled, an early sign of the hubris that would come to define Silicon Valley. But as demand for Fairchild’s semiconductors increased, the company suddenly had a desperate need for chemical engineers. One company executive rang Berkeley and asked for a list of the best students in the Chemistry Department. Grove was at the top of the list and was called to Palo Alto to meet Gordon Moore. “It was love at first sight,” Grove remembered. He was hired in 1963 and would spend the rest of his life building the chip industry alongside Noyce and Moore.

和張衡一樣，諾伊斯和摩爾認為只要他們能夠想出量產方法，晶片產業就不會有任何發展上限。諾伊斯意識到他在 MIT 課堂上認識的同學 Jay Lathrop 在攻讀研究生時發現了一種可以改變晶體管製造的技術。

諾伊斯立刻行動起來，聘請了 Lathrop 的實驗室夥伴、化學家詹姆斯·納爾來開發在費爾德公司的光學製圖技術。「除非我們能讓它發揮作用，否則我們就沒有公司了。」諾伊斯這樣想道。 像安迪·格羅夫這樣的生產工程師負責改善費爾德公司的製造過程。1956 年他逃離匈牙利的共產政府並到達紐約成為一名難民，他通過自己的努力進入了加州大學伯克利分校攻讀博士學位。1962 年他曾寫信給費爾德公司要求面試，卻被告知要稍後再試：「我們喜歡那些和其他人面試完後來和我們面試的年輕人。」拒絕信使格羅夫「受到了屈辱性的侮辱」，他回憶說。但隨著對費爾德公司的半導體需求不斷增加，公司突然迫切需要化學工程師。一位公司高管致電伯克利，要求列出化學系中最優秀的學生名單。格羅夫排在榜首，並被召集到帕羅奧圖與戈登·摩爾會面。「這是一見鍾情，」格羅夫回憶道。他於 1963 年獲得聘用，並在之後的一生中與諾伊斯和摩爾一同建立了晶片產業。

The Nobel Prize for inventing the transistor went to Shockley, Bardeen, and Brattain. Jack Kilby later won a Nobel for creating the first integrated circuit; had Bob Noyce not died at the age of sixty-two, he’d have shared the prize with Kilby. These inventions were crucial, but science alone wasn’t enough to build the chip industry. The spread of semiconductors was enabled as much by clever manufacturing techniques as academic physics. Universities like MIT and Stanford played a crucial role in developing knowledge about semiconductors, but the chip industry only took off because graduates of these institutions spent years tweaking production processes to make mass manufacturing possible. It was engineering and intuition, as much as scientific theorizing, that turned a Bell Labs patent into a world-changing industry.

發明晶體管的諾貝爾獎頒給了肖克利、巴丁和布拉丁。傑克·基爾比後來因為創造出第一個集成電路而獲得了諾貝爾獎；如果鮑伯·諾伊斯不在六十二歲去世，他將與基爾比分享這個獎項。這些發明都是至關重要的，但是僅靠科學是無法建立芯片產業的。半導體的普及同樣受益於巧妙的製造技術和學術物理學的發展。麻省理工學院和史丹福大學等大學在研究半導體方面發揮了至關重要的作用，但是芯片產業的興起僅是因為這些機構的畢業生花了多年時間調整生產過程，以實現大規模製造。除了科學理論化的部分之外，工程知識和直覺能力同樣起

到了至關重要的作用，將貝爾實驗室的專利變成了具有全球影響力的產業。

Shockley, who was widely recognized as one of the greatest theoretical physicists of his generation, eventually abandoned his effort to make a fortune and get his name in the *Wall Street Journal* . His contribution in theorizing the transistor was important. But it was the traitorous eight young engineers who abandoned his company, as well as a similar group at Texas Instruments, who turned Shockley’s transistors into a useful product—chips—and sold them to the U.S. military while learning how to mass-produce them. Armed with these capabilities, Fairchild and TI entered the mid-1960s with a new challenge: turning chips into a mass market product.

被广泛认为是他那一代中最伟大的理论物理学家之一，Shockley最终放弃了致富和被刊登在华尔街日报上的努力。他在晶体管理论上的贡献非常重要。但正是那些叛变的八个年轻工程师和德州仪器公司的类似团队将他的晶体管转化为了一种有用的产品 - 芯片，并将其出售给美国军方，同时学会了如何进行大规模生产。凭借这些能力，Fairchild和TI于1960年代中期迎来了新的挑战：将芯片变成一个大众市场产品。

CHAPTER 6 “I… WANT… TO… GET… RICH”

T he computers that guided the Apollo spacecraft and the Minuteman II missile provided the initial liftoff for America’s integrated circuit industry. By the mid-1960s, the U.S. military was deploying chips in weaponry of all types, from satellites to sonar, torpedoes to telemetry systems. Bob Noyce knew that military and space programs were crucial for Fairchild’s early success, admitting in 1965 that military and space applications would use “over 95% of the circuits produced this year.” But he always envisioned an even larger civilian market for his chips, though in the early 1960s no such market existed. He would have to create it, which meant keeping the military at arm’s length so that he—not the Pentagon—set Fairchild’s R&D priorities. Noyce declined most military research contracts, estimating that Fairchild never relied on the Defense Department for more than 4 percent of its R&D budget. “There are very few research directors anywhere in the world who are really adequate to the job” of assessing Fairchild’s work, Noyce explained confidently, “and they are not often career officers in the Army.”

指导阿波罗航天器和Minuteman II导弹的计算机为美国的集成电路工业提供了起始推动力。到了1960年代中期，美国军队在各种武器中部署芯片，从卫星到声纳，从鱼雷到遥测系统。鲍勃·诺伊斯知道，军事和太空计划对Fairchild早期的成功至关重要，在1965年承认，军事和太空应用将使用“今年生产的电路的95%以上”。但他总是设想他的芯片有一个更大的民用市场，尽管在1960年代初还不存在这样的市场。他将不得不创造它，这意味着保持与军方的距离，以便他（而不是五角大楼）设置Fairchild的研发重点。诺伊斯拒绝了大多数军事研究合同，估计Fairchild从未依赖国防部超过其研发预算的4%。诺伊斯自信地解释说：“世界上很少有任何研究主管真正能够评估Fairchild的工作，他们通常不是陆军的职业军官。”

Noyce had experienced government-directed R&D while fresh out of graduate school when he worked for Philco, an East Coast radio manufacturer with a big defense unit. “The direction of the research was being determined by people less competent,” Noyce recalled, complaining about the time he wasted writing progress reports for the military. Now that he was running Fairchild, a company seeded by a trust-fund heir, he had flexibility to treat the military as a customer rather than a boss. He chose to target much of Fairchild's R&D not at the military, but at mass market products. Most of the chips used in rockets or satellites must have civilian uses, too, he reasoned. The first integrated circuit produced for commercial markets, used in a Zenith hearing aid, had initially been designed for a NASA satellite. The challenge would be making chips that civilians could afford. The military paid top dollar, but consumers were price sensitive. What remained tantalizing, though, was that the civilian market was far larger than even the bloated budgets of the Cold War Pentagon. "Selling R&D to the government was like taking your venture capital and putting it into a savings account," Noyce declared. "Venturing is venturing; you want to take the risk."

當諾伊斯剛畢業工作時，就經歷了政府指導的研發。當時他在一家名為 Philco 的東海岸收音機製造商工作，並有一個大型的國防部門。"研究的方向是由不夠 kompetent 的人確定的，"諾伊斯回憶說，抱怨他浪費時間為軍方撰寫進度報告。現在他正在經營一家由信託基金繁殖的 Fairchild 公司，他有彈性將軍方視為客戶而不是老板。他選擇將 Fairchild 的大部分研發不朝向軍方，而是朝向大眾市場產品。他推斷火箭或衛星中使用的大多數芯片也必定具有平民用途。最初用於商業市場、在 Zenith 聽力助聽器中使用的首個集成電路最初是為 NASA 衛星設計的。然而，挑戰在於製作民用芯片。軍方支付高價，但消費者對價格敏感。令人心動的是，即使是冷戰五角大樓的臃腫預算，民用市場也遠遠超過了它。"把 R&D 方案出售給政府就像是將您的風險資本放入儲蓄帳戶中，"諾伊斯宣稱。"風險創業就是風險創業; 您希望冒風險。"

In Palo Alto, Fairchild Semiconductor was surrounded by firms that supplied the Pentagon, from aerospace to ammunition, radio to radar. Though the military bought chips from Fairchild, the Defense Department was more comfortable working with big bureaucracies than nimble startups. As a result, the Pentagon underestimated the speed at which Fairchild and other semiconductor startups would transform electronics. A Defense Department assessment from the late 1950s had praised radio giant RCA for having "the most ambitious microminiaturization program underway" while dismissively noting that Fairchild had only two scientists working on the company's leading circuit program. Defense contractor Lockheed Martin, which had a research facility just down the road in Palo Alto, had over fifty scientists in their microsystem electronics division, the Defense Department reported, implying that Lockheed was far ahead.

在帕洛阿尔托，费查德半导体周围都是为五角大楼提供供应的公司，包括航空航天、弹药、无线电和雷达等。尽管军方从费查德购买芯片，但国防部更习惯与庞大的官僚机构合作，而不是敏捷的初创企业。因此，五角大楼低估了费查德和其他半导体初创企业转变电子行业的速度。上世纪五十年代后期的国防部评估表扬了无线电业巨头RCA拥有“最有抱负的微型化计划”，并轻蔑地指出费查德只有两名科学家在公司的主要电路项目上工作。国防承包商洛克希德·马丁公司（Lockheed Martin）在帕洛阿尔托的研究设施中拥有50多名微系统电子学科学家，国防部称，表明洛克希德领先很多。

However, it was Fairchild’s R&D team that, under Gordon Moore’s direction, not only devised new technology but opened new civilian markets as well. In 1965, Moore was asked by *Electronics* magazine to write a short article on the future of integrated circuits. He predicted that every year for at least the next decade, Fairchild would double the number of components that could fit on a silicon chip. If so, by 1975, integrated circuits would have sixty-five thousand tiny transistors carved into them, creating not only more computing power but also lower prices per transistor. As costs fell, the number of users would grow. This forecast of exponential growth in computing power soon came to be known as Moore’s Law. It was the greatest technological prediction of the century.

因此，正是在戈登·穆尔的指导下，费尔柴尔德的研发团队不仅设计出新技术，而且还开拓了新的民用市场。1965年，电子杂志要求穆尔就集成电路的未来撰写一篇短文。他预测，至少在未来十年，费尔柴尔德每年都将把能够安装在硅芯片上的零部件数量翻倍。如果这样的话，到1975年，集成电路将拥有六万五千个微小的晶体管，不仅增加了计算能力，而且还降低了每个晶体管的价格。随着成本的降低，使用者数量将会增加。这种指数级别的计算能力增长预测很快就被称为摩尔定律。这是本世纪最伟大的技术预测。

If the computing power on each chip continued to grow exponentially, Moore realized, the integrated circuit would revolutionize society far beyond rockets and radars. In 1965, defense dollars still bought 72 percent of all integrated circuits produced that year. However, the features the military demanded were useful in business applications, too. “Miniaturization and ruggedness,” one electronics publication declared, “means good business.” Defense contractors thought about chips mostly as a product that could replace older electronics in all the military’s systems. At Fairchild, Noyce and Moore were already dreaming of personal computers and mobile phones.

如果每個定向晶片的運算能力持續呈指數增長，摩爾意識到，集成電路將在遠遠超越火箭和雷達的範圍內革命化社會。1965年，防禦支出仍買下當年生產的所有集成電路的72％。然而，軍方要求的功能在商業應用中也很有用。“微型化和牢固性”，一份電子刊物宣稱，“意味著良好的商業”。防衛承包商主要考虑的是将芯片用作可以替换所有军事系统中老化电子设备的产品。在菲尔德，努伊斯和摩尔已经梦想着个人电脑和移动电话。

When U.S. defense secretary Robert McNamara reformed military procurement to cut costs in the early 1960s, causing what some in the electronics industry called the “McNamara Depression,” Fairchild’s vision of chips for civilians seemed prescient. The company was the first to offer a full product line of off-the-shelf integrated circuits for civilian customers. Noyce slashed prices, too, gambling that this would drastically expand the civilian market for chips. In the mid-1960s, Fairchild chips that previously sold for $20 were cut to $2. At times Fairchild even sold products below manufacturing cost, hoping to convince more customers to try them.

當美國國防部長羅伯特·麥克納馬拉在1960年代初改革軍事採購以削減成本時，引起了一些電子行業人士所謂的“麥克納馬拉蕭條”，費爾柴爾德對於民用芯片的願景似乎是預見的。該公司是第一家為民用客戶提供一整套現成集成電路的公司。諾伊斯也大幅降價，冒險地認為這將大幅擴大芯片的民用市場。在1960年代中期，先前售價為20美元的費爾柴爾德芯片降至2美元。費爾柴爾德甚至有時以低於製造成本的價格出售產品，希望說服更多的客戶嘗試他們的產品。

Thanks to falling prices, Fairchild began winning major contracts in the private sector. Annual U.S. computer sales grew from 1,000 in 1957 to

18,700 a decade later. By the mid-1960s, almost all these computers relied on integrated circuits. In 1966, Burroughs, a computer firm, ordered 20 million chips from Fairchild—more than twenty times what the Apollo program consumed. By 1968, the computer industry was buying as many chips as the military. Fairchild chips served 80 percent of this computer market. Bob Noyce's price cuts had paid off, opening a new market for civilian computers that would drive chip sales for decades to come. Moore later argued that Noyce's price cuts were as big an innovation as the technology inside Fairchild's integrated circuits.

由于价格的下降，费尔柴尔德开始赢得私营部门的重要合同。美国每年的计算机销量从1957年的1,000台增长到10年后的18,700台，到了1960年代中期，几乎所有这些计算机都依赖于集成电路。1966年，计算机公司Burroughs从费尔柴尔德订购了2,000万个芯片，比阿波罗计划所消耗的还要多20倍。到1968年，计算机行业购买的芯片数量和军用数量一样多，费尔柴尔德的芯片服务了80%的计算机市场。鲍勃·诺伊斯的价格削减得到了回报，为民用计算机开创了一个新市场，这将推动芯片销售数十年。摩尔后来认为，诺伊斯的价格削减与费尔柴尔德集成电路内部的技术一样具有创新性。

By the end of the 1960s, after a decade of development, Apollo 11 was finally ready to use its Fairchild-powered guidance computer to carry the first human to the moon. The semiconductor engineers in California's Santa Clara Valley had benefitted immensely from the space race, which provided a crucial early customer. Yet by the time of the first lunar landing, Silicon Valley's engineers had become far less dependent on defense and space contracts. Now they were focused on more earthly concerns. The chip market was booming. Fairchild's success had already inspired several top employees to defect to competing chipmakers. Venture capital funding was pouring into startups that focused not on rockets but on corporate computers.

到了1960年代末，經過十年的開發，阿波羅11號終於可以使用由費爾德公司提供技術支持的導航電腦，去實現將第一位人類送上月球的歷史使命。加州聖塔克拉拉谷的半導體工程師們在太空競賽中受益匪淺，這也成為他們早期的一位重要客戶。然而在第一次登陸月球的時候，矽谷工程師們已經不再依賴防衛和太空合同。現在，他們更加關注於更為現實的問題。晶片市場正在蓬勃發展，費爾德的成功已經激

勵了一些優秀的員工轉而加入競爭對手的晶片製造商。風投資金也湧入了一些專注於企業電腦領域的初創企業，而不是太空性質的領域。

Fairchild, however, was still owned by an East Coast multimillionaire who paid his employees well but refused to give them stock options, viewing the idea of giving away equity as a form of "creeping socialism." Eventually, even Noyce, one of Fairchild's cofounders, began wondering whether he had a future at the firm. Soon *everyone* began looking for the exit. The reason was obvious. Alongside new scientific discoveries and new manufacturing processes, this ability to make a financial killing was the fundamental force driving forward Moore's Law. As one of Fairchild's employees put it in the exit questionnaire he filled out when leaving the company: " I… WANT… TO… GET… RICH."

然而，費爾德還是由一位東海岸的千萬富翁所擁有，他雖然支付高工資但拒絕給予員工股票選擇權，認為這樣做屬於"潛在的社會主義行為"。最終，就連費爾德的聯合創始人諾伊斯也開始懷疑自己在公司的未來。很快，每個人都開始尋找出路。原因很明顯。除了新的科學發現和新的製造工藝之外，謀取財務收益的能力是推動摩爾定律向前發展的基本力量。正如費爾德的一名員工在離開公司填寫的離職問卷中所說："我...想要發財。"

PART II — THE CIRCUITRY OF THE AMERICAN WORLD

CHAPTER 7 Soviet Silicon Valley

A couple months after Bob Noyce invented his integrated circuit at Fairchild Semiconductor, an unexpected visitor arrived in Palo Alto. In fall 1959, two years after Sputnik first orbited the earth, Anatoly Trutko, a semiconductor engineer from the Soviet Union, moved into a Stanford University dormitory called Crothers Memorial Hall. Though Cold War competition was near its peak, the two superpowers had agreed to begin student exchanges, and Trutko was one of a handful of students selected by the USSR and vetted by the U.S. State Department. He spent his year at Stanford studying America's most advanced technology with the country's leading scientists. He even attended lectures given by William Shockley, who'd abandoned his startup and was now a professor at the university. After one class, Trutko asked the Nobel Prize winner to sign a copy of his magnum opus *Electrons and Holes in Semiconductors* . "To Anatole," Shockley signed, before barking at the young scientist with complaints that the Soviet Union refused to pay royalties for the textbook's Russian translation.

在Bob Noyce于Fairchild Semiconductor发明了它的集成电路几个月后，一位意外的访客来到了Palo Alto。1959年秋，即苏联的"斯普特尼克"首次进入轨道两年后，半导体工程师Anatoly Trutko搬进了斯坦福大学的 Crothers Memorial Hall。尽管冷战竞争达到了顶峰，但两个超级大国已经同意开始学生交流，而Trutko是苏联挑选并经过美国国务院审查的少数学生之一。他在斯坦福度过了一年，研究了美国最先进的技术和顶尖科学家们的研究。他甚至参加了威廉·肖克利的讲座，肖克利放弃了他的创业公司，现在是该大学的教授。在一堂课后，Trutko要求这位诺贝尔奖获得者签署一份他的巨著《半导体中的电子和空穴》。肖克利在书上签了"给Anatole"，然后抱怨苏联拒绝为该教科书的俄文翻译支付版税。

America's decision to let Soviet scientists like Trutko study semiconductors at Stanford was surprising, given U.S. fears that the Soviet Union was catching up in science and technology. Yet every country's electronics industry was increasingly oriented toward Silicon Valley, which so totally set the standard and pace of innovation that the rest of the world had no choice but to follow—even America's adversaries. The Soviets didn't pay Shockley royalties, but they understood the value of semiconductors, translating Shockley's textbook into Russian just two years after it was published. As early as 1956, America's spies had been ordered to acquire Soviet semiconductor devices to test their quality and track their improvements. A CIA report in 1959 found that America was only two to four years ahead of the Soviets in quality and quantity of transistors produced. At least several of the early Soviet exchange students were KGB agents—suspected at the time, but not confirmed until decades later—forging an intimate connection between student exchanges and Soviet defense industrial goals.

美國決定讓像特魯特科這樣的蘇聯科學家在斯坦福學習半導體技術，這是令人驚訝的，因為美國擔心蘇聯在科學技術方面越來越強。但每個國家的電子產業越來越以硅谷為引領，硅谷如此完全地設定了創新的標準和節奏，以至於世界其他地區沒有任何選擇，只能跟隨，甚至美國的敵人也不例外。蘇聯人沒有付給肖克利版稅，但他們了解半導體的價值，並在肖克利的教科書發表兩年後將其翻譯成俄語。早在1956年，美國的間諜就已經被訂購獲得蘇聯半導體設備來測試它們的質量並跟踪其改進。1959年的一份中央情報局報告發現，美國在生產晶體管的質量和數量方面僅領先蘇聯2到4年。至少有幾位早期的蘇聯交換生是克格勃特工，當時被懷疑，直到幾十年後才得到證實，進一步建立了學生交流與蘇聯國防工業目標之間的密切聯繫。

Just like the Pentagon, the Kremlin realized that transistors and integrated circuits would transform manufacturing, computing, and military power. Beginning in the late 1950s, the USSR established new semiconductor facilities across the country and assigned its smartest scientists to build this new industry. For an ambitious young engineer like Yuri Osokin it was hard to imagine a more exciting assignment. Osokin had spent much of his childhood in China, where his father worked in a Soviet military hospital in the city of Dalian, on the shores of the Yellow Sea. From his youth, Osokin stood out for his encyclopedic memory for things like geography and the birthdays of famous people. After finishing school, he won entrance to a top academic institute in Moscow and specialized in semiconductors.

就像五角大楼一样，克里姆林宫意识到晶体管和集成电路将改变制造、计算和军事实力。自20世纪50年代末开始，苏联在全国建立了新的半导体设施，并指派最聪明的科学家建立这个新行业。对于一个雄心勃勃的年轻工程师像尤里•奥索金来说，很难想象有更令人兴奋的任务。奥索金的童年大部分时间都在中国度过，他的父亲在黄海岸边的大连市的苏联军事医院工作。从小，奥索金就以他对地理和名人生日等事物的全面记忆而脱颖而出。完成学业后，他获得了莫斯科一所顶尖学术研究所的入学资格，并专攻半导体。

Osokin was soon assigned to a semiconductor plant in Riga, staffed with fresh graduates from the country’s best universities, and ordered to build semiconductor devices for the Soviet space program and the military. Osokin was tasked by the factory’s director to build a circuit with multiple components on the same piece of germanium, something no one in the Soviet Union had previously done. He produced his prototype integrated circuit in 1962. Osokin and his colleagues knew they were at the cutting edge of Soviet science. They spent their days tinkering in labs and their evenings debating the theory of solid-state physics, with Osokin occasionally breaking out his guitar to accompany his colleagues in song. They were young, their work was exciting, Soviet science was rising, and several of the USSR’s Sputnik satellites were orbiting overhead, visible to the naked eye whenever Osokin put down his guitar and looked up into the night sky.

奥索金很快被派往里加的一个半导体工厂，该工厂聘用了来自该国最好大学的新毕业生，并被命令为苏联的太空计划和军队建造半导体器件。该工厂的主任要求奥索金在同一块锗上建立一个具有多个元件的电路，这在苏联以前从未做过。他在1962年生产了他的原型集成电路。奥索金和他的同事知道他们正处于苏联科学的前沿。他们整天在实验室里摆弄，晚上则辩论固态物理学理论，偶尔奥索金还拿出吉他伴唱。他们年轻，工作充满激情，苏联科学蓬勃发展，苏联的几颗“斯普特尼克”卫星在头顶上绕着地球飞行，只要奥索金放下吉他抬头望去，就能用肉眼看到它们在夜空中飞行。

Soviet leader Nikita Khrushchev was committed to outcompeting the United States in every sphere, from corn production to satellite launches. Khrushchev himself was more comfortable on collective farms than in electronics labs. He understood nothing about technology but was obsessed with the notion of "catching up and overtaking" the United States, as he repeatedly promised to do. Alexander Shokin, first deputy chairman of the Soviet State Committee on Radioelectronics, realized Khrushchev's urge to compete with the United States could be used to win more investment in microelectronics. "Imagine, Nikita Sergeyevich," Shokin told the Soviet leader one day, "that a TV can be made the size of a cigarette box." Such was the promise of Soviet silicon. "Catching up and overtaking" the United States seemed like a real possibility. As with another sphere where the Soviets had caught up to the United States—nuclear weapons—the USSR had a secret weapon: a spy ring.

蘇聯領袖尼基塔·赫魯晓夫致力于在各個領域中超過美國，從玉米生產到衛星發射。 赫魯晓夫自己更喜歡集體農場而不是電子實驗室。他對技術一無所知，但他痴迷于"追趕和超越"美國的想法，這是他一再承諾要做到的。 蘇聯國家無線電子委員會副主席亞歷山大·肖金意識到，可以利用赫魯晓夫與美國競爭的慾望來赢得更多關于微電子的投資。 "想象一下，尼基塔·谢尔盖耶维奇，"肖金有一天告诉蘇聯領袖，"可以做出一個大小與香煙盒相同的電視。" 這就是蘇聯矽的承諾。 "追趕和超越"美國似乎是一個真實的可能性。 正如在另一個蘇聯追趕美國的領域，核武器，蘇聯有一個秘密武器：一個間諜團。

Joel Barr was the son of two Russian Jews who immigrated to the U.S. to flee tsarist oppression. Barr grew up in poverty in Brooklyn before winning admission to the City College of New York to study electrical engineering. As a student, he fell in with a group of Communists and found himself sympathizing with their critique of capitalism and their argument that the Soviet Union was best placed to stand up to the Nazis. Via Communist Party contacts, he was introduced to Alfred Sarant, a fellow electrical engineer and member of the Young Communist League. They'd spend the remainder of their lives working together to further the Communist cause.

乔尔·巴尔是两位俄罗斯犹太人的儿子，他们移民到美国逃避沙皇的压迫。巴尔在布鲁克林贫困中长大，后来考入纽约市立大学学习电气工程。在学生时代，他加入了一个共产主义组织，对资本主义的批评以及苏联是最有能力抵御纳粹的国家的看法表示同情。通过共产党的联系，他认识了阿尔弗雷德·萨兰特，一位电气工程师和青年共产主义联

盟成员。他们一起工作，致力于推动共产主义事业，直到生命的最后。

In the 1930s, Barr and Sarant were integrated into an espionage ring led by Julius Rosenberg, the infamous Cold War spy. During the 1940s, Barr and Sarant worked on classified radars and other military systems at Western Electric and Sperry Gyroscope, two leading American technology firms. Unlike others in the Rosenberg ring, Barr and Sarant didn’t possess nuclear weapons secrets, but they had gained intimate knowledge about the electronics in new weapons systems. In the late 1940s, as the FBI began unraveling the KGB’s spy networks in the U.S., Rosenberg was tried and sentenced to death by electrocution alongside his wife, Ethel. Before the FBI could catch them, Sarant and Barr fled the country, eventually reaching the Soviet Union.

在1930年代，巴爾和薩蘭特被整合進了一個間諜圈子，由冷戰名間諜朱利葉斯·羅森伯格領導。在1940年代，巴爾和薩蘭特在西方電器和斯皮瑞陀羅盤兩家領先的美國科技公司工作，負責機密雷達和其他軍用系統的開發。與Rosenberg圈子中的其他人不同，巴爾和薩蘭特並沒有掌握核武器的機密，但他們對新武器系統的電子技術有著深入的了解。在1940年代末期，當FBI開始揭露在美國的KGB間諜網絡時，羅森伯格和他的妻子伊索爾被判電椅死刑。在FBI追捕之前，薩蘭特和巴爾逃離了美國，最終抵達蘇聯。

When they arrived, they told KGB handlers they wanted to build the world’s most advanced computers. Barr and Sarant weren’t experts in computers, but nor was anyone else in the Soviet Union. Their status as spies was, in itself, a much admired credential, and their aura gave them access to resources. In the late 1950s, Barr and Sarant began building their first computer, called UM—the Russian word for “mind.” Their work attracted the attention of Shokin, the bureaucrat who managed the Soviet electronics industry, and they partnered with him to convince Khrushchev that the USSR needed an entire city devoted to producing semiconductors, with its own researchers, engineers, labs, and production facilities. Even before the towns on the peninsula south of San Francisco had become known as Silicon Valley—a term that wasn’t coined until 1971—Barr and Sarant had dreamt up their own version in a Moscow suburb.

當他們到達時，他們告訴KGB控制者他們想要建造世界上最先進的計算機。Barr和Sarant並不是電腦專家，但蘇聯也沒有其他人是。他們作為間諜的地位本身就是一個非常令人欣賞的憑證，他們的光環使他們能夠獲得資源。在1950年代末期，Barr和Sarant開始建造他們的第一台計算機，名為UM-俄語“心靈”的意思。他們的工作引起了管理蘇聯電子產業的官僚Shokin的注意，他們與他合作說服赫魯雪夫，蘇聯需要一個專門生產半導體的城市，擁有自己的研究人員、工程師、實驗室和生產設施。即使在旧金山南部半岛的城鎮尚未被稱為“硅谷”，這個詞語直到1971年才被創造，Barr和Sarant在莫斯科的一個郊區就已經設想出了自己的版本。

To convince Khrushchev to fund this new city of science, Shokin arranged for the Soviet leader to visit Special Design Bureau of the Electronics Industry #2 in Leningrad. Behind the bulky, bureaucratic name—the Soviets never excelled at marketing—was an institute at the cutting edge of Soviet electronics. The Design Bureau spent weeks preparing for Khrushchev's visit, holding a dress rehearsal the day before to ensure that everything went according to plan. On May 4, 1962, Khrushchev arrived. To welcome the Soviet leader, Sarant dressed in a dark suit matching the color of his bushy eyebrows and carefully trimmed mustache. Barr stood nervously to Sarant's side, wiry glasses perched on his balding head. With Sarant in the lead, the two former spies showed Khrushchev the accomplishments of Soviet microelectronics. Khrushchev tested a tiny radio that fit in his ear and toyed with a simple computer that could print out his name. Semiconductor devices would soon be used in spacecraft, industry, government, aircraft—even "for the creation of a nuclear missile shield," Sarant confidently told Khrushchev. Then he and Barr led Khrushchev to an easel with pictures of a futuristic city devoted exclusively to producing semiconductor devices, with a vast fifty-two-story skyscraper at its center.

為了說服赫魯曉夫資助這座科學新城，肖金安排了蘇聯領袖參觀了位於列寧格勒的第二電子工業特別設計局。這個拙劣的官方名稱背後是一個處於蘇聯電子學領域前沿的研究院。他們費時數周準備，前一天還進行了排練，以確保一切都按計劃進行。1962年5月4日，赫魯曉夫來了。為了歡迎蘇聯領袖，薩蘭特穿了一套與他濃密的眉毛和修剪整齊的小鬍子相匹配的深色西裝。巴爾緊張地站在薩蘭特身旁，戴著薄線眼鏡，已經禿頭。薩蘭特帶著巴爾展示了蘇聯微電子的成就。赫魯

曉夫試用了一個能裝進耳朵的小型收音機，並玩弄了一個能打印他的名字的簡單電腦。薩蘭特自信地告訴赫魯曉夫，半導體器件很快就會被用於航天、工業、政府、飛機甚至“為創建核彈頭護盾”。然後，他和巴爾帶領赫魯曉夫到一個立有未來主義城市照片的畫架面前，該城市專注於生產半導體裝置，其中央有一座高達52層的摩天大樓。

Khrushchev was enamored of grand projects, especially those that he could claim credit for, so he enthusiastically endorsed the idea of building a Soviet city for semiconductors. He embraced Barr and Sarant in a bear hug, promising his full support. Several months later, the Soviet government approved plans to build a semiconductor city in the outskirts of Moscow. “Microelectronics is a mechanical brain,” Khrushchev explained to his fellow Soviet leaders. “It is our future.”

The USSR soon broke ground on the city of Zelenograd, the Russian word for “green city”—and, indeed, it was designed to be a scientific paradise. Shokin wanted it to be a perfect scientific settlement, with research laboratories and production facilities, plus schools, day cares, movie theaters, libraries, and a hospital—everything a semiconductor engineer could need. Near the center was a university, the Moscow Institute of Electronic Technology, with a brick façade modeled on English and American college campuses. From the outside, it seemed just like Silicon Valley, only a little less sunny.

赫鲁晓夫对大型工程着迷，特别是那些他能够声称功劳的项目，因此他热情地认可了在苏联建立一个半导体城市的想法。他热情地拥抱巴尔和萨兰特，承诺给予全部支持。几个月后，苏联政府批准了在莫斯科郊区建立半导体城市的计划。“微电子是机械大脑，”赫鲁晓夫向苏联领导人解释道，“这是我们的未来。”苏联很快开始了建设“绿城”（Zelenograd）的工作，这个俄语词意为“绿色城市”，它被设计成一个科学天堂。肖金希望它成为一个完美的科学定居点，具备研究实验室和生产设施，以及学校、日托、电影院、图书馆和医院——一切半导体工程师所需的设施。中心附近有一所大学，莫斯科电子技术学院，其砖墙外观模仿了英美大学校园。从外面看，它似乎就像硅谷，只是阳光不那么充沛。

CHAPTER 8 “Copy It”

A round the same time that Nikita Khrushchev declared his support for building Zelenograd, a Soviet student named Boris Malin returned from a year studying in Pennsylvania with a small device in his luggage—a Texas Instruments SN-51, one of the first integrated circuits sold in the United States. A thin man with dark hair and deep-set eyes, Malin was one of the Soviet Union’s leading experts on semiconductor devices. He saw himself as a scientist, not a spy. Yet Alexander Shokin, the bureaucrat in charge of Soviet microelectronics, believed the SN-51 was a device the Soviet Union must acquire by any means necessary. Shokin called Malin and a group of other engineers into his office, placed the chip under his microscope, and peered through the lens. “Copy it,” he ordered them, “one-for-one, without any deviations. I’ll give you three months.”

在尼基塔·赫鲁晓夫宣布支持建设泽连奥格勒德的同时，一名苏联学生Boris Malin从宾夕法尼亚州学习一年后携带着一款名为Texas Instruments SN-51的小型装置返回。这是美国出售的最早的集成电路之一。 Malin是个瘦削的男人，深邃的眼睛，是苏联半导体器件领域的专家之一。他视自己为一位科学家，而不是间谍。然而，负责苏联微电子的官僚亚历山大·肖金认为，SN-51是苏联必须通过任何手段获得的装置。肖金召集了Malin和其他一些工程师到他的办公室，将芯片放在显微镜下，并透过镜头仔细观察。他下令他们“一比一地复制它，不要有任何偏差。我会给你们三个月的时间。”

Soviet scientists reacted angrily to the suggestion they were simply copying foreign advances. Their scientific understanding was as advanced as that of America’s chemists and physicists. Soviet exchange students in the U.S. reported learning little from lectures by William Shockley that they couldn’t have studied in Moscow. Indeed, the USSR had some of the world’s leading theoretical physicists. When Jack Kilby was finally awarded the Nobel Prize in Physics in 2000 for inventing the integrated circuit (by then the co-inventor of the integrated circuit, Bob Noyce, had died), he shared the prize with a Russian scientist named Zhores Alferov, who’d conducted fundamental research in the 1960s on ways semiconductor devices could produce light.

The launch of Sputnik in 1957, the first space flight of Yuri Gagarin in 1961, and the fabrication of Osokin's integrated circuit in 1962 provided incontrovertible evidence that the Soviet Union was becoming a scientific superpower. Even the CIA thought the Soviet microelectronics industry was catching up rapidly.

苏联科学家对于他们只是简单复制外国的进步的建议非常愤怒。他们的科学理解与美国的化学家和物理学家同样先进。在美国的交换学生报告称，他们从威廉·肖克利的讲座中学不到任何莫斯科所没有的知识。实际上，苏联拥有一些世界领先的理论物理学家。当杰克·基尔比在2000年最终获得诺贝尔物理学奖，以表彰他发明了集成电路时（那时集成电路的共同发明人鲍勃·诺伊斯已经去世），他与一位名叫佐哈斯·阿尔费罗夫的俄罗斯科学家一起分享此奖。阿尔费罗夫曾在20世纪60年代进行了关于半导体器件如何产生光的基础研究。1957年的"斯普特尼克"首次航天，1961年尤里·加加林的首次太空飞行以及同年奥索金的集成电路制造无可辩驳地证明了苏联正在成为科学超级大国。连中央情报局都认为苏联微电子产业正在迅速赶上。

Shokin's "copy it" strategy was fundamentally flawed, however. Copying worked in building nuclear weapons, because the U.S. and the USSR built only tens of thousands of nukes over the entire Cold War. In the U.S., however, TI and Fairchild were already learning how to mass-produce chips. The key to scaling production was reliability, a challenge that American chipmakers like Morris Chang and Andy Grove fixated on during the 1960s. Unlike their Soviet counterparts, they could draw on the expertise of other companies making advanced optics, chemicals, purified materials, and other production machinery. If no American companies could help, Fairchild and TI could turn to Germany, France, or Britain, each of which had advanced industries of their own.

然而，Shokin的"抄袭策略"基本上是有缺陷的。在建立核武器方面，抄袭是行之有效的，因为在整个冷战期间，美国和苏联只建造了数万枚核武器。然而，在美国，TI和Fairchild已经学会了如何大规模生产芯片。扩大生产的关键在于可靠性，这是美国芯片制造商莫里斯·张和安迪·格罗夫在20世纪60年代关注的挑战。与苏联同行不同的是，他们可以利用其他制造先进光学、化学、纯化材料和其他生产机械的公司

的专业知识。如果没有美国公司能够提供帮助，Fairchild和TI可以转向德国、法国或英国，这些国家都有自己的先进工业。

The Soviet Union churned out coal and steel in vast quantities but lagged in nearly every type of advanced manufacturing. The USSR excelled in quantity but not in quality or purity, both of which were crucial to high-volume chipmaking. Moreover, the Western allies prohibited the transfer of many advanced technologies, including semiconductor components, to Communist countries via an organization called COCOM. The Soviets could often bypass COCOM restrictions using shell companies in neutral Austria or Switzerland, but this pathway was hard to use on a large-scale basis. So Soviet semiconductor facilities regularly had to work with machinery that was less sophisticated and with materials that were less pure, producing far fewer working chips as a result.

蘇聯大量生產煤炭和鋼鐵，但在幾乎所有的高級製造領域都落後。蘇聯以數量優勝而不是質量或純度，而這兩者對高產量的晶片制造非常重要。此外，西方盟國通過一個叫做COCOM的組織禁止向共產主義國家轉移許多先進技術，包括半導體元件。蘇聯通常可以通過在中立的奧地利或瑞士成立殼公司來繞過COCOM的限制，但這個途徑很難大規模使用。因此，蘇聯的半導體設施經常必須使用更不複雜的機器和不那麼純淨的材料，結果生產的工作芯片數量大大減少。

Spying could only get Shokin and his engineers so far. Simply stealing a chip didn’t explain how it was made, just as stealing a cake can’t explain how it was baked. The recipe for chips was already extraordinarily complicated. Foreign exchange students studying with Shockley at Stanford could become smart physicists, but it was engineers like Andy Grove or Mary Anne Potter who knew at what temperature certain chemicals needed to be heated, or how long photoresists should be exposed to light. Every step of the process of making chips involved specialized knowledge that was rarely shared outside of a specific company. This type of know-how was often not even written down. Soviet spies were among the best in the business, but the semiconductor production process required more details and knowledge than even the most capable agent could steal.

间谍活动只能帮助肖金和他的工程师们走得那么远。仅仅窃取一个芯片并不能解释它是如何制造的，就像仅仅窃取一个蛋糕无法解释它是如何烘焙的一样。芯片的配方已经非常复杂了。在斯坦福大学和肖克利一起学习的留学生可以成为聪明的物理学家，但像安迪·格罗夫或玛丽·安妮·波特这样的工程师知道某些化学品需要在什么温度下加热，或者光刻胶需要曝光多长时间。制造芯片的每一个步骤都涉及专业知识，这些知识很少在公司之外共享。这种专业技术通常甚至没有书面记录。苏联间谍是行业中最出色的之一，但半导体生产过程需要比最能干的特工窃取更多的细节和知识。

Moreover, the cutting edge was constantly changing, per the rate set out in Moore’s Law. Even if the Soviets managed to copy a design, acquire the materials and machinery, and replicate the production process, this took time. TI and Fairchild were introducing new designs with more transistors every year. By the mid-1960s, the earliest integrated circuits were old news, too big and power-hungry to be very valuable. Compared to almost any other any type of technology, semiconductor technology was racing forward. The size of transistors and their energy consumption was shrinking, while the computing power that could be packed on a square inch of silicon roughly doubled every two years. No other technology moved so quickly—so there was no other sector in which stealing last year’s design was such a hopeless strategy.

此外，随着摩尔定律所规定的速度不断变化，尖端技术也在不断更新。就算苏联设法复制设计，获得材料和机器并复制生产流程，这也需要时间。德州仪器和费尔柴尔德每年都会推出更多晶体管的新设计。到了1960年代中期，最早的集成电路已经过时，太大而且耗电量大，没有多少价值。和其他几乎所有其他技术相比，半导体技术一直在飞速前进。晶体管的尺寸和能源消耗正在缩小，而每平方英寸硅上的计算能力大致每两年就会翻倍。没有其他技术发展得这么快，所以没有其他领域能像抄袭去年的设计那样无望。

Soviet leaders never comprehended how the “copy it” strategy condemned them to backwardness. The entire Soviet semiconductor sector functioned like a defense contractor—secretive, top-down, oriented toward military systems, fulfilling orders with little scope for creativity. The copying process was “tightly controlled” by Minister Shokin, one of his subordinates remembered. Copying was literally hardwired into the Soviet semiconductor industry, with some chipmaking machinery using inches rather than centimeters to better replicate American designs, even though the rest of the USSR used the metric system. Thanks to the “copy it” strategy, the USSR started several years behind the U.S. in transistor technology and never caught up.

蘇聯領導人從未理解“抄襲”策略如何使他們陷入落後的境地。整個蘇聯半導體行業像防禦承包商一樣，保密、自上而下、面向軍事系統，履行訂單時幾乎沒有創造力的空間。其一項下屬回憶說，抄襲過程由 Shokin 部長嚴格控制。抄襲從字面上被硬編到蘇聯半導體行業中，一些晶片製造機械使用英寸而不是公分，以更好地複製美國的設計，即使整個蘇聯使用公制系統。由於“抄襲”策略，蘇聯在晶體管技術上始終落後於美國好幾年，也始終無法趕上。

Zelenograd might have seemed like Silicon Valley without the sunshine. It had the country’s best scientists and stolen secrets. Yet the two countries’ semiconductor systems couldn’t have been more different. Whereas Silicon Valley’s startup founders job-hopped and gained practical “on the factory floor” experience, Shokin called the shots from his ministerial desk in Moscow. Yuri Osokin, meanwhile, lived in obscurity in Riga, highly respected by his colleagues but unable to speak about his invention with anyone who lacked a security clearance. Young Soviet students didn’t pursue electrical engineering degrees, wanting to be like Osokin, because no one knew that he existed. Career advancement required becoming a better bureaucrat, not devising new products or identifying new markets. Civilian products were always an afterthought amid an overwhelming focus on military production.

綠城可能看起來像沒有陽光的矽谷。它擁有全國最好的科學家和竊取的秘密。然而，這兩個國家的半導體系統有著截然不同的方式。矽谷的初創公司創始人跳槽並獲得實踐“在工廠車間”的經驗，而舒金從莫斯科的部長桌上發號施令。與此同時，尤里·奧索金住在里加的黑暗中，他受到同事們的高度尊重，但不能與沒有安全許可證的人談論他的發明。年輕的蘇聯學生不會追求電機工程學位，想要像奧索金一樣，因為沒有人知道他的存在。職業晉升需要成為更好的官僚，而不

是設計新產品或識別新市場。民用產品始終是壓倒性的軍事生產的附帶產品。

Meanwhile, the “copy it” mentality meant, bizarrely, that the pathways of innovation in Soviet semiconductors were set by the United States. One of the most sensitive and secretive industries in the USSR therefore functioned like a poorly run outpost of Silicon Valley. Zelenograd was just another node in a globalizing network—with American chipmakers at the center.

与此同时，“复制它”的心态意味着苏联半导体创新的途径是由美国设定的，这是非常奇怪的。因此，苏联最敏感和最保密的行业之一就像硅谷运营不善的前哨一样。责任木格拉德只是全球化网络中的另一个节点，以美国芯片制造商为中心。

CHAPTER 9 The Transistor Salesman

W hen Japanese prime minister Hayato Ikeda met French president Charles de Gaulle amid the splendor of the Elysée Palace in November 1962, he brought a small gift for his host: a Sony transistor radio. De Gaulle was formalistic and ceremonious, a tradition-minded military man who saw himself as the incarnation of French *grandeur* . Ikeda, by contrast, thought his country's voters were straightforwardly materialistic, and promised to double their incomes within a decade. Japan was nothing but an "economic power," de Gaulle declared, huffing to an aide after the meeting that Ikeda behaved like a "transistor salesman." But it wouldn't be long before all the world was looking enviously at Japan, because the country's success selling semiconductors would make it far wealthier and more powerful than de Gaulle ever imagined.

當日本總理池田勇人在1962年11月在艾麗西宮殿的壯麗氛圍中會見法國總統戴高樂時，他為主人帶來了一個小禮物：一個Sony晶體管收音機。戴高樂是一個正式且隆重的人，一個傳統主義的軍人，他認為自己是法國偉大的化身。相比之下，池田認為他國的選民是直截了當的物質主義者，並承諾在十年內將他們的收入翻倍。法國總統戴高樂說，日本只是一個"經濟強國"，他在會議後對一名助手噓了一口氣說，池田的行為就像一名"晶體管推銷員"。但不久之後，全世界都將羨慕日本，因為該國成功出售半導體將使其比戴高樂想象的要富有和更強大。

Integrated circuits didn't only connect electronic components in innovative ways, they also knit together nations in a network, with the United States at its center. The Soviets inadvertently made themselves part of this network by copying Silicon Valley's products. Japan, by contrast, was deliberately integrated into America's semiconductor industry, a process supported by Japanese business elites and the U.S. government.

When World War II ended, some Americans had envisioned stripping Japan of its high-tech industries as punishment for starting a brutal war. Yet within a couple years of Japan's surrender, defense officials in Washington adopted an official policy that "a strong Japan is a better risk than a weak Japan."

Apart from a short-lived effort to shut down Japan's research into nuclear physics, the U.S. government supported Japan's rebirth as a technological and scientific power. The challenge was to help Japan rebuild its economy while binding it to an American-led system. Making Japan a transistor salesman was core to America's Cold War strategy.

綜合電路不僅以創新的方式連接了電子元件，還將國家紡織成一張網絡，以美國為中心。蘇聯通過抄襲硅谷的產品，無意中使自己成為這個網絡的一部分。相比之下，日本是有意成為美國半導體產業的一部分，這是由日本商業精英和美國政府支持的一種進程。 二戰結束後，一些美國人曾想過剝奪日本的高科技產業，以懲罰其發起的殘酷戰爭。然而，在日本投降後的幾年裡，華盛頓的國防官員採取了一項官方政策，即"強盛的日本比弱小的日本更為安全"。除了短暫關閉日本核物理研究的努力外，美國政府支持日本作為技術和科學強國的重生。挑戰在於幫助日本重建經濟，同時將其綁定到美國領導的體系中。讓日本成為晶體管推銷員是美國冷戰戰略的核心。

News about the invention of the transistor first trickled into the country via the U.S. military authorities who governed occupied Japan. Makoto Kikuchi was a young physicist in the Japanese government's Electrotechnical Laboratory in Tokyo, which employed some of the country's most advanced scientists. One day his boss called him into his office with interesting news: American scientists, Kikuchi's boss explained, had attached two metal needles to a crystal and were able to amplify a current. Kikuchi knew an extraordinary device had been discovered.

關於晶體管的發明消息最初通過美國軍方當局流入該國，後者當時統治著日本。菊池誠是日本政府位於東京的電気技術實驗室的一名年輕物理學家，該實驗室僱用了該國一些最先進的科學家。一天，他的老板召他進入辦公室，告訴他一個有趣的消息：美國科學家在晶體上固定了兩根金屬針，並能放大電流。菊池知道一個非凡的設備已被發現。

In bombed-out Tokyo, it was easy to feel isolated from the world's leading physicists, but U.S. occupation headquarters in Tokyo provided Japan's scientists access to journals like *Bell System Technical Journal* , *Journal of Applied Physics* , and *Physical Review* , which published the papers of

Bardeen, Brattain, and Shockley. These journals were otherwise impossible to obtain in postwar Japan. "I'd flick through the contents and whenever I saw the word 'semiconductor' or 'transistor,'" Kikuchi recounted, "my heart would start to pound." Several years later, in 1953, Kikuchi met John Bardeen when the American scientist traveled to Tokyo during a hot and humid September for a meeting of the International Union of Pure and Applied Physics. Bardeen was treated like a celebrity and was shocked by the number of people wanting to take his photo. "I've never seen so many flashbulbs in my life," he wrote his wife.

在遭受轟炸的東京，很容易就感到與世界頂尖的物理學家疏遠，但是美軍佔領總部提供了日本科學家閱讀Bell System Technical Journal、Journal of Applied Physics和Physical Review等雜誌的機會，這些雜誌發表了Bardeen、Brattain和Shockley的文章。在戰後的日本，否則很難獲得這些雜誌。 Kikuchi回憶說："我翻閱內容，每當看到'半導體'或'晶體管'這兩個詞，我的心就會開始怦怦跳。"幾年後的1953年，當美國科學家約翰·巴丁（John Bardeen）在一個悶熱潮濕的九月來到東京參加國際純粹和應用物理學聯合會會議時，Kikuchi見到了他。 Bardeen像名人一樣受到熱烈的歡迎，他對想拍照的人數感到震驚。"我從未見過這麼多閃光燈，"他寫信給妻子。

The same year Bardeen landed in Tokyo, Akio Morita took off from Haneda Airport for New York. The fifteenth-generation heir to one of Japan's most distinguished sake distilleries, Morita had been groomed since birth to take over the family business. Morita's father had wanted his son to become the sixteenth Morita to manage the sake business, but Akio Morita's childhood love of tinkering with electronics and a university degree in physics pointed in a different direction. During the war, this physics expertise may have saved his life, getting him sent to a research lab rather than the front lines.

同年，巴丁抵达东京，森田义郎从羽田机场飞往纽约。森田义郎是日本一家著名清酒酿造厂的第十五代继承人，自小就被培养为家族事业的接班人。森田义郎的父亲本想他成为管理清酒事业的第十六代森田人，但是他在童年时期对电子学的热爱和大学物理学学位让他的人生方向改变了。在战争期间，他的物理学专业知识可能拯救了他的生命，使他被派往研究实验室而不是前线。

Morita’s physics degree proved useful in postwar Japan, too. In April 1946, with the country still in ruins, Morita partnered with a former colleague named Masaru Ibuka to build an electronics business, which they soon named Sony, from the Latin *sonus* (sound) and the American nickname “sonny.” Their first device, an electric rice cooker, was a dud, but their tape recorder worked well and sold better. In 1948, Morita read about Bell Labs’ new transistor and immediately grasped its potential. It seemed “miraculous,” Morita recalled, dreaming of revolutionizing consumer devices.

盛田的物理学学位在战后的日本也证明是有用的。1946年4月，当时国家仍然是一片废墟，盛田与一位前同事名叫风间玛丽成立了一家电子公司，他们很快将其命名为Sony，来自拉丁语sonus（声音）和美国昵称“sonny”。他们的第一款产品——一款电饭煲，却不受欢迎，但他们的录音机表现良好，销量也不错。1948年，盛田读到贝尔实验室新的晶体管技术，并立即意识到它的潜力。盛田回忆说，它看起来是“神奇的”，他梦想着革新消费电子设备。

Upon landing in the United States in 1953, Morita was shocked by the country’s vast distances, open spaces, and extraordinary consumer wealth, especially compared to the deprivation of postwar Tokyo. *This country seems to have everything* , Morita thought. In New York, he met AT&T executives who agreed to issue him a license to produce the transistor. They told him to expect to manufacture nothing more useful than a hearing aid.

Morita understood what Charles de Gaulle did not: electronics were the future of the world economy, and transistors, soon embedded in silicon chips, would make possible unimaginable new devices. The smaller size and lower power consumption that transistors offered, Morita realized, were set to transform consumer electronics. He and Ibuka decided to bet the future of their company on selling these devices not only to Japanese customers, but to the world’s richest consumer market, America.

1953年抵达美国时，宫田惊叹于这个国家广袤的距离、开阔的空地和惊人的消费财富，尤其是和战后东京的贫困相比。这个国家好像什么都有，宫田想。在纽约，他遇到了美国电话电报公司的高管，他们同意发给他一个生产晶体管的许可证。他们告诉他，能生产的东西不会比助听器更有用。 宫田理解了夏尔·戴高乐没有意识到的东西：电子

是世界经济的未来，而晶体管，很快就会嵌入硅芯片中，使得无法想象的新设备变得可能。晶体管的更小尺寸和更低能耗，宫田意识到，将彻底改变消费电子。他和飞驰决定把他们公司的未来寄托在将这些设备销售给世界上最富裕的消费市场，美国上。

Japan’s government signaled its support for high tech, with Japan’s crown prince visiting an American radio research lab the same year Morita traveled to Bell Labs. Japan’s powerful Ministry of International Trade and Industry also wanted to support electronics firms, but the ministry’s impact was mixed, with bureaucrats at one point delaying Sony’s application to license the transistor from Bell Labs by several months on the grounds that it was “inexcusably outrageous” for the company to have signed a contract with a foreign firm without the ministry’s consent.

日本政府表示支持高科技，当年森田宏访问贝尔实验室时，日本皇太子也访问了美国一个无线电研究实验室。日本强大的国际贸易产业部也想支持电子公司，但该部门的影响力却是参差不齐。曾经，该部门的官员还以公司未经该部门同意与外国公司签订合同为由，拖延了索尼从贝尔实验室获得晶体管的许可申请数个月，认为这是“无法容忍的”行为。

Sony had the benefit of cheaper wages in Japan, but its business model was ultimately about innovation, product design, and marketing. Morita’s “license it” strategy couldn’t have been more different from the “copy it” tactics of Soviet Minister Shokin. Many Japanese companies had reputations for ruthless manufacturing efficiency. Sony excelled by identifying new markets and targeting them with impressive products using Silicon Valley’s newest circuitry technology. “Our plan is to lead the public with new products rather than ask them what kind of products they want,” Morita declared. “The public does not know what is possible, but we do.”

索尼在日本擁有較便宜的工資優勢，但其業務模式最終是關於創新、產品設計和市場營銷的。盛田的“授權”策略與蘇聯部長朔金的“模仿”策略截然不同。許多日本公司以殘酷的制造效率聞名。索尼優秀之處在於識別新市場並用硅谷最新的電路技術瞄準它們，推出令人印象深刻的產品。盛田宣布，“我們的計劃是通過新產品引領公眾，而不是問他們需要哪種產品。公眾不知道什麼是可能的，但我們知道。”

Sony’s first major success was transistor radios, such as the radio Prime Minister Ikeda had given de Gaulle. Several years earlier, Texas Instruments had tried to market transistor radios, but though it had the necessary technology, TI bungled the pricing and marketing and quickly abandoned the business. Morita saw an opening and was soon churning out tens of thousands of the devices.

Nevertheless, U.S. chip firms like Fairchild continued to dominate the cutting edge of chip production, such as its business related to corporate mainframe computers. Throughout the 1960s, Japanese firms paid sizeable licensing fees on intellectual property, handing over 4.5 percent of all chip sales to Fairchild, 3.5 percent to Texas Instruments, and 2 percent to Western Electric. U.S. chipmakers were happy to transfer their technology because Japanese firms appeared to be years behind.

索尼的首個成功是晶體管收音機，例如總理池田給戴高樂的收音機。數年前，得克薩斯儀器公司曾試圖銷售晶體管收音機，但由於定價和市場營銷技巧不佳，TI很快就放棄了這個業務。森田看到了這個機會，很快就生產出數萬個設備。然而，像費爾柴爾德之類的美國晶片公司繼續主宰著晶片生產的最前沿，比如與企業主機相關的業務。在整個20世紀60年代，日本企業要為知識產權支付大量的許可費，向費爾柴爾德支付全部晶片銷售額的4.5％，向得克薩斯儀器支付3.5％，向西部電器支付2％。美國晶片製造商樂意轉移他們的技術，因為日本企業似乎落後了幾年。

Sony’s expertise wasn’t in designing chips but devising consumer products and customizing the electronics they needed. Calculators were another consumer device transformed by Japanese firms. Pat Haggerty, the TI Chairman, had asked Jack Kilby to build a handheld, semiconductor-powered calculator in 1967. However, TI’s marketing department didn’t think there’d be a market for a cheap, handheld calculator, so the project stagnated. Japan’s Sharp Electronics disagreed, putting California-produced chips in a calculator that was far simpler and cheaper than anyone had thought possible. Sharp’s success guaranteed most calculators produced in the 1970s were Japanese made. If only TI had found a way to market its own branded devices earlier, Haggerty later lamented, TI “would have been the Sony of consumer electronics.” Replicating Sony’s product innovation and marketing expertise, however, proved just as hard as replicating America's semiconductor expertise.

索尼的专业知识并不在于设计芯片，而是在于设计消费品并定制他们所需要的电子产品。日本公司也将计算器变成了另一种消费设备。TI董事长Pat Haggerty在1967年要求Jack Kilby制造一款手持的半导体计算器。然而，TI的营销部门认为便宜的手持计算器没有市场需求，因此该项目停滞不前。日本夏普电子公司则持不同意见并在计算器中加入了加利福尼亚生产的芯片，生产了一款比任何人想象的都要简单和便宜的计算器。夏普的成功使得1970年代生产的大多数计算器都是日本制造的。如果TI早日找到了营销自己品牌设备的方法，Haggerty后来感慨道，TI会成为消费电子的"索尼"。然而，复制索尼的产品创新和营销专业知识与复制美国的半导体专业知识同样困难。

The semiconductor symbiosis that emerged between America and Japan involved a complex balancing act. Each country relied on the other for supplies and for customers. By 1964, Japan had overtaken the U.S. in production of discrete transistors, while American firms produced the most advanced chips. U.S. firms built the best computers, while electronics manufacturers like Sony and Sharp produced consumer goods that drove semiconductor consumption. Japan's exports of electronics—a mix of semiconductors and products that relied on them—boomed from $600 million in 1965 to $60 billion around two decades later.

美国和日本之间形成了半导体的互惠共生关系，其中涉及到复杂的平衡。每个国家都依赖另一个国家的供应和客户。到1964年，日本已经在离散晶体管的生产方面超过美国，而美国公司生产最先进的芯片。美国公司建造了最好的计算机，而像索尼和夏普这样的电子制造商生产消费品驱动了半导体的消耗。日本的电子出口（半导体和依赖它们的产品的混合物）从1965年的6亿美元猛增到大约二十年后的600亿美元。

Interdependence wasn't always easy. In 1959, the Electronics Industries Association appealed to the U.S. government for help lest Japanese imports undermine "national security"—and their own bottom line. But letting Japan build an electronics industry was part of U.S. Cold War strategy, so, during the 1960s, Washington never put much pressure on Tokyo over the issue.

Trade publications like *Electronics* magazine—which might have been expected to take the side of U.S. companies—instead noted that "Japan is a keystone in America's Pacific policy…. If she cannot enter into healthy commercial intercourse with the Western hemisphere and Europe, she will seek economic sustenance elsewhere," like Communist China or the Soviet Union. U.S. strategy required letting Japan acquire advanced technology and build cutting-edge businesses. "A people with their history won't be content to make transistor radios," President Richard Nixon later observed. They had to be allowed, even encouraged, to develop more advanced technology.

相互依存并非易事。1959年，电子工业协会向美国政府求助，以避免日本进口产品破坏"国家安全"和他们自己的底线。但是让日本建设电子产业是美国冷战战略的一部分，因此在上世纪60年代，华盛顿从未对这个问题对东京施加过多的压力。像《电子杂志》这样的贸易出版物——可能会预计支持美国公司一方——反而指出，"日本是美国太平洋政策的关键…... 如果她不能与西半球和欧洲进行健康的商业往来，她将寻求其他地方的经济支持，如共产主义中国或苏联。"美国的策略需要让日本获取先进技术并建立尖端企业。"一个有着历史的民族不会满足于制造晶体管收音机，"总统理查德·尼克松后来如是观察。他们必须被允许，甚至被鼓励，开发更先进的技术。

Japanese executives were no less committed to making this semiconductor symbiosis work. When Texas Instruments sought to become the first foreign chipmaker to open a plant in Japan, the company faced a thicket of regulatory barriers. Sony's Morita, who happened to be a friend of Haggerty, offered to help in exchange for a share of the profits. He told TI executives to visit Tokyo incognito, register at their hotel under false names, and never leave their hotel room. Morita visited the hotel clandestinely and proposed a joint venture: TI would produce chips in Japan, and Sony would manage the bureaucrats. "We will cover for you," he told the Texas Instruments executives. The Texans thought Sony was a "rogue operation," something they meant as a compliment.

日本的高管们同样致力于使这种半导体共生关系发挥作用。当德州仪器试图成为首家在日本开设工厂的外国芯片制造商时，该公司面临着一系列监管障碍。索尼的守田恭夫恰好是哈格蒂的朋友，他提出要在获得利润的前提下提供帮助。他告诉德州仪器的高管们保持匿名前往

东京，使用假名登记酒店，并且永远不要离开酒店房间。守田秘密访问酒店，提出合资企业的想法：德州仪器将在日本生产芯片，索尼将管理官僚。他告诉德州仪器的高管们：“我们会为你们撑腰。”德州人认为索尼是一个“流氓运营”，这是一种夸奖。

With Morita’s help, and after much red tape and green tea, Japan’s bureaucrats finally approved TI’s permits to open a semiconductor plant in Japan. For Morita, it was another coup, helping to make him one of the most famous Japanese businessmen on either side of the Pacific. For foreign policy strategists in Washington, more trade and investment links between the two countries tied Tokyo ever more tightly into a U.S.-led system. It was a victory for Japanese leaders like Prime Minister Ikeda, too. His goal of doubling Japanese incomes was achieved two years ahead of schedule. Japan won a new seat on the world stage thanks to intrepid electronics entrepreneurs like Morita. Transistor salesman was a position of far more influence than Charles de Gaulle could ever have imagined.

在Morita的幫助下，並經過許多繁文縟節和綠茶的努力之後，日本的官僚們終於批准了TI在日本開設半導體工廠的許可證。對於Morita來說，這是又一個重大成功，幫助他成為太平洋兩岸最著名的日本商人之一。對於華盛頓的對外政策戰略家來說，兩國之間的更多貿易和投資聯繫將東京越來越緊密地納入美國主導的體系。對於像總理池田的日本領導人來說，這也是一個勝利。他將日本收入翻倍的目標提前了兩年實現。由於像Morita這樣的勇敢的電子企業家，日本贏得了一個在世界舞台上的新席位。晶體管銷售員是比戴高樂想象的更有影響力的職位。

CHAPTER 10 “Transistor Girls”

“ T heir clothing was of the West, but their love rites were founded in the ancient pleasures of the East,” read the cover of *The Transistor Girls* , a trashy Australian novel from 1964. The plot involved Chinese gangsters, international intrigue, and women assembly line workers who “added to their incomes by extracurricular night-time activity.” The image on the front cover of *The Transistor Girls* showed a young Japanese woman, scantily clad, with a silhouette of a pagoda in the background. The back cover revealed a woman amid more orientalist imagery but with even less clothing.

《晶体管女孩》是一本1964年出版的澳大利亚低俗小说，封面上写着：“他们的服装来自西方，但他们的爱情仪式却源于东方的古老快乐。” 故事情节涉及中国黑帮、国际阴谋和女工厂生产线员工“通过业余夜间活动增加收入”。《晶体管女孩》封面上的形象是一个穿着暴露的年轻日本女子，背景是一座宝塔的轮廓。 背面揭示了一个女人置身于更多的东方主义意象中，但穿得更少。

It was mostly men who designed the earliest semiconductors, and mostly women who assembled them. Moore’s Law predicted the cost of computing power was about to plummet. But making Moore’s vision a reality wasn’t only a question of shrinking the size of each transistor on a chip. It also required a larger and cheaper supply of workers to assemble them.

Many employees of Fairchild Semiconductor joined the firm in search of riches or because of a love of engineering. Charlie Sporck came to Fairchild after being chased out of his previous job. A cigar smoking, hard-driving New Yorker, Sporck was fixated on efficiency. In an industry full of brilliant scientists and technological visionaries, Sporck’s expertise was in wringing productivity out of workers and machines alike. It was only thanks to tough managers like him that the cost of computing fell in line with the schedule Gordon Moore had predicted.

早期的半导体设计大多是由男性完成，而组装却主要由女性完成。摩尔定律预测了计算能力成本将会大幅降低。但要实现摩尔的愿景不仅仅是要缩小芯片上每个晶体管的尺寸，还需要更多、更便宜的工人来

组装它们。 许多威富半导体公司的员工加入这家公司是为了寻求财富或因为对工程学的热爱。查理·斯波克由于被逼离开先前的工作而来到威富。作为一个喜欢抽雪茄、目标高远、来自纽约的强势主管，斯波克固执地追求效率。在这个充满着杰出科学家和技术先驱的行业里，斯波克的专业是从工人和机器中挤取生产力。正是由于像他这样的严格管理者，计算成本才能按照戈登·摩尔的预测时间表得以降低。

Sporck had studied engineering at Cornell before being hired by GE in the mid-1950s at the firm's factory in Hudson Falls, New York. He was tasked with improving GE's process for manufacturing capacitors and proposed changing the factory's assembly line process. He believed his new technique would improve productivity, but the labor union that controlled GE's assembly line workers saw him as threatening their control over the production process. The union revolted, staging a rally against Sporck and burning him in effigy. The factory's management timidly backed down, promising the union that Sporck's changes would never be implemented.

斯波克曾在康奈尔大学学习工程学，在1950年代中期被通用电气公司聘用到位于纽约哈德逊福尔斯的工厂。他的任务是改进通用电气公司生产电容器的工艺，并提出更改工厂的装配线工艺。他相信他的新技术将提高生产效率，但掌控通用电气公司装配线工人的工会认为他威胁到他们对生产过程的控制。工会反叛，举行抗议斯波克并焚烧他的模拟人像的集会。工厂管理屈服了，承诺永远不会实施斯波克的改变。

To hell with this , Sporck thought. That night, he arrived home and started looking for other jobs. In August 1959, he saw an ad in the *Wall Street Journal* for a production manager role at a small company called Fairchild Semiconductor and sent in an application. Soon he was called into New York City for an interview in a hotel on Lexington Avenue. The two Fairchild employees who interviewed him were drunk after a boozy lunch and offered him a job on the spot. It was one of the best hiring decisions Fairchild made. Sporck had never been west of Ohio, but he accepted immediately, reporting for duty in Mountain View shortly thereafter.

该死这个工作，Sporck想到。那晚，他回到家里开始寻找其他工作。1959年8月，他在《华尔街日报》上看到一则广告，招聘一个名为费尔

柴尔德半导体的小公司的生产经理，并提交了申请。不久，他被叫到纽约市的一家位于莱克星顿大道的酒店面试。两名费尔柴尔德的雇员在餐后酗酒后变得醉醺醺的，便当场给了他一个职位。这是费尔柴尔德最好的聘用决策之一。Sporck从没有去过俄亥俄州以西的地方，但他立即加入了这家公司，并很快开始了工作。

Upon arrival in California, Sporck recalled, he was surprised that the firm "had virtually no competence in the handling of labor and labor unions. I brought this competence to my new employer." Many companies wouldn't have described a strategy of labor relations that culminated in management getting burned in effigy as "competent." But in Silicon Valley, unions were weak, and Sporck was committed to keeping it that way. He and his colleagues at Fairchild were "dead set" against unions, he declared. A practical, down-to-earth engineer, Sporck wasn't a stereotypical union buster. He kept his offices so austere that they were compared to an army barracks. Sporck was proud of giving most employees stock options, a practice that was virtually unknown in the old East Coast electronics firms. But he'd ruthlessly insist, in exchange, that these same employees commit to maximizing their productivity.

抵達加州後，Sporck回憶說，他驚訝地發現這家公司"在勞動力和工會處理方面幾乎沒有能力。我把這種能力帶給了我的新雇主。"許多公司不會把最終導致管理層被燒成草人的勞資關係策略描述為"有能力"。但在矽谷，工會很弱，Sporck致力於保持這種狀態。他和費爾柴爾德的同事們"毫不妥協"地反對工會，他宣稱。作為一個實際、務實的工程師，Sporck並不是一個刻板的反工會者。他的辦公室如此簡樸，被比作軍營。Sporck以給大部分員工股票期權為傲，這在老東海岸的電子公司幾乎是不知道的做法。但他會無情地要求這些員工在交換中致力於最大化他們的生產力。

Unlike East Coast electronics firms whose workforces tended to be male-dominated, most of the new chip startups south of San Francisco staffed their assembly lines with women. Women had worked in assembly line jobs in the Santa Clara Valley for decades, first in the fruit canneries that drove the valley's economy in the 1920s and 1930s, then in the aerospace industry during World War II. Congress's decision to ease immigration rules in 1965 added many foreign-born women to the valley's labor pool.

Chip firms hired women because they could be paid lower wages and were less likely than men to demand better working conditions. Production managers also believed women's smaller hands made them better at assembling and testing finished semiconductors. In the 1960s, the process of attaching a silicon chip to the piece of plastic on which it would sit first required looking through a microscope to position the silicon onto the plastic. The assembly worker then held the two pieces together as a machine applied heat, pressure, and ultrasonic vibration to bond the silicon to the plastic base. Thin gold wires were attached, again by hand, to conduct electricity to and from the chip. Finally, the chip had to be tested by plugging it into a meter— another step that at the time could only be done by hand. As demand for chips skyrocketed, so did the demand for pairs of hands that could assemble them.

与东海岸的电子公司工作人员主要为男性相反，旧金山以南的大多数新芯片创业公司的装配线员工都是女性。几十年来，女性在圣克拉拉谷的装配线工作，最初是在20世纪20年代和30年代推动该谷经济的水果罐头厂工作，然后是在二战期间的航空航天工业工作。1965年国会决定放宽移民规定，增加了许多外来妇女到该谷的劳动力资源。 芯片公司雇用女性，因为她们可以支付较低的工资，并且不像男性那样要求更好的工作条件。生产经理还相信女性较小的手能更好地组装和测试成品半导体。在20世纪60年代，将硅芯片固定在塑料片上的过程首先需要通过显微镜查看，将硅位置放在塑料上。然后，装配工将两个部件固定在一起，机器应用热力、压力和超声波振动来将硅固定在塑料基座上。薄金丝再次手工连接以传导电流到和从芯片。最后，芯片必须通过插到计量器中进行测试——这个时候只能手工完成。随着芯片需求的飞速增长，组装芯片的双手需求也越来越大。

Wherever they looked across California, semiconductor executives like Sporck couldn't find enough cheap workers. Fairchild scoured the U.S., eventually opening facilities in Maine—where workers had "a hatred for the labor unions," Sporck reported—and on a Navajo reservation in New Mexico that provided tax incentives. Even in the poorest parts of America, however, labor costs were substantial. Bob Noyce had made a personal investment in a radio assembly factory in Hong Kong, the British colony just across the border from Mao Zedong's Communist China. Wages were a tenth of the American average—around 25 cents an hour. “Why don’t you go take a look,” Noyce told Sporck, who was soon on a plane to check it out.

在加利福尼亚州，像斯波克这样的半导体高管们无论到哪里都找不到足够的廉价工人。Fairchild在美国各地搜寻，最终在缅因州开设了设施——那里的工人对工会“深恶痛绝”，斯波克报告道——以及在新墨西哥州的纳瓦霍保留地，提供税收激励。然而，即使在美国最贫困的地区，劳动成本也很高。鲍勃·内斯（Bob Noyce）曾在香港建立了一家无线电装配厂，投入了个人资金，这个英国殖民地就在毛泽东的共产主义中国边境上。工资是美国平均水平的十分之一左右——大约是每小时25美分。“你为什么不去看看，”内斯告诉斯波克，后者很快就坐飞机去查看了。

Some colleagues at Fairchild were apprehensive. “The Red Chinese are down your nose,” one warned, eying the thousands of People’s Liberation Army soldiers stationed on Hong Kong’s northern border. “You’re going to get run over.” But the radio factory Noyce had invested in illustrated the opportunity. “The Chinese labor, the girls working there, were exceeding everything that was ever known,” one of Sporck’s colleagues recalled. Assembly workers in Hong Kong seemed twice as fast as Americans, Fairchild executives thought, and more “willing to tolerate monotonous work,” one executive reported.

費爾柴爾德公司的一些同事感到擔憂。“紅色中國人就在你的鼻子下面，”一個人警告說，他眼睛注視著香港北部邊境部署的成千上萬的人民解放軍士兵。“你會被碾壓的。”但諾伊斯投資的廣播電臺工廠展現了機會。“在那裡工作的中國女工超越了以往任何人都知道的水平，”斯波克的一位同事回憶道。香港的裝配工似乎比美國人快了兩倍，費爾柴爾德的高管們認為，而且更“願意容忍單調的工作，”一名高管報告道。

Fairchild rented space in a sandal factory on Hang Yip Street, next to the old Hong Kong airport, right on the shore of Kowloon Bay. Soon a huge Fairchild logo several stories tall was mounted on the building, illuminating the junks sailing around Hong Kong’s harbor. Fairchild continued to make its silicon wafers in California but began shipping semiconductors to Hong Kong for final assembly. In 1963, its first year of operation, the Hong Kong facility assembled 120 million devices. Production quality was excellent, because low labor costs meant Fairchild could hire trained engineers to run assembly lines, which would have been prohibitively expensive in California.

菲尔德科技当时在香港九龙湾沿岸的恒业街一间制造凉鞋的工厂内租了空间。很快，一只好几层楼高的菲尔德商标被安装在建筑物上，照亮了航行在香港海港周围的大量船只。菲尔德继续在加利福尼亚州制造其硅晶圆，但开始将半导体运送到香港进行最终组装。1963年，香港工厂数量首年即组装了1.2亿只器件。生产质量优秀，因为低廉的人工成本意味着菲尔德可以聘请受过培训的工程师来运行生产线，这在加利福尼亚州将会造成高昂的费用。

Fairchild was the first semiconductor firm to offshore assembly in Asia, but Texas Instruments, Motorola, and others quickly followed. Within a decade, almost all U.S. chipmakers had foreign assembly facilities. Sporck began looking beyond Hong Kong. The city's 25-cent hourly wages were only a tenth of American wages but were among the highest in Asia. In the mid-1960s, Taiwanese workers made 19 cents an hour, Malaysians 15 cents, Singaporeans 11 cents, and South Koreans only a dime.

Sporck's next stop was Singapore, a majority ethnic Chinese city-state whose leader, Lee Kuan Yew, had "pretty much outlawed" unions, as one Fairchild veteran remembered. Fairchild followed by opening a facility in the Malaysian city of Penang shortly thereafter. The semiconductor industry was globalizing decades before anyone had heard of the word, laying the grounds for the Asia-centric supply chains we know today.

費爾柴爾德（Fairchild）是第一家將半導體組件外包到亞洲的公司，但德州儀器（Texas Instruments）、摩托羅拉（Motorola）和其他公司很快就跟進了。在十年內，幾乎所有美國芯片製造商都有海外裝配工廠。斯波克（Sporck）開始放眼香港以外，因為當時香港每小時25美分的工資，雖然只有美國工資的十分之一，但已經是亞洲最高水平之一。在1960年代中期，台灣工人每小時賺19美分，馬來西亞人15美分，新加坡人11美分，而南韓人只有10美分。 斯波克下一站是新加坡，這是一個以華人為主的城市國家，其領袖李光耀"幾乎已經取締了"工會，正如一位費爾柴爾德老將所記憶的。費爾柴爾德隨後在馬來

西亞檳城開設了一家工廠。在人們聽過"全球化"一詞之前，半導體行業就已經全球化，為我們今天所知的亞洲供應鏈打下了基礎。

Managers like Sporck had no game plan for globalization. He'd just as happily have kept building factories in Maine or California had they cost the same. But Asia had millions of peasant farmers looking for factory jobs, keeping wages low and guaranteeing they'd stay low for some time. Foreign policy strategists in Washington saw ethnic Chinese workers in cities like Hong Kong, Singapore, and Penang as ripe for Mao Zedong's Communist subversion. Sporck saw them as a capitalist's dream. "We had union problems in Silicon Valley," Sporck noted. "We never had any union problems in the Orient."

像斯波克这样的管理人员没有全球化的计划。如果缅因州或加利福尼亚的建厂成本相同，他一样乐意继续建厂。但亚洲有数百万农民正在寻找工厂工作，使工资保持低水平，并为一段时间内保持低水平提供保证。华盛顿的外交政策战略家认为，在香港、新加坡和槟城等城市的华人工人很容易受到毛泽东共产主义的颠覆。斯波克则将他们视为资本家的梦想。"我们在硅谷遇到了工会问题。"斯波克指出。"我们在东方从未遇到过任何工会问题。"

CHAPTER 11 Precision Strike

A bout halfway on the flight between the company's semiconductor plants in Singapore and Hong Kong during the early 1970s, Texas Instruments employees would occasionally peer out their aircraft window and look down on puffs of smoke rising from the battlefields on Vietnam's coastal plains. TI's staff across Asia were focused on making chips, not on the war. Many of their colleagues in Texas, however, thought about nothing else. TI's first major contract for integrated circuits had been for massive nuclear missiles like the Minuteman II, but the war in Vietnam required different types of weapons. The early bombing campaigns in Vietnam, like Operation Rolling Thunder, which stretched from 1965 to 1968, dropped over eight hundred thousand tons of bombs, more than was dropped in the Pacific Theater during all of World War II. This firepower had only a marginal impact on North Vietnam's military, however, because most of the bombs missed their targets.

在20世纪70年代初期，位于新加坡和香港的德州仪器半导体工厂间飞行时，员工们偶尔会从飞机窗口往下看，看到越南沿海平原上的战场冒出的烟雾。TI亚洲地区的员工们专注于芯片制作，而非战争。然而，他们在德克萨斯州的很多同事却想到的只有战争。TI最早的集成电路大型合同是为像"分钟人II"这样的巨型核导弹服务，但越南战争需要不同类型的武器。早期的轰炸行动，如从1965年到1968年持续的"滚动打击"行动，投下超过800,000吨炸弹，这比第二次世界大战期间在太平洋战区投下的炸弹还要多。然而，这种火力对北越军队的影响仅有较小的影响，因为大多数炸弹没有达到目标。

The Air Force realized it needed to fight smarter. The military had experimented with a variety of techniques for guiding its missiles and bombs, from using remote control to infrared seekers. Some of these weapons, like the Shrike missile, which was launched from planes and homed in on enemy radar facilities using a simple guidance system that pointed the missile toward the source of the radar's radio waves, proved reasonably effective. But many other guidance systems seemed hardly ever to work. As late as 1985, a Defense Department study found only four examples of air-to-air missiles downing an enemy aircraft outside of visual range. With limitations like these, it seemed impossible that guided munitions would ever decide the outcome of a war.

空军意识到需要更加聪明地作战。军队尝试了各种制导导弹和炸弹的技术，从遥控到红外线探测器。其中一些武器，如“蝗虫”导弹，从飞机发射并通过一个简单的制导系统指向雷达的无线电波源来跟踪敌方雷达设施，被证明相当有效。但是许多其他制导系统似乎很少起作用。直到1985年，国防部的一项研究发现，除了在视野范围外击落敌机的四个空对空导弹的例子之外，其他制导弹药的效果也不佳。面对这些限制，看起来制导弹药永远不可能决定战争的结果。

The problem with many guided munitions, the military concluded, was the vacuum tubes. The Sparrow III anti-aircraft missiles that U.S. fighters used in the skies over Vietnam relied on vacuum tubes that were hand-soldered. The humid climate of Southeast Asia, the force of takeoff and landings, and the rough-and-tumble of fighter combat caused regular failures. The Sparrow missile’s radar system broke on average once every five to ten hours of use. A postwar study found that only 9.2 percent of Sparrows fired in Vietnam hit their target, while 66 percent malfunctioned, and the rest simply missed.

從軍方得出的結論來看，許多制導武器存在的問題是真空管。美國戰機在越南天空使用的麻雀三號防空導彈依賴手工焊接的真空管。東南亞潮濕的氣候、起降的力量以及戰斗中的激烈碰撞導致了定期故障。麻雀導彈的雷達系統平均每使用五到十小時就會故障一次。戰後的研究發現，在越南發射的麻雀導彈中，只有9.2%命中目標，而66%發生故障，其餘就是錯失機會。

The military’s biggest challenge in Vietnam, however, was striking ground targets. At the start of the Vietnam War, bombs fell on average within 420 feet of their target, according to Air Force data. Attacking a vehicle with a bomb was therefore basically impossible. Weldon Word, a thirty-four-year-old project engineer at TI, wanted to change this. Word had penetrating blue eyes, a loud, deep, hypnotic voice, and a unique vantage point for thinking about the future of war. He’d just concluded a yearlong stint aboard a Navy ship gathering data for a new TI-developed sonar, an assignment that was mind-numbingly monotonous, but that demonstrated how much data military systems could collect with the right sensors and instrumentation. As early as the mid-1960s, Word was already envisioning using microelectronics to transform the military's kill chain. Advanced sensors on satellites and in airplanes would acquire targets, track them, guide missiles toward them, and confirm they were destroyed. It sounded like science fiction. But TI already produced the necessary components in its research labs.

然而，越战中军方面临的最大挑战是打击地面目标。根据空军数据，在越南战争开始阶段，炸弹的平均命中距离目标只有420英尺。因此，用炸弹攻击车辆基本上是不可能的。Weldon Word是TI公司的一名34岁项目工程师，他想改变这种情况。Word有着深邃蓝眼睛，嗓音低沉而富有催眠力，并拥有思考战争未来的独特视角。他刚刚结束了在一艘海军舰船上收集数据的为期一年的任务，这项任务非常乏味，但演示了军事系统可以通过正确的传感器和仪器收集大量数据。早在1960年代中期，Word就已经设想使用微电子技术改变军队的杀伤链。卫星和飞机上的先进传感器可以获得目标信息，跟踪目标，引导导弹击中目标，并确认目标被摧毁。这听起来像是科幻小说，但TI公司已经在其研究实验室生产出必要的组件。

The intercontinental ballistic missiles that TI had built chips for presented a relatively straightforward guidance challenge. They were launched from a fixed position on the ground, not from a plane flying at several hundred miles per hour while maneuvering to avoid enemy fire. ICBM targets didn't move either. The missiles themselves were only slightly impacted by wind and weather conditions as they careened downward from outer space at multiple times the speed of sound. They carried warheads big enough to make even a slight miss immensely destructive. It was vastly easier to hit Moscow from Montana than it was to hit a truck with a bomb dropped by an F-4 flying at a couple thousand feet.

TI所建造晶片使用的洲際彈道飛彈面對相對簡單的引導挑戰。它們是從地面固定位置發射，而不是從以數百英里每小時飛行並機動避免敵人火力攻擊的飛機上發射。ICBM目標也不會移動。這些飛彈本身只稍受風和天氣條件影響，因為它們從外層空間飛快地墜落，速度是聲音的多倍。它們攜帶的彈頭足以使即使是微小的失誤極其破壞性。從蒙大拿州命中莫斯科比從懸掛在數千英尺高空的F-4上投下炸彈打中卡車要容易得多。

This was a complex task, but Word understood that the best weapons were "cheap and familiar," one of his colleagues explained, guaranteeing that they could be used often in training and on the battlefield. The microelectronics had to be designed with as little complexity as possible. Every connection that had to be soldered increased the risks to reliability. The simpler the electronics, the more reliable and more power-efficient a system would be.

Many defense contractors were trying to sell the Pentagon expensive missiles, but Word told his team to build weapons priced like an inexpensive family sedan. He was on the lookout for a device that was simple and easy to use, enabling it to be quickly deployed on every type of airplane, embraced by each military service, and quickly adopted by U.S. allies, too.

這是一項複雜的任務，但Word了解到最好的武器是"廉價和熟悉的"，他的一位同事解釋道，保證它們可以經常用於培訓和戰場上。微電子設計必須盡可能地簡單。每個必須焊接的連接增加了可靠性風險。電子系統越簡單，它將會更可靠、更節能。 許多國防承包商試圖向五角大樓出售昂貴的導彈，但Word告訴他的團隊要建造價格像家用轎車一樣的武器。他在尋找一種簡單易用的設備，使它能夠快速部署在各種飛機上，被每個軍種所接納，並迅速被美國的盟友所採用。

In June 1965, Word flew to Florida's Eglin Air Force Base, where he met Colonel Joe Davis, the officer in charge of a program to acquire new equipment for use in Vietnam. Davis had learned to fly at age fifteen before joining the military and piloting both fighter and bomber missions in World War II and Korea. Afterward he commanded Air Force units both in Europe and the Pacific. He understood better than anyone what type of weapons would work in Air Force missions. When Word sat down in his office, Davis opened his desk drawer and pulled out a photo of the Thanh Hoa Bridge, a 540-foot-long metallic structure stretching across North Vietnam's Song Ma river, ringed with air defenses. Word and Davis counted eight hundred pockmarks around the bridge, each caused by an American bomb or rocket that missed its target. Dozens, maybe hundreds more bombs had fallen in the river and left no mark. The bridge was still standing. Could Texas Instruments do anything to help? Davis asked.

1965年6月，沃德飛往佛羅里達州的埃格林空軍基地，在那裡他遇到了駐越南新裝備採購項目負責人喬·戴維斯上校。戴維斯十五歲就開始學飛行，加入軍隊後曾執飞戰鬥机和轟炸机，参與第二次世界大戰和朝鮮戰爭的任務。之後，他在歐洲和太平洋指揮空軍部隊，深入了解什麼樣的武器能夠在空軍任務中派上用場。當沃德坐在他的辦公室裡時，戴維斯打開了他的抽屜，拿出了一張清晰的掃描照片，展示了越南北部松馬河上的清化橋，這是一座長達540英尺的金屬結構，在其周圍設有空中防禦設施。掃描照片上顯示，這座橋周圍有八百個彈孔，每個彈孔都是由一枚未能擊中目標的美國炸彈或火箭造成的。還有數十甚至上百枚炸彈落入河中，卻未留下任何痕跡。清化橋仍然屹立著。戴維斯問沃德，德州儀器公司能不能出一點力？

Word thought TI's expertise in semiconductor electronics could make the Air Force's bombs more accurate. Texas Instruments knew nothing about designing bombs, so Word started with a standard-issue bomb—the 750-pound M-117, 638 of which already had been dropped unsuccessfully around the Thanh Hoa Bridge. He added a small set of wings that could direct the bomb's flight as it fell from the sky. Finally, he installed a simple laser-guidance system that would control the wings. A small silicon wafer was divided into four quadrants and placed behind a lens. The laser reflecting off the target would shine through the lens onto the silicon. If the bomb veered off course, one quadrant would receive more of the laser's energy than the others, and circuitry would move the wings to reorient the bomb's trajectory so that the laser was shining straight through the lens.

沃德认为TI在半导体电子方面的专业知识可以让空军的炸弹更加准确。 德州仪器对设计炸弹一无所知，因此沃德从标准炸弹-750磅M-117开始，其中已经有638个炸弹在桑河大桥周围不成功地投放了。 他添加了一组小翅膀，可以在炸弹从天空中落下时指导其飞行。 最后，他安装了一个简单的激光制导系统，来控制这些翼。 小的硅晶圆分成四个象限并放置在透镜后面。 反射于目标上的激光将穿过透镜照射到硅上。 如果炸弹偏离轨迹，一个象限将会接收到更多的激光能量，电路将移动翅膀重新定向炸弹的轨迹，使激光直接穿过透镜发射。

Colonel Davis gave Texas Instruments nine months and $99,000 to deliver this laser-guided bomb, which, thanks to its simple design, quickly passed the Air Force's tests. On May 13, 1972, U.S. aircraft dropped twenty-four of the bombs on the Thanh Hoa Bridge, which until that day had been still standing amid hundreds of craters, like a monument to the inaccuracy of mid-century bombing tactics. This time, American bombs scored direct hits. Dozens of other bridges, rail junctions, and other strategic points were hit with new precision bombs. A simple laser sensor and a couple of transistors had turned a weapon with a zero-for-638 hit ratio into a tool of precision destruction.

戴维斯上校给了德州仪器九个月和99,000美元来交付这种激光制导炸弹，由于其简单的设计，它很快通过了空军的测试。1972年5月13日，美国飞机在桑河桥上投下了24枚炸弹，直到那一天，它仍然屹立在数百个弹坑中，像是对中世纪轰炸战术不准确的纪念碑。这一次，美国炸弹直接命中了目标。许多其他桥梁、铁路枢纽和其他战略要点也被新型精准炸弹攻击。一个简单的激光传感器和几个晶体管已经把一个零击中率为638的武器变成了一个精确毁灭工具。

In the end, the guerilla war in Vietnam’s countryside wasn’t a fight that aerial bombing could win. The arrival of TI’s Paveway laser-guided bombs coincided with America’s defeat in the war. When military leaders like General William Westmoreland predicted “combat areas that are under real- or near real-time surveillance” and “automated fire control,” many people heard echoes of the hubris that had dragged America into Vietnam in the first place. Outside a small number of military theorists and electrical engineers, therefore, hardly anyone realized Vietnam had been a successful testing ground for weapons that married microelectronics and explosives in ways that would revolutionize warfare and transform American military power.

最終，越南鄉村的游擊戰爭不是空襲就能贏得的戰鬥。TI公司Paveway激光制導炸彈的到來恰逢美國在戰爭中的失敗。當像威廉·韋斯特摩蘭將軍這樣的軍事領袖預測“實時監控下的戰鬥區域”和“自動化防火控制”時，許多人聽到了自大的回聲，這正是美國一開始卷入越南的原因。因此，除少數軍事理論家和電氣工程師外，幾乎沒有人意識到越南一直是一個將微電子技術和爆炸物結合的武器成功測試場，這將革新戰爭並轉變美國的軍事力量。

CHAPTER 12 Supply Chain Statecraft

T hough Texas Instruments executive Mark Shepherd had served in the Navy in Asia during World War II, Morris Chang quipped that his expertise in the region didn't extend beyond "bars and dancing girls." The son of a Dallas police officer, Shepherd had assembled his first vacuum tube at age six. He'd played a central role in building TI's semiconductor business, including supervising the division Jack Kilby worked in when the first integrated circuit was invented. With broad shoulders, a starched collar, slicked-back hair, and a taut smile, Shepherd looked like the Texas corporate titan that he was. Now he was poised to lead TI's strategy of offshoring some of its production to Asia.

即使德州仪器高管马克·谢泼德二战期间曾在亚洲服役，但莫里斯·张揶揄说他对该地区的专业知识仅限于"酒吧和舞女"。谢泼德是达拉斯警官的儿子，六岁时就组装了第一个真空管。他在建立德州仪器的半导体业务方面发挥了重要作用，还监督了杰克·基尔比工作的部门，那里发明了第一个集成电路。谢泼德肩膀宽阔、衣领挺拔、头发被梳理得平整，嘴角挂着紧绷的微笑，看起来就像德州的企业巨头一样。现在他准备领导德州仪器的战略，将一部分生产转移至亚洲。

Chang and Shepherd first visited Taiwan in 1968 as part of an Asian tour to select a location for a new chip assembly facility. The visit couldn't have gone worse. Shepherd reacted furiously when his steak was served with soy sauce, not the way it was usually prepared in Texas. His first meeting with Taiwan's powerful and savvy economy minister, K. T. Li, ended acrimoniously when the minister declared that intellectual property was something "imperialists used to bully less-advanced countries."

Li wasn't wrong to see Shepherd as an agent of America's empire. But unlike the North Vietnamese, who were trying to oust the United States from their country, Li eventually realized that Taiwan would benefit from integrating itself more deeply with the United States. Taiwan and the U.S. had been treaty allies since 1955, but amid the defeat in Vietnam, America's security promises were looking shaky. From South Korea to Taiwan, Malaysia to Singapore, anti-Communist governments were seeking assurance that

America’s retreat from Vietnam wouldn’t leave them standing alone. They were also seeking jobs and investment that could address the economic dissatisfaction that drove some of their populations toward Communism. Minister Li realized that Texas Instruments could help Taiwan solve both problems at once.

常和谢佩德于1968年首次访问了台湾，作为亚洲考察新芯片组装设施落户地点的一部分。这次访问可谓糟糕透顶。当时牛排被加了酱油，这是德克萨斯州的做法，但让谢佩德发怒不止。他与台湾强有力而精明的经济部长李光耀首次会晤时，气氛非常尴尬，李光耀宣称知识产权是“帝国主义者用来欺负不发达国家的东西”。 李光耀认为谢佩德是美国帝国主义在台湾的代理人，并非毫无道理。但与试图赶走美国的北越不同，最终李光耀认识到台湾需要更深入地融入美国。自1955年以来，台湾和美国一直是条约盟友，但在越南战争的失利中，美国的安全承诺看起来不牢靠。从韩国到台湾，从马来西亚到新加坡，反共政府都在寻求保证，以防美国从越南撤退后，他们会孤军奋战。他们还在寻求能解决某些民众因经济失意而转向共产主义的就业机会和投资。李部长认识到半导体巨头德州仪器公司可以帮助台湾一次解决这两个问题。

In Washington, U.S. strategists feared the coming collapse of American-backed South Vietnam would send shock waves across Asia. Foreign policy strategists perceived ethnic Chinese communities all over the region as ripe for Communist penetration, ready to fall to Communist influence like a cascade of dominoes. Malaysia’s ethnic Chinese minority formed the backbone of that country’s Communist Party, for example. Singapore’s restive working class was majority ethnic Chinese. Beijing was searching for allies—and probing for U.S. weakness.

在華盛頓，美國戰略家擔心美國支持的南越即將崩潰，會在整個亞洲引發震動。外交政策戰略家認為，在整個地區，華人社區都很容易被共產主義滲透，準備像多米諾骨牌一樣跌倒在共產主義影響下。例如，馬來西亞的華人少數民族形成了該國共產黨的支撐力量。新加坡不安的工人階層以華人為多數。北京正在尋找盟友——並探尋美國的弱點。

No one was more worried about the impending Communist victory in Vietnam than the government in Taiwan, which still claimed to rule all of China. The 1960s had been a good decade for Taiwan's economy but disastrous for its foreign policy. The island's dictator, Chiang Kai-shek, still dreamed of reconquering the mainland, but the military balance had shifted decisively against him. In 1964, Beijing tested its first atomic weapon. A thermonuclear weapon test shortly followed. Facing a nuclear China, Taiwan needed American security guarantees more than ever. Yet as the war in Vietnam dragged on, the U.S. cut economic aid for its friends in Asia, including in Taiwan, an ominous sign for a country so dependent on American support.

在越南共产党即将获胜时，拥有对中国所有统治权的台湾政府比任何人都更担心。20世纪60年代对台湾经济来说是一个好的十年，但是对其外交政策来说是灾难性的。该岛的独裁者蒋介石仍然梦想着收复大陆，但是军事平衡已经明显向不利于他的方向转变。1964年，北京进行了第一次核试验，不久后进行了氢弹试验。面对拥有核能力的中国，台湾比以往任何时候都更需要美国的安保保障。然而随着越南战争的拖延，美国削减了对其亚洲盟友的经济援助，包括对台湾，这对一个如此依赖美国支持的国家来说是一个不祥之兆。

Taiwanese officials like K. T. Li, who'd studied nuclear physics at Cambridge and ran a steel mill before steering Taiwan's economic development through the postwar decades, began crystallizing a strategy to integrate economically with the United States. Semiconductors were at the center of this plan. Li knew there were plenty of Taiwanese-American semiconductor engineers willing to help. In Dallas, Morris Chang urged his colleagues at TI to set up a facility in Taiwan. Many people would later describe the mainland-born Chang as "returning" to Taiwan, but 1968 was the first time he stepped foot on the island, having lived in the U.S. since fleeing the Communist takeover of China. Two of Chang's PhD classmates at Stanford were from Taiwan, however, and they convinced him the island had a favorable business climate and that wages would stay low.

台灣官員像李國鼎一樣，在劍橋大學學習核物理並開設鋼鐵工廠，然後引導台灣在戰後數十年中實現經濟發展，開始制定與美國經濟一體化的策略。半導體是這個計劃的核心。李國鼎知道有很多願意幫忙的

台裔美籍半導體工程師。在達拉斯，張忠謀敦促TI的同事在台灣建立一個工廠。許多人後來會形容出生於大陸的張忠謀“回”到台灣，但1968年是他第一次踏上這個島嶼，自中國共產黨掌權以來一直住在美國。然而，張忠謀在斯坦福大學的兩個博士班同學來自台灣，他們說服他這個島嶼有良好的商業氛圍，並且工資會保持低水平。

After initially accusing Mark Shepherd of being an imperialist, Minister Li quickly changed his tune. He realized a relationship with Texas Instruments could transform Taiwan’s economy, building industry and transferring technological know-how. Electronics assembly, meanwhile, would catalyze other investments, helping Taiwan produce more higher-value goods. As Americans grew skeptical of military commitments in Asia, Taiwan desperately needed to diversify its connections with the United States. Americans who weren’t interested in defending Taiwan might be willing to defend Texas Instruments. The more semiconductor plants on the island, and the more economic ties with the United States, the safer Taiwan would be. In July 1968, having smoothed over relations with the Taiwanese government, TI’s board of directors approved construction of the new facility in Taiwan. By August 1969, this plant was assembling its first devices. By 1980, it had shipped its billionth unit.

最初指責馬克·謝潑德是帝國主義者後，李部長很快改變了調調。他意識到與德州儀器（Texas Instruments）建立關係可以轉變台灣的經濟，建立產業並轉移技術知識。 同時，電子組裝可以催化其他投資，促進台灣生產更高價值的商品。隨著美國對在亞洲的軍事承諾日益懷疑，台灣迫切需要擴大與美國的聯繫。不願意捍衛台灣的美國人可能願意捍衛德州儀器。島上越多的半導體工廠，越多的與美國的經濟聯繫，台灣就越安全。1968年7月，在平息了與台灣政府的關係之後，德州儀器的董事會批准在台灣建立新工廠。到1969年8月，這個工廠就組裝了第一批設備。到1980年，它已經運出了十億個設備。

Taiwan wasn’t alone in thinking that semiconductor supply chains could provide economic growth and bolster political stability. In 1973, Singapore’s leader Lee Kuan Yew told U.S. president Richard Nixon he was counting on exports to “sop up unemployment” in Singapore. With the Singapore government’s support, TI and National Semiconductors built assembly facilities in the city-state. Many other chipmakers followed. By the end of the

1970s, American semiconductor firms employed tens of thousands of workers internationally, mostly in Korea, Taiwan, and Southeast Asia. A new international alliance emerged between Texan and Californian chipmakers, Asian autocrats, and the often ethnic-Chinese workers who staffed many of Asia's semiconductor assembly facilities.

台灣不是唯一一個認為半導體供應鏈可促進經濟增長並增強政治穩定的國家。1973年，新加坡的領袖李光耀告訴美國總統理察·尼克松，他指望出口可以“吸收失業問題”。在新加坡政府的支持下，德州儀器和國家半導體在這個城市國家建立了裝配設施，其它許多晶片製造商也紛紛跟進。到了1970年代末期，美國半導體公司在國際上聘用了數以萬計的員工，主要集中在韓國、台灣和東南亞。一個新的國際聯盟出現在得克薩斯和加利福尼亞的晶片製造商、亞洲專制政治領袖和許多亞洲半導體裝配設施的華裔工人之間。

Semiconductors recast the economies and politics of America's friends in the region. Cities that had been breeding grounds for political radicalism were transformed by diligent assembly line workers, happy to trade unemployment or subsistence farming for better paying jobs in factories. By the early 1980s, the electronics industry accounted for 7 percent of Singapore's GNP and a quarter of its manufacturing jobs. Of electronics production, 60 percent was semiconductor devices, and much of the rest was goods that couldn't work without semiconductors. In Hong Kong, electronics manufacturing created more jobs than any sector except textiles. In Malaysia, semiconductor production boomed in Penang, Kuala Lumpur, and Melaka, with new manufacturing jobs providing work for many of the 15 percent of Malaysian workers who had left farms and moved to cities between 1970 and 1980. Such vast migrations are often politically destabilizing, but Malaysia kept its unemployment rate low with many relatively well-paid electronics assembly jobs.

半導體產業顛覆了美國友邦的經濟和政治環境。原本政治激進的城市因為勤奮的生產線工人改變了命運，他們樂於放棄失業和生存性農業，轉而到工廠工作賺更多的錢。到了1980年代初，電子產業佔新加坡國內生產總值的7%，佔制造業工作的四分之一。而電子產品中有60%是半導體器件，其餘很大一部分也是無法沒有半導體器件就無法運作的商品。在香港，除了紡織業外，電子製造業提供的就業機會比

其他行業還多。在馬來西亞，半導體生產在檳城、吉隆坡和馬六甲繁榮起來，新的製造業工作使得在1970年至1980年期間，有15%的馬來西亞農民遷往城市。這種龐大的移居群眾經常會造成政治上的動盪，但馬來西亞通過提供許多相對高收入的電子組裝工作來維持低的失業率。

From South Korea to Taiwan, Singapore to the Philippines a map of semiconductor assembly facilities looked much like a map of American military bases across Asia. Yet even after the U.S. finally admitted defeat in Vietnam and drew down its military presence in the region, these trans-Pacific supply chains endured. By the end of the 1970s, rather than dominoes falling to Communism, America’s allies in Asia were even more deeply integrated with the U.S.

In 1977, Mark Shepherd returned to Taiwan and met again with K. T. Li, nearly a decade after their first meeting. Taiwan still faced a risk of Chinese invasion, but Shepherd told Li, “We consider this risk to be more than offset by the strength and dynamism of Taiwan’s economy. TI will stay and continue to grow in Taiwan,” he promised. The company still has facilities on the island today. Taiwan, meanwhile, has made itself an irreplaceable partner to Silicon Valley.

從南韓到臺灣，從新加坡到菲律賓，半導體裝配工廠的地圖看起來就像是一張充滿美國軍事基地的亞洲地圖。然而，即使美國最終承認在越戰中失敗並撤出該地區的軍事存在，這些跨太平洋的供應鏈仍然存在。到了20世紀70年代末，美國的亞洲盟友與美國的聯繫甚至更加緊密，而不是像多米諾骨牌一樣倒向了共產主義。 1977年，馬克·謝泼德返回臺灣，與李國鼎再度相遇，這是近10年來的第一次。臺灣仍然面臨著中國入侵的風險，但謝泼德告訴李國鼎：“我們認為臺灣經濟的實力和活力足以抵消這一風險。德州儀器將會留在臺灣並繼續成長，”他承諾道。該公司今天仍在該島擁有設施。與此同時，臺灣已經成為矽谷不可替代的合作夥伴。

CHAPTER 13 Intel's Revolutionaries

T he year 1968 seemed like a revolutionary moment. From Beijing to Berlin to Berkeley, radicals and leftists were poised to tear down the established order. North Vietnam's Tet Offensive tested the limits of American military power. Yet it was the *Palo Alto Times* that scooped the world's biggest newspapers by reporting on page 6 what, in hindsight, was the most revolutionary event of the year: "Founders Leave Fairchild; Form Own Electronics Firm."

The rebellion of Bob Noyce and Gordon Moore didn't look like the protests in California's East Bay, where Berkeley students and Black Panthers plotted violent uprisings and dreamt of abolishing capitalism. At Fairchild, Noyce and Moore were unhappy about their lack of stock options and sick of meddling from the company's head office in New York. Their dream wasn't to tear down the established order, but to remake it.

1968年似乎是一个革命性的时刻。从北京到柏林再到伯克利，激进派和左翼分子准备推翻旧秩序。北越的"春节攻势"测试了美国的军事力量极限。然而，帕洛阿尔托时报却在第六页报道了全球最大的报纸都没有想到的，事后看来是那一年最具革命性的事件："创始人离开费尔柴尔德，成立自己的电子公司。" 鲍勃·诺伊斯和戈登·摩尔的叛乱并不像加州东湾的伯克利学生和黑豹组织策划的暴乱，他们梦想废除资本主义。在费尔柴尔德，诺伊斯和摩尔不满股票期权的少和纽约公司总部的干预。他们的梦想不是推翻旧秩序，而是重建它。

Noyce and Moore abandoned Fairchild as quickly as they'd left Shockley's startup a decade earlier, and founded Intel, which stood for Integrated Electronics. In their vision, transistors would become the cheapest product ever produced, but the world would consume trillions and trillions of them. Humans would be empowered by semiconductors while becoming fundamentally dependent on them. Even as the world was being wired to the United States, America's internal circuitry was changing. The industrial era was ending. Expertise in etching transistors into silicon would now shape the world's economy. Small California towns like Palo Alto and Mountain View were poised to become new centers of global power.

諾伊斯和摩爾像十年前離開肖克利的創業公司一樣迅速地離開費爾康公司，並創立了英特爾（Intel），這代表集成電子。在他們的視野中，晶體管將成為生產成本最低的產品，但世界將消耗數不勝數的晶體管。人類將因半導體而得到賦權，同時變得根本依賴它們。即使世界正在與美國連接，美國的內部電路也正在改變。工業時代正在結束。在繪製晶體管到矽的專業知識下，加利福尼亞州的小鎮，如帕洛阿爾托和山景城，正準備成為新的全球強大中心。

Two years after its founding, Intel launched its first product, a chip called a dynamic random access memory, or DRAM. Before the 1970s, computers generally “remembered” data using not silicon chips but a device called a magnetic core, a matrix of tiny metal rings strung together by a grid of wires. When a ring was magnetized, it stored a 1 for the computer; a non-magnetized ring was a 0. The jungle of wires that strung the rings together could turn each ring’s magnetism off and on and could “read” whether a given ring was a 1 or a 0. The demand for remembering 1s and 0s was exploding, however, and wires and rings could only shrink so far. If the components got any smaller, the assemblers who weaved them together by hand would find them impossible to produce. As demand for computer memory exploded, magnetic cores couldn’t keep up.

英特尔成立两年之后，推出了其第一款产品，一种名为动态随机访问内存（DRAM）的芯片。在1970年代之前，计算机通常使用的是一种叫做磁心的装置来“记忆”数据，它是由一系列微小的金属环通过网格电线串在一起的。当一个环被磁化时，它为计算机存储一个1；一个未磁化的环则代表一个0。串接环的电线杂乱无章，可以打开和关闭每个环的磁性，并可以“读取”某个环是1还是0。然而，对于记忆1和0的需求正在爆炸，而电线和环的缩小只能走到这里，如果组件变得再小一点，手工编织它们的装配工人将发现它们难以生产。随着计算机存储需求的爆炸性增长，磁心无法跟上。

In the 1960s, engineers like IBM’s Robert Dennard began envisioning integrated circuits that could “remember” more efficiently than little metal rings. Dennard had long, dark hair that flowed below his ears, then shot out at a right angle, parallel to the ground, giving him the look of an eccentric genius. He proposed coupling a tiny transistor with a capacitor, a miniature storage device that is either charged (1) or not (0). Capacitors leak over time, so Dennard envisioned repeatedly charging the capacitor via the transistor. The chip would be called a dynamic (due to the repeated charging) random access memory, or DRAM. These chips form the core of computer memory up to the present day.

在1960年代，像IBM的Robert Dennard这样的工程师开始设想能够比小金属环更有效地“记忆”的集成电路。 Dennard拥有长长的黑发，下垂至耳朵以下，然后以直角的方式射出，与地面平行，使他看起来像个古怪的天才。 他建议将微小的晶体管与电容器耦合，电容器是一种微型存储设备，可以装入电荷（1）或不装入电荷（0）。 由于电容器会渗漏，因此Dennard设想通过晶体管重复充电电容器。 这种芯片被称为动态（由于重复充电）随机存取内存或DRAM。 直到今天，这些芯片仍然是计算机内存的核心。

A DRAM chip worked like the old magnetic core memories, storing 1s and 0s with the help of electric currents. But rather than relying on wires and rings, DRAM circuits were carved into silicon. They didn’t need to be weaved by hand, so they malfunctioned less often and could be made far smaller. Noyce and Moore bet that their new company, Intel, could take Dennard’s insight and put it on a chip far denser than a magnetic core could ever be. It only took one glance at a graph of Moore’s Law to know that so long as Silicon Valley could keep shrinking transistors, DRAM chips would conquer the business of computer memory.

一個動態隨機存取記憶體（DRAM）晶片的作用方式就像是舊磁芯存儲器，利用電流存儲1和0。但是，DRAM電路不依靠線路和環，而是雕刻在矽上。它們不需要手工編織，因此故障較少且可以做得更小。諾伊斯和摩爾打賭，他們的新公司英特爾可以利用丹納德的洞見，將其放在比磁芯更緻密的晶片上。只要硅谷能繼續縮小晶體管，DRAM晶片就能征服計算機記憶體的業務。

Intel planned to dominate the business of DRAM chips. Memory chips don’t need to be specialized, so chips with the same design can be used in many different types of devices. This makes it possible to produce them in large volumes. By contrast, the other main type of chips—those tasked with “computing” rather than “remembering”—were specially designed for each device, because every computing problem was different. A calculator worked differently than a missile's guidance computer, for example, so until the 1970s, they used different types of logic chips. This specialization drove up cost, so Intel decided to focus on memory chips, where mass production would produce economies of scale.

英特爾計劃主宰DRAM晶片的業務。記憶體晶片不需要專門化，因此設計相同的晶片可以用於許多不同類型的設備。這使得可以大量生產它們。相比之下，另一種主要類型的晶片──用於"計算"而不是"記憶"的晶片──為每個設備進行了特殊設計，因為每個計算問題都不同。例如，計算機的工作方式與導彈的制導計算機不同，因此直到20世紀70年代，它們使用不同類型的邏輯晶片。這種專門化推高了成本，因此英特爾決定專注於記憶體晶片，其中大量生產將產生規模經濟。

Bob Noyce could never resist an engineering puzzle, however. Even though he'd just raised several million dollars on the promise that his new company would build memory chips, he was quickly convinced to add a product line. In 1969, a Japanese calculator firm called Busicom approached Noyce with a request to design a complicated set of circuits for its newest calculator. Handheld calculators were the iPhones of the 1970s, a product that used the most advanced computing technologies to drive down price and put a powerful piece of plastic in everyone's pocket. Many Japanese firms built calculators, but they often relied on Silicon Valley to design and manufacture their chips.

鮑伯·諾伊斯永遠無法抗拒工程謎題的誘惑。即使他才剛籌集了數百萬美元的資金，承諾他的新公司會建造記憶晶片，但很快就被說服增加了一條產品線。 1969年，一家名為Busicom的日本計算器公司向諾伊斯提出要求，設計其最新計算器的複雜電路。手持計算器是20世紀70年代的iPhone，一種利用最先進的計算技術讓價格降低，讓每個人都可以把一個強大的塑料產品放在口袋裡。許多日本公司都建造計算器，但通常依靠硅谷設計和製造他們的芯片。

Noyce asked Ted Hoff, a soft-spoken engineer who'd arrived at Intel after an academic career studying neural networks, to handle Busicom's request. Unlike most Intel employees, who were physicists or chemists focused on the electrons zipping across chips, Hoff's background in computer architectures let him see semiconductors from the perspective of the systems they powered. Busicom told Hoff they'd need twelve different chips with twenty-four thousand transistors, all arranged in a bespoke design. He thought this sounded impossibly complicated for a small startup like Intel.

諾伊斯向泰德·霍夫提出了一個請求，這位輕聲細語的工程師在學術生涯中研究神經網絡並加入英特爾後負責處理Busicom的請求。與大多數專注于芯片上電子運動查看的物理學家或化學家不同，霍夫在計算機結構方面的背景使他能夠從它們所驅動的系統的角度看待半導體。Busicom告訴霍夫，他們需要一個定制設計的12種不同芯片，每個芯片有2.4萬個晶體管。他覺得這對於像英特爾這樣的小型初創企業來說聽起來不可思議複雜。

As he considered Busicom's calculator, Hoff realized computers face a tradeoff between customized logic circuits and customized software. Because chipmaking was a custom business, delivering specialized circuits for each device, customers didn't think hard about software. However, Intel's progress with memory chips—and the prospect they would become exponentially more powerful over time—meant computers would soon have the memory capacity needed to handle complex software. Hoff bet it would soon be cheaper to design a standardized logic chip that, coupled with a powerful memory chip programmed with different types of software, could compute many different things. After all, Hoff knew, no one was building memory chips more powerful than Intel's.

當 Hoff 考慮 Busicom 的計算機時，他意識到計算機面臨著定制邏輯電路和定制軟件之間的取捨。由於芯片制造是一個定制化的行業，為每個設備提供專門的電路，因此客戶並不會太關注軟件。然而，英特爾在存儲芯片方面的進展——以及它們隨著時間成指數級增長的前景——意味著計算機很快會擁有處理複雜軟件所需的內存容量。Hoff 打賭，設計一個標準化的邏輯芯片很快就會更便宜，再加上與不同類型軟件編程的強大內存芯片相結合，就能夠計算出許多不同的事情。毕竟，Hoff 知道，沒有人在建造比英特爾更強大的內存芯片。

Intel wasn't the first company to think about producing a generalized logic chip. A defense contractor had produced a chip much like Intel's for the computer on the F-14 fighter jet. However, that chip's existence was kept secret until the 1990s. Intel, however, launched a chip called the 4004 and described it as the world's first microprocessor—"a micro-programmable computer on a chip," as the company's advertising campaign put it. It could be used in many different types of devices and set off a revolution in computing.

英特尔并不是第一家考虑生产通用逻辑芯片的公司。一家国防承包商已经为F-14战斗机上的计算机生产了一款与英特尔类似的芯片。然而，这款芯片的存在一直保密到20世纪90年代。然而，英特尔推出了一款名为4004的芯片，并将其描述为世界上第一款微处理器——正如公司的广告宣传活动所称："一种可微编程的芯片计算机"。它可以用于许多不同类型的设备，并引发了计算机革命。

At his parents' fiftieth wedding anniversary party in 1972, Bob Noyce interrupted the festivities, held up a silicon wafer, and declared to his family: "This is going to change the world." Now general logic could be mass-produced. Computing was ready for its own industrial revolution and Intel had the world's most advanced assembly lines.

The person who best understood how mass-produced computing power would revolutionize society was a Caltech professor named Carver Mead. With piercing eyes and a goatee, Mead looked more like a Berkeley philosopher than an electrical engineer. He had struck up a friendship with Gordon Moore just after the founding of Fairchild, after Moore waltzed into Mead's Caltech office, pulled out a sock filled with Raytheon 2N706 transistors, and gave them to Mead for use in his electrical engineering classes. Moore soon hired Mead as a consultant, and for many years, the Caltech visionary spent each Wednesday at Intel's facilities in Silicon Valley. Though Gordon Moore had first graphed the exponential increase in transistor density in his famous 1965 article, Mead coined the term "Moore's Law" to describe it.

在1972年的父母50周年结婚纪念日聚会上，鲍勃·诺伊斯打断了庆祝活动，拿起一块硅片，对他的家人宣称："这将改变世界。"现在普通逻辑可大规模生产。计算机准备好迎来自己的工业革命，英特尔拥有世界上最先进的装配线。其中最了解大规模生产计算能力如何革新社会的人是一位名为卡弗·米德的加州理工学院教授。米德眼神犀利，留着

山羊胡子，看起来更像一个伯克利哲学家而不是电气工程师。在费尔柴尔德公司成立后不久，他与戈登·尔建立了友谊，在尔的加州理工办公室里走进去，拿出装满雷神公司2N706晶体管的袜子，交给米德用于他的电气工程课程。不久，戈登·尔雇佣米德为顾问，多年来，这位加州理工的远见卓识者每个星期三都在英特尔位于硅谷的设施中度过。尽管戈登·尔在他著名的1965年文章中首次绘制了晶体管密度的指数增长曲线，米德创造了“摩尔定律”这一术语来描述它。

“In the next ten years,” Mead predicted in 1972, “every facet of our society will be automated to some degree.” He envisioned “a tiny computer deep down inside of our telephone, or our washing machine, or our car” as these silicon chips became pervasive and inexpensive. “In the past 200 years we have improved our ability to manufacture goods and move people by a factor of 100,” Mead calculated. “But in the last 20 years there has been an increase of 1,000,000 to 10,000,000 in the rate at which we process and retrieve information.” A revolutionary explosion of data processing was coming. “We have computer power coming out of our ears.”

在1972年，米德预测：“在未来十年内，我们社会的每个方面都将在某种程度上自动化。”他设想“微小的计算机深埋在我们的电话、洗衣机或汽车内”，因为这些硅芯片变得普遍且廉价。“在过去的200年中，我们提高了100倍的生产商品和运输人员的能力，”米德计算。“但在过去20年中，我们处理和检索信息的速度已经增加了1,000,000到10,000,000。”数据处理的革命性爆炸即将到来。“我们手头上有计算机能力。”

Mead was prophesying a revolution with profound social and political consequences. Influence in this new world would accrue to people who could produce computing power and manipulate it with software. The semiconductor engineers of Silicon Valley had the specialized knowledge, networks, and stock options that let them write the rules of the future—rules everyone else would have to follow. Industrial society was giving way to a digital world, with 1s and 0s stored and processed on many millions of slabs of silicon spread throughout society. The era of the tech tycoons was dawning. “Society’s fate will hang in the balance,” Carver Mead declared. “The catalyst is the microelectronics technology and its ability to put more and more components into less and less space.” Industry outsiders only dimly perceived how the world was changing, but Intel’s leaders knew that if they succeeded in drastically expanding the availability of computing power, radical changes would follow. “ We are really the revolutionaries in the world today,” Gordon Moore declared in 1973, “not the kids with the long hair and beards who were wrecking the schools a few years ago.”

梅德正在预言一场将带来深刻社会和政治后果的革命。在这个新世界中，影响力将集中于能够产生计算能力并使用软件操纵它的人。硅谷的半导体工程师拥有专门的知识、网络和股票选择权，让他们能够制定未来的规则-所有其他人都必须遵循这些规则。工业社会正在让位于数字世界，1和0存储和处理在社会各个角落的数百万块硅片上。科技大亨时代正在来临。“卡弗·梅德宣称：“社会的命运将掌握在平衡中。”“催化剂是微电子技术及其将越来越多的元件放入越来越小的空间中的能力。”行业外人只是模糊地认识到世界正在发生变化，但英特尔的领导者知道，如果他们成功地大大扩展计算能力的供应，将会出现根本性的变化。戈登·穆尔在1973年宣称，“我们才是当今世界的革命者，而不是几年前摧毁学校的长发和胡子的孩子们。”

CHAPTER 14 The Pentagon's Offset Strategy

N o one benefitted more from Noyce and Moore's revolution than a cornerst one of the old order—the Pentagon. Upon arriving in Washington in 1977, William Perry felt "like a kid in a candy store." For a Silicon Valley entrepreneur like Perry, serving as undersecretary of defense for research and engineering was, he said, the "best job in the world." No one had a larger budget to buy technology than the Pentagon. And hardly anyone in Washington had so clear a view of how microprocessors and powerful memory chips could transform all the weapons and systems the Defense Department relied on.

諾伊斯和摩爾的革命中，沒有人比老秩序的基石——五角大樓更受益。威廉·佩里於1977年抵達華盛頓時，感覺像是在糖果店裡的孩子。對於像佩里這樣的硅谷企業家來說，擔任國防部研究和工程副部長是他說過的"世界上最好的工作"。沒有人比五角大樓有更大的預算來購買技術。在華盛頓幾乎沒有人有如此清晰的視野來看待微處理器和強大的記憶芯片如何改變國防部所依賴的所有武器和系統。

Unlike Bob Noyce or Gordon Moore, who were making a fortune by ignoring the government and selling chips for mass market calculators and mainframe computers, Perry knew the Pentagon intimately. The son of a Pennsylvania baker, he began his career as a Silicon Valley scientist working for Sylvania Electronic Defense Laboratories, a unit of the same electronics company that had hired Morris Chang after he graduated MIT. Working for Sylvania in California, Perry was tasked with designing highly classified electronics that monitored Soviet missile launches. In fall 1963, he'd been one of ten experts urgently called to Washington to examine new photographs taken by U-2 spy planes showing Soviet missiles in Cuba. At a young age, Perry was already seen as one of the country's top experts on military affairs.

與Bob Noyce或Gordon Moore不同，他們通過忽視政府並為大眾市場計算器和大型計算機出售芯片賺取了大量財富，而Perry對五角大樓非常了解。他是賓夕法尼亞面包師的兒子，曾在同一家電子公司的子公司——錫利凡尼亞電子防禦實驗室工作，這家公司在莫里斯・章生從

MIT畢業後也曾經雇用過他。在加利福尼亞州為錫利凡尼亞工作期間，Perry的任務是設計高度機密的電子設備，監視蘇聯的導彈發射。1963年秋季，他是十位緊急被召往華盛頓檢查由U-2偵察機拍攝的揭示蘇聯在古巴的導彈的專家之一。年輕的Perry已經被看作是該國軍事事務領域的頂級專家之一。

Perry’s job at Sylvania had catapulted him into America’s defense establishment. But he still lived in Mountain View. For an engineer surrounded by startups, old-school Sylvania began to seem bureaucratic and stodgy. Its technology was quickly becoming outdated. Its consumer and military products alike relied on vacuum tubes long after Silicon Valley’s chipmakers were churning out integrated circuits. Perry was intimately familiar with the advances in solid-state electronics all around him. He sang in the same Palo Alto madrigals choir as Bob Noyce. So, sensing the revolution that was underway, in 1963, Perry had set off on his own, founding his own firm to design surveillance devices for the military. To get the processing power he needed, Perry bought chips from his singing partner, Intel’s CEO.

佩里在Sylvania的工作使他进入了美国的国防体系。但他仍然住在Mountain View。对于一个被创业公司包围的工程师来说，传统的Sylvania开始显得官僚和古板。它的技术很快就过时了。无论是消费品还是军事产品，在硅谷的芯片制造商开始大量生产集成电路之后，它们都依赖于真空管。佩里非常熟悉周围的固态电子技术的进展。他和鲍勃·诺伊斯一样是帕洛阿尔托合唱团的成员。因此，感觉到正在发生的革命，1963年，佩里独自创立了自己的公司，为军方设计监控设备。为了获得所需的处理能力，佩里从他的歌唱搭档、英特尔的CEO那里购买芯片。

In sunny Silicon Valley it felt like “everything was new and anything was possible,” Perry would later remember. Viewed from the Pentagon upon his arrival in 1977, the world looked far darker. The U.S. had just lost the Vietnam War. Worse, the Soviet Union had almost completely eroded America’s military advantage, warned Pentagon analysts like Andrew Marshall. Born in Detroit, Marshall was a small man, with a bald head and a beaky nose, who stared inscrutably at the world from behind his glasses. He’d worked in a machine tools factory during World War II, before becoming one of the most influential government officials of the last half century. Marshall had been hired in 1973 to establish the Pentagon's Office of Net Assessment and was tasked with forecasting the future of war.

佩里后来回忆说，在阳光明媚的硅谷，感觉“一切都是崭新的，任何事情都是可能的”。但1977年他到达五角大楼时，整个世界看起来都显得更加阴暗。美国刚刚输掉了越南战争。更糟糕的是，像安德鲁·马歇尔这样的五角大楼分析师警告说，苏联几乎完全侵蚀了美国的军事优势。 马歇尔出生在底特律，身材矮小，光头，鹰钩鼻子，透过眼镜无情地凝视着世界。他曾在二战期间工作过一个机床工厂，后来成为了过去半个世纪最有影响力的政府官员之一。1973年，马歇尔被聘请建立五角大楼的网评局，并被赋予了预测战争未来的任务。

Marshall's grim conclusion was that after a decade of pointless fighting in Southeast Asia, the U.S. had lost its military advantage. He was fixated on regaining it. Though Washington had been shocked by Sputnik and the Cuban Missile Crisis, it wasn't until the early 1970s that the Soviets had built a big enough stockpile of intercontinental ballistic missiles to guarantee that enough of their atomic weapons could survive a U.S. nuclear strike to retaliate with a devastating atomic barrage of their own. More worrisome, the Soviet army had far more tanks and planes, which were already deployed on potential battlegrounds in Europe. The U.S.—facing pressure at home to cut military spending—simply couldn't keep up.

馬歇爾的嚴厲結論是，在東南亞的無意義戰爭持續了十年後，美國失去了軍事優勢。他著迷於重建它。儘管華盛頓對斯普特尼克和古巴導彈危機感到震驚，但直到20世紀70年代早期，蘇聯才建立了足夠大的洲際彈道導彈庫存，以確保他們的原子武器能夠在美國的核打擊中存活下來，並以毀滅性的原子彈雨進行報復。更令人擔憂的是，蘇聯軍隊擁有更多的坦克和飛機，已經部署在歐洲可能的戰場上。在國內面臨削減軍事開支的壓力下，美國根本無法跟上。

Strategists like Marshall knew the only answer to the Soviet quantitative advantage was to produce better quality weapons. But how? As early as 1972, Marshall wrote that the U.S. needed to take advantage of its "substantial and durable lead" in computers. "A good strategy would be to develop that lead and to shift concepts of warfare in ways that capitalize on it," he wrote. He envisioned "rapid information gathering," "sophisticated command and control," and "terminal guidance" for missiles, imagining munitions that could strike targets with almost perfect accuracy. If the future of war became a contest for accuracy, Marshall wagered, the Soviets would fall behind.

像马歇尔这样的战略家知道应对苏联的数量优势的唯一方法是生产更高质量的武器。但怎么做呢？早在1972年，马歇尔就写道，美国需要利用其在计算机上的"重大和持久领先优势"。他写道："一个好策略是发展这种领先优势，并以资本化方式转变战争概念。"他设想了"快速信息收集"、"复杂的指挥和控制"，以及导弹的"终端制导"，想象着能够几乎完美精准地打击目标的弹药。如果未来的战争成为精准度的竞争，马歇尔打赌苏联将落后。

Perry realized that Marshall's vision of the future of war would soon be possible due to the miniaturization of computing power. He was intimately familiar with Silicon Valley's semiconductor innovation, having used Intel's chips in his company's own devices. Many of the weapons systems used in the Vietnam War still relied on vacuum tubes, but chips in the newest handheld calculators offered vastly more computing power than an old Sparrow III missile. Put those chips in missiles, Perry wagered, and America's military would jump ahead of the Soviets.

佩里意识到，由于计算能力的微型化，马歇尔对未来战争的愿景很快就会变成可能。他对硅谷半导体创新非常熟悉，曾在公司的设备中使用英特尔芯片。越南战争中使用的许多武器系统仍然依赖于真空管，但是最新的手持计算器中的芯片比旧的Sparrow III导弹提供了更多的计算能力。佩里打赌，将这些芯片植入导弹中，美国军队将超越苏联。

Guided missiles would not only "offset" the USSR's quantitative advantage, he reasoned. They'd force the Soviets to undertake a ruinously expensive anti-missile effort in response. Perry calculated Moscow would need five to ten years and $30 to $50 billion to defend against the three thousand American cruise missiles that the Pentagon planned to field—and even then, the Soviets could only destroy half the incoming missiles if they were all fired at the USSR.

This was exactly the type of technology that Andrew Marshall had been looking for. Working with Jimmy Carter's secretary of defense, Harold Brown, Perry and Marshall pushed the Pentagon to invest heavily in new technologies: a new generation of guided missiles that used integrated circuits, not vacuum tubes; a constellation of satellites that could beam location coordinates to any point on earth; and—most important—a new program to jump-start the next generation of chips, to ensure that the U.S. kept its technological edge.

引導導彈不僅可以抵消蘇聯在數量上的優勢，他推斷。他們還會迫使蘇聯進行一個毀滅性昂貴的防導彈行動作出回應。派瑞估計莫斯科需要五到十年和三千億到五千億美元才能防禦五千枚美國巡航導彈，美國國防部計劃部署 - 即便如此，如果所有導彈針對蘇聯發射，蘇聯也只能摧毀其中一半。 這正是安德魯·馬歇爾一直在尋找的技術。派瑞和馬歇爾與吉米·卡特的國防部長哈羅德·布朗合作，推動五角大樓大量投資新技術：一個使用集成電路而非真空管的新一代導彈；一個能向地球上任何一點發送位置坐標的衛星星座；以及最重要的是，一個啟動下一代芯片的新計劃，以確保美國保持其技術優勢。

Led by Perry, the Pentagon poured money into new weapons systems that capitalized on America's advantage in microelectronics. Precision weapons programs like the Paveway were promoted, as were guided munitions of all types, from cruise missiles to artillery shells. Sensors and communications also began to leap forward with the application of miniaturized computing power. Detecting enemy submarines, for example, was largely a problem of developing accurate sensors and running the information they gathered through ever-more-complicated algorithms. With enough processing power, the military's acoustic experts wagered, it should be possible to distinguish a whale from a submarine from many miles away.

在佩里的带领下，五角大楼投入资金开发新武器系统，充分利用美国在微电子方面的优势。推广了Precision weapons programs（如Paveway），以及各种制导弹药，从巡航导弹到炮弹。传感器和通信也开始借助微型计算机的应用而跃升。例如，探测敌人的潜艇主要涉及的问题是开发准确的传感器，并将其收集的信息通过越来越复杂的算法进行处理。军方的声学专家打赌，在足够的处理能力下，应该能够在数英里之外区分出鲸鱼和潜艇。

Guided weaponry became more complex. New systems like the Tomahawk missile relied on far more sophisticated guidance systems than the Paveway, using a radar altimeter to scan the ground and match it with terrain maps preloaded into the missile's computer. This way, the missile could redirect itself if it veered off course. This type of guidance had been theorized decades earlier but was only possible to implement now that powerful chips were small enough to fit in a cruise missile.

Individual guided munitions were a powerful innovation, but they'd be even more impactful if they could share information. Perry commissioned a special program, run via the Pentagon's Defense Advanced Research Projects Agency (DARPA), to see what would happen if all these new sensors, guided weapons, and communications devices were integrated. Called " Assault Breaker," it envisioned an aerial radar that could identify enemy targets and provide location information to a ground-based processing center, which would fuse the radar details with information from other sensors. Ground-based missiles would communicate with the aerial radar guiding them toward the target. On final descent, the missiles would release submunitions that would individually home in on their targets.

引导武器变得更加复杂。新系统如"战斧"导弹依靠比"制导炸弹"更复杂的制导系统，使用雷达高度计来扫描地面并将其与导弹计算机预加载的地形图匹配。这样，如果导弹偏航，它可以重新定向。这种制导技术几十年前就已经被理论化了，但只有现在强大的芯片足够小，才能装入巡航导弹中。 单独的制导弹药是一个强大的创新，但如果它们可以共享信息，那就更具有影响力了。佩里委托五角大楼的国防高级研究计划局（DARPA）运行一个名为"攻坚破军"的特别计划，来看看所有这些新的传感器、制导武器和通信设备被整合在一起会发生什么。它设想了一种能够识别敌方目标并向地面处理中心提供位置信息的空中雷达。地面导弹将与引导它们朝向目标的空中雷达进行通信。在最后的下降过程中，导弹会释放子弹，这些子弹会单独瞄准它们的目标。

Guided weapons were giving way to a vision of automated war, with computing power distributed to individual systems in a way never before imaginable. This was only possible because the U.S. was on track "to increase the density of chips ten to a hundredfold," as Perry told an interviewer in 1981, promising comparable increases in computing power. “We will be able to put computers, which only ten years ago would have filled up this entire room, on a chip” and field “ ‘smart’ weapons at all levels.”

Perry’s vision was as radical as anything Silicon Valley had cooked up. Could the Pentagon really implement a high-tech program? By the time Perry left office in 1981, as the Carter presidency ended, journalists and members of Congress were attacking his gamble on precision strike. “Cruise Missiles: Wonder Weapon or Dud?” asked one columnist in 1983. Another equated Perry’s advanced technologies with “bells and whistles,” pointing out the frequent malfunctions and dismal kill ratio of ostensibly “smart” weapons like the vacuum tube–powered Sparrow missile.

引导式武器正被自动化战争的愿景所取代，计算能力被分配到个别系统中，这是以前所未有的。这只有在美国“成功地将芯片密度提高十到一百倍”的情况下才有可能，正如佩里1981年告诉一名采访者的那样，承诺计算能力同样增加。“我们将能够把这个房间的计算机，十年前只能装满这个房间的计算机，放在芯片上”，并在所有级别上部署“智能”武器。佩里的愿景和硅谷创造的任何东西一样激进。五角大楼真的能够实施高科技计划吗？佩里在卡特总统任期结束时离开办公室时，记者和国会议员抨击他对精确打击的赌博。“巡航导弹：神奇的武器还是废物？”一位专栏作家在1983年问道。另一位将佩里的先进技术与“摇铃和哨子”等同，并指出名义上“智能”武器如真空管驱动的麻雀导弹的频繁故障和惨淡的杀伤比率。

The advances in computing power that Perry’s vision required seemed like science fiction to many critics, who assumed guided missile technology would improve slowly because tanks and planes changed slowly, too. Exponential increases, which Moore’s Law dictated, are rarely seen and hard to comprehend. However, Perry wasn’t alone in predicting a “ten to a hundredfold” improvement. Intel was promising the very same thing to its customers. Perry grumbled that his congressional critics were “Luddites,” who simply didn’t understand how rapidly chips were changing.

佩里的愿景所需要的计算能力的进步在许多批评家看来就像科幻小说一样，他们认为制导导弹技术的改进会像坦克和飞机改变得那么慢。

指导摩尔定律的指数增长很少见，也难以理解。然而，佩里并不是唯一预测“十倍到一百倍”改进的人。英特尔也向其客户承诺了同样的事情。佩里抱怨他的国会批评家是“机械臂厌特派”，他们根本不了解芯片正在快速变化的事实。

Even after Perry left office, the Defense Department continued to pour money into advanced chips and the military systems they powered. Andrew Marshall continued his work at the Pentagon, already dreaming of the new systems these next-generation chips would make possible. Could semiconductor engineers deliver the progress Perry promised? Moore’s Law predicted that they could—but this was only a prediction, not a guarantee. Moreover, unlike when integrated circuits were first invented, the chip industry had become less focused on military production. Firms like Intel targeted corporate computers and consumer goods, not missiles. Only consumer markets had the volume to fund the vast R&D programs that Moore’s Law required.

即便是佩里卸任后，国防部依旧将大量资金投入先进芯片及其所驱动的军事系统中。安德鲁·马歇尔在五角大楼继续从事着他的工作，他已经开始憧憬这些下一代芯片所将能够实现的新系统。半导体工程师们能够交付佩里所承诺的进步吗？摩尔定律预测他们能够实现，但这只是一种预言，而非保证。此外，与当集成电路首次发明时不同，芯片行业已经不再专注于军事生产。像英特尔这样的公司针对的是企业电脑和消费品，而非导弹。只有消费市场才能为摩尔定律所需的庞大研发计划提供资金。

In the early 1960s, it had been possible to claim the Pentagon had created Silicon Valley. In the decade since, the tables had turned. The U.S. military lost the war in Vietnam, but the chip industry won the peace that followed, binding the rest of Asia, from Singapore to Taiwan to Japan, more closely to the U.S. via rapidly expanding investment links and supply chains. The entire world was more tightly connected to America’s innovation infrastructure, and even adversaries like the USSR spent their time copying U.S. chips and chipmaking tools. Meanwhile, the chip industry had catalyzed an array of new weapons systems that were remaking how the U.S. military would fight future wars. American power was being recast. Now the entire nation depended on Silicon Valley’s success.

在20世纪60年代初，曾经有人说五角大楼创造了硅谷。但十年过去了，形势逆转了。美国在越南战争中失败了，但芯片产业在战后赢得了和平，通过扩大投资和供应链将亚洲其他地区（从新加坡到台湾再到日本）与美国更紧密地联系在一起。整个世界都与美国的创新基础设施更紧密地联系在一起，即使是苏联这样的对手也花时间复制美国的芯片和芯片制造工具。与此同时，芯片产业催生了一系列新型武器系统，正在重新塑造美国军队未来作战的方式。美国的实力正在重新铸造。现在，整个国家都依赖于硅谷的成功。

PART III
LEADERSHIP LOST?

CHAPTER 15 “That Competition Is Tough”

“ E ver since you’ve written that paper, my life has been hell!” one chip salesman grumbled to Richard Anderson, a Hewlett-Packard executive tasked with deciding which chips met HP’s stringent standards. The 1980s were a hellish decade for the entire U.S. semiconductor sector. Silicon Valley thought it sat atop the world’s tech industry, but after two decades of rapid growth it now faced an existential crisis: cutthroat competition from Japan. When Anderson took the stage at an industry conference at Washington, D.C.’s historic Mayflower Hotel on March 25, 1980, the audience listened carefully, because everyone was trying to sell him their chips. Hewlett-Packard, the company he worked for, had invented the concept of a Silicon Valley startup in the 1930s, when Stanford grads Dave Packard and Bill Hewlett began tinkering with electronic equipment in a Palo Alto garage. Now it was one of America’s biggest tech companies—and one of the largest buyers of semiconductors.

一名芯片销售员向决定哪些芯片符合惠普严格标准的沃特洛-安德森（Richard Anderson）高管抱怨说：“自从你写了那篇论文，我的生活就变成了地狱！”20世纪80年代对整个美国半导体行业来说都是一个可怕的十年。硅谷自认为是世界技术产业的领袖，但经过两十年的快速增长，现在面临一个存在危机：来自日本的残酷竞争。1980年3月25日，在华盛顿特区历史悠久的梅花酒店举办的一场行业会议上，安德森登台发言时，听众非常认真，因为每个人都想向他销售自己的芯片。惠普是一家始于20世纪30年代斯坦福大学毕业生戴夫-帕卡德（Dave Packard）和比尔-休伊特（Bill Hewlett）在帕罗奥图车库tinkering 电子设备时发明了硅谷初创公司概念的公司。现在，它是美国最大的科技公司之一，也是半导体的最大买家之一。

Anderson’s judgment about a chip could shape the fate of any semiconductor company, but Silicon Valley’s salesmen were never allowed to wine and dine him. “Sometimes I let them take me out to lunch,” he admitted sheepishly. But the entire valley knew that he was the gatekeeper to almost everyone’s most important customer. His job gave him a panoramic view of the semiconductor industry, including how each company was performing.

In addition to American companies like Intel and TI, Japanese firms like Toshiba and NEC were now building DRAM memory chips—though most people in Silicon Valley didn't take these players seriously. U.S. chipmakers were run by the people who'd invented high-tech. They joked that Japan was the country of "click, click"—the sound made by cameras that Japanese engineers brought to chip conferences to better copy the ideas. The fact that major American chipmakers were embroiled in intellectual property lawsuits with Japanese rivals was interpreted as evidence that Silicon Valley was still well ahead.

安德森對晶片的評價能夠決定任何半導體公司的命運，但銷售人員從未被允許設法獲得他的身影。他羞怯地承認："有時候，我會讓他們請我吃午餐。" 但整個矽谷知道，他是幾乎每個人最重要的客戶的守門人。他的工作給了他全景視圖的半導體行業，包括每家公司的表現如何。除了美國公司如英特爾和TI外，日本企業如東芝和NEC現在也在建造DRAM內存芯片—盡管大多數矽谷人不會納入這些參與者。美國芯片製造商由發明高科技的人所管理。他們開玩笑說，日本是"咔嚓，咔嚓"的國家——這是日本工程師在晶片會議上帶來的相機發出的聲音，以更好地抄襲這些想法。美國主要芯片製造商與日本競爭對手發生知識產權訴訟的事實被解釋為證據，表明矽谷仍遙遙領先。

At HP, however, Anderson didn't simply take Toshiba and NEC seriously—he tested their chips and found that they were of far better quality than American competitors. None of the three Japanese firms reported failure rates above 0.02 percent during their first one thousand hours of use, he reported. The lowest failure rate of the three American firms was 0.09 percent—which meant four-and-a-half times as many U.S.-made chips were malfunctioning. The worst U.S. firm produced chips with 0.26 percent failure rates—over *ten* times as bad as the Japanese results. American DRAM chips worked the same, cost the same, but malfunctioned far more often. So why should anyone buy them?

然而，在惠普，安德森不仅仅认真对待东芝和NEC，而且测试了他们的芯片，并发现它们比美国竞争对手质量要好得多。他报告称，这三家日本公司在使用前一千个小时内未报告故障率超过0.02％。三家美国公司中最低的故障率为0.09％，这意味着出现故障的美国制造芯片数量是日本制造的四倍半。最糟糕的美国公司生产的芯片的故障率为

0.26％，比日本结果差了十倍以上。美国的DRAM芯片使用相同，成本相同，但故障率要高得多。那么为什么有人要购买它们呢？

Chips weren’t the only U.S. industry facing pressure from high-quality, ultra-efficient Japanese competitors. In the immediate postwar years, “Made in Japan” had been a synonym for “cheap.” But entrepreneurs like Sony’s Akio Morita had cast off this reputation for low price, replacing it with products that were as high quality as those of any American competitor. Morita’s transistor radios were the first prominent challenger to American economic preeminence, and their success emboldened Morita and his Japanese peers to set their sights even higher. American industries from cars to steel were facing intense Japanese competition.

薯片并非美国唯一面临来自高品质、超效率的日本竞争对手的行业。在战后初期，“日本制造”曾是“廉价”的代名词。但索尼的盛田昭夫这样的企业家已经抛弃了低价的声誉，推出了与任何美国竞争对手一样高质量的产品。盛田的晶体管收音机是首个挑战美国经济领先地位的突出者，他们的成功鼓舞了盛田及其日本同辈将目光更高地定在了其他美国产业如汽车和钢铁上。

By the 1980s, consumer electronics had become a Japanese specialty, with Sony leading the way in launching new consumer goods, grabbing market share from American rivals. At first Japanese firms succeeded by replicating U.S. rivals’ products, manufacturing them at higher quality and lower price. Some Japanese played up the idea that they excelled at implementation, whereas America was better at innovation. “We have no Dr. Noyces or Dr. Shockleys,” one Japanese journalist wrote, though the country had begun to accumulate its share of Nobel Prize winners. Yet prominent Japanese continued to downplay their country’s scientific successes, especially when speaking to American audiences. Sony’s research director, the famed physicist Makoto Kikuchi, told an American journalist that Japan had fewer geniuses than America, a country with “outstanding elites.” But America also had “ a long tail” of people “with less than normal intelligence,” Kikuchi argued, explaining why Japan was better at mass manufacturing.

到了1980年代，消费电子已经变成了日本的专长领域，索尼在推出新的消费品方面领先，从美国竞争对手那里夺得了市场份额。起初，日

本企业通过复制美国竞争对手的产品，以更高的质量和更低的价格制造出来而获得成功。一些日本人强调他们在实施方面的卓越，而美国更擅长创新。"我们没有诺伊斯博士或肖克利博士，"一位日本记者写道，尽管该国已经开始积累其获得诺贝尔奖的人数。然而，当对美国观众发表演讲时，杰出的日本人士继续淡化其国家的科学成就。索尼的研究主管，著名的物理学家菊池诚告诉一位美国记者，日本比美国少了更多的天才，而美国有“杰出的精英”。但菊池辩称，美国也有“低于正常智力”的人群，这就是为什么日本更擅长大规模制造的原因。

American chipmakers clung to their belief that Kikuchi was right about America’s innovation advantage, even though contradictory data was piling up. The best evidence against the thesis that Japan was an “implementer” rather than an “innovator” was Kikuchi’s boss, Sony CEO Akio Morita. Morita knew that replication was a recipe for second-class status and second-rate profits. He drove his engineers not only to build the best radios and TVs, but to imagine new types of products entirely.

In 1979, just months before Anderson’s presentation about quality problems in American chips, Sony introduced the Walkman, a portable music player that revolutionized the music industry, incorporating five of the company’s cutting-edge integrated circuits in each device. Now teenagers the world over could carry their favorite music in their pockets, powered by integrated circuits that had been pioneered in Silicon Valley but developed in Japan. Sony sold 385 million units worldwide, making the Walkman one of the most popular consumer devices in history. This was innovation at its purest, and it had been made in Japan.

美国的芯片制造商坚信Kikuchi的观点-美国有创新优势，尽管相反的数据不断积累。最有效反驳日本是“实施者”而不是“创造者”这一观点的证据之一是Kikuchi的老板，索尼公司的CEO Akio Morita。Morita知道复制是次等地位和次等利润的做法。他驱使他的工程师不仅建造最好的收音机和电视，而且想象全新类型的产品。1979年，在Anderson发布有关美国芯片质量问题的演示几个月前，索尼推出了Walkman，这是一款革新了音乐行业的便携式音乐播放器，每个设备包含了五个公司的尖端集成电路。现在全世界的青少年都可以将自己喜欢的音乐放在口袋里，由在硅谷开创而在日本开发的集成电路供电。索尼在全球

销售了3.85亿台设备，使Walkman成为历史上最受欢迎的消费设备之一。这是最纯粹的创新，是在日本完成的。

The U.S. had supported Japan's postwar transformation into a transistor salesman. U.S. occupation authorities transferred knowledge about the invention of the transistor to Japanese physicists, while policymakers in Washington ensured Japanese firms like Sony could easily sell into U.S. markets. The aim of turning Japan into a country of democratic capitalists had worked. Now some Americans were asking whether it had worked too well. The strategy of empowering Japanese businesses seemed to be undermining America's economic and technological edge.

美國曾支持日本在戰後轉型成為晶體管推銷員。美國佔領當局將關於晶體管的發明知識轉移給日本物理學家，而華盛頓的政策制定者則確保索尼等日本公司可以輕鬆銷售到美國市場。將日本變成民主資本主義國家的目標已經實現。現在有些美國人正在問，是否已經做得太好。賦予日本企業權力的策略似乎正在削弱美國的經濟和技術優勢。

Charlie Sporck, the executive who'd been burned in effigy while managing a GE production line, found Japan's productivity fascinating and frightening. After starting in the chip industry at Fairchild, Sporck left to run National Semiconductor, then a large producer of memory chips. Ultra-efficient Japanese competition seemed certain to put him out of business. Sporck had a hard-earned reputation for his ability to squeeze efficiency out of assembly line workers, but Japan's productivity levels were far ahead of anything his workers could accomplish.

史博克是曾在管理通用电气生产线时被人烧成雕像的高管。他发现日本的生产力既令人着迷又感到害怕。在费尔柴尔德从事芯片行业后，史博克离开并转向运营国家半导体，当时是一家大型的记忆芯片制造商。超级高效的日本竞争对手几乎肯定会让他破产。虽然史博克以挤压装配线工人的效率而声名狼藉，但日本的生产力水平远远超出了他的工人所能做到的任何事情。

Sporck sent one of his foremen and a group of assembly line workers to spend several months in Japan touring semiconductor facilities. When they returned to California, Sporck made a film about their experience. They reported that Japanese workers were “amazingly pro-company” and that “the foreman put a priority to the company over his family.” Bosses in Japan didn’t have to worry about getting burned in effigy. It was a “beautiful story,” Sporck declared. “It was something for all of our employees to see how that competition is tough.”

Sporck派遣了他的一位工头和一组组装线工人前往日本参观半导体设施，他们在几个月后返回加州，Sporck拍摄了一部关于他们经历的电影。他们报告说，日本工人“惊人地支持公司”，“工头把公司放在家庭之上”。日本的老板们不必担心自己被焚像烧毁。这是一个“美好的故事”，Sporck宣称。“这是所有员工看到竞争是多么激烈的故事。”

CHAPTER 16 “At War with Japan”

“ I don’t want to pretend I’m in a fair fight,” complained Jerry Sanders, CEO of Advanced Micro Devices. “I’m not.” Sanders knew something about fights. At age eighteen, he’d almost died after a brawl on Chicago’s South Side, where he grew up. After his body was found in a garbage can, a priest administered last rites, though he miraculously emerged from a coma three days later. He eventually landed a job in sales and marketing at Fairchild Semiconductor, working alongside Noyce, Moore, and Andy Grove before they left Fairchild to found Intel. Though his colleagues were mostly modest engineers, Sanders flashed expensive watches and drove a Rolls-Royce. He commuted weekly to Silicon Valley from Southern California, where he lived, because, one colleague recalled, he and his wife only really felt at home in Bel Air. After founding his own chip firm, AMD, in 1969, he spent much of the next three decades in a legal brawl with Intel over intellectual property disputes. “ I can’t walk away from a fight,” he admitted to a journalist.

“我不想假装自己在公平的战斗中。”——高级微处理器公司首席执行官杰瑞·桑德斯抱怨道。“我不在其中。”桑德斯对战斗有所了解。18岁时，他在他成长的芝加哥南部发生了一场斗殴后差点死亡。在他的尸体被发现在一个垃圾桶里之后，一位神父进行了最后的祈祷，尽管他在三天后奇迹般地从昏迷中醒来。他最终在菲尔奇尔德半导体公司获得了一份销售和营销工作，与诺伊斯，摩尔和安迪·格鲁夫在离开菲尔奇尔德创立英特尔之前一同工作。尽管他的同事们大多是谦虚的工程师，桑德斯却佩戴着昂贵的手表，开着劳斯莱斯。他每周都从加州南部通勤到硅谷，因为据一位同事回忆，他和妻子只有在贝尔·艾尔（Bel Air）才真正感到家的温暖。创立自己的芯片公司AMD后，他在接下来的30年中与英特尔进行了一场基于知识产权争议的法律斗争。“我无法逃避斗争，”他向记者承认。

“The chip industry was an incredibly competitive industry,” remembered Charlie Sporck, the executive who’d led the offshoring of chip assembly throughout Asia. “Knock ’em down, fight ’em, kill ’em,” Sporck explained, hitting his fists together to illustrate his point. With pride, patents, and millions of dollars at stake, the brawls between U.S. chipmakers often got personal, but there was still plenty of growth to go around. Japanese competition seemed different, however. If Hitachi, Fujitsu, Toshiba, and NEC succeeded, Sporck thought, they'd move the whole industry across the Pacific. "I worked specifically on TVs at GE," Sporck warned. "You can drive by that facility now, it's still empty…. We knew the dangers and we damn right well weren't gonna let that happen to us." Everything was at stake—jobs, fortunes, legacies, pride. "We're at war with Japan," Sporck insisted. "Not with guns and ammunition, but an economic war with technology, productivity, and quality."

"芯片行业竞争激烈，"曾领导芯片组装外包亚洲的高管查理·斯波克回忆道。"打压他们、与他们争斗、干掉他们，"斯波克说着时，拳头相互碰撞以阐明他的观点。由于财产权、专利权和数百万美元的利益都受到影响，美国芯片制造商之间的争斗通常个人成份浓厚，但仍然有大量的增长潜力可供利用。然而，斯波克认为，日本的竞争形势不同。如果日立、富士通、东芝和NEC取得成功，他们将把整个行业搬到太平洋另一侧。斯波克警告说："我曾在GE公司专门从事电视工作。你现在可以开车经过那个工厂，它现在还是空的。我们知道这种危险，不会允许发生这种情况。"一切都岌岌可危，就业、财富、遗产和自尊心。斯波克坚称："我们与日本开展经济战争，没有枪支和弹药的战争，只有技术、生产力和质量的经济战争。"

Sporck saw Silicon Valley's internal battles as fair fights, but thought Japan's DRAM firms benefitted from intellectual property theft, protected markets, government subsidies, and cheap capital. Sporck had a point about the spies. After a 5 a.m. rendezvous in the lobby of a Hartford, Connecticut, hotel on a cold November morning in 1981, Hitachi employee Jun Naruse handed over an envelope of cash and received in exchange a badge from a "consultant" at a company called Glenmar that promised to help Hitachi obtain industrial secrets. With the badge, Naruse gained entrance to a secret facility run by aircraft maker Pratt & Whitney and photographed the company's newest computer.

Sporck 視硅谷內部的爭戰為公平的戰鬥，但認為日本的DRAM公司從知識產權盜竊、受保護的市場、政府補貼和廉價資本中受益。關於間諜，Sporck 有一點道理。1981 年11 月的一個寒冷早晨，在康涅狄格州

哈特福德的一家旅館大堂進行了一次早上 5 點的會面後，日立員工成瀨純(Jun Naruse)交出了一個現金信封，換取了來自一家名叫Glenmar的「顧問」所提供的徽章，該公司承諾幫助日立獲取工業秘密。憑藉徽章，成瀨獲得了進入由飛機製造商普拉特·惠特尼 (Pratt & Whitney) 經營的秘密設施的權利，並拍攝了該公司最新的電腦。

After the photo shoot, Naruse's colleague on the West Coast, Kenji Hayashi, sent a letter to Glenmar proposing a "consultation service contract." Hitachi's senior executives authorized half a million dollars in payments to Glenmar to continue the relationship. But Glenmar was a front company; its employees were FBI agents. "It seems that Hitachi stepped into the trap," the company's spokesman sheepishly admitted, after Hitachi's employees were arrested and the story made the front page of the business section of the *New York Times* .

在拍照后，成員成員長谷健二向格蘭瑪公司提出了"諮詢服務合同"的建議函。日立的高級主管授權向格蘭瑪支付50萬美元，以繼續保持關係。但是格蘭瑪是一家幌子公司，其員工是聯邦調查局特工。"似乎日立掉進了陷阱，"該公司發言人承認，當日立的員工被逮捕並且這個故事登上了紐約時報的商業版面後。

Hitachi wasn't alone. Mitsubishi Electric faced similar charges. It wasn't only in semiconductors and computers that accusations of Japanese espionage and double-dealing swirled. Toshiba, the Japanese industrial conglomerate that by the mid-1980s was a world-leading DRAM producer, spent years fighting claims—true, it turned out—that the company sold the Soviets machinery that helped them build quieter submarines. There was no direct link between Toshiba's Soviet submarine deal and the company's semiconductor business, but many Americans saw the submarine case as further evidence of Japanese dirty dealing. The number of documented cases of illegal Japanese industrial espionage was low. But was this a sign that stealing secrets played only a small role in Japan's success, or evidence that Japanese firms were skilled at spycraft?

日立不是唯一一家遭到指控的公司，三菱电机也面临着类似指控。在半导体和计算机领域之外，指责日本从事间谍活动和双重交易的声音也不绝于耳。到了80年代中期，作为世界领先的动态随机存取存储器

（DRAM）生产商，日本工业集团东芝也花费多年时间抵制指控——结果证实，在这段时间，东芝曾向苏联出售帮助他们打造更加安静的潜艇的机器设备。尽管东芝与苏联潜艇案之间没有直接联系，但许多美国人却认为，这起潜艇案进一步证明了日本企业从事不正当交易的事实。目前已经有记录的日本非法工业间谍案件数量并不多。但这是因为窃取机密在日本成功中发挥的作用较小，还是因为日本公司擅长间谍活动？

Sneaking into rivals' facilities was illegal but keeping tabs on competitors was normal practice in Silicon Valley. So, too, was accusing rivals of pilfering employees, ideas, and intellectual property. America's chipmakers were constantly suing each other, after all. It took a decade of litigation between Fairchild and Texas Instruments to resolve the question of whether Noyce or Kilby had invented the integrated circuit, for example. Chip firms regularly poached rivals' star engineers, too, hoping not only to acquire experienced workers but also knowledge about their competitors' production processes. Noyce and Moore had left Shockley Semiconductor to found Fairchild, then left Fairchild to found Intel, where they hired dozens of Fairchild employees, including Andy Grove. Fairchild considered suing before deciding that it was unlikely to win a lawsuit against the geniuses who had built the chip industry. Tracking and emulating rivals was key to Silicon Valley's business model. Was Japan's strategy any different?

潜入竞争对手设施是非法的，但是监视竞争对手是硅谷的常规做法。指控竞争对手窃取员工、想法和知识产权也是如此。毕竟，美国的芯片制造商经常相互起诉。例如，解决了Fairchild和德州仪器之间的十年诉讼，以确定Noyce或Kilby发明了集成电路。芯片公司经常挖走对手的明星工程师，希望不仅获得有经验的工人，而且获得有关竞争对手生产过程的知识。Noyce和Moore离开Shockley Semiconductor成立Fairchild，然后离开Fairchild成立Intel，他们聘请了几十名Fairchild员工，包括Andy Grove在内。Fairchild在决定不太可能赢得一项诉讼之前曾考虑起诉这些建立芯片行业的天才。追踪和模仿竞争对手是硅谷业务模型的关键。而日本的策略有什么不同吗？

Sporck and Sanders pointed out that Japanese firms benefitted from a protected domestic market, too. Japanese firms could sell to the U.S., but Silicon Valley struggled to win market share in Japan. Until 1974, Japan imposed quotas limiting the number of chips U.S. firms could sell there. Even after these quotas were lifted, Japanese companies still bought few chips from Silicon Valley, even though Japan consumed a quarter of the world's semiconductors, which companies like Sony plugged into TVs and VCRs that were sold worldwide. Some big Japanese chip consumers such as NTT, Japan's national telecom monopoly, bought almost exclusively from Japanese suppliers. This was ostensibly a business decision, but NTT was government-owned, so politics likely played a role. Silicon Valley's low market share in Japan cost American companies billions of dollars in sales.

Sporck和Sanders指出，日本公司也受益于受保护的国内市场。日本公司可以向美国销售，但硅谷很难在日本赢得市场份额。直到1974年，日本实行限制额度，限制美国公司在那里销售芯片的数量。即使这些配额被取消，日本公司仍然很少从硅谷购买芯片，尽管日本消耗了全球四分之一的半导体，这些公司如索尼将其插入销往全球的电视和录像机中。一些大型日本芯片消费者，如日本的国家电信垄断企业NTT，几乎完全从日本供应商购买。这表面上是一个商业决策，但NTT是政府所有的，所以政治可能发挥了作用。硅谷在日本的低市场份额使美国公司损失了数十亿美元的销售额。

Japan's government subsidized its chipmakers, too. Unlike in the U.S., where antitrust law discouraged chip firms from collaborating, the Japanese government pushed companies to work together, launching a research consortium called the VLSI Program in 1976 with the government funding around half the budget. America's chipmakers cited this as evidence of unfair Japanese competition, though the $72 million the VLSI Program spent annually on R&D was about the same as Texas Instruments' R&D budget, and less than Motorola's. Moreover, the U.S. government was itself deeply involved in supporting semiconductors, though Washington's funding took the form of grants from DARPA, the Pentagon unit that invests in speculative technologies and has played a crucial role in funding chipmaking innovation.

日本政府也对其芯片制造商提供了资助。与美国反垄断法阻碍芯片公司合作不同，日本政府推动公司合作，并于1976年启动了名为VLSI计划的研究联盟，政府资助约占预算的一半。美国芯片制造商将此视为不公平的日本竞争证据，尽管VLSI计划每年耗费7200万美元用于研发，但这个数值与德州仪器的研发预算相当，低于摩托罗拉。此外，

美国政府也深度参与支持半导体，虽然华盛顿方面的资金形式来自于DARPA（国防部投资于专业技术的单位），该部门在资助芯片制造创新方面发挥了关键作用。

Jerry Sanders saw Silicon Valley's biggest disadvantage as its high cost of capital. The Japanese "pay 6 percent, maybe 7 percent, for capital. I pay 18 percent on a good day," he complained. Building advanced manufacturing facilities was brutally expensive, so the cost of credit was hugely important. A next-generation chip emerged roughly once every two years, requiring new facilities and new machinery. In the 1980s, U.S. interest rates reached 21.5 percent as the Federal Reserve sought to fight inflation.

杰里·桑德斯认为硅谷最大的劣势是其高昂的资本成本。他抱怨说，日本人"支付6％或7％的资本，而我在好日子里支付18％。"建造先进的制造设施是非常昂贵的，因此信贷成本非常重要。大约每两年出现一个新一代芯片，需要新设施和新机器。在20世纪80年代，由于美联储试图抵制通货膨胀，美国利率达到21.5％。

By contrast, Japanese DRAM firms got access to far cheaper capital. Chipmakers like Hitachi and Mitsubishi were part of vast conglomerates with close links to banks that provided large, long-term loans. Even when Japanese companies were unprofitable, their banks kept them afloat by extending credit long after American lenders would have driven them to bankruptcy. Japanese society was structurally geared to produce massive savings, because its postwar baby boom and rapid shift to one-child households created a glut of middle-aged families focused on saving for retirement. Japan's skimpy social safety net provided a further incentive for saving. Meanwhile, tight restrictions on stock markets and other investments left people with little choice but to stuff savings in bank accounts. As a result, banks were flush with deposits, extending loans at low rates because they had so much cash on hand. Japanese companies had more debt than American peers but nevertheless paid lower rates to borrow.

相比之下，日本的DRAM公司获得了更便宜的资金。像日立和三菱这样的芯片制造商是巨大财团的一部分，与提供大量长期贷款的银行有密切联系。即使日本公司不盈利，他们的银行也会借以维持其运营，而美国的放贷人早已将其推向破产。日本社会在结构上就被调整为生

产大量的储蓄，因为它的战后婴儿潮和快速转向一子家庭为以退休为目标的中年家庭创造了过剩的条件。日本的单薄社会保障网提供了进一步的储蓄刺激。与此同时，对股票市场和其他投资的严格限制使人们别无选择，只能将储蓄存放在银行账户中。结果，银行有大量存款，因为他们手头上有很多现金，所以借贷利率很低。日本公司的债务比美国同行多，但仍然支付更低的借贷利率。

With this cheap capital, Japanese firms launched a relentless struggle for market share. Toshiba, Fujitsu, and others were just as ruthless in competing with each other, despite the cooperative image painted by some American analysts. Yet with practically unlimited bank loans available, they could sustain losses as they waited for competitors to go bankrupt. In the early 1980s, Japanese firms invested 60 percent more than their U.S. rivals in production equipment, even though everyone in the industry faced the same cutthroat competition, with hardly anyone making much profit. Japanese chipmakers kept investing and producing, grabbing more and more market share. Because of this, five years after the 64K DRAM chip was introduced, Intel—the company that had pioneered DRAM chips a decade earlier—was left with only 1.7 percent of the global DRAM market, while Japanese competitors' market share soared.

憑藉低廉的資本，日本企業展開了一場不懈的市場份額爭奪戰。東芝、富士通等競爭對手同樣無情地競爭，儘管一些美國分析師描繪了互惠合作的形象。然而，由於可以獲得幾乎無限的銀行貸款，他們可以承擔損失，等待競爭對手破產。早在1980年代初，日本企業就比美國競爭對手多投資了60％的生產設備，即使整個行業都面臨著相同的殘酷競爭，幾乎沒有人賺取太多利潤。日本的芯片製造商繼續投資和生產，搶占越來越多的市場份額。因此，64K DRAM芯片推出五年後，原先開拓DRAM芯片的公司英特爾只剩下1.7％的全球DRAM市場份額，而日本競爭對手的市場份額卻急劇上升。

Japan's firms doubled down on DRAM production as Silicon Valley was pushed out. In 1984, Hitachi spent 80 billion yen on capital expenditure for its semiconductor business, compared to 1.5 billion a decade earlier. At Toshiba, spending grew from 3 billion to 75 billion; at NEC, from 3.5 billion to 110 billion. In 1985, Japanese firms spent 46 percent of the world's capital expenditure on semiconductors, compared to America's 35 percent.

By 1990, the figures were even more lopsided, with Japanese firms accounting for half the world's investment in chipmaking facilities and equipment. Japan's CEOs kept building new facilities so long as their banks were happy to foot the bill.

當硅谷被排擠出去時，日本企業加大了DRAM產量的投入。1984年，日立在其半導體業務上的資本支出為800億日元，相比十年前的15億，而東芝的支出從30億增加到了750億，NEC也從35億增加到了1100億。1985年，日本企業在半導體方面的資本支出佔全球的46％，而美國則佔35％。到了1990年，這些數字更加失衡，日本企業佔了全球一半的晶片製造設施和設備投資。只要他們的銀行樂意出資，日本的CEO們就繼續建立新設施。

The Japanese chipmakers argued that none of this was unfair. America's semiconductor firms got plenty of help from the government, especially via defense contracts. Anyway, American consumers of chips, like HP, had hard evidence that Japanese chips were simply better quality. So Japan's market share in DRAM chips grew every year during the 1980s, at the expense of American rivals. Japan's semiconductor surge seemed unstoppable, no matter the apocalyptic predictions of American chipmakers. Soon all of Silicon Valley would be left for dead, like teenage Jerry Sanders in a South Side garbage can.

日本的晶片製造商認為這些都不是不公平的。美國的半導體公司從政府得到了很多幫助，特別是通過國防合同。此外，像惠普這樣的晶片消費者有著堅實的證據表明，日本的晶片質量更好。因此，在20世紀80年代期間，日本在DRAM晶片的市場份額每年都在增長，而美國競爭對手卻處於劣勢。日本的半導體繁榮似乎不可阻擋，即使美國晶片製造商做出了世界末日般的預測。很快，整個矽谷就會像南邊一個垃圾箱裡的少年傑里·桑德斯一樣一蹶不振。

CHAPTER 17 “Shipping Junk”

A s the Japanese juggernaut tore through America’s high-tech industry, it wasn’t only companies producing DRAM chips that struggled. Many of their suppliers did, too. In 1981, GCA Corporation was being celebrated as one of America’s “hottest high-technology corporations,” growing rapidly by selling equipment that made possible Moore’s Law. In the two decades since physicist Jay Lathrop had first turned his microscope upside down to shine light on photoresist chemicals and “print” patterns on semiconductor wafers, the process of photolithography had become vastly more complicated. Long gone were the days of Bob Noyce driving up and down California’s Highway 101 in his old jalopy in search of movie camera lenses for Fairchild’s makeshift photolithography equipment. Now lithography was big business, and at the start of the 1980s, GCA was at the top.

當日本的巨人在美國高科技產業中肆虐時，不僅是生產DRAM芯片的公司受到了打擊，而且許多供應商也受到了影響。1981年，GCA公司被譽為美國最熱門的高科技公司之一，通過銷售實現了摩爾定律所必需的設備，並迅速擴張。自物理學家傑伊·拉斯羅普（Jay Lathrop）將他的顯微鏡倒過來照射光線至光阻化學物質，並在半導體晶圓上“印刷”圖案的兩十年來，光刻製程變得更加複雜。已經過去了鮑勃·諾伊斯（Bob Noyce）駕駛他的舊汽車在加利福尼亞101號公路上來回躲避電影攝影機鏡頭，用於Fairchild的臨時光刻設備的時代。現在光刻是一個龐大的行業，到了1980年代初期，GCA位居榜首。

Though photolithography had become far more precise than in the days of Jay Lathrop’s upside-down microscope, the principles remained the same. A light shined through masks and lenses, projecting focused shapes onto a silicon wafer covered with photoresist chemicals. Where light struck, the chemicals reacted with the light, allowing them to be washed away, exposing microscopic indentations on top of the silicon wafer. New materials were added in these holes, building circuits on the silicon. Specialized chemicals etched away the photoresist, leaving behind perfectly formed shapes. It often took five, ten, or twenty iterations of lithography, deposition, etching, and polishing to fabricate an integrated circuit, with the result layered like a geometric wedding cake. As transistors were miniaturized, each part of the lithography process—from the chemicals to the lenses to the lasers that perfectly aligned the silicon wafers with the light source—became even more difficult.

虽然光刻技术比杰伊 · 拉思罗普倒置显微镜时代更加精确，但其原理仍然是相同的。光经过掩模和镜头照射在覆盖着光敏物质化学药剂的硅晶圆上，投射出聚焦的形状。药剂与光线互动的地方，会让药剂发生反应，使其被冲刷掉，从而在硅晶圆上暴露出微小的凹陷。接着在这些洞里面加入新材料，在硅晶上建立电路。特定的药剂将光敏物质化学药剂腐蚀掉，只留下完美形状的设备。通常需要进行五到二十次光刻、沉积、腐蚀和抛光的迭代，才能制造出一个积体电路，最终的结果就像是一座几何形状的婚礼蛋糕。随着晶体管的微型化，从物质到镜头，再到将硅晶圆与光源完美对齐的激光等，光刻工艺中的每个部分都变得更加困难。

The world’s leading lens makers were Germany’s Carl Zeiss and Japan’s Nikon, though the U.S. had a few specialized lens makers, too. Perkin Elmer, a small manufacturer in Norwalk, Connecticut, had made bombsights for the U.S. military during World War II and lenses for Cold War satellites and spy planes. The company realized this technology could be used in semiconductor lithography and developed a chip scanner that could align a silicon wafer and a lithographic light source with almost perfect precision, which was crucial if the light was to hit the silicon exactly as intended. The machine moved the light across the wafer like a copy machine, exposing the photoresist-covered wafer as if it were being painted with lines of light. Perkin Elmer’s scanner could create chips with features approaching one micron—a millionth of a meter—in width.

世界领先的镜头制造商是德国的卡尔蔡司和日本的尼康，不过美国也有一些专业的镜头制造商。小型制造商Perkin Elmer位于康涅狄格州诺沃克，曾在二战期间为美国军方制造开瞄具，为冷战时期的卫星和间谍飞机制造镜头。该公司意识到这项技术可用于半导体光刻，并开发出一种芯片扫描仪，可以将硅片和光刻光源与几乎完美的精度对齐，这对于光线准确照射到硅片上至关重要。该机器将光线在硅片上移动，就像复印机一样，以线形光暴露在覆盖光刻胶的硅片上。Perkin

Elmer的扫描仪可创建的芯片特征宽度可达1微米，即一百万分之一米。

Perkin Elmer’s scanner dominated the lithography market in the late 1970s, but by the 1980s, it had been displaced by GCA, a company led by an Air Force officer–turned-geophysicist named Milt Greenberg, an ambitious, stubborn, foul-mouthed genius. Greenberg and an Air Force buddy founded GCA after World War II with seed capital from the Rockefellers. Trained as a military meteorologist, Greenberg had parlayed his knowledge of the atmosphere and his Air Force connections into work as a defense contractor, producing devices like high-altitude balloons that made measurements and took photographs of the Soviet Union.

在1970年代晚期，佩尔金埃尔默的扫描仪在镭射曝光市场上占据主导地位，但到了1980年代，它被一家名为GCA的公司取代，该公司由一位名叫米尔特·格林伯格的空军军官和地球物理学家领导，格林伯格是一位雄心勃勃、固执己见、语言粗俗的天才。格林伯格和他的空军战友在二战后由洛克菲勒家族提供的种子资金创立了GCA。作为一名军方气象学家，格林伯格利用他对大气层的知识和与空军的联系，成为国防承包商，生产高空气球等设备，用于测量和拍摄苏联的情况。

Greenberg’s ambitions soon flew even higher. The growth in the semiconductor industry showed that the real money was in the mass market, not in specialized military contracts. Greenberg thought his company’s high-tech optical systems—useful for military reconnaissance—could be deployed on civilian chips. At an industry conference in the late 1970s, where GCA was advertising its systems for chipmakers, Texas Instruments’ Morris Chang walked up to the GCA booth, started looking at the company’s equipment, and inquired whether, rather than scanning light across the length of a wafer, the firm’s equipment could move step-by-step, exposing each chip on the silicon wafer. Such a “stepper” would be far more accurate than the existing scanners. Though a stepper had never been devised, GCA’s engineers believed they could create one, providing higher-resolution imaging and thus smaller transistors.

格林伯格的野心很快就变得更加高涨。半导体行业的增长表明，真正的赚钱在于大众市场，而不是专门的军事合同。格林伯格认为，他公

司的高科技光学系统——在军事侦察方面很有用——可以部署在民用芯片上。在20世纪70年代后期的一次行业会议上，GCA在为芯片制造商推广其系统时，德州仪器(Morris Chang)走到GCA的展位上，开始观察该公司的设备，并询问是否可以在硅晶圆上一步步地移动，曝光每个芯片，而不是在整个晶圆上扫描光线。这种“步进器”比现有的扫描仪更精确。虽然之前从未设计过步进器，但GCA的工程师相信他们可以创造一个，提供更高分辨率的成像，从而制造更小的晶体管。

Several years later, in 1978, GCA introduced its first stepper. Sales orders began rolling in. Before the stepper, GCA had never made more than $50 million a year in revenue on its military contracts, but now it had a monopoly on an extraordinarily valuable machine. Revenue soon hit $300 million and the company’s stock price surged.

As Japan’s chip industry rose, however, GCA began to lose its edge. Greenberg, the CEO, imagined himself as a business titan, but he spent less time running the business and more hobnobbing with politicians. He broke ground on a major new manufacturing facility, betting that the early 1980s semiconductor boom would continue indefinitely. Costs spun out of control. Inventory was wildly mismanaged. One employee stumbled onto a million dollars’ worth of precision lenses sitting forgotten in a closet. Stories circulated of executives buying Corvettes on company credit cards. One of Greenberg’s founding partners admitted that the company was spending money like a “drunken sailor.”

在几年后的1978年，GCA推出了它的第一台步进电机。销售订单开始涌入。在步进电机之前，GCA在其军事合同上的年收入从未超过5000万美元，但现在它垄断了一种极其有价值的机器。收入很快达到了3亿美元，公司的股价也大幅上涨。 然而，随着日本芯片业的崛起，GCA开始失去优势。CEO格林伯格想象自己是一位商业巨头，但他花费的时间越来越少去管理业务，更多的时间和政治人物交往。他破土动工兴建一家重要的新制造设施，打赌早期的1980年代半导体繁荣将会无限期延续。成本失控。库存被极度管理不善。有一个员工无意中发现了一百万美元的精密透镜被遗忘在一个壁橱里。有关高管用公司信用卡买科尔维特轿车的故事传开了。格林伯格的几个创始合伙人承认该公司花费的钱就像“醉汉一样”。

The firm's excesses were poorly timed. The semiconductor industry had always been ferociously cyclical, with the industry skyrocketing upward when demand was strong, and slumping back when it was not. It didn't take a rocket scientist—and GCA had a handful on staff—to figure out that after the boom of the early 1980s, a downturn would eventually follow. Greenberg chose not to listen. "He didn't want to hear from the marketing department that 'there's going to be a downturn,'" one employee remembered. So the company entered the mid-1980s semiconductor slump heavily overextended. Global sales of lithography equipment fell by 40 percent between 1984 and 1986. GCA's revenue fell by over two-thirds. "If we had a competent economist on staff, we might have predicted it," one employee remembered. "But we didn't. We had Milt."

公司的过度扩张时间非常不当。半导体行业一直是激烈的周期性行业，当需求强劲时，行业会飙升，而需求不强时则会下滑。不需要火箭科学家——而GCA的员工都有一批——就能想到，在1980年代初繁荣期之后，经济下滑最终会到来。格林伯格选择不听。一位员工回忆说："他不想听市场部门的话，即'会有经济下滑'。"因此，公司在20世纪80年代中期进入半导体低迷期时过度铺张。全球光刻设备销售在1984年至1986年之间下降了40％。GCA的收入下降了超过三分之二。一位员工回忆说："如果我们有一位有能力的经济学家，我们可能会预测到这一点，但我们没有。我们有米尔特。"

Just as the market slumped, GCA lost its position as the only company building steppers. Japan's Nikon had initially been a partner of GCA, providing the precision lenses for its stepper. But Greenberg had decided to cut Nikon out, buying his own lens maker, New York–based Tropel, which made lenses for the U2 spy planes but which struggled to produce the number of high-quality lenses GCA needed. Meanwhile, GCA's customer service atrophied. The company's attitude, one analyst recounted, was "buy what we build and don't bother us." The company's own employees admitted that "customers got fed up." This was the attitude of a monopolist—but GCA was no longer a monopoly. After Greenberg stopped buying Nikon lenses, the Japanese company decided to make its own stepper. It acquired a machine from GCA and reverse engineered it. Soon Nikon had more market share than GCA.

隨著市場的下滑，GCA失去了獨一無二建造步進機的地位。日本的尼康最初是GCA的合作夥伴，為其步進機提供精密鏡頭。但 Greenberg 決定剔除尼康，購買自己的鏡頭製造商，位於紐約的 Tropel，該公司為 U2 間諜機製造鏡頭，但無法生產GCA所需的高品質鏡頭數量。同時，GCA的客戶服務也退化了。一位分析師回憶說，該公司的態度是“買我們所建造的，不要打擾我們”。該公司的員工承認“客戶感到厭倦”。這是壟斷者的態度，但GCA不再是壟斷。在Greenberg停止購買尼康鏡頭後，日本公司決定製造自己的步進機。它從GCA購買了一臺機器並進行了反向工程。不久，尼康的市場份額超過了GCA。

Many Americans blamed Japan’s industrial subsidies for GCA’s loss of lithography leadership. It was true that Japan’s VLSI program, which boosted the country’s producers of DRAM chips, also helped equipment suppliers like Nikon. As U.S. and Japanese firms traded accusations of unfair government help, commercial relations grew stormy. But GCA employees admitted that, though their technology was world class, the company struggled with mass production. Precision manufacturing was essential, since lithography was now so exact that a thunderstorm rolling through could change air pressure—and thus the angle at which light refracted—enough to distort the images carved on chips. Building hundreds of steppers a year required a laser focus on manufacturing and quality control. But GCA’s leaders were focused elsewhere.

許多美國人責備日本的產業補貼導致GCA失去光刻領導地位。事實上，日本的VLSI計劃不僅推動了該國的DRAM晶片生產商，還幫助了像尼康這樣的設備供應商。隨著美國和日本企業互相指責政府提供不公平的援助，商業關係變得風雨飄搖。但是，GCA的員工承認，儘管他們的技術是世界一流的，但公司在大規模生產方面遇到了困難。精密制造是必要的，因為光刻現在已經非常精確，以至於經過的一場雷暴可以改變空氣壓力，從而扭曲刻在晶片上的圖像。每年建造數百個刻步機需要專注於製造和質量控制。但是，GCA的領導人關注的是其他事情。

It was popular to interpret the decline of GCA as an allegory about Japan’s rise and America’s fall. Some analysts saw evidence of a broader manufacturing decay that started in steel, then afflicted cars, and was now spreading to high-tech industries. In 1987, Nobel Prize−winning MIT economist Robert Solow, who pioneered the study of productivity and economic growth, argued that the chip industry suffered from an "unstable structure," with employees job hopping between firms and companies declining to invest in their workers. Prominent economist Robert Reich lamented the "paper entrepreneurialism" in Silicon Valley, which he thought focused too much on the search for prestige and affluence rather than technical advances. At American universities, he declared, "science and engineering programs are foundering."

將GCA衰落解釋為日本崛起和美國衰落的寓言曾經非常流行。有些分析人士認為，這反映了一種廣泛的製造業衰退，從鋼鐵開始，侵蝕了汽車行業，現在正擴散到高科技行業。1987年，曾開創了生產率和經濟增長研究的諾貝爾經濟學獎得主，麻省理工學院的羅伯特·索洛（Robert Solow）認為，芯片行業遭受了一種"不穩定的結構"，員工在公司之間跳槽，公司不願意為員工投資。知名經濟學家羅伯特·萊希（Robert Reich）對矽谷的"紙上創業主義"表示了遺憾，他認為這過於關注聲望和富裕而不是技術進步。他聲稱，美國大學的"科學和工程項目正在瀕臨困境"。

American chipmakers' DRAM disaster was somewhat related to GCA's collapsing market share. The Japanese DRAM firms that were outcompeting Silicon Valley preferred to buy from Japanese toolmakers, benefitting Nikon at the expense of GCA. However, most of GCA's problems were homegrown, driven by unreliable equipment and bad customer service. Academics devised elaborate theories to explain how Japan's huge conglomerates were better at manufacturing than America's small startups. But the mundane reality was that GCA didn't listen to its customers, while Nikon did. Chip firms that interacted with GCA found it "arrogant" and "not responsive." No one said that about its Japanese rivals.

美國晶片製造商的DRAM災難在某種程度上與GCA市佔率下滑有關。那些在硅谷面臨競爭的日本DRAM公司更喜歡從日本工具製造商那裡購買，這使得Nikon受益而GCA受損。然而，GCA大部分問題都是自己造成的，因為設備不可靠，客戶服務不佳。學者們制定了繁複的理論，解釋了日本的巨型企業如何比美國的小型初創企業更擅長製造。但平凡的現實是，GCA沒有聽取其客戶的意見，而Nikon則做到了。與

GCA互動的晶片公司發現它“傲慢”和“不負責任”。沒有人對其日本競爭對手有這樣的說法。

By the mid-1980s, therefore, Nikon’s systems were far better than GCA’s—even when the skies were sunny. Nikon’s machines produced meaningfully better yields and broke down far less often. Before IBM transitioned to Nikon steppers, it hoped each machine it used would work seventy-five hours before needing downtime for adjustments or repairs, for example. Nikon’s customers averaged ten times that duration of continuous use.

Greenberg, GCA’s CEO, could never figure out how to fix the company. Up to the day he was ousted, he didn’t realize just how many of his company’s problems were internal. As he flew around the world on sales visits, drinking a Bloody Mary in first class, customers thought the firm was “shipping junk.” Employees complained that Greenberg was in hock to Wall Street, focused as much on the stock price as on the business model. To make end-of-year numbers, the company would collude with customers, shipping an empty crate with a user’s manual in December before delivering the machines themselves the subsequent year. However, it was impossible to cover up the company’s loss of market share. U.S. firms, with GCA as the leader, controlled 85 percent of the global market for semiconductor lithography equipment in 1978. A decade later this figure had dropped to 50 percent. GCA had no plan to turn things around.

因此，到了1980年代中期，尼康的系统已经比GCA的好得多——即使天气晴朗。尼康的机器产量更高，故障率远低于GCA。例如，在IBM过渡到尼康步进机之前，它希望每台机器在需要调整或修理之前工作75小时。而尼康的客户平均使用持续时间是这个数字的十倍。GCA的CEO格林伯格无法找到解决公司问题的方法。直到他被解职的那一天，他才意识到他的公司问题有多么内部化。当他坐在头等舱里喝着血腥玛丽飞往世界各地进行销售拜访时，客户们认为该公司在“出口垃圾”。员工们抱怨格林伯格被华尔街高利贷所迫，关注公司股价而不是商业模式。为了完成年度目标，公司会与客户勾结，在12月份运送一些只有使用说明书的空箱子，然后在随后的一年才发货。然而，公司丧失市场份额是无法掩盖的。美国公司，以GCA为首，于1978年控制了半导体光刻设备全球市场的85％。十年后，这个数字降至50％。GCA没有计划扭转局势。

Greenberg himself aimed criticism at the company's employees. "He would use unbelievable four-letter words," one subordinate remembered. Another recalled a decision to ban high-heeled shoes, which Greenberg thought ruined the company's carpets. As tension grew, the receptionist developed a code with fellow employees, turning on a ceiling light to denote that Greenberg was in the building, and turning it off when he left. Everyone could breathe a bit easier when he was out. But this couldn't stop America's lithography leader from hurtling toward crisis.

Greenberg本人也对该公司员工进行了批评。"他会使用不可思议的粗口，"一位下属回忆说。另一位员工回忆起一项禁止高跟鞋的决定，因为Greenberg认为这会毁坏公司的地毯。随着紧张局势的加剧，接待员与其他员工共同制定了一种代码，通过开关天花板的灯来标识Greenberg在建筑内，离开后则熄灭。他不在场时，每个人都可以轻松一些。但这无法阻止美国印刷领袖冲向危机。

CHAPTER 18 The Crude Oil of the 1980s

O n a chilly spring evening in Palo Alto, Bob Noyce, Jerry Sanders, and Charlie Sporck met under a sloping, pagoda-style roof. Ming's Chinese Restaurant was a staple of the Silicon Valley lunch circuit. But America's tech titans weren't at Ming's for its famous Chinese chicken salad. Noyce, Sanders, and Sporck had all started their careers at Fairchild: Noyce the technological visionary; Sanders the marketing showman; Sporck the manufacturing boss barking at his employees to build faster, cheaper, better. A decade later they'd become competitors as CEOs of three of America's biggest chipmakers. But as Japan's market share grew, they decided it was time to band together again. At stake was the future of America's semiconductor industry. Huddled over a table in a private dining room at Ming's, they devised a new strategy to save it. After a decade of ignoring the government, they were turning to Washington for help.

在帕羅奧多一個寒冷的春天傍晚，鮑勃·諾伊斯、傑里·桑德斯和查理·斯普克在一座傾斜的、樓閣式的屋頂下會面。明日樓中餐館是硅谷午餐之旅的主要目的地。但是美國的科技巨頭們不是來明日樓品嚐其著名的中國雞肉沙拉的。諾伊斯、桑德斯和斯普克都在費爾德公司開始他們的職業生涯：諾伊斯是技術領袖；桑德斯是市場營銷秀才；斯普克是製造主管，在催促他的員工更快、更便宜、更好地建造。十年後，他們成為美國三大晶片製造商的首席執行官，成為競爭對手。但隨著日本的市場份額增加，他們決定再次聯合起來。美國半導體工業的未來攸關重大。他們在明日樓的一個私人餐廳的桌子上商討了一個新策略。在十年忽視政府後，他們轉向華盛頓尋求幫助。

Semiconductors are the "crude oil of the 1980s," Jerry Sanders declared, "and the people who control the crude oil will control the electronics industry." As CEO of AMD, one of America's biggest chipmakers, Sanders had plenty of self-interested reasons to describe his main product as strategically crucial. But was he wrong? Throughout the 1980s, America's computer industry expanded rapidly, as PCs were made small enough and cheap enough for an individual home or office. Every business was coming to rely on them. Computers couldn't work without integrated circuits. Nor, by the 1980s, could planes, automobiles, camcorders, microwaves, or the Sony Walkman. Every American now had semiconductors in their houses and cars; many used dozens of chips daily. Like oil, they were impossible to live without. Didn't this make them "strategic"? Shouldn't America be worried Japan was becoming " the Saudi Arabia of semiconductors"?

半導體是"1980年代的石油"，傑裏·桑德斯宣稱，"控制石油的人將控制電子產業"。作為美國最大的晶片製造商之一AMD的CEO，桑德斯有足夠的自身利益理由將他的主要產品形容為戰略上至關重要的。但他錯了嗎？在1980年代，美國的電腦產業迅速擴張，因為PC變得足夠小和便宜，足以放在一個人的家或辦公室中。每家公司都開始依賴它們。沒有集成電路，電腦無法工作。到1980年代，飛機、汽車、攝像機、微波爐或索尼Walkman也無法工作。每個美國人現在都擁有家中和汽車中的半導體；許多人每天使用數十顆芯片。就像石油一樣，人們無法生存沒有它們。難道這不使它們成為"戰略性"嗎？美國不應該擔心日本正在成為"半導體沙特阿拉伯"嗎？

The oil embargoes of 1973 and 1979 had demonstrated to many Americans the risks of relying on foreign production. When Arab governments cut oil exports to punish America for supporting Israel, the U.S. economy plunged into a painful recession. A decade of stagflation and political crises followed. American foreign policy fixated on the Persian Gulf and securing its oil supplies. President Jimmy Carter declared the region one of "the vital interests of the United States of America." Ronald Reagan deployed the U.S. Navy to escort oil tankers in and out of the Gulf. George H. W. Bush went to war with Iraq in part to liberate Kuwait's oil fields. When America said that oil was a "strategic" commodity, it backed the claim with military force.

1973年和1979年的石油禁运向许多美国人证明了依赖外国生产的风险。当阿拉伯政府削减石油出口以惩罚支持以色列的美国时，美国经济陷入了痛苦的衰退。十年的滞胀和政治危机随之而来。美国外交政策关注波斯湾并保障其石油供应。吉米·卡特总统宣布该地区是"美利坚合众国的重要利益之一。"罗纳德·里根部署美国海军护送石油轮进出海湾。乔治·H·W·布什发动伊拉克战争的部分原因是解放科威特的石油田。当美国说石油是"战略"商品时，就用军事力量支持了这一说法。

Sanders wasn't asking for the U.S. to send the Navy halfway across the world to secure supplies of silicon. But shouldn't the government find a way to help its struggling semiconductor firms? In the 1970s, Silicon Valley firms had forgotten about the government as they replaced defense contracts with civilian computer and calculator markets. In the 1980s, they crawled sheepishly back to Washington. After their dinner at Ming's, Sanders, Noyce, and Sporck joined other CEOs to create the Semiconductor Industry Association to lobby Washington to support the industry.

桑德斯并没有要求美国向世界中心派遣海军来保障硅的供应。但政府难道不应该想办法帮助陷入困境的半导体公司吗？在上世纪七十年代，硅谷的公司在军工合同转向民用计算机和计算器市场时忘记了政府。在上世纪八十年代，它们羞怯地回到了华盛顿。在明记的晚宴后，桑德斯、诺伊斯和斯波尔克与其他首席执行官一起创建了半导体工业协会，游说华盛顿支持该行业。

When Jerry Sanders described chips as "crude oil," the Pentagon knew exactly what he meant. In fact, chips were even more strategic than petroleum. Pentagon officials knew just how important semiconductors were to American military primacy. Using semiconductor technology to "offset" the Soviet conventional advantage in the Cold War had been American strategy since the mid-1970s, when Bob Noyce's singing partner Bill Perry ran the Pentagon's research and engineering division. American defense firms had been instructed to pack their newest planes, tanks, and rockets with as many chips as possible, enabling better guidance, communication, and command and control. In terms of producing military power, the strategy was working better than anyone except Bill Perry had thought possible.

当杰瑞·桑德斯将芯片比作"原油"时，五角大楼非常了解他的意思。实际上，芯片甚至比石油更具战略性。五角大楼官员深知半导体对美国军事至高性的重要性。自从鲍勃·诺伊斯的歌唱搭档比尔·佩里主管五角大楼的研究和工程部门以来，使用半导体技术"抵消"冷战中苏联传统优势一直是美国的战略。美国国防公司被指示尽可能多地为他们的最新飞机、坦克和火箭装备芯片，从而实现更好的引导、通信和指挥控制。在生产军事力量方面，这一战略的效果比除了比尔·佩里以外的任何人都想象得到。

There was only one problem. Perry had assumed that Noyce and his other Silicon Valley neighbors would remain on top of the industry. But in 1986, Japan had overtaken America in the number of chips produced. By the end of the 1980s, Japan was supplying 70 percent of the world's lithography equipment. America's share—in an industry invented by Jay Lathrop in a U.S. military lab—had fallen to 21 percent. Lithography is "simply something we can't lose, or we will find ourselves completely dependent on overseas manufacturers to make our most sensitive stuff," one Defense Department official told the *New York Times* . But if the trends of the mid-1980s continued, Japan would dominate the DRAM industry and drive major U.S. producers out of business. The U.S. might find itself even more reliant on foreign chips and semiconductor manufacturing equipment than it was on oil, even at the depths of the Arab embargo. Suddenly Japan's subsidies for its chip industry, widely blamed for undermining American firms like Intel and GCA, seemed like a national security issue.

只有一个问题。佩里以为诺伊斯和他在硅谷的邻居们会一直保持行业领先地位。但是在1986年，日本在芯片生产方面已经超过了美国。到20世纪80年代末，日本供应了全球70%的光刻设备。美国在这个由美国军方实验室的杰伊·拉思罗普发明的行业中的份额已降至21％。"光刻技术是我们不能失去的东西，否则我们将完全依赖海外制造商制造我们最敏感的东西，"一名国防部官员告诉《纽约时报》。但如果20世纪80年代中期的趋势继续下去，日本将主导DRAM行业，迫使美国主要生产商退出市场。美国可能会发现自己比沙特阿拉伯禁运时期还更加依赖外国芯片和半导体制造设备。突然间，日本对其芯片产业的补贴被广泛指责为破坏英特尔和GCA等美国企业的国家安全问题。

The Defense Department recruited Jack Kilby, Bob Noyce, and other industry luminaries to prepare a report on how to revitalize America's semiconductor industry. Noyce and Kilby spent hours at brainstorming sessions in the Washington suburbs, working with defense industrial experts and Pentagon officials. Kilby had long worked closely with the Defense Department, given Texas Instruments' role as a major supplier of electronics for weapons systems. IBM and Bell Labs also had deep connections with Washington. But Intel's leaders had previously portrayed themselves as "Silicon Valley cowboys who didn't need anybody's help," as one defense official put it. The fact that Noyce was willing to spend time at the Defense Department was a sign of how serious a threat the semiconductor industry faced—and how dire the impact on the U.S. military could be.

国防部招募杰克·基尔比、鲍勃·诺伊斯和其他行业名人，准备报告如何重振美国的半导体产业。诺伊斯和基尔比在华盛顿市郊的头脑风暴会议上花费了数个小时，与国防工业专家和五角大楼官员一起工作。由于得克萨斯仪器公司是武器系统电子产品的主要供应商，因此基尔比与国防部一直密切合作。IBM和贝尔实验室也与华盛顿有着深厚联系。但英特尔的领导人之前曾将自己描绘成“硅谷的牛仔，不需要任何人的帮助”，如一位国防官员所说。诺伊斯愿意在国防部花时间是半导体行业面临的威胁有多严重，以及对美国军方可能产生多么严重的影响的标志。

The U.S. military was more dependent on electronics—and thus on chips—than ever before. By the 1980s, the report found, around 17 percent of military spending went toward electronics, compared to 6 percent at the end of World War II. Everything from satellites to early warning radars to self-guided missiles depended on advanced chips. The Pentagon's task force summarized the ramifications in four bullet points, underlining the key conclusions:

- U.S. military forces depend heavily on technological superiority to win .
- Electronics is the technology that can be leveraged most highly.
- Semiconductors are the key to leadership in electronics.
- U.S. defense will soon depend on foreign sources for state-of-the-art technology in semiconductors.

Of course, Japan was officially a Cold War ally—at least for now. When the U.S. had occupied Japan in the years immediately after World War II, it had written Japan's constitution to make militarism impossible. But after the two countries had signed a mutual defense pact in 1951, the U.S. began cautiously to encourage Japanese rearmament, seeking military support against the Soviet Union. Tokyo agreed, but it capped its military spending around 1 percent of Japan's GDP. This was intended to reassure Japan's neighbors, who viscerally remembered the country's wartime expansionism. However, because Japan didn't spend heavily on arms, it had more funds to invest elsewhere. The U.S. spent five to ten times more on defense relative to the size of its economy. Japan focused on growing its economy, while America shouldered the burden of defending it.

根据报告，美国军队比以往任何时候都更依赖电子设备，因此也更依赖于芯片。到了20世纪80年代，军队开支中约有17%用于电子设备，而二战结束时只有6%。从卫星到预警雷达再到自导弹，所有东西都依赖于先进的芯片。五角大楼的特别工作小组用四个要点总结了影响，强调了关键结论。 当然，日本正式是冷战盟友-至少目前是这样。当美国在二战后几年占领日本时，它写下了日本的宪法，以防止军国主义的出现。但是，在两国于1951年签署相互防卫条约后，美国开始谨慎地鼓励日本重新武装，寻求对抗苏联的军事支持。东京同意了，但它将其军费支出控制在日本GDP的1%左右。这旨在安抚那些真切记得日本战时扩张主义的邻国。然而，由于日本的军费开支不多，它有更多的资金用于其他领域的投资。相对于其经济规模而言，美国的国防开支是日本的五到十倍。日本专注于发展经济，而美国则肩负着其防御的重任。

The results were more spectacular than anyone had expected. Once derided as a country of transistor salesmen, Japan was now the world's second-largest economy. It was challenging American industrial dominance in areas that were crucial to U.S. military power. Washington had long urged Tokyo to let the United States contain the Communists while Japan expanded its foreign trade, but this division of labor no longer seemed very favorable to the United States. Japan's economy had grown at unprecedented speed, while Tokyo's success in high-tech manufacturing was now threatening America's military edge. Japan's advance had caught everyone by surprise. "You don't want the same thing to happen to semiconductors as happened to the TV industry, to the camera industry," Sporck told the Pentagon. "Without semiconductors you're in nowheresville."

結果比任何人預料的都更加壯觀。曾經被譏笑為晶體管推銷員的日本現在是世界第二大經濟體。它正在挑戰美國在對美軍事力量至關重要的領域中的工業主導地位。長期以來，華盛頓一直敦促東京讓美國遏制共產主義者，而日本則擴大其對外貿易。但這種分工對美國已經不再有利。日本的經濟以前所未有的速度增長，而東京在高科技製造方面的成功現在正在威脅美國的軍事優勢。日本的進展令人們感到驚

訝。"你不想看到半導體行業像電視行業、相機行業那樣的下場，" Sporck 告訴五角大廈。" 沒有半導體，你一無所有。”

CHAPTER 19 Death Spiral

“ W e’re in a death spiral,” Bob Noyce told a reporter in 1986. “Can you name a field in which the U.S. is not falling behind?” In his more pessimistic moments, Noyce wondered whether Silicon Valley would end up like Detroit, its flagship industry withering under the impact of foreign competition. Silicon Valley had a schizophrenic relationship with the government, simultaneously demanding to be left alone and requesting that it help. Noyce exemplified the contradiction. He’d spent his earliest days at Fairchild avoiding Pentagon bureaucracy while benefitting from the Cold War–era space race. Now he thought the government needed to help the semiconductor industry, but he still feared that Washington would impede innovation. Unlike in the days of the Apollo program, by the 1980s over 90 percent of semiconductors were bought by companies and consumers, not the military. It was hard for the Pentagon to shape the industry because the Defense Department was no longer Silicon Valley’s most important customer.

1986年，鮑勃·諾伊斯告訴一位記者：“我們正在陷入致命的螺旋中。你能夠說出一個領域，在這個領域，美國沒有落後嗎？” 在他更加悲觀的時刻，諾伊斯懷疑硅谷會不會像底特律一樣，其旗艦產業在外國競爭的影響下枯萎。硅谷與政府有著一種矛盾的關係，同時要求政府放手自己發展，卻又請求政府幫助。諾伊斯是這種矛盾的典型代表。他早年在費爾柴爾德度過了他的日子，避開五角大樓的官僚主義，同時受益於冷戰時期的太空競賽。現在他認為政府需要幫助半導體行業，但他仍然擔心華盛頓會阻礙創新。不像阿波羅計劃的日子，到了20世紀80年代，超過90%的半導體被公司和消費者購買，而不是軍方。因此，五角大樓很難主導這個產業的發展，因為國防部不再是硅谷最重要的客戶。

Moreover, in Washington there was little agreement on whether Silicon Valley merited government help. After all, many industries were suffering from Japanese competition, from car factories to steel mills. The chip industry and the Defense Department argued that semiconductors were “strategic.” But many economists argued that there was no good definition of what “strategic” meant. Were semiconductors more “strategic” than jet engines? Or industrial robots? “ Potato chips, computer chips, what’s the difference?” one Reagan Administration economist was widely quoted as saying. “They’re all chips. A hundred dollars of one or a hundred dollars of the other is still a hundred.” The economist in question denies having ever compared potatoes to silicon. But the point was a reasonable one. If Japanese firms could produce DRAM chips at a lower price, perhaps the U.S. was better off buying them and pocketing the cost savings. If so, American computers would be cheaper as a result—and the computer industry might advance more quickly.

此外，在華盛頓，關於硅谷是否值得政府幫助存在分歧。畢竟，從汽車工廠到鋼鐵廠，許多行業都受到日本競爭的打擊。晶片產業和國防部認為半導體是“戰略性的”。但許多經濟學家則認為，什麼是“戰略性”的定義不明確。半導體比噴氣發動機或工業機器人更“戰略性”嗎？一位里根政府的經濟學家被廣泛引用說，“薯片和電腦晶片有什麼區別？”他說，“它們都是晶片。一百美元的其中一種或一百美元的另一種仍然是一百美元。”所謂的經濟學家否認曾經把土豆和硅相比，但這個觀點是合理的。如果日本公司能夠以更低的價格生產DRAM晶片，也許美國最好買進它們並節省成本。如果是這樣，美國的電腦會更便宜，計算機行業可能會更快地發展。

The question of support for semiconductors was decided by lobbying in Washington. One issue on which Silicon Valley and free market economists agreed was taxes. Bob Noyce testified to Congress in favor of cutting the capital gains tax from 49 percent to 28 percent and advocated loosening financial regulation to let pension funds invest in venture capital firms. After these changes, a flood of money rushed into the venture capital firms on Palo Alto’s Sand Hill Road. Next, Congress tightened intellectual property protections via the Semiconductor Chip Protection Act, after Silicon Valley executives like Intel’s Andy Grove testified to Congress that legal copying by Japanese firms was undermining America’s market position.

半导体产业的支持问题是通过在华盛顿的游说解决的。在税收问题上，硅谷和自由市场经济学家都意见一致。鲍勃·诺伊斯在国会作证，支持将资本利得税从49％降至28％，并主张放宽金融监管，让养老基金投资于风险投资公司。在这些变化之后，大量的资金涌入了帕洛阿尔托的沙丘路风险投资公司。接下来，国会通过半导体芯片保护法收

紧了知识产权保护，此前像英特尔的安迪·格鲁夫这样的硅谷高管在国会作证，指出日本公司的合法复制正在削弱美国的市场地位。

As Japan’s DRAM market share grew, however, tax cuts and copyright changes seemed insufficient. The Pentagon was unwilling to bet its defense industrial base on the future impact of copyright law. Silicon Valley CEOs lobbied for even more help. Noyce estimated that he spent half his time in the 1980s in Washington. Jerry Sanders attacked the “subsidies and nurturing, targeting and protection of markets” that Japan had pursued. “The Japanese subsidies have been in the billions,” Sanders declared. Even after the U.S. and Japan reached an agreement to eliminate tariffs on semiconductor trade, Silicon Valley struggled to sell Japan more chips. Trade negotiators compared negotiating with the Japanese to peeling an onion. “The whole thing is a rather zen experience,” one U.S. trade negotiator reported, with discussions ending with philosophical questions like “what is an onion, anyway.” U.S. DRAM sales into Japan barely budged.

然而，隨著日本DRAM市場份額的增加，稅收減免和版權變革似乎不足以滿足需要。五角大廈不願意把其防禦產業基地押注在版權法律的未來影響上。矽谷的CEO們遊說要求更多的幫助。諾伊斯估計他80年代一半的時間都在華盛頓度過。傑瑞·桑德斯批評日本追求的“市場補貼和培育、定向和保護”。桑德斯宣稱，“日本的補貼已經達到了數十億美元”。即使美日雙方達成協議，消除半導體貿易上的關稅，矽谷依然難以向日本銷售更多的晶片。貿易談判代表將與日本人談判比作剝洋蔥。一名美國貿易談判代表報告說，“整個過程是一種相當禪意的體驗”，談判以哲學問題結束，例如“洋蔥到底是什麼”。美國DRAM向日本的銷售幾乎沒有增加。

Prodded by the Pentagon and lobbied by industry, the Reagan administration eventually decided to act. Even former free traders like Reagan’s secretary of state George Shultz concluded that Japan would only open its market if the U.S. threatened tariffs. America’s chip industry lodged a series of formal complaints against Japanese firms for “dumping” cheap chips in the U.S. market. The claim that Japanese firms were selling below production cost was hard to prove. U.S. firms cited Japanese competitors’ low cost of capital; Japan responded by saying that interest rates were lower across Japan’s economy. Both sides had a point.

受五角大楼促使和工业游说影响，里根政府最终决定采取行动。即使是鼓吹自由贸易的人，如里根的国务卿乔治·舒尔茨，也得出结论，只有美国威胁利用关税，日本才会开放其市场。美国的芯片行业对日本公司的“倾销”廉价芯片进行了一系列正式投诉，但难以证明日本公司的销售价格低于生产成本。美国公司引用日本竞争对手的低资本成本；而日本则回应称，日本经济的利率更低。双方都有一定道理。

In 1986, with the threat of tariffs looming, Washington and Tokyo cut a deal. Japan’s government agreed to put quotas on its exports of DRAM chips, limiting the number that were sold to the U.S. By decreasing supply, the agreement drove up the price of DRAM chips everywhere outside of Japan, to the detriment of American computer producers, which were among the biggest buyers of Japan’s chips. Higher prices actually benefitted Japan’s producers, which continued to dominate the DRAM market. Most American producers were already in the process of exiting the memory chip market. So despite the trade deal, only a few U.S. firms continued to produce DRAM chips. The trade restrictions redistributed profits within the tech industry, but they couldn’t save most of America’s memory chip firms.

1986年，隨著關稅威脅的出現，華盛頓和東京達成了協議。日本政府同意限制其DRAM晶片的出口配額，限制出售給美國的數量。協議通過減少供應，推高了日本以外的DRAM晶片價格，損害了美國電腦生產商的利益，而他們是日本晶片的最大買家之一。更高的價格實際上有利於日本的生產商，他們繼續主宰DRAM市場。大多數美國生產商已經在退出記憶體芯片市場的過程中了。因此，儘管有貿易協定，只有幾家美國公司繼續生產DRAM晶片。貿易限制在技術行業內重新分配利潤，但並不能拯救美國大多數的記憶體芯片公司。

Congress tried one final way to help. One of Silicon Valley’s complaints was that Japan’s government helped firms coordinate their R&D efforts and provided funds for this purpose. Many people in America’s high-tech industry thought Washington should replicate these tactics. In 1987, a group of leading chipmakers and the Defense Department created a consortium called Sematech, funded half by the industry and half by the Pentagon.

Sematech was based on the idea that the industry needed more collaboration to stay competitive. Chipmakers needed better manufacturing equipment, while the firms that produced this equipment needed to know what chipmakers were looking for. CEOs of equipment firms complained that "companies like TI, Motorola, and IBM… just would not open up about their technology." Without an understanding of what technology these companies were working on, it was impossible to sell to them. Chipmakers, meanwhile, grumbled about the reliability of the machines they depended on. In the late 1980s, Intel's equipment was running only 30 percent of the time due to maintenance and repairs, one employee estimated.

國會試圖最後一種方式來幫助。硅谷抱怨的其中一個問題是，日本政府幫助企業協調研發努力，並提供資金支持。美國高科技產業的許多人認為，華盛頓應該複製這些策略。1987年，一群領先的晶片製造商和國防部共同成立了一個名為Sematech的聯盟，由工業界和五角大樓各提供一半的資助。 Sematech的理念是，為了保持競爭力，產業需要更多的合作。晶片製造商需要更好的製造設備，而生產這些設備的企業需要了解晶片製造商所需。設備企業的CEO抱怨說，"像TI、摩托羅拉和IBM這樣的公司......只是不會公開他們的技術。"沒有了解這些企業正在開發的技術，就不可能向他們銷售產品。晶片製造商則抱怨依賴的機器的可靠性。一位員工估計，在1980年代後期，Intel的設備只有30％的時間運行，因為需要維修和保養。

Bob Noyce volunteered to lead Sematech. He was already de facto retired from Intel, having turned over the reins to Gordon Moore and Andy Grove a decade earlier. As the co-inventor of the integrated circuit and founder of two of America's most successful startups, he had the best technical and business credentials in the industry. No one could match his charisma or his connections in Silicon Valley. If anyone could resuscitate the chip industry, it was the person with the strongest claim to have created it.

鮑勃·諾伊斯自願領導Sematech。他早在十年前就已實際退休，把掌握權交給了戈登·摩爾和安迪·格羅夫。作為集成電路聯合發明人和兩家美國最成功的初創企業的創始人，他在行業中擁有最好的技術和商業背景。在硅谷，沒有人能比得上他的魅力或關係。如果有人能重振芯片行業，那就是對其最有發言權的人。

Under Noyce's leadership, Sematech was a strange hybrid, neither a company nor a university nor a research lab. No one knew exactly what it was supposed to do. Noyce started by trying to help manufacturing equipment companies like GCA, many of which had strong technology but struggled to create durable businesses or effective manufacturing processes. Sematech organized seminars on reliability and good management skills, offering a sort of mini-MBA. It also began coordinating between equipment companies and chipmakers to align their production schedules. There was no point in a chipmaker preparing a new generation of chipmaking technology if the lithography or deposition equipment wasn't ready. Equipment firms didn't want to launch a new piece of machinery unless chipmakers were prepared to use it. Sematech helped them agree on production schedules. This wasn't exactly the free market, but Japan's biggest firms had excelled with this type of coordination. Anyway, what other choice did Silicon Valley have?

在Noyce的领导下，Sematech是一个奇怪的混合体，既不是公司也不是大学或研究实验室。没人确切知道它应该做什么。Noyce的起点是试图帮助像GCA这样的制造设备公司，其中许多公司拥有强大的技术，但很难创建持久的业务或有效的制造流程。Sematech组织了可靠性和良好管理技能方面的研讨会，提供了一种迷你MBA。它还开始协调设备公司和芯片制造商之间的生产计划以对齐。如果光刻或沉积设备无法使用，那么芯片制造商准备新一代芯片制造技术是毫无意义的。设备公司不想推出新的机器，除非芯片制造商准备好使用它。Sematech帮助他们在生产计划上达成协议。这并不完全是自由市场，但日本最大的公司就是通过这种协调取得了成功。无论如何，硅谷还有其他选择吗？

Noyce's focus, however, was saving America's lithography industry. Fifty-one percent of Sematech funding went to American lithography firms. Noyce explained the logic simply: lithography got half the money because it was "half the problem" facing the chip industry. It was impossible to make semiconductors without lithography tools, but the only remaining major U.S. producers were struggling to survive. America might soon be reliant on foreign equipment. Testifying to Congress in 1989, Noyce declared that "Sematech may likely be judged, in large part, as to how successful it is in saving America's optical stepper makers."

然而，诺伊斯关注的是拯救美国的光刻技术产业。Sematech资金的51％用于美国的光刻技术公司。诺伊斯简单地解释了其逻辑：光刻技

术得到了一半的资金，因为它是半个面对芯片产业的问题。在没有光刻工具的情况下，制造半导体是不可能的，但是美国唯一剩下的主要生产商还在苦苦挣扎。美国可能很快会依赖外国设备。在1989年对国会作证时，诺伊斯宣布："在拯救美国的光刻技术制造商方面，Sematech可能会被认为是十分成功的。"

This was exactly what employees at GCA, the ailing Massachusetts manufacturer of lithography tools, were hoping to hear. After the company had invented the wafer stepper, a half decade of mismanagement and bad luck had left GCA a small player, far behind Japan's Nikon and Canon and the Netherlands' ASML. But when Peter Simone, GCA's president, called Noyce to discuss whether Sematech could help GCA, Noyce told him flatly: "You're done."

Few people in the chip industry could see how GCA could recover. Intel, which Noyce had founded, relied heavily on Nikon, GCA's primary Japanese competitor. "Why don't you come for one day," Simone proposed, hoping to convince Noyce that GCA could still produce cutting-edge machinery. Noyce agreed, and when he arrived in Massachusetts he decided that day to buy $13 million worth of GCA's newest equipment, as part of a program to share American-built semiconductor equipment with U.S. chipmakers and encourage them to buy more domestically produced tools.

這正是GCA員工所希望聽到的。在發明晶圓步進器後的五年內，管理不當和厄運使得GCA成為了一家小型企業，遠遠落後於日本的尼康和佳能，以及荷蘭的ASML。但當GCA總裁彼得·西蒙打電話給諾伊斯，詢問Sematech是否能幫助GCA時，諾伊斯果斷地告訴他："你們完了"。在晶片行業中，很少有人能夠看到GCA如何才能恢復元氣。諾伊斯創立的英特爾公司主要依賴於GCA的日本主要競爭對手尼康。"你為什麼不來一天？" 西蒙提議，希望說服諾伊斯GCA仍然能生產尖端機器。諾伊斯同意了，當他到達馬薩諸塞州時，他當天決定購買價值1300萬美元的GCA最新設備，作為一項計劃的一部分，該計劃旨在與美國晶片製造商共享美國製造的半導體設備，並鼓勵他們購買更多國內生產的工具。

Sematech bet hugely on GCA, giving the company contracts to produce deep-ultraviolet lithography equipment that was at the cutting edge of the industry's capabilities. GCA delivered far beyond expectations, living up to its earlier reputation for technological brilliance. Soon independent industry analysts were describing GCA's newest steppers as "the best in the world." The company even won a customer service award, casting off its reputation for being mediocre in that department. The software that GCA's machines used was far better than the company's Japanese rivals. "They were ahead of their time," recalled one lithography expert at Texas Instruments who tested GCA's newest machines.

Sematech 大力支持 GCA 公司，授予其生产深紫外光刻设备的合同，这些设备是行业技术能力的尖端产品。 GCA 远远超出了预期的表现，展现了早期的技术卓越声誉。不久，独立行业分析师便称赞 GCA 的最新步进机是"世界上最好的"。公司甚至还获得了客户服务奖项，摆脱了在这方面一直以来平庸的声誉。 GCA 机器使用的软件比该公司的日本竞争对手要好得多。 "他们领先于他们的时代，" 得克萨斯仪器公司的一位光刻专家回忆起测试 GCA 最新设备的情况。

But GCA still didn't have a viable business model. Being "ahead of your time" is good for scientists but not necessarily for manufacturing firms seeking sales. Customers had already gotten comfortable with equipment from competitors like Nikon, Canon, and ASML, and didn't want to take a risk on new and unfamiliar tools from a company whose future was uncertain. If GCA went bankrupt, customers might struggle to get spare parts. Unless a big customer could be convinced to sign a major contract with GCA, the company would spiral toward collapse. It lost $30 million between 1988 and 1992, despite $70 million in support from Sematech. Even Noyce could never convince Intel, the company he'd founded, to switch its allegiance from Nikon.

但是GCA仍然没有一个可行的商业模式。 对于寻求销售的制造企业而言，"领先时代"对科学家来说很好，但并非总是如此。 客户已经习惯了来自竞争对手尼康，佳能和ASML的设备，并不想冒险从一个未来不确定的公司购买新的和不熟悉的工具。 如果GCA破产，客户可能会难以获得备件。 除非能说服一个大客户签署与GCA的主要合同，否则该公司将向崩溃螺旋。 尽管Sematech提供了7000万美元的支持，但它在1988年至1992年间亏损了3000万美元。 即使诺伊斯无法说服他创立的英特尔公司放弃尼康作为领导。

In 1990, Noyce, GCA's greatest supporter at Sematech, died of a heart attack after his morning swim. He'd built Fairchild and Intel, invented the integrated circuit, and commercialized the DRAM chips and microprocessors that undergird all modern computing. Lithography, however, proved immune to Noyce's magic. By 1993, GCA's owner, a company called General Signal, announced it would sell GCA or close it. As the clock ticked toward this self-imposed deadline, no buyer could be found. Sematech, which had already provided millions in funding for GCA, decided to pull the plug. GCA appealed one final time to the government for help, with top national security officials considering whether U.S. foreign policy required saving GCA. They concluded nothing could be done. The company shut its doors and sold off its equipment, joining a long list of firms vanquished by Japanese competition.

1990年，英特爾及費爾柴爾德的創始人，也是GCA的最大支持者諾伊斯在游泳後心臟病發身亡。他創建了費爾柴爾德和英特爾，發明了集成電路，並商業化了支撐現代計算的DRAM芯片和微處理器。然而，光刻技術對諾伊斯的魔法免疫。到1993年，GCA的所有者——一家名為General Signal的公司，宣布要出售GCA或者關閉它。隨著時間倒計時，自我設限期限到來，找不到買家。已為GCA提供數百萬美元資金支持的Sematech決定斷然撤出。GCA最後一次向政府尋求幫助，國家安全高級官員考慮是否需要挽救GCA，結果得出無能為力的結論。公司關閉並賣掉其設備，成為日本競爭擊敗的公司長長名單上的一員。

CHAPTER 20 The Japan That Can Say No

A fter decades of making millions by selling Americans electronics, Sony's Akio Morita began to detect "a certain arrogance" in his American friends. When he first licensed transistor technology in the 1950s, the U.S. was the world's tech leader. Since then, America had faced crisis after crisis. The disastrous war in Vietnam, racial tension, urban unrest, the humiliation of Watergate, a decade of stagflation, a gaping trade deficit, and now industrial malaise. After each new shock, America's allure dimmed.

數十年來，索尼公司的盈利來自向美國人出售電子產品。而公司創辦人之一、森田恭雄（Akio Morita）開始察覺到，他的美國朋友逐漸展現出「某種傲慢」的態度。在五十年代時，森田恭雄所授權的晶體管技術，使得美國成為世界領先的科技國家。然而此後，美國陷入一次又一次的危機之中，例如：越戰慘敗、種族緊張、城市動盪、沃特蓋特醜聞、十年的停滯通脹以及龐大的貿易赤字，最终演變成工業式的萎靡不振。當每一次新的震撼發生時，美國的吸引力都在逐漸消失。

On his first trip abroad in 1953, Morita had seen America as a country "that seemed to have everything." He was served ice cream with a tiny paper umbrella on the top. "This is from your country," the waiter told him, a humiliating reminder of how far behind Japan was. Three decades later, however, everything had changed. New York had seemed "glamorous" on Morita's first visit in the 1950s. Now it was dirty, crime-ridden, and bankrupt.

Sony, meanwhile, had become a global brand. Morita redefined Japan's image abroad. The country was no longer seen as a producer of paper umbrellas for ice cream sundaes. Now it built the world's most high-tech goods. Morita, whose family owned a major stake in Sony, had gotten rich. He had a powerful network of friends on Wall Street and in Washington. He cultivated the art of the New York dinner party as meticulously as other Japanese approached a traditional tea ceremony. Whenever Morita was in New York, he hosted the city's rich and famous at his apartment on 82nd and Fifth, just across from the Metropolitan Museum of Art. Morita's wife Yoshiko even wrote a book explaining American dinner party customs to unfamiliar Japanese readers, titled *My Thoughts on Home Entertaining* . (Kimonos were discouraged; “whenever everyone wears the same kind of outfit, harmony is enhanced.”)

1953年，莫里塔第一次出国旅行，看到美国是一个"似乎拥有一切"的国家。他被端上一份有小纸伞的冰淇淋，服务员告诉他，“这是你们国家的东西”，这让他非常尴尬，因为这加深了日本的落后感。然而，三十年后，一切都变了。纽约在莫里塔的第一次访问中，似乎是“光鲜亮丽”的。现在它脏乱，犯罪横行，破产。与此同时，索尼已成为全球知名品牌。莫里塔重新定义了日本在国外的形象。这个国家不再被视为为冰淇淋圣代雨伞制造商。现在，它制造世界上最高科技的商品。作为索尼主要股东之一的莫里塔变得非常富有。他在华尔街和华盛顿拥有强大的人脉。他认真对待纽约的晚宴，就像其他日本人认真对待传统的茶道一样。每当莫里塔在纽约，他都会在自己位于第82和第五大道交界处的公寓里招待这个城市的富有和名人。莫里塔的妻子Yoshiko甚至写了一本书，名为《我对家庭招待的见解》，向不熟悉美国晚宴习俗的日本读者解释。该书建议不要穿和服; "当每个人都穿同样的服装时，就会增加和谐感。"

The Moritas enjoyed entertaining, but their dinner parties served a professional purpose, too. As commercial tension between the U.S. and Japan increased, Morita served as informal ambassador, explaining Japan to American powerbrokers. David Rockefeller was a personal friend. Morita dined with Henry Kissinger whenever the former secretary of state visited Japan. When private equity titan Pete Peterson took Morita to Augusta National, a golf club popular with CEOs, he was shocked to discover that “Akio had met them all.” Not only that—Morita arranged a dinner with each of his acquaintances while at Augusta. “He must have had about ten meals a day while he was staying here,” Peterson recounted.

莫里塔一家喜欢招待客人，但他们的晚宴也有职业目的。随着美国和日本之间的商业紧张关系加剧，莫里塔在向美国权力经纪人介绍日本方面充当了非正式的大使。戴维·洛克菲勒是他的个人朋友。莫里塔每次与前国务卿亨利·基辛格在日本会面时都会一同进餐。当私募股权巨头皮特·彼得森将莫里塔带到高桥国家高尔夫俱乐部时，他震惊地发现“昭夫（莫里塔）认识所有人”。这还不止——莫里塔在高桥期间还

安排了每个熟人的晚餐。“他在这里住宿期间一天至少吃了十顿饭，”彼得森回忆说。

Morita at first found the power and wealth represented by his American friends seductive. As America lurched from crisis to crisis, however, the aura around men like Henry Kissinger and Pete Peterson began to wane. Their country’s system wasn’t working—but Japan’s was. By the 1980s, Morita perceived deep problems in America’s economy and society. America had long seen itself as Japan’s teacher, but Morita thought America had lessons to learn as it struggled with a growing trade deficit and the crisis in its high-tech industries. “The United States has been busy creating lawyers,” Morita lectured, while Japan has “been busier creating engineers.” Moreover, American executives were too focused on “this year’s profit,” in contrast to Japanese management, which was “long range.” American labor relations were hierarchical and “old style,” without enough training or motivation for shop-floor employees. Americans should stop complaining about Japan’s success, Morita believed. It was time to tell his American friends: Japan’s system simply worked better.

起初，森田發現美國朋友所代表的權力和財富很具誘惑力。然而，當美國從危機到危機不斷地搖擺時，亨利·基辛格和皮特·彼得森等人的光環開始褪色。他們的國家體系不起作用，但日本的體系卻是如此。到了20世紀80年代，森田認為美國的經濟和社會存在深刻問題。美國長期以來一直認為自己是日本的老師，但森田認為美國需要學習一些課程，因為他們正在應對越來越大的貿易逆差和高科技行業的危機。“美國一直在忙於創造律師，” 森田講述道，“而日本則一直在為工程師進行更多工作。”此外，美國的高管太過關注“今年的利潤”，而日本的管理則是“長期計劃”。美國的勞資關係是階級式和“老式”的，對車間員工缺乏足夠的培訓和激勵。森田相信，美國人應該停止抱怨日本的成功。是時候告訴他的美國朋友了：日本的體系明顯運作更好。

In 1989, Morita set out his views in a collection of essays titled *The Japan That Can Say No* : *Why Japan Will Be First Among Equals* . The book was coauthored with Shintaro Ishihara, a controversial far-right politician. While just a university student, Ishihara had risen to fame by publishing a sexually charged novel titled *Season of the Sun* , which was awarded Japan’s most prestigious literary prize for new writers. He parlayed this fame, enhanced by derogatory diatribes against foreigners, into a parliamentary seat as a member of the ruling Liberal Democratic Party. In parliament, Ishihara agitated for Japan to assert itself internationally and to change the country's constitution, which had been dictated by U.S. occupation authorities after World War II, to let Tokyo build a powerful military.

1989 年，森田首次在一系列名为《日本能说不：为什么日本会成为平等的第一》的文章中阐述了他的观点。这本书的合作者是一个有争议的极右政治家石原慎太郎。虽然只是一名大学生，但石原凭借发表了一本充满性感的小说《太阳的季节》，荣获了日本新作家最负盛名的文学奖，因而走红。他通过攻击外国人的骂名，将这种名气转化成了议会席位，成为执政的自由民主党成员。在议会中，石原提出了日本在国际上主张自己的权利、修改国家宪法（这个宪法是二战后由美国占领当局制定的），以便让东京建立强大的军事力量。

It was hard to imagine a more provocative coauthor for Morita to have chosen as he lectured the United States about its internal crises. The book itself was a series of essays, some written by Morita and others by Ishihara. Morita's essays mostly rehashed his arguments about the failings of American business practices, though chapter titles such as "America, You Had Better Give Up Certain Arrogance" had a harsher tone than Morita usually expressed at New York dinner parties. Even the always gracious Morita found it difficult to mask his view that Japan's technological prowess had earned it a position among the world's great powers. "Militarily we could never defeat the United States," Morita told an American colleague at the time, "but economically we can overcome the United States and become number one in the world."

很难想象莫理田选择了一个更具挑衅性的合著者来讲述美国的内部危机。这本书是一系列论文的结集，有些是莫理田写的，有些是石原慎太郎写的。莫理田的文章大多重新阐述了他对美国商业行为失败的论点，尽管章节标题如："美国，你最好放弃某些傲慢态度"的语气比莫理田通常在纽约晚宴上表达的要强硬。即便是总是慷慨的莫理田也难以掩饰他的看法，即日本的技术实力已经赢得了在世界大国中的地位。"战争方面，我们永远不能打败美国，"莫理田当时告诉一位美国同事，"但在经济方面，我们可以克服美国，成为世界第一。"

Ishihara never hesitated to say exactly what he was thinking. His first novel was a story of unconstrained sexual urges. His political career embraced the most unsavory instincts of Japanese nationalism. His essays in *The Japan That Can Say No* called for Japan to declare independence from an overbearing America that had bossed Japan around for too long. “Let’s not give into America’s bluster!” one of Ishihara’s essays proclaimed. “Restrain America!” declared another. Japan’s far right had always been unhappy with their country’s secondary status in an America-led world. Morita’s willingness to coauthor a book with someone like Ishihara shocked many Americans, showing that a threatening nationalism still lurked within the capitalist class that Washington had cultivated. The U.S. strategy since 1945 had been to bind Japan to the U.S. via exchanges of trade and technology. Akio Morita was arguably the greatest beneficiary of America’s tech transfers and its market openness. If even *he* was questioning America’s leading role, Washington needed to rethink its game plan.

石原慎太郎從不猶豫地說出自己的想法。他的第一部小說講述了沒有限制的性衝動的故事。他的政治生涯擁抱了日本民族主義最不道德的本能。他在《可以對美說不的日本》一書中的文章呼籲日本宣布獨立於壓制日本太久的美國。其中一篇文章宣稱：“不要屈服於美國的咆哮！”，另一篇文章則宣告：“抑制美國！”。自由派一直對日本在以美國為首的世界中的次要地位感到不滿。森田的願意跟像石原慎太郎這樣的人合著一本書，令許多美國人感到震驚，顯示了一種威脅性的民族主義仍然存在於華盛頓栽培的資本家階級中。自1945年以來，美國的戰略一直是通過貿易和技術的交流來綁定日本和美國的關係。森田明治可以說是從美國的技術轉讓和市場開放中受益最大的。如果他甚至質疑美國的主導地位，華盛頓需要重新思考其遊戲計劃。

What made *The Japan That Can Say No* truly frightening to Washington was not only that it articulated a zero-sum Japanese nationalism, but that Ishihara had identified a way to coerce America. Japan didn’t need to submit to U.S. demands, Ishihara argued, because America relied on Japanese semiconductors. American military strength, he noted, required Japanese chips. “Whether it be mid-range nuclear weapons or inter-continental ballistic missiles, what ensures the accuracy of weapons is none other than compact, high-precision computers,” he wrote. “If Japanese semiconductors are not used, this accuracy cannot be assured.” Ishihara speculated that Japan could even provide advanced semiconductors to the USSR, tipping the military balance in the Cold War.

《能说不的日本》真正让华盛顿感到可怕的不仅是它表达了一种零和日本民族主义，而且石原慎太郎已经找到了迫使美国屈服的方法。石原慎太郎认为，日本不需要屈服于美国的要求，因为美国依赖于日本的半导体。他指出，美国的军事力量需要日本芯片。他写道："无论是中程核武器还是洲际导弹，保证精度的唯一手段便是紧凑的高精度计算机。如果不使用日本的半导体，就无法确保这种精度。"石原慎太郎推测，日本甚至可以向苏联提供先进的半导体，颠覆冷战时期的军事平衡。

"The 1-megabit semiconductors which are used in the hearts of computers, which carry hundreds of millions of circuits in an area which is one-third the size of your little fingernail, are only made in Japan," Ishihara noted. "Japan has nearly a 100 percent share of these 1-megabit semiconductors. "Now Japan is at least five years ahead of the U.S. in this area and the gap is widening," he continued. Computers using Japan's chips were "central to military strength and therefore central to Japanese power… in that sense, Japan has become a very important country."

"用於電腦核心、在小指甲三分之一大小的區域內承載著數以百萬計的電路的1兆位半導體只有日本製造，"石原裕次郎指出。"日本近乎擁有了100％的1兆位半導體市場份額。"現在，在這方面，日本至少比美國領先五年，差距正在擴大，"他繼續說道。使用日本產晶片的電腦"是軍事實力的核心，因此是日本實力的核心。從這個意義上說，日本已成為一個非常重要的國家。"

Other Japanese leaders appeared to take a similarly defiant nationalist view. One senior Foreign Ministry official was quoted as arguing that "Americans simply don't want to recognize that Japan has won the economic race against the West." Soon-to-be-prime-minister Kiichi Miyazawa publicly noted that cutting off Japanese electronics exports would cause "problems in the U.S. economy," and predicted that "the Asian economic zone will outdo the North American zone." Amid the collapse of its industries and its high-tech sector, America's future, a Japanese professor declared, was that of "a premier agrarian power, a giant version of Denmark."

其他日本領導人似乎持有類似的挑釁性民族主義觀點。一位高級外交部官員被引用為辯護說，“美國人只是不想承認日本在經濟競爭中擊敗了西方。” 即將成為首相的宮澤喜一公開表示，切斷日本的電子出口將會對“美國經濟造成問題”，並預測說“亞洲經濟區將會超越北美洲區”。當美國的工業和高科技產業崩潰時，一位日本教授宣稱，美國的未來是成為“一個頂尖的農業大國，一個巨大版本的丹麥。”

In the U.S., *The Japan That Can Say No* sparked fury. It was translated and circulated in unofficial form by the CIA. One irate congressman entered the entire book—still published in English only unofficially—into the Congressional Record to publicize it. Bookstores reported that customers in Washington were "going absolutely bananas" trying to find bootleg copies. Morita sheepishly had the official English translation published only with Ishihara's essays, without his contributions. "I now regret my association with this project," Morita told reporters, "because it has caused so much confusion. I don't feel U.S. readers understand that my opinions are separate from Ishihara's. My 'essays' express my opinions and his 'essays' express his opinions."

在美國，《能夠說不的日本》引起了憤怒。中央情報局將它翻譯成非官方版本流傳開來。一位憤怒的國會議員將整本書（仍然只有非官方的英文版）加入國會紀錄，以便公開。書店報告說，華盛頓地區的顧客「非常瘋狂」地想找到盜版的副本。莫里塔（Morita）害羞地只將官方英文翻譯與石原慎太郎的文章一起出版，而不包括他的貢獻。「我現在後悔參與這個項目，」莫里塔告訴記者，“因為它引起了太多的混亂。我不覺得美國讀者明白我的觀點與石原的觀點是不同的。我的『文章』表達了我的觀點，他的『文章』表達了他的觀點。”

Yet *The Japan That Can Say No* was controversial not because of its opinions, but because of the facts. The U.S. had fallen decisively behind in memory chips. If this trend persisted, geopolitical shifts would inevitably follow. It didn't take a far-right provocateur like Ishihara to recognize this; American leaders foresaw similar trends. The same year that Ishihara and Morita published *The Japan That Can Say No* , former defense secretary Harold Brown published an article that drew much the same conclusions. " High Tech Is Foreign Policy," Brown titled the article. If America's high-tech position was deteriorating, its foreign policy position was at risk, too.

然而，《能说不的日本》之所以引起争议，并非其观点，而是其事实。美国在存储芯片方面显然落后了。如果这种趋势持续下去，地缘政治格局势必会发生变化。不需要像石原慎太郎这样的极右翼挑衅者才能认识到这一点；美国领导人也预见到了类似的趋势。就在石原和森田出版《能说不的日本》的同一年，前国防部长哈罗德·布朗发表了一篇文章，得出了类似的结论。这篇文章的标题为“高科技即外交政策”。如果美国的高科技地位正在恶化，那么其外交政策地位也会面临风险。

This was an embarrassing admission for Brown, the Pentagon leader who’d hired Bill Perry in 1977 and empowered him to put semiconductors and computing power at the core of the military’s most important new weapons systems. Brown and Perry succeeded in convincing the military to embrace microprocessors, but they hadn’t anticipated Silicon Valley losing its lead. Their strategy paid off in terms of new weapons systems, but many of these now depended on Japan.

“Japan leads in memory chips, which are at the heart of consumer electronics,” Brown admitted. “The Japanese are rapidly catching up in logic chips and application-specific integrated circuits.” Japan also led in certain types of tools, like lithography equipment, needed to build chips. The best result Brown could foresee was a future in which the U.S. would protect Japan, but would do so with weapons powered by Japanese tech. America’s strategy to turn Japan into a transistor salesman seemed to have gone horribly wrong.

這對布朗來說是一個令人尷尬的承認，他是1977年聘請比爾·佩里的五角大樓領袖，授權他將半導體和計算能力置於軍事最重要的新武器系統的核心。布朗和佩里成功說服軍方擁抱微處理器，但他們沒有預料到矽谷會失去領先地位。他們的策略在新武器系統方面得到了回報，但許多這些系統現在依賴日本。 “日本在記憶芯片方面處於領先地位，這是消費電子產品的核心，”布朗承認。“日本人正在迅速追趕邏輯芯片和應用特定集成電路。”日本還在某些工具方面領先，例如建造芯片所需的光刻裝備。布朗能預見的最好的結果是，未來美國將保護日本，但將使用由日本技術帶動的武器。美國將日本變成一個晶體管銷售員的戰略似乎已經出了嚴重的偏差。

Would Japan, a first-class technological power, be satisfied with second-class military status? If Japan's success in DRAM chips was any guide, it was set to overtake the United States in almost every industry that mattered. Why wouldn't it seek military dominance, too? If so, what would the U.S. do? In 1987, the CIA tasked a team of analysts with forecasting Asia's future. They saw Japanese dominance of semiconductors as evidence of an emerging "Pax Niponica"—an East Asian economic and political bloc led by Japan. American power in Asia had been built on technological dominance, military might, and trade and investment links that knit together Japan, Hong Kong, South Korea, and the countries of Southeast Asia. From the first Fairchild assembly plant on Hong Kong's Kowloon Bay, integrated circuits had been an integral feature of America's position in Asia. U.S. chipmakers built facilities from Taiwan to South Korea to Singapore. These territories were defended from Communist incursions not only by military force but also by economic integration, as the electronics industry sucked the region's peasants off farms—where rural poverty often inspired guerilla opposition—into good jobs assembling electronic devices for American consumption.

日本作为一流的技术强国，会满足于二流的军事地位吗？以日本在DRAM芯片的成功为例，它几乎在所有有影响的行业中都超过了美国。为什么它不寻求军事优势呢？如果是这样，美国会怎么做？1987年，中央情报局指定了一组分析师，任务是预测亚洲的未来。他们将日本在半导体领域的主导地位视为出现“和谐日”的证据——由日本领导的东亚经济和政治集团。美国在亚洲的实力是基于技术主导、军事力量和结合了日本、香港、韩国和东南亚国家的贸易和投资联系。从第一个菲利浦集成电路装配工厂诞生于香港九龙湾的那一刻起，集成电路一直是美国在亚洲地位的一个重要特征。美国芯片制造商在台湾、韩国、新加坡等地建立了工厂。这些领土不仅通过经济一体化而不是军事力量，保卫了它们免受共产主义侵略，因为电子行业吸引了该地区的农民离开农场（在那里，农村贫困经常激发游击反对），进入制造美国消费电子设备的良好工作中。

America's supply chain statecraft had worked brilliantly in fending off Communists, but by the 1980s, the primary beneficiary looked to have been Japan. Its trade and foreign investment had grown massively. Tokyo's role in Asia's economics and politics was expanding inexorably. If Japan could so swiftly establish dominance over the chip industry, what would stop it from dethroning America’s geopolitical preeminence, too?

美国的供应链国家战略在抵御共产主义方面表现得非常出色，但到了1980年代，最主要的受益者似乎是日本。它的贸易和外国投资大幅增长。东京在亚洲经济和政治方面的地位不可遏制地扩大。如果日本能够如此迅速地确立芯片行业的主导地位，那么它为什么不能推翻美国的地缘政治霸主地位呢？

PART IV AMERICA RESURGENT

CHAPTER 21 The Potato Chip King

Micron made "the best damn widgets in the whole world," Jack Simplot used to say. The Idaho billionaire didn't know much about the physics of how his company's main product, DRAM chips, actually worked. The chip industry was full of PhDs, but Simplot hadn't finished eighth grade. His expertise was potatoes, as everyone knew from the white Lincoln Town Car he drove around Boise. "Mr. Spud," the license plate declared. Yet Simplot understood business in a way Silicon Valley's smartest scientists didn't. As America's chip industry struggled to adjust to Japan's challenge, cowboy entrepreneurs like him played a fundamental role in reversing what Bob Noyce had called a "death spiral" and executing a surprise turnaround.

美克龙（Micron）曾被杰克·辛普洛特（Jack Simplot）称为"全世界制造最好的零部件"。这位爱达荷州亿万富翁并不了解公司主要产品DRAM芯片的物理原理。 芯片行业充斥着博士，但辛普洛特连八年级都没有完成学业。正如人们从他在博伊西开的一辆白色林肯城市轿车可以看出的那样，"土豆先生"（Mr. Spud）的车牌宣示着他的专业领域是土豆。然而，辛普洛特以硅谷最聪明的科学家不知道的方式理解业务。当美国芯片行业努力适应日本的挑战时，像他这样的牛仔企业家在扭转鲍勃·诺伊斯（Bob Noyce）所说的"死亡螺旋"并实施惊人的逆转中发挥了基本作用。

Silicon Valley's resurgence was driven by scrappy startups and by wrenching corporate transformations. The U.S. overtook Japan's DRAM behemoths not by replicating them but by innovating around them. Rather than cutting itself off from trade, Silicon Valley offshored even more production to Taiwan and South Korea to regain its competitive advantage. Meanwhile, as America's chip industry recovered, the Pentagon's bet on microelectronics began to pay off as it fielded new weapons systems that no other country could match. America's unrivaled power during the 1990s and 2000s stemmed from its resurgent dominance in computer chips, the core technology of the era.

硅谷的复苏得益于充满活力的初创企业和痛苦的企业转型。美国不是通过复制日本的DRAM巨头，而是围绕它们进行创新来超越它们。硅

谷并没有切断与贸易的联系，而是将更多的生产外包到台湾和韩国，以恢复其竞争优势。与此同时，随着美国芯片行业的复苏，五角大楼对微电子学的赌注开始得到回报，因为它投入了新的武器系统，其他国家无法与之匹敌。在90年代和2000年代，美国在计算机芯片领域的复兴统治了行业，这也是当时的核心技术。

Of all the people to help revive America’s chip industry, Jack Simplot was the least likely candidate. He’d made his first fortune in potatoes, pioneering the use of machines to sort potatoes, dehydrate them, and freeze them for use in french fries. This wasn’t Silicon Valley–style innovation, but it earned him a massive contract to sell spuds to McDonald’s. At one point he supplied half the potatoes that McDonald’s used to make fries.

Micron, the DRAM firm that Simplot backed, at first seemed guaranteed to fail. When twin brothers Joe and Ward Parkinson founded Micron in the basement of a Boise dentist office in 1978, it was the worst possible time to start a memory chip company. Japanese firms were ramping up production of high-quality, low-priced memory chips. Micron’s first contract was to design a 64K DRAM chip for a Texas company called Mostek, but like every other American DRAM producer, it was beaten to the market by Fujitsu. Soon Mostek—the only customer for Micron’s chip design services—went bust. Amid an onslaught of Japanese competition, AMD, National Semiconductor, Intel, and other industry leaders abandoned DRAM production, too. Facing billion-dollar losses and bankruptcies, it seemed like all Silicon Valley might go bankrupt. America’s smartest engineers would be left flipping burgers. At least, the country still had plenty of french fries.

在所有幫助振興美國晶片產業的人中，傑克·辛普洛特似乎是最不可能的候選人。他在馬鈴薯方面賺了第一筆財富，開創了使用機器分類馬鈴薯、脫水，並將其冷凍供炸薯條使用的先河。這並不是硅谷所推崇的創新方式，但他因此贏得了向麥當勞出售馬鈴薯的巨額合同。曾經有一段時間，他供應了麥當勞用來製作薯條的一半馬鈴薯。 辛普洛特支持的DRAM公司“美光”的初期陷入了困境。當雙胞胎兄弟喬和沃德·帕金森在1978年在博伊西一家牙科診所的地下室創立“美光”時，這是開始創業的最糟糕時期。日本企業正在加大高品質、低價格的記憶體晶片的生產力度。美光的第一項合同是為德克薩斯州的一家公司“莫斯特克”設計一款64K DRAM晶片，但和其他美國DRAM生產商一樣，美

光被富士通打敗了。不久之後，唯一一個使用美光晶片設計服務的客戶莫斯特克就破產了。在日本競爭的猛攻下，AMD、國家半導體、英特爾和其他行業巨頭也放棄了DRAM生產。面對數十億美元的損失和破產，看起來整個硅谷都會破產。美國最聰明的工程師可能只能去翻煎漢堡了。至少，這個國家還有很多薯條。

As Japanese firms grabbed market share, CEOs of America’s biggest chip firms spent more and more time in Washington, lobbying Congress and the Pentagon. They set aside their free-market beliefs the moment Japanese competition mounted, claiming the competition was unfair. Silicon Valley angrily rejected the claim that there was no difference between potato chips and computer chips. Their chips merited government help, they insisted, because they were strategic in a way spuds weren’t.

Jack Simplot didn’t see anything wrong with potatoes. The argument that Silicon Valley deserved special help didn’t go very far in Idaho, a state with few tech companies. Micron had had to raise funds the hard way. Micron cofounder Ward Parkinson had gotten to know a Boise businessman named Allen Noble when he waded through Noble’s muddy potato field in a business suit trying to find a malfunctioning electric component in an irrigation system. The Parkinson brothers parlayed this connection into $100,000 in seed funding from Noble and a couple of his wealthy Boise friends. When Micron lost its contract to design chips for Mostek and decided to make its own chips, the Parkinsons needed more capital. So they turned to Mr. Spud, the richest man in the state.

隨著日本企業佔據了市場份額，美國最大的晶片公司CEO們花費越來越多時間在華盛頓遊說國會和五角大樓。一旦日本競爭加劇，他們便放棄了自由市場的信念，聲稱這種競爭是不公平的。矽谷對於“薯片和計算機芯片沒有區別”的說法感到憤怒。他們堅持自己的芯片值得得到政府的幫助，因為它們在某種程度上具有戰略意義，而土豆則沒有。
傑克·西姆普洛特（Jack Simplot）對馬鈴薯沒有什麼不好的地方。矽谷應得特殊幫助的論點在愛達荷州沒有得到很大的支持，因為該州幾乎沒有科技公司。Micron不得不艱難地籌集資金。Micron的聯合創始人沃德·帕金森（Ward Parkinson）在一次穿著商務西裝穿過阿倫·諾布爾（Allen Noble）泥濘的馬鈴薯田時認識了這位波伊茨商人。當他試圖在灌溉系統中找到一個故障的電氣元件時，帕金森兄弟便借此與諾布

爾及其幾個富有的波伊茨朋友獲得了10萬美元的種子資金。當Micron失去設計Mostek芯片的合同後，決定自行生產芯片，帕金森兄弟需要更多的資本。所以他們求助於那位最富有的土豆大亨，即該州最富有的人。

The Parkinson brothers first met Simplot at the Royal Café in downtown Boise, pouring sweat as they delivered their pitch to Idaho’s potato plutocrat. Transistors and capacitors didn’t mean much to Simplot, who was as close to the opposite of a Silicon Valley venture capitalist as you could get. He’d later preside over impromptu Micron board meetings each Monday at 5:45 a.m. at Elmer’s, a local greasy spoon that served stacks of buttermilk pancakes for $6.99. However, as all of Silicon Valley’s tech titans were fleeing DRAM chips amid the Japanese onslaught, Simplot instinctively understood that Ward and Joe Parkinson were entering the memory market at exactly the right time. A potato farmer like him saw clearly that Japanese competition had turned DRAM chips into a commodity market. He’d been through enough harvests to know that the best time to buy a commodity business was when prices were depressed and everyone else was in liquidation. Simplot decided to back Micron with $1 million. He’d later pour in millions more.

巴克森兄弟首次在Boise市中心的皇家咖啡厅与Simplot见面，并向这位爱达荷州的土豆大亨呈现了他们的计划。对于与硅谷风投背景迥异的Simplot来说，晶体管和电容器并不重要。后来，他会每周一早上5:45在当地的一间油腻小餐馆Elmer's主持即兴的Micron董事会会议，那里供应价格为6.99美元的厚饼煎饼。然而，随着硅谷科技巨头们在日本的进攻下逃离DRAM芯片市场，Simplot本能地意识到Ward和Joe Parkinson 正在恰好进入存储市场的正确时机。像他一样的土豆种植农民清楚地看到，日本的竞争已经将DRAM芯片变成了大宗商品市场。他经历过足够多的收获，知道在物价萎靡和其他所有人都在清算时购买商品业务是最好的时机。Simplot决定用100万美元支持Micron，后来他又投入了数百万美元。

America’s technology titans thought the Idaho country bumpkins didn’t have a clue. “I’d hate to say it’s over in memory chips,” said L. J. Sevin, a former Texas Instruments engineer who’d become an influential venture capitalist. “But it’s over.” At Intel, Andy Grove and Gordon Moore had reached the same conclusion. Texas Instruments and National Semiconductor announced losses and layoffs in their DRAM divisions. The future of the U.S. chip industry, the *New York Times* declared, was “grim.” So Simplot dove right in.

美国技术巨头们认为爱达荷州的乡巴佬们一窍不通。“我不想说存储芯片行业已经结束了，”曾担任德州仪器工程师后来成为有影响力的风险投资家的L.J. Sevin说。“但它确实已经结束了。”英特尔的安迪·格洛夫和戈登·摩尔也得出了同样的结论。德州仪器和国家半导体宣布了其DRAM业务的亏损和裁员情况。《纽约时报》宣布，美国芯片业的未来是“暗淡的”。所以，森普洛特便直接深入其中。

The Parkinson brothers played up their backcountry image, telling long, winding stories with a slight country drawl. In fact, they were as sophisticated as the founder of any Silicon Valley startup. Both had studied at Columbia University in New York, after which Joe worked as a corporate lawyer, while Ward designed chips at Mostek. But they embraced their Idaho outsider image. Their business model was to sweep into a market that America’s biggest chip firms were abandoning, so they weren’t going to make many friends anyway in Silicon Valley, which was still licking its wounds from the DRAM battles with Japan.

帕金森兄弟发扬他们的乡村形象，用一点带有南方口音的长篇故事来吸引人们。实际上，他们与任何硅谷初创企业的创始人一样精明。两人都曾在纽约的哥伦比亚大学学习，之后乔任职于一家公司律师事务所，而沃德则在Mostek设计芯片。但他们拥抱了自己作为爱达荷州的局外人的形象。他们的商业模式是进入美国最大的芯片公司正在放弃的市场，因此在硅谷并不会有很多朋友，那里还在从与日本的DRAM战斗中挥之不去的阴影中挣扎。

At first, Micron mocked Silicon Valley’s efforts to secure government help against the Japanese. The company sanctimoniously declined to join the Semiconductor Industry Association, the lobby group started by Bob Noyce, Jerry Sanders, and Charlie Sporck. “It was very clear to me that they had a different agenda,” Joe Parkinson declared. “Their strategy was, whatever the Japanese get into, let’s get out. The people who are dominant in the SIA are not taking the Japanese on. In my opinion, it’s a self-defeating strategy.”

一開始，美光嘲笑矽谷向政府尋求對抗日本的努力。公司公然拒絕加入由鮑勃·諾伊斯、傑里·桑德斯和查理·斯波克發起的半導體工業協會。喬·帕金森宣稱：“對我來說很明顯，他們有不同的議程。他們的策略是，不管日本人從事什麼，我們就退出。在我看來，SIA中占主導地位的人並不是在對抗日本人。依我之見，這是一種自我毀滅的策略。”。

Micron decided to challenge the Japanese DRAM makers at their own game, but to do so by aggressively cutting costs. Soon the company realized that tariffs might help, and reversed course, leading the charge for tariffs on imported Japanese DRAM chips. They accused Japanese producers of “dumping” chips in the U.S. below cost, harming American producers. Simplot was furious about Japan’s trade policies hurting his potato sales and his memory chips. “They’ve got a big tariff on potatoes,” he grumbled. “We’re paying through the nose on potatoes. We can out-tech ’em and we can out produce ’em. We’ll beat the hell out of ’em. But they’re giving those chips away.” That’s why he was demanding the government impose tariffs. “You ask why we go to the government? Cuz the law says they can’t do that.”

美光决定挑战日本DRAM制造商的游戏，但是通过积极地削减成本来做到这一点。很快公司意识到关税可能有所帮助，于是改变了策略，领导了对进口日本DRAM芯片的关税要求。他们指责日本制造商以低于成本的价格在美国“倾销”芯片，损害了美国制造商的利益。辛普洛特对日本的贸易政策损害了他的土豆销售和他的存储器芯片感到愤怒。“他们对土豆征收高额关税，”他抱怨道。“我们可以比他们更懂技术，生产能力也比他们更强。我们会打败他们。但是他们现在把芯片以极低的价格赠送出去。”这就是他要求政府征收关税的原因。“你问为什么我们求助于政府？因为法律规定他们不能那样做。”

The allegation that Japanese firms were cutting prices by too much was a bit rich coming from Simplot. Whether spud or semiconductor, he’d always said business success required being “the lowest-cost producer of the highest-quality product.” Anyway, Micron had a knack for cost cuts that none of its Silicon Valley or Japanese competitors could match. Ward Parkinson—“the engineering brains behind the organization,” one early employee remembered—had a talent for designing DRAM chips as efficiently as possible. While most of his competitors were fixated on shrinking the size of transistors and capacitors on each chip, Ward realized that if he shrunk the size of the chip itself, Micron could put more chips on each of the circular silicon wafers that it processed. This made manufacturing far more efficient. “It was by far the worst product on the market,” Ward joked, “but by far the least expensive to produce.”

日本企業削價太多的指控對於辛普洛特來說有些荒唐。無論是土豆還是半導體，他總是說商業成功需要成為“最高品質產品的最低成本生產者”。反正，美光有一種削減成本的本領，是其硅谷或日本競爭對手所無法匹敵的。沃德·帕金森——“該組織的工程智囊”，一位早期員工回憶說——擁有以最高效率設計DRAM芯片的天賦。當大多數競爭對手都著眼於縮小每個芯片上的晶體管和電容器的尺寸時，沃德意識到如果他縮小芯片本身的大小，美光可以在其加工的圓形矽晶圓上放置更多的芯片。這使得製造變得更加高效。沃德開玩笑說：“它是市場上最糟糕的產品，但是生產成本最低。”

Next, Parkinson and his lieutenants simplified the manufacturing processes. The more steps in manufacturing, the more time each chip took to make and the more room for errors. By the mid-1980s, Micron used far fewer production steps than its competitors, letting the company use less equipment, cutting costs further. They tweaked the lithography machines they bought from Perkin Elmer and ASML to make them more accurate than the manufacturers themselves thought possible. Furnaces were modified to bake 250 silicon wafers per load rather than the 150 wafers that was industry standard. Every step of the fabrication process that could handle more wafers or reduce production times meant lower prices. “We were figuring it out on the fly,” one early employee explained, so unlike other chipmakers, “we were prepared to do things that hadn’t been written in a paper before.” More than any of its Japanese or American competitors, the engineering expertise of Micron’s employees was directed toward cost cuts.

接下来，朴信治及其副手们简化了制造过程。制造过程中的步骤越多，每个芯片所需时间就越长，发生错误的空间也越大。到了1980年代中期，Micron使用的制造步骤比其竞争对手少得多，使公司使用更少的设备，进一步降低成本。他们调整了从Perkin Elmer和ASML购买的光刻机，使它们比制造商自己认为可能的更加精确。炉子被修改以每次烘烤250个硅片，而不是行业标准的150个硅片。每个能够处理更

多硅片或缩短生产时间的制造过程步骤都意味着更低的价格。"我们是在飞行中解决问题"，一位早期员工解释说，所以与其他芯片制造商不同，“我们准备做之前没有写在文献中的事情。”与其日本或美国竞争对手相比，Micron的员工的工程专业知识更加专注于削减成本。

Micron focused ruthlessly on costs because it had no choice. There was simply no other way for a small Idaho startup to win customers. It helped that land and electricity were cheaper in Boise than in California or in Japan, thanks in part to low-cost hydroelectric power. Survival was still a struggle. At one point, in 1981, the company's cash balances fell so low it could cover only two weeks of payroll. Micron scraped through that crisis, but amid another downturn a few years later it had to lay off half of its employees and cut salaries for the remainder. Since the earliest days of the business, Joe Parkinson had made sure employees realized that their survival depended on efficiency, going so far as to dim hallway lights at night to save on power bills when DRAM prices fell. Employees thought he was "maniacally" focused on costs—and it showed.

英特爾競爭對手 Micron 極其注重成本，因為這是一家來自愛達荷州的小型初創企業贏得客戶沒有其他方法。這得益於愛達荷州的土地和電力比加利福尼亞或日本更便宜，部分歸功於低成本的水電。存活仍然是一個挑戰。1981年，公司的現金餘額下降到只能支付兩周的工資。Micron 艱難地度過了這一危機，但在幾年後的另一次經濟衰退中，他不得不裁員一半的員工，削減其餘員工的工資。自從公司成立以來，Joe Parkinson 就一直讓員工意識到他們的生存取決於效率，甚至在 DRAM 價格下跌時在夜間調暗走廊燈光以節省電費。員工認為他是“瘋狂”的成本控制者，這一控制也得到體現。

Micron's employees had no choice but to keep the company alive. In Silicon Valley, if your employer went bust you could drive down Route 101 to the next chip firm or computer maker. Micron, by contrast, was in Boise. "We didn't have something else to do," one employee explained. "We either made DRAMs, or game over." It was a "hardworking, blue collar work ethic," another remembered, a "sweatshop mentality." "Memory chips is a brutal, brutal business," recalled an early employee who survived a series of painful DRAM market downturns.

美光（Micron）的员工别无选择，只能让公司继续存活下去。在硅谷，如果你的雇主破产了，你可以沿着101号公路开车到下一个芯片公司或计算机制造商。相比之下，美光位于博伊西（Boise）。一位员工解释说："我们没有其他事情可做。我们要么制造DRAM，要么结束。"另一个人记得这是一种"勤奋的蓝领工作道德"，是一种"血汗工厂的心态。"一位幸存于一系列痛苦的DRAM市场低迷的早期员工回忆说："内存芯片是一个非常残酷的行业。"。

Jack Simplot never lost faith. He'd survived downswings in every business he'd ever owned. He wasn't going to abandon Micron because of short-term price swings. Despite entering the DRAM market just as Japanese competition was peaking, Micron survived and eventually thrived. Most other American DRAM producers were forced out of the market in the late 1980s. TI kept manufacturing DRAM chips but struggled to make any money, and eventually sold its operations to Micron. Simplot's first $1 million investment eventually ballooned into a billion-dollar stake.

杰克·辛普洛从未失去信心。他经历过自己拥有的每个企业的低谷。他不会因短期价格波动而放弃Micron。尽管在日本竞争达到顶峰时进入DRAM市场，Micron仍然活下来并最终茁壮成长。大多数其他美国DRAM生产商在1980年代后期被迫退出市场。TI继续生产DRAM芯片，但无法赚钱，最终将其业务卖给了Micron。辛普洛的第一个100万美元的投资最终膨胀成了一个亿美元的股份。

Micron learned to compete with Japanese rivals like Toshiba and Fujitsu when it came to the storage capacity of each generation of DRAM chip and to outcompete them on cost. Like the rest of the DRAM industry, Micron's engineers bent the laws of physics as they made ever denser DRAM chips, providing the memory chips needed in personal computers. But advanced technology on its own wasn't enough to save America's DRAM industry. Intel and TI had plenty of technology but couldn't make the business work. Micron's scrappy Idaho engineers outmaneuvered rivals on both sides of the Pacific with their creativity and cost-cutting skill. After a decade of pain, the U.S. chip industry finally scored a win—and it was only possible thanks to the market wisdom of America's greatest potato farmer.

美光公司学会了与日本对手东芝和富士通比拼每一代DRAM芯片的存储能力，并在成本上超越他们。像DRAM行业的其他公司一样，美光的工程师们在制造越来越密集的DRAM芯片时违反了物理定律，为个人电脑提供了所需的存储芯片。但先进的技术本身并不能拯救美国的DRAM产业。英特尔和TI拥有丰富的技术，但无法使业务运作。美光的爱达荷州的工程师们以他们的创造力和降低成本的能力，在太平洋两岸的竞争对手中占据了优势。经过十年的痛苦，美国芯片产业终于赢得了一场胜利——这只有利用美国最伟大的土豆种植农民的市场智慧才有可能。

CHAPTER 22 Disrupting Intel

" L ook, Clayton, I'm a busy man and I don't have time to read drivel from academics," Andy Grove told Harvard Business School's most famous professor, Clayton Christensen. When the two of them made the cover of *Forbes* several years later, Christensen—six feet, eight inches tall—towered over Grove, whose balding head barely reached Christensen's shoulder. But Grove's intensity outshone that of everyone around him. He was a "butt-kicking Hungarian," his longtime deputy explained, "chewing on people's ankles, and yelling at them, and challenging them, and pushing as hard as he could." More than anything else did, Grove's tenacity saved Intel from bankruptcy and made it one of the world's most profitable and powerful companies.

"聽著，克萊頓，我是一個忙碌的人，沒時間讀那些學者們的廢話。"安迪·格羅夫（Andy Grove）對哈佛商學院最著名的教授克萊頓·克里斯滕森（Clayton Christensen）說道。幾年後當他們倆登上《福布斯》封面時，六尺八寸高的Christensen高聳在格羅夫的上方，而格羅夫只能親眼注視Christensen。但格羅夫的強烈氣氛讓他超越周遭所有人。他是一位"踢屁股的匈牙利人"，他的長期副手解釋道，"咬著人們的腳踝，大聲斥責他們，挑戰他們，盡他所能地推動。"最重要的是，格羅夫的韌性拯救了英特爾免於破產，使其成為世界上最有利潤和最強大的公司之一。

Professor Christiansen was famous for his theory of "disruptive innovation," in which a new technology displaces incumbent firms. As the DRAM business slumped, Grove realized that Intel—once synonymous with innovation—was now being disrupted. By the early 1980s, Grove was Intel's president, in charge of day-to-day operations, though Moore still played a major role. Grove described his management philosophy in his bestselling book *Only the Paranoid Survive* : "Fear of competition, fear of bankruptcy, fear of being wrong and fear of losing can all be powerful motivators." After a long day of work, it was fear that kept Grove flipping through his correspondence or on the phone with subordinates, worried he'd missed news of product delays or unhappy customers. On the outside, Andy Grove was living the American dream: a once-destitute refugee transformed into a tech titan. Inside this Silicon Valley success story was a Hungarian exile scarred by a childhood spent hiding from the Soviet and Nazi armies marching down Budapest streets.

克里斯蒂安森教授以“颠覆式创新”理论而闻名，即一种新技术取代了现有的公司。当DRAM业务低迷时，格罗夫意识到英特尔 - 曾经是创新的代名词 - 正被打乱了。到了1980年代初，格罗夫成为英特尔的总裁，负责日常运营，而摩尔仍起着重要作用。格罗夫在他的畅销书《唯有妄想者生存》中描述了他的管理哲学：“对竞争的恐惧、破产的恐惧、犯错的恐惧和输的恐惧都可以是强大的激励因素。”工作结束时，格罗夫因担心自己错过了产品延迟或不满意的客户的消息而翻阅信件或与下属通电话。在外部，安迪·格罗夫过着美国梦：一位曾经落魄的难民变成了技术巨头。在这个硅谷成功的故事中，是一个曾经在布达佩斯的街道上躲避苏联和纳粹军队的童年给了他深深的创伤。

Grove realized Intel’s business model of selling DRAM chips was finished. DRAM prices might recover from the price slump, but Intel would never win back market share. It had been “disrupted” by Japanese producers. Now it would either disrupt itself or fail. Exiting the DRAM market felt impossible. Intel had pioneered memory chips, and admitting defeat would be humiliating. It was like Ford deciding to get out of cars, one employee said. “How could we give up our identity?” Grove wondered. He spent much of 1985 sitting in Gordon Moore’s office at Intel’s Santa Clara headquarters, the two of them staring out the window at the Ferris wheel in the Great America amusement park in the distance, hoping that like one of the cabins on the Ferris wheel, the memory market would eventually hit bottom and begin circling up again.

葛洛夫意识到因售卖DRAM芯片而构建的英特尔商业模式已经结束。DRAM价格可能会从价格下跌中恢复过来，但英特尔永远无法夺回市场份额。它已被日本制造商“打败”。现在，它要么自我“打破”，要么失败。退出DRAM市场似乎不可能。英特尔开创了记忆芯片的先河，承认失败将是一种羞辱。就像福特决定退出汽车一样，某位员工说。葛洛夫想知道，“我们怎么能放弃我们的身份？”他在1985年的大部分时间里都坐在英特尔圣塔克拉拉总部的戈登·摩尔(Gordon Moore)办公

室里，两人一起盯着远处的美国大冒险乐园中的摩天轮，希望就像其中的一辆轿船一样，记忆市场最终会跌到谷底，然后开始向上旋转。

However, the disastrous DRAM numbers were impossible to deny. Intel would never make enough money in memory to justify new investments. It was a leader, though, in the small microprocessor market, where Japanese firms still lagged. And one development in that arena provided a glimmer of hope. In 1980, Intel had won a small contract with IBM, America's computer giant, to build chips for a new product called a personal computer. IBM contracted with a young programmer named Bill Gates to write software for the computer's operating system. On August 12, 1981, with the ornate wallpaper and thick drapes of the Waldorf Astoria's grand ballroom in the background, IBM announced the launch of its personal computer, priced at $1,565 for a bulky computer, a big-box monitor, a keyboard, a printer, and two diskette drives. It had a small Intel chip inside.

然而，灾难性的DRAM数字是不可否认的。英特尔在存储器方面无法赚到足够的钱来证明新的投资价值。但它在小型微处理器市场中却是领导者，而日本企业仍然落后。而这个领域的一个发展提供了一线希望。在1980年，英特尔赢得了与美国计算机巨头IBM的一个小合同，为一个名为个人电脑的新产品制造芯片。IBM与年轻的程序员比尔·盖茨签订了一份写计算机操作系统软件的合同。1981年8月12日，在华道夫·阿斯多利亚大厅壁纸的装饰和厚重的窗帘的背景下，IBM宣布推出个人电脑，售价为1,565美元，包括一个笨重的电脑、一个大盒子显示器、一个键盘、一台打印机和两个软盘驱动器。它里面有一个小型的英特尔芯片。

The microprocessor market seemed almost certain to grow. But the prospect that microprocessor sales could overtake DRAMs, which constituted the bulk of chip sales, seemed mind-boggling, one of Grove's deputies recalled. Grove saw no other choice. "If we got kicked out and the board brought in a new CEO, what do you think he would do?" Grove asked Moore, who wanted to keep producing DRAM chips. "He would get us out of memories," Moore admitted sheepishly. Finally, Intel decided to leave memories, surrendering the DRAM market to the Japanese and focusing on microprocessors for PCs. It was a gutsy gamble for a company that had been built on DRAMs. "Disruptive innovation" sounded attractive in Clayton

Christensen’s theory, but it was gut-wrenching in practice, a time of “gnashing of teeth,” Grove remembered, and “bickering and arguments.” The disruption was obvious. The innovation would take years to pay off, if it ever did.

微處理器市場似乎確定會增長。但微處理器銷售有可能超過占晶片銷售主體的動態隨機存取記憶體(DRAM)，這看起來很困難， 因此Groves的一名副手回憶到 。Groves認為沒有其他選擇了。 "如果我們被踢出去，董事會任命新任首席執行官，他會怎麼做？"想繼續生產DRAM晶片的Moore問。 Moore承認有點局促。最終，英特爾決定離開動態隨機存取記憶體，將DRAM市場讓給日本，專注於電腦微處理器。這對一個建立在DRAM上的公司來說是一個大膽的賭博。“ 破壞性創新 ” 在克萊頓·克里斯滕森的理論中聽起來很吸引人，但在實踐中卻是令人心碎的，“咬牙切齒”的時刻，Groves 記得 ， 還有“互相爭論的口角。” 隨之而來的混亂是明顯的，創新是否會產生效果，還需幾年的時間。

While waiting to see if his bet on PCs would work, Grove applied his paranoia with a ruthlessness Silicon Valley had rarely seen. Workdays started at 8 a.m. sharp and anyone who signed in late was criticized publicly. Disagreements between employees were resolved via a tactic Grove called “constructive confrontation.” His go-to management technique, quipped his deputy Craig Barrett, was “grabbing someone and slamming them over the head with a sledgehammer.”

This wasn’t the freewheeling culture Silicon Valley was known for, but Intel needed a drill sergeant. Its DRAM chips faced the same quality problems as those of other American chipmakers. When it had made money in DRAMs, it did so by being first to the market with a new design, not by being the leader in mass production. Bob Noyce and Gordon Moore had always fixated on maintaining cutting-edge tech. But Noyce admitted that he always found “the venture part” more fun than “the control part.” Grove loved control as much as anything, which is why Gordon Moore had first brought him to Fairchild in 1963: to solve the company’s production problems. When he followed Noyce and Moore to Intel, he was given the same role. Grove spent the rest of his life immersed in every detail of the company’s manufacturing processes and its business, driven by a nagging sense of fear.

在等待看看他对个人电脑的赌注是否奏效时，格鲁夫运用他的妄想症以一种硅谷很少见的无情方式。工作日从早上8点准时开始，任何签到迟到的人都会公开受到批评。员工之间的分歧通过一种格鲁夫称之为"建设性对抗"的策略得到解决。他的主要管理技巧是"抓住某人并用大锤击打他们的脑袋"，他的副手克雷格·巴雷特开玩笑说。这并不是硅谷以自由轻松而著称的文化，但英特尔需要一个军事教官。其DRAM芯片面临着与其他美国芯片制造商相同的质量问题。当其在DRAM芯片上赚钱时，是通过在市场上率先推出新的设计而不是成为大规模生产的领导者。鲍勃·诺伊斯和戈登·穆尔一直注重维护尖端技术。但诺伊斯承认他总是觉得"风险投资部分"比"控制部分"更有趣。格鲁夫与任何事物一样都热爱控制，这就是为什么戈登·穆尔在1963年首次将他带到费尔柴尔德解决公司的生产问题。当他跟着诺伊斯和穆尔来到英特尔时，他被赋予了同样的角色。格鲁夫花费了余生投身于公司制造过程和业务的每一个细节中，驱动他的是一种难以消除的恐惧感。

In Grove's restructuring plan, step one was to lay off over 25 percent of Intel's workforce, shutting facilities in Silicon Valley, Oregon, Puerto Rico, and Barbados. Grove's deputy described his boss's approach as: "Oh my god. Fire these two people, burn the ships, kill the business." He was ruthless and decisive in a way that Noyce and Moore never could have been. Step two was to make manufacturing work. He and Barrett relentlessly copied Japanese manufacturing methods. "Barrett basically took a baseball [bat] to manufacturing and said: 'Damn it! We are not going to get beaten by the Japanese,'" one subordinate recalled. He forced factory managers to visit Japan and told them: "This is how you are supposed to do it."

在Grove的重组计划中，第一步是裁员超过英特尔工作人员的25％，关闭硅谷、俄勒冈、波多黎各和巴巴多斯的设施。 Grove的副手描述了他老板的方法："天哪。解雇这两个人，烧掉船只，毁掉业务。"他的手段是毫不留情和果断的，这是Noyce和Moore所不能做的。第二步是让制造业工作起来。他和巴雷特不懈地复制日本的制造方法。一位下属回忆道："巴雷特基本上拿着棒球棒对制造业说：'该死的！我们不能被日本人打败。'"他强迫工厂经理前往日本，并告诉他们："这就是你们应该做的。"

Intel's new manufacturing method was called "copy exactly." Once Intel determined that a specific set of production processes worked best, they were replicated in all other Intel facilities. Before then, engineers had prided themselves on fine-tuning Intel's processes. Now they were asked not to think, but to replicate. "It was a huge cultural issue," one remembered, as a freewheeling Silicon Valley style was replaced with assembly line rigor. "I was perceived as a dictator," Barrett admitted. But "copy exactly" worked: Intel's yields rose substantially, while its manufacturing equipment was used more efficiently, driving down costs. Each of the company's plants began to function less like a research lab and more like a finely tuned machine.

英特尔的新制造方法被称为"完全复制"。一旦英特尔确定了最佳生产流程，它们被复制到所有其他英特尔设施中。在此之前，工程师们一直以微调英特尔的流程为荣。现在他们被要求不要思考，而是要复制。"这是一个巨大的文化问题，"一个人记得，因为放荡不羁的硅谷风格被装配线严格性取代。"我被看作是一个独裁者，"巴雷特承认。但"完全复制"起作用了：英特尔的产出率大幅提高，同时其制造设备被更有效地利用，从而降低成本。该公司的每个工厂都开始变得不再像研究实验室，而更像一个精密调优的机器。

Grove and Intel got lucky, too. Some of the structural factors that had favored Japanese producers in the early 1980s began to shift. Between 1985 and 1988, the value of the Japanese yen doubled against the dollar, making American exports cheaper. Interest rates in the U.S. fell sharply over the 1980s, reducing Intel's capital costs. Meanwhile, Texas-based Compaq Computer muscled in on IBM's PC market, driven by the realization that though it was hard to write operating systems or build microprocessors, assembling PC components into a plastic box was relatively straightforward. Compaq launched its own PCs using Intel chips and Microsoft software, priced far below IBM's PCs. By the mid-1980s, Compaq and other firms building "clones" of IBM's PC sold more units than IBM itself. Prices fell precipitously as computers were installed in every office and many homes. Except for Apple's computers, almost every PC used Intel's chips and Windows software, both of which had been designed to work smoothly together. Intel entered the personal computer era with a virtual monopoly on chip sales for PCs.

Grove和Intel也有些幸运。早在1980年代初期，有利于日本生产商的一些结构性因素开始转变。1985年至1988年间，日元对美元的价值翻了一番，使美国出口变得更便宜。美国的利率在1980年代急剧下降，从而降低了Intel的资本成本。与此同时，得克萨斯州的康柏电脑(COmpaq Computer)进入了IBM的个人电脑市场，他们认识到，虽然编写操作系统或构建微处理器很难，但将个人电脑组件组装成塑料盒相对容易。康柏使用英特尔芯片和微软软件推出了自己的PC，价格远低于IBM的PC。到1980年代中期，康柏和其他克隆IBM PC的公司的销售数量超过了IBM自身。随着电脑被安装在每个办公室和许多家庭中，价格急剧下跌。除了Apple的电脑外，几乎所有的PC使用英特尔芯片和Windows软件，这两者都被设计成能够顺畅地一起工作。英特尔进入了个人电脑时代，几乎垄断了PC芯片销售。

Grove’s restructuring of Intel was a textbook case of Silicon Valley capitalism. He recognized that the company’s business model was broken and decided to “disrupt” Intel himself by abandoning the DRAM chips it had been founded to build. The firm established a stranglehold on the market for PC chips, issuing a new generation of chip every year or two, offering smaller transistors and more processing power. Only the paranoid survive, Andy Grove believed. More than innovation or expertise, it was his paranoia that saved Intel.

葛羅夫重組英特爾是硅谷資本主義的典範。他意識到公司的商業模式已經失敗，決定通過放棄英特爾創立時就生產的DRAM芯片，自己“破壞”英特爾。公司建立了PC芯片市場的壟斷地位，每一至兩年推出一款新一代芯片，提供更小的晶體管和更強大的處理能力。安迪·葛羅夫相信：只有偏執狂才能存活。超越創新和專業知識，是他的偏執狂拯救了英特爾。

CHAPTER 23 “My Enemy’s Enemy”: The Rise of Korea

L ee Byung-Chul could make a profit selling almost anything. Born in 1910, just a year after Jack Simplot, Lee launched his business career in March 1938, a time when his native Korea was part of Japan’s empire, at war with China and soon with the United States. Lee’s first products were dried fish and vegetables, which he gathered from Korea and shipped to northern China to feed Japan’s war machine. Korea was an impoverished backwater, with no industry or technology, but Lee was already dreaming of building a business that would be “big, strong, and eternal,” he declared. He would turn Samsung into a semiconductor superpower thanks to two influential allies: America’s chip industry and the South Korean state. A key part of Silicon Valley’s strategy to outmaneuver the Japanese was to find cheaper sources of supply in Asia. Lee decided this was a role Samsung could easily play.

李秉聰幾乎可以賣出任何產品並獲利。生於1910年，僅比傑克·西姆普洛特晚一年，李於1938年3月開始了他的商業生涯，那時他的故鄉韓國是日本帝國的一部分，與中國以及將與美國交戰。李的第一批產品是從韓國收集的幹魚和蔬菜，運往中國北部以供日本的戰爭機器使用。韓國當時是一個貧窮的落後地區，沒有任何產業或技術，但李已經夢想著建立一個“龐大，強大且永恆”的企業。他將三星打造成一個半導體超級強國，得益於兩位有影響力的盟友：美國的晶片行業和南韓國家。矽谷超越日本的關鍵策略之一是在亞洲尋找更便宜的供應來源。李認為這是三星可以輕易扮演的角色。

South Korea was used to navigating between bigger rivals. Seven years after Lee founded Samsung, it could have been crushed in 1945, following Japan’s defeat by the United States. Yet Lee deftly pivoted, trading political patrons as smoothly as he hawked dried fish. He forged ties with the Americans who occupied the southern half of Korea after the war and fended off South Korean politicians who wanted to break up big business groups like his. He even kept hold of his assets when the Communist government in North Korea invaded the South—though, when the enemy briefly captured Seoul, a

Communist Party chief seized Lee's Chevrolet and drove it around the occupied capital.

南韓一向善於在大競爭對手之間運籌帷幄。李秉喆創立三星七年後，就在日本戰敗遭受美國打擊的情況下，差點被擊垮於1945年。但李秉喆靈活應對，熟練地交換政治贊助人，就像他推銷干魚一樣。他與戰後佔領南半部的美國人建立關係，抵擋住想要瓦解他的大型企業集團的南韓政治人物。當北韓共產主義政府入侵南韓時，他甚至保持了他的資產。儘管當敵人簡短地占領首爾時，共產黨領袖還是奪走了李秉喆的雪佛蘭車並在被佔領的首都開車兜風。

Lee expanded his business empire despite the war, navigating South Korea's complicated politics with finesse. When a military regime took power in 1961, the generals stripped Lee of his banks, but he survived with his other companies intact. He insisted Samsung was working for the good of the nation—and that the good of the nation depended on Samsung becoming a world-class company. "Serving the nation through business," the first part of the Lee family motto read. From fish and vegetables, he diversified into sugar, textiles, fertilizer, construction, banking, and insurance. He saw Korea's economic boom during the 1960s and 1970s as proof he was serving the nation. Critics, who noted that by 1960 he had become the richest person in South Korea, thought his wealth was evidence the nation—and its venal politicians—were serving him.

李在战争期间扩大了自己的商业帝国，并以精湛的技巧航行韩国复杂的政治局势。1961年军政府上台后，将李的银行剥夺了，但他靠其他公司幸存下来。他坚称三星是为了国家利益工作，而国家的利益取决于三星成为世界一流公司。"通过商业为国家服务"，李家庭训词的第一部分如是说。他从鱼和蔬菜开始，逐步扩展至糖、纺织品、化肥、建筑、银行和保险等领域。他认为，在1960年代和1970年代的韩国经济繁荣是他为国家服务的证明。批评人士注意到，到1960年时他已成为韩国最富有的人，认为他的财富证明了国家和其贪污的政客们是在为他服务。

Lee had long wanted to break into the semiconductor industry, watching companies like Toshiba and Fujitsu take DRAM market share in the late 1970s and early 1980s. South Korea was already an important location for outsourced assembly and packaging of chips made in the U.S. or Japan. Moreover, the U.S. government had helped fund the creation in 1966 of the Korea Institute of Science and Technology, and a growing number of Koreans were graduating from top U.S. universities or being trained in Korea by U.S.-educated professors. Even with a skilled workforce, though, it wasn't easy for firms to jump from basic assembly to cutting-edge chipmaking. Samsung had previously dabbled in simple semiconductor work but struggled to make money or produce advanced technology.

李喜欢潜心研究半导体产业，看着像东芝和富士通这样的公司在上世纪70年代末和80年代初占据了DRAM市场份额。韩国已经是美日芯片制造外包组装和包装的重要地点。此外，美国政府曾在1966年资助创立了韩国科技研究院，越来越多的韩国人从美国顶尖大学毕业或在韩国接受美国受过教育的教授的培训。即使拥有熟练的劳动力，公司也并不容易从基础组装跃升到前沿的芯片制造。三星以前曾尝试过简单的半导体工作，但难以赚钱或生产先进技术。

In the early 1980s, however, Lee sensed the environment changing. The brutal DRAM competition between Silicon Valley and Japan during the 1980s provided an opening. The South Korean government, meanwhile, had identified semiconductors as a priority. As Lee pondered Samsung's future, he traveled to California in spring 1982, visiting Hewlett-Packard's facilities and marveling at the company's technology. If HP could grow from a Palo Alto garage to a tech behemoth, surely a fish-and-vegetables shop like Samsung could, too. "It's all thanks to semiconductors," one HP employee told him. He also toured an IBM computer factory and was shocked he was allowed to take photographs. "There must be many secrets in your factory," he told the IBM employee giving him the tour. " They can't be replicated by mere observation," the employee confidently responded. Replicating Silicon Valley's success, though, was exactly what Lee planned to do.

然而，早在1980年代初期，李健熙就感觉到环境正在发生变化。硅谷和日本在20世纪80年代的激烈DRAM竞争提供了机会。与此同时，韩国政府已经确定半导体作为重点发展领域。当李健熙思考三星的未来时，他在1982年春天前往加利福尼亚，参观了惠普的设施，并对公司的技术赞叹不已。如果惠普可以从帕洛阿尔托的车库成长为科技巨头，那么一个鱼菜店如三星也肯定可以做到。 "这都要归功于半导

体，"惠普的一位员工告诉他。他还参观了IBM的计算机工厂，对方竟然允许他拍照，他感到震惊。 "你们的工厂肯定有很多秘密，"他对领他参观的IBM员工说。"这些秘密不能仅仅通过观察来复制，"员工自信地回答道。然而，复制硅谷的成功正是李健熙计划要做的。

Doing so would require many millions of dollars in capital expenditure, yet there was no guarantee it would work. Even for Lee, this was a big bet. He hesitated for months. Failure could bring down his entire business empire. South Korea's government, however, signaled it was willing to provide financial support. It had promised to invest $400 million to develop its semiconductor industry. Korea's banks would follow the government's direction and lend millions more. As in Japan, therefore, Korea's tech companies emerged not from garages, but from massive conglomerates with access to cheap bank loans and government support. In February 1983, after a nervous, sleepless night, Lee picked up the phone, called the head of Samsung's electronics division, and proclaimed: "Samsung will make semiconductors." He bet the company's future on semiconductors, and was ready to spend at least $100 million, he declared.

這樣做需要投入數百萬美元的資本支出，但並不保證會成功。即使對李家來說，這是一個重大的賭注。他猶豫了幾個月。失敗可能會毀掉他整個商業帝國。然而，韓國政府表示願意提供財政支持。他承諾投資4億美元發展半導體產業。韓國的銀行會跟隨政府的方向，貸款數百萬美元。正如日本一樣，因此韓國的科技公司不是從車庫中崛起，而是來自能夠獲得廉價銀行貸款和政府支持的大型企業集團。1983年2月，在經過一個緊張而不眠的晚上後，李家打電話給三星電子部門負責人，宣布："三星會製造半導體。"他把公司的未來押在了半導體上，並宣布準備花費至少1億美元。

Lee was a canny entrepreneur, and South Korea's government stood firmly behind him. Yet Samsung's all-in bet on chips wouldn't have worked without support from Silicon Valley. The best way to deal with international competition in memory chips from Japan, Silicon Valley wagered, was to find an even cheaper source in Korea, while focusing America's R&D efforts on higher-value products rather than commoditized DRAMs. U.S. chipmakers therefore saw Korean upstarts as potential partners. "With the Koreans around," Bob Noyce told Andy Grove, Japan's strategy of "dump no matter what the costs" wouldn't succeed in monopolizing the world's DRAM production, because the Koreans would undercut Japanese producers. The result would be "deadly" to Japanese chipmakers, Noyce predicted.

李偉是一個精明的企業家，而韓國政府堅定地支持他。然而，三星對芯片的全賭注不可能沒有來自矽谷的支持而實現。矽谷認為，應尋找更便宜的來源在韓國，以應對日本在記憶芯片方面的國際競爭，並將美國的研發重點放在更高價值的產品上，而不是定價低廉的DRAM。因此，美國的芯片製造商將韓國新興企業視為潛在的合作夥伴。 "有了韓國人在身邊，"鮑勃·諾伊斯告訴安迪·格羅夫，日本的"無論代價都要倒垃圾"的策略不會成功地壟斷全球DRAM的生產，因為韓國人會打破日本的價格優勢。諾伊斯預測，這將對日本的芯片製造商造成"致命"的打擊。

Intel therefore cheered the rise of Korean DRAM producers. It was one of several Silicon Valley firms to sign a joint venture with Samsung in the 1980s, selling chips Samsung manufactured under Intel's own brand and wagering that helping Korea's chip industry would reduce Japan's threat to Silicon Valley. Moreover, Korea's costs and wages were substantially lower than Japan's, so Korean firms like Samsung had a shot at winning market share even if their manufacturing processes weren't as perfectly tuned as the ultra-efficient Japanese.

因此，英特爾為韓國DRAM生產商的崛起感到高興。這是20世紀80年代與三星簽訂合資企業的幾家硅谷公司之一，出售三星生產的芯片，使用英特爾自己的品牌，並打賭幫助韓國的芯片行業會減少日本對硅谷的威脅。此外，韓國的成本和工資比日本低得多，因此像三星這樣的韓國公司即使他們的製造工藝不像超級高效的日本公司一樣完美，也有機會贏得市場份額。

U.S.-Japan trade tension helped Korean companies, too. After Washington threatened tariffs unless Japan stopped "dumping"—selling DRAM chips cheaply on the U.S. market—in 1986, Tokyo agreed to limit its sales of chips to the U.S. and promised not to sell at low prices. This provided an opening for Korean companies to sell more DRAM chips at higher prices. The Americans didn't intend for the deal to benefit Korean firms, but they were happy to see anyone but Japan producing the chips they needed.

The U.S. didn't simply provide a market for South Korean DRAM chips; it provided technology, too. With Silicon Valley's DRAM producers mostly near collapse, there was little hesitation about transferring top-notch technology to Korea. Lee proposed to license a design for a 64K DRAM from Micron, the cash-strapped memory chip startup, befriending its founder Ward Parkinson in the process. The Idahoans, looking for any money they could get, eagerly agreed even if it meant Samsung would learn many of their processes. "Whatever we did, Samsung did," Parkinson remembered, seeing the cash infusion that Samsung provided as "not crucial, but close" in helping Micron survive. Some industry leaders, like Gordon Moore, worried that some chip firms were so desperate they'd "part with increasingly valuable bits of technology." However, it was hard to make the case that DRAM technology was particularly valuable when most U.S. firms making memory chips were nearly bankrupt. Most of Silicon Valley was happy to work with Korean companies, undercutting Japanese competitors and helping make South Korea one of the world's leading centers of memory chipmaking. The logic was simple, as Jerry Sanders explained: " my enemy's enemy is my friend."

美國和日本的貿易緊張關係也幫助了韓國公司。在華盛頓威脅加徵關稅，除非日本停止在美國市場上低價出售DRAM芯片的情況下，日本同意限制其向美國銷售芯片，並承諾不低價出售。這為韓國公司提供了賣更高價格DRAM芯片的機會。美國人並不打算讓這筆交易為韓國公司帶來好處，但他們很高興除了日本之外的其他公司生產他們所需的芯片。 美國不僅為韓國DRAM芯片提供了市場，也提供了技術。由於矽谷DRAM生產商基本上接近崩潰，因此毫不猶豫地把頂級技術轉移到韓國。李在鼎向Micron公司的創始人沃德•帕金森提出授權設計64KDRAM的建議，並在此過程中結交了好友。愛達荷人迫切需要任何資金，即使這意味著三星將學會他們的許多技術，他們仍然熱切地同意了。帕金森記得，三星提供的資金幫助Micron生存"不是至關重要，但接近關鍵"。一些業界領袖，如戈登•摩爾，擔心一些芯片公司如此絕望，他們會"放棄越來越有價值的技術"。然而，當大部分製造記憶芯片的美國公司幾乎破產時，很難證明DRAM技術特別有價值。大多數矽谷人很高興與韓國公司合作，壓低日本競爭對手，幫助韓國成為世界領先的記憶芯片製造中心。正如傑里•桑德斯所解釋的邏輯：「我的敵人的敵人就是我的朋友。」

CHAPTER 24 “This Is the Future”

T he rebirth of America’s chip industry after Japan’s DRAM onslaught was only possible thanks to Andy Grove’s paranoia, Jerry Sanders’s bare-knuckle brawling, and Jack Simplot’s cowboy competitiveness. Silicon Valley’s testosterone and stock option−fueled competition often felt less like the sterile economics described in textbooks and more like a Darwinian struggle for the survival of the fittest. Many firms failed, fortunes were lost, and tens of thousands of employees were laid off. The companies like Intel and Micron that survived did so less thanks to their engineering skills—though these were important—than their ability to capitalize on technical aptitude to make money in a hypercompetitive, unforgiving industry.

美國晶片行業在日本DRAM的打擊後重生，全賴安迪·格羅夫的偏執狂、傑里·桑德斯的赤裸搏鬥和傑克·辛普洛特的牛仔競爭精神。矽谷的測試甚至感覺不像教科書中描述的無性經濟那樣乾淨，而更像是一場適者生存的達爾文式鬥爭。許多公司倒閉，財富流失，數萬名員工被解雇。像英特爾和美光這樣的公司之所以幸存下來，不僅僅是因為他們的工程技術（雖然這很重要），而是因為他們能夠利用技術上的才能，在一個極度競爭和不容情的行業中賺錢。

Yet Silicon Valley’s rebirth isn’t solely a story of heroic entrepreneurs and creative destruction. Alongside the rise of these new industrial titans, a new set of scientists and engineers were preparing a leap forward in chipmaking and devising revolutionary new ways to use processing power. Many of these developments occurred in coordination with government efforts, usually not the heavy hand of Congress or the White House, but the work of small, nimble organizations like DARPA that were empowered to take big bets on futuristic technologies—and to build the educational and R&D infrastructure that such gambles required.

然而，硅谷的复兴不仅仅是英雄企业家和创造性毁灭的故事。随着这些新兴工业巨头的崛起，一批新的科学家和工程师正在准备迈向芯片制造的飞跃，并设计出革命性的处理能力新方式。其中许多发展是与政府的努力协调进行的，通常不是国会或白宫的重手，而是像DARPA

这样的小型敏捷组织的工作，它们有权对未来技术进行大赌注，并构建这种冒险所需的教育和研发基础设施。

Competition from Japan’s high-quality, low-cost DRAM chips wasn’t the only problem Silicon Valley faced in the 1980s. Gordon Moore’s famous law predicted exponential growth in the number of transistors on each chip, but this dream was getting ever more difficult to realize. Through the late 1970s, many integrated circuits had been designed by the same process Intel’s Federico Faggin used to produce the first microprocessor. In 1971, Faggin had spent half a year crouched over his drafting table, sketching the design with Intel’s most advanced tools: a straightedge and color pencils. Then, this design was cut into Rubylith, a red film, using a penknife. A special camera projected the patterns carved in Rubylith onto a mask, a glass plate with a chrome covering that perfectly replicated the Rubylith’s pattern. Finally, light was shined through the mask and a set of lenses to project a tiny version of the pattern on a silicon wafer. After months of sketching and carving, Faggin had created a chip.

日本高品質，低成本的DRAM晶片所帶來的競爭並不是硅谷在80年代所面臨的唯一問題。戈登·摩尔的著名定律預測晶片上的晶體管數量呈指數級增長，但這一夢想越來越難實現。直到1970年代末期，許多集成電路都是使用Intel的費德里科·法金用來生產第一顆微處理器的過程設計的。在1971年，法金用Intel最先進的工具：一把直尺和彩色鉛筆花費了半年時間趴在草稿桌上設計了這款產品。然後，這個設計使用軟刮刀切成了一塊紅色薄膜Rubylith。一台特殊的相機將Rubylith上雕刻的圖案投射到一個光罩上，這個光罩是一個玻璃板，上面有一層鉻。最後，光經過這個光罩和一組透鏡被投射到矽晶片的一個微小版本上。經過幾個月的設計和雕刻，法金創造了一個晶片。

The problem was, while pencils and tweezers were adequate tools for an integrated circuit with a thousand components, something more sophisticated was needed for a chip with a million transistors. Carver Mead, the goateed physicist who was a friend of Gordon Moore, was puzzling over this dilemma when he was introduced to Lynn Conway, a computer architect at Xerox’s Palo Alto Research Center, where the concept of the personal computer with a mouse and a keyboard was just then being invented.

Conway was a brilliant computer scientist, but anyone who spoke with her discovered a mind that glistened with insights from diverse fields, astronomy to anthropology to historical philosophy. She had arrived at Xerox in 1973 in "stealth mode," she explained, following being fired from IBM in 1968 after undergoing a gender transition. She was shocked to find that the Valley's chipmakers were more like artists than engineers. High-tech tools were paired with simple tweezers. Chipmakers produced marvelously complex patterns on each block of silicon, but their design methods were those of medieval artisans. Each company's fab (fabrication plant) had a long, complicated, proprietary set of instructions for how chips must be designed if they were to be produced in that specific facility. Conway, whose training as a computer architect had taught her to think in terms of the standardized instructions on which any computer program is built, found this method bizarrely backward.

问题在于，虽然铅笔和镊子对于具有一千个元件的集成电路来说是足够的工具，但对于具有一百万个晶体管的芯片来说，需要更复杂的工具。戈登·摩尔的好友、留着山羊胡子的物理学家卡弗·米德在思考这个困境时，认识了林恩·康威，她是施乐帕罗奥多研究中心的计算机架构师，当时正发明个人电脑配备鼠标和键盘的概念。 康威是一位才华横溢的计算机科学家，但每个与她交谈的人都会发现她的头脑闪烁着各种领域的见解，从天文学到人类学再到历史哲学。她于1973年"隐蔽模式"下来到施乐，她解释说，这是在1968年进行性别转换后被IBM解雇后的结果。她震惊地发现，硅谷的芯片制造商更像艺术家而不是工程师。高科技工具和简单的镊子配对使用。芯片制造商在每个硅块的每个区块上制造出令人惊叹的复杂图案，但他们的设计方法是中世纪手工艺人的那种。每个公司的制造工厂都有一套漫长而复杂的专有指令，说明如果要在该特定设施中生产芯片，必须如何进行设计。作为一名计算机架构师，康威的培训教她按照任何计算机程序所建立的标准化指令思考，她发现这种方法非常落后。

Conway realized that the digital revolution Mead prophesied needed algorithmic rigor. After she and Mead were introduced by a mutual colleague, they began discussing how to standardize chip design. Why couldn't you program a machine to design circuits, they wondered. "Once you can write a program to do something," Mead declared, "you don't need anybody's tool kit, you write your own."

Conway and Mead eventually drew up a set of mathematical “design rules,” paving the way for computer programs to automate chip design. With Conway and Mead’s method, designers didn’t have to sketch out the location of each transistor but could draw from a library of “interchangeable parts” that their technique made possible. Mead liked to think of himself as Johannes Gutenberg, whose mechanization of book production had let writers focus on writing and printers on printing. Conway was soon invited by MIT to teach a course on this chip design methodology. Each of her students designed their own chips, then shipped the design to a fabrication facility for manufacturing. Six weeks later, having never stepped foot in a fab, Conway’s students received fully functioning chips in the mail. The Gutenberg moment had arrived.

康威意识到梅德所预言的数字革命需要算法的严谨性。在一位共同的同事介绍下，她和梅德开始讨论如何标准化芯片设计。他们想知道为什么不能编写一个程序来设计电路。梅德宣称：“一旦你能写一个程序来完成某事，你就不需要任何人的工具包，你可以编写自己的程序。”康威和梅德最终拟定了一套数学的“设计规则”，为计算机程序自动化芯片设计铺平了道路。使用康威和梅德的方法，设计师不需要手绘每个晶体管的位置，而是可以从其技术可能实现的“可互换零件”库中选择。梅德喜欢想象自己是约翰内斯·古腾堡，他的书籍生产机制使作家可以专注于写作，印刷工人可以专注于印刷。MIT随后邀请康威教授有关该芯片设计方法的课程。每位学生都设计自己的芯片，然后将设计发送到制造工厂进行制造。在六周后，康威的学生们从未进入制造工厂就在邮件中收到了完全正常运行的芯片，这个古腾堡时刻已经到来。

No one was more interested in what soon became known as the “Mead-Conway Revolution” than the Pentagon. DARPA financed a program to let university researchers send chip designs to be produced at cutting-edge fabs. Despite its reputation for funding futuristic weapons systems, when it came to semiconductors DARPA focused as much on building educational infrastructure so that America had an ample supply of chip designers. DARPA also helped universities acquire advanced computers and convened workshops with industry officials and academics to discuss research problems over fine wine. Helping companies and professors keep Moore’s Law alive, DARPA reasoned, was crucial to America’s military edge.

沒有人對後來被稱為“梅德 - 康威革命”的事情比五角大樓更感興趣。DARPA資助了一個計畫，讓大學研究人員可以將芯片設計發送到尖端晶圓廠進行生產。盡管DARPA以資助未來主義武器系統而聞名，但在半導體方面，DARPA同樣注重建立教育基礎架構，以便美國擁有充足的晶片設計師。 DARPA還幫助大學獲得先進的計算機，並召開工作坊，與行業官員和學者討論研究問題，並享受美酒。 DARPA認為，幫助公司和教授保持摩爾定律的活力對美國的軍事優勢至關重要。

The chip industry also funded university research on chip design techniques, establishing the Semiconductor Research Corporation to distribute research grants to universities like Carnegie Mellon and the University of California, Berkeley. Over the 1980s, a cadre of students and faculty from these two universities founded a series of startups that created a new industry—software tools for semiconductor design—that had never previously existed. Today, every chip company uses tools from each of three chip design software companies that were founded and built by alumni of these DARPA- and SRC-funded programs.

芯片行业还资助了关于芯片设计技术的大学研究，成立了半导体研究公司，向卡内基梅隆大学和加州大学伯克利分校等大学分发研究经费。在20世纪80年代，来自这两所大学的一批学生和教授创立了一系列初创企业，创造了一个新的行业——半导体设计的软件工具，这是以前从未存在过的。今天，每家芯片公司都使用三家芯片设计软件公司的工具，这三家公司由这些得到DARPA和SRC资助的计划的校友创立和建立。

DARPA also backed researchers studying a second set of challenges: finding new uses for chips’ growing processing power. Irwin Jacobs, an expert in wireless communication, was one such researcher. Born in Massachusetts to a family of restaurant owners, Jacobs had planned to follow his parents into the hospitality industry before falling in love with electrical engineering. He spent the 1950s playing around with vacuum tubes and IBM calculators. While pursuing his master’s degree at MIT, Jacobs studied antennas and electromagnetic theory and decided to focus his research on information theory—the study of how information can be stored and communicated.

DARPA也支持研究第二组挑战：寻找芯片日益增长的处理能力的新用途。无线通信专家Irwin Jacobs就是这样一位研究人员。Jacobs出生在麻省一个餐厅家庭，原本计划跟随父母进入酒店行业，后来却爱上了电子工程学。他在20世纪50年代玩弄真空管和IBM计算器。在麻省理工学院攻读硕士学位时，Jacobs研究了天线和电磁理论，决定将他的研究重心放在信息理论上，即如何存储和传输信息的研究。

Radios had been transmitting wirelessly for decades, but the demands for wireless communication were growing and spectrum space was limited. If you wanted a radio station at 99.5 FM, you had to ensure there wasn't one at 99.7 already, or the interference would make yours incomprehensible. The same principle applied to other forms of radio communication. The more information that was packed into a given slice of spectrum, the less room there was for error created by muddled signals bouncing off buildings and interfering with each other as they careened through airspace toward a radio receiver.

收音機已經無線傳輸了幾十年，但對無線通信的需求正在增加，而頻譜空間有限。如果你想要在99.5 FM擁有一個無線電台，你必須確保99.7還沒有一個，否則干擾會使你的無線電台變得難以理解。類似的原則也適用於其他形式的無線通信。隨著越來越多的信息被打包到一個給定的頻譜區域中，就越沒有容錯的空間，這是由於混亂的信號撞擊建築物和相互干擾，在空中碰撞並向無線電接收器運動所造成的。

Jacobs's longtime University of California, San Diego, colleague Andrew Viterbi had devised a complex algorithm in 1967 to decode a messy set of digital signals reverberating through noisy airwaves. It was praised by scientists as an excellent piece of theory, but Viterbi's algorithm seemed difficult to use in practice. The idea that normal radios would ever have the computing power to run complicated algorithms seemed implausible.

In 1971, Jacobs flew to St. Petersburg, Florida, to attend a conference of academics working on communications theory. Many of the professors had glumly concluded that their scholarly subfield—encoding data into radio waves—had reached its practical limits. The radio spectrum could only hold a limited number of signals before they became impossible to sort and interpret. Viterbi's algorithms provided a theoretical way to pack more data into the same radio spectrum, but no one had the computing power to apply these algorithms at scale. The process of sending data through the air seemed to have hit a wall. “Coding is dead,” one professor declared.

Jacob的長期合作夥伴，加州大學聖地牙哥分校的同事Andrew Viterbi在1967年設計了一種複雜的算法，用於解碼在嘈雜的空氣波中回響的一組數字信號。科學家們贊揚這是一個出色的理論，但Viterbi的算法在實際應用中似乎很難使用。正常的收音機永遠不可能擁有運行複雜算法的計算能力，這一想法似乎不可行。 1971年，Jacobs飛往佛羅里達州聖彼得堡市參加一個通信理論學者的會議。許多教授沮喪地得出結論：他們學術子領域——將數據編碼成無線電波已經達到了其實際限制。無線電頻譜只能容納有限數量的信號，否則就無法進行分類和解讀。Viterbi的算法提供了一種在同一無線電頻譜中打包更多數據的理論方法，但沒有人擁有在大規模應用這些算法的計算能力。發送數據的過程似乎已經碰到了瓶頸。「編碼已死」，一位教授宣稱。

Jacobs completely disagreed. Standing up from the back row, he held aloft a small chip and declared: “ This is the future.” Chips, Jacobs realized, were improving so rapidly that they’d soon be able to encode orders of magnitude more data in the same spectrum space. Because the number of transistors on a square inch of silicon was increasing exponentially, the amount of data that could be sent through a given slice of the radio spectrum was about to take off, too.

Jacobs, Viterbi, and several colleagues set up a wireless communications business called Qualcomm—quality communications—betting that ever-more-powerful microprocessors would let them stuff more signals into existing spectrum bandwidth. Jacobs initially won contracts from DARPA and NASA to build space communications systems. In the late 1980s, Qualcomm diversified into the civilian market, launching a satellite communications system for the trucking industry. But even by the early 1990s, using chips to send large quantities of data through the air seemed like a niche business.

雅各布斯完全不同意。他从后排站起来，举起一个小芯片，宣布：“这是未来”。雅各布斯意识到，芯片发展非常迅速，很快就能在相同的频谱空间内编码更多数据。由于每平方英寸硅上的晶体管数量呈指数增

长，能够通过给定的无线电频谱切片发送的数据量也将开始腾飞。 雅各布斯、维特比和几位同事创立了一家名为高通（Qualcomm）的无线通信企业，打赌更强大的微处理器会让他们将更多信号塞入现有频谱带宽中。雅各布斯最初赢得了来自DARPA和NASA的合同，用于构建太空通信系统。在1980年代末，高通开始向民用市场扩展业务，为卡车行业推出了卫星通信系统。但即使在1990年代初期，使用芯片通过空气发送大量数据似乎也只是一个细分领域的事业。

For a professor-turned-entrepreneur like Irwin Jacobs, DARPA funding and Defense Department contracts were crucial in keeping his startups afloat. But only some government programs worked. Sematech's effort to save America's lithography leader was an abject failure, for example. Government efforts were effective not when they tried to resuscitate failing firms, but when they capitalized on pre-existing American strengths, providing funding to let researchers turn smart ideas into prototype products. Members of Congress would no doubt have been furious had they learned that DARPA—ostensibly a defense agency—was wining and dining professors of computer science as they theorized about chip design. But it was efforts like these that shrank transistors, discovered new uses for semiconductors, drove new customers to buy them, and funded the subsequent generation of smaller transistors. When it came to semiconductor design, no country in the world had a better innovation ecosystem. By the end of the 1980s, a chip with a million transistors—unthinkable in the early 1970s, when Lynn Conway had arrived in Silicon Valley—had become a reality, when Intel announced its 486 microprocessor, a small piece of silicon packed with 1.2 million microscopic switches.

对于像欧文·雅各布斯这样从教授转型为企业家的人来说，DARPA的资助和国防部的合同对于维持他的初创公司至关重要。但只有一些政府项目真正奏效。例如，Sematech的挽救美国的光刻领袖的努力是一个彻底的失败。政府的努力在尝试挽救失败企业时是无效的，但它们通过利用现有的美国优势，向研究人员提供资金来让他们将聪明的想法转化为原型产品时是有效的。如果国会议员们得知DARPA——表面上是国防机构——在酒宴上招待计算机科学教授们，让他们在理论上探讨芯片设计，无疑会感到愤怒。但正是这样的努力缩小了晶体管，为半导体发现了新的用途，推动新的客户购买它们，并资助了下一代更小的晶体管的发展。就半导体设计而言，世界上没有哪个国家具有

更好的创新生态系统。到了1980年代末，一款拥有一百万个晶体管的芯片——当琳恩·康威抵达硅谷时，在20世纪70年代初还是难以想象的——成为现实，因为英特尔宣布了其486微处理器，一个充满了120万个微小开关的小硅片。

CHAPTER 25 The KGB's Directorate T

V ladimir Vetrov was a KGB spy, but his life felt more like a Chekhov story than a James Bond film. His KGB work was bureaucratic, his mistress far from a supermodel, and his wife more affectionate toward her shih tzu puppies than toward him. By the end of the 1970s, Vetrov's career, and his life, had hit a dead end. He despised his desk job and was ignored by his bosses. He detested his wife, who was having an affair with one of his friends. For recreation, he escaped to his log cabin in a village north of Moscow, which was so rustic that there was no electricity. Or he'd simply stay in Moscow and get drunk.

弗拉基米尔·维特罗夫是一名克格勃间谍，但他的人生更像是契诃夫的故事，而不是一部詹姆斯·邦德的电影。他的克格勃工作是官僚主义的，他的情妇远非超模，他的妻子对她的狮子狗比对他更亲热。到了1970年代末，维特罗夫的职业生涯和生活已经走到了死胡同。他憎恨他的办公室工作，被他的上司忽视。他憎恨他的妻子，她正在和他的一个朋友有染。作为娱乐，他逃到位于莫斯科北部村庄的原始木屋，那里没有电。或者他会简单地留在莫斯科，喝醉了。

Vetrov's life hadn't always been so dull. In the early 1960s, he'd earned a plum foreign posting in Paris, where as a "foreign trade official" he was tasked with gathering secrets from France's high-tech industries, per Minister Shokin's "copy it" strategy. In 1963, the same year the USSR established Zelenograd, the city of scientists working on microelectronics, the KGB established a new division, Directorate T, which stood for *teknologia* . The mission: "acquire Western equipment and technology," a CIA report warned, " and improve its ability to produce integrated circuits."

维特罗夫的生活并不总是这么平淡无奇。在1960年代初，他在外交部门获得了一份珍贵的巴黎驻外职务，作为一名"外贸官员"，他的任务是从法国高科技产业中收集情报，履行着部长肖金的"抄袭"战略。1963年，也是苏联成立研究微电子科学的科学城市谢连格勒的同一年，克格勃成立了一个名为T局的新部门，代表的是"技术"。任务

是“获取西方设备和技术”，CIA报告警告说，“并提高其生产集成电路的能力。”

In the early 1980s, the KGB reportedly employed around one thousand people to steal foreign technology. Around three hundred worked at foreign posts, with most of the rest on the eighth floor of the KGB’s imposing headquarters on Moscow’s Lubyanka Square, sitting atop the Stalin-era prison and torture chambers. Other Soviet intelligence services, like the military’s GRU, also had spies who focused on technology theft. The Soviet consulate in San Francisco reportedly had a team of sixty agents targeting the tech firms of Silicon Valley. They stole chips directly and bought them from the black market, supplied by thieves like the man called “One Eyed Jack,” who was caught in California in 1982 and accused of stealing chips from an Intel facility by hiding them in his leather jacket. Soviet spies also blackmailed Westerners with access to advanced technology. At least one British employee of a UK computer company living in Moscow died after “falling” from the window of his high-rise apartment building.

根据报道，在20世纪80年代初，克格勃雇佣了大约一千人来窃取外国技术。其中约三百人在外国岗位工作，其余大部分则在克格勃壮观的总部楼的八楼，坐落在莫斯科卢比扬卡广场上方，它是斯大林时代的监狱和酷刑室的顶部。像军方的军事情报局（GRU）这样的其他苏联情报机构也有专注于技术窃取的间谍。据报道，苏联在旧金山的领事馆有一个由60名特工组成的团队，专门针对硅谷的科技公司。他们直接窃取芯片，或从黑市购买，由像“独眼杰克”这样的窃贼提供，他于1982年在加利福尼亚被捕，并因在英特尔工厂偷窃芯片并将其藏在皮夹克中被指控。苏联间谍还勒索那些能够接触先进技术的西方人。至少有一名在莫斯科生活的英国计算机公司雇员因“跌落”高层公寓大楼而遇害。

Spying continued to play a fundamental role in Soviet semiconductors, as a group of Rhode Island fishermen discovered after pulling a strange metallic buoy out of the waters of the North Atlantic in fall 1982. They hadn’t expected to pick up advanced chips in their haul. When the mysterious buoy was sent to a military lab, however, it was identified as a Soviet listening device that used perfect replicas of Texas Instruments Series 5400 semiconductors. After Intel commercialized the microprocessor, meanwhile, Minister Shokin shut down a Soviet research unit trying to produce a similar device, in favor of copying American microprocessors.

諜報在蘇聯半導體產業中繼續扮演一個基礎性的角色，這在1982年秋季時一群羅德島漁民所發現的故事中有所體現。他們拉上了一個奇怪的金屬浮標，沒有想到會發現進階晶片。這個神秘的浮標被送到軍事實驗室進行檢驗，結果被確認為一個使用了完美複製德州儀器系列5400半導體的蘇聯聽裝置。與此同時，當英特爾商用化微處理器之後，修建部長什金關閉了一個試圖制造類似裝置的蘇聯研究單位，轉而複製美國的微處理器。

However, the “copy it” strategy was far less successful than Soviet surveillance buoys suggested. It was easy enough to steal a couple examples of Intel’s latest chips, or even to have an entire shipment of integrated circuits diverted to the USSR, usually via shell companies in neutral Austria or Switzerland. However, American counterintelligence occasionally unmasked the USSR’s agents operating in third countries, so this was never a reliable source of supply.

Stealing chip designs was only useful if they could be produced at scale in the USSR. This was difficult to do during the early Cold War but almost impossible by the 1980s. As Silicon Valley crammed more transistors onto silicon chips, building them became steadily harder. The KGB thought its campaign of theft provided Soviet semiconductor producers with extraordinary secrets, but getting a copy of a new chip didn’t guarantee Soviet engineers could produce it. The KGB began stealing semiconductor manufacturing equipment, too. The CIA claimed that the USSR had acquired nearly every facet of the semiconductor manufacturing process, including nine hundred Western machines for preparing materials needed for semiconductor fabrication; eight hundred machines for lithography and etching; and three hundred machines each for doping, packaging, and testing chips.

然而，“照搬策略”比苏联监测浮标所示的成功率低得多。窃取英特尔最新芯片的几个样本或者甚至将整批集成电路通过在中立国家奥地利或瑞士的壳公司转移至苏联似乎是很容易的。然而，美国反情报机构偶尔会揭穿在第三国家操作的苏联特工，因此这从未是一个可靠的供

应来源。只有当苏联能够大规模生产芯片设计时，窃取芯片设计才有用。在早期的冷战时期，这很难做到，但到了20世纪80年代几乎是不可能的。硅谷在芯片上压缩了更多的晶体管，制造芯片变得越来越困难。克格勃认为，他们的窃取活动为苏联半导体生产商提供了非凡的机密，但获取新芯片的副本并不能保证苏联工程师能够生产它们。克格勃开始窃取半导体制造设备。中央情报局声称，苏联已经获得了几乎所有半导体制造过程的方面，其中包括900台西方机器，用于准备半导体制造所需的材料;800台光刻和蚀刻机器;每种掺杂、封装和测试芯片的300台机器。

However, a factory needed a full suite of equipment, and when machines broke down, they needed spare parts. Sometimes spare parts for foreign machines could be produced in the USSR, but this introduced new inefficiencies and defects. The system of theft and replication never worked well enough to convince Soviet military leaders they had a steady supply of quality chips, so they minimized the use of electronics and computers in military systems.

It took time for the West to realize the scale of the theft. When the KGB first sent Vetrov to Paris in 1965, Directorate T was all but unknown. Vetrov and his colleagues worked undercover, often as employees of the Soviet Ministry of Foreign Trade. When Soviet agents visited foreign research labs, befriended executives, and tried to siphon the secrets of foreign industry, it looked as if they were simply conducting their “day job” as foreign trade officials.

然而，一家工厂需要一套完整的设备，当机器损坏时，他们需要备件。有时候，外国机器的备件可以在苏联生产，但这会引入新的低效率和缺陷。盗窃和复制的系统从来没有足够地运行好，以使苏联军事领导者相信他们拥有稳定的高质量芯片供应，因此他们将电子和计算机在军事系统中的使用最小化。 西方花费了很长一段时间才意识到这种盗窃的规模。当KGB在1965年第一次派遣维特罗夫前往巴黎时，T局几乎是无名的。维特罗夫和他的同事们秘密工作，常常扮演苏联外贸部的员工。当苏联特工参观外国研究实验室，结交高管，并试图获取外国工业的机密时，看起来好像他们只是在执行他们的“工作日”。

The operations of Directorate T might have remained a state secret had Vetrov not decided to add intrigue to his otherwise dull existence upon moving back to Moscow. By the early 1980s, his career had stalled, his marriage was ruined, and his life was falling apart. He was a spy like James Bond, but with more desk work and fewer martinis. He decided to make life more interesting by sending a postcard to a Parisian acquaintance who, he knew, was connected with the French intelligence services.

Soon Vetrov was passing dozens of documents about Directorate T to his French handler in Moscow. French intelligence code-named him “Farewell.” In total, he appears to have provided thousands of pages of documents from the heart of the KGB, unveiling a vast bureaucracy focused on stealing Western industrial secrets. A key priority: “advanced microprocessors,” for which the Soviet Union lacked not only skilled engineers but also the software needed to design cutting-edge processors and the equipment needed to produce them. Western spies were shocked at just how much the Soviets stole.

如果没有维特罗夫决定在返回莫斯科后增添一些神秘感，总局T的行动可能还是国家机密。到了20世纪80年代初，他的职业生涯停滞不前，婚姻也破裂了，生活变得零乱不堪。他像詹姆斯邦德一样是个间谍，但更多的是桌面工作，少了马提尼鸡尾酒。他决定通过给一位同巴黎人有关联的熟人寄明信片来让生活变得更有趣。这位熟人与法国情报机构有联系。 不久，维特罗夫就开始向他的法国处理者传递关于总局T的数十份文件。法国情报以他的一个化名“告别”来代号。综合来看，他似乎向心脏部位的KGB提交了数千页文件，揭露了一个致力于窃取西方工业机密的巨大官僚机构。一个关键的优先事项:“先进的微处理器”，苏联不仅没有熟练的工程师，而且还缺少设计尖端处理器所需的软件和生产所需的设备。西方间谍对苏联窃取的数量感到震惊。

In his routine of rendezvousing with French agents Vetrov had found a new activity, but he hadn’t found fulfillment. The French provided him with gifts from abroad, to keep Vetrov’s mistress happy, yet what Vetrov really wanted was for his wife to love him. He grew ever more delusional. On February 22, 1982, having told his son he planned to break off the relationship with his mistress, Vetrov stabbed her repeatedly in his car while parked along Moscow’s ring road. Only after he was apprehended by police did the KGB realize Vetrov had betrayed his country and handed the secrets of Directorate T to Western intelligence.

在与法国特工会面的常规中，维特洛夫找到了一种新的活动，但他并没有找到满足感。法国人通过提供国外的礼物来让维特洛夫的情妇感到高兴，但维特洛夫真正想要的是他妻子的爱。他变得越来越妄想。1982年2月22日，维特洛夫告诉儿子他计划结束与情妇的关系，在停在莫斯科环路边的车内多次刺伤了她。只有在他被警方逮捕后，克格勃才意识到维特洛夫背叛了他的国家，并将T局的机密交给了西方情报机构。

The French quickly shared information about Vetrov with U.S. and other allied intelligence services. The Reagan administration responded by launching Operation Exodus, which tightened customs checks on advanced technology. By 1985, the program had seized around $600 million worth of goods and resulted in around one thousand arrests. However, when it came to semiconductors, the Reagan administration's claim to have stopped the "massive hemorrhage of American technology to the Soviet Union" probably overstated the impact of tighter controls. The USSR's "copy it" strategy had actually benefitted the United States, guaranteeing the Soviets faced a continued technological lag. In 1985, the CIA conducted a study of Soviet microprocessors and found that the USSR produced replicas of Intel and Motorola chips like clockwork. They were always half a decade behind.

法國迅速與美國和其他盟國的情報服務機構分享了有關維特羅夫的信息。里根政府采取了行動進行流亡行動，收緊高科技產品的海關檢查。到1985年，該計劃已經查獲了價值約6億美元的貨物，並導致了大約1000人的逮捕。然而，就半導體而言，里根政府聲稱已經停止了"大量技術流失到蘇聯"的主張可能夸大了更多。蘇聯的"模仿"策略實際上使美國受益，確保了蘇聯繼續面臨技術滯后。 1985年，中央情報局對蘇聯微處理器進行了研究，發現蘇聯生產出英特爾和摩托羅拉芯片的複製品如時鐘般穩定。他們總是落后于半個世紀。

CHAPTER 26 “Weapons of Mass Destruction” : The Impact of the Offset

“ L ong-range, highly accurate, terminally guided combat systems, unmanned flying machines, and qualitatively new electronic control systems,” Soviet Marshal Nikolai Ogarkov predicted, would transform conventional explosives into “weapons of mass destruction.” Ogarkov served as chief of the general staff of the Soviet military from 1977 to 1984. In the West, he was most famous for leading the media offensive after the Soviets accidentally shot down a civilian airliner from South Korea in 1983. Rather than admit a mistake, he accused the plane’s pilots of being on a “deliberate, thoroughly planned intelligence mission” and declared that the airliner was “asking for it.” This wasn’t a message likely to win Ogarkov any friends in the West, but that was likely of little consequence to him since his life purpose was preparing for war with the United States.

苏联元帅尼古拉·奥加尔科夫预测，“远程、高精度、终端制导的战斗系统、无人机和全新的电子控制系统”将把常规炸药转化为“大规模杀伤性武器”。奥加尔科夫自1977年到1984年任苏联军队参谋长。在西方，他最著名的是在1983年苏联意外击落一架韩国民航客机事件后，领导媒体攻势。他没有承认错误，而是指责这架飞机的飞行员进行“有计划、计划周密的情报任务”，并宣称这架客机是“在招摇”。这并不是一个能赢得奥加尔科夫在西方任何朋友的信息，但对他来说也许毫无影响，因为他的生命目标是为与美国的战争做准备。

The Soviet Union had kept up with the Americans in the race to develop the crucial technologies of the early Cold War, building powerful rockets and a formidable nuclear stockpile. Now brawn was being replaced by computerized brains. When it came to the silicon chips undergirding this new driver of military power, the Soviet Union had fallen hopelessly behind. One popular Soviet joke from the 1980s recounted a Kremlin official who declared proudly, “Comrade, we have built the world’s biggest microprocessor!”

蘇聯在早期的冷戰競賽中與美國鏖戰，發展出強大的火箭和可怕的核庫存。現在，強壯的肌肉被計算機化的腦袋所取代。當談到支撐這種新軍事力量的矽晶片時，蘇聯已經落后得毫無救贖。一個流行的蘇聯笑話從1980年代開始就傳說著一名克里姆林宮的官員自豪地宣布：“同志們，我們已經建造了世界上最大的微處理器！”

By traditional metrics like numbers of tanks or troops, the Soviet Union had a clear advantage in the early 1980s. Ogarkov saw things differently: quality was overtaking quantity. He was fixated on the threat posed by America’s precision weapons. Combined with better surveillance and communication tools, the ability to strike targets accurately hundreds or even thousands of miles away was producing a “military-technical revolution,” Ogarkov argued to anyone who’d listen. The days of vacuum tube−guided Sparrow missiles missing 90 percent of their targets in the skies over Vietnam were long gone. The Soviet Union had many more tanks than the United States, but Ogarkov realized his tanks would soon be many times more vulnerable in a fight with the U.S.

以传统的坦克或部队数量为指标，苏联在80年代初显然具有明显的优势。然而，奥加尔科夫的看法则截然不同：质量已经超过了数量。他对美国精确武器构成的威胁着迷。加上更好的监视和通信工具，能够精确打击数百甚至数千英里外的目标正在产生“军事技术革命”，奥加尔科夫向任何愿意听的人阐述。在越南空中，真空管制导麻雀导弹的失靶率达到了90％，但那是很久以前的事了。苏联拥有更多的坦克比美国，但奥加尔科夫意识到在与美国作战时，他的坦克很快将比以前更加脆弱。

Bill Perry’s “offset strategy” was working, and the Soviet Union didn’t have a response. It lacked the miniaturized electronics and computing power that American and Japanese chipmakers produced. Zelenograd and other Soviet chipmaking facilities couldn’t keep up. Whereas Perry pushed the Pentagon to embrace Moore’s Law, the inadequacies of Soviet chipmaking taught the country’s weapons designers to limit use of complex electronics whenever possible. This was a viable approach in the 1960s, but by the 1980s this unwillingness to keep pace with advances in microelectronics guaranteed Soviet systems would remain “dumb” even as American weapons were learning to think. The U.S. had put a guidance computer powered by Texas

Instruments' chips onboard the Minuteman II missile in the early 1960s, but the Soviets' first missile guidance computer using integrated circuits wasn't tested until 1971.

比尔·佩里的"平衡策略"正在奏效，而苏联却没有应对措施。它缺乏美国和日本芯片制造商所生产的微型电子和计算能力。谢列诺格拉德和其他苏联芯片制造工厂无法跟上步伐。佩里推动五角大楼接受摩尔定律，而苏联芯片制造的不足则教导了该国武器设计师尽可能限制复杂电子的使用。这在20世纪60年代是一种可行的方法，但到了20世纪80年代，不愿跟上微电子领域的进步使苏联系统即使美国武器正在学会思考，仍然保持"笨拙"。美国早在20世纪60年代在"民兵II"导弹上装有德克萨斯仪器芯片驱动的制导计算机，但苏联的第一台使用集成电路的导弹制导计算机直到1971年才进行测试。

Accustomed to low-quality microelectronics, Soviet missile designers devised elaborate workarounds. Even the mathematics they plugged into their guidance computers was simpler, to minimize the strain on the onboard computer. Soviet ballistic missiles were generally told to follow a specific flight path toward their target, with the guidance computer adjusting the missile to put it back on the preprogrammed route if it deviated. By contrast, by the 1980s, American missiles calculated their own path to the target.

熟悉低质量微电子技术的苏联导弹设计师想出了精巧的解决方案。他们插入导引计算机的数学公式也更简单，以将对机载计算机的压力最小化。苏联弹道导弹通常被告知沿着朝向目标的特定飞行路径前进，导引计算机会根据需要调整导弹，让其回到预设的路线上，如有偏差。相对而言，在20世纪80年代，美国导弹会自行计算到达目标的路径。

By the mid-1980s, America's new MX missile was publicly estimated to land within 364 feet of its target 50 percent of the time. A roughly comparable Soviet missile, the SS-25, on average fell within twelve hundred feet of its target, according to estimates from a former Soviet defense official. In the grim logic of Cold War military planners, a difference of several hundred feet mattered hugely. It was easy enough to destroy a city, but both superpowers wanted the ability to knock out each other's nuclear arsenals. Even nuclear warheads needed a reasonably direct hit to disable a hardened missile silo. Enough direct hits, and one side could potentially compromise the adversary's nuclear forces in a surprise first strike. The most pessimistic Soviet estimates suggested that if the U.S. launched a nuclear first strike in the 1980s, it could have disabled or destroyed 98 percent of Soviet ICBMs.

到了20世纪80年代中期，美国的新MX导弹被公开估计能在50%的时间内准确落在目标周边的364英尺(约110.9米)范围内。根据一名前苏联国防官员的估算，一枚大致相当的苏联导弹SS-25平均落在目标周边1200英尺(约365.8米)的范围内。在冷战军事规划者的残酷逻辑中，几百英尺的差距是非常重要的。毁灭一个城市是很容易的，但是两个超级大国都想要摧毁对方的核武库。即使核弹头也需要相当直接的打击来使硬化的导弹发射井失去作战能力。足够多的直接打击，一方就有可能在突然袭击中削弱对手的核力量。最悲观的苏联估计表明，如果美国在1980年代发动核突袭，它可能已经失去了98%苏联洲际弹道导弹的作战能力或摧毁了它们。

The USSR didn't have any margin for error. The Soviet military had two other systems that could launch a nuclear attack on America: long-range bombers and missile submarines. Bomber fleets were widely agreed to be the weakest delivery system because they could be identified by radar shortly after taking off and shot down before launching their nuclear weapons. America's nuclear missile submarines, by contrast, were practically undetectable and therefore invincible. Soviet submarines were less secure, because the U.S. was learning to apply computing power to make its submarine detection systems far more accurate.

前蘇聯沒有任何錯誤的餘地。蘇聯軍隊還有其他兩個系統可以對美國發動核攻擊：遠程轟炸機和導彈潛艇。轟炸機飛行中很容易被雷達發現和擊落，因此被普遍認為是最弱的運輸系統。相比之下，美國的核導彈潛艇則幾乎不可被探測，因此無敵。蘇聯的潛艇安全性較低，因為美國正在學習應用計算技術，使其潛艇檢測系統變得更加準確。

The challenge in finding a submarine is to make sense of a cacophony of sound waves. Sound bounces off the seafloor at different angles and refracts differently through water depending on the temperature or the presence of schools of fish. By the early 1980s it was publicly admitted that the U.S. had plugged its submarine sensors into the Illiac IV, one of the most powerful supercomputers and the first using semiconductor memory chips, which were built by Fairchild. Illiac IV and other processing centers were connected via satellite to an array of sensors on ships, planes, and helicopters to track Soviet subs, which were highly vulnerable to American detection.

找到潛艇的挑戰是將一連串聲波的嘈雜聲音變得有意義。聲音在海底反彈時會以不同的角度反射，並且因水溫或魚群存在而經過不同的折射。到1980年代初，美國公開承認將其潛艇感測器連接到Illiac IV，這是最強大的超級計算機之一，並且是使用Fairchild製造的半導體記憶體晶片的第一台。Illiac IV和其他處理中心通過衛星與船舶、飛機和直升機上的一系列感測器相連接，以追蹤蘇聯潛艇，這些潛艇對美國的檢測非常脆弱。

When Ogarkov ran the numbers, he concluded that America's semiconductor-powered advantage in missile accuracy, antisubmarine warfare, surveillance, and command and control could enable a surprise strike to threaten the survivability of the Soviet nuclear arsenal. Nukes were supposed to be the ultimate insurance policy, but the Soviet military now felt "substantially inferior in strategic weapons," as one general put it.

Soviet military leaders feared a conventional war, too. Military analysts previously thought the Soviets' superiority in numbers of tanks and troops provided a decisive advantage in a conventional war. However, the Paveway bomb first used over Vietnam had been supplemented by a suite of new guided systems. Tomahawk cruise missiles could strike deep into Soviet territory. Soviet defense planners feared American conventionally armed cruise missiles and stealth bombers could disable Soviet command and control over their nuclear forces. The challenge threatened the very survival of the Soviet state.

當奧加科夫計算完之後，他得出結論：美國在導彈精度、反潛戰、監視和指揮控制方面的半導體優勢，能夠實現突然襲擊，威脅蘇聯核武庫的生存能力。 核武器被認為是最終的保險政策，但蘇聯軍方現在感到"在戰略武器方面明顯劣於美國"，如一位將軍所說。 蘇聯軍事領袖也擔憂常規戰爭。之前的軍事分析師認為，蘇聯在坦克和部隊數量上的優勢給常規戰爭帶來了決定性的優勢。然而，越戰時期首次使用的

Paveway炸彈已經得到了一系列新的引導系統的補充。 Tomahawk巡航導彈可以深入蘇聯領土。蘇聯防衛規劃者擔心美國裝備常規武器的巡航導彈和隱形轟炸機可以使蘇聯對其核力量的指揮控制癱瘓。這一挑戰威脅著蘇聯國家的生存。

The Kremlin wanted to revitalize its microelectronics industry but didn’t know how to do so. In 1987, Soviet leader Mikhail Gorbachev visited Zelenograd and called for “more discipline” in the city’s work. Discipline was part of Silicon Valley’s success, evident in Charlie Sporck’s fixation on productivity and Andy Grove’s paranoia. However, discipline alone couldn’t solve the Soviets’ basic problems.

One issue was political meddling. In the late 1980s, Yuri Osokin was removed from his job at the Riga semiconductor plant. The KGB had demanded that he fire several of his employees, one of whom had mailed letters to a woman in Czechoslovakia, a second who refused to work as an informant for the KGB, and a third who was a Jew. When Osokin refused to punish these workers for their “crimes,” the KGB ousted him and tried to have his wife fired, too. It was hard enough to design chips in normal times. Doing so while battling the KGB was impossible.

克里姆林宫想要振兴其微电子产业，但不知道如何才能做到。1987年，苏联领导人米哈伊尔·戈尔巴乔夫访问了捷列诺格勒，并呼吁该市的工作更加严格。纪律是硅谷成功的一部分，如查理·斯波克关注生产力和安迪·格鲁夫的偏执狂证明的那样。然而，光靠纪律无法解决苏联基本的问题。 一个问题是政治干涉。在1980年代末，尤里·奥索金在里加半导体工厂被解雇。克格勃要求他解雇几名员工，其中一名向捷克斯洛伐克的妇女寄信，第二名拒绝为克格勃当线人，第三名是犹太人。当奥索金拒绝因这些员工的"罪行"来处罚他们时，克格勃将其驱逐，并试图让他的妻子也被解雇。在正常情况下设计芯片已经很难，而在与克格勃的斗争中设计芯片就更加不可能了。

A second issue was overreliance on military customers. The U.S., Europe, and Japan had booming consumer markets that drove chip demand. Civilian semiconductor markets helped fund the specialization of the semiconductor supply chain, creating companies with expertise in everything from ultra-pure silicon wafers to the advanced optics in lithography equipment. The Soviet

Union barely had a consumer market, so it produced only a fraction of the chips built in the West. One Soviet source estimated that Japan alone spent eight times as much on capital investment in microelectronics as the USSR.

第二个问题是过度依赖军方客户。美国、欧洲和日本有繁荣的消费市场推动了芯片需求。民用半导体市场帮助资助了半导体供应链的专业化，打造出了从超纯硅晶圆到光刻设备先进光学技术等方方面面均具专业水平的公司。苏联几乎没有消费市场，因此只生产了西方芯片产量的一小部分。一位苏联消息人士估计仅日本一国就在微电子资本投资上花费了苏联八倍的金额。

A final challenge was that the Soviets lacked an international supply chain. Working with America’s Cold War allies, Silicon Valley had forged an ultra-efficient globalized division of labor. Japan led the production of memory chips, the U.S. produced more microprocessors, while Japan’s Nikon and Canon and the Netherland’s ASML split the market for lithography equipment. Workers in Southeast Asia conducted much of the final assembly. American, Japanese, and European companies jostled over their position in this division of labor, but they all benefitted from the ability to spread R&D costs over a far larger semiconductor market than the USSR ever had.

最后一个挑战是苏联没有一个国际供应链。硅谷与美国的冷战盟友合作，建立了一个超级高效的全球化分工体系。日本主导了存储芯片的生产，美国生产更多的微处理器，而日本的尼康和佳能以及荷兰的ASML共同分担了光刻设备市场。东南亚的工人完成了很多最后的装配工作。美国、日本和欧洲的公司互相争夺在这个分工体系中的位置，但是他们都从能够将研发成本扩展到比苏联更大的半导体市场中受益。

The USSR had only a handful of allies, most of whom weren’t much help. Soviet-dominated East Germany, which had a chip industry as advanced as Zelenograd, made a last-ditch effort in the mid-1980s to revitalize its semiconductor sector, drawing on a long tradition of precision manufacturing as well as world-leading optics produced by the Carl Zeiss company in the city of Jena. East German chip output grew rapidly in the late 1980s, but the industry was only able to produce memory chips less advanced than Japan’s, at ten times the price. Advanced Western manufacturing equipment remained hard to access, while East Germany had none of the cheap labor that Silicon Valley firms hired across Asia.

蘇聯只有幾個盟友，其中大部分沒什麼幫助。蘇聯控制的東德在1980年代中期做出了最後的努力，試圖重振其半導體產業，利用精密制造的傳統以及卡爾·蔡司公司在耶拿市生產的世界領先光學技術。東德的晶片產量在1980年代後期迅速增長，但該行業只能生產不如日本先進的記憶體晶片，且價格是日本的十倍。先進的西方製造設備仍然難以獲得，而東德沒有像硅谷公司在亞洲聘請的廉價勞動力。

The Soviet Union’s effort to reinvigorate its chipmakers failed completely. Neither the Soviets nor their socialist allies could ever catch up, despite vast espionage campaigns and huge sums poured into research facilities like those in Zelenograd. And just as the Kremlin’s response to Bill Perry’s “offset” was beginning to sputter out, the world was given a terrifying glimpse of the future of war on the battlefields of the Persian Gulf.

蘇聯重振其芯片制造商的努力完全失败了。儘管進行了大規模的間諜活動並投入了大量款項來建立像澤倫諾格勒這樣的研究設施，但蘇聯及其社會主義盟友始終無法追趕。正當克林姆林宮對比爾·佩里的“抵消”反應開始喪失動力時，世界在波斯灣戰場上看到了未來戰爭的可怕預覽。

CHAPTER 27 War Hero

E arly in the morning on January 17, 1991, the first wave of American F-117 stealth bombers took off from their airbases in Saudi Arabia, their black airframes quickly disappearing in the dark desert sky. Their target: Baghdad. The United States hadn't fought a major war since Vietnam, but now it had several hundred thousand troops along Saudi Arabia's northern border, tens of thousands of tanks awaiting orders to storm forward, dozens of naval ships positioned offshore, their guns and missile batteries aimed at Iraq. The American general leading the assault, Norman Schwarzkopf, was an infantryman by training, having served two tours in Vietnam. This time, he was trusting in stand-off weapons to deliver the first strike.

1991年1月17日清晨，第一批美國F-117隱形轟炸機從沙特阿拉伯的空軍基地起飛，它們的黑色機身在黑暗的沙漠天空中迅速消失。目標是巴格達。自越南戰爭以來，美國從未參與過大規模戰爭，但現在有數十萬名士兵部署在沙特阿拉伯的北部邊境，數以萬計的坦克在等待前進的命令，幾十艘海軍艦艇在海岸線外部署，它們的炮塔和導彈炮口瞄準伊拉克。領導這次攻擊的美國將軍諾曼·史瓦茲科夫曾在越南服役兩次，是一名步兵。這一次，他信任遠程武器發動第一波攻擊。

The twelve-story tall telephone exchange building on Baghdad's Rashid Street was the only target deemed important enough to be attacked by two F-117s. General Schwarzkopf's war plan depended on it being destroyed, knocking out part of Iraq's communications infrastructure. The two planes homed in on their target, releasing two-thousand-pound Paveway laser-guided bombs that tore through the facility and set it aflame. Suddenly the TV feed of CNN's reporters in Baghdad went dark. Schwarzkopf's pilots had scored a hit. Almost simultaneously, 116 Tomahawk cruise missiles fired from naval ships offshore slammed into their targets in and around Baghdad. The Persian Gulf War had begun.

巴格达的拉希德街上有一幢十二层高的电话交换建筑，这是唯一一个被认为重要到足以被两架F-117攻击的目标。施瓦茨科夫将军的战争计划取决于它被摧毁，破坏伊拉克的通信基础设施。两架飞机定位到目

标，释放了两枚2000磅的Paveway激光制导炸弹，撕裂了这个设施并点燃了它。CNN在巴格达记者的电视信号突然中断，施瓦茨科夫的飞行员得分。几乎同时，116枚从近海的军舰上发射的战斧巡航导弹猛烈袭击了巴格达及周边目标。波斯湾战争已经开始了。

A communications tower, a military command post, air force headquarters, power stations, and Saddam Hussein's country retreat—the first U.S. airstrikes sought to decapitate the Iraqi leadership and cut their communications, limiting their ability to track the war or communicate with their forces. Soon their military was in a disorganized retreat. CNN broadcast videos of hundreds of bombs and missiles striking Iraqi tanks. Warfare looked like a video game. But watching from Texas, Weldon Word knew this futuristic technology actually dated to the Vietnam War.

一座通信塔，一个军事指挥所，空军总部，发电站和萨达姆·侯赛因的乡间别墅——第一次美国空袭旨在肢解伊拉克领导层并切断其通讯，限制其跟踪战争或与其军队通讯的能力。很快，他们的军队开始疲惫不堪。CNN广播了数百枚炸弹和导弹击中伊拉克坦克的视频。战争看起来像一个电子游戏。但是，在德克萨斯州观看的韦尔登·沃德知道这种未来派技术实际上可以追溯到越南战争。

The Paveway laser-guided bombs that slammed into Baghdad's telephone exchange used the same basic system design as the first generation of Paveways that destroyed the Thanh Hoa Bridge in 1972. Those were built with a handful of transistors, a laser sensor, and a couple of wings strapped to an old "dumb" bomb. By 1991, Texas Instruments had updated the Paveway multiple times, with each new version replacing existing circuitry with more advanced electronics, reducing the number of components, increasing reliability, and adding new features. By the start of the Persian Gulf War, the Paveway had become the military's weapon of choice for the same reason Intel's microprocessors were used across the computer industry: they were widely understood, easy to use, and cost-effective. Paveways were always cheap, but they got cheaper over the course of the 1970s and 1980s. Thanks to their low cost, every pilot had dropped Paveways in training exercises. And they were highly versatile, too. Targets didn't need to be selected in advance but could be chosen on the battlefield. The hit rates, meanwhile, were almost as good as they looked on TV. Air Force studies conducted after the war found that non-precision munitions were far less accurate than pilots often claimed, while precision munitions like the Paveway bombs actually did better than claimed. Planes using laser guidance for their bomb strikes hit thirteen times as many targets as comparable planes without guided munitions.

引爆了巴格达电话交换中心的Paveway激光制导炸弹使用了与1972年摧毁Thanh Hoa大桥的第一代Paveways相同的基本系统设计。那些炸弹是用一些晶体管，一个激光感应器和几对翅膀装在一个旧“哑弹”上制成的。到1991年，得克萨斯仪器公司已经多次升级了Paveway，每一个新版本都用更先进的电子元件替换现有的电路、减少元件数量、增加可靠性并添加新特性。到波斯湾战争开始时，由于与英特尔微处理器一样得到广泛理解、易于使用且成本效益高，Paveway已成为军方的首选武器。Paveway一直很便宜，但在70年代和80年代的过程中越来越便宜。由于价格低廉，每位飞行员在训练中都使用过Paveway。它们也极其灵活。不需要预先选择目标，而可在战场上选择。同时，击中率几乎和电视上看到的一样好。战后美国空军的研究发现，非精密武器比飞行员宣称的要不准确得多，而像Paveway炸弹这样的精密武器实际上超过了预期。使用激光制导进行轰炸的飞机的目标打击率是没有精确制导弹药的可比飞机的13倍。

U.S. airpower proved decisive in the Persian Gulf War, decimating Iraqi forces while minimizing U.S. casualties. Weldon Word received an award for inventing the Paveway, improving its electronics, and driving down its cost so that each one was never more expensive than a jalopy, just as he had originally promised. It took several decades for people outside the U.S. military to realize how the Paveway and other weapons like it were changing war. But pilots who used these bombs knew just how transformative they were. “There are about ten thousand Americans who didn’t get killed because of you guys,” an Air Force officer told Word at the Pentagon award ceremony. Advanced microelectronics and a set of wings strapped to a bomb had transformed the nature of military power.

美國空軍在波斯灣戰爭中發揮了決定性作用，消滅伊拉克軍隊，同時將美國軍方的傷亡最小化。魏爾登·沃德因發明Paveway裝置、改進其電子設備並降低其成本，使每個裝置的價格再不比一輛破爛的車便宜，如他最初所承諾的一樣，而獲得獎項。數十年後，國外人士才意

識到Paveway和其他類似武器如何改變戰爭的本質。但使用這些炸彈的飛行員卻深刻知曉它們的重要性。空軍軍官在五角大廈的頒獎典禮上對沃德表示："因為你們，大約有一萬名美國人得以幸存。"先進的微型電子學和一對綁在炸彈上的翅膀已經改變了軍事力量的本質。

As Bill Perry watched the Persian Gulf War unfold, he knew laser-guided bombs were just one of dozens of military systems that had been revolutionized by integrated circuits, enabling better surveillance, communication, and computing power. The Persian Gulf War was the first major test of Perry's "offset strategy," which had been devised after the Vietnam War but never deployed in a sizeable battle.

In the years after Vietnam, the U.S. military had talked about its new capabilities, but many people didn't take them seriously. Military leaders like General William Westmoreland, who commanded American forces in Vietnam, promised that future battlefields would be automated. But the Vietnam War had gone disastrously despite America's wide technological advantage over the North Vietnamese. So why would more computing power change things? America's military mostly sat in its barracks during the 1980s, except for a few small operations against third-rate opponents like Libya and Grenada. No one was sure how the Pentagon's advanced gadgets would perform on real battlefields.

當比爾·佩里觀看波斯灣戰爭進行時，他知道激光制導炸彈只是數十種經過集成電路革新的軍事系統之一，使得監察、通信和計算能力得以提高。波斯灣戰爭是佩里的"抵消策略"的第一次重大考驗，這一策略是在越南戰爭之後制定的，但從未在一場大規模戰役中部署過。 在越戰之後的幾年裡，美國軍方一直在談論著它的新能力，但許多人並沒有將它們認真看待。像指揮美軍在越南的威廉·韋斯特摩蘭等軍事領袖承諾未來戰場將是自動化的，但是越戰儘管美國在技術上擁有廣泛的優勢，卻失敗了。那麼更多的計算能力會改變什麼呢？在20世紀80年代，美國的軍隊主要待在自己的營房裡，除了對利比亞和格林納達等第三等級的對手進行了一些小規模行動外，沒有人確定五角大樓的先進裝備在現實戰場上會表現如何。

Videos of Iraqi buildings, tanks, and airfields being destroyed by precision weapons made it impossible to deny: the character of war was changing.

Even the vacuum tube–powered Sidewinder air-to-air missiles that had missed most of their targets above Vietnam were now upgraded with more powerful, semiconductor-based guidance systems. They were six times as accurate in the Persian Gulf War as in Vietnam.

The new technologies Perry had pushed the Pentagon to develop during the late 1970s performed even beyond his expectations. The Iraqi military—armed with some of the best equipment the Soviet Union's defense industry produced—was helpless in the face of the American assault. "High-tech works," Perry proclaimed. "What's making all this work is weapons based on information instead of the volume of fire power," one military analyst explained to the media. "It's the triumph of silicon over steel," declared a *New York Times* headline. "War Hero Status Possible for the Computer Chip," read another.

伊拉克建筑物、坦克和机场被精准武器摧毁的视频让人无法否认：战争的性质正在发生变化。即使在越南，真空管动力的"走火"空对空导弹也错过了大部分目标，如今它们也升级为拥有更强大的半导体制导系统。在海湾战争中，它们的精度是越南战争时的六倍。 佩里在1970年代末推动五角大楼开发的新技术甚至超出了他的期望。装备苏联防卫工业生产的最佳装备的伊拉克军队在美国的攻势面前无能为力。"高科技奏效"，佩里宣称。"使所有这些奏效的是基于信息而不是火力量的武器，"一名军事分析家向媒体解释说。"这是硅胜过钢的胜利，"一篇《纽约时报》的标题如是说。"电脑芯片可能成为战争英雄"，另一篇如是说。

The reverberations from the explosions of Paveway bombs and Tomahawk missiles were felt as powerfully in Moscow as in Baghdad. The war was a "technological operation," one Soviet military analyst declared. It was "a struggle over the airwaves," another said. The result— Iraq's easy defeat—was exactly what Ogarkov had predicted. Soviet Defense Minister Dmitri Yazov admitted the Gulf War made the Soviet Union nervous about its air defense capabilities. Marshal Sergey Akhromeyev was embarrassed after his predictions of a protracted conflict were promptly disproven by Iraq's speedy surrender. CNN videos of American bombs guiding themselves through the sky and slamming through the walls of Iraqi buildings proved Ogarkov's forecasts about the future of war.

在莫斯科和巴格达同样强烈地感受到了碧寇炸弹和战斧导弹爆炸所带来的反响。其中一位苏联军事分析师认为，这场战争是一次“技术行动”，另一个则表示，这是一场“对广播波的斗争”。结果——伊拉克轻松被击败——正是奥加尔科夫预测的。苏联国防部长德米特里·亚佐夫承认，海湾战争让苏联对其防空能力感到不安。正如伊拉克迅速投降所证明的那样，谢尔盖·阿赫罗梅耶夫元帅的代表性预测遭到了反驳，这使他感到非常尴尬。美国炸弹自己引导穿过伊拉克建筑物的天空，并猛然撞穿了伊拉克建筑物的CNN视频证实了奥加尔科夫对于战争未来的预测。

CHAPTER 28 “The Cold War Is Over and You Have Won”

S ony’s Akio Morita had spent the 1980s jetting around the world, dining with Henry Kissinger, golfing at Augusta National, hobnobbing with other global elites in groups like the Trilateral Commission. He was treated as a business oracle and a representative of Japan—the world’s rising economic power—on the global stage. Morita found “Japan as Number One” easy to believe in because he was personally living it. Thanks to Sony’s Walkman and other consumer electronics, Japan had become prosperous and Morita had gotten rich.

索尼的盛田昭夫在1980年代周游世界，与亨利·基辛格进餐，在奥古斯塔国家高尔夫俱乐部打高尔夫球，与其他全球精英在三边委员会等团体中来往。他被视为商业先知和日本代表——世界上崛起的经济大国——在全球舞台上。盛田昭夫觉得“日本第一”很容易相信，因为他个人正在亲身体验这一点。由于索尼的随身听和其他消费电子产品，日本变得繁荣起来，而盛田昭夫也变得富有。

Then in 1990 crisis hit. Japan’s financial markets crashed. The economy slumped into a deep recession. Soon the Tokyo stock market was trading at half its 1990 level. Real estate prices in Tokyo fell even further. Japan’s economic miracle seemed to screech to a halt. Meanwhile, America was resurgent, in business and in war. In just a few short years, “Japan as Number One” no longer seemed very accurate. The case study in Japan’s malaise was the industry that had been held up as exemplary of Japan’s industrial prowess: semiconductors.

然后在1990年，危机来临。日本的金融市场崩盘，经济陷入深度衰退。不久之后，东京股市交易的水平只有1990年的一半。东京的房地产价格甚至跌得更低。日本经济奇迹似乎停滞了。与此同时，美国在商业和战争方面又崛起了。短短几年时间，“日本第一”似乎已经不再准确。日本萎靡不振的案例是曾经被视为日本工业实力典范的半导体行业。

Morita, now sixty-nine years old, watched Japan's fortunes decline alongside Sony's slumping stock price. He knew his country's problems cut deeper than its financial markets. Morita had spent the previous decade lecturing Americans about their need to improve production quality, not focus on "money games" in financial markets. But as Japan's stock market crashed, the country's vaunted long-term thinking no longer looked so visionary. Japan's seeming dominance had been built on an unsustainable foundation of government-backed overinvestment. Cheap capital had underwritten the construction of new semiconductor fabs, but also encouraged chipmakers to think less about profit and more about output. Japan's biggest semiconductor firms doubled down on DRAM production even as lower cost producers like Micron and South Korea's Samsung undercut Japanese rivals.

69歲的森田一直以來目睹著日本的財富和索尼的股價一起下降。他知道自己的國家問題根深蒂固，不僅局限於金融市場。森田在過去十年中一直教導美國人需要改善生產品質，而不是把重點放在金融市場的"賭博"上。但是隨著日本股市崩盤，該國的長期思維不再看起來那麼具有遠見。日本的表面優勢是建立在政府支持的過度投資基礎上的。廉價的資本支持了新半導體廠房的建設，但也促使芯片製造商不再把重心放在利潤上，而是更注重產量。日本最大的半導體公司在低成本生產商如美光和韓國的三星打破日本競爭對手的情況下，仍然專注於DRAM生產的倍增。

Japan's own media perceived overinvestment in the semiconductor sector, with newspaper headlines warning of "reckless investment competition" and "investment they cannot stop." CEOs of Japan's memory chip producers couldn't bring themselves to stop building new chip fabs, even if they weren't profitable. "If you start worrying" about overinvestment, one Hitachi executive admitted, "you can't sleep at night." So long as banks kept lending, it was easier for CEOs to keep spending than to admit they had no path to profitability. America's arm's-length capital markets hadn't felt like an advantage in the 1980s, but the risk of losing financing helped keep American firms on their toes. Japanese DRAM makers would have benefitted from Andy Grove's paranoia or Jack Simplot's wisdom about commodity market volatility. Instead, they all poured investment into the same market, guaranteeing that few made much money.

日本自己的媒體認為在半導體領域過度投資，警惕報紙標題警告“魯莽的投資競爭”和“不可停止的投資”。即使創造出來的晶片不盈利，日本的記憶芯片生產商CEO仍無法停止建造新的晶片廠。一位日立公司的高管坦言，“如果你开始担心”过度投资，“你将无法安睡”。只要银行继续贷款，对于CEO们来说，他们更容易花钱而不是承认他们没有盈利的道路。在20世纪80年代，美国的机构资本市场并不像现在这样有利可图，但是丧失财务支持的风险有助于使美国公司保持警惕。日本的DRAM制造商将从Andy Grove的偏执狂或Jack Simplot关于商品市场波动的智慧中受益。相反，他们都将投资倾注在同一个市场，确保只有少数人赚了很多钱。

Sony, which was unique among Japanese semiconductor firms in never betting heavily on DRAMs, succeeded in developing innovative new products, like specialized chips for image sensors. When photons strike their silicon, these chips create electric charges that are correlated to the strength of the light, letting the chips convert images into digital data. Sony was therefore well placed to lead the digital camera revolution, and the company’s chips that sense images today remain world-class. Even still, the company failed to cut investment in loss-making segments, and its profitability slumped beginning in the early 1990s.

索尼是日本半导体公司中唯一从未重点投资DRAM的公司，成功地开发了创新的新产品，如专门的图像传感器芯片。当光子击中它们的硅时，这些芯片会产生与光强相关的电荷，使芯片能够将图像转换成数字数据。因此，索尼很有前途带领数码相机革命，公司今天感测图像的芯片仍然是世界一流的。然而，该公司未能削减亏损部门的投资，其盈利能力从上世纪90年代初开始下降。

Most of Japan’s big DRAM producers, however, failed to take advantage of their influence in the 1980s to drive innovation. At Toshiba, a DRAM giant, a mid-ranking factory manager named Fujio Masuoka developed a new type of memory chip in 1981 that, unlike DRAM, could continue “remembering” data even after it was powered off. Toshiba ignored this discovery, so it was Intel that brought this new type of memory chip, commonly called “flash” or NAND, to market.

The biggest error that Japan's chip firms made, however, was to miss the rise of PCs. None of the Japanese chip giants could replicate Intel's pivot to microprocessors or its mastery of the PC ecosystem. Only one Japanese firm, NEC, really tried, but it never won more than a tiny share of the microprocessor market. For Andy Grove and Intel, making money on microprocessors was a matter of life or death. Japan's DRAM firms, with massive market share and few financial constraints, ignored the microprocessor market until it was too late. As a result, the PC revolution mostly benefitted American chip firms. By the time Japan's stock market crashed, Japan's semiconductor dominance was already eroding. In 1993, the U.S. retook first place in semiconductor shipments. In 1998, South Korean firms had overtaken Japan as the world's largest producers of DRAM, while Japan's market share fell from 90 percent in the late 1980s to 20 percent by 1998.

然而，大部分日本的DRAM生产商，并未利用他们在20世纪80年代的影响力来推动创新。作为DRAM巨头的东芝，一名中层工厂经理名叫增岡藤夫在1981年开发了一种新型存储芯片，与DRAM不同，它可以记住数据，即使断电也不会丢失。然而东芝忽视了这一发现，因此是英特尔将这种新型存储芯片，通常称为"闪存"或"NAND"，带到市场的。 然而，日本芯片公司犯下的最大错误是错过了PC的兴起。日本芯片巨头中没有一家能复制英特尔向微处理器的转变或其掌握的PC生态系统。只有一家日本公司NEC真正尝试了，但它从未赢得微处理器市场的更多份额。对于安迪·格鲁夫和英特尔来说，赚取微处理器的钱是生死存亡的问题。拥有巨大的市场份额和少量财务限制的日本DRAM公司，忽视了微处理器市场，直到为时已晚。因此，PC革命主要使美国芯片公司受益。当日本股市崩溃时，日本的半导体主导地位已经受到侵蚀。在1993年，美国重新夺回了半导体出货量第一的位置。在1998年，韩国公司已超过日本成为世界上最大的DRAM生产商，而日本的市场份额从20世纪80年代末期的90％下降到1998年的20％。

Japan's semiconductor ambitions had underwritten the country's expanding sense of its global position, but this foundation now looked brittle. In *The Japan That Can Say No* , Ishihara and Morita had argued Japan could use chip dominance to exert power over both the United States and the USSR. But when war finally came, in the unexpected arena of the Persian Gulf, American military might astounded most observers. In the first war of the digital era, Japan declined to join the twenty-eight countries that sent troops to the Gulf to eject Iraqi forces from Kuwait. Instead, Tokyo participated by sending checks to pay for coalition armies and to support Iraq's neighbors. As American Paveway laser-guided bombs pummeled Iraqi tank columns, this financial diplomacy looked impotent.

日本的半导体野心曾经支持着该国对其全球地位的不断扩张，但这个基础现在看起来已经脆弱不堪。在《能说不的日本》一书中，石原慎太郎和森田恒郎曾经认为，日本可以利用芯片主导地位来对美国和苏联施加压力。但当战争最终爆发在波斯湾这个意想不到的领域时，美国的军事实力让大多数观察者惊叹不已。在数字时代的第一场战争中，日本拒绝加入那二十八个向波斯湾派出军队将伊拉克军队赶出科威特的国家中。相反，东京通过向军事联盟提供支票和支持伊拉克的邻国来参与。当美国的Paveway激光制导炸弹轰炸伊拉克坦克列时，这种金融外交看起来毫无作为能力。

Morita suffered a stroke in 1993 that caused debilitating health problems. He retreated from public view and spent most of the remainder of his life in Hawaii, before dying in 1999. Morita's coauthor, Ishihara, kept insisting that Japan needed to assert itself on the world stage. Like a broken record, he published *The Asia That Can Say No* in 1994 followed by *The Japan That Can Say No Again* several years later. But to most Japanese, Ishihara's argument no longer made sense. In the 1980s, he'd been right to predict chips would shape the military balance and define the future of technology. But he was wrong to think those chips would be made in Japan. The country's semiconductor firms spent the 1990s shrinking in the face of America's resurgence. The technological basis for Japan's challenge to American hegemony began to crumble.

森田在1993年中風，導致身體健康極度受損。他隱居了公共視野，餘生大部分時間都在夏威夷度過，於1999年去世。森田的合作者石原則卻不斷強調日本需要在世界舞台上發揮作用。他像唱片機一樣，於1994年發表《能夠說不的亞洲》後又過了幾年，又出版了《能夠再次說不的日本》。但對大多數日本人來說，石原的論點已不再合理。在1980年代，他對預測芯片將形成軍事平衡和定義未來技術的觀點是正確的。但他錯誤地認為這些芯片會在日本製造。日本的半導體公司在

美國重新崛起的壓力下，在1990年代開始縮小。日本挑戰美國霸權的技術基礎開始崩潰。

The only other serious challenger to the United States, meanwhile, was careening toward collapse. In 1990, having recognized that efforts to overcome technological backwardness via command methods and the “copy it” strategy were hopeless, Soviet leader Mikhail Gorbachev arrived in Silicon Valley for an official visit. The city’s tech tycoons treated him with a feast fit for a tsar. David Packard and Apple’s Steve Wozniak sat alongside Gorbachev as he was wined and dined. Gorbachev made no secret of why he chose to visit California’s Bay Area. “The ideas and technologies of tomorrow are born here in California,” he declared in a speech at Stanford. This was exactly what Marshal Ogarkov had been warning his fellow Soviet leaders of for over a decade.

然而，唯一另一个认真挑战美国的国家却正在走向崩溃。1990年，苏联领袖米哈伊尔·戈尔巴乔夫认识到通过命令方式和“抄袭”战略克服技术落后是没希望的后，他来到了硅谷进行官方访问。该市的科技巨头们举行了一场适合沙皇的盛宴招待他。David Packard和苹果公司的Steve Wozniak与戈尔巴乔夫坐在一起，一起享受了美酒佳肴。在斯坦福大学的演讲中，戈尔巴乔夫毫不掩饰他为什么选择访问加利福尼亚湾区的原因：“未来的思想和技术在加利福尼亚州诞生”，这正是Ogarkov元帅在十年前一直向苏联领导层发出的警告。

Gorbachev promised to end the Cold War by withdrawing Soviet troops from Eastern Europe, and he wanted access to American technologies in exchange. Meeting with America’s tech executives, he encouraged them to invest in the USSR. When Gorbachev visited Stanford University, he high-fived spectators as he walked around campus. “The Cold War is now behind us,” the Soviet leader told an audience at Stanford. “Let’s not wrangle over who won it.”

But it was obvious who won, and why. Ogarkov had identified the dynamic a decade earlier, though at the time he hoped the USSR might overcome it. Like the rest of the Soviet military leadership, he’d grown more pessimistic over time. As early as 1983, Ogarkov had gone so far as to tell American journalist Les Gelb—off the record—that “the Cold War is over and you have won.” The Soviet Union’s rockets were as powerful as ever. It had the world’s largest nuclear arsenal. But its semiconductor production couldn’t keep up, its computer industry fell behind, its communications and surveillance technologies lagged, and the military consequences were disastrous. “All modern military capability is based on economic innovation, technology, and economic strength,” Ogarkov explained to Gelb. “Military technology is based on computers. You are far, far ahead of us with computers…. In your country, every little child has a computer from age 5.”

戈尔巴乔夫承诺通过从东欧撤回苏联军队来结束冷战，他希望换取美国技术的使用权。在与美国科技行业高管会面时，他鼓励他们在苏联投资。当戈尔巴乔夫访问斯坦福大学时，他与围观群众击掌称庆。苏联领袖在斯坦福的演讲中对观众说：“冷战已经过去了，让我们不要争论谁赢了它。”但赢家和原因显而易见。虽然奥加尔科夫十年前就已经确定了这一动态，但他当时还希望苏联能够克服它。就像苏联军队其他领导人一样，他随着时间的推移变得更加悲观。早在1983年，奥加尔科夫就曾私下告诉美国记者莱斯·吉尔布：“冷战结束了，你们赢了。”苏联的火箭依然强大。它拥有世界上最大的核武库。但是它的半导体生产跟不上，其计算机产业落后，其通信和监控技术也滞后，军事后果是灾难性的。奥加尔科夫向吉尔布解释道：“所有现代军事能力都基于经济创新、技术和经济实力。军事技术基于计算机。你们在计算机方面远远领先于我们……在你们国家，每个小孩从5岁起就有一台电脑。”

After the easy defeat of Saddam Hussein’s Iraq, America’s vast new fighting power was visible to everyone. This caused a crisis in the Soviet military and the KGB, who were embarrassed yet afraid to admit how decisively they were outgunned. The security chiefs led a demoralized coup attempt against Gorbachev that sputtered out after three days. It was a pathetic end for a once-powerful country, which couldn’t come to terms with the painful decline in its military power. The Russian chip industry faced humiliation of its own, with one fab reduced in the 1990s to producing tiny chips for McDonald’s Happy Meal toys. The Cold War was over; Silicon Valley had won.

在萨达姆·侯赛因的伊拉克轻松被击败后，美国庞大的新军事力量被所有人看到。这引起了苏联军方和克格勃的危机，他们感到尴尬却又害

怕承认他们被打败了。安全部门领导了一次士气低落的政变，但在三天后就无力继续了。这是一个曾经强大的国家的可悲结局，它无法接受其军事实力痛苦的衰落。俄罗斯芯片工业也面临着自己的耻辱，其中一个生产基地在1990年代被降级为生产麦当劳Happy Meal玩具的微小芯片。冷战结束了，硅谷赢得了胜利。

PART V

INTEGRATED CIRCUITS, INTEGRATED WORLD?

CHAPTER 29 “We Want a Semiconductor Industry in Taiwan”

I n 1985, Taiwan’s powerful minister K. T. Li called Morris Chang into his office in Taipei. Nearly two decades had passed since Li had helped convince Texas Instruments to build its first semiconductor facility on the island. In the twenty years since then, Li had forged close ties with Texas Instrument’s leaders, visiting Pat Haggerty and Morris Chang whenever he was in the U.S. and convincing other electronics firms to follow TI and open factories in Taiwan. In 1985, he hired Chang to lead Taiwan’s chip industry. “We want to promote a semiconductor industry in Taiwan,” he told Chang. “Tell me,” he continued, “how much money you need.”

1985年，台灣強大的李先生在臺北的辦公室裡召募了張忠謀。自從李先生協助說服德州儀器在島上建造其第一個半導體設施已經過去了近20年。自那時以來，李先生已經與德州儀器的領導人建立了密切的聯繫，每當他在美國時，就會拜訪派特·哈格蒂和張忠謀，並說服其他電子公司跟隨德州儀器在台灣開設工廠。1985年，他聘請張忠謀來領導台灣的晶片產業。他告訴張忠謀：“我們想在台灣推廣半導體產業。告訴我，你需要多少錢。”

The 1990s were the years when the word “globalization” first became commonly used, though the chip industry had relied on international production and assembly since the earliest days of Fairchild Semiconductor. Taiwan had deliberately inserted itself into semiconductor supply chains since the 1960s, as a strategy to provide jobs, acquire advanced technology, and to strengthen its security relationship with the United States. In the 1990s, Taiwan’s importance began to grow, driven by the spectacular rise of the Taiwan Semiconductor 164Manufacturing Company, which Chang founded with strong backing from the Taiwanese government.

九十年代是「全球化」一詞變得普遍使用的年代，不過晶片產業從費爾柴德半導體時代起就一直依賴國際生產和組裝。台灣自六十年代開始有意將自己融入半導體供應鏈，作為提供就業、取得先進技術和加強與美國安全關係之策略。在九十年代，台灣的重要性開始增長，其

中又以張忠謀領導並得到台灣政府的大力支持所創立的台積電公司崛起最為矚目。

When Chang was hired by Taiwan's government in 1985 to lead the country's preeminent electronics research institute, Taiwan was one of Asia's leaders in assembling semiconductor devices—taking chips made abroad, testing them, and attaching them to plastic or ceramic packages. Taiwan's government had tried breaking into the chipmaking business by licensing semiconductor manufacturing technology from America's RCA and founding a chipmaker called UMC in 1980, but the company's capabilities lagged far behind the cutting edge. Taiwan boasted plenty of semiconductor industry jobs, but captured only a small share of the profit, since most money in the chip industry was made by firms designing and producing the most advanced chips. Officials like Minister Li knew the country's economy would keep growing only if it advanced beyond simply assembling components designed and fabricated elsewhere.

當張正忠於1985年被台灣政府聘請領導該國頂級電子研究機構時，台灣是亞洲在組裝半導體器件方面的領袖之一，將國外製造的晶片進行測試，然後將其附著在塑料或陶瓷封裝上。台灣政府曾試圖通過從美國RCA獲得半導體製造技術的許可和成立一家名為UMC的晶片製造商來進入晶片製造行業，但該公司的能力遠落後於尖端。台灣擁有豐富的半導體產業就業機會，但由於大多數芯片行業的利潤由設計和生產最先進的芯片的公司獲得，因此只佔很小的份額。像李部長這樣的官員知道，如果台灣的經濟僅停留在裝配由其他地方設計和製造的零部件方面，它的經濟將只會繼續增長。

When Morris Chang had first visited Taiwan in 1968, the island was competing with Hong Kong, South Korea, Singapore, and Malaysia. Now Samsung and South Korea's other big conglomerates were pouring funds into the most advanced memory chips. Singapore and Malaysia were trying to replicate South Korea's shift from assembling semiconductors to fabricating them, though with less success than Samsung. Taiwan had to improve its capabilities constantly simply to maintain its position in the bottom rungs of the semiconductor supply chain.

當張忠謀於1968年首次訪問臺灣時，島嶼正與香港、韓國、新加坡和馬來西亞競爭。現在，三星和韓國的其他大型企業正在向最先進的存儲器芯片注入資金。新加坡和馬來西亞正在試圖複製韓國從半導體裝配到製造的轉變，但效果不如三星。臺灣必須不斷提高能力，僅僅為了維持其在半導體供應鏈底層的位置。

The biggest threat was the People’s Republic of China. Across the Taiwan Strait, Mao Zedong had died in 1976, reducing the threat of imminent invasion. But China now posed an economic challenge. Under its new, post-Mao leadership, China began integrating into the global economy by attracting some of the basic manufacturing and assembly jobs that Taiwan had used to lift itself out of poverty. With lower wages and several hundred million peasants eager to trade subsistence farming for factory jobs, China’s entry into electronics assembly threatened to put Taiwan out of business. It amounted to economic “warfare,” Taiwanese officials complained to visiting Texas Instruments executives. It was impossible to compete with China on price. Taiwan had to produce advanced technology itself.

最大的威脅來自中華人民共和國。在臺灣海峽對岸，毛澤東於1976年去世，緩和了即將發生入侵的威脅。但現在中國帶來了經濟上的挑戰。在新的后毛時代領導層下，中國開始融入全球經濟體系，吸引了一些基礎制造和組裝工作，這些工作曾經幫助臺灣擺脫貧困。擁有較低的工資和幾億渴望從農業轉入工廠工作的農民，中國的進入對電子組裝行業構成威脅，可能會讓臺灣經濟破產。臺灣官員向到訪的德州儀器高層抱怨，這相當于經濟“戰爭”。臺灣無法在價格上與中國競爭，必須自己生產先進技術。

K. T. Li turned to the person who’d first helped bring semiconductor assembly to Taiwan: Morris Chang. After over two decades with Texas Instruments, Chang had left the company in the early 1980s after being passed over for the CEO job and “put out to pasture,” he’d later say. He spent a year running an electronics company in New York called General Instrument, but resigned soon after, dissatisfied with the work. He’d personally helped build the world’s semiconductor industry. TI’s ultra-efficient manufacturing processes were the result of his experimentation and expertise in improving yields. The job he’d wanted at TI—CEO—would have placed him at the top of the chip industry, on par with Bob Noyce or Gordon Moore. So when the government of Taiwan called, offering to put him in charge of the island’s chip industry and providing a blank check to fund his plans, Chang found the offer intriguing. At age fifty-four, he was looking for a new challenge.

李國鼎求助於將半導體裝配引入臺灣的第一人：張忠謀。在德州儀器（Texas Instruments）工作了二十多年後，張忠謀在1980年代初因錯失CEO職位而被“被動退休”。他曾親自參與建設世界半導體行業，TI的超高效製造工藝就是他改善良率實驗和專業知識的成果。在TI擔任CEO的工作會讓他成為晶片行業的頂尖人物，與鮑伯·諾伊斯（Bob Noyce）或戈登·摩爾（Gordon Moore）齊名。因此，當台灣政府提供了管理台灣晶片行業的機會並提供白紙支票資金支援時，張忠謀發現這個機會非常有吸引力。當時他已經54歲，正在尋找一個新的挑戰。

Though most people speak of Chang “returning” to Taiwan, his strongest connection to the island was the Texas Instruments facilities that he helped establish, and by Taiwan’s claim to be the legitimate government of China, the country that Chang grew up in, but that he hadn’t visited since fleeing nearly four decades earlier. By the mid-1980s, the place Chang had lived the longest was Texas. He held a U.S. security clearance for defense-related work at TI. He was arguably more Texan than Taiwanese. “Taiwan was a strange place to me,” he’d later recall.

大多數人談論張董「回到」台灣，但他與島嶼最密切的聯繫是他協助建立的德州儀器工廠，以及台灣聲稱是中國合法政府的主張，這是張董成長的國家，但他逃離這個國家已經接近40年，從未回訪。到了1980年代中期，張董在德州的居住時間最長。他持有美國安全憑證，在TI從事與國防有關的工作。他可能比台灣人更像德州人。「台灣對我而言是一個陌生的地方，」他後來回憶道。

However, building Taiwan’s semiconductor industry sounded like an exciting challenge. Directing the Taiwanese government’s Industrial Technology Research Institute, the position that Chang was formally offered, would place him at the center of Taiwan’s chip development efforts. The promise of government financing sweetened the deal. Being placed de facto in charge of the island’s semiconductor sector guaranteed Chang wouldn’t have to answer to anyone except ministers like K. T. Li, who promised to give him wide leeway. Texas Instruments never handed out blank checks like this. Chang knew he'd need a lot of money, because his business plan was based on a radical idea. If it worked, it would upend the electronics industry, placing him—and Taiwan—in control of the world's most advanced technology.

然而，發展台灣的半導體產業聽起來像是一個刺激人心的挑戰。成為台灣政府工業技術研究院的負責人，意味著張忠謀將置身於台灣晶片發展的中心。政府提供的資金承諾更是讓這個工作變得更為甜美。被置於事實上掌管島上半導體產業的位置，保證了張忠謀不必向任何人負責，除了像李國鼎這樣的部長，他保證將給予張忠謀足夠的空間。德州儀器無法像這樣無保留地提供資金。張忠謀知道他需要很多錢，因為他的商業計劃基於一個激進的想法。如果行得通的話，這將顛覆電子產業，讓他和台灣掌握全球最先進的科技。

As early as the mid-1970s, while still at TI, Chang had toyed with the idea of creating a semiconductor company that would manufacture chips designed by customers. At the time, chip firms like TI, Intel, and Motorola mostly manufactured chips they had designed in-house. Chang pitched this new business model to fellow TI executives in March 1976. "The low cost of computing power," he explained to his TI colleagues, "will open up a wealth of applications that are not now served by semiconductors," creating new sources of demand for chips, which would soon be used in everything from phones to cars to dishwashers. The firms that made these goods lacked the expertise to produce semiconductors, so they'd prefer to outsource fabrication to a specialist, he reasoned. Moreover, as technology advanced and transistors shrank, the cost of manufacturing equipment and R&D would rise. Only companies that produced large volumes of chips would be cost-competitive.

早在1970年代中期，張忠謀在德州儀器任職時就曾考慮創立一家半導體公司，以製造客戶設計的晶片。當時，像德州儀器、英特爾和摩托羅拉這樣的晶片公司主要是製造自己內部設計的晶片。1976年3月，張忠謀向德州儀器的同事們推銷這種新的商業模式。他向德州儀器的同事們解釋說："計算能力的低成本將開發出大量目前未服務於半導體的應用"，在從電話到汽車再到洗碗機等所有產品中，晶片的使用率會不斷提高。製造這些商品的公司缺乏製造半導體的專業知識，因此他們更願意將生產外包給專業公司。此外，隨著技術的進步和晶體管的縮

小，製造設備和研發的成本將上漲，只有生產大量的晶片的公司才能具有成本競爭力。

TI’s other executives weren’t convinced. At the time, in 1976, there weren’t any “fabless” companies that designed chips but lacked their own fabs, though Chang predicted such companies would soon emerge. Texas Instruments was already making plenty of money, so gambling on markets that didn’t yet exist seemed risky. The idea was quietly binned.

Chang never forgot the foundry concept. He thought it was ripening as time passed, particularly after Lynn Conway and Carver Mead’s revolution in chip design made it far easier to separate chip design from manufacturing, which they thought would create a Gutenberg moment for semiconductors.

德州儀器（Texas Instruments）的其他高管并不信服。当时，也就是1976年，没有任何设计芯片但没有自己的工厂的“无晶圆厂商”，尽管张忠谦预测这样的公司很快会出现。德州儀器已经赚了很多钱，所以冒险去投资尚不存在的市场似乎是有风险的。这个想法被悄悄地放弃了。张忠谦从未忘记晶圆厂的概念。随着时间的推移，他认为这个概念越来越成熟，尤其是在林恩·康威（Lynn Conway）和卡弗·米德（Carver Mead）的芯片设计革命之后，从制造中分离芯片设计变得更加容易，他们认为这将为半导体创造一个古腾堡时刻。

In Taiwan, some of the island’s electrical engineers were thinking along similar lines. Chintay Shih, who helped run Taiwan’s Industrial Technology Research Institute, had invited Mead to visit Taiwan in the mid-1980s to share his vision of Gutenberg for semiconductors. The idea of separating chip design and manufacturing had therefore already been percolating in Taiwan for several years before Minister K. T. Li offered Morris Chang a blank check to build Taiwan’s chip industry.

Minister Li followed through on his promise to find the money for the business plan Chang drew up. The Taiwanese government provided 48 percent of the startup capital for TSMC, stipulating only that Chang find a foreign chip firm to provide advanced production technology. He was turned down by his former colleagues at TI and by Intel. “Morris, you’ve had a lot of good ideas in your time,” Gordon Moore told him. “This isn’t one of them.” However, Chang convinced Philips, the Dutch semiconductor company, to put up $58 million, transfer its production technology, and license intellectual property in exchange for a 27.5 percent stake in TSMC.

在臺灣，一些島上的電力工程師也在考慮類似的想法。幫助管理臺灣工業技術研究院的石進泰邀請Mead前往臺灣，在1980年代中期傳達他對於半導體版古騰堡印刷術的願景。因此，在李國章提供白紙支票建立臺灣晶片產業幾年前，臺灣已經展開分離晶片設計和製造的概念。李部長信守他的諾言，為長敏造就的商業計畫找到資金。中華民國政府為台積電提供了48%的創業資本，條件僅是長敏找到一家外國晶片公司提供先進的生產技術。他曾向德州儀器和英特爾求助，但都遭到拒絕。“長敏，你過去提出很多好想法，”戈登·摩爾告訴他。“但這不是其中之一。”然而，長敏說服荷蘭半導體公司飞利浦出资5800万美元，轉讓生產技術，並授權知识产权，以换取其在台積電中的27.5%股权。

The rest of the capital was raised from wealthy Taiwanese who were “asked” by the government to invest. “What generally happened was that one of the ministers in the government would call a businessman in Taiwan,” Chang explained, “to get him to invest.” The government asked several of the island’s wealthiest families, who owned firms that specialized in plastics, textiles, and chemicals, to put up the money. When one businessman declined to invest after three meetings with Chang, Taiwan’s prime minister called the stingy executive and reminded him, “The government has been very good to you for the last twenty years. You better do something for the government now.” A check for Chang’s chip foundry arrived soon after. The government also provided generous tax benefits for TSMC, ensuring the company had plenty of money to invest. From day one, TSMC wasn’t really a private business: it was a project of the Taiwanese state.

其余资金则从台湾富有的人中筹集，他们被政府“要求”进行投资。“通常的情况是政府的其中一名部长会打电话给台湾的商人”张忠谋解释道，“希望他投资。”政府要求该岛上的几个最富裕的家族，他们拥有专门从事塑料、纺织品和化学品的公司，提供资金。当一个商人在三次会议后拒绝投资后，台湾的总理打电话给这个小气的高管并提醒他：“在过去的20年中，政府对您非常好。现在您最好为政府做些什么。”张忠谋的芯片工厂很快就收到了支票。政府还为TSMC提供慷慨

的税收优惠，确保公司有足够的资金进行投资。从一开始，TSMC实际上并不是一个私有企业：它是台湾国家的一个项目。

A crucial ingredient in TSMC’s early success was deep ties with the U.S. chip industry. Most of its customers were U.S. chip designers, and many top employees had worked in Silicon Valley. Morris Chang hired Don Brooks, another former Texas Instruments executive, to work as TSMC’s president from 1991 to 1997. “Most of the guys who reported to me, down two levels,” Brooks recalled, “all had some experience in the U.S… they all worked for Motorola, Intel, or TI.” Throughout much of the 1990s, half of TSMC’s sales were to American companies. Most of the company’s executives, meanwhile, trained in top doctoral programs at U.S. universities.

台積電早期成功的關鍵因素之一是與美國晶片產業的緊密聯繫。大部分的客戶都是美國晶片設計師，而且許多高層員工曾在矽谷工作。張忠謀聘請了另一位前德州儀器高管唐納德·布魯克斯擔任台積電總裁，從1991年到1997年。"幾乎所有報告給我下屬的人，往下兩級"，布魯克斯回憶道，"都有一些在美國的經驗...他們都曾在摩托羅拉、英特爾或德州儀器工作。"在20世紀90年代的大部分時間裡，台積電一半的銷售額都來自美國公司。此外，公司的大多數高管都在美國的頂尖博士課程中受過訓練。

This symbiosis benefitted Taiwan and Silicon Valley. Before TSMC, a couple of small companies, mostly based in Silicon Valley, had tried building businesses around chip design, avoiding the cost of building their own fabs by outsourcing the manufacturing. These “fabless” firms were sometimes able to convince a bigger chipmaker with spare capacity to manufacture their chips. However, they always had second-class status behind the bigger chipmakers’ own production plans. Worse, they faced the constant risk that their manufacturing partners would steal their ideas. In addition, they had to navigate manufacturing processes that were slightly different at each big chipmaker. Not having to build fabs dramatically reduced startup costs, but counting on competitors to manufacture chips was always a risky business model.

這種共生關係對台灣和矽谷都受益。在台積電之前，幾家小公司，大部分都位於矽谷，嘗試圍繞晶片設計建立企業，通過外包製造來避免

建造自己的晶片工廠成本。這些“無廠半導體”公司有時能夠說服一個有閒置產能的大型晶片製造商製造他們的晶片。然而，他們始終處於大型晶片製造商自己的生產計劃後方，甚至更差。更糟的是，他們面臨持續風險，即其製造合作夥伴會竊取他們的想法。此外，他們必須應對每個大型晶片製造商略有不同的製造過程。不必建造晶片工廠大大降低了啟動成本，但依靠競爭對手製造晶片始終是一種風險商業模式。

The founding of TSMC gave all chip designers a reliable partner. Chang promised never to design chips, only to build them. TSMC didn't compete with its customers; it succeeded if they did. A decade earlier, Carver Mead had prophesied a Gutenberg moment in chipmaking, but there was one key difference. The old German printer had tried and failed to establish a monopoly over printing. He couldn't stop his technology from quickly spreading across Europe, benefitting authors and print shops alike.

In the chip industry, by lowering startup costs, Chang's foundry model gave birth to dozens of new "authors"—fabless chip design firms—that transformed the tech sector by putting computing power in all sorts of devices. However, the democratization of authorship coincided with a monopolization of the digital printing press. The economics of chip manufacturing required relentless consolidation. Whichever company produced the most chips had a built-in advantage, 169improving its yield and spreading capital investment costs over more customers. TSMC's business boomed during the 1990s and its manufacturing processes improved relentlessly. Morris Chang wanted to become the Gutenberg of the digital era. He ended up vastly more powerful. Hardly anyone realized it at the time, but Chang, TSMC, and Taiwan were on a path toward dominating the production of the world's most advanced chips.

TSMC 的成立為所有芯片設計師提供了一個可靠的合作夥伴。張忠謀承諾永不設計芯片，只生產芯片。TSMC不與其客戶競爭，只有當他們成功時，TSMC才能成功。 十年前，卡佛·梅德曾預言了晶片製造的古騰堡時刻，但有一個關鍵的不同之處：古德堡印刷廠曾試圖建立印刷的壟斷，但失敗了。他無法阻止他的技術在歐洲迅速傳播，使作者和印刷店受益。在芯片行業中，透過降低啟動成本，張忠謀的晶圓代工模式引發了許多新的“作者” - 沒有晶片設計方案的公司 - 從而使計

算能力在各種設備中得以實現，改變了科技行業。然而，作者身份的民主化與數字印刷機的壟斷化相吻合。芯片製造的經濟因素要求不斷合並。生產最多芯片的公司即有內在優勢，提高其產量並將資本投資成本分散到更多客戶身上。 在1990年代，TSMC的業務蓬勃發展，其製造工藝不斷改進。莫里斯·張希望成為數字時代的古騰堡。他最終變得極其強大。當時幾乎沒有人意識到它，但張忠謀、TSMC和台灣正在走向主導世界上最先進芯片生產的道路。

CHAPTER 30 “All People Must Make Semiconductors”

I n 1987, the same year that Morris Chang founded TSMC, several hundred miles to the southwest a then-unknown engineer named Ren Zhengfei established an electronics trading company called Huawei. Taiwan was a small island with big ambitions. It had deep connections not just with the world’s most advanced chip companies but also thousands of engineers who’d been educated at universities like Stanford and Berkeley. China, by contrast, had a vast population but was impoverished and technologically backward. A new policy of economic openness had caused trade to boom, however, particularly via Hong Kong, through which goods could be imported or smuggled. Shenzhen, where Huawei was founded, sat just across the border.

1987年，同年台積電創辦人張忠謀創立了公司時，距離數百英里以南的一位名叫任正非的未知工程師成立了一家名叫華為的電子貿易公司。台灣是一個擁有宏大抱負的小島嶼，不僅與世界上最先進的晶片公司有著深厚的聯繫，而且還有成千上萬在斯坦福和伯克萊等大學接受過教育的工程師。相比之下，中國人口眾多，但貧困落後。然而，一項經濟開放的新政策已經使貿易繁榮起來，特別是通過香港，貨物可以進口或走私。華為成立的深圳就坐落在邊境的另一邊。

In Taiwan, Morris Chang set his sights on building some of the world’s most advanced chips and winning Silicon Valley giants as his customers. In Shenzhen, Ren Zhengfei bought cheap telecommunications equipment in Hong Kong and sold it for a higher price across China. The equipment he traded used integrated circuits, but the idea of producing his own chips would have seemed absurd. In the 1980s, the Chinese government, led by minister of the electronics industry and later president of China Jiang Zemin, identified electronics as a priority. At the time, the most advanced, widely used chip that China produced domestically was a DRAM with roughly the same storage capacity as the first DRAM Intel had brought to market in the early 1970s, putting China over a decade behind the cutting edge.

在台湾，张忠谋着眼于打造全球最先进的芯片，并赢得硅谷巨头为他的客户。在深圳，任正非在香港购买了廉价的通信设备，并在中国境内以比购买价高的价格出售。他交易的设备使用集成电路，但生产自己的芯片的想法似乎太荒谬了。在20世纪80年代，中国政府，由电子工业部长兼后来的中国国家主席江泽民领导，将电子作为重点产业。当时，中国国内生产的最先进、最广泛使用的芯片是一种存储容量与英特尔在20世纪70年代初推出的第一款DRAM相当的DRAM，这使中国落后于前沿技术超过十年。

Were it not for Communist rule, China might have played a much larger role in the semiconductor industry. When the integrated circuit was invented, China had many of the ingredients that helped Japan, Taiwan, and South Korea attract American semiconductor investment, like a vast, low-cost workforce and a well-educated scientific elite. However, after seizing power in 1949, the Communists looked at foreign connections with suspicion. For someone like Morris Chang, returning to China after finishing his studies at Stanford would have meant certain poverty and possible imprisonment or death. Many of the best graduates from China's universities before the revolution ended up working in Taiwan or in California, building the electronics capabilities of the PRC's primary rivals.

假如不是因為共產主義統治，中國在半導體行業中可能發揮了更大的作用。在集成電路被發明時，中國擁有許多有助於日本、台灣和韓國吸引美國半導體投資的因素，例如廣大的低成本勞動力和受過良好教育的科學精英。但是，1949年掌權後，共產黨對外國聯繫持懷疑態度。對於像莫里斯·張這樣的人，在斯坦福完成學業後回到中國意味著必定會生活在貧困中，甚至可能會被監禁或處死。革命前來自中國大學的許多優秀畢業生最終在台灣或加利福尼亞州工作，為中華人民共和國的主要競爭對手建立了電子技術能力。

China's Communist government, meanwhile, made the same mistakes the Soviet Union did, though in more extreme forms. As early as the mid-1950s, Beijing had identified semiconductor devices as a scientific priority. Soon, they were calling on the skills of researchers at Peking University and other scientific centers—including some scientists who'd been trained before the revolution at Berkeley, MIT, Harvard, or Purdue. By 1960, China had established its first semiconductor research institute, in Beijing. Around the same time, the country began manufacturing simple transistor radios. In 1965, Chinese engineers forged their first integrated circuit, a half decade after Bob Noyce and Jack Kilby.

与此同时，中国的共产党政府也犯了苏联同样的错误，只不过更为极端。早在1950年代中期，北京就将半导体器件确定为科学优先事项。不久之后，他们就开始动员北京大学和其他科学中心的研究人员，包括一些在革命前受过伯克利、麻省理工、哈佛或普渡大学培训的科学家。到1960年，中国在北京建立了第一个半导体研究所。同时，该国开始生产简单的晶体管收音机。1965年，中国工程师铸造了他们的第一个集成电路，比鲍勃·诺伊斯和杰克·基尔比晚了半个世纪。

However, Mao's radicalism made it impossible to attract foreign investment or conduct serious science. The year after China produced its first integrated circuit, Mao plunged the country into the Cultural Revolution, arguing that expertise was a source of privilege that undermined socialist equality. Mao's partisans waged war on the country's educational system. Thousands of scientists and experts were sent to work as farmers in destitute villages. Many others were simply killed. Chairman Mao's "Brilliant Directive issued on July 21, 1968" insisted that "it is essential to shorten the length of schooling, revolutionize education, put proletarian politics in command…. Students should be selected from among workers and peasants with practical experience, and they should return to production after a few years study."

然而，毛泽东的激进主义使得吸引外国投资或进行严肃的科学研究成为不可能。中国生产出第一批集成电路的一年后，毛泽东将国家陷入了文化大革命，称专业知识是削弱社会主义平等的特权源泉。毛泽东的支持者对全国的教育系统发动了战争，数千名科学家和专家被派往贫穷的乡村工作。许多人也被直接杀害。毛主席在1968年7月21日发布的"光荣指示"中坚称"缩短学制、革命化教育、把无产阶级政治放在统帅位置……学生应该从有工农业生产经验的工人和农民中选拔出来，在几年的学习之后他们就应该回到生产队。"

The idea of building advanced industries with poorly educated employees was absurd. Even more so was Mao's effort to keep out foreign technology and ideas. U.S. restrictions prevented China from buying advanced semiconductor equipment, but Mao added his own self-imposed embargo. He wanted complete self-reliance and accused his political rivals of trying to infect China’s chip industry with foreign parts, even though China couldn’t produce many advanced components itself. His propaganda machine urged support for “the earth-shaking mass movement for the… independent and self-reliant development of the electronic industry.”

以受过良好教育的员工来建立先进的产业的想法是荒谬的。更荒谬的是毛泽东试图阻止外国技术和思想的进入。美国的限制阻止了中国购买先进的半导体设备，但毛泽东又加上了自己的自我实施禁运。他想要完全自给自足，并指责他的政治对手试图通过外国零部件感染中国的芯片产业，尽管中国自己并不能生产许多先进部件。他的宣传机器呼吁支持“为实现电子工业自主独立发展而进行的地动山摇的群众运动”。

Mao wasn’t simply skeptical of foreign chips; at times he worried that all electronic goods were intrinsically anti-socialist. His political rival Liu Shaoqi had endorsed the idea that “modern electronic technology” would “bring about a big leap forward for our industry” and would “make China the first newly industrialized socialist power with first-rate electronic technology.” Mao, who always associated socialism with smokestacks, attacked the idea. It was “reactionary,” one of Mao’s supporters argued, to see electronics as the future, when it was obvious that “only the iron and steel industry should play a leading role” in building a socialist utopia in China.

毛泽东对外国芯片持怀疑态度的问题远不止于此，有时他担忧所有电子产品本质上都是反社会主义的。他的政治对手刘少奇赞同“现代电子技术”将为“我们的工业带来巨大飞跃”并会让中国“成为具有一流电子技术的第一个新工业化社会主义大国”的想法。但毛泽东总是将社会主义与烟囱联系在一起，攻击这个想法。毛的一位支持者认为，把电子学视为未来是“反动的”，显然“只有铁钢工业才应在建立中国社会主义乌托邦中发挥领导作用”。

In the 1960s, Mao won the political struggle over the Chinese semiconductor industry, downplaying its importance and cutting its ties with foreign technology. Most of China’s scientists resented the chairman for ruining their research—and their lives—by sending them to live on peasant farms to study proletarian politics rather than semiconductor engineering. One leading Chinese expert in optics who was sent to the countryside survived rural reeducation on a diet of rough grains, boiled cabbage, and an occasional grilled snake, as he waited for Mao's radicalism to subside. While China's small cadre of semiconductor engineers were hoeing China's fields, Maoists exhorted the country's workers that " all people must make semiconductors," as if every member of the Chinese proletariat could forge chips at home.

在1960年代，毛泽东在中国半导体产业的政治斗争中获胜，淡化了其重要性，切断了与外国技术的联系。大多数中国科学家因被派往农村进行无产阶级政治学习而不是半导体工程研究而憎恨主席，因为这破坏了他们的研究和生活。一位在光学方面的中国领先专家被派往农村，在等待毛泽东的激进主义消退时，以粗粮、煮白菜和偶尔的烤蛇为食，幸存下来。而中国小型的半导体工程师们则在田间劳作，而毛派则呼吁全国工人"所有人都必须制造半导体"，仿佛中国无产阶级的每个成员都能在家里锻造芯片。

One tiny speck of Chinese territory escaped the horrors of the Cultural Revolution. Thanks to a quirk of colonialism, Hong Kong was still governed temporarily by the British. As most Chinese were meticulously memorizing the quotations of their crazed chairman, Hong Kong workers were diligently assembling silicon components at Fairchild's plant overlooking Kowloon Bay. A couple hundred miles away in Taiwan, multiple U.S. chip firms had facilities employing thousands of workers in jobs that were low-paying by California's standards but far better than peasant farming. Just as Mao was sending China's small set of skilled workers to the countryside for socialist reeducation, the chip industry in Taiwan, South Korea, and across Southeast Asia was pulling peasants from the countryside and giving them good jobs at manufacturing plants.

一塊微小的中國領土成功逃離了文化大革命的恐懼。得益於殖民主義的怪癖，香港仍由英國暫時管治。當大部分中國人熱衷於胡亂引用他們瘋狂領袖的語錄時，香港的工人們勤奮地在遠眺九龍灣的費爾柴爾德工廠裝配矽元件。數百英里外的台灣，多家美國晶片公司在其設施中雇傭了數千名員工，這些工作根據加州的標準是低薪的，但比農民勞作要好得多。正如毛澤東派遣中國的少量技能工人到農村接受社會

主義教育一樣，台灣、南韓和整個東南亞的晶片行業正在從農村中招募農民，為他們在製造廠提供良好的工作機會。

The Cultural Revolution began to wane as Mao’s health declined in the early 1970s. Communist Party leaders eventually called scientists back from the countryside. They tried picking up the pieces in their labs. But China’s chip industry, which had lagged far behind Silicon Valley before the Cultural Revolution, was now far behind China’s neighbors, too. During the decade in which China had descended into revolutionary chaos, Intel had invented microprocessors, while Japan had grabbed a large share of the global DRAM market. China accomplished nothing beyond harassing its smartest citizens. By the mid-1970s, therefore, its chip industry was in a disastrous state. “Out of every 1,000 semiconductors we produce, only one is up to standard,” one party leader complained in 1975. “So much is being wasted.”

文化大革命在毛泽东健康状况恶化的早期开始消退。共产党领导人最终让科学家离开农村，试图在实验室里拾起碎片。但在文化大革命前，中国的芯片产业远远落后于硅谷，文革期间更是被邻国远远甩在身后。在中国陷入革命混乱的十年中，英特尔发明了微处理器，日本则占据了全球DRAM市场的大部分份额。而中国除了骚扰最聪明的公民之外，没有取得任何成果。因此，到了20世纪70年代中期，中国的芯片产业处于灾难性的状态。“我们生产的每1,000个半导体中，只有一个能达到标准，”一位党领导人在1975年发牢骚说，“浪费太多了。”

On September 2, 1975, John Bardeen landed in Beijing, two decades after he’d won his first Nobel Prize with Shockley and Brattain for inventing the transistor. In 1972, he had become the only person to win a second Nobel in physics, this time for work on superconductivity. In the world of physics, no one was more renowned, though Bardeen was the same modest man who’d been unfairly outshone by Shockley in the late 1940s. As he approached retirement, he devoted more time to building connections between American and foreign universities. When a delegation of prominent American physicists was being assembled to visit China in 1975, Bardeen was asked to join.

1975年9月2日，约翰·巴丁来到北京，这是他和肖克利、布拉廷一起发明晶体管获得第一次诺贝尔奖两十年后的事。在1972年，他又因超导

体方面的工作获得了第二次诺贝尔物理学奖。在物理学界，没有人比巴丁更有声望，尽管他在1940年代末被肖克利不公正地盖过。随着退休的临近，他把更多时间用于建立美国和外国大学的联系。当一支由美国著名物理学家组成的代表团于1975年前往中国时，巴丁被邀请加入。

With the Cultural Revolution winding down, China's leaders were trying to set aside their revolutionary fervor and befriend the Americans. At the time of Bardeen's visit, Mao was ill; he would die the next year. Bardeen's delegation reminded the Chinese of the technology that friendship with America could provide. This visit was a sign of how much had changed since the depths of the Cultural Revolution. A decade earlier, the Nobel Prize winner would have been denounced as a counterrevolutionary agent and not welcomed by China's leading research institutes in Beijing, Shanghai, Nanjing, and Xian. But still, much of the Maoist legacy remained. The Americans were told that Chinese scientists didn't publish their research because they opposed "self-glorification."

隨著文化大革命逐漸結束，中國領導人試圖擺脫革命熱情，與美國人友好相處。在巴丁訪問期間，毛澤東生病了，他將在下一年去世。巴丁的代表團提醒中國人關於與美國友好關係所能提供的技術。這次訪問是文化大革命低谷以來發生的巨大變化的一個信號。十年前，這位諾貝爾獎得主會被譴責為反革命分子，不會受到中國北京、上海、南京和西安等主要研究機構的歡迎。但是，毛澤東的遺產仍然存在。中國人告訴美國人，中國科學家不發表研究，因為他們反對"自我榮耀"。

Bardeen knew something about scientists obsessed with self-glorification from his work with Shockley, who unfairly claimed all the credit for inventing the transistor. The example of Shockley—a brilliant scientist but a failed businessman—demonstrated that the link between capitalism and self-glorification wasn't as straightforward as Maoist doctrine suggested. Bardeen told his wife that despite claims of equality he found Chinese society regimented and hierarchical. The political minders who watched over China's semiconductor scientists certainly had no parallel in Silicon Valley.

巴丁从与肖克利的合作中知道一些沉迷于自我吹嘘的科学家，肖克利不公正地声称发明了晶体管所有的功劳。肖克利是个杰出的科学家，但是失败的商人，这一点表明了资本主义和自我吹嘘之间的联系不像毛泽东思想所暗示的那样直接。巴丁告诉他的妻子，尽管有平等的声称，但他认为中国社会有规定性和等级制度。监管中国半导体科学家的政治干预者显然与硅谷没有任何相似之处。

Bardeen and his colleagues left China impressed with the country's scientists, but China's semiconductor manufacturing ambitions seemed hopeless. Asia's electronics revolution had completely passed by mainland China. Silicon Valley chip firms employed thousands of workers, often ethnic Chinese, in plants from Hong Kong to Taiwan, Penang to Singapore. But the People's Republic had spent the 1960s denouncing capitalists while its neighbors were trying desperately to attract them. A study in 1979 found that China had hardly any commercially viable semiconductor production and only fifteen hundred computers in the entire country.

巴丁和他的同事们离开中国时对该国的科学家留下了深刻印象，但中国的半导体制造抱负似乎是毫无希望的。亚洲的电子革命完全绕过了中国大陆。硅谷芯片公司在香港、台湾、槟城和新加坡的工厂聘请了数千名工人，其中很多是华人。然而，在邻国拼命吸引资本主义者的时候，中国人民共和国在1960年代谴责资本主义。一项1979年的研究发现，中国几乎没有商业可行的半导体生产，整个国家只有1500台计算机。

Mao Zedong died the year after Bardeen's visit to China. The old dictator was replaced, after a few years, by Deng Xiaoping, who promised a policy of "Four Modernizations" to transform China. Soon China's government declared that "science and technology" were "the crux of the Four Modernizations." The rest of the world was being transformed by a technological revolution, and China's scientists realized that chips were at the core of this change. The National Science Conference held in March 1978, just as Deng Xiaoping was consolidating power, placed semiconductors at the center of its agenda, hoping that China could use advances in semiconductors to help develop new weapons systems, consumer electronics, and computers.

毛澤東在貝爾丹訪問中逝世的第二年去世。幾年後，老獨裁者由鄧小平取代，他承諾實行“四個現代化”政策，以改變中國。不久之後，中國政府宣布“科學技術”是“四個現代化的關鍵”。世界其他地方正在經歷技術革命，中國的科學家意識到芯片是這一變革的核心。1978年3月舉行的全國科學大會正值鄧小平鞏固權力之際，把半導體放在了議程中心，希望中國能利用半導體的進步來開發新武器系統、消費電子產品和計算機。

The political goal was clear: China needed its own semiconductors, and it couldn't rely on foreigners. Newspaper *Guangming Ribao* set the tone, calling on readers in 1985 to abandon "the formula of 'the first machine imported, the second machine imported, and the third machine imported' " and replace it with " 'the first machine imported, the second made in China, and the third machine exported.' " This "Made in China" obsession was hardwired into the Communist Party's worldview, but the country was hopelessly behind in semiconductor technology—something that neither Mao's mass mobilization nor Deng's diktat could easily change.

政治目标很明确：中国需要自己的半导体，不能依赖外国。《光明日报》设定了这个基调，号召1985年的读者们放弃“第一台机器进口，第二台机器进口，第三台机器进口”的公式，用“第一台机器进口，第二台在中国制造，第三台机器出口”的公式替换它。这种“中国制造”的迷恋已经深入共产党的世界观，但中国在半导体技术方面远远落后——这是毛泽东的大规模动员和邓小平的敕令都不容易改变的。

Beijing called for more semiconductor research, but government decrees alone couldn't produce scientific inventions or viable industries. The government's insistence that chips were strategically important caused China's officials to try to control chipmaking, embroiling the sector in bureaucracy. When rising entrepreneurs like Huawei's Ren Zhengfei began building electronics businesses in the late 1980s, they had no choice but to rely on foreign chips. China's electronics assembly industry was built on a foundation of foreign silicon, imported from the United States, Japan, and increasingly Taiwan—which the Communist Party still considered part of "China," but which remained outside its control.

北京呼吁进行更多的半导体研究，但光是政府命令并不能产生科学发明或可行的产业。政府坚持芯片在战略上的重要性，导致中国官员试图控制芯片制造，卷入了官僚主义。当像华为的任正非等初创企业家在1980年代末开始建立电子业务时，他们别无选择，只能依靠外国芯片。中国的电子组装业建立在外国硅的基础上，从美国、日本和越来越多的台湾进口，而共产党仍然将台湾视为“中国”的一部分，但它仍然在其控制之外。

CHAPTER 31 “Sharing God’s Love with the Chinese”

R ichard Chang just wanted to “share God’s love with the Chinese.” The Bible didn’t say much about semiconductors, but Chang had a missionary’s zeal to bring advanced chipmaking to China. A devout Christian, the Nanjing-born, Taiwan-raised, Texas-trained semiconductor engineer convinced Beijing’s rulers in 2000 to give him vast subsidies to build a semiconductor foundry in Shanghai. The facility was designed exactly to his specifications, even including a church, thanks to special permission from China’s normally atheist government. The country’s leaders were willing to compromise on their opposition to religion if Chang could finally bring them modern semiconductor fabrication. Yet even with the full-fledged support of the government, Chang still felt like David as he struggled with the semiconductor industry’s goliaths, especially Taiwan’s TSMC.

Richard Chang 只是想 "分享上帝的爱给中国人"。圣经没有多少关于半导体的内容，但 Chang 充满传教士热情，希望将先进的芯片制造技术带到中国。作为虔诚的基督教徒，出生于南京、成长于台湾、在德克萨斯州接受培训的半导体工程师说服了北京的统治者，在 2000 年获得了为在上海建立一个半导体生产车间的巨额补贴。该设施是根据他的规格设计的，甚至还包括一座教堂，得益于中国通常信仰无神论的政府的特别许可。如果 Chang 能最终带来现代半导体制造技术，中国的领导人愿意在他们反对宗教上做出妥协。然而，即使在得到政府的充分支持下，Chang 仍然感觉自己像大卫一样在与半导体行业的巨头，尤其是台湾的 TSMC 抗争。

The geography of chip fabrication shifted drastically over the 1990s and 2000s. U.S. fabs made 37 percent of the world’s chips in 1990, but this number fell to 19 percent by 2000 and 13 percent by 2010. Japan’s market share in chip fabrication collapsed, too. South Korea, Singapore, and Taiwan each poured funds into their chip industries and rapidly increased output. For example, Singapore’s government funded fabrication facilities and chip design centers in partnership with companies like Texas Instruments, Hewlett-Packard, and Hitachi, building a vibrant semiconductor sector in the city-state. The Singaporean government also tried replicating TSMC, establishing a foundry called Chartered Semiconductor, though the company never performed as well as its Taiwanese rival.

芯片制造业的地理位置在1990年至2000年代发生了巨大变化。美国于1990年制造了全世界37%的芯片，但到了2000年只有19%，到2010年则只有13%。日本的芯片制造市场份额也大幅下降。韩国、新加坡和台湾各自向其芯片产业投入资金，并迅速增加了产量。例如，新加坡政府与德州仪器、惠普和日立等公司合作，资助了制造设施和芯片设计中心，建立了一个充满活力的半导体行业。新加坡政府还试图复制台积电，成立了一家名为查尔特半导体的铸造厂，但该公司从未像它的台湾竞争对手那样表现出色。

South Korea’s semiconductor industry did even better. After dethroning Japan’s DRAM producers and becoming the world’s leading memory chipmaker in 1992, Samsung grew rapidly through the rest of that decade. It fended off competition in the DRAM market from Taiwan and Singapore, benefitting from formal government support and from unofficial government pressure on South Korea’s banks to provide credit. This financing mattered because Samsung’s main product, DRAM memory chips, required brute financial force to reach each successive technology node—spending that had to be sustained even during industry downturns. The DRAM market was like a game of chicken, one Samsung executive explained. In good times, the world’s DRAM companies would pour money into new factories, pushing the market toward overcapacity, driving down prices. Carrying on spending was ruinously expensive, but stopping investments, even for a single year, risked ceding market share to rivals. No one wanted to blink first. Samsung had the capital to keep investing after its rivals were forced to cut back. Its memory chip market share grew inexorably.

韓國的半導體產業表現更出色。在1992年推翻日本DRAM生產者的王位並成為世界領先的記憶體芯片製造商後，三星在那個十年中快速增長。它在DRAM市場上擊退了來自台灣和新加坡的競爭，受益於政府的正式支持以及非正式的政府壓力迫使韓國的銀行提供信貸。這種融資很重要，因為三星的主要產品DRAM記憶體芯片需要強大的財務力量才能到達每一個後續的技術節點 - 即使在行業下滑期間也需要維持這樣的支出。DRAM市場就像玩鷹豆遊戲，一位三星高管解釋說。在

繁榮時期，全球DRAM公司將投入大量資金興建新工廠，推動市場過度供應，拉低價格。繼續支出成本極高，但停止投資，即使只有一年的時間，也冒著把市場份額讓給競爭對手的風險。沒人想先眨眼。三星有資本在競爭對手被迫削減支出後繼續投資。其記憶體芯片市場份額不斷增長。

China had the most potential to upend the semiconductor industry, given its growing role assembling the electronic devices into which most of the world's chips were slotted. By the 1990s, decades had passed since the country's first ill-fated efforts at semiconductor production were interrupted by Maoist radicalism. China had become the world's workshop, and cities like Shanghai and Shenzhen were centers of electronics assembly—the type of work that had propelled Taiwan's economy several decades earlier. However, China's leaders knew the real money was in the components that powered electronics, above all in semiconductors.

中國因其在組裝大多數電子設備的角色越來越重要，有潛力顛覆半導體行業。自從毛激進份子中斷該國首次半導體生產的失敗努力以來，數十年已過去。中國已成為世界工廠，而上海和深圳等城市是電子裝配的中心 - 這是數十年前推動台灣經濟發展的工作類型。然而，中國的領導人知道真正的錢在驅動電子產品的元件，尤其是半導體中。

China's chip manufacturing capabilities in the 1990s lagged far behind Taiwan and South Korea, to say nothing of the United States. Even though China's economic reforms were in full swing, smugglers still found it profitable to bring chips illegally into the country by stuffing suitcases full of them and crossing the border from Hong Kong. But as China's electronics industry matured, smuggling chips began to seem less appealing than making them.

Richard Chang saw bringing chips to China as his life's calling. Born in 1948 to a military family in Nanjing, the former capital, his family fled China after the Communists took power, arriving in Taiwan when he was only one year old. In Taiwan, he grew up in a community of mainlanders who treated residence on the island as a temporary sojourn. The expected collapse of the People's Republic never came, leaving people like Chang in a permanent state of identity crisis, seeing themselves as Chinese but living on an island that, in political terms, was drifting ever further away from the land of their birth. After finishing university, Chang moved to the U.S., completing a graduate degree in Buffalo, New York, before taking a job at Texas Instruments, where he worked with Jack Kilby. He became an expert in operating fabs, running TI's facilities around the world, from the U.S. to Japan, Singapore to Italy.

1990年代，中国的芯片制造能力远远落后于台湾和韩国，更不用说美国了。尽管中国的经济改革正在全面展开，走私分子仍然发现将芯片非法带入中国非常有利可图，他们会塞满行李箱，从香港越境而来。但随着中国电子工业的成熟，走私芯片开始变得不如生产它们有吸引力。 张少宏把把芯片带到中国视为自己一生的事业。他于1948年出生于南京，一个军人家庭，家人在中国共产党掌权后逃离中国，他只有一岁就到台湾。在台湾，他成长于一个把在岛上居住视为短暂旅居的大陆人社区。但人民共和国的预期崩溃从未发生过，这使得像张少宏这样的人处于一种永久的身份危机状态，他们认为自己是中国人，但是生活在一个在政治上与他们的出生地越来越远的岛上。完成大学学业后，张少宏移居美国，在纽约布法罗完成了研究生学业后，到得克萨斯仪器公司工作，与杰克·基尔比合作。他成为了一个运营晶圆厂的专家，管理TI遍布世界的设施，从美国到日本，新加坡到意大利。

Most of the early results of China's government efforts to subsidize the construction of a domestic semiconductor industry weren't impressive. Some fabs were built in China, such as a joint venture in Shanghai between China's Huahong and Japan's NEC. NEC received a sweet financial deal from the Chinese government in exchange for promising to bring its technology to China. However, NEC made sure that Japanese experts were in charge; Chinese workers were only allowed to undertake basic activities. "We cannot say this industry is a Chinese industry," one analyst was quoted as saying. It was just a "wafer fab located in China." China gained little expertise from the joint venture.

中国政府为补贴国内半导体产业建设所付出的努力，最初的大多数成果并不令人印象深刻。在中国建立了一些晶圆厂，例如中国华虹和日本NEC的合资企业在上海。NEC在向中国政府承诺将其技术引入中国的交换中获得了优惠的财务交易。然而，NEC确保日本专家掌控一切，中国工人只允许从事基本活动。"我们不能说这个行业是中国的行

业，”一位分析师被引述为说。 它只是一个“位于中国的晶圆厂”。中国从这个合资企业中获得的经验甚少。

Grace Semiconductor, another chip firm founded in Shanghai, in 2000, involved a similar mix of foreign investment, state subsidies, and failed technology transfer. Grace was a venture between Jiang Mianheng, son of Chinese president Jiang Zemin, and Winston Wang, scion of a Taiwanese plastics dynasty. The idea of attracting Taiwanese participation in China's chip industry made sense given the island's success in semiconductors, while the involvement of a child of a Chinese president helped secure government support. The company even hired Neil Bush, a younger brother of President George W. Bush, to advise on "business strategies," paying him $400,000 annually for his insight. This star-studded leadership team may have kept Grace out of political trouble, but the company's technology lagged and it struggled to acquire customers, never winning more than a small share of China's foundry business, a sliver of the world's total.

2000年在上海成立的另一家芯片公司——格莱半导体，也涉及到了外资、国家补贴和失败的技术转移的类似组合。格莱半导体是江泽民之子蒋柳燕和台湾塑料王朝的继承人王文洋之间的风险投资合资企业。吸引台湾参与中国的芯片产业是有道理的，考虑到台湾在半导体领域的成功，而一位中国总统的孩子的参与又有助于获得政府的支持。该公司甚至聘请了乔治·W·布什总统的弟弟尼尔·布什担任“商业策略”顾问，以便获取他的见解，并每年支付他40万美元的报酬。这个星光熠熠的领导团队可能使格莱半导体避免了政治上的麻烦，但它的技术落后，难以获得客户，从未赢得中国代工业务的大份额，只占世界总份额的一小部分。

If anyone could build a chip industry in China, it was Richard Chang. He wouldn't rely on nepotism or on foreign help. All the knowledge needed for a world-class fab was already in his head. While working at Texas Instruments, he'd opened new facilities for the company around the world. Why couldn't he do the same in Shanghai? He founded the Semiconductor Manufacturing International Corporation (SMIC) in 2000, raising over $1.5 billion from international investors like Goldman Sachs, Motorola, and Toshiba. One analyst estimated that half of SMIC's startup capital was provided by U.S. investors. Chang used these funds to hire hundreds of foreigners to operate SMIC’s fab, including at least four hundred from Taiwan.

如果有人能在中国建立一个芯片产业，那就是Richard Chang。他不会依赖裙带关系或外来帮助。全球一流的工厂所需的所有知识都已经在他的头脑中了。在德州仪器公司工作期间，他开设了该公司在世界各地的新设施。为什么他不能在上海做同样的事情呢？他于2000年创立了中芯国际集成电路制造有限公司(SMIC)，从高盛、摩托罗拉和东芝等国际投资者那里筹集了超过15亿美元的资金。一位分析师估计，SMIC的一半启动资金来自美国投资者。张在用这些资金雇佣了数百名外籍人员来运营SMIC的工厂，其中至少有四百名来自台湾。

Chang’s strategy was simple: do as TSMC had done. In Taiwan, TSMC had hired the best engineers it could find, ideally with experience at American or other advanced chip firms. TSMC bought the best tools it could afford. It focused relentlessly on training its employees in the industry’s best practices. And it took advantage of all the tax and subsidy benefits that Taiwan’s government was willing to provide.

SMIC followed this road map religiously. It hired aggressively from overseas chipmakers, especially from Taiwan. For much of its first decade of operation, a third of SMIC’s engineering personnel were hired from overseas. In 2001, according to analyst Doug Fuller, SMIC employed 650 local engineers compared with 393 who were recruited from overseas, mostly from Taiwan and the U.S. Through the end of the decade, roughly a third of engineering employees were hired from abroad. The company even had a slogan, “one old staffer brings along two new ones,” emphasizing the need for experienced foreign-trained employees to help local engineers learn. SMIC’s local engineers learned quickly, and were soon perceived to be so capable they began receiving job offers from foreign chipmakers. The company’s success in domesticating technology was only possible thanks to this foreign-trained workforce.

張汝京的策略很簡單：仿效台積電。在台灣，台積電聘請了最好的工程師，最好擁有在美國或其他先進晶片公司的經驗。台積電買了能負擔得起的最好的工具。它不斷專注於訓練員工掌握行業最佳實踐。並且利用台灣政府提供的所有稅收和補貼優惠。中芯國際公司

(pinyin:Zhōng xiàn guó jì gōng sī)忠實地遵循了這個路線圖。它積極地聘請海外晶片製造商的員工，特別是來自台灣。在其運營的前十年中，SMIC的三分之一工程人員來自海外。據分析師道格·福勒(Doug Fuller)在2001年的數據，SMIC僱用了650名當地工程師，而僅有393名是從海外招聘來的，其中大部分來自台灣和美國。到本世紀末，約有三分之一的工程員是從國外招聘來的。這家公司甚至還有一個口號："一位老員工帶來兩位新員工"，強調需要有經驗的外國訓練過的員工來幫助本地工程師學習。SMIC的當地工程師學得非常快，很快被認為非常有能力，開始收到來自外國晶片製造商的工作邀請。這個公司在國產化技術方面的成功僅有可能得益於這些接受過海外培訓的工人。

Like China's other chip startups, SMIC benefitted from vast government support, like a five-year corporate tax holiday and reduced sales tax on chips sold in China. SMIC milked these benefits, but at first it didn't depend on them. Unlike rivals who focused more on hiring politicians' children than on manufacturing quality, Chang ramped up production capacity and adopted technology that was near the cutting edge. By the end of the 2000s SMIC was only a couple years behind the world's technology leaders. The company seemed on track to become a top-notch foundry, perhaps eventually capable of threatening TSMC. Richard Chang soon won contracts to build chips for industry leaders like his former employer, Texas Instruments. SMIC listed its shares on the New York Stock Exchange in 2004.

和中国其他芯片初创公司一样，中芯国际受益于政府的庞大支持，如五年的减税优惠和在中国销售的芯片的减少销售税。中芯国际利用了这些好处，但起初并不依赖它们。与那些更关注招聘政治家子女而非制造质量的竞争对手不同，常总增加了生产能力并采用了接近前沿的技术。到2000年代末，中芯国际只比世界技术领先者落后几年。该公司似乎正在成为一家一流的晶圆厂，也许有朝一日能够威胁台积电。理查德·常很快赢得了建造芯片的合同，这些芯片是为他的前雇主德州仪器生产的。中芯国际于2004年在纽约证券交易所上市。

Now TSMC had competition from multiple foundries in different countries in East Asia. Singapore's Chartered Semiconductor, Taiwan's UMC and Vanguard Semiconductor, and South Korea's Samsung—which entered the foundry business in 2005—were also competing with TSMC to produce chips designed elsewhere. Most of these companies were subsidized by their governments, but this made chip production cheaper, benefitting the mostly American fabless semiconductor designers they served. Fabless firms, meanwhile, were in the early stages of launching a revolutionary new product chock-full of complex chips: the smartphone. Offshoring had reduced manufacturing costs and spurred more competition. Consumers benefitted from low prices and from previously unthinkable devices. Wasn’t this exactly how globalization was designed to work?

現在，台積電（TSMC）在東亞不同國家的多家晶圓廠競爭中。新加坡的特許半導體、台灣的聯電和先鋒半導體、以及韓國的三星——這些公司從2005年開始進入晶圓代工業務，與TSMC競爭生產其他地方設計的晶片。這些公司大多受到其政府的資助，但這降低了晶片生產成本，使它們為主要提供服務的美國無廠半導體設計公司帶來了好處。同時，無廠公司正在推出一款充滿複雜晶片的革命性新產品：智能手機。離岸外包降低了製造成本，刺激了更多的競爭。消費者從低價和以前無法想像的設備中受益。這難道不是全球化的預期效果嗎？

CHAPTER 32 Lithography Wars

W hen John Carruthers sat down in a meeting room at Intel's headquarters in Santa Clara, California, in 1992, he didn't expect that asking Intel CEO Andy Grove for $200 million was going to be easy. As a leader of Intel's R&D efforts, Carruthers was used to making big bets. Some worked, and others didn't, but Intel's engineers had as good a batting average as anyone in the industry. By 1992, Intel was again the world's biggest chipmaker, on the strength of Grove's decision to focus Intel's efforts on microprocessors for PCs. It was flush with cash and as committed as ever to Moore's Law.

當約翰·卡拉瑟斯於1992年在加州聖塔克拉拉的英特爾總部的會議室坐下時，他並沒有預計向英特爾CEO安迪·格羅夫要求2億美元會很容易。作為英特爾研發工作的領導者，卡拉瑟斯習慣於進行大型投注。有些效果不錯，有些則不然，但英特爾的工程師在行業中顯示出了與任何人一樣的成功率。到1992年，由於格羅夫決定專注於PC的微處理器，英特爾再次成為了世界最大的芯片製造商。它財源廣進，對摩爾定律的承諾一如既往。

Carruthers's request stretched far beyond the usual for R&D projects, however. Along with everyone else in the industry, Carruthers knew existing lithography methods would soon be unable to produce the ever-smaller circuits that next-generation semiconductors required. Lithography companies were rolling out tools using deep ultraviolet light, with wavelengths of 248 or 193 nanometers, invisible to the human eye. But it wouldn't be long before chipmakers would be asking for even more lithographic precision. He wanted to target "extreme ultraviolet" (EUV) light, with a wavelength of 13.5 nanometers. The smaller the wavelength, the smaller the features that could be carved onto chips. There was only one problem: most people thought extreme ultraviolet light was impossible to mass-produce.

然而，卡拉瑟斯的要求远远超出了研发项目的通常范畴。与行业中的其他人一样，卡拉瑟斯知道现有的光刻方法很快就无法生产下一代半导体所需的越来越小的电路。光刻公司正在推出使用深紫外光的工

具，其波长为248或193纳米，对人眼不可见。但不久之后，芯片制造商将会要求更高的光刻精度。他想瞄准“极紫外”(EUV)光，其波长为13.5纳米。波长越小，可以雕刻到芯片上的特征就越小。只有一个问题：大多数人认为极紫外光无法实现大规模生产。

“You mean to tell me you’re going to spend money on something that we don’t even know if it’s gonna work?” Grove asked skeptically. “Yeah, Andy, that’s called research,” Carruthers retorted. Grove turned to Gordon Moore, Intel’s former CEO, who remained an advisor to the company. “What would you do, Gordon?” “Well, Andy, what other choices do you have?” Moore asked. The answer was obvious: none. The chip industry would either learn to use ever smaller wavelengths for lithography, or the shrinking of transistors—and the law named after Moore—would come to a halt. Such an outcome would be devastating for Intel’s business and humiliating for Grove. He gave Carruthers $200 million to spend developing EUV lithography. Intel would eventually spend billions of dollars on R&D and billions more learning how to use EUV to carve chips. It never planned to make its own EUV equipment, but needed to guarantee that at least one of the world’s advanced lithography firms would bring EUV machines to market so that Intel would have the tools needed to carve ever-smaller circuits.

格罗夫皱着眉头问道：“你是说你要花钱去投资一个我们甚至不确定是否有效的项目？”“没错，安迪，这就叫做研究。”卡鲁瑟斯反驳道。格罗夫转向英特尔前CEO兼公司顾问戈登·摩尔。“你会怎么做，戈登？”“嗯，安迪，你还有其他选择吗？”摩尔问道。答案显而易见：没有。芯片产业将不得不学会使用更小的波长来进行光刻，否则，晶体管的缩小——以及以摩尔定律命名的该现象将停止。这样的结果对英特尔的业务来说将是灾难性的，对格罗夫来说也将是一种耻辱。他给了卡鲁瑟斯2亿美元来开发EUV光刻技术。英特尔最终将在研发上花费数十亿美元，学习如何使用EUV来雕刻芯片。它从未打算制造自己的EUV设备，但需要确保世界上至少有一家先进的光刻公司推出EUV机器，以便英特尔拥有雕刻越来越小的电路所需的工具。

More than at any point since Jay Lathrop had turned his microscope upside down in his U.S. military lab, in the 1990s the future of lithography was in doubt. Three existential questions hung over the lithography industry: engineering, business, and geopolitics. In the early days of chipmaking, transistors were so big that the size of the light waves used by lithography tools barely mattered. But Moore’s Law had progressed to the point where the scale of light waves—a couple hundred nanometers, depending on the color—impacted the precision with which circuits could be etched. By the 1990s, the most advanced transistors were measured in the hundreds of nanometers (billionths of a meter), but it was already possible to envision far smaller transistors with features just a dozen nanometers in length.

从Jay Lathrop在他的美国军事实验室里将显微镜倒过来以来，光刻技术的未来面临着历史以来最大的疑问。光刻技术行业中有三个存在性问题：工程、商业和地缘政治。在芯片制造的早期阶段，晶体管非常大，以至于光刻工具使用的光波大小几乎没有任何影响。但是摩尔定律已经发展到使光波的规模（取决于颜色）影响了电路刻蚀的精度的程度。到了20世纪90年代，最先进的晶体管被测量为几百纳米（十亿分之一米），但已经可以预见到具有长度仅为几十纳米的特征的远小于此尺度的晶体管。

Producing chips at this scale, most researchers believed, required more precise lithography tools to shoot light at photoresist chemicals and carve shapes on silicon. Some researchers sought to use beams of electrons to carve chips, but electron beam lithography was never fast enough for mass production. Others placed their bet on X-rays or extreme ultraviolet light, each of which reacted with different sets of photoresist chemicals. At the annual international conference of lithography experts, scientists debated which technique would win out. It was a time of “lithography wars,” one participant put it, between competing groups of engineers.

生产如此规模的芯片，大多数研究人员认为需要更精确的光刻工具，以将光照射到光刻胶化学物质上，并在硅上雕刻形状。一些研究人员试图使用电子束来雕刻芯片，但电子束光刻速度不足以进行大规模生产。其他人则押注于X射线或极紫外线光，每种技术都与不同的光刻胶化学物质反应。在光刻专家的年度国际会议上，科学家们就哪种技术将胜出展开了争论。正如一位参与者所说的，“这是一个光刻之战”的时代，竞争的是工程师的不同团队。

The “war” to find the next, best type of beam to shoot at silicon wafers was only one of three contests underway over the future of lithography. The second battle was commercial, over which company would build the next generation of lithography tools. The enormous cost of developing new lithography equipment pushed the industry toward concentration. One or at most two companies would dominate the market. In the United States, GCA had been liquidated, while Silicon Valley Group, a lithography firm descended from Perkin Elmer, lagged far behind the market leaders, Canon and Nikon. U.S. chipmakers had fended off the Japanese challenge of the 1980s, but American lithography toolmakers hadn't.

尋找下一個最好的發射光束到矽晶片的「戰爭」只是三個關於拼搏中的其中一個，其餘兩個是商業上的爭鬥，即由哪家公司建造下一代的光刻工具。開發新的光刻設備的巨大成本將推動行業向集中化的方向發展，最多只會有一到兩家公司主宰市場。在美國，GCA已經清算，而類似培根艾爾默的光刻公司矽谷集團遠遠落後於市場領導者佳能和尼康。美國晶片製造商曾抵擋了上世紀80年代的日本挑戰，但美國光刻工具製造商卻未能如此。

The only real competitor to Canon and Nikon was ASML, the small but growing Dutch lithography company. In 1984, Philips, the Dutch electronics firm, had spun out its internal lithography division, creating ASML. Coinciding with the collapse in chip prices that sank GCA's business, the spinoff was horribly timed. What's more, Veldhoven, a town not far from the Dutch border with Belgium, seemed an unlikely place for a world-class company in the semiconductor industry. Europe was a sizeable producer of chips, but it was very clearly behind Silicon Valley and Japan.

唯一真正的佳能和尼康竞争对手是荷兰小而不断壮大的晶体光刻公司ASML。1984年，荷兰电子公司飞利浦分拆了内部光刻分部，创办了ASML。正值芯片价格崩盘，导致GCA的业务崩溃，这个分拆的时机非常不妙。此外，离荷比边境不远的费尔多芬似乎是一个不太可能成为半导体工业世界级公司的地方。欧洲是芯片的重要生产国，但显然落后于硅谷和日本。

When Dutch engineer Frits van Hout joined ASML in 1984 just after completing his master's degree in physics, the company's employees asked whether he'd joined voluntarily or was forced to take the job. Beyond its tie with Philips, "we had no facilities and no money," van Hout remembered.

Building vast in-house manufacturing processes for lithography tools would have been impossible. Instead, the company decided to assemble systems from components meticulously sourced from suppliers around the world. Relying on other companies for key components brought obvious risks, but ASML learned to manage them. Whereas Japanese competitors tried to build everything in-house, ASML could buy the best components on the market. As it began to focus on developing EUV tools, its ability to integrate components from different sources became its greatest strength.

当荷兰工程师弗里茨·范·豪特于1984年在完成物理学硕士学位后加入ASML时，公司员工问他是否自愿加入或被迫接受工作。除了与飞利浦的联合外，"我们没有设施和没有钱，"范豪特回忆道。为光刻工具建立庞大的内部制造流程是不可能的。相反，公司决定从世界各地精心选择的供应商组装系统。依赖其他公司的关键组件带来了明显的风险，但ASML学会了管理它们。与日本竞争对手试图自己制造一切不同，ASML能够购买市场上最好的组件。随着开始专注于开发EUV工具，其整合来自不同来源的组件的能力成为了其最大的优势。

ASML’s second strength, unexpectedly, was its location in the Netherlands. In the 1980s and 1990s, the company was seen as neutral in the trade disputes between Japan and the United States. U.S. firms treated it like a trustworthy alternative to Nikon and Canon. For example, when Micron, the American DRAM startup, wanted to buy lithography tools, it turned to ASML rather than relying on one of the two main Japanese suppliers, each of which had deep ties with Micron’s DRAM competitors in Japan.

ASML’s history of being spun out of Philips helped in a surprising way, too, facilitating a deep relationship with Taiwan’s TSMC. Philips had been the cornerstone investor in TSMC, transferring its manufacturing process technology and intellectual property to the young foundry. This gave ASML a built-in market, because TSMC’s fabs were designed around Philips’s manufacturing processes. An accidental fire in TSMC’s fab in 1989 helped, too, causing TSMC to buy an additional nineteen new lithography machines, paid for by the fire insurance. Both ASML and TSMC started as small firms on the periphery of the chip industry, but they grew together, forming a partnership without which advances in computing today would have ground to a halt.

ASML的第二個優勢出乎意料地在於其位於荷蘭。在20世紀80年代和90年代，該公司被視為在日本和美國之間的貿易糾紛中是中立的。美國公司將其視為對Nikon和Canon的可信賴替代品。例如，當美國的DRAM初創企業Micron想要購買光刻機時，它轉向ASML，而不是依賴其中兩個主要的日本供應商之一，這兩家供應商都與Micron在日本的DRAM競爭對手有著深厚的關係。 ASML從Philips中分離出來的歷史也以出人意料的方式幫助了它，促進了與台灣的TSMC之間的深入關係。Philips是TSMC的基石投資者，將其製造過程技術和知識產權轉移給這家年輕的晶圓廠。這為ASML帶來了一個內置的市場，因為TSMC的晶圓廠是根據Philips的製造過程設計的。 TSMC在1989年的一次意外火災也起了幫助作用，這迫使TSMC購買了額外的19台新的光刻機，由火災保險支付。ASML和TSMC都是芯片行業邊緣的小公司，但它們共同成長，形成了一個合作夥伴關係，如果沒有這種關係，今天的計算機進步將會停滯不前。

The partnership between ASML and TSMC pointed to the third “lithography war” of the 1990s. This was a political contest, though few people in industry or government preferred to think in those terms. At the time, the U.S. was celebrating the end of the Cold War and cashing in its peace dividend. Measured by technological, military, or economic power, the U.S. towered above the rest of the world, allies and adversaries alike. One influential commentator declared the 1990s a “unipolar moment,” in which America’s dominance was unquestioned. The Persian Gulf War had demonstrated America’s terrifying technological and military might.

在ASML和台积电之间的合作揭示了90年代的第三次“光刻机战争”。尽管在行业和政府中，很少有人愿意以政治竞争来看待这个问题。当时，美国正在庆祝冷战的结束，并且兑现其和平红利。无论从技术、军事还是经济实力来衡量，美国都高高在上，包括其盟友和对手在内。一位有影响力的评论家宣布，90年代是美国霸权的“单极时刻”，其主导地位毋庸置疑。波斯湾战争展示了美国令人惊恐的技术和军事力量。

When Andy Grove was preparing to approve Intel’s first major investment in EUV lithography research in 1992, it was easy to see why even the chip industry, which had emerged out of the Cold War military-industrial complex, had concluded politics no longer mattered. Management gurus promised a future “borderless world” in which profits not power would shape the global business landscape. Economists spoke of accelerating globalization. CEOs and politicians alike embraced these new intellectual fashions. Intel, meanwhile, was again on top of the semiconductor business. It had fended off its Japanese rivals and now all but monopolized the global market for the chips that powered personal computers. It has made a profit every year since 1986. Why should it worry about politics?

1992年，安迪·格罗夫准备批准英特尔在极紫外光微影技术方面的第一次主要投资时，即使芯片行业是从冷战军工复合体中崛起的，也很容易看出政治不再重要的原因。管理大师们承诺未来将是一个“无国界的世界”，利润而非权力将塑造全球商业格局。经济学家谈论着全球化加速。CEO和政治家都拥抱这些新的思想潮流。与此同时，英特尔再次掌握了半导体业务的领先地位。它挫败了日本竞争对手，现在几乎垄断了驱动个人计算机的芯片全球市场。自1986年以来，它每年都有盈利。它为什么要担心政治呢？

In 1996, Intel forged a partnership with several of the laboratories operated by the U.S. Department of Energy, which had expertise in optics and other fields needed to make EUV work. Intel assembled a half dozen other chipmakers to join the consortium, but Intel paid for most of it and was the “95 percent gorilla” in the room, one participant remembered. Intel knew that the researchers at Lawrence Livermore and Sandia National Labs had the expertise to build a prototype EUV system, but their focus was on the science, not on mass production.

1996年，英特尔与美国能源部运营的几个实验室建立了合作伙伴关系，这些实验室掌握了制造EUV所需的光学和其他领域的专业知识。英特尔组建了另外六家芯片制造商加入联盟，但英特尔支付了大部分费用，并且是当时“95%的大佬”。参与其中的一位人员表示，英特尔知道劳伦斯利弗莫尔和桑迪亚国家实验室的研究人员有建造原型EUV系统的专业知识，但他们的重点是科学研究，而非大规模生产。

Intel’s goal was “to make stuff, not just to measure it,” Carruthers explained, so the company began searching for a company to commercialize and mass-produce EUV tools. It concluded no American firm could do it. GCA was no more. America’s biggest remaining lithography firm was Silicon Valley

Group (SVG), which lagged technologically. The U.S. government, still sensitive from the trade wars of the 1980s, didn't want Japan's Nikon and Canon to work with the national labs, though Nikon itself didn't think EUV technology would work. ASML was the only lithography firm left.

英特尔的目标是“制造东西，而不仅仅是测量它”，卡鲁瑟斯解释道，因此该公司开始寻找一个公司来商业化和大规模生产EUV工具。它得出的结论是，没有美国公司能够做到这一点。GCA不复存在了。美国仅剩的最大光刻公司是硅谷集团(SVG)，技术落后。由于上个世纪八十年代的贸易战仍然让美国政府心有余悸，它不希望日本的尼康和佳能与国家实验室合作，尽管尼康本身认为EUV技术行不通。ASML是唯一剩下的光刻公司。

The idea of giving a foreign company access to the most advanced research coming out of America's national labs raised some questions in Washington. There was no immediate military application for EUV technology, and it still wasn't clear that EUV would work. Nevertheless, if it did, the U.S. would be reliant on ASML for a tool fundamental to all computing. Except for a few officials in the Defense Department, hardly anyone in Washington was concerned. Most people saw ASML and the Dutch government as reliable partners. More important to political leaders was the impact on jobs, not geopolitics. The U.S. government required ASML to build a facility in the U.S. to manufacture components for its lithography tools and supply American customers and employ American staff. However, much of ASML's core R&D would take place in the Netherlands. Key decision makers from the Commerce Department, the National Labs, and the companies involved say they don't recall political considerations playing much if any role in the government's decision to let this arrangement proceed.

將美國國家實驗室中最先進的研究成果提供給外國公司的想法，在華盛頓引起了一些問題。EUV技術還沒有明確的軍事應用，也還不清楚EUV是否可行。然而，如果EUV可行，美國將依賴ASML提供的計算機基礎工具。除了國防部的一些官員外，華盛頓幾乎沒有人擔心這個問題。大多數人認為ASML和荷蘭政府是可靠的合作夥伴。對政治領袖更重要的是就業的影響，而不是地緣政治。美國政府要求ASML在美國建立生產光刻工具零件以及為美國客戶提供支援和雇用美國人的工廠。然而，ASML的核心研發大部分將在荷蘭進行。商務部、國家實

驗室和相關公司的關鍵決策者表示，他們不記得政治因素在政府決定讓這個安排進行方面起到什麼作用。

Despite long delays and huge cost overruns, the EUV partnership slowly made progress. Locked out of the research at the U.S. national labs, Nikon and Canon decided not to build their own EUV tools, leaving ASML as the world's only producer. In 2001, meanwhile, ASML bought SVG, America's last major lithography firm. SVG already lagged far behind industry leaders, but again questions were raised about whether the deal suited America's security interests. Inside DARPA and the Defense Department, which had funded the lithography industry for decades, some officials opposed the sale. Congress raised concerns, too, with three senators writing President George W. Bush that "ASML will wind up with all of the U.S. government's EUV technology."

儘管長時間的延誤和極度的成本超支，歐盟輻射減影技術的合作夥伴關係緩慢取得進展。在被美國國家實驗室的研究所排除在外的情況下，佳能和尼康決定不建造自己的輻射減影工具，只讓ASML成為世界上唯一的生產商。同時，在2001年，ASML收購了美國最後一家重要的半導體製造公司SVG。SVG已經遠落後於產業領導者，但是這再次引起了關於這筆交易是否符合美國安全利益的質疑。在曾經資助半導體製造業數十年的DARPA和國防部內部，有些官員反對這筆交易。國會也提出了關注，三位參議員致信總統喬治·W·布什，表示"ASML最終將擁有美國政府所有的輻射減影技術"。

This was undeniably true. But America's power was at its peak. Most people in Washington thought globalization was a good thing. The dominant belief in the U.S. government was that expanding trade and supply chain connections would promote peace by encouraging powers like Russia or China to focus on acquiring wealth rather than geopolitical power. Claims that the decline of America's lithography industry would imperil security were seen as out of touch with this new era of globalization and interconnection. The chip industry, meanwhile, simply wanted to build semiconductors as efficiently as possible. With no large-scale U.S. lithography firms remaining, what choice did they have but to bet on ASML?

這是不可否認的真實。但美國的力量正處於巔峰。華盛頓大部分人認為全球化是一件好事。美國政府的主流信念是，擴大貿易和供應鏈聯繫將通過鼓勵像俄羅斯或中國這樣的大國專注於獲取財富而非地緣政治權力，來促進和平。聲稱美國平版印刷行業的衰落將危及安全的說法被認為與全球化和互聯互通的新時代脫節。與此同時，芯片行業的愿望僅僅是尽可能高效地构建半导体。由于美国已经没有大规模的平版印刷公司，他们还有什么选择，而不是押注于ASML呢？

Intel and other big chipmakers argued that the sale of SVG to ASML was crucial to developing EUV—and thus fundamental to the future of computing. “Without the merger,” Intel’s new CEO Craig Barrett argued in 2001, “the development path to the new tools in the U.S. will be delayed.” With the Cold War over, the Bush administration, which had just taken power, wanted to loosen technology export controls on all goods except those with direct military applications. The administration described the strategy as “building high walls around technologies of the highest sensitivity.” EUV didn’t make the list.

英特爾和其他大型晶片製造商認為，SVG被出售給ASML對於EUV的開發至關重要，因此對於計算機的未來至關重要。 "如果沒有并購，"英特爾的新任首席執行官Craig Barrett在2001年表示，"美國開發新工具的路徑將被延遲。"隨著冷戰的結束，剛上任的布什政府希望放松對所有商品的技術出口管制，除了直接與軍事應用相關的商品。該政府將此戰略描述為“在最高敏感性技術周圍建造高牆”。EUV並沒有被列入此清單。

The next-generation EUV lithography tools would therefore be mostly assembled abroad, though some components continued to be built in a facility in Connecticut. Anyone who raised the question of how the U.S. could guarantee access to EUV tools was accused of retaining a Cold War mindset in a globalizing world. Yet the business gurus who spoke about technology spreading globally misrepresented the dynamic at play. The scientific networks that produced EUV spanned the world, bringing together scientists from countries as diverse as America, Japan, Slovenia, and Greece. However, the manufacturing of EUV wasn’t globalized, it was monopolized. A single supply chain managed by a single company would control the future of lithography.

下一代EUV光刻机多数将在海外组装，尽管某些组件仍在康涅狄格的工厂生产。那些提出美国如何确保获得EUV工具的问题的人被指责在全球化的世界中仍沉浸在冷战思维中。然而，谈及技术在全球范围内的传播的商业大亨们曾歪曲了事情的真相。生产EUV的科学网络遍布全球，拥有来自美国、日本、斯洛文尼亚和希腊等不同国家的科学家。然而，EUV的制造并没有全球化，而是被垄断了。由单一公司控制的单一供应链将掌控光刻技术的未来。

CHAPTER 33 The Innovator’s Dilemma

S teve Jobs stood alone on a dark stage at the 2006 Macworld conference, wearing his trademark blue jeans and a black turtleneck. An audience of hundreds of tech buffs waited anxiously for Silicon Valley’s prophet to speak. Jobs turned toward his left, and blue smoke erupted on the far side of the stage. A man in a white bunny suit—the type used by semiconductor workers to keep their fabs ultra-clean—walked through the smoke, across the stage, right up to Jobs. He took off his head covering and grinned: it was Intel CEO Paul Otellini. He handed Jobs a large silicon wafer. “Steve, I want to report that Intel is ready.”

史蒂夫·乔布斯站在2006年Macworld会议上的黑暗舞台上，穿着他标志性的蓝色牛仔裤和黑色高领衫。数百名科技迷焦急地等待着硅谷的先知发言。乔布斯转向他的左边，舞台的远端冒出蓝色的烟雾。一名身穿白色兔子服装的男子——半导体工人为保持超清洁的制造车间而使用的那种——穿过烟雾，走过舞台，来到乔布斯面前。他取下头饰，咧嘴一笑：这个人是英特尔CEO Paul Otellini。他递给乔布斯一个大的硅晶片。“史蒂夫，我要报告，英特尔已经准备好了。”

This was classic Steve Jobs theater, but it was a typical Intel business coup. By 2006, Intel already supplied the processors for most PCs, having spent the previous decade successfully fending off AMD, the only other major company producing chips on the x86 instruction set architecture—a foundational set of rules that govern how chips compute—that was the industry standard for PCs. Apple was the only major computer-maker that didn’t use x86-based chips. Now, Jobs and Otellini announced, this would change. Mac computers would have Intel chips inside. Intel’s empire would grow, and its stranglehold on the PC industry would tighten.

這是史蒂夫·賈伯斯經典的演講風格，但這是一次典型的英特爾商業陰謀。到2006年，英特爾已為大多數個人電腦提供處理器，之前十年成功地抵禦了AMD，這是唯一一家以x86指令集架構生產芯片的其他主要公司，而這是PC行業的行業標準，它是規定芯片如何計算的基礎性規則。蘋果是唯一一家不使用基於x86的芯片的主要計算機製造商。現

在，賈伯斯和奧泰林尼宣布，這將會改變。Mac電腦將搭載英特爾芯片。英特爾的帝國將會成長，它對PC行業的掌控將會加強。

Jobs was already a Silicon Valley icon, having invented the Macintosh and pioneered the idea that computers could be intuitive and easy to use. In 2001, Apple released the iPod, a visionary product showing how digital technology could transform any consumer device. Intel’s Otellini couldn’t have been more different from Jobs. He was hired to be a manager, not a visionary. Unlike Intel’s prior CEOs—Bob Noyce, Gordon Moore, Andy Grove, and Craig Barrett—Otellini’s background was not in engineering or physics, but in economics. He’d graduated with an MBA, not a PhD. His time as CEO saw influence shift from chemists and physicists toward managers and accountants. This was barely perceptible at first, though employees noted that executives’ shirts became steadily whiter and they wore ties more often. Otellini inherited a company that was enormously profitable. He saw his primary task as keeping profit margins as high as possible by milking Intel’s de facto monopoly on x86 chips, and he applied textbook management practices to defend it.

乔布斯早已成为硅谷的标志性人物，他发明了麦金塔并开创了电脑可以直观易用的观念。2001年，苹果推出了iPod，这是一款具有远见的产品，展示了数字技术如何转变任何消费设备。英特尔的奥特林尼与乔布斯有着截然不同的背景。他被聘为管理人员，而不是一个有远见的领袖。与英特尔以前的CEO——鲍勃·诺伊斯、戈登·摩尔、安迪·格鲁夫和克雷格·巴雷特不同，奥特林尼的背景不是工程或物理，而是经济学。他获得了MBA学位，而不是博士学位。在他担任CEO期间，影响力从化学家和物理学家转向了经理人和会计师。这一变化起初几乎不可察觉，不过员工们注意到高管们的衬衣逐渐变得更白，他们也更频繁地系领带。奥特林尼继承了一家极其赚钱的公司。他认为自己的主要任务是通过利用英特尔在x86芯片领域的事实垄断来让利润率保持尽可能高，并采用教科书式的管理实践来维护它。

The x86 architecture dominated PCs not because it was the best, but because IBM’s first personal computer happened to use it. Like Microsoft, which provided the operating system for PCs, Intel controlled this crucial building block for the PC ecosystem. This was partially by luck—IBM could have chosen Motorola’s processors for its first PCs—but also partly due to Andy

Grove's strategic foresight. At staff meetings in the early 1990s, Grove would sketch an image illustrating his vision of the future of computing: a castle surrounded by a moat. The castle was Intel's profitability; the moat, defending the castle, was x86.

x86 架构之所以主导了个人电脑，不是因为它是最好的，而是因为IBM 的第一台个人电脑恰好使用了它。就像为个人电脑提供操作系统的微软一样，英特尔控制着个人电脑生态系统的关键组成部分。这部分是靠运气实现的——IBM 可能会选择 Motorola 的处理器作为其第一个个人电脑的芯片，但也部分得归功于安迪·格鲁夫的战略远见。在上世纪 90 年代早期的员工会议上，格鲁夫会画一个形象来说明他对未来计算的愿景：一个被护城河围绕的城堡。城堡代表英特尔的盈利能力，护城河则是 x86。

In the years since Intel first adopted the x86 architecture, computer scientists at Berkeley had devised a newer, simpler chip architecture called RISC that offered more efficient calculations and thus lower power consumption. The x86 architecture was complex and bulky by comparison. In the 1990s, Andy Grove had seriously considered switching Intel's main chips to a RISC architecture, but ultimately decided against it. RISC was more efficient, but the cost of change was high, and the threat to Intel's de facto monopoly was too serious. The computer industry was designed around x86 and Intel dominated the ecosystem. So x86 defines most PC architectures to this day.

自 Intel 採用 x86 架構以來的這些年裡，伯克利的計算機科學家們已經設計出一種更新、更簡單的芯片架構，稱為 RISC，能夠提供更有效的計算，因此功耗更低。相比之下，x86 架構比較複雜笨重。在 1990 年代，安迪·格羅夫曾嚴肅考慮將英特爾的主要芯片轉換為 RISC 架構，但最終決定不這樣做。RISC 更為高效，但更換的成本很高，對英特爾的實質壟斷地位構成了嚴重威脅。計算機行業是建立在 x86 架構基礎之上的，而英特爾主宰了這個生態系統。因此，直到今天，x86 仍是大多數個人電腦架構的定義。

Intel's x86 instruction set architecture also dominates the server business, which boomed as companies built ever larger data centers in the 2000s and then as businesses like Amazon Web Services, Microsoft Azure, and Google Cloud constructed the vast warehouses of servers that create "the cloud," on which individuals and companies store data and run programs. In the 1990s and early 2000s, Intel had only a small share of the business of providing chips for servers, behind companies like IBM and HP. But Intel used its ability to design and manufacture cutting-edge processor chips to win data center market share and establish x86 as the industry standard there, too. By the mid-2000s, just as cloud computing was emerging, Intel had won a near monopoly over data center chips, competing only with AMD. Today, nearly every major data center uses x86 chips from either Intel or AMD. The cloud can't function without their processors.

英特爾的x86指令集架構也主宰著伺服器業務，該業務在2000年代公司建立越來越大的資料中心以及像亞馬遜網絡服務、微軟Azure和谷歌雲等企業構建的巨大的服務器倉庫中蓬勃發展，這些服務器倉庫創造了“雲”，個人和公司可以在其中儲存數據和運行程序。在1990年代和2000年代初期，英特爾只佔據了為服務器提供芯片業務的一小部分份額，落後於IBM和惠普等公司。但英特爾利用其設計和製造先進的處理器芯片的能力贏得了數據中心市場份額，並在那裡建立了x86作為行業標準。到了2000年代中期，正當雲計算興起之際，英特爾已經贏得了幾近壟斷的數據中心芯片市場，僅與AMD競爭。現今，幾乎所有主要的數據中心都使用來自英特爾或AMD的x86芯片。沒有它們的處理器，雲無法運作。

Some companies tried challenging x86's position as the industry standard in PCs. In 1990, Apple and two partners established a joint venture called Arm, based in Cambridge, England. The aim was to design processor chips using a new instruction set architecture based on the simpler RISC principles that Intel had considered but rejected. As a startup, Arm faced no costs of shifting away from x86, because it had no business and no customers. Instead, it wanted to replace x86 at the center of the computing ecosystem. Arm's first CEO, Robin Saxby, had vast ambitions for the twelve-person startup. “We have got to be the global standard,” he told his colleagues. “That's the only chance we've got.”

一些公司試圖挑戰x86在個人電腦業務中的行業標準地位。1990年，蘋果公司和兩家合作夥伴成立了一家名為Arm的合資企業，總部設在英國劍橋。旨在設計使用基於簡單的RISC原則的新指令集架構的處理器芯片，這是英特爾曾考慮但拒絕的方案。作為一家初創公司，Arm面

臨著轉向x86的成本，因為它沒有業務和客戶。相反，它想要取代x86成為計算生態系統的核心。 Arm的第一任CEO Robin Saxby對這家只有12人的初創公司有著巨大的雄心壯志。“我們必須成為全球標準，”他告訴同事。“那是我們唯一的機會。”

Saxby had climbed the ranks at Motorola’s European semiconductor divisions before working at a European chip startup that failed because its manufacturing processes underperformed. He understood the limits of relying on in-house manufacturing. “Silicon is like steel,” he insisted in the early debates over Arm’s strategy. “It’s a commodity…. We should build chips over my dead body.” Instead, Arm adopted a business model of selling licenses for use of its architecture and letting any other chip designer buy them. This presented a new vision of a disaggregated chip industry. Intel had its own architecture (x86) on which it designed and produced many different chips. Saxby wanted to sell his Arm architecture to fabless design firms that would customize Arm’s architecture for their own purposes, then outsource the manufacturing to a foundry like TSMC.

Saxby曾在摩托罗拉的欧洲半导体部门爬上了职业阶梯，然后到一家欧洲的芯片初创公司工作，该公司由于制造工艺表现不佳而失败了。他理解依赖内部制造的局限性。在Arm的战略早期辩论中，他坚持认为：“硅就像钢铁，是一个商品……我们应该在我死后才建造芯片。”相反，Arm采取了销售使用其架构的许可证并让任何其他芯片设计师购买的商业模式。这呈现了一个分散的芯片行业的新愿景。英特尔拥有自己的架构（x86），在其上设计并生产了许多不同的芯片。Saxby希望将他的Arm架构出售给“无晶圆厂设计企业（fabless design firms）”，它们将为自己的目的定制Arm的架构，然后外包制造给像TSMC这样的晶圆厂。

Saxby didn’t simply dream of rivaling Intel, but of disrupting its business model. However, Arm failed to win market share in PCs in the 1990s and 2000s, because Intel’s partnership with Microsoft’s Windows operating system was simply too strong to challenge. However, Arm’s simplified, energy-efficient architecture quickly became popular in small, portable devices that had to economize on battery use. Nintendo chose Arm-based chips for its handheld video games, for example, a small market that Intel never paid much attention to. Intel’s computer processor oligopoly was too profitable to justify thinking about niche markets. Intel didn't realize until too late that it ought to compete in another seemingly niche market for a portable computing device: the mobile phone.

Saxby不仅仅梦想着与英特尔竞争，而是想打破它的商业模式。然而，Arm在20世纪90年代和21世纪2000年代未能在个人电脑市场上赢得市场份额，因为英特尔与微软Windows操作系统的合作实在太强大了，无法挑战。然而，Arm的简化、节能的架构很快在需要节省电池使用的小型便携设备中变得流行。例如，任天堂选择了基于Arm的芯片来制作它的手持视频游戏，这是英特尔从未过多关注的小市场。英特尔的电脑处理器垄断利润太高，无法证明其在考虑利基市场的成本效益。直到太迟，英特尔才意识到自己应该在另一个看似利基的便携式计算设备市场上竞争：移动电话。

The idea that mobile devices would transform computing wasn't new. Carver Mead, the visionary Caltech professor, had predicted as much in the early 1970s. Intel, too, knew that PCs wouldn't be the final stage in the evolution of computing. The company invested in a series of new products over the course of the 1990s and 2000s, like a Zoom-esque video conferencing system that was two decades ahead of its time. But few of these new products caught on, less for technical reasons than because they were all far less profitable than Intel's core business of building chips for PCs. They never attracted support from inside Intel.

移动设备将改变计算机的概念并非新鲜事。早在1970年代，具有远见卓识的加州理工学院教授卡弗·梅德就预测了这一点。英特尔也知道PC不会是计算机演化的最终阶段。在1990年代和2000年代，该公司投资了一系列新产品，如Zoom式视频会议系统，这比其时代落后了二十年。但并非出于技术原因，这些新产品中很少有能达到Intel核心业务——为PC构建芯片的盈利水平。它们从未得到Intel内部的支持。

Mobile devices had been a regular source of discussion at the company since the early 1990s, when Andy Grove was still CEO. At one meeting at Intel's Santa Clara headquarters in the early 1990s, an executive waved his Palm Pilot in the air and declared: "These devices will grow up and replace the PC." But the idea of pouring money into mobile devices seemed like a wild gamble at a time when there was far more money to be made selling processors for PCs. So Intel decided not to enter the mobile business until it was too late.

自1990年代初期时，移动设备就已成为公司的常见话题，当时安迪·格鲁夫仍担任CEO。在一次于英特尔圣克拉拉总部的会议上，一名高管挥舞着他的Palm Pilot并宣称："这些设备将成长并取代PC。"但在当时，投入移动设备的资金似乎是一个疯狂的赌博，因为销售PC处理器可以赚更多的钱。因此，英特尔决定不进入移动业务，直到为时已晚。

Intel's dilemma could have been easily diagnosed by the Harvard professor who'd advised Andy Grove. Everyone at Intel knew Clayton Christensen and his concept of "the innovator's dilemma." However, the company's PC processor business looked likely to print money for a very long time. Unlike in the 1980s, when Grove reoriented Intel away from DRAM at a time when the company was bleeding money, in the 1990s and 2000s, Intel was one of America's most profitable firms. The problem wasn't that no one realized Intel ought to consider new products, but that the status quo was simply too profitable. If Intel did nothing at all, it would still own two of the world's most valuable castles—PC and server chips—surrounded by a deep x86 moat.

英特爾的困境可以很容易地被那位曾经为安迪·格魯夫提供意见的哈佛教授診斷出来。英特爾的每个人都知道克莱頓·克里斯滕森和他的"創新者的困境"概念。然而，公司的個人電腦處理器業務看起來仍有很長時間可以賺錢。不像上世紀80年代，當格魯夫在公司流血時重新調整英特爾遠離DRAM，而在1990年代和2000年代，英特爾已成為美國最有利可圖的公司之一。問題不是沒有人意識到英特爾應考慮新產品，而是現狀實在太有利可圖。如果英特爾什麼都不做，它仍然擁有世界上最有價值的兩座城堡 - PC和服務器芯片 - 周圍是一個深深的x86護城河。

Shortly after the deal to put Intel's chips in Mac computers, Jobs came back to Otellini with a new pitch. Would Intel build a chip for Apple's newest product, a computerized phone? All cell phones used chips to run their operating systems and manage communication with cell phone networks, but Apple wanted its phone to function like a computer. It would need a powerful computer-style processor as a result. “They wanted to pay a certain price,” Otellini told journalist Alexis Madrigal after the fact, “and not a nickel more…. I couldn’t see it. It wasn’t one of these things you can make up on volume. And in hindsight, the forecasted cost was wrong and the volume was 100× what anyone thought.” Intel turned down the iPhone contract.

在把英特尔芯片放入苹果电脑的交易不久之后，乔布斯向奥特林尼提出了一个新的建议。英特尔是否能为苹果最新的产品——一款计算机化的手机——制造芯片？所有的手机都使用芯片来运行其操作系统并管理与手机网络的通信，但是苹果想要其手机像电脑一样运作，因此需要强大的计算机式处理器。奥特林尼事后告诉记者亚历克西斯·马德里加尔：“他们想要支付一定的价格，而不是一分钱更多……我无法筹措。这不是可以靠数量解决的问题。回过头来看，预计的成本是错误的，而数量是任何人都没有想到的100倍。”因此，英特尔拒绝了iPhone合同。

Apple looked elsewhere for its phone chips. Jobs turned to Arm’s architecture, which unlike x86 was optimized for mobile devices that had to economize on power consumption. The early iPhone processors were produced by Samsung, which had followed TSMC into the foundry business. Otellini’s prediction that the iPhone would be a niche product proved horribly wrong. By the time he realized his mistake, however, it was too late. Intel would later scramble to win a share of the smartphone business. Despite eventually pouring billions of dollars into products for smartphones, Intel never had much to show for it. Apple dug a deep moat around its immensely profitable castle before Otellini and Intel realized what was happening.

蘋果公司轉向其他地方尋找其手機芯片。 Jobs 選擇了 Arm 的架構，這與 x86 架構不同，它針對需要節省能源的移動設備進行了優化。早期的 iPhone 处理器由三星生產，三星隨後進入了晶圓代工業務。奧特林尼預測 iPhone 將成為一個利基產品，結果證明他錯了。然而，他意識到這個錯誤時已經為時已晚。英特爾後來亂了奪取智能手機市場的一席之地。儘管最終向智能手機產品注入了數十億美元，英特爾仍然沒有多少成果。奧特林尼和英特爾意識到正在發生的事情之前，蘋果公司已經在其利潤豐厚的城堡周圍挖掘了很深的護城河。

Just a handful of years after Intel turned down the iPhone contract, Apple was making more money in smartphones than Intel was selling PC processors. Intel tried several times to scale the walls of Apple's castle but had already lost first-mover advantage. Spending billions for second place was hardly appealing, especially since Intel's PC business was still highly profitable and its data center business was growing quickly. So Intel never found a way to win a foothold in mobile devices, which today consume nearly a third of chips sold. It still hasn't.

僅僅幾年之後，Intel拒絕了iPhone合約，而蘋果在智能手機市場的收入已經超過了Intel在銷售PC處理器方面的收入。Intel曾多次試圖攀登蘋果雄城的城牆，但已經失去先發優勢。花費數十億美元來爭奪第二名是很不吸引人的，特別是因為Intel的PC業務仍然極其盈利，其數據中心業務也在快速增長。因此，Intel從未找到在移動設備中佔據一席之地的方法，而這些移動設備現在佔據了近三分之一的芯片銷售量。它還沒有找到。

Intel's missed opportunities in the years since Grove left the scene all had a common cause. Since the late 1980s, Intel has made a quarter trillion dollars in profit, even before adjusting for inflation, a track record that few other companies have matched. It has done this by charging a ton for PC and server chips. Intel could sustain high prices because of the optimized design processes and advanced manufacturing that Grove had honed and bequeathed to his successors. The company's leadership consistently prioritized the production of chips with the highest profit margin.

自格羅夫離開後的這幾年，英特爾錯失了很多機會，這背後有一個共同的原因。從1980年代末開始，英特爾已經賺取了將近兩千五百億美元的利潤，即使不考慮通貨膨脹，這樣的成績也很少見。該公司通過高價售賣個人電腦和服務器芯片來實現這一目標。英特爾之所以能夠維持高價格，是由於格羅夫先生所磨煉和繼承的優化設計流程和先進制造技術。該公司的領導層始終優先考慮生產利潤最高的芯片。

This was a rational strategy—no one wants products with low profit margins—but it made it impossible to try anything new. A fixation on hitting short-term margin targets began to replace long-term technology leadership. The shift in power from engineers to managers accelerated this process. Otellini, Intel’s CEO from 2005 to 2013, admitted he turned down the contract to build iPhone chips because he worried about the financial implications. A fixation on profit margins seeped deep into the firm—its hiring decisions, its product road maps, and its R&D processes. The company’s leaders were simply more focused on engineering the company’s balance sheet than its transistors. “It had the technology, it had the people,” one former finance executive at Intel reminisced. “It just didn’t want to take the margin hit.”

這是一個理性的策略——沒有人想要低利潤產品——但它使得嘗試任何新事物變得不可能。短期利潤目標的追求開始取代長期科技領先地位。工程師失去權力，而管理者的權力則加速了這個過程。2005年至2013年期間擔任Intel CEO的Otellini承認拒絕了建造iPhone芯片的合同，因為他擔心財務影響。利潤率的著迷深深滲透到了公司的招聘決策、產品路線圖和研發過程中。公司的領袖只是更關注於設計公司的資產負債表，而非晶體管。“它擁有技術，它擁有人才，”一位曾在Intel任職財務主管回憶道，“它只是不想承受利潤損失。”

CHAPTER 34 Running Faster?

A ndy Grove was dining at a Palo Alto restaurant in 2010 when he was introduced to three Chinese venture capitalists who were touring Silicon Valley. He'd stepped down as Intel's chairman in 2005 and was now a simple retiree. The company he'd built and then rescued was still immensely profitable. It made money even in 2008 and 2009, though Silicon Valley's unemployment rate spiked above 9 percent. However, Grove didn't view Intel's past success as an argument for complacency. He was as paranoid as ever. Seeing Chinese venture capitalists investing in Palo Alto made him wonder: Was Silicon Valley smart to be offshoring production at a time of mass unemployment?

安迪·格罗夫（Andy Grove）2010年在帕洛阿尔托一家餐厅用餐时，认识了三名巡游硅谷的中国风险投资家。他在2005年卸任英特尔（Intel）的董事长，现在只是一名普通的退休人员。他建立并挽救的公司仍然极其赚钱。即使在2008年和2009年，硅谷的失业率飙升至9%以上，它仍有盈利。但是，格罗夫并不认为英特尔过去的成功足以证明自己已经趋于满足。他一如既往地偏执，看到中国的风险投资家在帕洛阿尔托投资，让他想到，当时大规模失业的情况下，硅谷外包生产是否明智？

As a Jewish refugee from Nazi and Soviet armies, Grove was no nativist. Intel hired engineers from the world over. It operated facilities on multiple continents. However, Grove was worried about the offshoring of advanced manufacturing jobs. The iPhone, which had been introduced just three years earlier, exemplified the trend. Few of the iPhone's components were built in the U.S. Though offshoring started with low-skilled jobs, Grove didn't think it would stop there, whether in semiconductors or any other industry. He worried about lithium batteries needed for electric vehicles, where the U.S. made up a tiny share of the market despite having invented much of the core technology. His solution: "Levy an extra tax on the product of offshored labor. If the result is a trade war, treat it like other wars— fight to win."

作为纳粹和苏联军队的犹太难民，Grove 不是本土主义者。英特尔聘请了来自世界各地的工程师，它在多个大陆都开设了工厂。然而，

Grove 对先进制造业的离岸化感到担忧。iPhone 是三年前推出的，它展现了这一趋势。iPhone 的少数部件在美国制造。尽管离岸化始于低技能工作，但 Grove 认为它不会止步于此，无论在半导体还是其他任何行业。他对用于电动汽车的锂电池感到担忧，尽管美国在核心技术上发明了很多，但却占市场的一小部分。他的解决方案是："在离岸劳动产品上征收额外税款。如果结果是贸易战，把它视为其他战争 - 奋力争胜。"

Many people chose to write off Grove as a representative of a bygone era. He'd built Intel a generation earlier, before the internet existed. His company missed the mobile phone and was living off the fruits of its x86 monopoly. In the early 2010s, Intel retained the world's most advanced semiconductor process technology, introducing smaller transistors before rivals, with the same regular cadence it had been known for since the days of Gordon Moore. However, the gap between Intel and rivals like TSMC and Samsung had begun to shrink.

許多人選擇將Grove視為過時時代的代表。在互聯網尚未存在之前，他已經建立了英特爾公司一代人。他的公司錯過了手機，並且正在從其x86壟斷份額中獲利。在2010年代初，英特爾保留了全球最先進的半導體製程技術，比競爭對手更早推出了更小的晶體管，同樣地保持了自戈登·摩爾（Gordon Moore）時代以來的規律節奏。然而，英特爾與台積電和三星等競爭對手之間的差距已經開始縮小。

Moreover, Intel's business was now overshadowed by other tech firms with different business models. Intel had been one of the world's most valuable companies in the early 2000s, but had been overtaken by Apple, whose new mobile ecosystem didn't rely on Intel's chips. Intel missed the rise of the internet economy. Facebook, founded in 2006, was by 2010 worth nearly half as much as Intel. It would soon become several times more valuable. The Valley's biggest chipmaker could retort that the internet's data was processed on its server chips and accessed on PCs reliant on its processors. Yet producing chips was less profitable than selling ads on apps. Grove idolized "disruptive innovation," but by the 2010s, Intel's business was being disrupted. His lament of Apple's offshored assembly lines fell on deaf ears.

此外，英特爾的業務現在被其他擁有不同業務模式的科技公司掩蓋。英特爾曾經是世界上最有價值的公司之一，在2000年代初就已經名列前茅，但被新的移動生態系統不依靠英特爾芯片的蘋果公司超越。英特爾錯過了互聯網經濟的興起。成立於2006年的Facebook，到2010年，其價值幾乎達到了英特爾的一半。它很快就會變得更加有價值。矽谷最大的晶片製造商可以反駁，指出互聯網的數據是在其伺服器晶片上處理的，並在依靠其處理器的個人電腦上進行訪問。但生產晶片的利潤不如在應用程序上銷售廣告。格羅夫崇尚“破壞性創新”，但到2010年代，英特爾的業務正在遭受破壞。他對蘋果的外包裝配線的哀嘆落了空。

Even in the semiconductor space, Grove’s doom-filled prophesies were widely rejected. True, new semiconductor foundries like TSMC were largely offshore. Yet foreign foundries produced chips largely designed by American fabless firms. Moreover, their fabs were full of U.S.-made manufacturing equipment. Offshoring to Southeast Asia had been central to the chip industry’s business model since Fairchild Semiconductor—Andy Grove’s first employer—opened its initial assembly plant in Hong Kong.

Grove wasn’t convinced. “Abandoning today’s ‘commodity’ manufacturing can lock you out of tomorrow’s emerging industry,” he declared, pointing to the electric battery industry. The U.S. “lost its lead in batteries thirty years ago when it stopped making consumer electronics devices,” Grove wrote. Then it missed PC batteries, and now was far behind on batteries for electric vehicles. “I doubt they will ever catch up,” he predicted in 2010.

即使在半導體領域，格魯夫的厄運預言也被廣泛地拒絕。的確，像台積電這樣的新型半導體製造廠大多數在海外。然而，外國製造廠生產的芯片大部分是由美國Fabless公司設計的。此外，它們的工廠裝備大多數是由美國製造的設備。自Fairchild Semiconductor—格魯夫的第一份工作，開設了在香港的最初裝配廠以來，到東南亞的離岸外包已成為芯片行業的商業模式的核心。 格魯夫並不信服。“放棄今天的‘商品’製造同樣會讓你失去明天新興產業的機會，”他宣稱，並指出了電池工業。美國“在三十年前停止生產消費電子產品時失去了電池技術的優勢”格魯夫寫道。然後，在PC電池方面失掉了優勢，現在在電動車電池方面也落後許多。他在2010年預測：“我懷疑他們將永遠無法迎頭趕上”。

Even within the semiconductor industry, it was easy to find counterpoints to Grove's pessimism about offshoring expertise. Compared to the situation in the late 1980s, when Japanese competitors were beating Silicon Valley in terms of DRAM design and manufacturing, America's chip ecosystem looked healthier. It wasn't only Intel that was printing immense profits. Many fabless chip designers were, too. Except for the loss of cutting-edge lithography, America's semiconductor manufacturing equipment firms generally thrived during the 2000s. Applied Materials remained the world's largest semiconductor toolmaking company, building equipment like the machines that deposited thin films of chemicals on top of silicon wafers as they were processed. Lam Research had world-beating expertise in etching circuits into silicon wafers. And KLA, also based in Silicon Valley, had the world's best tools for finding nanometer-sized errors on wafers and lithography masks. These three toolmakers were rolling out new generations of equipment that could deposit, etch, and measure features at the atomic scale, which would be crucial for making the next generation of chips. A couple Japanese firms—notably, Tokyo Electron—had some comparable capabilities to America's equipment makers. Nevertheless, it was basically impossible to make a leading-edge chip without using some American tools.

即使在半导体行业内部，也很容易找到与格罗夫对于外包专业知识的悲观看法相反的观点。与20世纪80年代日本的竞争对手在DRAM设计和制造方面击败硅谷相比，美国的芯片生态系统看起来更为健康。赚取巨额利润的不仅仅是英特尔。许多无晶圆厂芯片设计师也是。除了失去尖端光刻技术外，美国半导体制造设备公司在2000年代一般繁荣。应用材料仍然是全球最大的半导体制造商，建造像将化学物质的薄膜沉积在硅片上处理一样的设备。Lam研究在将电路蚀刻到硅片方面具有世界领先的专业知识。总部也设在硅谷的KLA拥有在硅片和光刻掩模上发现纳米级错误的最佳工具。这三家设备制造商正在推出新一代设备，可以在原子尺度下沉积、蚀刻和测量特征，这对于制造下一代芯片至关重要。还有几家日本公司，尤其是东京电子具有与美国设备制造商相当的能力。尽管如此，基本上不可能制造出不使用一些美国工具的领先芯片。

The same was true for designing chips. By the early 2010s, the most advanced microprocessors had a billion transistors on each chip. The software capable of laying out these transistors was provided by three

American firms, Cadence, Synopsys, and Mentor, which controlled around three-quarters of the market. It was impossible to design a chip without using at least one of these firms' software. Moreover, most of the smaller firms providing chip design software were U.S.-based, too. No other country came close.

相同的情况也适用于芯片设计。到了2010年代初期，最先进的微处理器每个芯片上都有十亿个晶体管。能够布局这些晶体管的软件是由三家美国公司Cadence、Synopsys和Mentor提供的，它们控制了市场的三分之二。设计芯片时至少要使用这三家公司中的一家提供的软件。此外，大多数提供芯片设计软件的小型公司也都是总部设在美国的。其他任何一个国家都没有其竞争力。

When analysts on Wall Street and in Washington looked at Silicon Valley, they saw a chip industry that was profitable and advancing technologically. There were, of course, some risks of relying so heavily on a couple of facilities in Taiwan to manufacture a large share of the world's chips. In 1999, an earthquake measuring 7.3 on the Richter scale struck Taiwan, knocking out power across much of the country, including from two nuclear power plants. TSMC's fabs lost power, too, threatening the company's production and many of the world's chips.

當華爾街和華盛頓的分析師看向硅谷時，他們看到了一個盈利和技術進步的晶片行業。當然，如此大量依賴臺灣的幾個工廠來製造世界上大部分的晶片，有一些風險。 1999年，一場規模7.3級的地震襲擊台灣，導致該國大部分地區以及兩座核電廠的停電。 台積電的晶圓廠也斷電了，威脅了該公司的生產和全球許多晶片的供應。

Morris Chang was quickly on the phone with Taiwanese officials to ensure the company got preferential access to electricity. It took a week to get four of the company's five fabs back online; the fifth took even longer. However, disruptions were limited and the market for consumer electronics reverted to normal within a month. However, the 1999 earthquake was only the third strongest the island had suffered in the twentieth century; it was easy to imagine stronger seismic shocks. TSMC's customers were told that the company's facilities could tolerate earthquakes measuring 9 on the Richter scale, of which the world has experienced five since 1900. This was not a claim that anyone wanted to test. However, TSMC could always point out that Silicon Valley sat atop the San Andreas Fault, so bringing manufacturing back to California wasn't much safer.

張忠謀緊急通過電話聯繫台灣官員，以確保公司優先獲得電力供應。公司的五個晶圓廠中有四個在一周內恢復運營，第五個則需要更長的時間。然而，破壞有限，消費電子市場在一個月內恢復正常。然而，1999年的地震僅是20世紀島嶼上發生的第三強。可以想象會有更強的地震。 TSMC告訴客戶，該公司的設施可以承受9級的地震，自1900年以來全世界發生了五次。這不是任何人想要測試的說法。然而，TSMC總是可以指出，硅谷位於聖安德魯斯斷層上，所以把生產帶回加利福尼亞並不會更安全。

A more difficult question was how the U.S. government should adjust its controls on foreign sales of semiconductor technology to account for an increasingly international supply chain. Except for a couple of small chipmakers that produced specialized semiconductors for the U.S. military, Silicon Valley giants downgraded their relations with the Pentagon during the 1990s and 2000s. When they'd faced Japanese competition in the 1980s, Silicon Valley CEOs spent plenty of time in the halls of Congress. Now they didn't think they needed government help. Their main concern was for government to get out of the way, by signing trade deals with other countries and removing controls on exports. Many officials in Washington backed the industry's calls for looser controls. China had ambitious companies like SMIC, but the consensus in Washington was that trade and investment would encourage China to become a "responsible stakeholder" of the international system, as influential diplomat Robert Zoellick put it.

美国政府应如何调整对外销售半导体技术的控制，以适应日益国际化的供应链，是一个更具有难度的问题。除了为美国军方生产专业半导体的几家小型芯片制造商外，硅谷巨头在二十一世纪前十年降低了与五角大楼之间的关系。当他们在上世纪八十年代面对日本的竞争时，硅谷首席执行官们在国会大厦中花费了很多时间。现在，他们认为自己不需要政府援助。他们的主要关注点是政府切通过与其他国家签订贸易协议和取消出口管制来商业化，让其他国家走开。华盛顿的许多官员支持行业呼吁放宽控制。中国拥有像中芯国际这样有雄心的企

业，但华盛顿的共识是贸易和投资将鼓励中国成为“国际体系的负责任利益相关方”，如有影响力的外交家罗伯特·佐利克所说。

Moreover, popular theories about globalization made it sound almost impossible to impose strict controls. Controls had been hard enough to enforce during the Cold War, sparking regular disputes between the U.S. and allies about what equipment could be sold to the Soviets. Unlike the USSR, China in the 2000s was far more integrated into the world economy. Washington concluded that export controls would do more harm than good, hurting U.S. industry without preventing China from buying goods from firms in other countries. Japan and Europe were eager to sell almost anything to the PRC. No one in Washington had the stomach for a fight with allies about export controls, especially as U.S. leaders were focused on befriending their Chinese counterparts.

此外，全球化的流行理论几乎让严格控制成为不可能。即使是在冷战期间，控制已经非常艰难，经常引起美国和盟国之间的争议，涉及哪些设备可以出售给苏联。与苏联不同，2000年代的中国更加深入地融入了世界经济体系。华盛顿认为，出口管制会损害美国产业，而不会阻止中国从其他国家的企业购买商品。日本和欧洲渴望向中国销售几乎任何产品。在美国领导人重视与中国同行交往时，他们也没有胃口与盟友在出口管制问题上展开争斗。

A new consensus in Washington formed around the idea that the best policy was to “run faster” than America’s rivals. “The likelihood that the United States will grow dependent on any one country, much less China, for any one product, especially semiconductors, is exceedingly small,” predicted one American expert. The U.S. went so far as to give China’s SMIC special status as a “validated end-user,” certifying that the company didn’t sell to the Chinese military and was thus exempt from certain export controls. Other than a handful of legislators—mostly Southern Republicans who still looked at China as though the Cold War had never ended—almost everyone in Washington backed the strategy of “running faster” than rivals.

華盛頓形成了一個新共識，認為最好的政策是比美國的競爭對手“跑得更快”。“美國會依賴任何一個國家，尤其是中國，生產任何產品，特別是半導體芯片的可能性非常小，”一位美國專家預測。美國甚至授予

中國SMIC“驗證的最終用戶”特殊地位，證明該公司非在售予中國軍方，因此免除了某些出口管制。除了少數立法者 - 大多數仍然把中國看作冷戰從未結束的南方共和黨人之外，華盛頓的幾乎所有人都支持“比競爭對手跑得更快”的戰略。

“Run faster” was an elegant strategy with only a single problem: by some key metrics, the U.S. *wasn’t* running faster, it was losing ground. Hardly anyone in government bothered to do the analysis, but Andy Grove’s gloomy predictions about the offshoring of expertise were partially coming true. In 2007, the Defense Department commissioned a study from former Pentagon official Richard Van Atta and several colleagues to assess the impact of semiconductor industry “globalization” on the military’s supply chains. Van Atta had worked on defense microelectronics for several decades and had lived through the rise and fall of Japan’s chip industry. He wasn’t prone to overreaction and understood how a multinational supply chain made the industry more efficient. In peacetime, this system worked smoothly. However, the Pentagon had to think about worst-case scenarios. Van Atta reported that the Defense Department’s access to cutting-edge chips would soon depend on foreign countries because so much advanced fabrication was moving abroad.

“跑得更快”是一种优雅的策略，只有一个问题：根据一些关键指标，美国并没有跑得更快，而是在失去地位。政府中几乎没有人去分析这个问题，但是安迪·格鲁夫的悲观预测关于专业知识的海外转移正在部分地变成现实。2007年，国防部委托前五角大楼官员理查德·范·阿塔和几位同事进行一项研究，评估半导体“全球化”对军方供应链的影响。范·阿塔已经从事国防微电子行业数十年，经历了日本芯片行业的兴衰。他不容易过分反应，并且了解跨国供应链如何使该行业更加有效率。在和平时期，这个系统可以很顺畅地运作。然而，国防部不得不考虑最坏的情况。范·阿塔报告称，国防部对先进芯片的获取将很快取决于外国，因为很多高级制造正在转移到海外。

Amid the hubris of America’s unipolar moment, hardly anyone was willing to listen. Most people in Washington simply concluded the U.S. was “running faster” without even glancing at the evidence. However, the history of the semiconductor industry didn’t suggest that U.S. leadership was guaranteed. America hadn’t outrun the Japanese in the 1980s, though it did in the 1990s.

GCA hadn’t outrun Nikon or ASML in lithography. Micron was the only DRAM producer able to keep pace with East Asian rivals, while many other U.S. DRAM producers went bust. Through the end of the 2000s, Intel retained a lead over Samsung and TSMC in producing miniaturized transistors, but the gap had narrowed. Intel was running more slowly, though it still benefitted from its more advanced starting point. The U.S. was a leader in most types of chip design, though Taiwan’s MediaTek was proving that other countries could design chips, too. Van Atta saw few reasons for confidence and none for complacency. “The U.S. leadership position,” he warned in 2007, “will likely erode seriously over the next decade.” No one was listening.

在美国独超的时刻，几乎没有人愿意倾听。华盛顿的大多数人仅仅得出结论，美国在加速奔跑而没有看证据。然而，半导体行业的历史并没有表明美国能够保证领导地位。尽管在1990年代赶超了日本，但美国并没有在1980年代超过日本。GCA在光刻技术方面并没有超越Nikon或ASML。Micron是唯一能够与东亚竞争对手并驾齐驱的DRAM生产商，而许多其他美国DRAM生产商都破产了。到2000年代末，英特尔在生产微型晶体管方面仍然领先于三星和台积电，但差距已经缩小。英特尔的速度更慢了，但仍然受益于其更先进的起点。美国在大多数芯片设计方面都是领导者，但台湾的联发科正在证明其他国家也可以设计芯片。范阿塔认为没有多少信心，并且没有自满的理由。他在2007年警告说，“美国的领导地位可能在未来十年内严重侵蚀。”没有人在听。

PART VI

OFFSHORING INNOVATION?

CHAPTER 35 “Real Men Have Fabs”

J erry Sanders, the Rolex-clad, Rolls Royce−driving brawler who founded AMD, liked to compare owning a semiconductor fab with putting a pet shark in your swimming pool. Sharks cost a lot to feed, took time and energy to maintain, and could end up killing you. Even still, Sanders was sure of one thing: he’d never give up his fabs. Though he had studied electrical engineering as an undergraduate at the University of Illinois, he was never a manufacturing guy. He moved up the ranks in sales and marketing at Fairchild Semiconductor, making his name as the company’s most flamboyant and successful salesman.

創辦了AMD的穿著勞力士手表、開著勞斯萊斯輪軸的打鬥者傑瑞·桑德斯喜歡把擁有半導體製造廠比作在游泳池中投放寵物鯊魚。鯊魚需要花費大量的成本、時間和精力來維護，最終還可能會致命傷人。即便如此，桑德斯確信一件事：他永遠不會放棄自己的製造廠。儘管他在伊利諾伊大學攻讀電氣工程，但他從未是製造業的人。他在費爾柴爾德半導體的銷售和市場部門中晉升，成為公司最引人注目和成功的推銷員之一。

His specialty was sales, but Sanders never dreamed of giving up AMD’s manufacturing facilities, even as the rise of foundries like TSMC made it possible for big chip firms to consider divesting their manufacturing operations and outsourcing to a foundry in Asia. Having brawled with the Japanese for DRAM market share in the 1980s and with Intel for the PC market in the 1990s, Sanders was committed to his fabs. He thought they were crucial to AMD’s success.

Even he admitted, though, that it was becoming harder to make money while owning and operating a fab. The problem was simple: each generation of technological improvement made fabs more expensive. Morris Chang had drawn a similar conclusion several decades earlier, which is why he thought TSMC’s business model was superior. A foundry like TSMC could fabricate chips for many chip designers, wringing out efficiencies from its massive production volumes that other companies would find difficult to replicate.

桑德斯的专长是销售，但他从未想过放弃AMD的制造设施，即使像台积电这样的晶圆厂的崛起使得大型芯片公司考虑将制造业务剥离并外包至亚洲的晶圆厂。在80年代与日本人争夺DRAM市场份额以及在90年代与英特尔竞争PC市场之后，桑德斯坚持使用自己的生产基地。他认为这对AMD的成功至关重要。尽管如此，他也承认，拥有和运营生产基地越来越难赚钱。问题很简单：每一代技术改进都使生产基地变得更加昂贵。莫里斯·张几十年前就得出了类似的结论，这就是为什么他认为台积电的商业模式更为优越。像台积电这样的晶圆厂可以为许多芯片设计师制造芯片，从其巨大的生产量中挤出效率，其他公司很难复制。

Not all sectors of the chip industry faced similar dynamics, but many did. By the 2000s, it was common to split the semiconductor industry into three categories. “Logic” refers to the processors that run smartphones, computers, and servers. “Memory” refers to DRAM, which provides the short-term memory computers need to operate, and flash, also called NAND, which remembers data over time. The third category of chips is more diffuse, including analog chips like sensors that convert visual or audio signals into digital data, radio frequency chips that communicate with cell phone networks, and semiconductors that manage how devices use electricity.

不是所有芯片行业的领域都面临着类似的动态，但许多行业确实如此。到了21世纪，将半导体行业分为三类已经很常见。“逻辑”指的是运行智能手机、计算机和服务器的处理器。“存储器”指的是DRAM，它为计算机提供短期内存所需，Flash也被称为NAND，可以记住数据。第三类芯片更为分散，包括模拟芯片，如将视觉或音频信号转换为数字数据的传感器，与手机网络通信的射频芯片，以及管理设备如何使用电力的半导体。

This third category has not been primarily dependent on Moore’s Law to drive performance improvements. Clever design matters more than shrinking transistors. Today around three-quarters of this category of chips are produced on processors at or larger than 180 nanometers, a manufacturing technology that was pioneered in the late 1990s. As a result, the economics of this segment are different from logic and memory chips that must relentlessly shrink transistors to remain on the cutting edge. Fabs for these types of chips generally don’t need to race toward the smallest transistors every couple of years, so they're substantially cheaper, on average requiring a quarter the capital investment of an advanced fab for logic or memory chips. Today, the biggest analog chipmakers are American, European, or Japanese. Most of their production occurs in these three regions, too, with only a sliver offshored to Taiwan and South Korea. The largest analog chipmaker today is Texas Instruments, which failed to establish an Intel-style monopoly in the PC, data center, or smartphone ecosystems but remains a medium-sized, highly profitable chipmaker with a vast catalog of analog chips and sensors. There are many other U.S.-based analog chipmakers now, like Onsemi, Skyworks, and Analog Devices, alongside comparable companies in Europe and Japan.

这第三类芯片的性能提升并不主要依赖于摩尔定律，而是更注重巧妙的设计，比晶体管的缩小更重要。如今约三分之三的这类芯片是在处理器上生产的，处理器的制造工艺达到或大于180纳米，这一技术是在20世纪90年代开创的。因此，这个领域的经济学与逻辑和存储芯片不同，后者必须不断缩小晶体管才能保持领先地位。这些芯片的工厂通常不需要每两年就追求最小规模的晶体管，因此它们比起逻辑或存储芯片的先进工厂要便宜得多，平均只需要资本投资的四分之一。如今，最大的模拟芯片制造商是美国、欧洲或日本的公司。他们的大部分生产也发生在这三个地区，只有一小部分外包到台湾和韩国。目前最大的模拟芯片制造商是德州仪器公司（Texas Instruments），它没有在个人电脑、数据中心或智能手机生态系统中建立像英特尔那样的垄断地位，但仍是一家规模中等、利润丰厚、拥有庞大模拟芯片和传感器目录的芯片制造商。还有其他一些美国模拟芯片制造商，如Onsemi、Skyworks和Analog Devices，以及欧洲和日本的类似公司。

The memory market, by contrast, has been dominated by a relentless push toward offshoring production to a handful of facilities, mostly in East Asia. Rather than a diffuse set of suppliers centered in advanced economies, the two main types of memory chip—DRAM and NAND—are produced by only a couple of firms. For DRAM memory chips, the type of semiconductor that defined Silicon Valley's clash with Japan in the 1980s, an advanced fab can cost $20 billion. There used to be dozens of DRAM producers, but today there are only three major producers. In the late 1990s, several of Japan's struggling DRAM producers were consolidated into a single company, called Elpida, which sought to compete with Idaho's Micron and with Korea's

Samsung and SK Hynix. By the end of the 2000s, these four companies controlled around 85 percent of the market. Yet Elpida struggled to survive and in 2013 was bought by Micron. Unlike Samsung and Hynix, which produce most of their DRAM in South Korea, Micron’s long string of acquisitions left it with DRAM fabs in Japan, Taiwan, and Singapore as well as in the United States. Government subsidies in countries like Singapore encouraged Micron to maintain and expand fab capacity there. So even though an American company is one of the world’s three biggest DRAM producers, most DRAM manufacturing is in East Asia.

相反，記憶體市場已被不懈地推向將生產外包到一些設施中心，主要位於東亞。DRAM和NAND這兩種主要的記憶芯片不再由分散於先進經濟體中的供應商生產，而是只由幾家公司生產。對於DRAM記憶芯片，即定義硅谷與日本在1980年代爭奪的半導體類型，先進的晶圓廠成本可能高達200億美元。曾經有數十家DRAM生產商，但現在只有三家主要生產商。在20世紀90年代末，幾家日本陷入困境的DRAM生產商被合併成一家公司，名為愛普達，希望與愛達荷州的美光和韓國的三星和SK Hynix競爭。到2000年代末，這四家公司控制了市場大約85％的份額。然而，愛普達在生存方面遇到了困難，並於2013年被美光收購。不像三星和SK Hynix主要在韓國生產大部分DRAM，美光通過一系列收購得到了在日本、台灣和新加坡以及美國的DRAM晶圓廠。像新加坡這樣的國家的政府補貼鼓勵美光維持和擴大那裡的晶圓廠容量。因此，即使一家美國公司是世界三大DRAM生產商之一，大部分DRAM生產仍在東亞。

The market for NAND, the other main type of memory chip, is also Asia-centric. Samsung, the biggest player, supplies 35 percent of the market, with the rest produced by Korea’s Hynix, Japan’s Kioxia, and two American firms—Micron and Western Digital. The Korean firms produce chips almost exclusively in Korea or China, but only a portion of Micron and Western Digital’s NAND production is in the U.S., with other production in Singapore and Japan. As with DRAM, while U.S. firms play a major role in NAND production, the share of U.S.-based fabrication is substantially lower.

NAND的市場也集中在亞洲。三星作為最大的玩家，佔據著35%的市場份額，其餘由韓國的Hynix、日本的Kioxia和兩家美國公司Micron和Western Digital生產。韓國公司幾乎專門在韓國或中國生產芯片，但

Micron和Western Digital的NAND生產只有一部分在美國，在新加坡和日本還有其他生產線。和DRAM一樣，雖然美國公司在NAND生產中發揮著重要作用，但美國生產的佔比要低得多。

America's second-rate status in memory chip output, however, is nothing new. It dates to the late 1980s, when Japan first overtook the U.S. in DRAM output. The big shift in recent years is the collapse in the share of logic chips produced in the United States. Today, building an advanced logic fab costs $20 billion, an enormous capital investment that few firms can afford. As with memory chips, there's a correlation between the number of chips a firm produces and its yield—the number of chips that actually work. Given the benefits of scale, the number of firms fabricating advanced logic chips has shrunk relentlessly.

然而，美國在記憶體晶片產量方面的次級地位並非什麼新鮮事。這可以追溯到1980年代末期，當時日本首先在DRAM產量方面超過了美國。近年來的一個重大轉變是，美國生產的邏輯晶片份額崩潰了。如今，建立一個先進的邏輯芯片廠需要200億美元的巨額資本投資，而很少有公司能夠承擔這樣的成本。像記憶體晶片一樣，一個公司生產晶片的數量和其產品運行的良率是有關聯的。考慮到規模效益，生產先進邏輯芯片的公司數量已經不斷減少。

With the prominent exception of Intel, many key American logic chipmakers have given up their fabs and outsourced manufacturing. Other formerly major players, like Motorola or National Semiconductor, went bankrupt, were purchased, or saw their market share shrink. They were replaced by fabless firms, which often hired chip designers from legacy semiconductor firms but outsourced fabrication to TSMC or other foundries in Asia. This let fabless companies focus on their strength—chip design—without requiring simultaneous expertise in fabricating semiconductors.

除了英特爾之外，許多關鍵的美國邏輯晶片製造商已經放棄了他們的晶圓廠並外包生產。其他曾經的主要玩家，例如摩托羅拉或國家半導體，破產、被收購或看到他們的市場份額縮減。它們被晶圓廠外的公司所取代，後者經常從傳統的半導體公司聘請晶片設計師，但將製造工作外包給台積電或其他亞洲的晶圓廠。這讓晶圓廠外的公司專注於

他們的強項 - 晶片設計 - 而不需要同時在製造半導體上具備專業知識。

So long as Sanders was CEO, AMD, the company he founded, stayed in the business of manufacturing logic chips, like processors for PCs. Old-school Silicon Valley CEOs kept insisting that separating the fabrication of semiconductors from their design caused inefficiencies. But it was culture, not business reasoning, that kept chip design and chip fabrication integrated for so long. Sanders could still remember the days of Bob Noyce tinkering away in Fairchild's lab. His argument in favor of keeping AMD's manufacturing in-house relied on macho-man posturing that was quickly going out of date. When he heard a quip from a journalist in the 1990s that "real men have fabs," he adopted the phrase as his own. "Now hear me and hear me well," Sanders declared at one industry conference. "Real men have fabs."

只要桑德斯还是CEO，他创立的AMD公司就会继续生产逻辑芯片，比如个人电脑的处理器。老派的硅谷CEO们一直坚持认为将半导体的制造与设计分离会导致低效率。但长期以来，让芯片设计和制造集成在一起的是文化，而不是商业理念。桑德斯仍然记得鲍勃·诺伊斯在费尔柴尔德实验室里修补芯片的日子。他支持保持AMD内部制造的论点基于一种快要过时的男子气概。在上个世纪九十年代，当他听到一名记者开玩笑说"真正的男人有晶圆厂"时，他就把这一说法当成自己的口头禅。"现在你们听好了，"桑德斯在一次业内会议上宣布，"真正的男人有晶圆厂。"

CHAPTER 36 The Fabless Revolution

" R eal men" might have fabs, but Silicon Valley's new wave of semiconductor entrepreneurs didn't. Since the late 1980s, there's been explosive growth in the number of fabless chip firms, which design semiconductors in-house but outsource their manufacturing, commonly relying on TSMC for this service. When Gordon Campbell and Dado Banatao founded Chips and Technologies, which is generally considered the first fabless firm, in 1984, one friend alleged it "wasn't a real semiconductor company," since it didn't build its own chips. However, the graphics chips they designed for PCs proved popular, competing with products built by some of the industry's biggest players. Eventually Chips and Technologies faded and was purchased by Intel. However, it had proved that a fabless business model could work, requiring only a good idea and a couple of million dollars in startup capital, a tiny fraction of the money needed to build a fab.

"真正的男人"可能拥有工厂，但硅谷的新一代半导体创业者并没有。自上世纪80年代末以来，无晶圆厂（fabless）芯片公司数量爆炸性增长，它们在内部设计半导体，但外包制造，通常依赖台积电提供此服务。当戈登·坎贝尔（Gordon Campbell）和达多·巴纳塔奥（Dado Banatao）于1984年创立通用半导体（Chips and Technologies）时，一位朋友声称它"不是真正的半导体公司"，因为它没有建造自己的芯片。然而，他们为个人电脑设计的图形芯片非常受欢迎，与业内一些最大的公司生产的产品竞争。最终，通用半导体逐渐消失，并被英特尔（Intel）收购。但它证明了一个无晶圆厂的商业模式可以运作，只需一个好点子和几百万美元的启动资金，这是建造晶圆厂所需资金的一小部分。

Computer graphics remained an appealing niche for semiconductor startups, because unlike PC microprocessors, in graphics Intel didn't have a de facto monopoly. Every PC maker, from IBM to Compaq, had to use an Intel or an AMD chip for their main processor, because these two firms had a de facto monopoly on the x86 instruction set that PCs required. There was a lot more competition in the market for chips that rendered images on screens. The emergence of semiconductor foundries, and the driving down of startup costs, meant that it wasn't only Silicon Valley aristocracy that could compete to build the best graphics processors. The company that eventually came to dominate the market for graphics chips, Nvidia, had its humble beginnings not in a trendy Palo Alto coffeehouse but in a Denny's in a rough part of San Jose.

電腦圖形仍是半導體初創企業所吸引的一個利基，因為與個人電腦微處理器不同，英特爾在圖形方面並沒有實質壟斷。每個PC制造商，從IBM到康柏，都必須使用英特爾或AMD芯片作為其主處理器，因為這兩家公司在PC所需的x86指令集上具有事實上的壟斷地位。在顯示屏上渲染圖像的芯片市場上有更多競爭。半導體晶圓廠的出現和初創成本的降低意味著不只是硅谷貴族可以競爭建立最好的圖形處理器。最終主導圖形芯片市場的公司——Nvidia，其謙卑的開始不是在時尚的Palo Alto咖啡館，而是在聖何塞的一家粗魯的Denny's餐廳中。

Nvidia was founded in 1993 by Chris Malachowsky, Curtis Priem, and Jensen Huang, the latter of whom remains CEO today. Priem had done fundamental work on how to compute graphics while at IBM, then worked at Sun Microsystems alongside Malachowsky. Huang, who was originally from Taiwan but had moved to Kentucky as a child, worked for LSI, a Silicon Valley chipmaker. He became the CEO and the public face of Nvidia, always wearing dark jeans, a black shirt, and a black leather jacket, and possessing a Steve Jobs−like aura suggesting that he'd seen far into the future of computing.

Nvidia於1993年由Chris Malachowsky、Curtis Priem和現任CEO黃仁勳（Jensen Huang）創立。Priem曾在IBM的圖形計算領域做出基礎性研究，之後與Malachowsky一起在Sun Microsystems工作。Huang原籍台灣，但在童年時移民肯塔基，曾在矽谷晶片製造商LSI工作。他成為Nvidia的CEO和公眾形象，經常穿著深色牛仔褲、黑色襯衫和黑色皮夾克，具有類似於Steve Jobs的氣質，表明他已經預見了未來計算的發展方向。

Nvidia's first set of customers—video and computer game companies—might not have seemed like the cutting edge, yet the firm wagered that the future of graphics would be in producing complex, 3D images. Early PCs were a dull, drab, 2D world, because the computation required to display 3D images was immense. In the 1990s, when Microsoft Office introduced an animated, paperclip called Clippy that sat at the side of the screen and dispensed advice, it represented a leap forward in graphics—and often caused computers to freeze.

Nvidia首批客户——视频和电脑游戏公司——可能并不是前沿，但该公司打赌图形的未来在于生产复杂的3D图像。早期的个人电脑是单调、平淡的2D世界，因为显示3D图像所需的计算量极大。在20世纪90年代，当Microsoft Office引入一个名叫Clippy的动画纸夹，它坐在屏幕旁边并提供建议，它代表了图形技术的飞跃——而且经常会导致计算机死机。

Nvidia not only designed chips called graphics processor units (GPUs) capable of handling 3D graphics, it also devised a software ecosystem around them. Making realistic graphics requires use of programs called shaders, which tell all the pixels in an image how they should be portrayed in, say, a given shade of light. The shader is applied to each of the pixels in an image, a relatively straightforward calculation conducted over many thousands of pixels. Nvidia's GPUs can render images quickly because, unlike Intel's microprocessors or other general-purpose CPUs, they're structured to conduct lots of simple calculations—like shading pixels—simultaneously.

Nvidia不僅設計了被稱為圖形處理器單元（GPU）的晶片來處理3D圖形，還為其開發了一個軟件生態系統。製作逼真的圖形需要使用稱為着色器（Shader）的程序，它告訴圖像中的所有像素在特定光線下應該如何呈現。該着色器應用於圖像中的每個像素，這是一個相對簡單的計算，通常涉及數千個像素。 Nvidia的GPU可以快速渲染圖像，因為與Intel的微處理器或其他通用CPU不同，它們的結構可以同時進行許多簡單的計算，如着色像素。

In 2006, realizing that high-speed parallel computations could be used for purposes besides computer graphics, Nvidia released CUDA, software that lets GPUs be programmed in a standard programming language, without any reference to graphics at all. Even as Nvidia was churning out top-notch graphics chips, Huang spent lavishly on this software effort, at least $10 billion, according to a company estimate in 2017, to let any programmer—not just graphics experts—work with Nvidia's chips. Huang gave away CUDA for free, but the software only works with Nvidia's chips. By making the chips useful beyond the graphics industry, Nvidia discovered a vast new market for parallel processing, from computational chemistry to weather forecasting. At the time, Huang could only dimly perceive the potential growth in what would become the biggest use case for parallel processing: artificial intelligence.

2006年，Nvidia意识到高速并行计算可用于除了计算机图形以外的其他用途。因此，该公司推出了CUDA软件，使GPU可以使用标准编程语言进行编程，而不需要任何与图形有关的内容。即使Nvidia推出了一流的图形处理器，Huang仍然在这项软件工作上慷慨投资，根据公司2017年的估计，投入了至少100亿美元，以让任何程序员（而不仅仅是图形专家）都能使用Nvidia的芯片。Huang免费提供CUDA，但该软件仅适用于Nvidia芯片。通过使芯片在图形行业之外也有用处，Nvidia发现了一个巨大的新市场，可用于计算化学、天气预报等并行处理。当时，Huang只能隐约感受到这种并行处理的最大用例——人工智能的潜力增长。

Today Nvidia's chips, largely manufactured by TSMC, are found in most advanced data centers. It's a good thing the company didn't need to build its own fab. At the startup stage, it would probably have been impossible to raise the necessary sums. Giving a couple million dollars to chip designers working in a Denny's was already a gamble. Betting over a hundred million dollars—the cost of a new fab at the time—would have been a stretch even for Silicon Valley's most adventurous investors. Moreover, as Jerry Sanders noted, running a fab well is expensive and time-consuming. It's hard enough simply to design top-notch chips, as Nvidia did. If it had also had to manage its own manufacturing processes, it probably wouldn't have had the resources or the bandwidth to plow money into building a software ecosystem.

今天，Nvidia的芯片大多由台积电制造，在大多数先进的数据中心中都能找到。幸好该公司没有需要建立自己的晶圆厂。在创业阶段，筹集必要的资金可能是不可能的。 在Denny的的芯片设计师中支付几百万美元已经是一场冒险。 投入一亿美元，也就是当时新晶圆厂的成

本，甚至对于硅谷最具冒险精神的投资者来说也是一个挑战。而且，正如Jerry Sanders所指出的，管理晶圆厂需要高昂的成本和耗费时间。像Nvidia所做的那样设计顶尖芯片已经很难了。如果还要管理自己的制造过程，可能就没有足够的资源或带宽来投入资金建立软件生态系统。

Nvidia wasn’t the only fabless company pioneering new use cases for specialized logic chips. Irwin Jacobs, the communications theory professor who’d held aloft a microprocessor and declared “This is the future!” at an academic conference in the early 1970s, now believed the future had arrived. Mobile phones—big, black bricks of plastic that were attached to the dashboard or floor of a car—were about to enter their second generation (2G) of technology. Phone companies were trying to agree on a technology standard that would let their phones communicate with one other. Most companies wanted a system called “time-division multiple access,” whereby data from multiple phone calls would be transmitted on the same radio-wave frequency, with data from one call slotted into the radio-wave spectrum when there was a moment of silence in a different call.

Nvidia不是唯一一个在专用逻辑芯片领域开创新用途的无厂商公司。通信理论教授Irwin Jacobs曾在20世纪70年代的一次学术会议上高举着微处理器大声宣布“这就是未来！”如今，他相信未来已经来临。移动电话即将进入第二代技术(2G)，它们是一种大而黑的塑料砖，可以附着在汽车的仪表盘或地板上。电话公司正在努力达成一个技术标准，使它们的手机能够相互通信。大多数公司都想要一种叫做“时分多址”的系统，通过该系统，多个电话呼叫的数据将在同一无线电波频率上传输，当其他呼叫的静默时刻出现时，一个呼叫的数据将被插入无线电波谱中。

Jacobs, whose faith in Moore’s Law was as strong as ever, thought a more complicated system of frequency-hopping would work better. Rather than keeping a given phone call on a certain frequency, he proposed moving call data between different frequencies, letting him cram more calls into available spectrum space. Most people thought he was right in theory, but that such a system would never work in practice. Voice quality would be low, they argued, and calls would be dropped. The amount of processing needed to move call data between frequencies and have it interpreted by a phone on the other end seemed enormous.

雅各布對摩爾定律的信心仍然堅定不移，他認為更複雜的頻率跳躍系統會更好地發揮作用。他建議將呼叫數據在不同頻率之間移動，讓他能夠將更多的呼叫塞入可用的頻譜空間中。大多數人認為他的理論是正確的，但這樣的系統在實踐中永遠不會起作用。他們爭辯說，語音質量將很差，呼叫將會中斷。移動呼叫數據並通過另一端的手機進行解釋所需的處理量似乎很大。

Jacobs disagreed, founding a company called Qualcomm—Quality Communications—in 1985 to prove the point. He built a small network with a couple cell towers to prove it would work. Soon the entire industry realized Qualcomm's system would make it possible to fit far more cell phone calls into existing spectrum space by relying on Moore's Law to run the algorithms that make sense of all the radio waves bouncing around.

For each generation of cell phone technology after 2G, Qualcomm contributed key ideas about how to transmit more data via the radio spectrum and sold specialized chips with the computing power capable of deciphering this cacophony of signals. The company's patents are so fundamental it's impossible to make a cell phone without them. Qualcomm soon diversified into a new business line, designing not only the modem chips in a phone that communicate with a cell network, but also the application processors that run a smartphone's core systems. These chip designs are monumental engineering accomplishments, each built on tens of millions of lines of code. Qualcomm has made hundreds of billions of dollars selling chips and licensing intellectual property. But it hasn't fabricated any chips: they're all designed in-house but fabricated by companies like Samsung or TSMC.

雅各布不同意，于1985年成立了一家名为高通（Qualcomm）的公司，以证明这一点。他建立了一个小型网络，配备了几座手机塔来证明它会起作用。很快，整个行业意识到，高通的系统可以通过依赖摩尔定律运行对所有无线电波随意移动进行理解的算法，从而使更多的手机通话能够适应现有的频谱空间。 对于2G后的每一代手机技术，高通都提出了关于如何通过无线电频谱传输更多数据的关键思想，并销售具有解密这些信号的计算能力的专业芯片。该公司的专利是如此的基础

性，以至于没有它们，就不可能制造手机。高通很快进入了一个新的业务领域，不仅设计了通信网络中与手机通信的调制解调器芯片，还设计了运行智能手机核心系统的应用处理器。这些芯片设计是巨大的工程成就，每个芯片都建立在数千万行代码的基础上。高通通过销售芯片和许可知识产权赚取了数千亿美元的收入。但它没有制造任何芯片：它们都是在本公司内部设计，然后由三星或台积电等公司制造。

It’s easy to lament the offshoring of semiconductor manufacturing. But companies like Qualcomm might not have survived if they’d had to invest billions of dollars each year building fabs. Jacobs and his engineers were wizards at cramming data into the radio-wave spectrum and devising ever-more-clever chips to decode the meaning of these signals. As was the case with Nvidia, it was a good thing they didn’t have to try to be semiconductor manufacturing experts, too. Qualcomm repeatedly considered opening its own fabrication facilities, but always decided against it, given the cost and complexity involved. Thanks to TSMC, Samsung, and other companies willing to produce their chips, Qualcomm’s engineers could focus on their core strengths in managing spectrum and in semiconductor design.

抱怨半导体制造业被外包很容易。但像高通这样的公司，如果他们不得不每年投资数十亿美元建立芯片工厂，可能就无法存活下来了。雅各布斯和他的工程师是将数据压缩到无线电波谱中并设计出更为聪明的芯片来解码这些信号的巫师。就像英伟达一样，很庆幸他们不必也要成为半导体制造业的专家。高通曾多次考虑开设自己的制造厂，但始终放弃了，鉴于这涉及到的成本和复杂性。由于台积电、三星和其他愿意生产他们芯片的公司，高通的工程师可以专注于他们在频谱管理和半导体设计方面的核心优势。

There were many other U.S. chip firms that benefitted from a fabless model, letting them produce new chip designs without having to spend billions building an in-house fab. Entire new categories of chips emerged that were fabricated only at TSMC and other foundries rather than in-house. Field-programmable gate arrays, chips that can be programmed for different uses, were pioneered by companies like Xilinx and Altera, both of which relied on outsourced manufacturing from their earliest days. The biggest change, however, wasn’t simply new types of chips. By making possible mobile phones, advanced graphics, and parallel processing, fabless firms enabled entirely new types of computing.

许多其他美国芯片公司也受益于无厂设计模式，让它们能够制造新的芯片设计，而不必花费数十亿建造内部工厂。完全新的芯片类别出现了，这些芯片仅在台积电和其他晶圆厂进行制造，而不是内部工厂。可现场可编程门阵列芯片，即可编程用途的芯片，由像赛灵思和Altera这样的公司开创，这两家公司在最早的日子里都依赖外部制造。然而，最大的变化不仅仅是新型芯片。通过实现移动电话、高级图像和并行处理，无厂设计公司使得全新的计算类型成为可能。

CHAPTER 37 Morris Chang's Grand Alliance

J erry Sanders may have promised never to give up his fabs, but the generation of engineers who came of age designing chips with penknives and tweezers was leaving the scene. Their replacements had been trained in the new discipline of computer science, and many knew semiconductors primarily through the new chip design software programs that emerged out of the 1980s and 1990s. To many people in Silicon Valley, Sanders's romantic attachment to fabs seemed as out of touch as his macho swagger. The new class of CEOs who took over America's semiconductor firms in the 2000s and 2010s tended to speak the language of MBAs as well as PhDs, chatting casually about capex and margins with Wall Street analysts on quarterly earnings calls. By most measures this new generation of executive talent was far more professional than the chemists and physicists who'd built Silicon Valley. But they often seemed stale in comparison to the giants who preceded them.

樂力山或許曾經承諾永遠不會放棄他的晶圓廠，但與他一同時代、用剪刀和鉗子設計晶片的工程師們已陸續淡出舞台。他們的接班人則是受過現代電腦科學訓練的一群人，對於半導體的認識主要來自20世紀80年代和90年代所出現的新晶片設計軟體。對於許多矽谷的人來說，樂力山對晶圓廠的浪漫情懷似乎已經跟不上時代，他那種瑰麗的姿態已變得陳舊。在2000年代和2010年代接手美國半導體公司的新一代CEO們除了擁有博士學位外，還能夠靈活地運用MBA中學到的知識，能輕鬆地和華爾街分析師討論資本支出和利潤率等問題。從許多指標來看，這些新一代的領導才能比曾經建立矽谷的化學家和物理學家更為專業。然而，與他們之前的巨人相比，他們常常顯得乏味。

An era of wild wagers on impossible technologies was being superseded by something more organized, professionalized, and rationalized. Bet-the-house gambles were replaced by calculated risk management. It was hard to escape the sense that something was lost in the process. Of the chip industry's founders, only Morris Chang remained, smoking his pipe in his office in Taiwan, a habit he defended as good for 216his health, or at least for his mood. In the 2000s, even Chang began to think about succession planning. In

2005, aged seventy-four, he stepped down from the role of CEO, though he remained chairman of TSMC. Soon there'd be no one left who remembered working in the lab alongside Jack Kilby or drinking beers with Bob Noyce.

野蠻的科技應用已成為過去，現在科技產業更趨向組織化、專業化、合理化的發展。大膽的賭注被計算風險管理所取代。人們難以避免感受到這個過程中失去了某些東西。在晶片行業的創始人中，只有張忠謀仍然存在，在台灣的辦公室裏吸著煙斗，他堅稱這是對他的健康或至少對他的心情有益的習慣。在2000年代，連張忠謀也開始考慮繼任計劃。2005年，他在74歲時辭去了CEO的職務，但仍是台積電的董事長。不久，再也沒有人記得和傑克·基爾比（Jack Kilby）一起在實驗室工作或和鮑伯·諾伊斯（Bob Noyce）喝啤酒的情景。

The changing of the guard atop the chip industry accelerated the splitting of chip design and manufacturing, with much of the latter offshored. Five years after Sanders retired from AMD, the company announced it was dividing its chip design and fabrication businesses. Wall Street cheered, reckoning the new AMD would be more profitable without the capital-intensive fabs. AMD spun out these facilities into a new company that would operate as a foundry like TSMC, producing chips not only for AMD but other customers, too. The investment arm of the Abu Dhabi government, Mubadala, became the primary investor in the new foundry, an unexpected position for a country known more for hydrocarbons than for high-tech. CFIUS, the U.S. government body that reviews foreign purchases of strategic assets, waved the sale through, judging that it had no national security implications. But the fate of AMD's production capabilities would end up shaping the chip industry—and guaranteeing that the most advanced chipmaking would take place offshore.

頂尖晶片行業的守望交替加速拆分了晶片設計和製造，其中許多製造都外移。桑德斯退休五年後，AMD宣布將其晶片設計和製造業務分開。華爾街歡呼雀躍，認為新的AMD將更有利可圖，而無須投入大量資本支持的晶片製造廠。AMD將這些設施拆分成一家新公司，該公司類似於TSMC的鑄造廠，不僅生產AMD的晶片，還為其他客戶生產晶片。阿布達比政府的投資機構穆巴達拉成為新鑄造廠的主要投資者，這是一個意外的位置，因為這個國家更多以碳氫化合物而不是高科技聞名。美國政府檢查外國對戰略資產的購買機構CFIUS通過了這筆出

售，判斷這筆交易對國家安全沒有任何影響。但AMD的生產能力的命運最終將塑造晶片行業，並確保最先進的晶片製造將在海外進行。

GlobalFoundries, as this new company that inherited AMD’s fabs was known, entered an industry that was as competitive and unforgiving as ever. Moore’s Law marched forward through the 2000s and early 2010s, forcing cutting-edge chipmakers to spend ever larger sums rolling out a new, more advanced manufacturing process roughly once every two years. Smartphone, PC, and server chips quickly migrated to each new “node,” taking advantage of increased processing power and lower power consumption as transistors were more densely packed. Each node transition required ever more expensive machinery to produce.

GlobalFoundries以承繼AMD工廠的新公司身份進入了一個同樣具競爭性和嚴苛度的產業。摩爾定律持續地推進著這個產業在二零零零年代和二零一零年代初期，強迫先進晶片製造商每兩年推出一次更先進的生產工藝，不斷地為此花費更多的資金。智能手機、個人電腦和伺服器晶片快速地移至每個新的“節點”，利用逐漸更緊密地打包的晶體管來提高處理能力和降低能源消耗。每次節點轉移都需要使用越來越昂貴的機器設備。

For many years, each generation of manufacturing technology was named after the length of the transistor’s gate, the part of the silicon chip whose conductivity would be turned on and off, creating and interrupting the circuit. The 180nm node was pioneered in 1999, followed by 130nm, 90nm, 65nm, and 45nm, with each generation shrinking transistors enough to make it possible to cram roughly twice as many in the same area. This reduced power consumption per transistor, because smaller transistors needed fewer electrons to flow through them.

多年以来，每一代制造技术都是以晶体管门长命名的，晶体管门是硅片的部分，其电导性将被开启和关闭，从而创建和中断电路。180纳米节点是在1999年首创的，随后是130纳米，90纳米，65纳米和45纳米，每一代都将晶体管缩小到足以在相同的区域内塞入大约两倍。这减少了每个晶体管的功耗，因为更小的晶体管需要更少的电子流经它们。

Around the early 2010s, it became unfeasible to pack transistors more densely by shrinking them two dimensionally. One challenge was that, as transistors were shrunk according to Moore's Law, the narrow length of the conductor channel occasionally caused power to "leak" through the circuit even when the switch was off. On top of this, the layer of silicon dioxide atop each transistor became so thin that quantum effects like "tunneling"—jumping through barriers that classical physics said should be insurmountable—began seriously impacting transistor performance. By the mid-2000s, the layer of silicon dioxide on top of each transistor was only a couple of atoms thick, too small to keep a lid on all the electrons sitting in the silicon.

大约在2010年代初，通过二维缩小晶体管来更密集地打包它们变得不可行。其中一个挑战是，随着晶体管按摩尔定律缩小，导体通道的狭窄长度有时会导致电力在电路关闭时"泄漏"。除此之外，每个晶体管上方的二氧化硅层也变得如此薄，以至于量子效应如"隧穿"——跃过经典物理认为应该不可逾越的屏障——开始严重影响晶体管的性能。到了2000年代中期，每个晶体管上方的二氧化硅层只有几个原子厚度，太小而无法保持硅中的所有电子。

To better control the movement of electrons, new materials and transistor designs were needed. Unlike the 2D design used since the 1960s, the 22nm node introduced a new 3D transistor, called a FinFET (pronounced finfet), that sets the two ends of the circuit and the channel of semiconductor material that connects them on top of a block, looking like a fin protruding from a whale's back. The channel that connects the two ends of the circuit can therefore have an electric field applied not only from the top but also from the sides of the fin, enhancing control over the electrons and overcoming the electricity leakage that was threatening the performance of new generations of tiny transistors. These nanometer-scale 3D structures were crucial for the survival of Moore's Law, but they were staggeringly difficult to make, requiring even more precision in deposition, etching, and lithography. This added uncertainty about whether the major chipmakers would all flawlessly execute the switch to FinFET architectures or whether one might fall behind.

為了更好地控制電子的運動，需要新的材料和晶體管設計。不同於自1960年代以來使用的2D設計，22納米節點介紹了一種新的3D晶體管，稱為FinFET（發音為finfet），它將電路的兩端和連接它們的半導體材

料通道置於一個方塊的頂部，看起來像一條從鯨魚背部突出的鰭。連接電路兩端的通道因此可以從鰭的側面施加電場，增強對電子的控制並克服正在威脅新一代微小晶體管性能的電漏問題。這些納米級的3D結構對摩爾定律的生存至關重要，但製造它們非常困難，需要更精確的沉積、蝕刻和光刻技術。這增加了一些不確定性，即主要芯片製造商是否都能完美地轉換到FinFET架構，或者是否會有一家落後。

When GlobalFoundries was established as an independent company in 2009, industry analysts thought it was well placed to win market share amid this race toward 3D transistors. Even TSMC was worried, the company's former executives admit. GlobalFoundries had inherited a massive fab in Germany and was building a new, cutting-edge facility in New York. Unlike its rivals, it would be basing its most advanced production capacity in advanced economies, not in Asia. The company had a partnership with IBM and Samsung to jointly develop technology, making it straightforward for customers to contract with either GlobalFoundries or with Samsung to produce their chips. Moreover, fabless chip design firms were hungry for a credible competitor to TSMC, because the Taiwanese behemoth already had around half of the world's foundry market.

當GlobalFoundries於2009年成立為獨立公司時，行業分析師認為它在這場向3D晶體管的競爭中具有良好的市場佔有率。即使是TSMC也感到擔憂，該公司的前高管坦承。GlobalFoundries在德國繼承了一個龐大的晶圓廠，並正在紐約建立一個全新的尖端設施。與其競爭對手不同，它將在先進的經濟體中建立其最先進的生產能力，而不是在亞洲。該公司與IBM和三星有合作夥伴關係，共同開發技術，使客戶可以簡單地與GlobalFoundries或三星簽約生產他們的芯片。此外，無廠商晶片設計公司渴望有一個可靠的TSMC競爭對手，因為這家台灣巨頭已經擁有全球一半的晶片代工市場。

The only other major competitor was Samsung, whose foundry business had technology that was roughly comparable to TSMC's, though the company possessed far less production capacity. Complications arose, though, because part of Samsung's operation involved building chips that it designed in-house. Whereas a company like TSMC builds chips for dozens of customers and focuses relentlessly on keeping them happy, Samsung had its own line of smartphones and other consumer electronics, so it was *competing* with many of its customers. Those firms worried that ideas shared with Samsung's chip foundry might end up in other Samsung products. TSMC and GlobalFoundries had no such conflicts of interest.

唯一的另一家主要競爭對手是三星，該公司的晶片代工業務的技術與台積電差不多，但生產能力遠不及台積電。然而，問題出現了，因為三星的一部分業務涉及自主設計晶片。而像台積電這樣的公司為數十家客戶生產晶片，並不斷關注客戶的滿意度。三星有自己的智能手機和其他消費電子產品系列，因此他們與許多客戶競爭。這些公司擔心與三星的晶片代工共享的想法可能會出現在其他三星產品中。台積電和GlobalFoundries沒有這樣的利益衝突。

The move to FinFET transistors wasn't the only shock to the chip industry that coincided with the establishment of GlobalFoundries. TSMC faced substantial manufacturing problems with its 40nm process, giving GlobalFoundries a chance to distinguish itself from its large rival. Moreover, the 2008−2009 financial crisis was threatening to reorder the chip industry. Consumers stopped buying electronics, so tech firms stopped ordering chips. Semiconductor purchases slumped. It felt like an elevator careening down an empty shaft, one TSMC executive recalled. If anything could disrupt the chip industry, a global financial crisis was it.

随着GlobalFoundries的建立，转向FinFET晶体管并不是唯一使芯片行业震惊的事情。 TSMC在其40纳米工艺方面遇到了相当大的制造问题，为GlobalFoundries提供了机会，使其与其大型竞争对手区别开来。此外，2008-2009年的金融危机已经威胁到重新排列芯片行业。消费者停止购买电子产品，因此科技公司停止了订购芯片。半导体采购量下降。一位TSMC高管回忆说，感觉就像电梯在一个空荡荡的电梯井中猛然下坠。如果有什么东西可能会破坏芯片行业，那就是全球金融危机。

Morris Chang wasn't about to give up dominance of the foundry business, though. He'd lived through every industry cycle since his old colleague Jack Kilby invented the integrated circuit. He was sure this downturn would eventually end, too. Companies that were overextended would be pushed out of business, leaving those that invested during the downturn positioned to grab market share. Moreover, Chang realized as early as anyone how smartphones would transform computing—and therefore how they would change the chip industry, too. The media focused on young tech tycoons like Facebook's Mark Zuckerberg, but seventy-seven-year-old Chang had a perspective that few could match. Mobile devices would be a "game-changer" for the chip industry, he told *Forbes* , perceiving them as heralding shifts as significant as the PC had brought. He was committed to winning the lion's share of this business, whatever the cost.

然而，張忠謀並沒有放棄在晶片製造業中的主導地位。自從他的老同事傑克·基爾比（Jack Kilby）發明集成電路以來，他一直生活在產業循環中。他相信這次的衰退也最終會結束。那些過度擴張的公司會被淘汰，留下那些在衰退期間進行投資的公司佔據市場份額。此外，張忠謀比任何人都早意識到智能手機將改變電腦，從而改變晶片行業。儘管媒體關注年輕的科技巨頭如Facebook的馬克·扎克伯格，但77歲的張忠謀擁有少數人可以與之匹敵的觀點。他告訴福布斯，《移動設備將成為改變遊戲規則的元素》，認為它們所帶來的變化將像個人電腦帶來的變化一樣重要。他決心不惜一切代價贏得這個市場的最大份額。

Chang realized that TSMC could pull ahead of rivals technologically because it was a neutral player around which other companies would design their products. He called this TSMC's "Grand Alliance," a partnership of dozens of companies that design chips, sell intellectual property, produce materials, or manufacture machinery. Many of these companies compete with each other, but since none fabricate wafers, none compete with TSMC. TSMC could therefore coordinate between them, setting standards that most other companies in the chip industry would agree to use. They had no choice, because compatibility with TSMC's processes was crucial for almost every company. For fabless firms, TSMC was their most competitive source of manufacturing services. For equipment companies and materials firms, TSMC was often their biggest customer. As smartphones began to take off, driving up demand for silicon, Morris Chang sat at the center. "TSMC knows it is important to use everyone's innovation," Chang declared, "ours, that of the equipment makers, of our customers, and of the IP providers. That's the power of the Grand Alliance." The financial implications of this were profound. "The combined R&D spending of TSMC and its ten biggest customers," he bragged "exceeds that of Samsung and Intel together." The old model of integrating design and manufacture would struggle to compete when the rest of the industry was coalescing around TSMC.

張忠謀意識到台積電可以在技術方面領先競爭對手，因為它是一個中立的公司，其他公司會圍繞它來設計他們的產品。他稱這為台積電的“大聯盟”，這是數十個公司的合作夥伴，他們設計芯片、銷售知識產權、生產材料或製造機械。這些公司中的許多人互相競爭，但由於沒有人製造晶圓，因此沒有人與台積電競爭。台積電因此可以在它們之間協調，設定大多數芯片行業中的標準。他們別無選擇，因為與台積電的工藝相容對幾乎所有公司都至關重要。對於無廠協（fabless）公司，台積電是其最有競爭力的製造服務來源。對於設備公司和材料公司，台積電通常是他們最大的客戶。當智能手機開始蓬勃發展並推動矽產品需求上升時，張忠謀坐在中心位置。“台積電知道使用每個人的創新都很重要，”張忠謀宣稱，“我們的、設備制造商的、客戶的和知識產權提供商的。這就是大聯盟的力量。”這種做法的財務影響深遠。他自誇：“台積電和其十大客戶的研發投資總和超過了三星和英特爾的總和。”當整個行業正在圍繞台積電聚集時，集成設計和製造的舊模式將難以競爭。

TSMC’s position at the center of the semiconductor universe required it to have capacity to produce chips for all its biggest customers. Doing so wouldn’t be cheap. Amid the financial crisis, Chang’s handpicked successor, Rick Tsai, had done what nearly every CEO did—lay off employees and cut costs. Chang wanted to do the opposite. Getting the company’s 40nm chipmaking back on track required investing in personnel and technology. Trying to win more smartphone business—especially that of Apple’s iPhone, which launched in 2007 and which initially bought its key chips from TSMC’s archrival, Samsung—required massive investment in chipmaking capacity. Chang saw Tsai’s cost cutting as defeatist. “There was very, very little investment,” Chang told journalists afterward. “I had always thought that the company was capable of more…. It didn’t happen. There was stagnation.”

台積電在半導體世界中央的地位要求它擁有為所有最大客戶生產芯片的能力，而這不會便宜。在金融危機期間，張忠謀親自挑選的繼任者蔡力行做了幾乎每位CEO都做的事情——裁員和削減成本。張忠謀想要做相反的事情。將公司的40納米晶片製造回歸正軌需要投資於人員

和技術。試圖贏得更多智能手機業務——特別是蘋果的iPhone，在2007年推出，最初從台積電的主要競爭對手三星購買其關鍵的芯片——需要大量投資於晶片製造能力。張忠謀認為蔡力行的削減成本是失敗主義的表現。張忠謀事後告訴記者：“幾乎沒有投資。我一直認為公司有更多的能力...但卻沒有實現，停滯不前。”

So Chang fired his successor and retook direct control of TSMC. The company’s stock price fell that day, as investors worried he’d launch a risky spending program with uncertain returns. Chang thought the real risk was accepting the status quo. He wasn’t about to let a financial crisis threaten TSMC in the race for industry leadership. He had a half-century-long track record at chipmaking, a reputation he’d honed since the mid-1950s. So at the depths of the crisis Chang rehired the workers the former CEO had laid off and doubled down on investment in new capacity and R&D. He announced several multibillion-dollar increases to capital spending in 2009 and 2010 despite the crisis. It was better “to have too much capacity than the other way around,” Chang declared. Anyone who wanted to break into the foundry business would face the full force of competition from TSMC as it raced to capture the booming market for smartphone chips. “ We’re just at the start,” Chang declared in 2012, as he launched into his sixth decade atop the semiconductor industry.

所以張忠謀解雇了他的繼任者，重新直接掌控台積電。當天股價下跌，投資者擔心他會啟動一項風險投資計劃，回報不確定。張忠謀認為，接受現狀才是真正的風險。他不會讓財務危機威脅台積電在行業領導地位的競爭中。他自中1950年代以來一直在芯片製造方面擁有半個世紀的成功經驗和聲譽。因此，在危機最深時，張忠謀重新雇傭了被前任CEO解雇的員工，加倍投資於新的生產能力和研發。盡管危機四伏，他仍然宣布了2009年和2010年的多項幾十億美元資本支出增加。張忠謀宣稱：““與其容量不足，不如多一些”，任何想進入銅廠業務的人都將面臨來自台積電的強大競爭力。“我們只是剛開始，” 張忠謀在2012年宣布，他已經在半個世紀中站在半導體行業的頂端。

CHAPTER 38 Apple Silicon

T he greatest beneficiary of the rise of foundries like TSMC was a company that most people don't even realize designs chips: Apple. The company Steve Jobs built has always specialized in hardware, however, so it's no surprise that Apple's desire to perfect its devices includes controlling the silicon inside. Since his earliest days at Apple, Steve Jobs had thought deeply about the relationship between software and hardware. In 1980, when his hair nearly reached his shoulders and his mustache covered his upper lip, Jobs gave a lecture that asked, "What is software?" "The only thing I can think of," he answered, "is software is something that is changing too rapidly, or you don't exactly know what you want yet, or you didn't have time to get it into hardware."

像台積電這樣的晶圓廠的崛起最大的受益者是一家大多數人甚至不知道設計芯片的公司：蘋果。史蒂夫·賈伯斯建立的公司一直專注於硬件，因此蘋果想要完善其設備，包括控制內部的硅。自他在蘋果最早期的日子開始，史蒂夫·賈伯斯就深入思考軟件和硬件之間的關係。1980年，當他的頭髮幾乎到達肩膀，他的鬍鬚覆蓋了上唇時，賈伯斯發表了一場關於"什麼是軟件？"的講座。"我能想到的唯一一件事是，軟件是一種變化太快的東西，或者你還不確定你想要什麼，或者你沒有時間將其納入硬件中。"

Jobs didn't have time to get all his ideas into the hardware of the first-generation iPhone, which used Apple's own iOS operating system but outsourced design and production of its chips to Samsung. The revolutionary new phone had many other chips, too: an Intel memory chip, an audio processor designed by Wolfson, a modem to connect with the cell network produced by Germany's Infineon, a Bluetooth chip designed by CSR, and a signal amplifier from Skyworks, among others. All were designed by other companies.

乔布斯没有时间将他所有的想法都融入到第一代iPhone的硬件中，该手机使用了苹果自己的iOS操作系统，但外包其芯片的设计和生产给了三星。这款革命性的新手机还有许多其他芯片，包括英特尔的存储

芯片、由沃尔夫森设计的音频处理器、由德国因芬尼昂生产的连接蜂窝网络的调制解调器、由CSR设计的蓝牙芯片以及来自Skyworks的信号放大器，所有这些芯片都是由其他公司设计的。

As Jobs introduced new versions of the iPhone, he began etching his vision for the smartphone into Apple’s own silicon chips. A year after launching the iPhone, Apple bought a small Silicon Valley chip design firm called PA Semi that had expertise in energy-efficient processing. Soon Apple began hiring some of the industry’s best chip designers. Two years later, the company announced it had designed its own application processor, the A4, which it used in the new iPad and the iPhone 4. Designing chips as complex as the processors that run smartphones is expensive, which is why most low- and midrange smartphone companies buy off-the-shelf chips from companies like Qualcomm. However, Apple has invested heavily in R&D and chip design facilities in Bavaria and Israel as well as Silicon Valley, where engineers design its newest chips. Now Apple not only designs the main processors for most of its devices but also ancillary chips that run accessories like AirPods. This investment in specialized silicon explains why Apple’s products work so smoothly. Within four years of the iPhone’s launch, Apple was making over 60 percent of all the world’s profits from smartphone sales, crushing rivals like Nokia and BlackBerry and leaving East Asian smartphone makers to compete in the low-margin market for cheap phones.

當Jobs介紹iPhone的新版本時，他開始將他對智能手機的願景烙印在蘋果自己的硅芯片中。在推出iPhone一年後，蘋果收購了一家名為PA Semi的硅谷芯片設計公司，該公司擁有節能處理方面的專業知識。不久之後，蘋果開始聘請了一些行業中最好的芯片設計師。兩年後，該公司宣布已經設計了自己的應用處理器，即A4，並將其用于新iPad和iPhone 4上。設計像運行智能手機的處理器這樣複雜的芯片很昂貴，這就是為什麼大多數低端和中端智能手機公司從像高通這樣的公司購買現成芯片的原因。然而，蘋果在巴伐利亞和以色列以及硅谷投資了大量的研發和晶片設計設施，該公司的工程師在這裡設計最新的芯片。現在，蘋果不僅為大多數設備設計主處理器，還設計運行AirPods等配件的附加芯片。這種專用硅的投資解釋了為什麼蘋果的產品運行得如此流暢。在iPhone推出的四年內，蘋果從智能手機銷售中獲得了超過60％的全球利潤，擊潰了諸如諾基亞和黑莓之類的競爭對手，讓東亞智能手機製造商競爭便宜手機的低利潤市場。

Like Qualcomm and the other chip firms that powered the mobile revolution, even though Apple designs ever more silicon, it doesn't build any of these chips. Apple is well known for outsourcing assembly of its phones, tablets, and other devices to several hundred thousand assembly line workers in China, who are responsible for screwing and gluing tiny pieces together. China's ecosystem of assembly facilities is the world's best place to build electronic devices. Taiwanese companies, like Foxconn and Wistron, that run these facilities for Apple in China are uniquely capable of churning out phones, PCs, and other electronics. Though the electronics assembly facilities in Chinese cities like Dongguan and Zhengzhou are the world's most efficient, however, they aren't irreplaceable. The world still has several hundred million subsistence farmers who'd happily fasten components into an iPhone for a dollar an hour. Foxconn assembles most of its Apple products in China, but it builds some in Vietnam and India, too.

就像高通和其他芯片公司推动移动革命一样，尽管苹果设计了越来越多的硅片，但它并不制造这些芯片。苹果以外包其手机、平板电脑和其他设备的组装而著称，这些工作由数十万名中国组装线工人负责将小小的零件拧紧和粘合在一起。中国的组装设施生态系统是世界上最好的电子设备制造地。像富士康和纬创这样在中国为苹果运营这些设施的台湾公司独具能力生产手机、PC和其他电子产品。尽管像东莞和郑州这样的中国城市的电子组装设施是世界上最高效的，但它们并非不可替代。世界上仍有数亿的自给自足的农民愿意以每小时一美元的报酬将组件安装到 iPhone 上。富士康在中国组装了大部分的苹果产品，但也在越南和印度建立了一些工厂。

Unlike assembly line workers, the chips inside smartphones are very difficult to replace. As transistors have shrunk, they've become ever harder to fabricate. The number of semiconductor companies that can build leading-edge chips has dwindled. By 2010, at the time Apple launched its first chip, there were just a handful of cutting-edge foundries: Taiwan's TSMC, South Korea's Samsung, and—perhaps—GlobalFoundries, depending on whether it could succeed in winning market share. Intel, still the world's leader at shrinking transistors, remained focused on building its own chips for PCs and servers rather than processors for other companies' phones. Chinese foundries like SMIC were trying to catch up but remained years behind.

與製造流水線上的工人不同，智能手機內部的晶片非常難以更換。隨著晶體管的縮小，它們變得越來越難製造。能夠建造尖端晶片的半導體公司數量已經減少。到了2010年，當蘋果推出第一個芯片時，只剩下少數幾家尖端製造商：台灣的台積電、南韓的三星以及可能是GlobalFoundries，取決於它是否能贏得市場份額。英特爾仍然是縮小晶體管技術的世界領先者，繼續專注於為 PC 和服務器建造自己的芯片，而不是為其他公司的手機製造處理器。中國的中芯國際也在努力追趕，但仍遠遠落後。

Because of this, the smartphone supply chain looks very different from the one associated with PCs. Smartphones and PCs are both assembled largely in China with high-value components mostly designed in the U.S., Europe, Japan, or Korea. For PCs, most processors come from Intel and are produced at one of the company's fabs in the U.S., Ireland, or Israel. Smartphones are different. They're stuffed full of chips, not only the main processor (which Apple designs itself), but modem and radio frequency chips for connecting with cellular networks, chips for WiFi and Bluetooth connections, an image sensor for the camera, at least two memory chips, chips that sense motion (so your phone knows when you turn it horizontal), as well as semiconductors that manage the battery, the audio, and wireless charging. These chips make up most of the bill of materials needed to build a smartphone.

因此，智能手机供应链与PC的供应链看起来截然不同。PC和智能手机都主要在中国组装，使用大部分由美国、欧洲、日本或韩国设计的高价值元件。对于PC来说，大多数处理器都来自英特尔公司，在美国、爱尔兰或以色列的其中一个工厂生产。智能手机则不同。它们充满芯片，不仅是主处理器（由苹果公司自己设计），还有用于连接蜂窝网络的调制解调器和射频芯片、用于WiFi和蓝牙连接的芯片、相机图像传感器、至少两个内存芯片、感应动作的芯片（所以您的手机知道何时将其水平放置），以及管理电池、音频和无线充电的半导体。这些芯片占了构建智能手机所需的大部分材料清单的大部分。

As semiconductor fabrication capacity migrated to Taiwan and South Korea, so too did the ability to produce many of these chips. Application processors, the electronic brain inside each smartphone, are mostly produced in Taiwan and South Korea before being sent to China for final assembly inside a phone's plastic case and glass screen. Apple's iPhone processors are fabricated exclusively in Taiwan. Today, no company besides TSMC has the skill or the production capacity to build the chips Apple needs. So the text etched onto the back of each iPhone—“Designed by Apple in California. Assembled in China”—is highly misleading. The iPhone’s most irreplaceable components are indeed designed in California and assembled in China. But they can only be made in Taiwan.

隨著半導體製造能力遷移到台灣和韓國，許多晶片的生產能力也隨之而來。應用處理器，即每個智能手機中的電子大腦，大部分在被送到中國進行最終組裝之前是在台灣和韓國製造的。蘋果的iPhone處理器是在台灣專門製造的。今天，除台積電之外，沒有任何一家公司具有建造蘋果所需芯片的技能或生產能力。因此，每個iPhone背面刻有的文字 - “由蘋果在加利福尼亞設計。在中國組裝” - 是非常誤導的。iPhone最不可替代的組件確實是在加利福尼亞設計並在中國組裝的，但它們只能在台灣製造。

CHAPTER 39 EUV

A pple isn't the only company in the semiconductor business with a bewilderingly complex supply chain. By the late-2010s, ASML, the Dutch lithography company, had spent nearly two decades trying to make extreme-ultraviolet lithography work. Doing so required scouring the world for the most advanced components, the purest metals, the most powerful lasers, and the most precise sensors. EUV was one of the biggest technological gambles of our time. In 2012, years before ASML had produced a functional EUV tool, Intel, Samsung, and TSMC had each invested directly in ASML to ensure the company had the funding needed to continue developing EUV tools that their future chipmaking capabilities would require. Intel alone invested $4 billion in ASML in 2012, one of the highest-stakes bets the company ever made, an investment that followed billions of dollars of previous grants and investments Intel had spent on EUV, dating back to the era of Andy Grove.

蘋果不是唯一一家擁有極為複雜供應鏈的半導體公司。到了2010年代後期，荷蘭的微影技術公司ASML已經花費近20年的時間嘗試使極紫外光微影技術運作。為此，他們需要在世界各地尋找最先進的元件、最純淨的金屬、最強大的鐳射和最精確的感應器。EUV是當代最大的技術擲博之一。在ASML成功生產出EUV工具之前的2012年，英特爾、三星和台積電已經直接投資ASML，確保該公司有足夠的資金繼續開發未來晶片製造所需的EUV工具。僅僅是2012年，英特爾就為ASML投資了40億美元，這是英特爾有史以來最高風險的投資之一，這筆投資還跟隨著英特爾之前花費在EUV上數十億美元的諾貝爾獎得主安迪·格羅夫時代的資助和投資。

The idea behind EUV lithography tools was little changed from when Intel and a consortium of other chip firms had given several of America's national labs "what felt like infinite money for solving an impossible problem," as one of the scientists who worked on the project put it. The concept remained much the same as Jay Lathrop's upside-down microscope: create a pattern of light waves by using a "mask" to block some of the light, then project the light onto photoresist chemicals applied to a silicon wafer. The light reacts with photoresists, making it possible to deposit material or etch it away in perfectly formed shapes, producing a working chip.

欧盟紫外光刻工具背后的理念与英特尔和其他芯片公司提供给几个美国国家实验室“解决一个不可能的问题的无限金钱”的想法几乎没有改变，就像其中一个参与该项目的科学家所说的那样。 这个概念与Jay Lathrop的倒置显微镜基本相同：通过使用“掩膜”阻挡一些光来创建光波的图案，然后将光投射到涂在硅基板上的光致抗性化学物质上。 光通过光致抗性物质反应，使得可以在完美形成的形状中沉积或蚀去材料，从而生产出工作芯片。

Lathrop had used simple visible light and off-the-shelf photoresists produced by Kodak. Using more complex lenses and chemicals, it eventually became possible to print shapes as small as a couple hundred nanometers on silicon wafers. The wavelength of visible light is itself several hundred nanometers, depending on the color, so it eventually faced limits as transistors were made ever smaller. The industry later moved to different types of ultraviolet light with wavelengths of 248 and 193 nanometers. These wavelengths could carve shapes more precise than visible light, but they, too, had limits, so the industry placed its hope on extreme ultraviolet light with a wavelength of 13.5 nanometers.

Lathrop曾使用柯达制造的简单可见光和现成的光致抗性材料。随着使用更复杂的透镜和化学试剂，最终能够在硅晶圆上印刷像几百纳米这样小的形状。可见光的波长本身就有几百纳米，取决于颜色，因此随着晶体管变得更小，最终面临着限制。后来，该行业转向具有248和193纳米波长的不同类型的紫外线。这些波长可以雕刻比可见光更精细的形状，但它们也面临着限制，因此该行业寄希望于具有13.5纳米波长的极端紫外线。

Using EUV light introduced new difficulties that proved almost impossible to resolve. Where Lathrop used a microscope, visible light, and photoresists produced by Kodak, all the key EUV components had to be specially created. You can’t simply buy an EUV lightbulb. Producing enough EUV light requires pulverizing a small ball of tin with a laser. Cymer, a company founded by two laser experts from the University of California, San Diego, had been a major player in lithographic light sources since the 1980s. The company’s engineers realized the best approach was to shoot a tiny ball of tin measuring thirty-millionths of a meter wide moving through a vacuum at a speed of around two hundred miles per hour. The tin is then struck twice with a laser, the first pulse to warm it up, the second to blast it into a plasma with a temperature around half a million degrees, many times hotter than the surface of the sun. This process of blasting tin is then repeated fifty thousand times per second to produce EUV light in the quantities necessary to fabricate chips. Jay Lathrop's lithography process had relied on a simple bulb for a light source. The increase in complexity since then was mind-boggling.

使用EUV光引入了新的困难，几乎不可能解决。Lathrop使用了显微镜，可见光和柯达生产的光刻胶，而所有关键的EUV组件都必须经过特殊制造。你不能简单地买一个EUV灯泡。产生足够的EUV光需要用激光将一小块锡球粉碎。Cymer是一家由加利福尼亚大学圣迭戈分校的两位激光专家创立的公司，自20世纪80年代以来一直是光刻光源的主要参与者。该公司的工程师们意识到最好的方法是射出一个直径为三千万分之一米的小球，以大约每小时两百英里的速度在真空中移动。然后用激光两次击打锡球，第一次脉冲加热它，第二次脉冲将其轰击成等于太阳表面温度的半百万度等离子体。然后重复这种轰击锡的过程，每秒钟五万次，以产生必要数量的EUV光来制造芯片。杰伊·拉瑟普的光刻工艺的光源是简单的灯泡。自那时以来的复杂程度令人难以置信。

Cymer's light source only worked, though, thanks to a new laser that could pulverize the tin droplets with sufficient power. This required a carbon dioxide−based laser more powerful than any that previously existed. In summer 2005, two engineers at Cymer approached a German precision tooling company called Trumpf to see if it could build such a laser. Trumpf already made the world's best carbon dioxide−based lasers for industrial uses like precision cutting. These lasers were monuments of machining in the best German industrial tradition. Because around 80 percent of the energy a carbon dioxide laser produces is heat and only 20 percent light, extracting heat from the machine is a key challenge. Trumpf had previously devised a system of blowers with fans that turned a thousand times a second, too fast to rely on physical bearings. Instead, the company learned to use magnets, so the fans floated in air, sucking heat out of the laser system without grinding against other components and imperiling reliability.

Cymer的光源之所以能工作，要歸功於一種能以足夠功率粉碎錫小滴的新型激光器。這需要一種基於二氧化碳的激光器，比以前任何激光器都要強大。2005年夏季，Cymer的兩名工程師向一家名為Trumpf的德國精密工具公司請教，該公司能否建造這樣的激光器。Trumpf已經為工業用途，如精密切割，製造了世界上最好的基於二氧化碳的激光器。這些激光器是德國最好的工業傳統的機械雕塑品。由於基於二氧化碳的激光器產生的能量中大約80％是熱能，只有20％是光線，因此從機器中提取熱量是一個關鍵挑戰。Trumpf以前已經設計了一個風機系統，風扇每秒轉千次，轉得太快以至於不能依賴物理軸承。相反，該公司學會使用磁鐵，使風扇漂浮在空氣中，從激光系統中吸收熱量，無需與其他元件摩擦，危及可靠性。

Trumpf had a reputation and a track record for delivering the precision and reliability Cymer needed. Could it deliver the power? Lasers for EUV needed to be substantially more powerful than the lasers Trumpf already produced. Moreover, the precision Cymer demanded was more exacting than anything Trumpf had previously dealt with. The company proposed a laser with four components: two “seed” lasers that are low power but accurately time each pulse so that the laser can hit 50 million tin drops a second; four resonators that increase the beam’s power; an ultra-accurate “beam transport system” that directs the beam over thirty meters toward the tin droplet chamber; and a final focusing device to ensure the laser scores a direct hit, millions of times a second.

特朗普夫公司因其提供精密可靠的服务而受到 Cymer 的好评和信任。但问题是，他们的激光能源能否满足要求？光刻机用的 EUV 激光必须比特朗普夫公司现有的激光更强大。此外，Cymer 要求的精度比任何之前由特朗普夫公司处理过的要求都更高。公司提出了一个激光器，它包括四个部分：两个“种子”激光器，它们功率低但能够准确计时每一个脉冲，以便激光器能够每秒击中 5 千万个锡滴；四个共振腔会增加光束的功率；一个超精确的“光束传输系统”，将光束定向引导到锡小圆液室约三十米的距离；最后是一个聚焦设备，以确保激光以每秒数百万次的速度直接击中目标。

Every step required new innovations. Specialized gases in the laser chamber had to be kept at constant densities. The tin droplets themselves reflected light, which threatened to shine back into the laser and interfere with the system; to prevent this, special optics were required. The company needed industrial diamonds to provide the “windows” through which the laser exited the chamber, and had to work with partners to develop new, ultra-pure diamonds. It took Trumpf a decade to master these challenges and produce lasers with sufficient power and reliability. Each one required exactly 457,329 component parts.

每个步骤都需要新的创新。必须保持激光腔中的专用气体的恒定密度。锡液滴本身会反射光，这可能会反射回激光并干扰系统，为防止这种情况，需要特殊光学器件。该公司需要工业金刚石来提供激光从腔体中走出的“窗口”，并且必须与合作伙伴一起开发新的超纯金刚石。Trumpf花了十年的时间来掌握这些挑战并生产出具有足够功率和可靠性的激光器。每个激光器都需要精确的457,329个组件。

After Cymer and Trumpf found a way to blast tin so it emits sufficient EUV light, the next step was to create mirrors that collected the light and directed it toward a silicon chip. Zeiss, the German company that builds the world’s most advanced optical systems, had built mirrors and lenses for lithography systems since the days of Perkin Elmer and GCA. The difference between the optics used in the past and those required by EUV, however, was about as vast as the contrast between Lathrop’s lightbulb and Cymer’s system of blasting tin droplets.

在Cymer和Trumpf发现一种方法来冲击锡，使其发出足够的EUV光之后，下一步是创建可以收集光线并将其引导到硅芯片的镜子。德国的Zeiss公司建造了世界上最先进的光学系统，自Perkin Elmer和GCA时代以来一直为光刻系统建造镜子和透镜。然而，过去使用的光学和EUV所需要的光学之间的差距几乎就像Lathrop的电灯泡和Cymer的震荡锡液滴系统之间的对比一样巨大。

Zeiss’s primary challenge was that EUV is difficult to reflect. The 13.5nm wavelength of EUV is closer to X-rays than to visible light, and as is the case with X-rays, many materials absorb EUV rather than reflect it. Zeiss began developing mirrors made of one hundred alternating layers of molybdenum and silicon, each layer a couple nanometers thick. Researchers in Lawrence Livermore National Lab had identified this as an optimal EUV mirror in a paper published in 1998, but building such a mirror with nanoscale precision proved almost impossible. Ultimately, Zeiss created mirrors that were the smoothest objects ever made, with impurities that were almost imperceptibly small. If the mirrors in an EUV system were scaled to the size of Germany, the company said, their biggest irregularities would be a tenth of a millimeter. To direct EUV light with precision, they must be held perfectly still, requiring mechanics and sensors so exact that Zeiss boasted they could be used to aim a laser to hit a golf ball as far away as the moon.

蔡司公司的主要挑战是EUV很难反射。EUV的波长为13.5纳米，比可见光更接近X射线，与X射线一样，许多材料吸收EUV而非反射它。蔡司开始开发由一百层钼和硅交替制成的镜子，每层只有几纳米厚。劳伦斯利弗莫尔国家实验室的研究人员在1998年发表的一篇论文中将其视为最佳EUV镜子，但以纳米级精度构建这样的镜子几乎是不可能的。最终，蔡司创造了平滑度最高的物体，杂质几乎难以察觉。该公司表示，如果将EUV系统中的镜子缩放到德国的大小，它们的最大不规则性将达到1/10毫米。为了精确控制EUV光线，镜子必须保持完全静止，需要机械和传感器的精度如此之高，以至于蔡司自夸它们可以用来瞄准一颗在月球上的高尔夫球。

For Frits van Houts, who took over leadership of ASML’s EUV business in 2013, the most crucial input into an EUV lithography system wasn’t any individual component, but the company’s own skill in supply chain management. ASML engineered this network of business relationships “ like a machine,” van Houts explained, producing a finely tuned system of several thousand companies capable of meeting ASML’s exacting requirements. ASML itself only produced 15 percent of an EUV tool’s components, he estimated, buying the rest from other firms. This let it access the world’s most finely engineered goods, but it also required constant surveillance.

對於於2013年接掌ASML EUV事業領導的Frits van Houts來說，將EUV曝光系統帶入最重要的輸入不是任何個別的部件，而是企業自身在供應鏈管理方面的技巧。van Houts解釋說，ASML像製造機器一樣設計了這個商業關係網絡，製造了一個能夠滿足ASML嚴格要求的幾千家公司的精密調校系統。他估計，ASML自己只生產EUV工具15％的零件，其餘部分則是從其他公司購買的。這讓它可以訪問世界上最精密的商品，但也需要不斷的監控。

The company had no choice but to rely on a single source for the key components of an EUV system. To manage this, ASML drilled down into its suppliers' suppliers to understand the risks. ASML rewarded certain suppliers with investment, like the $1 billion it paid Zeiss in 2016 to fund that company's R&D process. It held all of them, however, to exacting standards. "If you don't behave, we're going to buy you," ASML's CEO Peter Wennink told one supplier. It wasn't a joke: ASML ended up buying several suppliers, including Cymer, after concluding it could better manage them itself.

公司不得不依靠单一供应商获得EUV系统的关键组件。为了管理这个问题，ASML深入到其供应商的供应商领域，以了解风险。ASML为某些供应商提供了投资回报，例如2016年向蔡司支付的10亿美元资金，用于资助该公司的研发过程。然而，它将所有供应商都置于严格的标准之下。 "如果你不守规矩，我们就买下你，" ASML的CEO彼得·温恩克告诉了一位供应商。这不是玩笑：ASML最终收购了几家供应商，包括Cymer，得出结论认为它可以自行更好地管理它们。

The result was a machine with hundreds of thousands of components that took tens of billions of dollars and several decades to develop. The miracle isn't simply that EUV lithography works, but that it does so reliably enough to produce chips cost-effectively. Extreme reliability was crucial for any component that would be put in the EUV system. ASML had set a target for each component to last on average for at least thirty thousand hours—around four years—before needing repair. In practice, repairs would be needed more often, because not every part breaks at the same time. EUV machines cost over $100 million each, so every hour one is offline costs chipmakers thousands of dollars in lost production.

结果是一个有成千上万个零件，耗费数十亿美元和数十年才能开发出的机器。奇迹不仅在于EUV光刻技术的工作原理，而在于它可以可靠地、具有成本效益地生产芯片。极高的可靠性对于任何要组装EUV系统的组件都至关重要。ASML设定了每个组件平均至少持续三万小时（约四年）不需维修的目标。实际上，由于不是每个部件同时损坏，因此修理通常需要更频繁。EUV机器成本超过1亿美元，因此每小时离线都会让芯片制造商损失数千美元的生产。

EUV tools work in part because their software works. ASML uses predictive maintenance algorithms to guess when components need to be replaced before they break, for example. It also uses software for a process called computational lithography to print patterns more exactly. The atomic-level unpredictability in light waves' reaction with photoresist chemicals created new problems with EUV that barely existed with larger-wavelength lithography. To adjust for anomalies in the way light refracts, ASML's tools project light in a pattern that differs from what chipmakers want imprinted on a chip. Printing an "X" requires using a pattern with a very different shape but which ends up creating an "X" when the light waves hit the silicon wafer.

EUV 工具的部分原因在于它们的软件。例如，ASML 使用预测性维护算法，在组件损坏之前猜测何时需要更换。它还使用了称为计算光刻的过程的软件来更精确地打印图案。与较大波长的光刻相比，光波与光阻化学物质的反应的原子级不可预测性，在 EUV 中创造了几乎不存在的新问题。为了调整光的折射中的异常，ASML 的工具投射出与芯片制造商所希望印刷在芯片上的图案不同的图案。打印"X"需要使用形状非常不同但最终会在光波击中硅晶片时创建一个"X"的图案。

The final product—chips—work so reliably because they only have a single component: a block of silicon topped with other metals. There are no moving parts in a chip, unless you count the electrons zipping around inside. Producing advanced semiconductors, however, has relied on some of the most complex machinery ever made. ASML's EUV lithography tool is the most expensive mass-produced machine tool in history, so complex it's impossible to use without extensive training from ASML personnel, who remain on-site for the tool's entire life span. Each EUV scanner has an ASML logo on its side. But ASML's expertise, the company readily admits, was its ability to orchestrate a far-flung network of optics experts, software designers, laser companies, and many others whose capabilities were needed to make the dream of EUV a reality.

最终产品芯片之所以能够如此可靠地运作，是因为它们只有一个部件：一个镶嵌有其他金属的硅块。芯片中没有任何活动部件，除非你算上电子在里面快速移动。然而，生产先进的半导体制造业，却依赖于一些有史以来最复杂的机器。ASML的EUV光刻工具是史上生产成本最昂贵的机床，如此复杂以至于不经过ASML人员的广泛培训就无

法使用，他们会在工具的整个生命周期内一直留在现场。每个EUV扫描仪都有ASML标志。但是，ASML公司坦承，其专业知识在于能够协调遍布世界各地的光学专家、软件设计师、激光公司以及许多其他所需的能力，以使EUV的梦想成为现实。

It’s easy to lament the offshoring of manufacturing, as Andy Grove did during the final years of his life. That a Dutch company, ASML, had commercialized a technology pioneered in America’s National Labs and largely funded by Intel would undoubtedly have rankled America’s economic nationalists, had any been aware of the history of lithography or of EUV technology. Yet ASML’s EUV tools weren’t really Dutch, though they were largely assembled in the Netherlands. Crucial components came from Cymer in California and Zeiss and Trumpf in Germany. And even these German firms relied on critical pieces of U.S.-produced equipment. The point is that, rather than a single country being able to claim pride of ownership regarding these miraculous tools, they are the product of many countries. A tool with hundreds of thousands of parts has many fathers.

抱怨制造业外包是很容易的，就像安迪·格罗夫在他生命的最后几年里所做的。荷兰公司ASML商业化了美国国家实验室开创的技术，并且大多数由Intel资助，这无疑会激怒美国的经济民族主义者，如果他们了解过显影技术或EUV技术的历史。然而，ASML的EUV工具并不是荷兰的，“荷兰制造”的工具关键部件来自加利福尼亚州的Cymer、德国的Zeiss和Trumpf。而这些德国公司甚至也依赖于美国生产的关键设备。关键是，这些神奇的工具并非是单个国家能够拥有所有权，它们是多个国家的产物。具有数十万个零件的工具有许多“父亲”。

“Will it work?” Andy Grove had asked John Carruthers, before investing his first $200 million in EUV. After three decades of investment, billions of dollars, a series of technological innovations, and the establishment of one of the world’s most complex supply chains, by the mid-2010s, ASML’s EUV tools were finally ready to be deployed in the world’s most advanced chip fabs.

安迪·格罗夫（Andy Grove）在向约翰·卡瑟斯（John Carruthers）投资其首笔2亿美元用于微影(VUV)技术前曾经问道：“这会行吗？” 经过三十年的投资、数十亿美元的支出、一系列技术创新和建立了世界上最

复杂的供应链之一，到了2010年代中期，ASML的EUV工具终于可以在世界上最先进的芯片厂商中推广使用了。

CHAPTER 40 “There Is No Plan B”

I n 2015, Tony Yen was asked what would happen if the new extreme-ultraviolet lithography tool that ASML was developing didn’t work. Yen had spent the prior twenty-five years working at the cutting edge of lithography. In 1991 he’d been hired fresh out of MIT by Texas Instruments, where he tinkered with one of the final lithography tools GCA produced before going bankrupt. He then joined TSMC in the late 1990s just as deep-ultraviolet lithography tools, which produced light with a wavelength of 193 nanometers, were coming online. For nearly two decades, the industry relied on these tools to fabricate ever-smaller transistors, using a series of optical tricks like shooting light through water or through multiple masks to enable light waves measuring 193nm to pattern shapes a fraction of the size. These tricks kept Moore’s Law alive, as the chip industry shrank transistors from the 180nm node in the late 1990s through the early stages of 3D FinFET chips, which were ready for high-volume manufacturing by the mid-2010s.

2015年，Tony Yen被问及如果ASML开发的新型极紫外光刻机无法运行会怎样。 Yen在前25年一直在半导体的光刻技术领域工作。1991年，他在MIT毕业后被德州仪器聘用，在GCA破产之前调整了其中一台最终的光刻机。然后，他在1990年代末加入了台积电，就在深紫外光刻机（产生波长为193纳米的光线）量产之前。近20年来，该行业一直依靠这些工具来制造越来越小的晶体管，使用一系列光学技巧，如通过水或多个掩模射入光线，以使193nm波长的光波形成所需图案尺寸的形状。这些技巧使摩尔定律保持有效，芯片行业将晶体管从1990年代末的180nm节点缩小到3D FinFET芯片的早期阶段，这些芯片在2010年代中期已准备好进行大规模生产。

However, there were only so many optical tricks that could help 193nm light carve smaller features. Each new workaround added time and cost money. By the mid-2010s, it might have been possible to eke out a couple additional improvements, but Moore’s Law needed better lithography tools to carve smaller shapes. The only hope was that the hugely delayed EUV lithography tools, which had been in development since the early 1990s, could finally be made to work at a commercial scale. What was the alternative? “There is no Plan B,” Yen knew.

然而，有限的光学技巧只能帮助193纳米光刻制作更小的特征。每一个新的变通方案都增加了时间和成本。到了2010年代中期，或许还能推进一些改进，但摩尔定律需要更好的光刻工具来刻画更小的形状。唯一的希望是长期延误的EUV光刻技术能够在商业层面上得以实现。否则，还有什么其他选择呢？“没有备选方案。”Yen知道这一点。

Morris Chang bet more heavily on EUV than anyone else in the semiconductor industry. The company’s lithography team was divided over whether EUV tools were ready for high-volume manufacturing, but Shang-yi Chiang, the soft-spoken engineer who headed TSMC’s R&D and was widely credited for the company’s top-notch manufacturing technology, was convinced EUV was the only path forward. Chiang was born in Chongqing where, like Morris Chang, his family had fled from Japanese armies during World War II. He grew up in Taiwan before studying electrical engineering at Stanford and landing jobs at TI in Texas and then at HP in Silicon Valley. When TSMC called out of the blue with a job offer—and a massive signing bonus—he moved back to Taiwan in 1997 to help build the company. In 2006, he tried retiring in California, but when TSMC faced a delay with its 40nm manufacturing process in 2009, a frustrated Morris Chang ordered Chiang back to Taiwan and over a meal of beef noodle soup asked him to again take up the responsibility of managing R&D.

張忠謀在半導體行業中比任何人都更加看重極紫外技術。公司的微影團隊在是否EUV工具已準備好進入高產能製造方面分裂不同，但靜默的工程師蔣尚義卻堅信EUV是未來的唯一出路。蔣尚義生於重慶，與張忠謀一樣，他的家人曾在二次世界大戰期間逃離日軍。他在台灣長大，並在斯坦福攻讀電機工程，之後在德州儀器和硅谷的惠普公司工作。當TSMC突然提出工作聘用他的時候，同時提供了巨額簽約金，他於1997年回到台灣幫助建設公司。2006年，他試圖在加州退休，但當TSMC在2009年面臨40nm制造工藝延誤時，張忠謀的失望感驅使蔣尚義回到台灣，並在一餐牛肉麵的晚餐上，要求他重新接手管理研發工作。

Having worked in Texas and California as well as in Taiwan, Chiang was always struck by the ambition and the work ethic that drove TSMC. The ambition stemmed from Morris Chang's vision of world-beating technology, evident in his willingness to spend huge sums expanding TSMC's R&D team from 120 people in 1997 to 7,000 in 2013. This hunger permeated the entire company. "People worked so much harder in Taiwan," Chiang explained. Because manufacturing tools account for much of the cost of an advanced fab, keeping the equipment operating is crucial for profitability. In the U.S., Chiang said, if something broke at 1 a.m., the engineer would fix it the next morning. At TSMC, they'd fix it by 2 a.m. "They do not complain," he explained, and "their spouse does not complain" either. With Chiang back in charge of R&D, TSMC charged forward toward EUV. He had no difficulty finding employees to work all night long. He requested that three EUV scanners for testing purposes be built in the middle of one of the company's biggest facilities, Fab 12, and in the company's partnership with ASML he spared no expense in testing and improving EUV tools.

江先生曾在德州、加州和台灣工作，並永遠被台積電的野心和工作態度所感動。這個野心源於張忠謀對世界頂尖技術的願景，顯示在他願意花巨額資金擴大台積電的研發團隊，從1997年的120人擴大到2013年的7,000人。這種渴望貫穿整個公司。"人們在台灣工作得更努力，"江解釋道。由於製造工具佔先進晶圓廠的成本很大，因此保持設備運作對盈利至關重要。江先生說，在美國，如果凌晨1點時發生了什麼問題，工程師將在隔天早上修理。在台積電，他們會在凌晨2點修好。"他們不抱怨，"他解釋道，"他們的配偶也不抱怨。"江先生重新負責研發後，台積電向著EUV前進。他輕而易舉地找到了願意整夜工作的員工。他要求在公司最大的設施之一Fab 12的中央建造三臺EUV掃描器進行測試，在與阿斯麥爾（ASML）的合作中，他不遺餘力地測試和改進EUV工具。

Like TSMC, Samsung, and Intel, GlobalFoundries was considering adopting EUV as it prepared for its own 7nm node. From its creation, GlobalFoundries knew it needed to grow if it was to thrive. The company had inherited AMD's fabs, but it was far smaller than its rivals. To grow, GlobalFoundries had bought Chartered Semiconductor, a Singapore-based foundry, in 2010. Several years later, in 2014, it bought IBM's microelectronics business, promising to produce chips for Big Blue, which had decided to go fabless for the same reason as AMD. IBM executives used to share an image of the computing ecosystem: an upside-down pyramid with semiconductors at the bottom, on which all other computing depended. Yet though IBM had played a fundamental role in the growth of the semiconductor business, its leaders concluded that fabricating chips made no financial sense. Facing a decision to invest billions to build a new advanced fab, or billions on high-margin software, they chose the latter, selling their chip division to GlobalFoundries.

像台積電、三星和英特爾一樣，GlobalFoundries在準備進入7納米節點時考慮采用EUV技術。自創立之初，GlobalFoundries就知道如果要茁壯成長，必須擴張。該公司繼承了AMD的晶圓廠，但比其競爭對手要小得多。為了擴大規模，GlobalFoundries於2010年收購了新加坡的晶圓廠Chartered Semiconductor。幾年後的2014年，它收購了IBM的微電子業務，承諾為Big Blue生產芯片，後者為了和AMD達成相同的目標，決定走從無晶圓廠到有晶圓廠的路線。IBM的高管曾分享過一張關於計算機生態系統的圖像：一個倒置的金字塔，底部是半導體，其他所有計算都依賴於此。然而，盡管IBM在半導體業務的發展中扮演了基礎性的角色，但該公司的領導人得出的結論是，製造芯片沒有經濟效益。面對投資數十億美元建造新的先進晶圓廠還是投資數十億美元從事高利潤的軟件業務的選擇，他們選擇了後者，將其晶片部門出售給了GlobalFoundries。

By 2015, thanks to these acquisitions, GlobalFoundries was by far the biggest foundry in the United States and one of the largest in the world, but it was still a minnow compared to TSMC. GlobalFoundries competed with Taiwan’s UMC for status as the world’s second-largest foundry, with each company having about 10 percent of the foundry marketplace. However, TSMC had over 50 percent of the world’s foundry market. Samsung only had 5 percent of the foundry market in 2015, but it produced more wafers than anyone when its vast production of chips designed in-house (for example, memory chips and chips for smartphone processors) were included. Measured by thousands of wafers per month, the industry standard, TSMC had a capacity of 1.8 million while Samsung had 2.5 million. GlobalFoundries had only 700,000.

截至2015年，多亏这些收购，GlobalFoundries成为美国迄今为止最大的晶圆代工厂之一，也是全球最大的晶圆代工厂之一，但与TSMC相比仍然是小鱼小虾。GlobalFoundries与台湾的联电争夺世界第二大晶圆代工厂的地位，每家公司在晶圆市场上占有约10％。然而，TSMC拥有全球50％以上的晶圆市场。 2015年，三星只占据晶圆市场的5％，但当其自主设计的芯片生产量（例如内存芯片和智能手机处理器芯片）纳入考虑时，三星的晶圆数量超过了任何一家公司。根据行业标准（以每月千片为单位），TSMC的产能为180万，而三星的产能为250万。GlobalFoundries只有70万。

TSMC, Intel, and Samsung were certain to adopt EUV, though they had different strategies about when and how to embrace it. GlobalFoundries was less confident. The company had struggled with its 28nm process. To reduce the risk of delays, it decided to license its 14nm process from Samsung rather than develop it in-house, a decision that didn't suggest confidence in its R&D efforts.

By 2018, GlobalFoundries had purchased several EUV lithography tools and was installing them in its most advanced facility, Fab 8, when the company's executives ordered them to halt work. The EUV program was being canceled. GlobalFoundries was giving up production of new, cutting-edge nodes. It wouldn't pursue a 7nm process based on EUV lithography, which had already cost $1.5 billion in development and would have required a comparable amount of additional spending to bring online. TSMC, Intel, and Samsung had financial positions that were strong enough to roll the dice and hope they could make EUV work. GlobalFoundries decided that as a medium-sized foundry, it could never make a 7nm process financially viable. It announced it would stop building ever-smaller transistors, slashed R&D spending by a third, and quickly turned a profit after several years of losses. Building cutting-edge processors was too expensive for everyone except the world's biggest chipmakers. Even the deep pockets of the Persian Gulf royals who owned GlobalFoundries weren't deep enough. The number of companies capable of fabricating leading-edge logic chips fell from four to three.

台積電、英特爾和三星肯定會採用EUV，但它們有不同的策略來採用它的時間和方式。GlobalFoundries則不太自信。該公司曾在其28nm工

藝上遇到困難。為了減少延遲的風險，它決定從三星許可其14nm工藝，而不是在內部開發，這個決定並不表明它對自己的研發工作充滿信心。 到2018年，GlobalFoundries已經購買了幾個EUV光刻機並將它們安裝在其最先進的Fab 8設施中，當時公司高管命令它們停止工作。EUV計劃被取消了。GlobalFoundries放棄生產新的尖端節點。它不會追求基於EUV光刻的7nm工藝，該技術在開發上已經耗資15億美元，還需要相當數量的額外支出才能啟用。台積電、英特爾和三星有足夠強大的財務地位來賭一把，希望他們能使EUV成功。GlobalFoundries認為作為一家中等規模的晶圓廠，它永遠無法使7nm工藝在財務上可行。它宣布停止建造越來越小的晶體管，將研發支出削減了三分之一，並在數年的虧損之後迅速實現盈利。製造尖端處理器對於除了全球最大的晶片製造商之外的所有人來說都太昂貴了。即使是擁有GlobalFoundries的波斯灣王室也資源不足。能夠製造領先的邏輯芯片的公司數量從四個降至三個。

CHAPTER 41 How Intel Forgot Innovation

A t least the United States could count on Intel. The company had an unparalleled position in the semiconductor industry. The old leadership was long gone—Andy Grove died in 2016, while Gordon Moore, now in his nineties, retired to Hawaii—but the reputation of having commercialized the DRAM and invented the microprocessor remained. No company had a better track record combining innovative chip design with manufacturing prowess. Intel's x86 architecture remained the industry standard for PCs and data centers. The PC market was stagnant, because it seemed nearly everyone already had a PC, but it remained remarkably profitable for Intel, providing billions of dollars a year that could be reinvested into R&D. The company spent over $10 billion a year on R&D throughout the 2010s, four times as much as TSMC and three times more than the entire budget of DARPA. Only a couple of companies in the world spent more.

至少美國能夠依靠英特爾。該公司在半導體行業擁有無與倫比的地位。舊的領導層早已離去——安迪·格羅夫於2016年去世，而現年九十多歲的戈登·摩爾退休到夏威夷——但將DRAM商業化和發明微處理器的聲譽仍然存在。在創新芯片設計和製造實力方面，沒有一家公司有著更好的成績記錄。英特爾的x86架構仍然是PC和數據中心的行業標準。PC市場停滯不前，因為幾乎每個人都已經擁有了一台PC，但對於英特爾來說仍然非常有利可圖，每年提供數十億美元以便重新投資研發。該公司在2010年代投入了超過100億美元用於研發，是台積電的四倍，也比DARPA的整個預算多三倍。世界上只有幾家公司花費比英特爾更多。

As the chip industry entered the EUV era, Intel looked poised to dominate. The company had been crucial to EUV's emergence, thanks to Andy Grove's initial $200 million bet on the technology in the early 1990s. Now, after billions of dollars of investment—a substantial portion of which had come from Intel—ASML had finally made the technology a reality. Yet rather than capitalizing on this new era of shrinking transistors, Intel squandered its lead, missing major shifts in semiconductor architecture needed for artificial intelligence, then bungling its manufacturing processes and failing to keep up with Moore's Law.

隨著晶片產業進入極紫外線時代，英特爾（Intel）似乎準備好佔據主導地位。由於安迪·格羅夫（Andy Grove）在上世紀90年代初期最初投資2億美元發展技術，英特爾對於EUV的出現至關重要。現在，在經歷了眾多億萬美元的投資之後，其中相當大一部分來自英特爾，ASML終於實現了這一技術。然而，英特爾沒有充分利用這個尺度縮小新時代，錯過了人工智能所需的主要半導體架構轉變，接著在製造過程中出了問題，無法跟上摩爾定律。

Intel remains enormously profitable today. It's still America's biggest and most advanced chipmaker. However, its future is more in doubt than at any point since Grove's decision in the 1980s to abandon memory and bet everything on microprocessors. It still has a shot at regaining its leadership position over the next half decade, but it could just as easily end up defunct. What's at stake isn't simply one company, but the future of America's chip fabrication industry. Without Intel, there won't be a single U.S. company—or a single facility outside of Taiwan or South Korea—capable of manufacturing cutting-edge processors.

英特爾公司今天仍然是利潤豐厚的公司。它依然是美國最大、最先進的晶片製造商。然而，自格羅夫在1980年代放棄記憶體，把所有賭注都放在微處理器上以來，其未來的命運比以往任何時候都更加不確定。在未來的五年內，它仍有機會恢復領先地位，但也可能財政破產。問題不僅僅是公司的問題，而是關乎美國芯片製造業的未來。如果沒有英特爾，美國就沒有一家公司——也沒有一個除台灣或南韓以外的工廠能夠製造尖端處理器。

Intel entered the 2010s as an outlier in Silicon Valley. Most of America's biggest firms in the market for logic chips, including Intel's archrival AMD, had sold their fabs and focused only on design. Intel stuck stubbornly to its integrated model—combining semiconductor design and manufacturing in one company—which executives there thought was still the best way to churn out chips. The company's design and manufacturing processes were optimized for each other, Intel's leaders argued. TSMC, by contrast, had no choice but to adopt generic manufacturing processes that could work just as well for a Qualcomm smartphone processor as an AMD server chip.

英特爾進入2010年代時是矽谷的一個異數。市場上大部分的美國最大邏輯芯片公司，包括英特爾的競爭對手AMD，都已經出售了他們的半導體晶圓廠，只集中做設計。英特爾堅持採用整合模式 - 將半導體設計與製造融為一體的公司，高管們認為這仍然是製造芯片的最好方法。英特爾的設計和製造過程相互優化，該公司的領導層表示。相比之下，台積電只能採用通用製造過程，既能適用於高通智能手機處理器也能適用於AMD服務器芯片。

Intel was right to perceive some benefits of an integrated model, but there were substantial downsides. Because TSMC manufactures chips for many different companies, it now fabricates nearly three times as many silicon wafers per year as Intel, so it has more chance to hone its process. Moreover, where Intel saw chip design startups as a threat, TSMC saw potential customers for manufacturing services. Because TSMC had only a single value proposition—effective manufacturing—its leadership focused relentlessly on fabricating ever-more-advanced semiconductors at lower cost. Intel's leaders had to split their attention between chip design and chip manufacturing. They ended up bungling both.

英特爾正確地看到了整合模式的一些好處，但也存在著實質性的弊端。因為臺積電為許多不同公司製造晶片，所以它現在每年製造的矽晶圓數量幾乎是英特爾的三倍，因此有更多的機會磨練其過程。此外，英特爾看到晶片設計初創公司是一個威脅，而臺積電則看到了製造服務的潛在客戶。由於臺積電只有一個價值主張 - 有效的製造 - 其領導層無情地專注於以更低成本製造更先進的半導體。英特爾的領導者必須將注意力分散在芯片設計和芯片製造之間。他們最終兩者都搞砸了。

Intel's first problem was artificial intelligence. By the early 2010s, the company's core market, supplying PC processors, had stalled. Today, other than gamers, hardly anyone excitedly upgrades their PC when a new model is released, and most people don't think much about which type of processor is inside. Intel's other main market—selling processors for servers in data centers—boomed over the 2010s. Amazon Web Services, Microsoft Azure, Google Cloud, and other companies built networks of vast data centers, which provided the computing power that made possible "the cloud." Most of the data we use online is processed in one of these companies' data centers, each of which is full of Intel chips. But in the early 2010s, just as Intel completed its conquest of the data center, processing demands began to shift. The new trend was artificial intelligence—a task that Intel's main chips were poorly designed to address.

英特爾的第一個問題是人工智能。到了2010年代初期，公司的核心市場，供應個人電腦處理器，已經停滯不前。現在除了遊戲玩家以外，幾乎沒有人會在新型號推出時興奮地升級自己的個人電腦，大部分人對於內部處理器的型號也不太關心。英特爾的另一個主要市場是為數據中心的伺服器提供處理器，在2010年代蓬勃發展。Amazon Web Services、Microsoft Azure、Google Cloud和其他公司建立了大型的數據中心網絡，提供了實現「雲端」的計算能力。我們在線使用的大部分數據都在這些公司的數據中心中進行處理，而每個數據中心都充滿了英特爾芯片。但在2010年代初期，就在英特爾完成對數據中心的征服之時，處理需求開始轉變。新趨勢是人工智能─這是英特爾主要芯片的設計缺陷所無法解決的任務。

Since the 1980s, Intel has specialized in a type of chip called a CPU, a central processing unit, of which a microprocessor in a PC is one example. These are the chips that serve as the "brain" in a computer or data center. They are general-purpose workhorses, equally capable of opening a web browser or running Microsoft Excel. They can conduct many different types of calculations, which makes them versatile, but they do these calculations serially, one after another.

It's possible to run any AI algorithm on a general-purpose CPU, but the scale of computation required for AI makes using CPUs prohibitively expensive. The cost of *training* a single AI model—the chips it uses and the electricity they consume— can stretch into the millions of dollars. (To *train* a computer to recognize a cat, you have to show it a lot of cats and dogs so it learns to distinguish between the two. The more animals your algorithm requires, the more transistors you need.)

自1980年代以来，英特尔公司专门从事一种被称为中央处理器（CPU）的芯片，其中个人电脑中的微处理器就是其中之一。这些芯片可以作为计算机或数据中心的“大脑”，是通用型马力车，同样能够打开网页浏览器或运行Microsoft Excel等程序。它们可以进行许多种不同类型的计算，因此非常灵活，但它们要一个个地按序列进行这些计算。 可以在通用型CPU上运行任何AI算法，但AI所需的计算量使使用CPU变得过于昂贵。训练单个AI模型的成本（它使用的芯片和它们消耗的电力）可能会达到数百万美元。（要让计算机识别猫，必须向其展示大量猫和狗的照片，以便它学习区分二者。你的算法需要的动物越多，你就需要更多的晶体管。）

Because AI workloads often require running the same calculation repeatedly, using different data each time, finding a way to customize chips for AI algorithms is crucial to making them economically viable. Big cloud computing companies like Amazon and Microsoft, which operate the data centers on which most companies' algorithms run, spend tens of billions of dollars annually buying chips and servers. They also spend vast sums providing electricity for these data centers. Wringing efficiencies out of their chips is a necessity as they compete to sell companies space in their "cloud." Chips optimized for AI can work faster, take up less data center space, and use less power than general-purpose Intel CPUs.

因为人工智能工作负载通常需要反复运行相同的计算，每次使用不同的数据，为AI算法定制芯片的方式至关重要，这是使它们经济可行的关键。 像亚马逊和微软这样的大型云计算公司运营着大多数公司算法运行的数据中心，每年花费数十亿美元购买芯片和服务器，并为这些数据中心提供大量电力。 挤压芯片的效率对于它们竞争出售“云”空间的公司来说是必要的。 为AI优化的芯片可以比通用的英特尔CPU更快，占用更少的数据中心空间，并且使用更少的电力。

In the early 2010s, Nvidia—the designer of graphic chips—began hearing rumors of PhD students at Stanford using Nvidia's graphics processing units (GPUs) for something other than graphics. GPUs were designed to work differently from standard Intel or AMD CPUs, which are infinitely flexible but run all their calculations one after the other. GPUs, by contrast, are designed to run multiple iterations of the same calculation at once. This type of "parallel processing," it soon became clear, had uses beyond controlling pixels of images in computer games. It could also train AI systems efficiently. Where a CPU would feed an algorithm many pieces of data, one after the other, a GPU could process multiple pieces of data simultaneously. To learn to recognize images of cats, a CPU would process pixel after pixel, while a GPU could "look" at many pixels at once. So the time needed to train a computer to recognize cats decreased dramatically.

在2010年代初，設計顯示芯片的Nvidia開始聽到斯坦福大學的博士生使用Nvidia的圖形處理單元（GPU）進行一些與圖形無關的操作的傳言。 GPU的設計與標準的Intel或AMD CPU不同，其可靈活無限，但所有計算都是一個接一個執行。相比之下，GPU的設計是同時運行同一個計算的多個迭代。很快就清楚，這種"並行處理"除了控制計算機遊戲圖像的像素之外，還可以有效地訓練AI系統。如果CPU一次處理許多數據，GPU可以同時處理多個數據片段。要學會識別貓的圖像，CPU會逐像素進行處理，而GPU可以"一次性"檢查許多像素。因此，訓練計算機識別貓的時間大大減少了。

Nvidia has since bet its future on artificial intelligence. From its founding, Nvidia outsourced its manufacturing, largely to TSMC, and focused relentlessly on designing new generations of GPUs and rolling out regular improvements to its special programming language called CUDA that makes it straightforward to devise programs that use Nvidia's chips. As investors bet that data centers will require ever more GPUs, Nvidia has become America's most valuable semiconductor company.

Its ascent isn't assured, however, because in addition to buying Nvidia chips the big cloud companies—Google, Amazon, Microsoft, Facebook, Tencent, Alibaba, and others—have also begun designing their own chips, specialized to their processing needs, with a focus on artificial intelligence and machine learning. For example, Google has designed its own chips called Tensor processing units (TPUs), which are optimized for use with Google's TensorFlow software library. You can rent the use of Google's simplest TPU in its Iowa data center for $3,000 per month, but prices for more powerful TPUs can reach over $100,000 monthly. The cloud may sound ethereal, but the silicon on which all our data lives is very real—and very expensive.

自成立以来，英伟达一直将其制造外包，主要由台积电负责，专注于设计新一代GPU，并不断推出名为CUDA的特殊编程语言的改进版本，从而使编写使用英伟达芯片的程序变得简单。随着投资者押注数据中心将需要更多GPU，英伟达已成为美国市值最高的半导体公司。然而，它的崛起并不确定，因为除了购买英伟达芯片之外，大型云公司——谷歌、亚马逊、微软、Facebook、腾讯、阿里巴巴等——也已经开始设计专门用于他们处理需求的芯片，重点关注人工智能和机器学习。例如，谷歌已经设计了自己的芯片，称为Tensor处理器单元（TPU），它们被优化用于Google的TensorFlow软件库。您可以租用Google在艾奥瓦州的数据中心中最简单的TPU，每月费用为3,000美元，但更强大的TPU的价格可以超过100,000美元每月。云听起来可能很玄乎，但我们所有数据所存在的硅是非常真实且非常昂贵的。

Whether it will be Nvidia or the big cloud companies doing the vanquishing, Intel’s near-monopoly in sales of processors for data centers is ending. Losing this dominant position would have been less problematic if Intel had found new markets. However, the company’s foray into the foundry business in the mid-2010s, where it tried to compete head-on with TSMC, was a flop. Intel tried opening its manufacturing lines to any customers looking for chipmaking services, quietly admitting that the model of integrated design and manufacturing wasn’t nearly as successful as Intel’s executives claimed. The company had all the ingredients to become a major foundry player, including advanced technology and massive production capacity, but succeeding would have required a major cultural change. TSMC was open with intellectual property, but Intel was closed off and secretive. TSMC was service-oriented, while Intel thought customers should follow its own rules. TSMC didn’t compete with its customers, since it didn’t design any chips. Intel was the industry giant whose chips competed with almost everyone.

无论是Nvidia还是大型云计算公司，英特尔在数据中心处理器销售方面的几乎垄断地位即将结束。如果英特尔发现了新的市场，失去这个主导地位将会不那么令人担心。然而，在2010年代中期，英特尔进军晶圆代工业务，试图与TSMC正面竞争，但却失败了。英特尔试图向任何寻找芯片制造服务的客户开放其生产线，并悄悄承认，整合设计与制造的模式远不如其高管所声称的那么成功。虽然英特尔拥有先进的技术和巨大的生产能力，但要想成功需要进行重大文化变革。

TSMC开放知识产权，而英特尔则具有封闭和神秘的性质。TSMC以服务为导向，而英特尔则认为客户应该遵循其自己的规则。TSMC不与其客户竞争，因为其不设计任何芯片。英特尔是在芯片几乎与所有人竞争的行业巨头。

Brian Krzanich, who was Intel’s CEO from 2013 to 2018, insisted publicly that “I’ve been basically running our foundry business for the last few years” and described the effort as “strategically important.” But it didn’t look that way to customers, who thought the company failed to put foundry customers first. Inside Intel, the foundry business wasn’t treated as a priority. Compared to making PC and data center chips—which remained highly profitable businesses—the new foundry venture had little internal support. So Intel’s foundry business won only a single major customer while in operation in the 2010s. It was shuttered after just several years.

Intel 的 CEO Brian Krzanich 在 2013 年到 2018 年间坚称“过去几年里，我基本上一直在运作我们的晶圆厂业务”，并将此努力描述为“战略性重要”。但客户并未这样认为，他们认为这家公司没有将晶圆厂客户放在第一位。在 Intel 内部，晶圆厂业务并未被视为优先事项。与制造个人电脑和数据中心芯片的高利润业务相比，新的晶圆厂业务的内部支持较少。因此，Intel 的晶圆厂业务只赢得了一位主要客户，而且在 2010 年代运营了几年之后就被停业了。

As Intel approached its fiftieth anniversary in 2018, decay had set in. The company’s market share was shrinking. The bureaucracy was stultifying. Innovation happened elsewhere. The final straw was Intel’s bungling of Moore’s Law, as the company faced a series of delays to planned improvements in its manufacturing process, which it is still struggling to rectify. Since 2015, Intel has repeatedly announced delays to its 10nm and 7nm manufacturing processes, even as TSMC and Samsung have charged ahead.

The company has done little to explain what went wrong. Intel has now spent half a decade announcing “temporary” manufacturing delays, the technical details of which are obscured in the secrecy of employee nondisclosure agreements. Most people in the industry think many of the company’s problems stem from Intel’s delayed adoption of EUV tools. By 2020, half of all EUV lithography tools, funded and nurtured by Intel, were installed at TSMC. By contrast, Intel had only barely begun to use EUV in its manufacturing process.

當 Intel 史無前例地迎來其 50 周年紀念時，公司已經開始走下坡路。公司市佔率不斷萎縮，繁文縟節的官僚體系更是壓垮了企業的創新精神。最讓人失望的是，Intel 在 Moore 定律的實踐上犯了致命的錯誤，這項 50 年的引領先鋒工作被公司一連串的製造進程延誤擱置，而 Intel 在這個問題上仍在掙扎求解。自 2015 年以來，Intel 已多次延遲其 10nm 和 7nm 制造工藝，而 TSMC 和三星等競爭對手卻不斷取得了進展。然而，Intel 公司鮮少對外公開解釋為何出錯，此前數年多次宣布的"臨時"制造工藝延遲更让人迷茫。問題背後的技術细节都包含在員工保密協議的神秘黑匣子里，大多數業內人士認為制造工藝上的迟缓采用是 Intel 众多问题的根源之一，直到 2020 年，由 Intel 負责投资和助力孵化的 EUV 技術进展到全球布局的一半领域时，TSMC 以中国制造工业的速度超越了 Intel 的步伐，Intel 才勉强在制造过程中使用了 EUV 科技。

As the decade ended, only two companies could manufacture the most cutting-edge processors, TSMC and Samsung. And so far as the United States was concerned, both were problematic for the same reason: their location. Now the entire world's production of advanced processors was taking place in Taiwan and Korea—just off the coast from America's emerging strategic competitor: the People's Republic of China.

隨著這個十年的結束，只有兩家公司能夠製造最尖端的處理器，台積電和三星。就美國而言，兩者同樣存在問題：它們的地理位置。現在，全球先進處理器的生產都在台灣和韓國進行，就在美國新興的戰略競爭對手——中華人民共和國的海岸線附近。

PART VII CHINA'S CHALLENGE

CHAPTER 42 Made in China

“ W ithout cybersecurity there is no national security,” declared Xi Jinping, general secretary of the Chinese Communist Party, in 2014, “ and without informatization, there is no modernization.” The son of one of China’s earliest Communist Party leaders, Xi had studied engineering in college before ascending the ranks of Chinese politics thanks to his chameleonlike knack for appearing to be whatever a given audience thought it wanted. To Chinese nationalists, his program of a “Chinese Dream” promised national rejuvenation and great power status. To businesses, he pledged economic reform. Some foreigners even saw him as a closet democrat, with the *New Yorker* declaring right after he took power that Xi was “a leader who realizes that China must undertake real political reform.” The only certainty was Xi’s talent as a politician. His own views were hidden behind pursed lips and a feigned smile.

在2014年，中國共產黨總書記習近平宣稱：“沒有網絡安全就沒有國家安全，沒有信息化就沒有現代化。”作為中國最早的共產黨領袖之一的兒子，習近平在上大學時學習了工程學，後來由於他的多變才能，順利爬升中國政治的職位。對於中國民族主義者來說，他提出的“中國夢”計劃承諾了國家的振興和大國地位。對於企業界，他承諾進行經濟改革。甚至有些外國人覺得他是一名秘密的民主主義者，因《紐約客》在他上台后宣稱習近平是一位“領袖，了解到中國必須進行真正的政治改革。”唯一確定的是，習近平是一位有天賦的政治家，他的觀點常常藏在緊閉的嘴唇和一個假笑之中。

Behind this smile is a gnawing sense of insecurity that has driven Xi’s policies during the decade he’s ruled China. The primary risk, he believed, was the digital world. Most observers thought Xi had little to fear when it came to guaranteeing his own digital security. China’s leaders have the world’s most effective system of internet control, employing many thousands of censors to police online chatter. China’s firewall made a huge swath of the internet inaccessible to its citizens, decisively disproving Western predictions that the internet would be a liberalizing political force. Xi felt strong enough online to mock the Western belief that the internet would spread democratic values. “The internet has turned the world into a global village,” Xi declared, sidestepping the fact that many of the world’s most popular websites, like Google and Facebook, were banned in China. He had a different type of global network in mind than the utopians of the early internet age—a network that China’s government could use to project power. “We must march out, deepen international internet exchange and collaboration, and vigorously participate in the construction of ‘One Belt, One Road,’ ” he declared on a different occasion, referring to his plan to enmesh the world in Chinese-built infrastructure that included not only roads and bridges but network equipment and censorship tools.

这个微笑背后隐藏着Xi统治中国十年来驱使他政策的一种折磨人的不安全感。他认为主要的风险来自数字世界。大多数观察家认为在保障自己的数字安全方面，Xi没有什么好担心的。中国领导人有着全球最有效的互联网控制系统，雇用了数千名审查员来监管在线聊天。中国的防火墙使其公民无法访问互联网的大片区域，彻底证明了西方对互联网将成为自由化政治力量的预测是错误的。Xi觉得他在网上很强大，可以嘲笑西方人认为互联网会传播民主价值观的看法。“互联网已经把世界变成了一个全球村庄”， Xi宣称，回避了许多世界上最受欢迎的网站，如谷歌和Facebook，在中国被禁止的事实。他心中的全球网络与早期互联网时代的乌托邦主义者有所不同，这是中国政府可以用来扩大影响力的网络。“我们必须走出去，深化国际互联网交流与合作，并积极参与‘一带一路’的建设”，他在另一次发言中宣称，这指的是他的计划将世界纳入中国建造的基础设施网，其中不仅包括道路和桥梁，还包括网络设备和审查工具。

No country has been more successful than China at harnessing the digital world for authoritarian purposes. It has tamed America’s tech giants. Google and Facebook were banned and replaced by homegrown firms like Baidu and Tencent, which, technologically, are close matches with their American rivals. The U.S. tech firms that have won access to the Chinese market, like Apple and Microsoft, were allowed in only after agreeing to collaborate with Beijing’s censorship efforts. Far more than any other country, China has made the internet subservient to its leaders’ wishes. Foreign internet and software companies either signed on to whatever censorship rules the Communist Party desired or lost access to a vast market.

沒有國家能夠像中國一樣成功地利用數字世界來實現專制目的。 它已經征服了美國的科技巨頭。 谷歌和 Facebook 被禁止，取而代之的是像百度和騰訊這樣的本土公司，從技術上講，它們與美國的競爭對手非常接近。 美國科技公司，像蘋果和微軟，獲得了進入中國市場的許可，但只有在同意與北京的審查工作合作之後才被允許進入。 與任何其他國家相比，中國使互聯網成為了領導人願望的奴隸。 外國的互聯網和軟件公司要麼遵守共產黨希望的審查規則，要麼失去了進入廣闊市場的機會。

Why, then, was Xi Jinping worried about digital security? The more China's leaders studied their technological capabilities, the less important their internet companies seemed. China's digital world runs on digits—1s and 0s—that are processed and stored mostly by imported semiconductors. China's tech giants depend on data centers full of foreign, largely U.S.-produced, chips. The documents that Edward Snowden leaked in 2013 before fleeing to Russia demonstrated American network-tapping capabilities that surprised even the cyber sleuths in Beijing. Chinese firms had replicated Silicon Valley's expertise in building software for e-commerce, online search, and digital payments. But all this software relies on foreign hardware. When it comes to the core technologies that undergird computing, China is staggeringly reliant on foreign products, many of which are designed in Silicon Valley and almost all of which are produced by firms based in the U.S. or one of its allies.

那么，为什么习近平会担心数字安全呢？中国领导人研究了他们的技术能力后，他们的互联网公司似乎越来越不重要了。中国的数字世界运行在数字1和0上，这些数字主要由进口的半导体处理和存储。中国的科技巨头依赖着充满外国（主要是美国）生产芯片的数据中心。爱德华·斯诺登在2013年逃往俄罗斯之前泄露的文件展示了美国的网络窃听能力，这甚至惊讶了北京的网络侦察专家。中国公司复制了硅谷在电子商务、在线搜索和数字支付方面的专业知识。但所有这些软件都依赖于外国硬件。当涉及到支撑计算机的核心技术时，中国极度依赖于外国产品，其中许多是由硅谷设计，几乎所有生产这些产品的公司都是美国或其盟国的企业。

Xi thought this presented an untenable risk. “However great its size, however high its market capitalization, if an internet enterprise critically relies on the outside world for core components, the ‘vital gate’ of the supply chain is grasped in the hands of others,” Xi declared in 2016. Which core technologies most worry Xi? One is a software product, Microsoft Windows, which is used by most PCs in China, despite repeated efforts to develop competitive Chinese operating systems. Yet even more important in Xi’s thinking are the chips that power China’s computers, smartphones, and data centers. As he noted, “Microsoft’s Windows operating system can only be paired with Intel chips.” So most computers in China needed American chips to function. During most years of the 2000s and 2010s, China spent more money importing semiconductors than oil. High-powered chips were as important as hydrocarbons in fueling China’s economic growth. Unlike oil, though, the supply of chips is monopolized by China’s geopolitical rivals.

习认为这代表了一种不可承受的风险。“无论其规模多大，市值多高，如果一个互联网企业的核心组件需要依赖外部世界，供应链的“重要关口”将掌握在他人手中，“2016年习在声明中宣称。哪些核心技术最让习感到担忧？ 一种是软件产品Microsoft Windows，尽管中国一直在不断努力开发具有竞争力的中国操作系统，但大多数PC使用Microsoft Windows。然而，在习的想法中更为重要的是，这些芯片驱动着中国的计算机，智能手机和数据中心。他指出，“微软的Windows操作系统只能与英特尔芯片配对。”因此，中国大多数计算机需要美国芯片才能运行。在2000年代和2010年代的大多数年份，中国花费的进口半导体资金都比石油还要多。高功率芯片在推动中国经济增长方面与烃类一样重要。然而，与石油不同的是，芯片的供应被中国地缘政治竞争对手所垄断。

Most foreigners struggled to comprehend why China felt nervous. Hadn’t the country built vast tech firms worth hundreds of billions of dollars? Newspaper headlines repeatedly declared China one of the world’s leading tech powers. When it came to artificial intelligence, the country was one of the world’s two *AI Superpowers* , according to a widely discussed book by Kai-Fu Lee, former head of Google China. Beijing built a twenty-first-century fusion of AI and authoritarianism, maximizing use of surveillance technology. But even the surveillance systems that track China’s dissidents and its ethnic minorities rely on chips from American companies like Intel and Nvidia. All of China’s most important technology rests on a fragile foundation of imported silicon.

大多数外国人很难理解为什么中国感到紧张。难道这个国家没有建设价值数百亿美元的庞大科技公司吗？新闻头条经常宣称中国是世界领先的科技强国之一。在人工智能方面，根据谷歌中国前总裁李开复的一本广受讨论的书籍，该国是世界上两个AI超级大国之一。北京建立了一个21世纪的人工智能和专制主义融合体系，最大化利用监视技术。但是，即使追踪中国异见人士和少数民族的监视系统也依赖于英特尔和英伟达等美国公司的芯片。中国所有最重要的技术都依赖于进口硅。

Chinese leaders didn’t need to be paranoid to think their country should build more chips at home. It wasn’t just about avoiding supply chain vulnerability. Like its neighbors, China can only win more valuable business if it produces what Beijing’s leaders call “core technologies”—products the rest of the world can’t live without. Otherwise, China risks continuing the low-profit pattern of what has occurred with the iPhone. Millions of Chinese are involved in assembling the phones, but when the devices are sold to end users Apple makes most of the money, with much of the rest accruing to the makers of the chips inside each phone.

中國領導人無需偏執地認為他們的國家應該在家鄉建造更多芯片。這不僅僅是為了避免供應鏈的脆弱性。像其鄰居一樣，只有生產北京領導人所謂的“核心技術” - 其他國家不能沒有的產品，中國才能贏得更有價值的業務。否則，中國面臨著繼續iPhone低利潤模式的風險。數百萬中國人參與組裝手機，但是當設備銷售給最終用戶時，蘋果公司賺取了大部分錢，其餘的大部分利潤都歸屬於每個手機內部芯片的製造商。

The question for China’s leaders was how to pivot to producing the kind of chips the world coveted. When Japan, Taiwan, and South Korea wanted to break into the complex and high-value portions of the chip industry, they poured capital into their semiconductor companies, organizing government investment but also pressing private banks to lend. Second, they tried to lure home their scientists and engineers who’d been trained at U.S. universities and worked in Silicon Valley. Third, they forged partnerships with foreign firms but required them to transfer technology or train local workers. Fourth, they played foreigners off each other, taking advantage of competition between Silicon Valley firms—and, later, between Americans and Japanese

—to get the best deal for themselves. “We want to promote a semiconductor industry in Taiwan,” the island’s powerful minister, K. T. Li, had told Morris Chang while founding TSMC. Was it any surprise that Xi Jinping wanted one, too?

中国领导人面临的问题是如何转向生产世界所追求的芯片。当日本、台湾和韩国想要进入芯片行业的复杂和高价值部分时，它们注资其半导体公司，组织政府投资，但也敦促私人银行提供贷款。其次，它们试图吸引在美国大学接受过培训并在硅谷工作的科学家和工程师回国。第三，他们与外国公司建立伙伴关系，但要求它们转移技术或培训当地工人。第四，他们让外国人互相竞争，利用硅谷公司之间以及后来的美国人和日本人之间的竞争来取得最好的交易。台湾强大的部长李开复在创立TSMC时曾告诉莫里斯?张：“我们想在台湾推广半导体产业。”难道习近平不也想要一个吗？

CHAPTER 43 “Call Forth the Assault”

I n January 2017, Xi took the stage at the World Economic Forum in the Swiss ski resort of Davos, three days before Donald Trump’s inauguration as U.S. president, to outline China’s economic vision. As Xi promised “win-win outcomes” via a “dynamic, innovation-driven growth model,” the audience of CEOs and billionaires applauded politely. “No one will emerge as a winner in a trade war,” the Chinese president declared, in a none-too-subtle dig at his incoming American counterpart. Three days later in Washington, Trump delivered a shockingly combative inaugural address, condemning “other countries making our products, stealing our companies and destroying our jobs.” Rather than embracing trade, Trump declared that “protection will lead to great prosperity and strength.”

2017年1月，習近平在瑞士滑雪勝地達沃斯世界經濟論壇發表演講，就中國經濟願景進行了闡述。當習近平承諾通過“動態創新驅動增長模式”實現“雙贏結果”時，CEO和億萬富翁的觀眾禮貌地鼓掌。 "沒有人能從貿易戰中獲勝," 中國主席宣布，這是對即將上任的美國對手的一種不太含蓄的反擊。三天後，特朗普在華盛頓發表了一個令人震驚的有關貿易的就職演說，譴責“其他國家生產我們的產品、偷竊我們的公司並破壞我們的就業”。特朗普宣布，“保護會帶來巨大的繁榮和力量”。

Xi’s speech was the sort of claptrap that global leaders were supposed to say when addressing business tycoons. The media fawned over his supposed defense of economic openness and globalization against populist shocks like Trump and Brexit. “Xi sounding rather more presidential than US president-elect,” tweeted talking-head Ian Bremmer. “Xi Jinping Delivers a Robust Defence of Globalisation,” reported the lead headline in the *Financial Times*. “World Leaders Find Hope for Globalization in Davos Amid Populist Revolt,” the *Washington Post* declared. “The international community is looking to China,” explained Klaus Schwab, the chair of the World Economic Forum.

习近平的讲话是全球领导人在面对商业大亨时应该说的那种废话。媒体对他所谓的为经济开放和全球化而辩护，以对抗特朗普和英国退欧

的民粹主义冲击进行了献媚。“Xi比美国当选总统听起来更像总统，”说话人伊恩·布雷默在推特上说。 "Xi Jinping发表有力的全球化防御"，金融时报的主要标题报道。 "世界领袖在执政中心中找到全球化的希望在民粹主义的背景下爆发"，《华盛顿邮报》宣称。“国际社会正在寻求中国，”世界经济论坛的主席克劳斯·施瓦布解释说。

Months before his Davos debut, Xi had struck a different tone in a speech to Chinese tech titans and Communist Party leaders in Beijing for a conference on “cyber security and informatization.” To an audience that included Huawei founder Ren Zhengfei, Alibaba CEO Jack Ma, high-profile People’s Liberation Army (PLA) researchers, and most of China’s political elite, Xi exhorted China to focus on “gaining breakthroughs in core technology as quickly as possible.” Above all, “core technology” meant semiconductors. Xi didn’t call for a trade war, but his vision didn’t sound like trade peace, either. “We must promote strong alliances and attack strategic passes in a coordinated manner. We must assault the fortifications of core technology research and development…. We must not only call forth the assault, we must also sound the call for assembly, which means that we must concentrate the most powerful forces to act together, compose shock brigades and special forces to storm the passes.” Donald Trump, it turned out, wasn’t the only world leader who mixed martial metaphors with economic policy. The chip industry faced an organized assault by the world’s second-largest economy and the one-party state that ruled it.

在达沃斯首次亮相数月之前，习近平在北京向中国科技巨头和共产党领袖发表演讲，参加了一场关于“网络安全和信息化”的会议。他向包括华为创始人任正非、阿里巴巴CEO马云、知名的解放军研究员以及中国大部分政治精英在内的观众们呼吁，要关注“尽快在核心技术方面取得突破”。最重要的是，“核心技术”意味着半导体。习近平没有呼吁贸易战，但他的愿景也不像是寻求贸易和平。“我们必须促进强大的联盟并协调攻击战略要塞。我们必须攻击核心技术研发的要塞……我们不仅要发起进攻，还要发出集结的号召，这意味着我们必须集中最强大的力量一起行动，组成冲击旅和特种部队攻破要塞。”唐纳德·特朗普并不是唯一一个将武术隐喻用于经济政策的世界领袖。芯片行业面临着由全球第二大经济体和执政党国家发起的有组织攻势。

China's leaders were counting on a mix of market and military methods to develop advanced chips at home. Though Xi had jailed his rivals and become China's most powerful leader since Mao Zedong, his control over China was far from absolute. He could lock up dissidents and censor even the most veiled criticism online. But many facets of Xi's economic agenda, from industrial restructuring to financial market reform, remained stillborn, obstructed by Communist Party bureaucrats and local government officials who preferred the status quo. Officials often dragged their feet when faced with instructions from Beijing that they disliked.

中國領導人原本打算結合市場和軍事手段，在國內發展高端晶片。雖然習近平囚禁了他的競爭對手並成為自毛澤東以來中國最有權力的領導人，但他對中國的控制遠非絕對。他可以監禁異見人士，甚至審查最隱晦的在線批評。但習的經濟議程許多方面，從產業重組到金融市場改革，仍然無法實現，被中共官僚和地方政府官員所阻礙，他們更喜歡現狀。當面對他們不喜歡的北京指示時，官員們常常故意拖延。

Xi's military rhetoric wasn't solely a tactic for mobilizing lazy bureaucrats, however. With every year that passed, the precariousness of China's technological position became clearer. China's imports of semiconductors increased year after year. The chip industry was changing in ways that weren't favorable to China. "The scale of investment has risen rapidly and market share has accelerated to the concentration of dominant firms," China's State Council noted in one technology policy report. These dominant firms—TSMC and Samsung chief among them—would be extremely difficult to displace. Yet demand for chips was "exploding," China's leaders realized, driven by "cloud computing, the Internet of Things, and big data." These trends were dangerous: chips were becoming even more important, yet the design and production of the most advanced chips was monopolized by a handful of companies, all located outside of China.

然而，习近平的军事言辞并不仅仅是动员懒惰官僚的策略。随着每一年的过去，中国技术地位的危险性变得越来越清晰。中国的半导体进口量逐年增加。芯片行业正在以不利于中国的方式变化。"投资规模迅速增长，市场份额加速向主导企业集中，"中国国务院在一份科技政策报告中指出。其中的主导企业，包括台积电和三星等，将极其难以替代。然而，中国的领导人们意识到，由"云计算、物联网和大数据"驱

动的芯片需求正在“爆炸性地增长”。这些趋势很危险：芯片变得越来越重要，但最先进的芯片的设计和制造却被少数公司垄断，而这些公司全部位于中国以外。

China’s problem isn’t only in chip fabrication. In nearly every step of the process of producing semiconductors, China is staggeringly dependent on foreign technology, almost all of which is controlled by China’s geopolitical rivals—Taiwan, Japan, South Korea, or the United States. The software tools used to design chips are dominated by U.S. firms, while China has less than 1 percent of the global software tool market, according to data aggregated by scholars at Georgetown University’s Center for Security and Emerging Technology. When it comes to core intellectual property, the building blocks of transistor patterns from which many chips are designed, China’s market share is 2 percent; most of the rest is American or British. China supplies 4 percent of the world’s silicon wafers and other chipmaking materials; 1 percent of the tools used to fabricate chips; 5 percent of the market for chip designs. It has only a 7 percent market share in the business of fabricating chips. None of this fabrication capacity involves high-value, leading-edge technology.

中国的问题不仅在芯片制造方面。在生产半导体的几乎每一个环节中，中国都极度依赖外国技术，几乎全部由中国的地缘政治对手——台湾、日本、韩国或美国控制。用于设计芯片的软件工具被美国公司主导，据乔治城大学安全与新兴技术中心的学者汇总的数据显示，中国在全球软件工具市场中的份额不到1％。当涉及到核心知识产权时，大多数芯片设计的晶体管图案的构建块，中国的市场份额为2％；大部分是美国或英国的。中国供应了全球4％的硅片和其他芯片制造材料；1％的用于制造芯片的工具；5％的芯片设计市场。它只占芯片制造业务的7％市场份额。这些制造能力都不涉及高价值、领先技术。

Across the entire semiconductor supply chain, aggregating the impact of chip design, intellectual property, tools, fabrication, and other steps, Chinese firms have a 6 percent market share, compared to America’s 39 percent, South Korea’s 16 percent, or Taiwan’s 12 percent, according to the Georgetown researchers. Almost every chip produced in China can also be fabricated elsewhere. For advanced logic, memory, and analog chips, however, China is crucially dependent on American software and designs;

American, Dutch, and Japanese machinery; and South Korean and Taiwanese manufacturing. It's no wonder that Xi Jinping was worried.

根據喬治城大學的研究，從晶片設計、智慧財產、工具、製造等步驟整合影響，中國公司在整個半導體供應鏈中占6%的市場份額，相比之下，美國佔39%，韓國佔16%，台灣佔12%。幾乎每一個在中國生產的晶片也可以在其他地方製造。然而，對於先進的邏輯、記憶體和模擬晶片，中國卻關鍵依賴美國的軟體和設計，荷蘭和日本的設備，以及韓國和台灣的製造。習近平之所以擔心也就不足為奇了。

As China's tech firms pushed further into spheres like cloud computing, autonomous vehicles, and artificial intelligence, their demand for semiconductors was guaranteed to grow. The x86 server chips that remain the workhorse of modern data centers are still dominated by AMD and Intel. There's no Chinese firm that produces a commercially competitive GPU, leaving China reliant on Nvidia and AMD for these chips, too. The more China becomes an AI superpower, as Beijing's boosters promise and as China's government hopes, the more the country's reliance on foreign chips will increase, unless China finds a way to design and manufacture its own. Xi's call to "compose shock brigades and special forces to storm the passes" seemed urgent. China's government set out a plan called Made in China 2025, which envisioned reducing China's imported share of its chip production from 85 percent in 2015 to 30 percent by 2025.

隨著中國的科技公司不斷向雲計算、自動駕駛和人工智慧等領域推進，對半導體的需求也必然增長。現代數據中心的關鍵技術之一的x86 伺服器芯片仍由 AMD 和 Intel 主導。中國沒有生產商生產具有商業競爭力的 GPU 芯片，因此，中國在這些芯片方面上仍依賴 Nvidia 和 AMD。正如北京的支持者承諾，以及中國政府所希望的那樣，中國越成為一個人工智慧超級大國，中國對國外芯片的依賴會越來越高，除非中國找到一種方法來設計和製造自己的芯片。習近平的"組建衝鋒隊和特種部隊攻克難關"的呼聲顯得很緊迫。中國政府制定了一項名為《中國製造2025》的計劃，旨在將中國的晶片生產進口份額由2015年的85%降至2025年的30%。

Every Chinese leader since the founding of the People's Republic wanted a semiconductor industry, of course. Mao's Cultural Revolution dream that every worker could produce their own transistors had been an abject failure. Decades later, Chinese leaders recruited Richard Chang to found SMIC and "share God's love with the Chinese." He built a capable foundry, but it struggled to make money and suffered a series of bruising intellectual property lawsuits with TSMC. Eventually Chang was ousted and private-sector investors were displaced by the Chinese state. By 2015, a former official from China's Ministry of Industry and Information was named chairman, solidifying the relationship between SMIC and the Chinese government. The firm continued to lag meaningfully behind TSMC in manufacturing prowess.

自中华人民共和国成立以来，每位中国领导人都希望有一个半导体产业，毛泽东的"每个工人都能生产自己的晶体管"的文化大革命梦想已经彻底失败了。几十年后，中国领导人招募Richard Chang创办SMIC，并"与中国分享上帝的爱"，他建立了一个有能力的晶圆厂，但它难以盈利，并与TSMC发生了一系列惨痛的知识产权诉讼。最终，Chang被罢免，私营投资者被中国国家取代。到了2015年，一名来自中国工业和信息化部的官员被任命为主席，巩固了SMIC和中国政府之间的关系。该公司在制造能力方面仍然明显落后于TSMC。

SMIC, meanwhile, was the comparative success story in China's fabrication industry. Huahong and Grace, two other Chinese foundries, won little market share, in large part because the state-owned firms and municipal governments that controlled them meddled incessantly in business decisions. One former CEO of a Chinese foundry explained that every governor wanted a chip fab in his province and offered a mix of subsidies and veiled threats to ensure a facility was built. So China's foundries ended up with an inefficient collection of small facilities spread across the country. Foreigners saw immense potential in the Chinese chip industry, but only if disastrous corporate governance and business processes could somehow be fixed. "When a Chinese firm said, 'Let's open a joint venture,'" one European semiconductor executive explained. "I heard, 'Let's lose money.'" The joint ventures that did emerge were generally addicted to government subsidies and rarely produced meaningful new technology.

SMIC在中国的制造业中是一个比较成功的故事。华虹和格力等另外两家中国晶圆厂的市场份额很小，主要是因为控制它们的国有企业和地

方政府不断干预业务决策。一位前中国晶圆厂的CEO解释说，每个省长都想在他的省建立一家芯片工厂，并提供混合型的补贴和隐晦的威胁来确保设施建成。因此，中国晶圆厂最终拥有了一个分散在全国各地的低效集合。外国人看到了中国芯片行业的巨大潜力，但前提是必须修复灾难性的公司治理和业务流程。一个欧洲半导体行业的高管解释说，“当一家中国公司说‘让我们合资吧’时，我会听到‘让我们亏钱吧’。”出现的合资企业通常沉迷于政府补贴，很少生产有意义的新技术。

China’s subsidy strategy of the 2000s hadn’t created a leading-edge domestic chip industry. Yet doing nothing—and tolerating continued dependence on foreign semiconductors—wasn’t politically tolerable. So as early as 2014, Beijing had decided to double down on semiconductor subsidies, launching what became known as the “Big Fund” to back a new leap forward in chips. Key “investors” in the fund include China’s Ministry of Finance, the state-owned China Development Bank, and a variety of other government-owned firms, including China Tobacco and investment vehicles of the Beijing, Shanghai, and Wuhan municipal governments. Some analysts hailed this as a new “venture capital” model of state support, but the decision to force China’s state-owned cigarette company to fund integrated circuits was about as far from the operating model of Silicon Valley venture capital as could be.

中国在2000年代的补贴战略并没有创造出领先的国内芯片产业。然而，不做任何事情，容忍继续依赖外国半导体是政治上无法容忍的。因此，早在2014年，北京已经决定加倍补贴半导体，推出了被称为“大基金”的计划，以支持芯片的新飞跃。该基金的主要“投资者”包括中国财政部、国有的中国开发银行以及其他政府所有的公司，包括中国烟草和北京、上海和武汉市政府的投资工具。一些分析师称这是国家支持的新“风险投资”模式，但强制中国的国有烟草公司资助集成电路与硅谷风险投资的运营模式相去甚远。

Beijing was right to conclude the country’s chip industry needed more money. In 2014, when the fund was launched, advanced fabs cost well over $10 billion. SMIC reported revenue of just a couple billion dollars per year throughout the 2010s, less than a tenth of TSMC. It would be impossible to replicate TSMC’s investment plans with private-sector funding alone. Only a government could take such a gamble. The amount of money China’s put into chip subsidies and “investments” is hard to calculate, since much of the spending is done by local governments and opaque state-owned banks, but it’s widely thought to measure in the tens of billions of dollars.

北京正确地得出结论，该国的芯片产业需要更多资金。2014年，当该基金成立时，先进的晶圆厂造价超过100亿美元。几乎整个2010年代，中芯国际公司的年收入仅为数十亿美元，不到台积电的十分之一。只有政府才能承担这样的赌注，私营部门的资金不足以复制台积电的投资计划。中国投入芯片补贴和“投资”的资金数量很难计算，因为大部分支出是由地方政府和不透明的国有银行完成，但有广泛的认为这些资金总额高达数百亿美元。

China was disadvantaged, however, by the government’s desire not to build connections with Silicon Valley, but to break free of it. Japan, South Korea, the Netherlands, and Taiwan had come to dominate important steps of the semiconductor production process by integrating deeply with the U.S. chip industry. Taiwan’s foundry industry only grew rich thanks to America’s fabless firms, while ASML’s most advanced lithography tools only work thanks to specialized light sources produced at the company’s San Diego subsidiary. Despite occasional tension over trade, these countries have similar interests and worldviews, so mutual reliance on each other for chip designs, tools, and fabrication services was seen as a reasonable price to pay for the efficiency of globalized production.

中国曾处于不利地位，这是因为政府希望摆脱与硅谷的联系而不是建立联系。日本、韩国、荷兰和台湾已经通过与美国芯片产业的深度融合，主导了半导体生产流程的重要环节。台湾的晶圆代工行业只有美国的无厂设计公司才能赚得丰厚利润，ASML公司最先进的光刻工具也只能依靠其位于圣迭戈的子公司生产的专业光源。尽管偶尔会有贸易摩擦，这些国家有相似的利益和世界观，因此相互依赖于芯片设计、工具和制造服务被视为全球化生产效率的合理代价。

If China only wanted a bigger part in this ecosystem, its ambitions could’ve been accommodated. However, Beijing wasn’t looking for a better position in a system dominated by America and its friends. Xi’s call to “assault the fortifications” wasn’t a request for slightly higher market share. It was about remaking the world’s semiconductor industry, not integrating with it. Some economic policymakers and semiconductor industry executives in China would have preferred a strategy of deeper integration, yet leaders in Beijing, who thought more about security than efficiency, saw interdependence as a threat. The Made in China 2025 plan didn't advocate economic integration but the opposite. It called for slashing China's dependence on imported chips. The primary target of the Made in China 2025 plan is to reduce the share of foreign chips used in China.

如果中國只想在這個生態系統中佔據更大的份額，其野心可能會被容納。然而，北京並不是在尋求在由美國及其友邦主導的系統中更好的位置。習近平的"攻城掠地"的呼籲不是要求稍微增加市場份額，而是關於重塑全球半導體產業，而不是與之融合。一些經濟政策制定者和中國半導體行業高管可能希望深層次地融入，但北京的領導人，他們更關心安全而不是效率，認為相互依存是一種威脅。《中國製造2025》計劃不僅沒有提倡經濟一體化，反而是相反的。它呼籲減少中國對進口芯片的依賴。《中國製造2025》計劃的主要目標是減少中國使用外國芯片的份額。

This economic vision threatened to transform trade flows and the global economy. Since Fairchild Semiconductor's first facility in Hong Kong, trade in chips had helped build globalization. The dollar values at stake in China's vision of reworking semiconductor supply chains were staggering. China's import of chips—$260 billion in 2017, the year of Xi's Davos debut—was far larger than Saudi Arabia's export of oil or Germany's export of cars. China spends more money buying chips each year than the entire global trade in aircraft. No product is more central to international trade than semiconductors.

這種經濟願景威脅著轉變貿易流程和全球經濟。自從費爾柴爾德半導體在香港的第一家工廠成立以來，芯片貿易一直有助於全球化的發展。中國重新定義半導體供應鏈的願景涉及的金額驚人，2017年，中國芯片進口額達2600億美元，遠超沙特阿拉伯的石油出口額或德國汽車出口額。中國每年購買芯片的費用比全球航空貿易額還要高。沒有任何產品比半導體更加關鍵於國際貿易。

It wasn't only Silicon Valley's profits that were at risk. If China's drive for self-sufficiency in semiconductors succeeded, its neighbors, most of whom had export-dependent economies, would suffer even more. Integrated circuits made up 15 percent of South Korea’s exports in 2017; 17 percent of Singapore’s; 19 percent of Malaysia’s; 21 percent of the Philippines’; and 36 percent of Taiwan’s. Made in China 2025 called all this into question. At stake was the world’s most dense network of supply chains and trade flows, the electronics industries that had undergirded Asia’s economic growth and political stability over the past half century.

不只是硅谷的利润受到威胁。如果中国在半导体自给自足方面取得成功，那么其邻国，其中大部分都是出口型经济，将会遭受更大的影响。如集成电路在2017年占据了韩国出口总额的15％；新加坡占17％；马来西亚占19％；菲律宾占21％；而台湾更高达36％。《中国制造2025》对此都提出了质疑。亚洲经济增长与政治稳定所依赖的电子产业，涉及最为密集的供应链和贸易流程，也因此承受着巨大的风险。

Made in China 2025 was just a plan, of course. Governments often have plans that fail abjectly. China’s track record in spurring production of cutting-edge chips was far from impressive. Yet the tools China could bring to bear—vast government subsidies, state-backed theft of trade secrets, and the ability to use access to the world’s second-largest consumer market to force foreign firms to follow its writ—gave Beijing unparalleled power to shape the future of the chip industry. If any country could pull off such an ambitious transformation of trade flows, it was China. Many countries in the region thought Beijing might succeed. Taiwan’s tech industry began worrying about what Taiwanese called the “red supply chain”—the mainland firms muscling into high-value electronics components Taiwan had previously dominated. It was easy to imagine semiconductors would be next.

“中国制造2025”只是一项计划。政府常常制定计划，但常常失败。中国在刺激尖端芯片生产方面的记录远非令人满意。然而，中国可以动用的工具，如巨额政府补贴、国家支持的窃取商业机密以及利用世界第二大消费市场的准入权迫使外国企业遵循其命令，赋予北京塑造芯片产业未来的无与伦比的权力。如果有任何国家能够完成如此雄心勃勃的贸易流转转型，那一定是中国。许多区域国家认为北京可能会成功。台湾的科技产业开始担心台湾所称的“红色供应链”，即入侵其之

前主导的高价值电子组件的大陆企业。很容易想象半导体会是下一个目标。

Xi Jinping’s call for China’s government and its companies to “assault the fortifications of core technology research” reverberated around East Asia long before it made much impact in the West. Donald Trump’s proclamations about protectionism garnered millions of retweets, but Beijing had a plan, powerful tools, and a forty-year track record of surprising the world with China’s economic and technological capabilities. This vision of semiconductor independence promised to upend globalization, transforming the production of one of the world’s most widely traded and most valuable goods. No one in the audience of Xi’s speech at Davos in 2017 noticed what was at stake behind the platitudes, but even a populist like Trump couldn’t have imagined a more radical reworking of the global economy.

习近平呼吁中国政府和企业“攻击核心技术研究的要塞”，这个呼声在西方产生影响之前就已经在东亚引起回响。唐纳德·特朗普对保护主义的宣言赢得了数百万次转发，但北京有一个计划，强大的工具和40年令人惊叹的经济和技术能力。半导体独立的愿景承诺颠覆全球化，改变了世界上最广泛交易和最有价值的商品之一的生产。在2017年的达沃斯演讲中，没有人注意到平凡之后隐藏的利益，但就连像特朗普这样的民粹主义者也不能想象一个更激进的全球经济重塑。

CHAPTER 44 Technology Transfer

“ I f you’re a country, as China is, of 1.3 billion people, you would want an IT industry,” IBM CEO Ginni Rometty told the audience at the 2015 China Development Forum, an annual event hosted by China’s government in Beijing. “I think some firms find that perhaps frightening. We, though, at IBM… find that to be a great opportunity.” Of all America’s tech firms, none had a closer relationship to the U.S. government than IBM. For nearly a century, the company had built advanced computer systems for America’s most sensitive national security applications. IBM staff had deep personal relationships with officials in the Pentagon and in U.S. intelligence agencies. When Edward Snowden stole and leaked documents about America’s foreign intelligence operations before fleeing to Moscow, it wasn’t a surprise to find IBM under suspicion for collaborating with American cyber sleuths.

IBM CEO金妮·罗梅蒂在由中国政府主办的2015年中国发展论坛上告诉观众：“如果你是一个拥有13亿人口的国家，比如中国，你会希望拥有一家IT工业公司。”“我认为有些公司可能会感到害怕。但是我们IBM公司却认为这是一个巨大的机会。”在所有美国科技公司中，没有一家公司比IBM与美国政府的关系更近了。近一个世纪以来，该公司为美国最敏感的国家安全应用程序构建了先进的计算机系统。IBM员工与五角大楼和美国情报机构的官员之间有着深厚的个人关系。当爱德华·斯诺登盗取并泄露有关美国外国情报行动的文件，并逃往莫斯科时，发现IBM被怀疑与美国的网络侦查人员合作，这并不令人意外。

After the Snowden leaks, IBM’s sales in China slumped by 20 percent as Chinese firms turned elsewhere for servers and networking equipment. IBM’s CFO, Martin Schroeter, told investors that “China is going through a very significant economic set of reforms,” an eloquent way of explaining that the Chinese government was punishing IBM by restricting its sales. Rometty decided to offer Beijing an olive branch in the form of semiconductor technology. She made a series of visits to China in the years after 2014, meeting with top Chinese officials like Premier Li Keqiang, Beijing mayor Wang Anshun, and Vice Premier Ma Kai, who was personally in charge of China’s efforts to upgrade its chip industry. IBM told the media that

Rometty's visits to Beijing were intended "to emphasize the tech giant's commitment to local partnerships, future cooperation, and information security," as a report by the Reuters news agency put it. China's state-run Xinhua news service was even more blunt about the quid pro quo, reporting that Rometty and Ma discussed "enhancing cooperation in integrated circuit" development.

斯諾登洩露後，IBM在中國的銷售額下降了20%，因為中國企業轉向其他地方購買服務器和網絡設備。IBM的首席財務官馬丁·施羅特告訴投資者，"中國正在經歷一個非常重要的經濟改革"，實際上是在解釋中國政府對IBM進行了限制銷售的懲罰。羅梅蒂決定通過半導體技術向北京伸出橄欖枝。自2014年之後的幾年裡，她多次訪問中國，會見了像李克強總理、北京市市長王安順和負責中國芯片產業升級工作的馬凱副總理等中國高級官員。IBM告訴媒體，羅梅蒂訪問北京是為了"強調這家科技巨頭致力於本地伙伴關係、未來合作和信息安全"，正如路透社的一份報告所述。中國的官方新華社在回報中，更是直截了當地表示，羅梅蒂和馬凱討論了"加強集成電路開發合作"。

In its drive for semiconductor self-sufficiency, one of Beijing's focus areas was chips for servers. The mid-2010s were very much like today where the world's data centers rely mostly on chips using the x86 instruction set architecture, though Nvidia's GPUs were beginning to win market share. Only three companies had the necessary intellectual property to produce x86 chips: America's Intel and AMD as well as a small Taiwanese company called Via. In practice, Intel dominated the market. IBM's "Power" chip architecture had once played a major role in corporate servers but had lost out in the 2010s. Some researchers thought that Arm's architecture—popular in mobile devices—might also play a role in future data centers, though at the time Arm-based chips had little server market share. Whatever the architecture, China had virtually no domestic capability to produce competitive data center chips. China's government set out to acquire this technology, strong-arming U.S. companies and pressuring them to transfer technology to Chinese partners.

為實現半導體自給自足，北京的重點之一是伺服器芯片。二十一世紀十年代中期的情況很像今天，世界的數據中心主要依賴使用x86指令集架構的芯片，盡管Nvidia的GPU正在贏得市場份額。只有三家公司擁

有生產x86芯片所需的知識產權：美國的英特爾和AMD以及一家名為Via的小型台灣公司。實際上，英特爾壟斷了市場。IBM的Power芯片架構曾在企業伺服器中發揮重要作用，但在二十一世紀十年代失去了競爭力。一些研究人員認為，Arm架構-在移動設備中很受歡迎-也可能在未來的數據中心中發揮作用，盡管當時基於Arm的芯片在伺服器市場上佔有很少的市場份額。無論是什麼架構，中國幾乎沒有生產競爭力數據中心芯片的本土能力。中國政府開始謀求獲取這項技術，強迫美國公司並向中國的合作夥伴轉移技術。

Intel, which dominated sales of semiconductors for servers, had few incentives to cut deals with Beijing over data center processors (though it was separately doing deals with Chinese state-backed firms and local governments in the market for mobile chips and NAND memory chips, where Intel's position was weaker). The American chipmakers that had lost data center market share to Intel, however, were looking for a competitive advantage. At IBM, Rometty announced a change of strategy that would appeal to Beijing. Rather than trying to sell chips and servers to Chinese customers, she announced, IBM would open its chip technology to Chinese partners, enabling them, she explained, to "create a new and vibrant ecosystem of Chinese companies producing homegrown computer systems for the local and international markets." IBM's decision to trade technology for market access made business sense. The firm's technology was seen as second-rate, and without Beijing's imprimatur it was unlikely to reverse its post-Snowden market shrinkage. IBM was simultaneously trying to shift its global business from selling hardware to selling services, so sharing access to its chip designs seemed logical.

英特尔在服务器半导体销售中占主导地位，因此几乎没有动力与北京方面就数据中心处理器达成协议（尽管在移动芯片和NAND存储芯片市场上，英特尔的地位较弱，仍在与支持中国国家的公司和地方政府分别达成协议）。然而，已经失去数据中心市场份额的美国芯片制造商正在寻求竞争优势。在IBM，罗梅蒂宣布了一项能够吸引北京方面的策略变化。她宣布，IBM将把其芯片技术开放给中国合作伙伴，使他们能够“创建一个新的、充满活力的中国公司生产本地和国际市场的国产计算机系统的生态系统。”对IBM来说，以技术换市场准入是有商业意义的。该公司的技术被认为是次等的，如果没有北京的认可，它不太可能扭转其在Snowden事件后市场萎缩的局面。IBM同时正试图将

其全球业务从销售硬件转向销售服务，因此分享其芯片设计的访问权似乎是合乎逻辑的。

For China’s government, however, this partnership wasn’t solely about business. One of the individuals working with IBM’s newly available chip technology was the former cyber security chief of China’s nuclear missile arsenal, Shen Changxiang, the *New York Times* reported. Just a year earlier, Shen had been warning of the “huge security risks” in working with U.S. firms. Now he appeared to have concluded that IBM’s offer to turn over chip technology supported Beijing’s semiconductor strategy and China’s national interests.

然而，對於中國政府而言，這個合作並不僅僅是為了商業利益。據《紐約時報》報導，IBM新的芯片技術開發過程中，有一名參與者就是中國核導彈庫的前網絡安全主管沈昌祥。就在一年前，沈昌祥還在警告稱與美國公司合作存在“巨大的安全風險”。現在，他似乎已經得出結論，即IBM提供的芯片技術轉讓符合北京的半導體戰略並有益於中國的國家利益。

IBM wasn’t the only company willing to help Chinese firms develop data center chips. Around the same time, Qualcomm, the company specializing in chips for smartphones, was trying to break into the data center chip business using an Arm architecture. Simultaneously, Qualcomm was battling Chinese regulators who wanted it to slash the fees it charged Chinese firms that licensed its smartphone chip technology, a key source of Qualcomm’s revenue. As the biggest market for Qualcomm’s chips, China had enormous leverage over the company. So some industry analysts saw a connection when, shortly after settling the pricing dispute with Beijing, Qualcomm agreed to a joint venture with a Chinese company called Huaxintong to develop server chips. Huaxintong didn’t have a track record in advanced chip design, but it was based in Guizhou Province, then governed by an up-and-coming Chinese party official named Chen Min’er, industry analysts noted.

IBM不是唯一一家愿意帮助中国企业开发数据中心芯片的公司。大约在同一时间，专门为智能手机提供芯片的高通公司也试图利用Arm体系结构进入数据中心芯片业务。与此同时，高通公司正在与中国监管

机构斗争，后者希望其降低向获得智能手机芯片技术许可的中国企业收取的费用，这是高通公司收入的一个重要来源。作为高通芯片最大的市场，中国对该公司有着巨大的影响力。因此，一些行业分析人士看到了一种联系，即在与北京解决价格争端不久之后，高通公司便同一家名为华芯通的中国公司达成了合资协议，以开发服务器芯片。行业分析人士指出，华芯通在先进芯片设计方面并没有记录，但它的总部位于贵州省，当时由一个正在崛起的中国党内官员陈敏尔所领导。

The Qualcomm-Huaxintong joint venture didn’t last long. It was closed in 2019 after producing little of value. But some of the expertise developed appears to have transferred to other Chinese companies building Arm-based data center chips. For example, Huaxintong participated in a consortium to develop energy-efficient chips that included Phytium, another Chinese firm building Arm-based chips. At least one chip design engineer appears to have left Huaxintong in 2019 to work for Phytium, which the U.S. later alleged had helped the Chinese military design advanced weapons systems like hypersonic missiles.

高通华信通合资公司的运营时间并不长，在生产价值较低后于2019年关闭。但是，该公司开发的一些专业知识似乎已经转移到其他中国公司构建基于Arm架构的数据中心芯片中。例如，华信通参与了一个开发节能芯片的联合体，其中包括另一家中国公司飞腾，该公司也在构建基于Arm架构的芯片。至少有一名芯片设计工程师于2019年离开华信通加入飞腾公司。而美国随后指控飞腾公司帮助中国军方设计高超音速导弹等先进武器系统。

The most controversial example of technology transfer, however, was by Intel’s archrival, AMD. In the mid-2010s, the company was struggling financially, having lost PC and data center market share to Intel. AMD was never on the brink of bankruptcy, but it wasn’t far from it, either. The company was looking for cash to buy time as it brought new products to market. In 2013, it sold its corporate headquarters in Austin, Texas, to raise cash, for example. In 2016, it sold to a Chinese firm an 85 percent stake in its semiconductor assembly, testing, and packaging facilities in Penang, Malaysia, and Suzhou, China, for $371 million. AMD described these facilities as “world-class.”

然而，最具争议性的技术转让例子是由英特尔的竞争对手AMD完成的。在2010年代中期，由于在个人电脑和数据中心市场份额上输给英特尔，该公司面临财务困境。AMD从未濒临破产，但也与此接近。该公司正在寻找现金以购买时间，推出新产品。例如，在2013年，该公司出售了其位于德克萨斯州奥斯汀的企业总部以筹集资金。在2016年，它以3.71亿美元的价格向中国公司出售了位于马来西亚槟城和中国苏州的半导体组装、测试和封装设施的85%股权。AMD将这些设施描述为"世界一流"。

That same year, AMD cut a deal with a consortium of Chinese firms and government bodies to license the production of modified x86 chips for the Chinese market. The deal, which was deeply controversial within the industry and in Washington, was structured in a way that didn't require the approval of CFIUS, the U.S. government committee that reviews foreign purchases of American assets. AMD took the transaction to the relevant authorities in the Commerce Department, who don't "know anything about microprocessors, or semiconductors, or China," as one industry insider put it. Intel reportedly warned the government about the deal, implying that it harmed U.S. interests and that it would threaten Intel's business. Yet the government lacked a straightforward way to stop it, so the deal was ultimately waved through, sparking anger in Congress and in the Pentagon.

同年，AMD与一家中国财团和政府机构达成协议，授权生产针对中国市场的修改版x86芯片。该协议在业界和华盛顿内部极具争议之际达成，它的构造方式避免了需要审批外国购买美国资产的美国政府委员会CFIUS的批准。AMD将该交易提交给商务部的相关部门，但据业内人士称，这些官员"对微处理器、半导体、或中国一无所知"。英特尔据称已向政府发出了有关该交易的警告，暗示它会损害美国的利益，并威胁到英特尔的业务。然而政府缺少一种简单明了的办法来阻止它，因此该交易最终被通过，引发了国会和五角大楼的愤怒。

Just as AMD finalized the deal, its new processor series, called "Zen," began hitting the market, turning around the company's fortunes, so AMD ended up not depending on the money from its licensing deal. However, the joint venture had already been signed and the technology was transferred. The *Wall Street Journal* ran multiple stories arguing that AMD had sold "crown jewels" and "the keys to the kingdom." Other industry analysts suggested the transaction was designed to let Chinese firms claim to the Chinese government they were designing cutting-edge microprocessors in China, when in reality they were simply tweaking AMD designs. The transaction was portrayed in English-language media as a minor licensing deal, but leading Chinese experts told state-owned media the deal supported China's effort to domesticate "core technologies" so that "we no longer can be pulled around by our noses." Pentagon officials who opposed the deal agree that AMD scrupulously followed the letter of the law, but say they remain unconvinced the transaction was as innocuous as defenders claim. "I continue to be very skeptical we were getting the full story from AMD," one former Pentagon official says. The *Wall Street Journal* reported that the joint venture involved Sugon, a Chinese supercomputer firm that has described "making contributions to China's national defense and security" as its "fundamental mission." AMD described Sugon as a "strategic partner" in press releases as recently as 2017, which was guaranteed to raise eyebrows in Washington.

正當 AMD 完成交易時，它的新處理器系列「Zen」開始進入市場，扭轉了公司的命運，因此 AMD 最終沒有依賴授權交易的資金。然而，合資企業已經簽署，技術已經轉移。《華爾街日報》發表了多篇文章，稱 AMD 已經出售了「寶石王冠」和「王國大門的鑰匙」。其他行業分析師則認為，交易旨在讓中國企業聲稱在中國設計尖端微處理器，而實際上他們只是調整了 AMD 的設計。這項交易在英語媒體中被描繪為一項小型授權交易，但領先的中國專家告訴國有媒體，這項交易支持中國的「核心技術本地化」努力，使「我們不再被牽著鼻子走」。反對這項交易的五角大樓官員表示，AMD 嚴格遵循法律的字眼，但他們表示仍然對辯護者所聲稱的交易並不無辜感到懷疑。一位前五角大樓官員表示：「我仍然非常懷疑我們從 AMD 那裡得到了完整的信息。」《華爾街日報》報導，這項合資企業涉及曙光信息產業有限公司，一家中國超級計算機公司，將「為中國的國防和安全做出貢獻」描述為其「根本任務」。AMD 曾在 2017 年的新聞稿中將曙光描述為「戰略合作夥伴」，這必然引起華盛頓的關注。

What's clear is that Sugon wanted help to build some of the world's leading supercomputers, which are commonly used for developing "nuclear weapons and hypersonic weapons," as Commerce Secretary Gina Raimondo explained in 2021. Sugon itself has advertised its links to the Chinese military, according to Elsa Kania, a leading American expert on the Chinese military. Even after the Trump administration decided to blacklist Sugon, severing the relationship with AMD, chip industry analyst Anton Shilov found Sugon circuit boards with AMD chips that it shouldn't have been able to buy. AMD told journalists it had not provided technical support for the device in question and wasn't sure how Sugon acquired the chips.

很明显，曙光想在世界一流超级计算机的建设方面得到帮助，这些计算机通常用于开发"核武器和高超音速武器"，正如商务部长吉娜·雷蒙多在2021年所解释的那样。根据中国军事领域的美国顶尖专家埃尔莎·卡尼亚的说法，曙光自己也宣传了与中国军队的联系。即使是在特朗普政府决定将曙光列入黑名单、切断与AMD关系之后，芯片行业分析师安东·希洛夫还发现曙光电路板上有AMD芯片，而它本不应该能够购买到这些芯片。AMD告诉记者，它没有为涉及的设备提供技术支持，也不确定曙光如何获得这些芯片。

The Chinese market was so enticing that companies found it nearly impossible to avoid transferring technology. Some companies were even induced to transfer control of their entire China subsidiaries. In 2018, Arm, the British company that designs the chip architecture, spun out its China division, selling 51 percent of Arm China to a group of investors, while retaining the other 49 percent itself. Two years earlier, Arm had been purchased by Softbank, a Japanese company that has invested billions in Chinese tech startups. Softbank was therefore dependent on favorable Chinese regulatory treatment for the success of its investments. It faced scrutiny from U.S. regulators, who worried that its exposure to China made it vulnerable to political pressure from Beijing. Softbank had purchased Arm in 2016 for $40 billion, but it sold a 51 percent stake in the China division—which according to Softbank accounted for a fifth of Arm's global sales—for only $775 million.

中國市場如此誘人，以致公司幾乎無法避免轉移技術。有些公司甚至被誘使轉讓其整個中國子公司的控制權。2018年，英國芯片設計公司Arm將其中國分部分拆，將Arm China的51％出售給一群投資者，同時保留其餘的49％。早在兩年前，Arm就被日本公司Softbank收購，Softbank已在中國科技初創企業上投資了數十億美元。因此，Softbank對其投資的成功取決於中國的有利監管待遇。它面臨著美國監管機構

的審查，他們擔心其對中國的暴露使其容易受到北京政府的政治壓力。Softbank於2016年以400億美元購買了Arm，但它只以7.75億美元的價格出售了Arm中國部門的51％股份，根據Softbank的說法，該部門佔了Arm全球銷售額的五分之一。

What was the logic of spinning off Arm China? There's no hard evidence that Softbank faced pressure from Chinese officials to sell the company's Chinese subsidiary. Arm executives were open, however, in describing the logic. "If somebody was building [a system on a chip] for China military or China surveillance," one Arm executive told *Nikkei Asia* , "China wants to have it only inside China. With this kind of new joint venture, this company can develop that. In the past this is something we couldn't do." "China wants to be secure and controllable," this executive continued. "Ultimately they want to have control of their technology…. If it's based on the technology that we bring, we could benefit from that," he explained. Neither the Japanese officials who regulate Softbank, the UK officials who regulate Arm, nor the American officials with jurisdiction over a substantial portion of Arm's intellectual property chose to investigate the implications.

分拆Arm China的逻辑是什么？没有确凿证据表明软银面临中国官员的压力出售公司的中国子公司。然而，Arm的高管在描述逻辑时是公开的。"如果有人为中国军方或中国监视构建芯片系统，"一位Arm高管告诉日经亚洲，"中国希望它只在中国内部。有了这种新的合资企业，这家公司就可以发展出这种芯片。过去我们做不到这一点。""中国希望安全可控，"这位高管继续说道。"最终，他们希望掌控自己的技术……如果它基于我们带来的技术，我们可以从中受益，"他解释道。既不是监管软银的日本官员，也不是监管Arm的英国官员，也不是在Arm的大部分知识产权上具有管辖权的美国官员选择调查其影响。

Chip firms simply can't ignore the world's largest market for semiconductors. Chipmakers jealously guard their critical technologies, of course. But almost every chip firm has non-core technology, in subsectors that they don't lead, that they'd be happy to share for a price. When companies are losing market share or in need of financing, moreover, they don't have the luxury of focusing on the long term. This gives China powerful levers to induce foreign chip firms to transfer technology, open production facilities, or license intellectual property, even when foreign companies realize they're helping develop competitors. For chip firms, its often easier to raise funds in China than on Wall Street. Accepting Chinese capital can be an implicit requirement for doing business in the country.

晶片公司无法忽略全球最大半导体市场。当然，晶片制造商会密切保护自己的关键技术。但几乎每个晶片公司都有非核心技术，在它们不领先的子行业中，它们会高兴地分享，只要有一定的代价。此外，当公司失去市场份额或需要融资时，它们没有专注于长期的奢侈，这使得中国有强大的工具来诱导外国晶片公司转移技术、开放生产设施或许可知识产权，即使外国公司意识到它们正在帮助发展竞争对手。对于晶片公司来说，通常在中国筹集资金比在华尔街容易。接受中国资金可能是在该国开展业务的隐含要求。

Viewed on their own terms, the deals that IBM, AMD, and Arm struck in China were driven by reasonable business logic. Collectively, they risk technology leakage. U.S. and UK chip architectures and designs as well as Taiwanese foundries have played a central role in the development of China's supercomputer programs. Compared to a decade ago, though its capabilities still meaningfully lag the cutting edge, China is substantially less reliant on foreigners to design and produce chips needed in data centers. IBM CEO Ginni Rometty was right to sense "great opportunity" in technology transfer agreements with China. She was only wrong in thinking her firm would be the beneficiary.

從自身的角度來看，IBM、AMD和Arm在中國達成的協議是理性商業邏輯的結果。然而，總體而言，這些協議存在技術外流的風險。美國、英國的晶片架構和設計以及台灣的晶圓代工廠對中國的超級計算機計劃發展起了至關重要的作用。與十年前相比，儘管其能力仍然明顯落後於前沿，但中國在設計和生產數據中心所需的芯片方面已大幅減少對外國人的依賴。IBM CEO金尼·羅梅蒂(Ginni Rometty)正確地認為在技術轉移協議方面與中國達成"巨大機遇"，但她錯誤地認為自己的公司將受益。

CHAPTER 45 “Mergers Are Bound to Happen”

F or Zhao Weiguo, it was a long, winding road from a childhood raising pigs and sheep along China’s western frontier to being celebrated as a chip billionaire by Chinese media. Zhao ended up in rural China after his father was banished for writing subversive poems during the Cultural Revolution, but he never planned to accept a life rearing livestock in the countryside. He won entrance to Tsinghua University, one of the best in China, and pursued a degree in electrical engineering. Tsinghua had led China’s semiconductor efforts since the industry’s earliest days in China, but it isn’t clear how much expertise in transistors and capacitors Zhao developed as a student. He worked at a tech firm after finishing his bachelor’s degree, then pivoted toward investing as a vice president of Tsinghua Unigroup. This company was established by his alma mater to turn the university’s scientific research into profitable businesses, but it appears to have invested heavily in real estate. Zhao built a reputation as a corporate dealmaker and set himself on a path toward a billion-dollar fortune.

對趙偉國來說，從在中國西部邊境養豬養羊的童年到被中國媒體譽為芯片富豪的道路是漫長而曲折的。趙的父親因在文化大革命期間寫顛覆詩篇而被流放到農村，趙也隨之落腳在農村。但他從未計劃好接受在農村養殖家畜的生活。他通過了中國最好的大學之一清華大學的入學考試，並攻讀了電子工程學位。清華大學自中國半導體行業之初就一直引領中國的半導體技術發展，但趙在學生時代究竟學會了多少有關晶體管和電容器的專業知識還不清楚。他在取得學士學位後進入一家科技公司工作，然後轉向投資，擔任清華紫光集團的副總裁。這家公司由他的母校創立，旨在將大學的科研成果轉化為有利可圖的企業，但它似乎在房地產方面投入了大量資金。趙建立了企業交易的聲譽，開始踏上通向十億美元財富的道路。

In 2004, Zhao launched his own investment fund, Beijing Jiankun Group, investing in real estate, mining, and other sectors where high-level political connections are usually crucial to success. Rich financial returns followed, with Zhao reportedly turning 1 million yuan of initial invested capital into 4.5 billion. In 2009, Zhao used this wealth to buy a 49 percent stake in his former employer, Tsinghua Unigroup. The university continued to own the other 51 percent of shares. It was a bizarre transaction: a private real-estate investment firm now owned nearly half of a company that was supposed to be monetizing technologies produced by China's premier research university. But Tsinghua Unigroup was never simply a "normal" company. The son of former Chinese president Hu Jintao—said to be a "personal friend" of Zhao's—served as Communist Party secretary for the holding company that owned Unigroup. The president of Tsinghua University throughout the 2000s, meanwhile, was a college roommate of Xi Jinping.

2004年，趙欽啟動了自己的投資基金北京建坤集團，投資於房地產、采礦和其他高層次政治關係通常對成功至關重要的行業。財務回報豐厚，據報導，趙先生把100萬元的初始投資本金轉化為45億元。2009年，他利用這些財富收購了前僱主清華紫光集團49%的股份，而該大學仍然持有其它51%的股份。這是一筆奇怪的交易：一個私人房地產投資公司現在擁有一家應該貨幣化中國領先研究大學生產的技術50%的股份。但清華紫光集團從來就不只是一家“普通”的公司。據稱是趙的“個人朋友”的前中國主席胡錦濤的兒子擔任著這個擁有紫光集團的控股公司的中共秘書。在2000年代，清華大學的校長是習近平的大學室友。

In 2013, four years after buying his stake in Tsinghua Unigroup, and just before China's Communist Party announced new plans to provide vast subsidies to the country's semiconductor firms, Zhao decided it was time to invest in the chip industry. He denies that Tsinghua Unigroup's semiconductor strategy was a response to the government's wishes. "Everyone thinks that the government is pushing the development of the chip sector, but it's not like that," he told *Forbes* in 2015. Instead, he takes credit for attracting Beijing's attention to the sector. "Companies did some stuff first and then the government started to notice…. All our deals are market oriented."

2013年，在購入清華紫光股權四年後，就在中國共產黨宣布向國內半導體公司提供巨額補貼的新計劃之前，趙中正決定投資芯片產業。他否認清華紫光的半導體戰略是對政府意願的回應。“每個人都認為政府在推動芯片產業發展，但實際情況並非如此，”他在2015年告訴福布斯雜誌。相反，他為吸引北京對該產業的關注而負責。“公司做了一些事情，然後政府開始注意到...... 我們所有的交易都是市場導向的。”

“Market oriented” is not how most analysts would describe Zhao’s strategy. Rather than investing in the best chip firms, he tried buying anything on the market. His explanation of Tsinghua’s investment strategy didn’t suggest nuance or sophistication. “If you carry your gun up the mountain, you just don’t know if there’s game there,” he was quoted as saying. “Maybe you’ll catch a deer, maybe a goat, you just don’t know.” Nevertheless, he was a confident hunter. The world’s chip firms were his prey.

Even given his fortune, which was estimated at $2 billion, the sums Zhao spent building his chip empire were shocking. In 2013, Tsinghua Unigroup started its shopping spree at home, spending several billion dollars buying two of China’s most successful fabless chip design companies, Spreadtrum Communications and RDA Microelectronics, which made low-end chips for smartphones. Zhao declared the merger would produce “enormous synergies in China and abroad,” though nearly a decade on there’s little evidence any synergies have materialized.

多數分析師不認為「市場導向」是趙的策略。他沒有試著投資最好的晶片企業，反而是嘗試購買市場上任何一個東西。他對清華的投資策略的解釋沒有任何細微之處或複雜度。據報導他表示: 「如果你攜帶你的槍上山，你就不知道那裡是否有獵物。也許你會捕捉到一隻鹿、一隻山羊，你就不知道。」然而他是一位充滿自信的獵人。全球的晶片企業都是他的獵物。 即使有估算為20億美元的財富，趙用來建立他的晶片帝國的數字令人驚訝。 2013年，清華紫光公司在國內開始瘋狂購物，花費數十億美元購買了中國最成功的兩家無廠半導體設計公司，展訊通信和瑞芯微電子，它們生產適用於智能手機的低端晶片。趙宣布合併將產生「在中國和國外的巨大協同效應」，但近十年來沒有任何證據表明有任何協同效應產生。

A year later, in 2014, Zhao cut a deal with Intel to couple Intel’s wireless modem chips with Tsinghua Unigroup’s smartphone processors. Intel hoped the tie-up would boost its sales in China’s smartphone market, while Zhao wanted his companies to learn from Intel’s chip design expertise. He was open about Tsinghua Unigroup’s goals: semiconductors were China’s “national priority,” he said. Working with Intel would “accelerate the technology development and further strengthen the competitiveness and market position of Chinese semiconductor companies.”

一年后，2014年，赵曾与英特尔达成协议，将英特尔的无线调制解调器芯片与清华紫光手机处理器相结合。英特尔希望这种合作能够提高其在中国智能手机市场的销售额，而赵则希望他的公司能够从英特尔的芯片设计专业知识中学习。他公开表示，半导体是中国的“国家优先事项”。与英特尔合作将“加速技术发展，进一步加强中国半导体公司的竞争力和市场地位”。

Zhao’s partnership with Intel had some business logic behind it, but many other decisions didn’t appear driven by a desire to make a profit. For example, Tsinghua Unigroup offered to fund XMC (later acquired by YMTC), a Chinese firm trying to break into the NAND memory chip market. The company’s CEO admitted at one public event that he initially asked for $15 billion to build a new fab but was told to take $24 billion instead, “on the basis that if they were going to be serious about being a world leader then they needed to match the world leaders’ investment.” Even the goatherders Zhao grew up alongside in western China would have recognized he was handing out multibillion-dollar checks with reckless abandon. When it later emerged that in addition to semiconductors, Tsinghua Unigroup was also investing in real estate and online gambling, it was barely a surprise.

赵刚与英特尔合作背后有一些商业逻辑，但许多其他决策似乎并不是出于赚钱的愿望驱动。例如，清华紫光集团提供资金支持西部存储（华为旧欧）进军NAND存储芯片市场。该公司的CEO在一次公开活动上承认，他最初要求150亿美元建立新工厂，但被告知要取得240亿美元，"因为如果他们想要成为世界领导者，就需要与世界领导者的投资相匹配"。甚至赵刚在西部成长的牧羊人也会认识到他在毫不犹豫地分发数十亿美元的支票。当后来出现清华紫光集团除半导体外还投资于房地产和在线赌博时，几乎没有人感到惊讶。

China’s state-backed “Big Fund,” meanwhile, announced plans to invest an initial tranche of over $1 billion in Tsinghua Unigroup. This provided a stamp of government approval for the company’s strategy. Zhao turned his efforts overseas. It wasn’t enough to own China’s fabless companies or attract foreign firms to invest in China. He wanted to control the commanding heights of the world’s chip industry. He hired several leading Taiwanese semiconductor executives, including the former CEO of UMC, Taiwan’s second biggest foundry. In 2015, Zhao visited Taiwan himself and pressed the island to lift its restrictions on Chinese investment in sectors like chip design and fabrication. He bought a 25 percent stake in Taiwan's Powertech Technology, which assembles and tests semiconductors, a transaction that was allowed under Taiwan's rules. He pursued stakes and joint ventures with several of Taiwan's other large chip assemblers.

与此同时，中国国家支持的"大基金"宣布计划在清华紫光集团投资超过10亿美元的首期资金，这为该公司的战略提供了政府批准的印章。赵崇祚将努力转向海外。拥有中国的无晶圆厂商或吸引外国公司来投资中国还不够。他想控制世界芯片产业的制高点。他聘请了几名领先的台湾半导体高管，包括台湾第二大晶圆代工厂联华电子的前任首席执行官。2015年，赵崇祚亲自访问台湾，并敦促该岛解除对中国投资芯片设计和制造等行业的限制。他购买了台湾宝鼎科技25%的股份，该公司组装和测试半导体，这是符合台湾规则的交易。他追求与台湾其他大型芯片组装商的股份和联营关系。

However, Zhao's real interest was in buying the island's crown jewels—MediaTek, the leading chip designer outside the U.S., and TSMC, the foundry on which almost all the world's fabless chip firms rely. He floated the idea of buying a 25 percent stake in TSMC and advocated merging MediaTek with Tsinghua Unigroup's chip design businesses. Neither transaction was legal under Taiwan's existing foreign investment rules, but when Zhao returned from Taiwan he took the stage at a public conference in Beijing and suggested China should ban imports of Taiwanese chips if Taipei didn't change these restrictions.

然而，趙的真正興趣在於收購島上的皇冠珠寶——美滴科技，美國以外的領先芯片設計公司，以及致力於支援全球所有無廠設計晶片公司的晶圓代工廠台積電。他提出收購台積電25%的股權以及將聯發科與清華紫光的晶片設計業務合併的想法。這些交易在台灣現有的外國投資法規下都是非法的，但是當趙從台灣返回時，在北京的一個公眾會議上，他建議如果台北不改變這些限制，中國應該禁止進口台灣晶片。

This pressure campaign put TSMC and MediaTek in a bind. Both companies were crucially reliant on the Chinese market. Most of the chips TSMC produced were assembled into electronics goods in workshops across China.

The idea of selling Taiwan’s technological crown jewels to a state-backed investor on the mainland made little sense. The island would end up dependent on Beijing. Besides abolishing its military or welcoming occupation by the People’s Liberation Army, it was hard to think of a step that would do more to undermine Taiwan’s autonomy.

這種壓力攻勢讓台積電（TSMC）和聯發科技（MediaTek）感到束手無策。兩家公司都極為依賴中國市場。TSMC生產的大多數芯片都是在中國各地的工廠裝配成電子產品。把台灣的科技明珠賣給大陸的國有投資者實在是不明智的做法。這樣做會讓台灣變得依賴北京。除了廢除軍隊或歡迎解放軍的佔領外，很難想像會有什麼措施更能破壞台灣的自治。

Both TSMC and MediaTek issued statements vaguely expressing openness to Chinese investment. Morris Chang said his only stipulations were “if the price is right and if it is beneficial to shareholders”—hardly the response one would expect about a deal that threatened to undermine Taiwan’s economic independence. But Chang also warned that if Chinese investors could appoint members to Taiwanese companies’ boards of directors, “it will not be that easy to protect intellectual property.” MediaTek said it was supportive of efforts “to join hands and raise the status and competitiveness of the Chinese and Taiwanese enterprises in the global chip industry”—but only if the Taiwanese government allowed. In Taipei, the government seemed to be wobbling, however. John Deng, the island’s economy minister, suggested relaxing Taiwan’s restrictions on Chinese investment in the chip sector. Amid Chinese pressure, he signaled that greater Chinese control of Taiwan’s chip sector was inevitable. “You cannot escape from this issue,” Deng told journalists. But amid a contentious presidential election in Taiwan, the government delayed any policy changes.

台積電和聯發科都發表了含糊其辭的聲明，表達對中國投資的開放態度。張忠謀表示，他的唯一條件是“如果價格合適，且對股東有利” - 這無疑是一個威脅台灣經濟獨立的交易所會期望的回應。但張忠謀還警告說，如果中國投資者能夠任命台灣公司董事會成員，“保護知識產權就不會那麼容易”。聯發科表示支持“攜手提高中國和台灣企業在全球芯片行業的地位和競爭力”，但前提是需要台灣政府允許。然而，在台北，政府似乎動搖了。該島的經濟部長鄧振中建議放寬台灣對中國

在晶片行業的投資限制。在中國的壓力下他暗示，中國對台灣晶片產業的控制是不可避免的。“你逃脫不了這個問題”，鄧告訴記者。但在一場充滿爭議的台灣總統選舉中，政府推遲了任何政策變更。

Soon Zhao set his sights on America’s semiconductor industry. In July 2015, Tsinghua Unigroup floated the idea of buying Micron, the American memory chip producer, for $23 billion, which would have been the largest ever Chinese purchase of a U.S. company in any industry. Unlike in the case of Taiwan’s tech titans and its economic technocrats, Tsinghua’s efforts to purchase Micron were firmly rebuffed. Micron said it didn’t think the transaction was realistic given the U.S. government’s security concerns. Soon after, in September 2015, Tsinghua Unigroup tried again, extending a $3.7 billion offer for a 15 percent stake in another U.S. company that made NAND memory chips. CFIUS, the U.S. government body that assesses foreign investment, rejected this on security grounds.

很快，趙著眼於美國的半導體行業。2015年7月，清華紫光提出收購美國存儲芯片生產商美光的想法，價值230億美元。這將是中國在任何行業中對美國公司收購的最大規模。與台灣的科技巨頭和經濟技術官僚不同，清華收購美光的努力被堅決拒絕了。美光表示，基於美國政府的安全擔憂，它認為這筆交易不現實。在此之後，2015年9月，清華再次嘗試，以37億美元的價格購入一家NAND存儲芯片制造公司的15％股權。美國外國投資評估委員會(CFIUS)以安全理由拒絕了這一提議。

Then, in spring 2016, Tsinghua quietly bought 6 percent of the shares in Lattice Semiconductor, another U.S. chip firm. “This is purely a financial investment,” Zhao told the *Wall Street Journal* . “We don’t have any intention at all to try to acquire Lattice.” Scarcely weeks after the investment was publicized, Tsinghua Unigroup began to sell its shares in Lattice. Shortly thereafter, Lattice received a buyout offer from a California-based investment firm called Canyon Bridge, which journalists from Reuters revealed had been discreetly funded by the Chinese government. The U.S. government firmly rejected the deal.

然后在2016年春季，清华大学悄悄地购买了美国芯片公司Lattice Semiconductor 6%的股份。 "这仅仅是一项金融投资," 赵欣告诉《华尔街日报》 "我们根本没有试图收购 Lattice 的任何意图." 投资公开后不

久，清华联合开始出售它在Lattice的股份。很快，Lattice收到了来自加州投资公司Canyon Bridge的收购要约，路透社的记者透露该公司被中国政府秘密资助。美国政府坚定地拒绝了这笔交易。

The same investment fund simultaneously bought Imagination, a UK-based chip designer in financial distress. The transaction was carefully structured to exclude Imagination's U.S. assets so that Washington didn't block it, too. British regulators waved the deal through, only to find themselves regretting the decision when, three years later, the new owners tried to restructure the board of directors with officials appointed by a Chinese government investment fund.

The problem wasn't simply that Chinese government-linked funds were buying up foreign chip firms. They were doing so in ways that violated laws about market manipulation and insider trading. While Canyon Bridge was maneuvering to purchase Lattice Semiconductor, for example, one of Canyon Bridge's cofounders tipped off a colleague in Beijing, passing along details about the transaction via WeChat and at meetings in a Starbucks in Beijing. His colleague bought stock based on this knowledge; the Canyon Bridge executive was convicted of insider trading.

同一筆投資基金同時收購了處於財務困境中的英國晶片設計公司Imagination。此次交易經過精心的結構設計，將Imagination的美國資產排除在外，以免華盛頓阻止該交易。英國監管機構批准了這項交易，但三年後，新的所有者試圖通過由中國政府投資基金任命的官員重組董事會，英國監管機構後悔地發現了這個決定。 問題不僅在於中國與政府有關的基金正在收購外國晶片公司，而是他們以違反市場操縱和內部交易法律的方式進行收購。例如，在Canyon Bridge策畫購併Lattice Semiconductor的同時，其中一位Canyon Bridge的聯合創始人透過微信和在北京星巴克的會議中傳遞有關交易的細節給他的北京同事。基於這個知識，他的同事買入了股票，而Canyon Bridge的高管因內部交易被定罪。

For his part, Zhao saw himself as simply a committed entrepreneur. "Mergers between big U.S. and Chinese companies are bound to happen," he declared. "They should be viewed from a business perspective instead of being treated under nationalist or political contexts." But Tsinghua Unigroup's activities were impossible to comprehend from the perspective of business logic. There were too many Chinese state-owned and state-financed “private equity” firms circling the world’s semiconductor companies to describe this as anything other than a government-led effort to seize foreign chip firms. “Call forth the assault,” Xi Jinping had demanded. Zhao, Tsinghua Unigroup, and other government-backed “investment” vehicles were simply following these publicly announced instructions. Amid this frenzied dealmaking, Tsinghua Unigroup announced in 2017 that it had received new “investment”: around $15 billion from the China Development Bank and $7 billion from the Integrated Circuit Industry Investment Fund—both owned and controlled by the Chinese state.

趙先生視自己為一位忠誠的企業家，“大型美國和中國公司之間的合併注定會發生，”他宣稱，“應該從商業角度來看待，而不應該通過民族主義或政治背景來對待。”但清華紫光的活動從商業邏輯的角度來看是不可理解的。有太多中國國有和國有資金的“私募”公司圍繞著世界各地的半導體公司，這只能被描述為一種政府主導的收購外國芯片公司的努力。“發起攻擊”，習近平曾要求。趙、清華紫光和其他政府支持的“投資”工具只是遵循了這些公開宣布的指示。在這場瘋狂的交易中，清華紫光宣布在2017年獲得了新的“投資”：來自中國開發銀行約150億美元和集成電路產業投資基金約70億美元，這兩家銀行均由中國國家所擁有和控制。

CHAPTER 46 The Rise of Huawei

W hen Ren Zhengfei gives media interviews in the headquarters of Huawei, the Chinese technology company he founded, his crisply tailored jacket and slacks, unbuttoned collar, and vivacious smile make him seem just like any Silicon Valley executive. In some ways he is. His company's telecom equipment—the radios on cell towers that transmit calls, pictures, and emails to and from smartphones—forms the backbone of the world's mobile internet. Huawei's smartphone unit, meanwhile, was until recently one of the world's largest, rivaling Apple and Samsung in numbers of phones sold. The company provides other types of tech infrastructure, too, from undersea fiber-optic cables to cloud computing. In many countries it's impossible to use a phone without using some of Huawei's equipment—as difficult as it is to use a PC without Microsoft products or to surf the internet (outside of China) without Google. However, Huawei is different from the world's other big tech companies in one major way: its two-decade-long struggle with America's national security state.

當任正非在他創立的中國科技公司華為的總部接受媒體採訪時，他身穿整齊的夾克和西褲、敞開的領口以及生氣勃勃的微笑讓他看起來就像任何一位硅谷高管。在某些方面，他確實也是。他的公司的電信設備——位於手機塔上傳輸通話、圖片和電子郵件的收發器——構成了世界移動互聯網的基礎。華為的智能手機單元在一段時間內也是世界上最大的之一，與蘋果和三星相媲美，銷售的手機數量不少。此外，該公司還提供其他類型的技術基礎設施，從海底光纖纜線到雲計算。在許多國家，無法不使用華為的設備來使用手機，就像沒有使用微軟產品就不能用電腦一樣，沒有使用 Google 就不能在互聯網上瀏覽（在中國以外）。然而，與世界上其他大型科技公司的區別在於，華為與美國的國家安全體制進行了長達二十年的搏鬥。

Reading American newspaper headlines about Huawei's role in Chinese government spying, it would be easy to conclude that the company emerged as an appendage of China's security agencies. The ties between Huawei and the Chinese state are well documented but explain little about how the company built a globe-spanning business. To understand the company's expansion, it’s more helpful to compare Huawei’s trajectory to a different tech-focused conglomerate, South Korea’s Samsung. Ren was born a generation after Samsung’s Lee Byung-Chul, but the two moguls have a similar operating model. Lee built Samsung from a trader of dried fish into a tech company churning out some of the world’s most advanced processor and memory chips by relying on three strategies. First, assiduously cultivate political relationships to garner favorable regulation and cheap capital. Second, identify products pioneered in the West and Japan and learn to build them at equivalent quality and lower cost. Third, globalize relentlessly, not only to seek new customers but also to learn by competing with the world’s best companies. Executing these strategies made Samsung one of the world’s biggest companies, achieving revenues equivalent to 10 percent of South Korea’s entire GDP.

阅读美国报纸关于华为在中国政府间谍活动中的作用的头条新闻，很容易得出结论，该公司是中国安全机构的附属物。华为和中国政府之间的联系是有据可查的，但并不能完全解释该公司如何建立起一家横跨全球的企业。要了解该公司的扩张，与其比较的是一家不同的科技集团——韩国的三星。任正非比三星的李秉九晚生一代，但这两位大亨有相似的运作模式。李秉九通过依靠三种策略，将三星由一家干鱼贸易商发展成一家涌现出一些世界上最先进的处理器和存储芯片的科技公司。第一，刻苦培养政治关系，以获取有利的监管和廉价资本。第二，确定在西方和日本开创的产品，并学习以相同的质量和更低的成本来建造它们。第三，无情地全球化，不仅是为了寻找新客户，还要通过与世界上最好的公司竞争来学习。实行这些策略使三星成为世界上最大的公司之一，实现的收入相当于韩国整个GDP的10％。

Could a Chinese firm execute a similar set of strategies? Most of China’s tech firms tried a different approach with a less global focus. For all the country’s export prowess, China’s internet firms make almost all their money inside of China’s domestic market, where they’re protected by regulation and censorship. Tencent, Alibaba, Pinduoduo, and Meituan would be minnows were it not for their home market dominance. When Chinese tech firms have gone abroad, they’ve often struggled to compete.

By contrast, Huawei has embraced foreign competition from its earliest days. Ren Zhengfei’s business model has been fundamentally different from

Alibaba's or Tencent's. He's taken concepts pioneered abroad, produced quality versions at lower cost, and sold them to the world, grabbing international market share from international rivals. This business model made Samsung's founders rich and put the company at the center of the world's tech ecosystem. Until very recently, Huawei seemed to be on the same path.

一家中国公司能否执行类似的策略？大多数中国科技公司采用了一个不那么全球化的方法。尽管中国在出口方面非常强大，但中国的互联网公司几乎全部赚钱来自于国内市场，受到监管和审查的保护。如果不是其在本土市场的主导地位，腾讯、阿里巴巴、拼多多和美团将成为小鱼小虾。当中国科技公司走出国门时，往往难以竞争。相比之下，华为从其早期开始就积极拥抱外国竞争。任正非的商业模式与阿里巴巴或腾讯的截然不同。他借鉴国外先进概念，生产出质量更高但价格更低的产品，并将其销售到世界各地，从国际竞争对手中夺取了国际市场份额。这种商业模式让三星的创始人们富裕起来，并让公司成为了世界技术生态系统的中心。直到最近，华为似乎也走上了同样的道路。

The company's international orientation was visible from its founding in 1987. Ren had grown up in a family of high school teachers in rural Guizhou Province in southern China. He'd trained as an engineer in Sichuan's capital of Chongqing before serving in the Chinese army, where he says he worked in a factory producing synthetic fiber for garments. After reportedly leaving the army (some skeptics wonder about the circumstances, and if he actually did cut ties with the military completely), he moved to Shenzhen, then a small town just across the border from Hong Kong. At the time, Hong Kong was still ruled by the British, a small outpost of prosperity along the otherwise impoverished South China coast. China's leaders had begun implementing economic reforms about a decade earlier, experimenting with letting individuals form private companies as a means of spurring economic growth. Shenzhen was one of several cities selected as a "special economic zone," where restrictive laws were canceled and foreign investment was encouraged. The city boomed as Hong Kong money flowed in and as China's would-be entrepreneurs flocked to the city in search of freedom from regulation.

该公司的国际化方向自1987年成立以来就显而易见了。任正非在中国南部贵州省一个高中教师家庭中长大。他曾在四川省会重庆接受工程师培训，之后在中国军队服役，他称自己曾在一家生产合成纤维服装的工厂工作。据报道，任正非离开军队后（一些怀疑者对此持质疑态度，怀疑他是否完全与军队断绝关系），他搬到了深圳，当时它只是毗邻香港的一个小城镇。当时香港仍然由英国管理，是中国南海岸贫困地区的一个繁华前哨。中国领导人大约十年前开始实施经济改革，试图让个人组建私营公司以推动经济增长。深圳是几个被选为“特殊经济区”的城市之一，那里取消了限制法律并鼓励外国投资。随着香港的资金流入和中国的企业家们涌往深圳寻求摆脱监管限制，城市繁荣起来。

Ren saw an opportunity to import telecom switches, the equipment that connects one caller to another. With $5,000 in startup capital, he began importing this gear from Hong Kong. When his partners across the border realized he was making good money by reselling their equipment, they cut him off, so Ren decided to build his own equipment. By the early 1990s, Huawei had several hundred people working in R&D, largely focused on building switching equipment. Since those days, the telecom infrastructure has merged with digital infrastructure. The same cell towers that transmit calls also send other types of data. So Huawei’s equipment now plays an important—and in many countries, crucial—role in transmitting the world’s data. Today it is one of the world’s three biggest providers of equipment on cell towers, alongside Finland’s Nokia and Sweden’s Ericsson.

任（Ren）看到进口电信交换机这个机会，这种设备连接一个呼叫者和另一个呼叫者。他用5000美元的启动资金从香港开始进口这些设备。当他在边境对面的合作伙伴意识到他通过转售他们的设备赚了不少钱时，他们切断了与他的联系，所以Ren决定建造自己的设备。到了1990年代初，华为已经有数百名员工在研发领域工作，并主要专注于建造交换设备。自那时以来，电信基础设施已经与数字基础设施合并。传输电话的同一基站也能发送其他类型的数据。因此，华为的设备现在在传输全球数据方面扮演着重要的——甚至在许多国家，是至关重要的——角色。今天，它是世界上三大电信塔设备供应商之一，与芬兰的诺基亚和瑞典的爱立信并列。

Huawei's critics often allege that its success rests on a foundation of stolen intellectual property, though this is only partly true. The company has admitted to some prior intellectual property violations and has been accused of far more. In 2003, for example, Huawei acknowledged that 2 percent of the code in one of its routers was copied directly from Cisco, an American competitor. Canadian newspapers, meanwhile, have reported that the country's spy agencies believe there was a Chinese-government-backed campaign of hacking and espionage against Canadian telecom giant Nortel in the 2000s, which allegedly benefitted Huawei.

华为的批评者经常指责其成功基于窃取知识产权的基础，尽管这只是部分真实。该公司已承认存在一些先前的知识产权侵犯，并被指控犯有更多。例如，2003年，华为承认其一款路由器中的2%代码直接从美国竞争对手思科公司复制而来。与此同时，加拿大报纸报道称，该国的间谍机构认为在2000年代存在着一场支持中国政府的黑客和间谍活动，针对加拿大电信巨头诺特尔，这场活动据称使华为受益。

Theft of intellectual property may well have benefitted the company, but it can't explain its success. No quantity of intellectual property or trade secrets is enough to build a business as big as Huawei. The company has developed efficient manufacturing processes that have driven down costs and built products that customers see as high-quality. Huawei's spending on R&D, meanwhile, is world leading. The company spends several times more on R&D than other Chinese tech firms. Its roughly $15 billion annual R&D budget is paralleled by only a handful of firms, including tech companies like Google and Amazon, pharmaceutical companies like Merck, and carmakers like Daimler or Volkswagen. Even when weighing Huawei's track record of intellectual property theft, the company's multibillion-dollar R&D spending suggests a fundamentally different ethos than the "copy it" mentality of Soviet Zelenograd, or the many other Chinese firms that have tried to break into the chip industry on the cheap.

知識產權的盜竊可能有利於企業，但這並不能解釋華為的成功。任何量的知識產權或商業機密都不足以建立像華為這樣龐大的企業。該公司已開發出高效的製造工藝，降低了成本，生產出被客戶認為是高品質的產品。同時，華為在研發方面的支出是世界領先的。該公司在研發方面的支出比其他中國科技公司高出幾倍。其每年約150億美元的研

發預算僅與少數公司相當，包括像Google和Amazon這樣的科技公司、Merck這樣的制藥公司以及Daimler或Volkswagen這樣的汽車製造商。即使考慮到華為的知識產權盜竊記錄，該公司數十億美元的研發支出表明其根本上不同於蘇聯澤列諾格拉德的“抄袭”心態，或者其他許多中國企業試圖用廉價的方式進入芯片行業的心態。

Huawei executives say they invest in R&D because they've learned from Silicon Valley. Ren reportedly brought a group of Huawei executives to tour the U.S. in 1997, visiting companies like HP, IBM, and Bell Labs. They left convinced of the importance not only of R&D, but also of effective management processes. Starting in 1999, Huawei hired IBM's consulting arm to teach it to operate like a world-class company. One former IBM consultant said Huawei spent $50 million in 1999 on consulting fees, at a time when its entire revenue was less than a billion dollars. At one point it employed one hundred IBM staff to redo business processes. “They weren't too daunted by the engineering tasks,” this former consultant reported, but “they felt they were a hundred years behind when it came to economic knowledge and business knowledge.” Thanks to IBM and other Western consultants, Huawei learned to manage its supply chain, anticipate customer demand, develop top-class marketing, and sell products worldwide.

华为高管们表示，他们投资研发是因为他们向硅谷学习。据报道，任正非曾带领一群华为高管在1997年来美国参观惠普、IBM和贝尔实验室等公司。他们离开时深信不疑，认为不仅需要研发，还要有有效的管理流程。自1999年起，华为雇用了IBM的咨询部门，教它如何运营世界级公司。一位曾在IBM工作的顾问说，当时华为整个收入不到10亿美元，但它花费了5000万美元的咨询费用。曾一度聘用100名IBM员工重新设计业务流程。这位前顾问报告说，“他们并不害怕工程任务”，但“他们觉得在经济知识和商业知识方面落后了一百年”。由于IBM和其他西方咨询公司的帮助，华为学会了管理供应链、预测客户需求、开发顶级营销和在全球范围内销售产品。

Huawei coupled this with a militaristic ethos that the company celebrates as “wolf-culture.” Calligraphy on the wall of one of the company's research lab reads “Sacrifice is a soldier's highest cause. Victory is a soldier's greatest contribution,” according to a *New York Times* report. In the context of the chip industry, though, Ren Zhengfei's militarism wasn't that unique. Andy

Grove wrote a bestseller about the benefits of paranoia. Morris Chang, meanwhile, said that he'd studied Stalingrad, the bloodiest battle of World War II, for lessons about business.

华为将这一点与一种军事主义理念相结合，该公司将之称为“狼文化”。据《纽约时报》报道，该公司一个研究实验室的墙上写着：“牺牲是士兵的最高使命。胜利是士兵的最大贡献。”然而，在芯片行业的背景下，任正非的军事主义并不是那么独特。安迪·格罗夫写了一本关于偏执症益处的畅销书。与此同时，张忠谋说他研究了斯大林格勒，二战中最血腥的战斗，以从中获得关于经商的经验教训。

In addition to Western consulting firms, Huawei had help from another powerful institution: China's government. At different points in its development, Huawei has benefitted from support from the local government in Shenzhen, from state-owned banks, and from the central government in Beijing. A *Wall Street Journal* review of total subsidies provided by the Chinese government reached a figure of $75 billion, in the form of subsidized land, state-backed credit, and tax deductions at a scale far above what most Western companies get from their governments, though the benefits provided to Huawei might not be too different from what other East Asian governments provide to priority companies.

除了西方咨询公司，华为还得到了中国政府的帮助。在不同的发展阶段，华为受益于深圳当地政府、国有银行和北京中央政府的支持。《华尔街日报》对中国政府提供的总补贴进行了审查，达到了750亿美元的规模，以补贴土地、国家支持信贷和税收减免的形式提供，在规模上远超大多数西方公司从其政府获得的福利，尽管提供给华为的福利可能与其他东亚国家提供给重要公司的福利没什么不同。

The scale of state support for an ostensibly private firm has raised red flags, especially in the United States. China's leaders have certainly been supportive of the company's global expansion. Even in the mid-1990s, when Huawei was still a small company, top Chinese officials like Vice Premier Wu Bangguo visited the company and promised to support it. Vice Premier Wu also traveled abroad with Ren Zhengfei to help Huawei sell telecom equipment in Africa. Yet it's hard to distinguish whether this amounted to special support for Huawei or was simply standard operating procedure given China’s mercantilist approach to international trade and the fuzzy boundaries between public and private property.

國家對貌似私人公司的支持規模引起了警示，尤其是在美國。中國的領導人當然支持該公司的全球擴張。即使在90年代中期，華為仍然是一個小公司時，像副總理吴邦国這樣的中國高官，也曾拜訪華為並承諾支持它。吴副總理還与任正非一起出訪非洲，幫助華為銷售電信設備。然而，很難區分這是否等同於對華為的特殊支持，還是僅僅是中國的重商主義對國際貿易的標準操作程序，以及公共與私人財產之間的模糊邊界。

The lack of clarity about Ren’s transition from the People’s Liberation Army to Huawei remains puzzling. The company’s complex and opaque ownership structure has also provoked reasonable questions. Huawei executive Ken Hu’s argument to a U.S. congressional inquiry that Ren Zhengfei’s membership in the Chinese Communist Party was just like how “some American businessmen are Democrat or Republican,” sounded to U.S. analysts like willful obfuscation of the Communist Party’s role in the company’s governance. Nevertheless, the thesis that Huawei was purpose built by the Chinese state has never had strong evidence behind it.

對於任從軍轉型到華為的模糊不清，仍然令人困惑。公司複雜而不透明的所有權結構也引起了合理的質疑。華為執行官胡厚儀在美國國會聽證會上辯稱，任正非是中國共產黨的成員，就像“一些美國商人是民主黨或共和黨”的說法，聽起來對美國分析師來說就像是有意混淆公司治理中的共產黨角色。然而，華為是由中國國家特意建立這一論點，從未有明確的證據支持它。

Huawei’s rise has, however, worked in the interests of the Chinese state, as the company grabbed market share and embedded its equipment in the world’s telecom networks. For many years, despite the warning of America’s spy agencies, Huawei spread rapidly across the world. As it grew, incumbent Western firms selling telecom equipment were forced to merge or pushed out of the market. Canada’s Nortel went bankrupt. Alcatel-Lucent, the company that inherited Bell Labs after AT&T was broken up, sold its operations to Finland’s Nokia.

然而，华为的崛起符合中国国家的利益，因为该公司占据了市场份额，并嵌入了世界电信网络的设备中。多年来，尽管美国间谍机构发出了警告，华为仍在全球迅速扩张。随着华为的发展，销售电信设备的西方老牌公司被迫合并或退出市场。加拿大的诺特尔破产了。AT&T被拆分后继承贝尔实验室的阿尔卡特-朗讯将其业务出售给芬兰的诺基亚。

Huawei's ambitions only grew. Having provided the infrastructure that makes phone calls possible, it started selling phones, too. Soon its smartphones were among the world's best sellers. By 2019 the company lagged only Samsung measured by number of units sold. Huawei still made substantially less money per phone than either Samsung or Apple, the latter of which had the marketing and the ecosystem to charge vastly higher prices. However, Huawei's ability to enter the smartphone market and quickly seize a leading position put Apple and Samsung on notice.

华为的野心不断增长。作为提供电话通讯基础设施的公司，它也开始销售手机。很快，其智能手机成为全球最畅销的产品之一。到2019年，该公司在销售数量方面仅落后于三星。然而，华为每部手机的利润仍远远低于三星和苹果，后者拥有营销和生态系统，可以收取大幅度更高的价格。然而，华为进入智能手机市场并迅速取得领先地位的能力，使苹果和三星受到了警告。

Moreover, Huawei was making progress designing some of the critical chips in its own phones. Company insiders say the firm's chip design ambitions accelerated in March 2011, when an earthquake off Japan's east coast caused a tsunami that slammed into the country. The world's attention focused on the Fukushima Daiichi nuclear reactor that was damaged by the flooding, but inside Huawei, executives worried about the threat to the company's supply chain. Like every major producer of electronics, Huawei relied on Japanese providers for crucial components in their telecom gear and smartphones and feared the disaster might cause immense delays. In the end, Huawei got lucky. Few of its component suppliers saw production knocked out for long. However, the company asked its consultants to determine its supply chain risk. They reported that the company had two key vulnerabilities: access to Google's Android operating system, the core software on which all non-

Apple smartphones run, and the supply of the semiconductors that every smartphone requires.

此外，华为正在为其手机设计一些关键芯片取得进展。内部人员表示，该公司的芯片设计雄心从2011年3月加速，当时日本东海岸发生地震，引发了一场海啸冲击该国。世界关注的焦点是受洪水破坏的福岛第一核电站，但在华为内部，高管们担心公司供应链的威胁。像每一个电子设备的主要生产商一样，华为依赖日本供应商提供其电信设备和智能手机的关键部件，担心此次灾难可能会导致巨大的生产延误。最终，华为走了运。其组件供应商很少经历长时间的生产中断。然而，该公司要求其顾问确定其供应链风险。他们报告说，该公司有两个关键漏洞：使用Google的安卓操作系统，所有非苹果智能手机都运行其核心软件，以及每个智能手机都需要的半导体供应。

The company identified the 250 most important semiconductors that its products required and began designing as many as possible in-house. These chips were largely related to the business of building telecom base stations but also included the application processors for the company’s smartphones, semiconductors that were monstrously complex and required the most advanced chipmaking technology. Like Apple and most other leading chip firms, Huawei chose to outsource fabrication of these chips, because it needed to use manufacturing processes that, at most, a couple companies could provide. Taiwan’s TSMC was the natural place to turn.

公司確認了其產品所需的最重要的 250 種半導體，並開始盡可能多地在內部設計這些芯片。這些芯片主要與建設電信基站的業務有關，但也包括公司智能手機的應用處理器，這些半導體極其複雜，需要最先進的芯片製造技術。與蘋果和其他大多數領先的晶片公司一樣，華為選擇外包這些晶片的製造，因為它需要使用最多只有幾家公司能提供的製造工藝。台灣的 TSMC 是自然的選擇。

By the end of the 2010s, Huawei’s HiSilicon unit was designing some of the world’s most complex chips for smartphones and had become TSMC’s second-largest customer. Huawei’s phones still required chips from other companies, too, like memory chips or various types of signal processors. But mastering the production of cell phone processors was an impressive feat. America’s near monopoly on the world’s most profitable chip design businesses was under threat. This was more evidence that Huawei was successfully replicating what South Korea's Samsung or Japan's Sony had done decades earlier: learning to produce advanced technology, winning global markets, investing in R&D, and challenging America's tech leaders. Moreover, Huawei seemed uniquely well placed for a new era of ubiquitous computing that would accompany the rollout of the next generation of telecom infrastructure: 5G.

到2010年代末，華為的海思半導體單元正在為智能手機設計一些世界上最複雜的芯片，並成為台積電的第二大客戶。華為的手機仍需要其他公司的芯片，例如記憶芯片或各種類型的信號處理器。但掌握手機處理器的生產是一項驚人的壯舉。美國在全球最有利可圖的芯片設計業務上的近乎壟斷地位受到了威脅。這是華為成功複製韓國的三星或日本的索尼幾十年前所做的事情的更多證據：學習生產先進技術、贏得全球市場、投資研發，並挑戰美國的技術領袖。此外，華為似乎獨具特色，適應下一代電信基礎設施的全面計算時代：5G的推出。

CHAPTER 47 The 5G Future

W hen Ren Zhengfei started importing telephone switches from Hong Kong, network gear couldn't do much beyond connecting one phone to another. In the early days of telephones, switching had been done by hand, with rows of women seated in front of a wall of plugs, connecting them in different combinations depending on who was calling. By the 1980s, humans had been replaced by electronic switches, which often relied on semiconductor devices. Even still, it took switching gear the size of a closet to manage a single building's worth of telephone lines. Today, telecom providers are more reliant than ever on silicon, but a closet's worth of gear can process calls, texts, and video, now often sent via radio networks rather than landlines.

當任正非從香港開始進口電話交換機時，網路設備除了將一部電話連接到另一部電話之外，沒有太多其他功能。在電話的早期，交換工作是由手動完成的，一排排的女工坐在一堵插座墻前，根據打電話的人士，以不同的組合方式進行連接。到了1980年代，人類已被電子交換機所取代，這些交換機通常依賴於半導體設備。即使如此，一個櫃子大小的交換設備仍需要管理一個建築物內的電話線路。如今，電信提供商比以往更依賴硅，但一個櫃子大小的設備可以處理電話、短信和視頻，現在通常是通過無線網絡傳送，而不是通過有線電話網路。

Huawei has mastered the latest generation of equipment to send calls and data via cell networks, called 5G. Yet 5G isn't really about phones—it's about the future of computing, and therefore, it's about semiconductors. The "G" in 5G stands for generation. We've already cycled through four generations of mobile networking standards, each of which required new hardware on phones and in cell towers. Just as Moore's Law has let us pack more transistors onto chips, there's been a steady increase in the number of 1s and 0s flying to and from cell phones via radio waves. 2G phones could send picture texts; 3G phones opened websites; and 4G made it possible to stream video from almost anywhere. 5G will provide a similar leap forward.

华为已经掌握了通过蜂窝网络发送语音和数据的最新一代设备，称为5G。然而，5G并不只是关于手机——它涉及到计算的未来，因此，它

涉及到半导体。5G中的“G”代表着代际。我们已经经历了四代移动网络标准，每一代都需要手机和手机塔上的新硬件。正如摩尔定律让我们在芯片上装更多的晶体管一样，通过无线电波发送和接收的1和0的数量也不断增加。2G手机可以发送图片信息；3G手机可以浏览网页；而4G使得在几乎任何地方都可以通过流式传输视频。5G将提供类似的飞跃。

Most people today take their smartphone for granted, but it’s only thanks to ever more powerful semiconductors that we no longer marvel at picture texts and are instead frustrated with split-second delays in video streaming. The modem chips that manage a phone’s connection with cell networks make it possible to send many more 1s and 0s in the radio waves via a phone’s antenna.

There’s been a comparable change in the chips hidden inside a cell network and atop cell towers. Sending 1s and 0s through the air while minimizing dropped calls or delays to video streaming is staggeringly complicated. The amount of space available in the relevant part of the radio-wave spectrum is limited. There are only so many radio-wave frequencies, many of which aren’t optimal for sending lots of data or transmitting over long distances. Telecom firms have therefore relied on semiconductors to pack ever more data into existing spectrum space. “Spectrum is far more expensive than silicon,” explains Dave Robertson, a chip expert at Analog Devices, which specializes in semiconductors that manage radio transmission. Semiconductors have therefore been fundamental to the ability to send more data wirelessly. Chip designers like Qualcomm found new ways to optimize transmission of data via the radio spectrum, and chipmakers like Analog Devices have made semiconductors called radio frequency transceivers that can send and receive radio waves with more precision while using less power.

如今，大多数人认为智能手机是理所当然的，但这仅仅是因为随着半导体技术的不断发展，我们不再惊叹于图文信息的传输，而是对视频传输中每一秒的延迟感到沮丧。手机中处理手机网络连接的调制解调器芯片，使得通过手机天线发送更多的1和0成为了可能。 同时，在手机网络和蜂窝塔的芯片中也发生了相似的变化。通过空气传输1和0，同步避免通话中断和视频传输的延迟是极其复杂的。相关的无线电波

谱中空间的可用量是有限的。无线电波频率非常有限，其中许多并不适合大量数据传输或跨越长距离的传输。因此，电信公司依赖于半导体技术，以在现有频谱空间中打包更多数据。"频谱比硅还昂贵，"安纳洛格（Analog Devices）的芯片专家戴夫·罗伯逊（Dave Robertson）解释道，这家公司专门生产管理无线电传输的半导体。半导体因此成为了通过无线方式发送更多数据的重要基础。像高通（Qualcomm）这样的芯片设计师发现了通过无线电频谱来优化数据传输的新方法，而像安纳洛格这样的芯片制造商则制造了称为无线电频率收发器的半导体，可以用更高的精度发送和接收无线电波，同时使用更少的电源。

The next generation of network technology, 5G, will make possible the wireless transmission of even more data. Partly, this will be via even more intricate methods of sharing spectrum space, which require more complex algorithms and more computing power on phones and in cell towers so that 1s and 0s can be slotted in even the tiniest free space in the wireless spectrum. Partly, 5G networks will send more data by using a new, empty radio frequency spectrum that was previously considered impractical to fill. Advanced semiconductors make it possible not only to pack more 1s and 0s into a given frequency of radio waves, but also to send radio waves farther and target them with unprecedented accuracy. Cell networks will identify a phone’s location and send radio waves directly toward a phone, using a technique called beamforming. A typical radio wave, like one that sends music to your car radio, sends signals out in every direction because it doesn’t know where your car is. This wastes power and creates more waves and more interference. With beamforming, a cell tower identifies a device’s location and sends the signal it needs only in that direction. Result: less interference and stronger signals for everyone.

下一代網路技術，5G，將使更多數據得以無線傳輸。部分原因在於更複雜的頻譜空間共享方法，需要更複雜的算法和更多細胞塔內的電腦處理能力，以便將1和0填入無線頻譜中即使是最微小的空隙。此外，5G網絡會利用先前被認為不可行的全新、空曠的無線電頻譜發送更多數據。高級半導體不僅可以將更多的1和0打包到一定的無線電波頻率中，而且還可以發送更遠和以前所未有的準確性地定位所需的信號。蜂窩網絡會識別一個手機的位置並向手機直接發送無線電波，這被稱為波束成型技術。典型的無線電波，就像發送音樂到汽車收音機的一個，向每個方向發送信號，因為它不知道汽車的位置。這浪費電力，

創造更多的波和干擾。使用波束成型，細胞塔識別設備的位置並僅向該方向發送所需的信號。結果是：對於每個人而言，干擾較少且信號更強大。

Faster networks capable of carrying more data won't simply let existing phones run faster—they'll change the way we think about mobile computing. In the age of 1G networks, cell phones were too expensive for most people to own. With 2G networks, we came to assume that phones could send text messages as well as voice. Today, we expect phones and tablets to have almost all the features of PCs. As it becomes possible to send even more data over cell networks, we'll connect ever more devices to the cell network. The more devices we have, the more data they'll produce, which will require more processing power to make sense of.

更快、能夠攜帶更多數據的網路不僅讓現有手機運行更快 - 它們將改變我們對移動運算的看法。在1G網路時代，手機對很多人來說太昂貴了。有了2G網路，我們開始認為手機既能發送文字短信，還能發送語音。如今，我們期望手機和平板電腦幾乎擁有個人電腦的所有功能。隨著通過蜂窩網路發送更多數據變得更為可能，我們將會將越來越多的設備連接到蜂窩網路上。我們所擁有的設備越多，它們產生的數據就越多，這就需要更多的處理能力來理解和處理。

The promise of connecting many more devices to cell networks and harvesting data from them may not sound revolutionary. You may not think a 5G network can brew better coffee, but it won't be long until your coffeemaker is collecting and processing data on the temperature and quality of each cup it produces. There are innumerable ways in business and industry that more data and more connectivity will produce better service and lower cost, from optimizing how tractors drive across fields to coordinating robots on assembly lines. Medical devices and sensors will track and diagnose more conditions. The world has far more sensory information than our current ability to digitize, communicate, and process.

連接更多設備到蜂窩網絡並從它們中收集數據的承諾聽起來可能不那麼革命性。你可能不認為5G網絡能夠沖泡出更好的咖啡，但不久後你的咖啡機將收集和處理每杯咖啡的溫度和質量數據。從優化拖拉機穿越田野的方式到協調裝配線上的機器人，商業和工業中有無數的方式

可以通過更多的數據和更多的互聯性產生更好的服務和更低的成本。醫療設備和傳感器將跟踪和診斷更多情況。世界上的感官信息遠遠超過我們目前的數字化、通信和處理能力。

There’s no better case study showing how connectivity and computing power will turn old products into digitized machines than Tesla, Elon Musk’s auto company. Tesla’s cult following and soaring stock price have attracted plenty of attention, but what’s less noticed is that Tesla is also a leading chip designer. The company hired star semiconductor designers like Jim Keller to build a chip specialized for its automated driving needs, which is fabricated using leading-edge technology. As early as 2014, some analysts were noting that Tesla cars “ resemble a smartphone.” The company has been often compared to Apple, which also designs its own semiconductors. Like Apple’s products, Tesla’s finely tuned user experience and its seemingly effortless integration of advanced computing into a twentieth-century product—a car—are only possible because of custom-designed chips. Cars have incorporated simple chips since the 1970s. However, the spread of electric vehicles, which require specialized semiconductors to manage the power supply, coupled with increased demand for autonomous driving features foretells that the number and cost of chips in a typical car will increase substantially.

沒有比特斯拉更好的案例研究來展示連接和運算功率如何將舊產品變成數字化機器。這家由埃隆·馬斯克創立的汽車公司Tesla的追隨者熱情高漲，股價飆升，受到了很多關注，但鮮有人注意到，Tesla也是一家領先的芯片設計公司。該公司聘請了像Jim Keller這樣的明星半導體設計師來製作專門用於自動駕駛需求的芯片，該芯片使用最先進的技術製造。早在2014年，一些分析師就已經指出，Tesla汽車“類似於智能手機”。該公司經常被比作蘋果公司，蘋果公司也設計自己的半導體。與蘋果的產品一樣，Tesla精心調整的用戶體驗及其對二十世紀產品（汽車）的高超的運算技術的看似不費吹灰之力的整合，僅有基於自定義設計的芯片才能實現。自20世紀70年代以來，汽車已經將簡單的芯片納入其內。然而，電動汽車的普及需要特殊的半導體來管理電源供應，加上對自動駕駛功能的需求增加，典型汽車中的芯片數量和成本將大大增加。

Cars are only the most prominent example of how the ability to send and receive more data will create more demand for computing power—in devices on the "edge" of the network, in the cell network itself, and in vast data centers. Around 2017, as telecom companies around the world began signing contracts with equipment providers to build 5G networks, it emerged that China's Huawei was in a leading position, offering gear that was perceived by the industry to be high-quality and competitively priced. Huawei looked likely to play a bigger role in the construction of 5G networks than any other company, overtaking Sweden's Ericcson and Finland's Nokia, the only other main producers of the equipment on cell towers.

汽車僅是如何能夠傳送和接收更多數據所創造的計算機功率需求的最突出示例——在網絡"邊緣"的設備中、在蜂窩網絡本身中以及在巨大的數據中心中。大約在2017年，當全球電信公司開始與設備供應商簽訂建設5G網絡的合同時，中國的華為公司處於領先位置，提供被行業認為高質量和具競爭力的設備。華為看起來可能在建設5G網絡方面扮演比其他公司更重要的角色，超過瑞典的愛立信和芬蘭的諾基亞，這是唯一在蜂窩塔上設備方面的主要生產商。

Inside Huawei's equipment on cell towers, like that of its rivals, is a large quantity of silicon. One study of Huawei's radio units, by the Japanese newspaper *Nikkei Asia* , found a heavy reliance on U.S.-made chips, like field-programmable gate arrays from Lattice Semiconductor, the Oregon company that Tsinghua Unigroup had bought and then sold a minority stake in several years earlier. Texas Instruments, Analog Devices, Broadcom, and Cypress Semiconductor also designed and built chips that Huawei's radio gear relied on. According to this analysis, American chips and other components constitute nearly 30 percent of the cost of each Huawei system. However, the main processor chip was designed domestically by Huawei's HiSilicon chip design arm and fabricated at TSMC. Huawei hadn't reached technological self-sufficiency. It relied on multiple foreign chip firms to produce specialized semiconductors and on TSMC to fabricate the chips it designed in-house. Yet Huawei produced some of the most complex electronics in each radio system and understood the details of how to integrate all the components.

华为的电信基站设备中，和其它竞争对手一样也有大量的硅芯片。日本报纸《日经亚洲》一项针对华为的无线电设备的研究发现，它很大程度上依赖于美国制造的芯片，比如由清华紫光收购并在几年前部分出售的俄勒冈州公司Lattice Semiconductor提供的可编程门阵列。德州仪器、模拟器件公司、博通公司和赛普拉斯半导体也都供应华为射频设备所需的芯片。根据此项分析，美国芯片和其他组件占华为每个系统成本的近30%。不过，主处理器芯片由华为旗下的海思半导体设计，由TSMC制造。华为还没有达到技术上自给自足的地步，它依赖多个外国芯片公司生产专门的半导体，并且依靠TSMC制造自己在内部设计的芯片。不过华为也在每个无线电系统中生产了一些最复杂的电子产品，并且对如何将所有组件集成起来的细节了如指掌。

With Huawei’s design arm proving itself world-class, it wasn’t hard to imagine a future in which Chinese chip design firms were as important customers of TSMC as Silicon Valley giants. If the trends of the late 2010s were projected forward, by 2030 China’s chip industry might rival Silicon Valley for influence. This wouldn’t simply disrupt tech firms and trade flows. It would also reset the balance of military power.

隨著華為的設計部門證明自己是世界級的，很容易想像到未來中國的芯片設計公司將成為台積電和硅谷巨頭一樣重要的客戶。如果延續2010年代末的趨勢，到2030年，中國的芯片產業可能會與硅谷一樣具有影響力。這不僅會扰乱科技公司和貿易流程，還會重置軍事力量的平衡。

CHAPTER 48 The Next Offset

F rom swarms of autonomous drones to invisible battles in cyberspace and across the electromagnetic spectrum, the future of war will be defined by computing power. The U.S. military is no longer the unchallenged leader. Long gone are the days when the U.S. had unrivaled access to the world's seas and airspace, guaranteed by precision missiles and all-seeing sensors. The shock waves that reverberated around the world's defense ministries after the 1991 Persian Gulf War—and the fear that the surgical strikes that had defanged Saddam's army could be used against any military in the world—was felt in Beijing like a "psychological nuclear attack," according to one account. In the thirty years since that conflict, China has poured funds into high-tech weaponry, abandoning Mao-era doctrines of waging a low-tech People's War and embracing the idea that the fights of the future will rely on advanced sensors, communications, and computing. Now China is developing the computing infrastructure an advanced fighting force requires.

從一群自主飛行的無人機到電腦領域中看不見的戰爭，戰爭的未來將受計算能力所定義。美國軍方不再是無可匹敵的領袖。美國擁有世界海洋及空域的無與倫比的優勢、精確導彈和全方位感應的日子已經過去。1991年波斯灣戰爭後，在全球國防部門掀起的震撼波動，以及醫治沙姆德軍隊的外科手術打擊可能會被用在世界上任何軍隊中的恐懼，對北京造成一次「心理核攻擊」，根據某一份報告。在過去的30年中，中國將資金注入高科技武器，放棄毛澤東時代提倡的低技術，並接受未來戰鬥將依賴先進感測、通訊和計算的觀點。現在，中國正在開發先進作戰部隊所需的計算基礎架構。

Beijing's aim isn't simply to match the U.S. system-by-system, but to develop capabilities that could "offset" American advantages, taking the Pentagon's concept from the 1970s and turning it against the United States. China has fielded an array of weapons that systematically undermine U.S. advantages. China's precision anti-ship missiles make it extremely dangerous for U.S. surface ships to transit the Taiwan Strait in a time of war, holding American naval power at bay. New air defense systems contest America's ability to dominate the airspace in a conflict. Long-range land attack missiles threaten the network of American military bases from Japan to Guam. China’s anti-satellite weapons threaten to disable communications and GPS networks. China’s cyberwar capabilities haven’t been tested in wartime, but the Chinese would try to bring down entire U.S. military systems. Meanwhile, in the electromagnetic spectrum, China might try to jam American communications and blind surveillance systems, leaving the U.S. military unable to see enemies or communicate with allies.

北京的目标不仅是与美国系统地匹敌，而且是开发能够“抵消”美国优势的能力，将五十年代这个“防护”概念转变为对美国的攻击。中国已经装备了一系列武器，有条不紊地破坏美国的优势。中国的精准反舰导弹使美国水面舰艇在战争时的台湾海峡通行极为危险，使美国海军力量无法进入该地区。新型防空系统对美国在冲突中主导空中领域的能力提出质疑。远程陆地攻击导弹威胁到从日本到关岛的美国军事基地网络。中国的反卫星武器威胁到通信和GPS网络的瘫痪。中国的网络战能力尚未经受过战时考验，但中国人会试图摧毁整个美国军事系统。同时，在电磁频谱方面，中国可能会试图干扰美国的通信和盲目监视系统，使美国军方无法看到敌人或与盟友通信。

Undergirding all these capabilities is a belief in Chinese military circles that warfare is not simply becoming “informationized” but “intelligentized”—inelegant military jargon that means applying artificial intelligence to weapons systems. Of course, computing power has been central to warfare for the past half century, though the quantity of 1s and 0s that can be harnessed to support military systems is millions of times larger than decades earlier. What’s new today is that America now has a credible challenger. The Soviet Union could match the U.S. missile-for-missile but not byte-for-byte. China thinks it can do both. The fate of China’s semiconductor industry isn’t simply a question of commerce. Whichever country can produce more 1s and 0s will have a serious military advantage, too.

所有这些能力的基础是中国军界的信念，即战争不仅仅是成为"信息化"，而是变得"智能化"——这是不雅的军事术语，意味着将人工智能应用于武器系统。当然，计算能力已经是战争的核心，过去半个世纪以来，可以用来支持军事系统的1和0的数量比几十年前多了数百万倍。今天的新情况是，美国现在有了一个可信的挑战者。苏联可以与美国在导弹上匹配，但在字节上却无法比拟。中国认为它两者都做得

到。中国半导体产业的命运不仅仅是商业问题。任何一个能够生产更多1和0的国家也将拥有严重的军事优势。

What factors will define this computing race? In 2021, a group of American tech and foreign policy grandees chaired by former Google CEO Eric Schmidt released a report predicting that “China could surpass the United States as the world’s AI superpower.” Chinese leaders appear to agree. As China military expert Elsa Kania notes, the PLA has been talking about “ AI weapons” for at least a decade, referring to systems that use “AI to pursue, distinguish, and destroy enemy targets automatically.” Xi Jinping himself has urged the PLA to “accelerate the development of military intelligentization” as a defense priority.

什麼因素將決定這場計算競賽？2021年，由前Google CEO Eric Schmidt主持的一群美國科技和外交政策大佬發布了一份報告，預測“中國可能超過美國成為世界人工智能超級大國”。中國領導人似乎也同意這一點。中國軍事專家Elsa Kania指出，解放軍至少十年來一直在談論“人工智能武器”，指的是使用“人工智能自動追踪、區分和摧毀敵方目標”的系統。習近平本人已經敦促解放軍將“加速發展軍事智能化”作為一項防衛優先事項。

The idea of military AI evokes images of killer robots, but there are many spheres where applying machine learning can make military systems better. Predictive maintenance—learning when machines need to be fixed—is already helping keep planes in the sky and ships at sea. AI-enabled submarine sonars or satellite imagery can identify threats more accurately. New weapons systems can be designed more quickly. Bombs and missiles can be aimed more accurately, especially when it comes to moving targets. Autonomous vehicles in the air, underwater, and on land are already learning to maneuver, identify adversaries, and destroy them. Not all of this is as revolutionary as phrases like “AI weapons” might imply. We’ve had self-guided, fire-and-forget missiles for decades, for example. But as weapons get smarter and more autonomous, their demands for computing power only grow.

军事人工智能的想法引起了杀人机器人的形象，但在许多领域应用机器学习可以使军事系统变得更好。预测性维护-学习何时修理机器-已

经帮助保持飞机在天空中和船在海上。具有AI功能的潜艇声纳或卫星图像可以更准确地识别威胁。新武器系统可以更快地设计。炸弹和导弹可以更准确地瞄准，尤其是针对移动目标。空中、水下和陆地上的自主车辆已经学会操纵、识别对手并摧毁他们。并不是所有的这些都像“AI武器”这样的短语所暗示的那样具有革命性。例如，我们几十年来一直拥有自引导的快速导弹。但随着武器变得更加智能和自主，它们对计算能力的需求只会增加。

It isn’t guaranteed that China will win the race to develop and deploy systems empowered by artificial intelligence, in part because this “race” isn’t about a single technology but about complex systems. The Cold War arms race, it’s worth remembering, wasn’t won by the first country to shoot a satellite into space. Yet China’s capabilities when it comes to AI systems are undeniably impressive. Georgetown University’s Ben Buchanan has noted that a “triad” of data, algorithms, and computing power are needed to harness AI. With the exception of computing power, China’s capabilities may already equal the United States’.

并不保证中国会赢得发展和部署人工智能系统的竞赛，部分原因在于这场“竞赛”不仅仅是单一技术的比拼，而是复杂系统的竞争。值得记住的是，冷战时期的军备竞赛并不是由第一个将卫星送入太空的国家赢得的。然而，中国在人工智能系统方面的能力是毋庸置疑的。乔治城大学的本·布坎南指出，利用人工智能需要一个“三元”组合的数据、算法和计算能力，除了计算能力之外，中国的能力可能已经与美国旗鼓相当。

When it comes to accessing the type of data that can be fed into AI algorithms, neither China nor the U.S. has a clear advantage. Beijing’s boosters argue the country’s surveillance state and its massive population let it collect more data, though the ability to amass data about China’s populace probably doesn’t help much in the military sphere. No amount of data about online shopping habits or the facial structure of all of China’s 1.3 billion citizens will train a computer to recognize the sounds of a submarine lurking in the Taiwan Strait, for example. China doesn’t have any built-in advantages in gathering data relevant to military systems.

在访问可输入人工智能算法的数据类型方面，中国和美国都没有明显的优势。北京的支持者认为，该国的监控状态和其庞大的人口让它收集更多数据，尽管积累有关中国公众的数据能力可能对军事领域帮助不大。例如，关于所有13亿公民的网购习惯或面部结构的数据也不能训练计算机识别在台湾海峡潜伏的潜艇的声音。中国在收集与军事系统相关的数据方面没有任何内在优势。

It’s harder to say whether one side has an advantage when it comes to devising clever algorithms. Measured by the number of AI experts, China appears to have capabilities that are comparable to America’s. Researchers at MacroPolo, a China-focused think tank, found that 29 percent of the world’s leading researchers in artificial intelligence are from China, as opposed to 20 percent from the U.S. and 18 percent from Europe. However, a staggering share of these experts end up working in the U.S., which employs 59 percent of the world’s top AI researchers. The combination of new visa and travel restrictions plus China’s effort to retain more researchers at home may neutralize America’s historical skill at stripping geopolitical rivals of their smartest minds.

關於設計巧妙算法哪一方更具優勢，並不好說。就AI專家人數而言，中國的能力似乎與美國相當。一個關注中國的智庫MacroPolo的研究人員發現，全球29%的領先人工智慧研究者來自中國，而美國和歐洲的比例分別為20%和18%。然而，這些專家中驚人的一部分最終卻在美國工作，美國僱用了全球59%的頂尖AI研究人員。新的簽證和旅行限制相結合，再加上中國努力留住更多研究人員，可能會抵消美國在剝奪地緣政治對手聰明人才方面的歷史技能。

In the third part of Buchanan’s “triad,” computing power, the United States still has a substantial lead, though it has eroded significantly in recent years. China is still staggeringly dependent on foreign semiconductor technology—in particular, U.S.-designed, Taiwan-fabricated processors—to undertake complex computation. It isn’t only Chinese smartphones and PCs that rely on foreign chips. So, too, do most Chinese data centers—which explains why the country has tried so hard to acquire technology from companies like IBM and AMD. One Chinese study has estimated that as many as 95 percent of GPUs in Chinese servers running artificial intelligence workloads are designed by Nvidia, for example. Chips from Intel, Xilinx, AMD, and others are crucially important in Chinese data centers. Even under the most optimistic projections, it will be half a decade before China can design competitive chips and the software ecosystem around them, and far longer before it can manufacture these chips domestically.

在布坎南的「三部曲」中的第三部分中，美國在計算能力方面仍然具有相當領先優勢，儘管近年來已大幅縮減。中國仍然極度依賴外國半導體技術，特別是美國設計、台灣製造的處理器，才能進行複雜的計算。不僅是中國智慧型手機和個人電腦依賴外國晶片，大多數中國資料中心也是如此，這就解釋了為什麼該國一直努力從IBM和AMD等公司獲得技術。一項中國研究估計，運行人工智慧工作負載的中國伺服器中高達95％的GPU是由Nvidia設計的。Intel、Xilinx和AMD等公司的晶片對中國資料中心至關重要。即使在最樂觀的預測下，中國也需要五年左右才能設計有競爭力的晶片及其周邊軟體生態系統，而在能夠國產這些晶片之前還需要更長時間。

For many Chinese military systems, however, acquiring U.S.-designed, Taiwan-fabricated chips hasn’t been difficult. A recent review of 343 publicly available AI-related People’s Liberation Army procurement contracts, by researchers at Georgetown University, found that less than 20 percent of the contracts involved companies that are subject to U.S. export controls. In other words, the Chinese military has had little difficulty simply buying cutting-edge U.S. chips off-the-shelf and plugging them into military systems. The Georgetown researchers found that Chinese military suppliers even advertise on their websites their use of American chips. The Chinese government’s controversial policy of “Civil Military Fusion,” an effort to apply advanced civilian technology to military systems, looks like it’s working. Absent a major change in U.S. export restrictions, the People’s Liberation Army will acquire much of the computing power it needs by simply buying it from Silicon Valley.

不过，对于许多中国军事系统来说，获取美国设计、台湾制造的芯片并不困难。乔治城大学研究人员最近对公开的343份与人工智能有关的解放军采购合同进行了审查，发现不到20%的合同涉及受美国出口管制限制的企业。换句话说，中国军方很容易就能够购买到先进的美国芯片，然后将其插入军事系统中。乔治城研究人员发现，中国军方供应商甚至在其网站上宣传使用美国芯片。中国政府颇具争议的“军民融

合”政策旨在将先进的民用技术应用于军事系统，看起来正在发挥作用。在美国出口限制没有发生重大变化的情况下，解放军将通过从硅谷简单购买来获得其所需的大部分计算能力。

Of course, the People’s Liberation Army isn’t the only military trying to apply advanced computing to weapons systems. As the fighting power of China’s military has grown, the Pentagon has realized it needs a new strategy. In the mid-2010s, officials like Secretary of Defense Chuck Hagel began speaking about a need for a new “offset,” evoking the effort of Bill Perry, Harold Brown, and Andrew Marshall during the 1970s to overcome the USSR’s quantitative advantage. The U.S. faces the same basic dilemma today: China can deploy more ships and planes than the U.S., especially in theaters that matter, like the Taiwan Strait. “We will never try to match our opponents or our competitors tank for tank, plane for plane, person for person,” declared Bob Work, the former deputy defense secretary who is the intellectual godfather of this new offset, in a clear echo of the logic of the late 1970s. The U.S. military will only succeed, in other words, if it has a decisive technological advantage.

当然，人民解放军并不是唯一一支试图在武器系统中应用先进计算技术的军队。随着中国军队的战斗力增强，五角大楼已经意识到需要一种新的战略。在2010年代中期，像国防部长查克·黑格尔这样的官员开始谈论需要一种新的“抵消”策略，提到了比尔·佩里、哈罗德·布朗和安德鲁·马歇尔在20世纪70年代克服苏联数量优势所做出的努力。今天，美国面临着同样的基本困境：中国可以在台湾海峡等重要的战区部署更多的船只和飞机。“我们永远不会试图与对手或竞争对手以坦克对坦克、飞机对飞机、人对人的方式匹配，”这个新的“抵消”策略的知识之父、前国防部副部长鲍勃·沃克明确重申了20世纪70年代的逻辑。换言之，只有在拥有决定性技术优势的情况下，美国军队才能获得成功。

What will this technological advantage look like? The 1970s offset was driven by “digital microprocessors, information technologies, new sensors, stealth,” Work has argued. This time, it will be “advances in Artificial Intelligence (AI) and autonomy.” The U.S. military is already fielding the first generation of new autonomous vehicles, like Saildrone, an unmanned windsurfer that can spend months roving the oceans while tracking submarines or intercepting adversaries' communications. These devices cost a tiny fraction of a typical Navy ship, letting the military field many of them and providing platforms for sensors and communications across the world's oceans. Autonomous surface ships, planes, and submarines are also being developed and deployed. These autonomous platforms will require artificial intelligence to guide them and make decisions. The more computing power that can be put on board, the smarter decisions they'll make.

這個技術優勢會是什麼樣子？沃克認為，1970年代的抵銷是由「數位微處理器、資訊科技、新式感應器、隱形技術」所推動。而這一次，則是「人工智慧 (AI) 和自主性的進步」。美國軍方已經開始陸續部署新一代的自主載具，例如 Saildrone，一種能在海上漂浮數月的無人風帆船，可以追蹤潛艇或截獲敵方通訊。這些裝置只需花費較少的成本即可建造，讓軍方可以部署多個，提供在世界各洋面的感測器和通訊平臺。自主性的地面、空中和水下載具也正在開發和部署當中。這些自主性載具需要人工智慧進行指導和決策。更多的電腦運算能力可以應用於這些載具中，讓它們做出更加智慧的決策。

DARPA developed the technology that made the 1970s offset possible; now it's devising systems that promise new computing-enabled transformations in warfare. DARPA leaders envision "computers distributed across the battlespace that can all communicate and coordinate with one another," from the largest naval ship to the tiniest drone. The challenge isn't simply to embed computing power in a single device, like a guided missile, but to network thousands of devices across a battlefield, letting them share data and putting machines in a position to make more decisions. DARPA has funded research programs on " human-machine teaming," envisioning, for example, a piloted fighter jet flying alongside several autonomous drones that are an additional set of eyes and ears for the human pilot.

DARPA研发了使1970年代抵消成为可能的技术；现在，它正在设计系统，承诺在战争中实现新的计算变革。 DARPA领导者设想"分布在战场上的计算机可以相互通信和协调"，从最大的海军舰艇到最小的无人机。挑战不仅在于将计算能力嵌入单个设备（如制导导弹），而是将数千个设备网络连接到战场上，使它们共享数据并使机器能够作出更多决策。 DARPA已资助关于"人机协作"的研究计划，并设想了一架可搭载多个自主无人机的驾驶战斗机，作为人类驾驶员的额外耳目。

Just as the Cold War was decided by electrons zipping around the guidance computers of American missiles, the fights of the future may be decided in the electromagnetic spectrum. The more the world's militaries rely on electronic sensors and communication, the more they'll have to battle for access to the spectrum space needed to send messages or to detect and track adversaries. We've only had a glimpse of what wartime electromagnetic spectrum operations will look like. For example, Russia has used a variety of radar and signals jammers in its war against Ukraine. The Russian government also reportedly obstructs GPS signals around President Vladimir Putin's official travel, perhaps as a security measure. Not coincidentally, DARPA is researching alternative navigation systems that aren't reliant on GPS signals or satellites, to enable American missiles to hit their targets even if GPS systems are down.

正如冷戰時期是由美國導彈指揮計算機中的電子所決定，未來的戰鬥可能會在電磁波譜上決定。全球軍隊越來越多地依賴電子傳感器和通訊，他們將不得不爭奪訊號傳輸或檢測和跟蹤對手所需的譜空間。我們只看到了未來戰時電磁波譜操作的一瞥。例如，俄羅斯在與烏克蘭的戰爭中使用了各種雷達和信號幹擾器。據報導，俄羅斯政府還阻礙總統弗拉基米爾·普京的官方旅行周圍的GPS信號，可能作為一種安全措施。不巧的是，DARPA正在研究不依賴GPS信號或衛星的替代導航系統，以使美國導彈在GPS系統崩潰時仍能準確打擊目標。

The battle for the electromagnetic spectrum will be an invisible struggle conducted by semiconductors. Radar, jamming, and communications are all managed by complex radio frequency chips and digital-analog converters, which modulate signals to take advantage of open spectrum space, send signals in a specific direction, and try to confuse adversaries' sensors. Simultaneously, powerful digital chips will run complex algorithms inside a radar or jammer that assess the 289signals received and decide what signals to send out in a matter of milliseconds. At stake is a military's ability to see and to communicate. Autonomous drones won't be worth much if the devices can't determine where they are or where they're heading.

電磁譜的戰爭將是由半導體進行的看不見的鬥爭。雷達、干擾和通信都由複雜的無線電頻率芯片和數模轉換器管理，這些芯片調製信號以利用開放的頻譜空間，在特定方向上發送信號，並試圖混淆對手的傳

感器。同時，強大的數字芯片將在雷達或干擾器內運行複雜算法，評估接收到的信號並在幾毫秒內決定發送哪些信號。在這裡賭注是軍隊的視野和溝通能力。如果無人機無法確定它們的位置或方向，則它們將不會有多大價值。

The warfare of the future will be more reliant than ever on chips—powerful processors to run AI algorithms, big memory chips to crunch data, perfectly tuned analog chips to sense and produce radio waves. In 2017, DARPA launched a new project called the Electronics Resurgence Initiative to help build the next wave of militarily relevant chip technology. In some ways, DARPA's renewed interest in chips stems naturally from its history. It funded pioneering scholars like Caltech's Carver Mead and catalyzed research into chip design software, new lithography techniques, and transistor structures.

未来的战争将比以往任何时候都更加依赖芯片——强大的处理器来运行人工智能算法，大容量存储芯片来处理数据，精密调校的模拟芯片来感知和产生无线电波。2017年，DARPA启动了一个名为"电子再起计划"的新项目，旨在帮助构建下一代具有军事相关性的芯片技术。在某些方面，DARPA对芯片的重新关注自然而然地源于其历史。它资助了先驱学者，如卡尔特克的卡弗·米德，并催化了芯片设计软件、新的光刻技术和晶体管结构的研究。

Yet DARPA and the U.S. government have found it harder than ever to shape the future of the chip industry. DARPA's budget is a couple billion dollars per year, less than the R&D budgets of most of the industry's biggest firms. Of course, DARPA spends a lot more on far-out research ideas, whereas companies like Intel and Qualcomm spend most of their money on projects that are only a couple years from fruition. However, the U.S. government in general buys a smaller share of the world's chips than ever before. The U.S. government bought almost all the early integrated circuits that Fairchild and Texas Instruments produced in the early 1960s. By the 1970s, that number had fallen to 10−15 percent. Now it's around 2 percent of the U.S. chip market. As a buyer of chips, Apple CEO Tim Cook has more influence on the industry than any Pentagon official today.

然而，DARPA和美国政府发现，比以往任何时候都更难塑造芯片行业的未来。 DARPA的预算每年仅为几十亿美元，少于大多数行业最大公

司的研发预算。当然，DARPA在前沿研究方面的支出要多得多，而像英特尔（Intel）和高通（Qualcomm）这样的公司则将大部分资金投入到即将实现成果的项目上。然而，美国政府整体上购买的全球芯片份额比以往任何时候都要少。美国政府购买了Fairchild和Texas Instruments在20世纪60年代早期生产的几乎所有早期集成电路。到了1970年代，这个数字已降至10-15％。现在它约占美国芯片市场的2％。作为芯片买家，苹果（Apple）首席执行官蒂姆·库克（Tim Cook）对行业的影响力比今天的五角大楼官员任何一个更大。

Making semiconductors is so expensive that even the Pentagon can’t afford to do it in-house. The National Security Agency used to have a chip fab at its headquarters in Maryland’s Fort Meade. In the 2000s, however, the government decided it was too expensive to keep upgrading per the cadence dictated by Moore’s Law. Today even *designing* a leading-edge chip—which can cost several hundred million dollars—is too expensive for all but the most important projects.

Both the U.S. military and the government’s spy agencies outsource the production of their chips to “trusted foundries.” This is relatively straightforward for many types of analog or radio frequency chips, where the U.S. has world-class capabilities. When it comes to logic chips, though, this poses a dilemma. Intel’s production capabilities are just behind the leading edge, though the company mostly produces chips for its own PC and server businesses. TSMC and Samsung, meanwhile, keep their most cutting-edge fabrication capabilities in Taiwan and South Korea. And a large share of chip assembly and packaging also takes place in Asia. As the Defense Department tries to use more off-the-shelf components to reduce cost, it will buy even more devices from abroad.

製造半導體非常昂貴，即使是五角大廈也負擔不起在內部進行生產。國家安全局曾在馬里蘭州的福特·米德堡總部擁有一個晶片製造廠，但在2000年代，政府決定根據摩爾定律所規定的節奏升級成本太高。今天，即使是設計領先的晶片也需要耗費數億美元，只有最重要的項目才能負擔得起。 美國軍方和政府間諜機構都將芯片生產外包給“可信任的晶片廠”。這在許多類型的模擬或射頻晶片方面相對簡單，因為美國擁有世界一流的能力。然而，當談到邏輯芯片時，這就產生了兩難。英特爾的生產能力只略遜於領先水平，但該公司主要生產自己的

個人電腦和服務器業務的芯片。與此同時，台灣和韓國的TSMC和三星保留了它們最尖端的製造能力。芯片組裝和封裝的很大一部分也發生在亞洲。隨著國防部試圖使用更多的現成零件以降低成本，它將從國外購買更多的設備。

The military worries that chips fabricated or assembled abroad are more susceptible to tampering, with back doors added or errors written in. However, even chips designed and produced domestically can have unintended vulnerabilities. In 2018, researchers discovered two fundamental errors in Intel's widely used microprocessor architecture called Spectre and Meltdown, which enabled the copying of data such as passwords—a huge security flaw. According to the *Wall Street Journal* , Intel first disclosed the flaw to customers, including Chinese tech companies, before notifying the U.S. government, a fact that only intensified Pentagon officials' concern about their declining influence over the chip industry.

軍方擔心境外製造或組裝的晶片更容易遭到篡改，加入後門或錯誤寫入。然而，就連在國內設計和生產的晶片也可能存在不受預期的漏洞。2018年，研究人員在英特爾廣泛使用的微處理器架構中發現了兩個基本錯誤，稱為Spectre和Meltdown，這樣可以複製敏感數據，例如密碼，這是一個巨大的安全漏洞。根據《華爾街日報》的報導，英特爾首先向客戶（包括中國科技公司）披露了這個缺陷，而沒有通知美國政府，這增強了五角大廈官員對於他們在芯片行業中影響力下降的擔憂。

DARPA is investing in technology that can guarantee chips are tamper-free or to verify they're manufactured exactly as intended. Long gone are the days when the military could count on firms like TI to design, manufacture, and assemble cutting-edge analog and digital electronics all onshore. Today there's simply no way to avoid buying some things from abroad—and buying many from Taiwan. So DARPA's betting on technology to enable a "zero trust" approach to microelectronics: trust nothing and verify everything, via technologies like tiny sensors implanted on a chip that can detect efforts to modify it.

DARPA正在投资于能够确保芯片无法被篡改或验证它们是否按预期制造的技术。军方曾经可以依靠像TI这样的公司设计、制造和组装最先

进的模拟和数字电子设备，但这些日子已经过去了。如今，无法避免从海外购买一些东西，而从台湾购买的物品更是数不胜数。因此，DARPA押注于技术来实现对微电子学的“零信任”方法：毫不信任，一切验证，通过诸如植入在芯片上的微小传感器等技术来检测修改其的努力。

All these efforts to use microelectronics to spur a new “offset” and reestablish a decisive military advantage over China and Russia, however, assume the U.S. will keep its lead in chips. That’s now looking like a risky bet. The era of the “run faster” strategy saw the U.S. fall behind in certain segments of the chipmaking process, most notably in the growing dependence on Taiwan for building advanced logic chips. Intel, which for three decades had been America’s chip champion, has now very clearly stumbled. Many people in the industry think it has fallen decisively behind. Meanwhile, China is pouring billions of dollars into its chip industry while pressuring foreign companies to turn over sensitive technology. For every major chip firm, the Chinese consumer market is far more important a customer than the U.S. government.

所有這些利用微電子學推動一個新的“抵銷”並重新確立對中國和俄羅斯的決定性軍事優勢的努力都假設美國會保持芯片領先地位。現在這看起來像是一個冒險的賭注。在“跑得更快”的策略時代，美國在芯片製造過程的某些部分落後，尤其是在越來越依賴台灣建造先進邏輯芯片方面。英特爾，三十年來一直是美國的晶片冠軍，現在明顯已經失敗。行業中許多人認為它已經明顯落後。同時，中國正在向其芯片行業注入數十億美元，同時向外國公司施加壓力，要求其交出敏感技術。對每一個主要的芯片公司來說，中國的消費市場比美國政府更重要。

Beijing’s efforts to acquire advanced technology, the deep interconnections between the U.S. and Chinese electronics industries, and the two countries’ mutual reliance on fabrication in Taiwan all raise questions. America was already running slower. It’s now betting the future of its military on a technology over which its dominance is slipping. “This idea of pulling ahead with an offset,” argues Matt Turpin, an official who worked on the issue at the Pentagon, “is nearly impossible if the Chinese are in the car with us.”

北京為了取得先進技術，美中電子產業之間的深層聯繫，以及兩國對台灣製造的相互依賴，都引發了問題。美國已經開始減緩了步伐。現在，它把軍事未來押注在一個技術上，而其主宰地位正在滑落。“如果中國人和我們一起坐車，那麼超前的概念幾乎是不可能的，”曾在五角大廈處理此問題的官員Matt Turpin表示。

“Call forth the assault,” Xi Jinping declared. China’s leaders have identified their reliance on foreign chipmakers as a critical vulnerability. They’ve set out a plan to rework the world’s chip industry by buying foreign chipmakers, stealing their technology, and providing billions of dollars of subsidies to Chinese chip firms. The People’s Liberation Army is now counting on these efforts to help it evade U.S. restrictions, though it can still buy legally many U.S. chips in its pursuit of “military intelligentization.” For its part, the Pentagon has launched its own offset, after admitting that China’s military modernization has closed the gap between the two superpowers’ militaries, especially in the contested waters off China’s coast. Taiwan isn’t simply the source of the advanced chips that both countries’ militaries are betting on. It’s also the most likely future battleground.

习近平宣称：“发动攻击。”中国领导人已经确定他们对外国芯片制造商的依赖是一个重要的弱点。他们制定了一个计划，通过购买外国芯片制造商、窃取技术并为中国芯片公司提供数十亿美元的补贴来重新组织世界芯片业。人民解放军现在指望这些努力帮助其避开美国的限制，尽管在追求“军事智能化”方面仍然可以合法购买许多美国芯片。对此，五角大楼已经启动了自己的抵消措施，承认中国的军事现代化已经缩小了两个超级大国军队的差距，特别是在中国海域的争议水域。台湾不仅是两国军队押注的先进芯片的来源，也是最有可能成为未来战场的地方。

PART VIII THE CHIP CHOKE

CHAPTER 49 “Everything We’re Competing On”

I ntel’s CEO Brian Krzanich couldn’t hide his anxiety about China’s push to seize a bigger share of the world’s chip industry. As chairman in 2015 of the Semiconductor Industry Association, the U.S. chip industry’s trade group, Krzanich was tasked with hobnobbing with U.S. government officials. Usually this meant asking for tax cuts or reduced regulation. This time, the topic was different: convincing the U.S. government to do something about China’s massive semiconductor subsidies. America’s chip firms were all caught in the same bind. China was a crucial market for almost every U.S. semiconductor firm, either because these firms sold directly to Chinese customers or because their chips were assembled into smartphones or computers in China. Beijing’s strong-arm methods forced U.S. chip firms to stay silent about China’s subsidies, even though the Chinese government had adopted a formal policy of trying to cut them out of China’s supply chain.

英特尔公司首席执行官布莱恩·克拉萨尼奇(Brian Krzanich)对中国在全球芯片行业中占据更大份额的努力感到担忧。作为美国芯片行业贸易团体——半导体工业协会的主席，在2015年，克拉萨尼奇的任务是与美国政府官员接触。通常情况下，这意味着请求减税或减少监管。这一次，话题有所不同：说服美国政府采取措施应对中国政府的大规模半导体补贴。美国的芯片公司都陷入了同样的困境。中国是几乎所有美国半导体公司的关键市场，这些公司或直接向中国客户销售，或者他们的芯片被组装成智能手机或计算机在中国市场上销售。中国政府的强硬手段迫使美国芯片公司对中国的补贴保持沉默，即便中国政府已采取正式政策试图削减这些补贴。

Obama administration officials were used to complaints about China from industries like steel or solar panels. High tech was supposed to be America’s specialty, a sphere where it had a competitive advantage. So when senior administration officials perceived a “palpable sense of fear in his eyes” when meeting with Krzanich, they were worried. Intel’s CEOs had a long history of paranoia, of course. But now there was more reason than ever for the company, and the entire U.S. chip industry, to be worried. China had driven U.S. solar panel manufacturing out of business. Couldn’t it do the same in semiconductors? “This massive $250 billion fund is going to bury us,” one Obama official worried, referencing the subsidies China’s central and local governments have promised to support homegrown chipmakers.

奧巴馬政府官員經常從鋼鐵或太陽能板等產業聽到對中國的抱怨。高科技本應是美國的專長領域，也是具有競爭優勢的領域。因此，當高級政府官員在與克茲尼奇會面時感覺到他眼中有一種“明顯的恐懼感”時，他們感到擔心。英特爾的CEO們當然一直以來都有妄想症。但現在，公司和整個美國晶片行業更有原因感到擔憂了。中國已經將美國太陽能板製造業逼出了市場。它不能在半導體領域做到同樣的事情嗎？“這個龐大的2500億美元基金將把我們埋葬，”一位奧巴馬官員擔心地說，他指的是中國中央和地方政府承諾支持國產晶片製造商的補貼。

By around 2015, from deep in the U.S. government, gears slowly began to shift. The government’s trade negotiators saw China’s chip subsidies as a flagrant violation of international agreements. The Pentagon nervously watched China’s efforts to apply computing power to new weapons systems. The intelligence agencies and Justice Department unearthed more evidence of collusion between China’s government and its industries to push out American chip firms. Yet the twin pillars of American tech policy—embracing globalization and “running faster”—were deeply ingrained, not only by the industry’s lobbying, but also by Washington’s intellectual consensus. Moreover, most people in Washington barely knew what a semiconductor was. The Obama administration moved slowly on semiconductors, one person involved in the effort recalled, because many senior officials simply didn’t see chips as an important issue.

大約在2015年，美國政府內部開始緩慢轉變。政府的貿易談判代表認為中國的晶片補貼是對國際協議的公然違反。五角大樓神經緊張地關注著中國將計算能力應用於新武器系統的努力。情報機構和司法部揭示了更多中國政府與其產業共謀推出美國晶片公司的證據。然而，美國技術政策的雙重支柱 — embracing globalization和“running faster”——不僅深深植根於該行業的遊說中，也是華盛頓的智力共識。此外，華盛頓的大多數人幾乎不知道什麼是半導體。 一名參與這一努力的人回憶說，奧巴馬政府對半導體的行動緩慢，因為許多高級官員根本不認為晶片是一個重要問題。

It wasn't until the final days of the Obama administration, therefore, that the government began to act. In late 2016, six days before that year's presidential election, Commerce Secretary Penny Pritzker gave a high-profile address in Washington on semiconductors, declaring it "imperative that semiconductor technology remains a central feature of American ingenuity and a driver of our economic growth. We cannot afford to cede our leadership." She identified China as the central challenge, condemning "unfair trade practices and massive, non-market-based state intervention" and cited "new attempts by China to acquire companies and technology based on their government's interest—not commercial objectives," an accusation driven by Tsinghua Unigroup's acquisition spree.

因此，政府直到奥巴马政府末期才开始采取行动。在2016年的总统选举前六天，商务部长庇尼·普利兹克在华盛顿发表了一次关于半导体的高调讲话，宣布"半导体技术保持作为美国创新的中心特色和推动我们经济增长的驱动力是必要的。我们不能放弃领导地位。"她认定中国是最大的挑战，谴责"不公平的贸易行为和巨大的、非市场化的国家干预"，并引用"中国试图通过不以商业目的为导向的政府兴趣收购公司和技术的新尝试"，这一指控由清华紫光的收购狂潮驱动。

With little time left in the Obama administration, however, there wasn't much Pritzker could do. Rather, the administration's modest goal was to start a discussion that—it hoped—the incoming Hillary Clinton administration would carry forward. Pritzker also ordered the Commerce Department to conduct a study of the semiconductor supply chain and promised to "make clear to China's leaders at every opportunity that we will not accept a $150 billion industrial policy designed to appropriate this industry." But it was easy to condemn China's subsidies. It was far harder to make them stop.

然而，在奥巴马政府快要结束时，普利兹克没有太多可以做的事情。政府的目标是启动一场讨论，希望即将到来的希拉里•克林顿政府可以继续进行。普利兹克还命令商务部对半导体供应链进行研究，并承诺"在每个机会上向中国领导人明确表示，我们不会接受旨在占用该行业的1500亿美元产业政策。"但是，谴责中国的补贴很容易，但是要让它们停止却难度极大。

Around the same time, the White House commissioned a group of semiconductor executives and academics to study the future of the industry. They issued a report days before Obama left office, which urged the U.S. to double down on its existing strategy. Its primary recommendation was: “win the race by running faster”—advice that could have been copied and pasted from the 1990s. The need to keep innovating was obviously important. The continuation of Moore’s Law was a competitive necessity. But during the decades Washington thought it was “running faster,” its adversaries had grown their market share while the entire world had become frighteningly reliant on a handful of vulnerable choke points, in particular Taiwan.

大約同時，白宮委託一組半導體行業高管和學者研究該行業的未來。他們在歐巴馬離任前幾天發布了一份報告，敦促美國加倍致力於現有策略。其主要建議是：“通過跑得更快贏得競賽”，這些建議可以複製或黏貼自20世紀90年代。保持創新當然很重要，維持摩爾定律是競爭的必要條件。但是，在華盛頓認為自己正在“跑得更快”的幾十年裡，其對手已經增加了市場份額，而整個世界尤其是臺灣依賴於少數脆弱的絞喉點，這讓人感到令人恐懼。

In Washington and in the chip industry, almost everyone had drunk their own Kool-Aid about globalization. Newspapers and academics alike reported that globalization was in fact “global,” that technological diffusion was unstoppable, that other countries’ advancing technological capabilities were in the U.S. interest, and that even if they weren’t, nothing could halt technological progress. “Unilateral action is increasingly ineffective in a world where the semiconductor industry is globalized,” the Obama administration’s semiconductor report declared. “Policy can, in principle, slow the diffusion of technology, but it cannot stop the spread.” Neither of these claims was backed by evidence; they were simply assumed to be true. However, “globalization” of chip fabrication hadn’t occurred; “Taiwanization” had. Technology hadn’t diffused. It was monopolized by a handful of irreplaceable companies. American tech policy was held hostage to banalities about globalization that were easily seen to be false.

在华盛顿和芯片行业中，几乎所有人都对全球化饮了自己的果汁。报纸和学者们一致报道说全球化实际上是“全球性的”，技术扩散是不可阻挡的，其他国家先进的技术能力符合美国的利益，即使不符合也无

法阻止技术进步。奥巴马政府的半导体报告宣称："在半导体工业全球化的环境下，单边行动日益无效。""政策原则上可以减缓技术传播的速度，但无法阻止其传播。"这两个说法都没有依据，它们只是被认为是真实的。然而，芯片制造的"全球化"并没有发生；"台湾化"正在进行中。技术并没有扩散，它被几家不可替代的公司垄断了。美国的技术政策被平庸的全球化陈词滥调所束缚，这些陈词滥调很容易被证明是错误的。

America's technological lead in fabrication, lithography, and other fields had dissipated because Washington convinced itself that companies should compete but that governments should simply provide a level playing field. A laissez-faire system works if every country agrees to it. Many governments, especially in Asia, were deeply involved in supporting their chip industries. However, U.S. officials found it easier to ignore other countries' efforts to grab valuable chunks of the chip industry, instead choosing to parrot platitudes about free trade and open competition. Meanwhile, America's position was eroding.

美國在製造、印刷和其他領域的技術領先地位已經消失，因為華盛頓讓自己相信公司應該競爭，但政府只應提供一個公平競爭的環境。如果每個國家都同意，自由放任的系統會奏效。許多政府，尤其是亞洲地區，深度參與支持其晶片行業。然而，美國官員發現忽略其他國家爭奪晶片產業有價值的份額似乎更容易，而選擇背誦有關自由貿易和公開競爭的陳詞濫調。與此同時，美國的地位正在被侵蝕。

In polite company in Washington and Silicon Valley, it was easier simply to repeat words like multilateralism, globalization, and innovation, concepts that were too vacuous to offend anyone in a position of power. The chip industry itself—deeply fearful of angering China or TSMC—put its considerable lobbying resources behind repeating false platitudes about how "global" the industry had become. These concepts fit naturally with the liberal internationalist ethos that guided officials of both political parties amid America's unipolar moment. Meetings with foreign companies and governments were more pleasant when everyone pretended that cooperation was win-win. So Washington kept telling itself that the U.S. was running faster, blindly ignoring the deterioration in the U.S. position, the rise in

China’s capabilities, and the staggering reliance on Taiwan and South Korea, which grew more conspicuous every year.

在華盛頓和硅谷的有禮貌的交往中，最好隨口輕輕說幾句關於多邊主義、全球化和創新這樣的空泛詞語，這些概念不會得罪任何有權勢的人。芯片行業本身對觸怒中國或台積電深感擔憂，因此它動用了大量的遊說資源，不斷重申關於行業“全球化”的虛假陳腔濫調。這些概念自然符合自由主義國際主義的精神，該精神指導著兩個政黨的官員在美國的單極時期。在外國公司和政府的會議上，當每個人都假裝合作是雙贏時，氛圍更加愉快。因此，華盛頓一直在對自己說，美國跑得更快，盲目忽略了美國地位的惡化、中國能力的崛起以及對台灣和韓國的驚人依賴，這種依賴每年都越來越明顯。

Deep in the U.S. government, however, the national security bureaucracy was coming to adopt a different view. This part of the government is paid to be paranoid, so it’s no surprise security officials viewed China’s tech industry more skeptically and its government more cynically. Many officials worried that China’s leverage over the world’s critical technology systems was growing. They also presumed China would use its position as the world’s key manufacturer of electronics to insert back doors and to spy more effectively, just as the U.S. had done for decades. Pentagon officials devising weapons of the future began to realize how reliant they’d be on semiconductors. Officials focused on telecom infrastructure, meanwhile, worried that U.S. allies were buying less telecom equipment from Europe and the U.S. and more from Chinese firms like ZTE and Huawei.

然而，在美国政府深层的国家安全机构中，却采取了不同的看法。这部分政府的职责就是要做到极度警惕，所以安全官员更加怀疑中国的科技产业，并对其政府持更加愤世嫉俗的态度。许多官员担心中国对全球关键技术系统的影响力正在增长。他们也认为中国将利用其作为世界关键电子产品制造商的地位，插入后门并更有效地进行间谍活动，就像美国几十年来一直在做的那样。设计未来武器的五角大楼官员开始意识到他们对半导体的依赖程度。与此同时，关注电信基础设施的官员担心美国的盟友正在从欧洲和美国少购买电信设备，而更多地从中兴和华为这样的中国公司购买。

U.S. intelligence had voiced concerns about Huawei's alleged links to the Chinese government for many years, though it was only in the mid-2010s that the company and its smaller peer, ZTE, started attracting public attention. Both companies sold competing telecom equipment; ZTE was state-owned, while Huawei was private but was alleged by U.S. officials to have close ties with the government. Both companies had spent decades fighting allegations that they'd bribed officials in multiple countries to win contracts. And in 2016, during the final year of the Obama administration, both were accused of violating U.S. sanctions by supplying goods to Iran and North Korea.

美國情報部門多年來一直對華為涉嫌與中國政府有聯繫表示擔憂，但直到2010年代中期，這家公司及其較小的競爭對手中興開始引起公眾關注。兩家公司都出售競爭性的電信設備；中興是國有企業，而華為則是私營企業，但據美國官員指稱，華為與政府有密切關係。兩家公司都經歷了數十年的打擊指控，聲稱它們在多個國家賄賂官員以贏得合同。在2016年，即奧巴馬政府的最後一年，兩家公司都被指控違反美國的制裁法，向伊朗和北韓提供商品。

The Obama administration considered imposing financial sanctions on ZTE, which would have severed the company's access to the international banking system, but instead opted to punish the company in 2016 by restricting U.S. firms from selling to it. Export controls like this had previously been used mostly against military targets, to stop the transfer of technology to companies supplying components to Iran's missile program, for example. But the Commerce Department had broad authority to prohibit the export of civilian technologies, too. ZTE was highly reliant on American components in its systems—above all, American chips. However, in March 2017, before the threatened restrictions were implemented, the company signed a plea deal with the U.S. government and paid a fine, so the export restrictions were removed before they'd taken force. Hardly anyone understood just how drastic a move it would have been to ban a major Chinese tech company from buying U.S. chips.

奧巴馬政府曾考慮對中興通訊實行財政制裁，該措施會使該公司失去國際銀行系統的接入，但最終選擇於2016年對其實施懲罰，限制美國企業向其銷售。像這樣的出口管制措施以前主要用於軍事目標，例

如，阻止向供應伊朗導彈計劃零件的公司轉移技術。但商務部有廣泛的權力，可以禁止出口民用技術。中興通訊的系統高度依賴美國元件——特別是美国芯片。然而，在威脅實施限制之前的2017年3月，該公司與美國政府達成了認罪協議，支付了一筆罰款，因此出口限制在生效前就被撤銷了。幾乎沒有人了解禁止一家重要的中國科技公司購買美國芯片會帶來多麼嚴重的影響。

ZTE’s plea deal was signed just as the Trump administration took office. Trump repeatedly attacked China for “ripping us off,” but he had little interest in policy details and none in technology. His focus was on trade and tariffs, where his officials like Peter Navarro and Robert Lighthizer tried and mostly failed to reduce the bilateral trade deficit and slow offshoring. Far from the political limelight, however, on the National Security Council, a handful of discreet officials led by Matt Pottinger, a former journalist and Marine, who eventually rose to become Trump’s deputy national security advisor, were transforming America’s policy toward China, casting off several decades of technology policy in the process. Rather than tariffs, the China hawks on the NSC were fixated on Beijing’s geopolitical agenda and its technological foundation. They thought America’s position had weakened dangerously and Washington’s inaction was to blame. “This is really important,” one Trump appointee reported an Obama official telling him during the presidential transition, regarding China’s technological advances, “but there’s nothing you can do.”

ZTE的辩护协议是在特朗普政府上任之际签署的。特朗普多次攻击中国“诈骗”美国，但他对政策细节几乎没有兴趣，对技术更是毫不关心。他的重点是贸易和关税，他的官员Peter Navarro和Robert Lighthizer试图并大多失败地减少双边贸易逆差和减缓离岸外包。然而，在政治聚光灯之外，国家安全委员会(NSC)的一小撮谨慎官员由一位前记者和海军陆战队员Matt Pottinger领导，他最终晋升为特朗普的副国家安全顾问，正在转变美国对华政策，在此过程中，抛弃了几十年的技术政策。与关税不同，NSC的中国鹰派专注于北京的地缘政治议程和其技术基础。他们认为美国的地位已经危险地削弱，而华盛顿的不作为是归咎于此。“这真的很重要，”特朗普任命的一名官员在总统过渡期间向一名奥巴马官员报告说，关于中国的技术进步，“但你无能为力。”

The new administration's China team didn't agree. They concluded, as one senior official put it, " that everything we're competing on in the twenty-first century… all of it rests on the cornerstone of semiconductor mastery." Inaction wasn't a viable option, they believed. Nor was "running faster"—which they saw as code for inaction. "It would be great for us to run faster," one NSC official put it, but the strategy didn't work because of China's "enormous leverage in forcing the turnover of technology." The new NSC adopted a much more combative, zero-sum approach to technology policy. From the officials in the Treasury Department's investment screening unit to those managing the Pentagon's supply chains for military systems, key elements of the government began focusing on semiconductors as part of their strategy for dealing with China.

新政府的中国团队并不同意。他们得出结论，正如一名高级官员所说，"我们在21世纪所竞争的一切……全部建立在半导体掌握的基础之上。"他们认为无所作为是不可行的，跑得更快也不行，他们把这看作是无所作为的密码。一个国家安全委员会官员说："对我们来说跑得更快会很好，但这个策略不可行，因为中国在迫使技术转让方面有着巨大的影响力。"新的国家安全委员会采取了更具有攻击性、零和博弈的技术政策。从财政部投资筛查部门的官员到管理五角大楼军事系统供应链的官员，政府的关键部门开始将半导体作为应对中国的战略的一部分。

This made the semiconductor industry's leaders deeply uncomfortable. They wanted the government's help but feared Chinese retaliation. The chip industry would happily accept lower taxes or reduced regulation, both of which would make doing business in the U.S. more attractive, but it didn't want to have to change its multinational business model. It didn't help matters that many in Silicon Valley detested Trump. Intel's CEO Brian Krzanich faced a backlash after agreeing to hold a fundraiser for Trump when he was a candidate. Then, after joining an advisory council convened by the White House, Krzanich later resigned from it. Even when industry executives overlooked Trump's domestic policies, his volatility made him a problematic ally. Announcing tariffs via tweet was never a tactic that would impress CEOs.

這件事情讓半導體行業領袖感到相當不安。他們希望政府提供幫助，但同時也擔憂中國會報復。晶片行業可以接受降低稅收或減少監管，這兩者都可以讓在美國開展業務更具吸引力，但他們不想改變多國企業的商業模式。許多硅谷人嫌惡特朗普，也沒有幫助這種情況。英特爾公司的CEO布萊恩·克扎尼奇在特朗普競選期間同意為他舉辦一次籌款活動，遭到了反感。然後，加入白宮召開的一個顧問委員會後，克扎尼奇後來又辭去了該職位。即使業界高管無視了特朗普的國內政策，他的不穩定性也使他成為一個有問題的盟友。通過推特宣布關稅決定從來都不是一種讓CEO們印象深刻的策略。

However, the messages coming from the chip industry weren't any more coherent than the contradictory leaks from the Trump White House. Publicly, semiconductor CEOs and their lobbyists urged the new administration to work with China and encourage it to comply with trade agreements. Privately, they admitted this strategy was hopeless and feared that state-supported Chinese competitors would grab market share at their expense. The entire chip industry depended on sales to China—be it chipmakers like Intel, fabless designers like Qualcomm, or equipment manufacturers like Applied Materials. One U.S. semiconductor executive wryly summed things up to a White House official: "Our fundamental problem is that our number one customer is our number one competitor."

然而，芯片行业传达的信息和特朗普白宫的矛盾泄露一样不连贯。公开地，半导体首席执行官和他们的说客敦促新政府与中国合作，并鼓励其遵守贸易协定。私下里，他们承认这种战略是没有希望的，并担心国家支持的中国竞争对手会以他们的损失抢占市场份额。整个芯片行业都依赖于对中国的销售，无论是像英特尔这样的芯片制造商，还是像高通这样的无厂商设计师，或者是像应用材料这样的设备制造商。一位美国半导体高管嘲讽地向白宫官员总结了问题："我们的根本问题是，我们的头号客户是我们的头号竞争对手。"

The China hawks on the National Security Council concluded that America's semiconductor industry needed to be saved from itself. Left to the whim of their shareholders and to market forces, chip firms would slowly transfer staff, technology, and intellectual property to China until Silicon Valley was hollowed out. The U.S. needed a stronger export control regime, the China hawks believed. They thought Washington's discussion about export controls had been hijacked by the industry, letting Chinese firms acquire too much advanced chipmaking design and machinery. Administration officials cited the revolving door between the Commerce Department and law firms who worked for the chip industry and lobbied against export controls, though these officials were also among the few people in the government who understood the complexity of semiconductor supply chains. Because of this revolving door, Trump administration officials believed, regulations allowed too much technological leakage, weakening America's position relative to China.

国家安全委员会的中国鹰派认为，美国半导体产业需要拯救自己。如果完全随股东和市场力量的意愿行事，芯片公司将逐渐将员工、技术和知识产权转移到中国，直到硅谷成为一个空壳。中国鹰派认为，美国需要一个更强大的出口管制制度。他们认为，华盛顿关于出口管制的讨论已经被业界劫持，导致中国公司获取了过多的先进芯片制造设计和设备。尽管这些官员也是少数几个理解半导体供应链复杂性的人员，但他们引用了商务部和代表芯片行业的律师之间的"旋转门"，并游说反对出口管制的做法。特朗普政府的官员们认为，由于这种"旋转门"，法规允许了太多的技术泄漏，削弱了美国相对于中国的地位。

Amid the fire and fury of President Trump's Twitter feed, most people barely noticed how different parts of the government—from Congress to the Commerce Department, from the White House to the Pentagon—were refocusing on semiconductors in ways unseen in Washington since the late 1980s. Media attention focused on Trump's "trade war" with Beijing and his tariff hikes, carefully announced to maximize media attention. Among the many products that Trump imposed tariffs on were chips, causing some analysts to see semiconductors as mostly a trade issue. Within the government's national security bureaucracy, though, the president's tariffs and his trade war were seen as a distraction from the high-stakes technological struggle underway.

在特朗普总统的推特账户上充满火与怒的同时，大多数人没有注意到政府不同部门，从国会到商务部、从白宫到五角大楼，都在以自上世纪80年代末以来的方式重新关注半导体。媒体的关注点集中在特朗普与北京的"贸易战"和他宣布的关税上，旨在最大限度地获得媒体关注。特朗普对许多产品征收关税，其中包括芯片，使一些分析师认为

半导体主要是一个贸易问题。然而，在政府的国家安全机构中，总统的关税和贸易战被视为高风险技术斗争的分心。

In April 2018, as Trump's trade dispute with China escalated, the U.S. government concluded that ZTE had violated the terms of its plea agreement by providing false information to U.S. officials. Wilbur Ross, Trump's commerce secretary, took it "very personally," according to one aide, since he'd played a role in negotiating the deal with ZTE the previous year. The Commerce Department began reimposing the restrictions on U.S. firms' ability to sell to ZTE, a decision that moved through the bureaucracy "almost without anyone knowing," according to one participant. When the rules snapped back, ZTE was again cut off from its ability to buy U.S. semiconductors, among other products. If the U.S. didn't change policy, the company would careen toward collapse.

2018年4月，特朗普与中国的贸易纠纷越发激烈，美国政府认为中兴违反了认罪协议，向美国官员提供虚假信息。特朗普的商务部长威尔伯·罗斯据一位助手称，对此"感到很个人化"，因为他曾参与上一年与中兴的协商。商务部于是开始重新实施对美国公司销售给中兴的限制，这一决定"几乎没有人知道"就已经在官僚机构中通过了，导致中兴再次无法购买美国的半导体等产品。如果美国政策没有改变，该公司将陷入崩溃。

Trump himself was more interested in trade than technology, however. He saw the potential strangulation of ZTE simply as leverage over Xi Jinping. So when the Chinese leader proposed doing a deal, Trump eagerly accepted the offer, tweeting that he'd find a way to keep ZTE in business out of concern for the company "losing too many jobs in China." Soon ZTE agreed to pay another fine in exchange for regaining access to U.S. suppliers. Trump thought he'd gained leverage in the trade war, though this proved illusory. Washington's China hawks thought he'd been duped by officials like Treasury Secretary Steven Mnuchin, who repeatedly urged Trump to offer concessions to Beijing. What the ZTE saga showed above all was the extent to which all the world's major tech firms relied on U.S. chips. Semiconductors weren't simply the "cornerstone" of "everything we're competing on," as one administration official had put it. They could also be a devastatingly powerful weapon.

特朗普本人更关心贸易而非技术。然而，他将中兴可能被扼杀的潜力仅仅看作对习近平的杠杆。所以当中国领导人提出达成交易时，特朗普急切地接受了这个提议，并发推文表示他将找到方法让中兴继续在业务上运转，因为他担心该公司“在中国失去了太多的工作机会”。很快，中兴同意再次支付罚款以恢复对美国供应商的访问。特朗普认为他在贸易战中获得了优势，尽管这被证明是虚幻的。美国的中国鹰派认为，他被像财政部长史蒂芬·姆努钦这样的官员所欺骗，这些官员一再敦促特朗普对北京作出让步。中兴玄幻剧最重要的一点是，所有世界主要的科技公司都依赖美国芯片。半导体并不仅仅是正如一位政府官员所说的“我们所在的所有领域的‘基石’”。它们还可以成为毁灭性的有力武器。

CHAPTER 50 Fujian Jinhua

" C lear computer data," Kenny Wang typed into Google, searching for a program to cover his tracks as he downloaded confidential files from Micron's network. Unsatisfied with Google's results, he tried a different search. "Clear computer use records," he entered. Eventually he found and ran a program called CCleaner, apparently trying to wipe files off his company-supplied HP laptop. This didn't stop investigators from discovering he'd downloaded nine hundred files from his employer, Micron, America's memory chip champion, which he put on a USB drive and uploaded to Google Drive. "Micron Confidential / Do Not Duplicate," the files were labeled. Wang wasn't simply duplicating files: he planned to duplicate Micron's secret recipe for cutting-edge DRAM chips, downloading files detailing Micron's chip layouts, details for how the company made masks for its lithography processes, and test and yield details—secrets that would have taken several years and hundreds of millions of dollars to replicate, Micron estimated.

肯尼·王在谷歌上键入"清除电脑数据"，搜索一个程序来掩盖他从Micron网络中下载的机密文件的踪迹。对谷歌的结果不满意，他尝试了不同的搜索。"清除电脑使用记录"，他输入。最终他找到并运行了一个叫做CCleaner的程序，试图从公司提供的惠普笔记本电脑上删除文件。这并没有阻止调查人员发现他从雇主Micron下载了900个文件，将其放在了一个USB驱动器上并上传到了谷歌云盘。"Micron Confidential / Do Not Duplicate"，这些文件被标记。王不仅仅是在复制文件：他计划复制Micron先进DRAM芯片的保密配方，下载详细说明Micron芯片布局的文件，该公司如何为其光刻过程制作掩模的细节，以及测试和产量的细节——Micron估计这些秘密需要数年时间和数亿美元才能复制。

Three companies dominate the world's market for DRAM chips today, Micron and its two Korean rivals, Samsung and SK Hynix. Taiwanese firms spent billions trying to break into the DRAM business in the 1990s and 2000s but never managed to establish profitable businesses. The DRAM market requires economies of scale, so it's difficult for small producers to be price competitive. Though Taiwan never succeeded in building a sustainable memory chip industry, both Japan and South Korea had focused on DRAM chips when they first entered the chip industry in the 1970s and 1980s. DRAM requires specialized know-how, advanced equipment, and large quantities of capital investment. Advanced equipment can generally be purchased off-the-shelf from the big American, Japanese, and Dutch toolmakers. The know-how is the hard part. When Samsung entered the business in the late 1980s, it licensed technology from Micron, opened an R&D facility in Silicon Valley, and hired dozens of American-trained PhDs. Another, faster, method for acquiring know-how is to poach employees and steal files.

如今，三家公司主宰了DRAM芯片的全球市场，其中包括美光和其两家韩国竞争对手三星和SK海力士。台湾企业曾在20世纪90年代和2000年代投入数十亿美元尝试打进DRAM业务，但从未成功建立盈利业务。DRAM市场需要规模经济，因此小型生产商很难在价格上竞争。虽然台湾从未成功建立可持续的存储芯片行业，但日本和韩国在20世纪70年代和80年代初进入芯片行业时都把重点放在DRAM芯片上。DRAM需要专业的技术知识、先进的设备和大量的资本投资。先进的设备通常可以从大型美国、日本和荷兰工具制造商那里购买到。而技术知识则是最关键的。当三星在20世纪80年代末进入业务时，它从美光获得了技术许可，开设了一个硅谷的研发设施，并雇用了数十名接受过美国培训的博士。更快捷的获得技术知识的方法是挖人和偷窃文件。

China’s Fujian Province is right across the straits from Taiwan. In the harbor of Fujian’s historic port city of Xiamen sits the Taiwanese-controlled island of Kinmen, which Mao Zedong’s armies repeatedly shelled during the tensest moments of the Cold War. The relationship between Taiwan and Fujian Province is close but not always friendly. Yet when the government of Fujian Province decided to open a DRAM chipmaker called Jinhua and provided it with over $5 billion in government funding, Jinhua wagered that a partnership with Taiwan was its best path to success. Taiwan didn’t have any leading memory chip companies, but it did have DRAM facilities, which Micron had purchased in 2013.

中國福建省位於臺灣海峽對岸。在福建省的歷史港口城市廈門的海港中，坐落著由臺灣控制的金門島，這個島嶼在冷戰時期最緊張的時刻，曾多次遭到毛澤東的軍隊轟炸。臺灣和福建省之間的關係密切，但不總是友好的。然而，當福建省政府決定開設一家名為晉華的DRAM晶片制造商並提供超過50億美元的政府資金支持時，晉華打賭與臺灣合作是其實現成功的最佳途徑。臺灣沒有領先的記憶體晶片公司，但是它確實擁有DRAM設施，這些設施是美光在2013年購買的。

Micron wasn’t going to provide any help to Jinhua, which it saw as a dangerous competitor. If Jinhua could ever learn to master DRAM technology, the massive government subsidies it received would provide a major competitive advantage, letting it flood the DRAM market with cheap chips, reducing profit margins at Micron, Samsung, and Hynix. The big three DRAM firms had spent decades investing in ultra-specialized technology processes, which not only created the most advanced memory chips on earth, but also had produced a regular cadence of improvements and cost reductions. Their expertise was defended by patents, but even more important was the know-how that only their engineers had.

美光并不打算向晋华提供任何帮助，因为它被视为一个危险的竞争对手。如果晋华能够掌握DRAM技术，那么它获得的巨额政府补贴将提供重要的竞争优势，让它用廉价芯片淹没DRAM市场，降低美光、三星和现代的利润率。这三大DRAM公司已经投资了几十年的超专业技术工艺，不仅创造了世界上最先进的存储芯片，而且还产生了定期的改进和成本降低。他们的专业知识受到专利的保护，但更重要的是只有他们的工程师才有的知识。

To compete, Jinhua had to acquire this manufacturing know-how by means fair or foul. There’s a long history in the chip industry of acquiring rivals’ technology, dating back to the string of allegations about Japanese intellectual property theft in the 1980s. Jinhua’s technique, however, was closer to the KGB’s Directorate T. First, Jinhua cut a deal with Taiwan’s UMC, which fabricated logic chips (not memory chips), whereby UMC would receive around $700 million in exchange for providing expertise in producing DRAM. Licensing agreements are common in the semiconductor industry, but this agreement had a twist. UMC was promising to provide DRAM technology, but it wasn’t in the DRAM business. So in September 2015, UMC hired multiple employees from Micron's facility in Taiwan, starting with the president, Steven Chen, who was put in charge of developing UMC's DRAM technology and managing its relationship with Jinhua. The next month, UMC hired a process manager at Micron's Taiwan facility named J. T. Ho. Over the subsequent year, Ho received a series of documents from his former Micron colleague, Kenny Wang, who was still working at the Idaho chipmaker's facility in Taiwan. Eventually, Wang left Micron to move to UMC, bringing nine hundred files uploaded to Google Drive with him.

为了竞争，金华需要通过公正或非法手段获取这种制造技术。在芯片行业存在着一长串关于日本知识产权盗窃的指控历史，此现象可以追溯到上世纪八十年代。然而，金华的技术更接近于克格勃T局。首先，金华与台湾联华电子公司达成协议，由联华制造逻辑芯片（而非存储芯片），联华将获得约7亿美元的费用，以换取在制造DRAM方面提供专业知识。半导体行业普遍存在许可协议，但此协议有一个扭曲的地方。联华承诺提供DRAM技术，但它并不从事DRAM业务。因此，自2015年9月开始，联华从美光在台湾的设施中聘用了多名员工，包括总裁Steven Chen，他负责开发联华的DRAM技术并管理其与金华的关系。次月，联华聘用了美光台湾工厂的工艺经理J.T.Ho。在随后的一年中，Ho接到了他在美光的前同事Kenny Wang发来的一系列文件。最终，Wang离开美光，加入联华，并将上传到Google Drive的九百个文件带来了。

Taiwanese prosecutors were notified by Micron of the conspiracy and started gathering evidence by tapping Wang's phone. They soon accumulated enough evidence to bring charges against UMC, which had since filed for patents on some of the technology it stole from Micron. When Micron sued UMC and Jinhua for violating its patents, they countersued in China's Fujian Province. A Fujian court ruled that Micron was responsible for violating UMC and Jinhua's patents—patents that had been filed using material stolen from Micron. To "remedy" the situation, Fuzhou Intermediate People's Court banned Micron from selling twenty-six products in China, the company's biggest market.

台灣的檢察官在美光通報陰謀後，透過竊聽王雪紅的電話蒐集證據。他們很快就累積了足夠的證據對聯電提出控訴，聯電後來還申請了一些他們從美光竊取的技術專利。當美光控告聯電和晶華侵犯其專利

時，他們在中國福建省提起反訴。福建一家法院裁定，美光對聯電和晶華的專利構成侵犯，而這些專利是使用從美光盜竊而來的材料申請的。為了"紓解"這種情況，福州中級人民法院禁止美光在中國銷售其二十六種產品，這是該公司最大的市場。

This was a perfect case study of the state-backed intellectual property theft foreign companies operating in China had long complained of. The Taiwanese naturally understood why the Chinese preferred not to abide by intellectual property rules, of course. When Texas Instruments first arrived in Taiwan in the 1960s, Minister K. T. Li had sneered that "intellectual property rights are how imperialists bully backward countries." Yet Taiwan had concluded it was better to respect intellectual property norms, especially as its companies began developing their own technologies and had their own patents to defend. Many intellectual property experts predicted that China would soon begin stealing less IP as its companies produced more sophisticated goods. However, the evidence for this thesis was mixed. Efforts by the Obama administration to cut a deal with China's spy agencies whereby they agreed to stop providing stolen secrets to Chinese companies lasted only long enough for Americans to forget about the issue, at which point the hacking promptly restarted.

這是一個完美的案例，說明中國國家支持的知識產權盜竊是外國公司長期抱怨的問題。台灣人自然明白中國人為什麼不想遵守知識產權規則。當得克薩斯儀器公司在1960年代首次來臺灣時，李國鼎部長曾嘲笑說："知識產權就是帝國主義者欺負落後國家的手段。"然而台灣已經得出結論，即遵守知識產權規範是更好的選擇，特別是在它的公司開始開發自己的技術並擁有自己的專利時。許多知識產權專家預測中國將很快開始盜竊更少的知識產權，因為其企業正在生產更複雜的產品。然而，這個論點的證據並不一致。奧巴馬政府努力與中國的間諜機構達成協議，同意不再向中國企業提供偷來的秘密，這種協議只持續了足夠長的時間，讓美國人忘記這個問題，隨即黑客攻擊便重新開始了。

Micron had little reason to expect a fair trial in China. Winning court cases in Taiwan or California meant little when kangaroo courts in Fujian could lock the company out of its biggest market. Around the same time, Veeco, an American producer of semiconductor manufacturing equipment, had launched an intellectual property suit in U.S. courts against a Chinese competitor, AMEC, which countersued in a Fujian provincial court—the same province where Micron's competitor was located. A New York judge issued a preliminary injunction in Veeco's favor. The Fujian court retaliated with a preliminary injunction of its own, banning Veeco from importing machinery to China, a move that occurs in only 0.01 percent of Chinese patent cases, according to research by Berkeley professor Mark Cohen, an expert on Chinese law. Whereas the U.S. court case took months, the Fujian court reached its decision in just nine business days. The ruling itself is still secret.

美光在中國沒有理由指望一場公正的審判。在台灣或加利福尼亞州贏得法庭訴訟對福建的袋鼠法庭把公司排除於其最大市場帶來的影響微乎其微。同時，半導體製造設備美國生產商Veeco在美國法院對中國競爭對手AMEC提起知識產權訴訟，對方在福建省法院反訴，而福建省恰好是美光的競爭對手所在地。一名紐約法官對Veeco利益發出初步禁令。福建法院進行報復性反擊，發佈其自己的初步禁令，禁止Veeco進口機器到中國，根據加州大學柏克萊分校教授Mark Cohen對中國法律的專業診斷，這種情況在中國專利案件中僅發生了0.01％。而美國法院需要幾個月的時間，福建法院只用了九個工作日便作出了裁決。裁決本身仍然保密。

Micron seemed set to face a similar fate. With Micron's secrets at Jinhua's disposal, some analysts thought it would only be a few years before Jinhua was producing DRAM chips at scale—at which point it wouldn't matter if Micron was let back into the Chinese market, because Jinhua would be producing chips using Micron's technology and selling them at subsidized prices. Had this occurred during the Obama administration, the case would have resulted in stern statements but little else. American CEOs, knowing they couldn't count on serious U.S. government backing, would have tried to cut a deal with Beijing, surrendering their intellectual property in hopes of regaining access to the Chinese market. Jinhua, knowing to expect nothing worse than an angry press release, would have squeezed the company as hard as it could. Other foreign firms would have stayed quiet even though they knew they could be next.

美光似乎注定要面临同样的命运。有了锦华掌握的美光机密，一些分析师认为，只需几年时间，锦华就能规模化生产DRAM芯片，届时，

即使美光被允许重新进入中国市场，也没有关系，因为锦华将使用美光的技术生产芯片并以补贴价格销售。 如果这发生在奥巴马政府期间，该案件只会导致严厉声明而已。美国首席执行官知道他们无法依靠美国政府的严肃支持，他们会试图与北京达成协议，放弃知识产权，以期重新获得进入中国市场的机会。 锦华知道除了一份愤怒的新闻稿外不会有更严厉的处罚，因此会尽其所能挤压公司。 其他外国企业虽然知道下一个可能是他们，但他们仍然保持沉默。

The China hawks on the NSC were determined to change this dynamic. They saw the Micron case as the type of unfair trade that Trump had promised to fix, even though the president himself displayed no particular interest in Micron. Some administration officials advocated imposing financial sanctions on Jinhua, using powers set out in an executive order on cyber espionage signed by President Obama in 2015, though the order hadn’t been used against a major Chinese company. After deliberating, the Trump administration decided to use the same tool it had deployed against ZTE, reasoning that it made more sense to address a trade dispute with a trade regulation. Jinhua was cut off from buying U.S. equipment for manufacturing chips.

國家安全委員會的中國鷹派決心改變這種動態。他們認為Micron案件是不公平貿易的例子，而特朗普總統對Micron並沒有顯示出特別的興趣。一些政府官員主張對晋華實施財務制裁，使用歐巴馬總統在2015年簽署的一項針對网络间谍活动的行政命令赋予的权力，尽管这项命令并未用于对抗一家重要的中国公司。在經過深思熟慮之後，特朗普政府決定使用與對待中興的相同方式對待晋華，理由是使用貿易規定處理貿易争端更加合理。晋華被切斷了購買美國芯片製造設備的渠道。

U.S. companies like Applied Materials, Lam Research, and KLA are part of a small oligopoly of companies that produce irreplaceable machinery, like the tools that deposit microscopically thin layers of materials on silicon wafers or recognize nanometer-scale defects. Without this machinery—much of it still built in the U.S.—it’s impossible to produce advanced semiconductors. Only Japan has companies producing some comparable machinery, so if Tokyo and Washington agreed, they could make it impossible for any firm, in any country, to make advanced chips. After detailed consultations with officials at Japan's powerful Ministry of Economics, Trade, and Industry, the Trump administration was confident Tokyo supported a tough move against Jinhua and would ensure Japanese companies didn't undercut American restrictions on the firm. This gave the U.S. a powerful new tool to put out of business any chipmaker, anywhere in the world. Some of the doves in the Trump administration, like Treasury Secretary Mnuchin, were nervous. But Commerce Secretary Wilbur Ross, who had the authority to impose export controls, thought "why the fuck wouldn't we use this?" according to one aide. So after Jinhua paid invoices to the U.S. firms that supplied its crucial chipmaking tools, the U.S. banned their export. Within months, production at Jinhua ground to a halt. China's most advanced DRAM firm was destroyed.

美國公司，如應用材料、Lam Research和KLA，是生產不可替代的機器的小寡頭公司之一，這些機器能在矽晶圓上沉積微觀薄層材料或識別納米級缺陷。如果沒有這些機器——其中多數仍在美國建造——就不可能生產先進的半導體。只有日本有公司生產一些可比機器，因此如果東京和華盛頓同意，他們可以讓任何國家的公司都無法生產先進的芯片。在與日本強大的經濟產業省官員進行了詳細諮詢後，特朗普政府確信東京支持對錦華實施嚴厲行動，並確保日本企業不會削弱對這家公司的美國限制。這為美國提供了一個強大的新工具，可以將全球任何芯片製造商關閉。特朗普政府中的一些鴿派人士，如財政部長姆努欽，感到不安。但是，有權實施出口管制的商務部長威爾伯·羅斯認為，"為什麼我們不使用這個呢？"一位助手說。因此，在錦華支付了提供其關鍵芯片製造工具的美國公司發票之後，美國禁止了它們的出口。幾個月後，錦華的生產停滯不前。中國最先進的DRAM公司被摧毀了。

CHAPTER 51 The Assault on Huawei

“ I call it the spyway,” President Trump explained to the hosts of *Fox & Friends* , one of his favorite TV programs, when asked about Huawei. “We don’t want their equipment in the United States because they spy on us…. They know everything.” It was hardly a revelation that tech infrastructure could be used to pilfer confidential information. After former National Security Agency employee Edward Snowden defected to Russia in 2013 while releasing many of the agency’s most closely held secrets, news of American cyber sleuths’ capabilities were regularly discussed in the world’s newspapers. China’s impressive hacking capabilities were also well known after a string of high-profile breaches of ostensibly secret U.S. government data.

当被问及华为时，“我称之为间谍网，”特朗普总统向他最喜欢的电视节目“福克斯与朋友们”主持人解释道，“我们不希望他们的设备进入美国，因为他们会监视我们……他们知道一切。”这并不是一个揭示技术基础设施可能被用来窃取机密信息的新闻。在前国家安全局雇员爱德华·斯诺登在2013年叛逃到俄罗斯的同时，公布了该机构最密切保持的秘密后，美国网络侦探的能力经常在全球报纸上讨论。中国令人印象深刻的黑客能力也是众所周知的，尤其在一系列高调的攻击看似机密的美国政府数据后。

Within the Pentagon and the NSC, Huawei was seen less as an espionage challenge—though U.S. officials had little doubt the company would support Chinese spycraft—than as the first battle in a long struggle for technological dominance. Matt Turpin, a Pentagon official who’d worked on the military’s new offset strategy, saw Huawei as symptomatic of a broader problem in the U.S. tech industry: Chinese firms “were effectively inside the system with the United States,” given that they designed chips with U.S. software, produced them using U.S. machinery, and often plugged them into devices built for American consumers. Given this, it was impossible “for the United States to ‘out-innovate’ China and then deny them the fruits of that innovation.” Huawei and other Chinese firms were assuming central roles in tech subsectors that the U.S. thought it needed to dominate to retain a technological advantage over China, militarily and strategically. “Huawei became really a proxy for everything we had done wrong with our tech competition with China,” another senior Trump administration official put it.

在五角大楼和国家安全委员会内部，华为被视为一场长期争夺技术主导权的第一次战斗，而不是间谍活动的挑战——尽管美国官员毫不怀疑该公司将支持中国间谍活动。曾参与军方新的抵消战略的五角大楼官员马特·特尔平认为，华为是美国科技产业面临的更大问题的典型表现：中国企业“在实际上已经进入美国体系内”，因为它们使用美国软件设计芯片、使用美国机器生产芯片，并经常将其插入为美国消费者建造的设备中。鉴于此，美国“不可能赶超中国再否认他们从中获得的成果”。华为和其他中国企业正在承担起美国认为需要主导的科技子领域的核心角色，以在军事和战略上保持对中国的技术优势。“华为实际上成为了我们在与中国的科技竞争中犯下的所有错误的代理人，”另一位高级特朗普政府官员说。

Concern about Huawei wasn’t confined to the Trump administration or the United States. Australia had banned Huawei from 5G networks after its security services concluded the risk simply couldn’t be mitigated, even if Huawei turned over access to all its software source code and hardware. Australian prime minister Malcolm Turnbull had at first been skeptical of an outright ban. According to Australian journalist Peter Hartcher, Turnbull bought himself a 474-page-book titled *A Comprehensive Guide to 5G Security* to study the topic so that he could ask better questions of his tech experts. Eventually he was convinced he had no choice but to ban the firm. Australia became the first country to formally cut Huawei’s equipment from its 5G networks, a decision that was soon followed by Japan, New Zealand, and others.

对于华为的担忧不仅仅局限于特朗普政府或美国。在澳大利亚，安全机构得出结论，即使华为交出所有软件源代码和硬件访问权限，风险也无法降低，因此禁止华为参与5G网络。最初，澳大利亚总理马尔科姆·特恩布尔对于彻底禁止持怀疑态度。据澳大利亚记者彼得·哈切尔称，特恩布尔买了一本名为《5G安全综合指南》的474页书来学习这个话题，以便更好地向技术专家提问。最终，他相信自己别无选择，只能禁止这家公司。澳大利亚成为第一个正式从其5G网络中剔除华为设备的国家，这一决定很快被日本、新西兰和其他国家追随。

Not every country had the same threat assessment. Many of China's neighbors were skeptical of the company and unwilling to take risks with network security. In Europe, by contrast, several traditional American allies looked warily at the Trump administration's pressure campaign to convince them to ban Huawei. Some close American allies in Eastern Europe openly banned the company, like Poland, which also in 2019 arrested a former company executive on espionage charges. France also quietly imposed strict restrictions. Other big European countries tried to find a middle ground. Germany, which exports large quantities of cars and machinery to China, was warned by the Chinese ambassador of "consequences" if it banned Huawei. "The Chinese government will not stand idly by," the Chinese diplomat threatened.

不是每个国家都有相同的威胁评估。中国的许多邻国对该公司持怀疑态度，并不愿冒网络安全风险。相比之下，欧洲有几个传统的美国盟友对特朗普政府的压力活动持谨慎态度，试图说服他们禁止华为。一些美国的亲密盟友在东欧公开禁止了该公司，例如波兰，在2019年还因间谍指控逮捕了一名前公司高管。法国也悄悄地实施了严格的限制。其他大型欧洲国家试图找到一个平衡点。德国向中国出口大量汽车和机械，在禁止华为方面受到了中国大使的警告，如果禁止华为，将会带来"后果"。这位中国外交官威胁说，"中国政府不会袖手旁观"。

Ultimately the Trump administration expected pushback from Germany, which it saw as a free-riding ally on a range of issues. The bigger surprise was Britain, which despite its "special relationship" with the United States was spurning U.S. requests to ban Huawei from the UK's 5G networks and, instead, buy equipment from alternative suppliers like Sweden's Ericsson or Finland's Nokia. In 2019, the UK government's National Cyber Security Centre concluded the risk of Huawei systems could be managed without a ban.

特朗普政府最终预料到德国会反对，因为它认为德国是在多个问题上的一个懒散的盟友。更令人惊讶的是英国，尽管与美国有着"特殊关系"，却拒绝了美国要求禁止华为进入英国5G网络并改为从其他供应商（如瑞典的爱立信或芬兰的诺基亚）购买设备的请求。2019年，英

国政府的国家网络安全中心得出结论，华为系统的风险可以在没有禁令的情况下得到控制。

Why did Australian and British cybersecurity experts differ in their assessment of Huawei risk? There's no evidence of technical disagreements. UK regulators were quite critical of deficiencies in Huawei's cybersecurity practices, for example. The debate was really about whether China should be stopped from playing an ever-larger role in the world's tech infrastructure. Robert Hannigan, former head of the UK's signals intelligence agency, argued that "we should accept that China will be a global tech power in the future and start managing the risk now, rather than pretending the west can sit out China's technological rise." Many Europeans also thought China's technological advance was inevitable and therefore not worth trying to stop.

为什么澳大利亚和英国的网络安全专家在评估华为风险时存在差异？没有技术上的分歧证据。例如，英国监管机构对华为的网络安全实践存在不足进行了相当严厉的批评。真正的争议在于是否应该阻止中国在全球技术基础设施中扮演越来越重要的角色。英国信号情报机构的前负责人罗伯特·汉尼根认为，"我们应该接受中国在未来将成为全球科技强国，并开始管理风险，而不是假装西方可以对中国技术崛起置身事外。"许多欧洲人也认为中国的技术进步是不可避免的，因此不值得试图阻止。

The United States government didn't agree. The issue with Huawei went far beyond the debate over whether the company helped tap phones or pilfer data. Huawei executives' admission that they'd violated U.S. sanctions on Iran angered many in Washington but was ultimately a sideshow. The real issue was that a company in the People's Republic of China had marched up the technology ladder—from, in the late 1980s, simple phone switches to, by the late 2010s, the most advanced telecom and networking gear. Its annual R&D spending now rivaled American tech giants like Microsoft, Google, and Intel. Of all China's tech firms, it was the most successful exporter, giving it detailed knowledge of foreign markets. It not only produced hardware for cell towers, it also designed cutting-edge smartphone chips. It had become TSMC's second biggest customer, behind only Apple. The pressing question was: Could the United States let a Chinese company like this succeed?

美國政府不同意。華為的問題遠遠超出了公司是否幫助竊聽電話或窺探數據的爭論。華為高管承認違反美國對伊朗的制裁激怒了華盛頓的許多人，但這最終只是次要問題。真正的問題是，來自中華人民共和國的一家公司已經走上了技術之路 - 從晚1980年代的簡單電話交換開始到晚2010年代的最先進的通信和網絡設備。它的年度研發開支現在與微軟、谷歌和英特爾等美國科技巨頭相媲美。在中國的所有科技公司中，它是最成功的出口商，因此對外國市場有著詳細的了解。它不僅生產塔式基站硬件，還設計尖端的智能手機芯片。它已成為TSMC的第二大客戶，僅次於蘋果公司。迫切的問題是：美國能讓這樣一家中國公司成功嗎？

Questions like this made many people in Washington uncomfortable. For a generation, America’s elite had welcomed and enabled China’s economic rise. The United States had also encouraged technology companies across Asia, providing market access to Japanese firms like Sony during the years of Japan’s rapid growth and doing the same for South Korea’s Samsung several decades later. Huawei’s business model wasn’t much different from that of Sony or Samsung when they first won a major position in the world’s tech ecosystem. Wasn’t a bit more competition a good thing?

像这样的问题让华盛顿许多人感到不舒服。几十年来，美国的精英们一直欢迎并支持中国经济的崛起。美国还鼓励亚洲各地的科技公司，为日本索尼等公司提供市场准入，对韩国三星公司在几十年后也是如此。华为的商业模式与索尼或三星在首次在世界科技生态系统中赢得重要地位时并没有太大的区别。难道更多的竞争不是一件好事吗？

On the National Security Council, however, competition with China was now seen primarily in zero-sum terms. These officials interpreted Huawei not as a commercial challenge but as a strategic one. Sony and Samsung were tech firms based in countries that were allied with the U.S. Huawei was a national champion of America’s primary geopolitical rival. Viewed through this lens, Huawei’s expansion was a threat. Congress wanted a tougher, more combative policy, too. “The United States needs to strangle Huawei,” Republican senator Ben Sasse declared in 2020. “Modern wars are fought with semiconductors and we were letting Huawei use our American designs.”

然而，在国家安全委员会，与中国的竞争现在主要被视为零和博弈。这些官员将华为解读为战略挑战，而非商业挑战。索尼和三星是总部位于与美国结盟的国家的技术公司。华为是美国主要地缘政治对手的国家冠军。从这个角度来看，华为的扩张是一种威胁。国会也希望出台更强硬、更有进攻性的政策。共和党参议员本·萨斯在2020年宣称："美国需要扼杀华为。现代战争是通过半导体进行的，我们让华为使用了我们的美国设计。"

The point was less that Huawei was directly supporting China's military than that the company was advancing China's overall level of chip design and microelectronics know-how. The more advanced electronics the country produced, the more cutting-edge chips it would buy, and the more the world's semiconductor ecosystem would rely on China, at the expense of the United States. Moreover, targeting China's highest-profile tech firm would send a message worldwide, warning other countries to prepare to take sides. Hobbling Huawei's rise became a fixation of the administration.

重點不在於華為是否直接支持中國的軍事，而在於該公司推進了中國整體芯片設計和微電子知識水平的提高。國家生產的電子元件越先進，就會購買越先進的芯片，世界半導體生態系統更依賴中國，而美國將付出代價。此外，瞄準中國最高檔的科技公司會向全世界發出一個信息，警告其他國家準備站在哪一邊。削弱華為的崛起成為該政府的固著點。

When the Trump administration first decided to turn up its pressure on Huawei, it prohibited the sale of U.S.-made chips to the company. This restriction alone was devastating, given that Intel chips are ubiquitous and many other U.S. companies manufacture all-but-irreplaceable analog chips. Yet after decades of offshoring, far less of the semiconductor production process took place in the United States than previously. For example, Huawei produced the chips that it designed not in the U.S.—which lacked facilities capable of building advanced smartphone processors—but at Taiwan's TSMC. Restricting the export of U.S.-made goods to Huawei would do nothing to stop TSMC from fabricating advanced chips for Huawei.

當特朗普政府首次決定對華為施加壓力時，禁止向該公司出售美國製造的芯片。這個限制本身已經非常嚴重，因為英特爾芯片普及而且許多其他美國公司製造了幾乎無法替代的模擬芯片。然而，在數十年的外包之後，半導體生產過程在美國的比例比以前要少得多。例如，華為設計的芯片在不具備建造先進智能手機處理器的美國境內並不生產，而是在臺灣的TSMC生產。限制向華為出口美國製造的商品並不會阻止TSMC為華為製造先進的芯片。

One might have expected the offshoring of chipmaking to have reduced the U.S. government's ability to restrict access to advanced chip fabrication. It would certainly have been easier to cut off Huawei if all the world's advanced chipmaking was still based on U.S. soil. However, the U.S. still had cards to play. For example, the process of offshoring chip fabrication had coincided with a growing monopolization of chip industry choke points. Nearly every chip in the world uses software from at least one of three U.S.-based companies, Cadence, Synopsys, and Mentor (the latter of which is owned by Germany's Siemens but based in Oregon). Excluding the chips Intel builds in-house, all the most advanced logic chips are fabricated by just two companies, Samsung and TSMC, both located in countries that rely on the U.S. military for their security. Moreover, making advanced processors requires EUV lithography machines produced by just one company, the Netherlands' ASML, which in turn relies on its San Diego subsidiary, Cymer (which it purchased in 2013), to supply the irreplaceable light sources in its EUV lithography tools. It's far easier to control choke points in the chipmaking process when so many essential steps require tools, materials, or software produced by just a handful of firms. Many of these choke points remained in American hands. Those that didn't were mostly controlled by close U.S. allies.

人們可能預期晶片製造外包將會減少美國政府限制進入先進晶片製造領域的能力，如果全球所有先進晶片製造仍然基於美國境內，將可以更輕易地阻止華為進入市場。然而，美國仍然有籌碼可供運用。例如，晶片製造外包進程與晶片產業獨佔性擴大同步進行。世界各地的幾乎每個晶片都使用至少三家以美國為基地的公司之一的軟件，分別是Cadence、Synopsys和Mentor（後者由德國西門子擁有，但基於俄勒岡州）。除了英特爾公司內部建造的晶片外，所有最先進的邏輯晶片都是由兩家公司生產，分別是三星和TSMC，它們都位於依靠美國軍

事保障的國家。此外，製造先進處理器需要使用由荷蘭ASML公司生產的EUV光刻機，而ASML公司又依賴其位於聖地亞哥的子公司Cymer（該公司於2013年被收購）提供與EUV光刻技術不可替代的光源。當如此多的關鍵步驟需要僅由少數公司生產的工具、材料或軟件時，更容易控制晶片製造過程中的瓶頸。許多這些瓶頸仍然掌握在美國手中。那些沒有掌握的瓶頸大多由親密的美國盟友控制。

Around this time, two academics, Henry Farrell and Abraham Newman, noticed that international political and economic relations were increasingly impacted by what they called “weaponized interdependence.” Countries were more intwined than ever, they pointed out, but rather than defusing conflicts and encouraging cooperation, interdependence was creating new venues for competition. Networks that knit together nations had become a domain of conflict. In the financial sphere, the U.S. had weaponized other countries’ reliance on access to the banking system to punish Iran, for example. These academics worried that the U.S. government’s use of trade and capital flows as political weapons threatened globalization and risked dangerous unintended consequences. The Trump administration, by contrast, concluded it had unique power to weaponize semiconductor supply chains.

在這個時候，兩位學者亨利·法雷爾和亞伯拉罕·紐曼注意到，國際政治和經濟關係越來越受到他們所稱的“武器化相互依存”的影響。他們指出，國家之間的網絡織網關係比以往任何時候都更加緊密，但相互依存並沒有化解沖突和促進合作，而是創造了新的競爭場所。在金融領域，美國曾利用其他國家對銀行系統的依賴來懲罰伊朗。這些學者擔心，美國政府將貿易和資本流動當作政治武器使用，威脅全球化並冒險引發危險的意外後果。相比之下，特朗普政府認為自己有獨特的能力武器化半導體供應鏈。

In May 2020, the administration tightened restrictions on Huawei further. Now, the Commerce Department declared, it would “protect U.S. national security by restricting Huawei’s ability to use U.S. technology and software to design and manufacture its semiconductors abroad.” The new Commerce Department rules didn’t simply stop the sale of U.S.-produced goods to Huawei. They restricted any goods made with U.S.-produced technology from being sold to Huawei, too. In a chip industry full of choke points, this meant almost any chip. TSMC can’t fabricate advanced chips for Huawei without using U.S. manufacturing equipment. Huawei can't design chips without U.S.-produced software. Even China's most advanced foundry, SMIC, relies extensively on U.S. tools. Huawei was simply cut off from the world's entire chipmaking infrastructure, except for chips that the U.S. Commerce Department deigned to give it a special license to buy.

2020年5月，美國政府進一步收緊了對華為的限制措施。美國商務部宣布，為了「保護美國國家安全」，限制華為使用美國技術和軟件來設計和製造海外的半導體。新的商務部規定不僅停止了向華為出售美國製造的商品，還限制出售任何使用美國技術製造的商品給華為。在充滿瓶頸的晶片產業中，這幾乎意味著所有晶片都受到限制。台積電不能在不使用美國製造設備的情況下為華為製造先進的晶片。華為無法在沒有美國生產的軟件的情況下設計晶片。即使是中國最先進的晶圓廠，中芯國際，也大量依賴美國工具。因此，除了美國商務部冠以特殊許可獲得的晶片之外，華為被徹底切斷了全球晶片製造基礎設施的供應。

The world's chip industry quickly began implementing the U.S. rules. Even though the U.S. was trying to eviscerate its second-largest customer, TSMC's chairman, Mark Liu, promised not only to abide by the letter of the law but also its spirit. "This is something that can be solved not solely through the interpretation of the rules, but also has to do with the intentions of the U.S. government," he told journalists. Since then, Huawei's been forced to divest part of its smartphone business and its server business, since it can't get the necessary chips. China's rollout of its own 5G telecoms network, which was once a high-profile government priority, has been delayed due to chip shortages. After the U.S. restrictions took place, other countries, notably Britain, decided to ban Huawei, reasoning that in the absence of U.S. chips the company would struggle to service its products.

世界芯片产业迅速开始实施美国的规定。虽然美国试图削弱第二大客户，台积电董事长刘德音承诺不仅遵守法律的字面意思，而且也尊重其精神。"这不仅可以通过规定的解释解决，还必须考虑到美国政府的意图，"他告诉记者。自那时起，华为被迫出售其部分智能手机业务和服务器业务，因为它无法获得必要的芯片。中国原本备受关注的5G电信网络的推出由于芯片短缺而延迟。在美国限制实施后，其他国家，

特别是英国，决定禁止华为，理由是在没有美国芯片的情况下，该公司将难以为其产品提供服务。

The assault on Huawei was followed by blacklisting multiple other Chinese tech firms. After discussions with the United States, the Netherlands decided not to approve the sale of ASML's EUV machines to Chinese firms. Sugon, the supercomputer company that AMD described in 2017 as a "strategic partner," was blacklisted by the U.S. in 2019. So, too, was Phytium, a company that U.S. officials say has designed chips for supercomputers that were used to test hypersonic missiles, according to a report in the *Washington Post* . Phytium's chips were designed using U.S. software and produced in Taiwan at TSMC. Access to the semiconductor ecosystem of America and its allies enabled Phytium's growth. However, the company's reliance on foreign software and manufacturing left it critically vulnerable to U.S. restrictions.

对华为的攻击随后导致了对多个其他中国科技公司的黑名单制裁。在与美国的讨论后，荷兰决定不批准将ASML的EUV机器销售给中国公司。2017年，AMD曾将超级计算机公司曙光描述为“战略合作伙伴”，但它在2019年被美国列入黑名单。华盛顿邮报的一份报道称，美国官员表示，曙光设计了用于测试高超声速导弹的超级计算机芯片。曙光的芯片是使用美国软件设计并在台湾TSMC生产的。美国及其盟友的半导体生态系统对曙光的增长至关重要。然而，该公司对外国软件和制造的依赖使其极易受到美国限制的影响。

Ultimately, though, the American assault on China's tech firms has been a limited strike. Many of China's biggest tech companies, like Tencent and Alibaba, still face no specific limits on their purchases of U.S. chips or their ability to have TSMC manufacture their semiconductors. SMIC, China's most advanced producer of logic chips, faces new restrictions on its purchases of advanced chipmaking tools, but it has not been put out of business. Even Huawei is allowed to buy older semiconductors, like those used for connecting to 4G networks.

然而，美國對中國科技公司的攻擊其實是有限度的。許多中國最大的科技公司，比如騰訊和阿里巴巴，仍然沒有針對它們購買美國芯片或請TSMC製造半導體設施的具體限制。中國最先進的邏輯晶片生產商

中芯國際，雖然其購買先進芯片製造工具的限制有所升級，但並未令其倒閉。連華為也可以購買舊款半導體，比如用於連接4G網絡的那些。

Nevertheless, it's surprising that China's done nothing to retaliate against the hobbling of its most global tech firm. It has repeatedly threatened to punish U.S. tech firms but never pulled the trigger. Beijing said it was drawing up an "unreliable entity list" of foreign companies that endanger Chinese security, but it doesn't appear to have added any firms to the list. Beijing has evidently calculated that it's better to accept that Huawei will become a second-rate technology player than to hit back against the United States. The U.S., it turns out, has escalation dominance when it comes to severing supply chains. "Weaponized interdependence," one former senior official mused after the strike on Huawei. "It's a beautiful thing."

然而，令人惊讶的是，中国并没有采取任何行动来报复其最具全球影响力的科技公司受到限制。它一再威胁要惩罚美国科技公司，但从未采取行动。北京表示正在制定一份涉及危害中国安全的外国企业"不可靠实体清单"，但似乎没有将任何企业列入该清单。北京显然已经计算了，接受华为成为次一流技术公司的事实要比反击美国更好。结果证明，美国在切断供应链方面具有升级优势。"武器化依存"，一位前高官在对华为的打击之后思考道。"真是太妙了。"

CHAPTER 52 China's Sputnik Moment?

W hen the Chinese city of Wuhan locked down on January 23, 2020, amid a tsunami of cases of COVID-19, it faced some of the harshest, longest restrictions of any city at any point in the pandemic. The COVID virus and the disease it caused was still little understood. China's government had suppressed discussion of the virus until it ripped through Wuhan and was spreading across China and the world. The government belatedly shut down travel in and out of Wuhan, imposing checkpoints on the city's perimeter, shuttering businesses, and ordering almost all the city's 10 million people not to leave their apartments until the lockdown ended. Never before had such a massive metropolis simply frozen. Highways were empty, sidewalks desolate, airports and train stations closed. Except for hospitals and grocery stores, almost everything was shut.

當2020年1月23日中國城市武漢因COVID-19病例的海嘯進行封鎖時，它面臨著疫情期間任何城市所面臨的最嚴厲、最長時間的限制之一。該病毒及其引發的疾病仍並不充分了解。中國政府對病毒的討論一直被壓制，直到它席捲武漢並在中國及全世界傳播。政府遲緩地封鎖了武漢的出入境，對城市周邊實行檢查站，關閉企業，並命令幾乎所有城市的1000萬人不得離開公寓，直到封鎖解除為止。空前的大型都市從未如此冰封。高速公路空無一人，人行道荒涼，機場和火車站關閉。除了醫院和雜貨店，幾乎一切都關閉了。

Except for one facility, that is. Yangzte Memory Technologies Corporation (YMTC), based in Wuhan, is China's leading producer of NAND memory, a type of chip that's ubiquitous in consumer devices from smartphones to USB memory sticks. There are five companies that make competitive NAND chips today; none are headquartered in China. Many industry experts, however, think that of all types of chips, China's best chance at achieving world-class manufacturing capabilities is in NAND production. Tsinghua Unigroup, the semiconductor slush fund that invested in chip companies worldwide, provided YMTC with at least $24 billion in funding, alongside China's national chip fund and the provincial government.

除了一家企業以外。總部位於武漢的揚子江存儲器件科技有限公司(YMTC)是中國領先的NAND存儲器件生產商，該類晶片在從智能手機到USB存儲器的消費者設備中無處不在。目前有五家公司生產競爭性NAND晶片，但沒有一家總部位於中國。然而，許多行業專家認為，在所有晶片類型中，中國實現世界級制造能力的最佳機會在於NAND生產。清華紫光集團作為全球芯片公司的投資基金，除了中國國家芯片基金和省政府外，還為YMTC提供了至少240億美元的資金。

So great is China's government support for YMTC that even during the COVID lockdown it was allowed to keep working, according to *Nikkei Asia* , a Japanese newspaper with some of the best coverage of China's chip industry. Trains passing through Wuhan carried special passenger cars specifically for YMTC employees, letting them enter Wuhan despite the lockdown. The company was even hiring for Wuhan-based positions in late February and early March 2020, as the rest of the country remained frozen. China's leaders were willing to do almost anything in their fight against the coronavirus, but their effort to build a semiconductor industry took priority.

中國政府對YMTC的支持非常大，即使在COVID封鎖期間，該公司也被允許繼續運作。據日本報紙日經亞洲報導，該報對中國芯片行業的報導是最好的。經過武漢的火車會有特別的客車專門運輸YMTC的員工，這讓他們能夠進入封鎖區域。該公司甚至在2020年2月底到3月初招聘武漢的職位，而其他地區仍然被凍結。中國的領導人在對抗冠狀病毒的鬥爭中願意做任何事情，但他們建立半導體工業的努力是優先的。

It's commonly argued that the escalating tech competition with the United States is like a "Sputnik moment" for China's government. The allusion is to the United States' fear after the launch of Sputnik in 1957 that it was falling behind its rival, driving Washington to pour funding into science and technology. China certainly faced a Sputnik-scale shock after the U.S. banned sales of chips to firms like Huawei. Dan Wang, one of the smartest analysts of China's tech policy, has argued that American restrictions have "boosted Beijing's quest for tech dominance" by catalyzing new government policies to support the chip industry. In the absence of America's new export controls, he argues, Made in China 2025 would have ended up like China's previous industrial policy efforts, with the government wasting substantial sums of money. Thanks to U.S. pressure, China's government may provide Chinese chipmakers more support than they'd otherwise have received.

普遍认为，与美国的不断升级的技术竞争对于中国政府来说，就像是一个"斯普特尼克时刻"。这个比喻源于1957年苏联发射人造卫星后，美国担心自己正在落后其竞争对手，推动华盛顿向科学和技术注入资金。在美国禁止向华为等公司出售芯片之后，中国确实面临了一个斯普特尼克级别的冲击。中国科技政策最聪明的分析师之一丹·王认为，美国的限制措施通过催化新的政府政策来支持芯片产业，推动了北京追求技术主导地位的进程。他认为，如果没有美国的新出口管制，中国制造2025年将会像中国以前的产业政策努力一样，政府将浪费大量的资金。由于美国的压力，中国政府为中国芯片制造商提供的支持可能比他们本来会获得的更多。

The debate is about whether the U.S. should try to derail China's growing chip ecosystem—thereby spurring an inevitable counterreaction—or whether it's smarter simply to invest at home while hoping China's chip drive peters out. U.S. restrictions have certainly catalyzed a new wave of government support for Chinese chipmakers. Xi Jinping recently appointed his top economic aide, Liu He, to serve as a "chip czar," managing the country's semiconductor efforts. There's no doubt that China's spending billions to subsidize chip firms. Whether this funding produces new technology remains to be seen. For example, the city of Wuhan is home not only to YMTC, China's brightest hope for NAND chip parity, but also to the country's biggest recent semiconductor scam.

該辯論是關於美國是否應試圖阻止中國不斷增長的晶片生態系統-從而引發不可避免的反制，還是更明智的是在國內投資，希望中國的晶片驅動力量會消退。美國的限制措施無疑引發了中國晶片制造商新一波的政府支持。習近平最近任命了他的經濟副手劉鶴擔任"晶片大王"，管理該國半導體業務。毫無疑問，中國正在耗巨資補貼晶片企業。這些資金是否會帶來新技術還有待觀察。例如，武漢市不僅是中國最有希望達到NAND芯片水平的YMTC的總部，還是該國最大的近期半導體騙局發生地。

The case of Wuhan Hongxin (HSMC) shows the risk of shoveling money into semiconductors without asking enough questions. According to a Chinese media report that's since been removed from the internet, HSMC was founded by a group of scam artists who carried fake business cards that read "TSMC—Vice President" and spread rumors that their relatives were top Communist Party officials. They duped the Wuhan local government into investing in their company, then used the funds to hire as CEO TSMC's former head of R&D. With him on board, they acquired a deep-ultraviolet lithography machine from ASML, then used this feat to raise more funds from investors. But the factory in Wuhan was a shoddily built copy of an old TSMC facility; HSMC was still trying to produce its first chip when the company went bust.

武漢宏芯（HSMC）的案例表明，在向半導體投入資金之前，未提出足夠的問題可能存在風險。據一份已經從互聯網上刪除的中國媒體報導，HSMC由一群詐騙分子創立，他們攜帶假的商務名片，上面寫著"台積電 - 副總裁"，並傳播謠言稱自己的親戚是高級共產黨官員。他們欺騙了武漢當地政府投資公司，然後用這筆資金聘請了台積電的前研發負責人擔任CEO。有了他的幫助，他們從ASML購買了一台深紫外線光刻機，然後利用這個成就向投資者籌集了更多資金。但是武漢的廠房是一個劣質的複製品，模仿了一個舊的台積電設施;當公司破產時，HSMC仍在試圖生產第一個芯片。

It isn't only provincial experiments that have failed. Tsinghua Unigroup recently ran out of cash after its global acquisition spree and defaulted on some of its bonds. Even Tsinghua CEO Zhao Weiguo's top-level political connections weren't enough to save the firm, though the chip companies it owns will likely survive mostly unscathed. An official from China's government planning agency publicly lamented that the country's chip industry had "no experience, no technology, no talent." This is an overstatement, but it's clear that billions of dollars have been wasted in China on semiconductor projects that are either hopelessly unrealistic or, like HSMC, blatant frauds. If China's Sputnik moment inspires more state-backed semiconductor programs like these, the country won't be on a path to technological independence.

不僅是省級實驗失敗了，清華紫光近期在進行全球併購的過程中現金流告竭並且有債券自然災害。儘管清華總裁趙偉國具有極高的政治關係，但公司還是無法挽救。儘管其擁有的晶片公司可能幾乎完好無

損。中國政府規劃機構的一名官員公開抱怨中國的晶片行業“沒有經驗、沒有技術、沒有人才”。這並非事實，但可以看出中國在半導體項目上浪費了數十億美元，這些項目要麼是不切實際的，要麼像華航微電子一樣是顯然的欺詐。如果中國的人造衛星時刻激勵著更多的國家支持的半導體計畫，那麼這個國家就不會走向技術獨立。

In an industry with such a multinational supply chain, technological independence was always a pipe dream, even for the United States, which remains the world’s biggest semiconductor player. For China, which lacks competitive firms in many parts of the supply chain, from machinery to software, technological independence is even more difficult. For complete independence, China would need to acquire cutting-edge design software, design capabilities, advanced materials, and fabrication know-how, among other steps. China will no doubt make progress in some of these spheres, yet some are simply too expensive and too difficult for China to replicate at home.

在具有如此跨國供應鏈的產業中，技術獨立一直是一個空想，即使對於仍然是全球最大半導體玩家的美國也是如此。對於中國來說，由於缺乏供應鏈中許多部分的競爭企業，從機械到軟件的技術獨立更加困難。要實現完全獨立，中國需要掌握最先進的設計軟件、設計能力、先進材料和製造技術等方面。中國無疑會在其中一些方面取得進展，然而有些方面對中國來說太昂貴、太難以在國內複制。

Consider, for example, what it would take to replicate one of ASML’s EUV machines, which have taken nearly three decades to develop and commercialize. EUV machines have multiple components that, on their own, constitute epically complex engineering challenges. Replicating just the laser in an EUV system requires perfectly identifying and assembling 457,329 parts. A single defect could cause debilitating delays or reliability problems. No doubt the Chinese government has deployed some of its best spies to study ASML’s production processes. However, even if they’ve already hacked into the relevant systems and downloaded design specs, machinery this complex can’t simply be copied and pasted like a stolen file. Even if a spy were to gain access to specialized information, they’d need a PhD in optics or lasers to understand the science—and even still, they’d lack the three decades of experience accumulated by the engineers who've developed EUV.

舉例來說，考慮要複製一台ASML的EUV機器需要做到什麼，這種機器花費近三十年的時間進行研發和商業化。EUV機器由多個部件組成，每個部件本身都是極其複雜的工程挑戰。僅複製EUV系統中的激光器就需要完美地識別和組裝457,329個零件。一個小小的缺陷就可能導致嚴重的延遲或可靠性問題。毫無疑問，中國政府已經派遣了一些最好的間諜來研究ASML的生產工藝。然而，即使他們已經入侵了相關系統並下載了設計規格，這種複雜的機器也不能像偷來的文件一樣簡單地複製和粘貼。即使間諜獲得了專門信息的訪問權限，他們也需要有光學或激光學的博士學位才能理解科學原理，而且他們還會缺乏EUV開發工程師三十年累積的經驗。

Perhaps in a decade China *can* succeed in building its own EUV scanner. If so, the program will cost tens of billions of dollars, but—in a revelation that is bound to be discouraging—when it's ready it will no longer be cutting edge. By that time, ASML will have introduced a new generation tool, called high-aperture EUV, which is scheduled to be ready in the mid-2020s and cost $300 million per machine, twice the cost of the first generation EUV machine. Even if a future Chinese EUV scanner works just as well as ASML's current equipment—hard to imagine, given that the U.S. will try to restrict its ability to access components from other countries—Chinese chipmakers using this hypothetical alternative EUV machine will struggle to produce profitably with it, because by 2030, TSMC, Samsung, and Intel will have already used their own EUV scanners for a decade, during which time, they'll have perfected their use and paid down the cost of these tools. They'll be able to sell chips produced with EUV for far cheaper than a Chinese company using a hypothetical Chinese-built EUV tool.

也许在未来十年内，中国可以成功建造自己的EUV扫描仪。如果是这样，这项计划将耗费数百亿美元，但是令人泄气的是，当它准备好的时候，它将不再是尖端技术。到那个时候，ASML将会推出一个新一代的工具，称为高光圈EUV，计划在2020年代中期推出，每台机器成本为3亿美元，是第一代EUV机器成本的两倍。即使未来的中国EUV扫描仪与ASML当前的设备一样好，也很难想象，因为美国将试图限制它从其他国家获取零部件的能力。使用这种假想的另类EUV机器的中

国芯片制造商将难以实现盈利，因为到2030年，TSMC、三星和英特尔将已经使用他们自己的EUV扫描仪十年，而这段时间内，他们将完善其使用并偿还了这些工具的成本。他们将能够以比使用假想的中国制造的EUV工具更便宜的价格出售用EUV生产的芯片。

EUV machines are just one of many tools that are produced via multinational supply chains. Domesticating every part of the supply chain would be impossibly expensive. The global chip industry spends over $100 billion annually on capital expenditures. China would have to replicate this spending in addition to building a base of expertise and facilities that it currently lacks. Establishing a cutting-edge, all-domestic supply chain would take over a decade and cost well over a trillion dollars in that period.

歐V機器只是通過跨國供應鏈生產的眾多工具之一。國產化供應鏈的每個部分都將是極其昂貴的。全球芯片行業每年花費逾1,000億美元的資本支出。中國必須在這些支出之外再複製這種支出，並建立一個它目前缺乏的專業知識和設施基礎。建立一個領先的全國供應鏈需要十多年時間，而在此期間的成本將超過一萬億美元。

This is why, despite the rhetoric, China’s not actually pursuing an all-domestic supply chain. Beijing recognizes this is simply impossible. China would like a non-U.S. supply chain, but because of America’s heft in the chip industry and the extraterritorial power of its export regulations, a non-American supply chain is also unrealistic, except perhaps in the distant future. What is plausible is for China to reduce its reliance on the United States in certain spheres and to increase its overall weight in the chip industry, weaning itself off as many choke-point technologies as possible.

因此，儘管口號喊得震天響，中國實際上並沒有追求全國產供應鏈。北京意識到這是不可能的。中國希望形成一個非美國供應鏈，但由於美國芯片行業的影響力和其出口管制的超國界權力，除非在遙遠的未來，否則形成一個非美國供應鏈也是不現實的。可行的方法是供中國在某些領域減少對美國的依賴，並增加其在芯片行業的整體重量，最大限度地避免受到卡點技術的影響。

One of China’s core challenges today is that many chips use either the x86 architecture (for PCs and servers) or the Arm architecture (for mobile devices); x86 is dominated by two U.S. firms, Intel and AMD, while Arm, which licenses other companies to use its architecture, is based in the UK. However, there's now a new instruction set architecture called RISC-V that is open-sourced, so it's available to anyone without a fee. The idea of an open-source architecture appeals to many parts of the chip industry. Anyone who currently must pay Arm for a license would prefer a free alternative. Moreover, the risk of security defects may be lower, because the open nature of an open-source architecture like RISC-V means that more engineers will be able to verify details and identify errors. For the same reason, the pace of innovation may be faster, too. These two factors explain why DARPA has funded a variety of projects related to developing RISC-V. Chinese firms have also embraced RISC-V, because they see it as geopolitically neutral. In 2019, the RISC-V Foundation, which manages the architecture, moved from the U.S. to Switzerland for this reason. Companies like Alibaba are designing processors based on the RISC-V architecture with this in mind.

中国今天面临的一个核心挑战是许多芯片使用x86架构（用于个人电脑和服务器）或Arm架构（用于移动设备）; x86由两个美国公司，英特尔和AMD，垄断，而许可其他公司使用其架构的Arm总部位于英国。然而，现在有一种名为RISC-V的新指令集架构已经开源，因此任何人都可以免费使用。开放源代码架构的想法对芯片产业的许多部分都很吸引人。任何目前必须向Arm支付许可费的人都会更喜欢免费的替代品。此外，安全缺陷的风险可能会更低，因为RISC-V等开源架构的开放性意味着更多工程师将能够验证细节并识别错误。出于同样的原因，创新速度也可能更快。这两个因素解释了为什么DARPA资助了多个与开发RISC-V相关的项目。中国企业也拥抱RISC-V，因为他们认为它是地缘政治中立的。 2019年，管理该架构的RISC-V基金会为此原因从美国搬到了瑞士。像阿里巴巴这样的公司正在基于RISC-V架构设计处理器，考虑到这一点。

In addition to working with emerging architectures, China's also focusing on older process technology to build logic chips. Smartphones and data centers require the most cutting-edge chips, but cars and other consumer devices often use older process technology, which is sufficiently powerful and far cheaper. Most of the investment in new fabs in China, including at companies like SMIC, is in production capacity at lagging-edge nodes. SMIC has already shown that China has the workforce to produce competitive lagging-edge logic chips. Even if U.S. export restrictions get tighter, they're unlikely to prohibit the export of decades-old manufacturing equipment. China's also investing heavily in emerging semiconductor materials like silicon carbide and gallium nitride, which are unlikely to displace pure silicon in most chips but will likely play a bigger role in managing the power systems in electric vehicles. Here, too, China probably has the requisite technology, so government subsidies may help it win business on price.

除了使用新兴架构，中国也专注于使用旧的工艺技术来制造逻辑芯片。智能手机和数据中心需要最先进的芯片，但汽车和其他消费设备通常使用旧的工艺技术，这些技术足够强大且成本更低。中国在新晶圆厂的大部分投资，包括在中芯国际等公司，都是在滞后的节点上进行产能扩张。中芯国际已经表明中国有生产具有竞争力滞后逻辑芯片的劳动力。即使美国的出口限制更加严格，它们不太可能禁止出口几十年前的制造设备。中国也在投资于新兴半导体材料，如碳化硅和氮化镓，在大多数芯片中不太可能取代纯硅，但可能在电动汽车的功率系统中扮演更重要的角色。在这方面，中国可能具有必要的技术，因此政府补贴可能有助于它赢得价格战的业务。

The worry for other countries is that China's slew of subsidies will let it win market share across multiple parts of the supply chain, especially those that don't require the most advanced technologies. Barring severe new restrictions on access to foreign software and machinery, China looks likely to play a much bigger role in producing non-cutting-edge logic chips. In addition, it's pouring money into the materials needed to develop power management chips for electric vehicles. China's YMTC, meanwhile, has a real chance to win a chunk of the NAND memory market. Across the chip industry, estimates suggest that China's share of fabrication will increase from 15 percent at the start of the decade to 24 percent of global capacity by 2030, overtaking Taiwan and South Korea in terms of volume. China will almost certainly still lag technologically. But if more of the chip industry moves to China, the country will have more leverage in demanding technology transfer. It will become more costly for the U.S. and other countries to impose export restrictions, and China will have a broader pool of workers from which to draw. Almost all of China's chip firms are dependent on government support, so they're oriented toward national goals as much as commercial ones. "Making profits and going public… are not the priority” at YMTC, one executive told the *Nikkei Asia* newspaper. Instead, the company’s focused on “building the country’s own chips and realizing the Chinese dream.”

其他国家的担忧是，中国的众多补贴将让其在供应链的多个部分赢得市场份额，尤其是不需要最先进技术的部分。除非严格限制外国软件和机器的使用，否则中国很可能在生产非先进逻辑芯片方面扮演更大的角色。此外，中国正在向开发电动车所需的电源管理芯片所需的材料投入资金。与此同时，中国的长江存储有赢得NAND存储器市场一部分的真正机会。根据估计，跨越芯片行业，中国的制造份额将从本十年初的15％增加到2030年的全球产能的24％，超过台湾和韩国的量。中国几乎肯定仍将落后于技术。但是，如果芯片工业中的更多部分搬迁至中国，那么中国将更有力地要求技术转移。对于美国和其他国家实施出口限制将变得更加昂贵，而中国将有更广泛的工人基础可以使用。几乎所有中国的芯片公司都依赖于政府支持，因此它们的导向与商业目标同等重要。一位高管告诉《日经亚洲》报：“赚钱和上市……不是长江存储的首要任务。”相反，该公司专注于“建设国家自己的芯片，实现中国梦想。”

CHAPTER 53 Shortages and Supply Chains

“ F or too long as a nation, we haven’t been making the big, bold investments we need to outpace our global competitors,” President Biden declared to a screenful of CEOs. Sitting in the White House under a painting of Teddy Roosevelt, holding aloft a twelve-inch silicon wafer, Biden looked into the Zoom screen and castigated the executives for “falling behind on research and development and manufacturing…. We have to step up our game,” he told them. Many of the nineteen executives on the screen agreed. To discuss America’s response to the chip shortage, Biden invited foreign companies like TSMC alongside U.S. chipmakers like Intel, as well as prominent users of semiconductors who were suffering severe semiconductor shortages. The CEOs of Ford and GM weren’t normally invited to high-level meetings about chips, and normally they wouldn’t have been interested. But over the course of 2021, as the world’s economy and its supply chains convulsed between pandemic-induced disruptions, people around the world began to understand just how much their lives, and often their livelihoods, depended on semiconductors.

「作為一個國家，我們已經太長時間沒有進行必要的大規模投資以超越我們的全球競爭對手。」拜登總統對著一群 CEO 壓低聲音說。他坐在白宮的一幅熊群中，手握著一塊 12 英寸的矽晶片，朝著 Zoom 螢幕說責備這些高管們「在研發和生產上落後了......我們必須提高我們的地位。」許多在屏幕上的十九位高管表示同意他的看法。為了討論美國對芯片短缺的應對，拜登不僅邀請了國際公司像 TSMC，以及美國芯片製造商，如英特爾，還有使用半導體技術但遭受嚴重芯片短缺的知名品牌。福特和通用的 CEO 通常不會受邀參加與芯片有關的高級會議，而且通常他們對此也不感興趣。但是在 2021 年的幾個月裡，當世界經濟和供應鏈在大流行病引起的干擾中進行大幅震動時，全球的人們開始意識到他們的生活和生計往往取決於半導體。」

In 2020, just as the United States began to impose a chip choke on China, cutting off some of the country’s leading tech companies from accessing U.S. chip technology, a second chip choke began asphyxiating parts of the world economy. Certain types of chips became difficult to acquire, especially the types of basic logic chips that are widely used in automobiles. The two chip chokes were partially interrelated. Chinese firms like Huawei had been stockpiling chips since at least 2019, in preparation for potential future U.S. sanctions, while Chinese fabs were buying as much manufacturing equipment as possible in case the U.S. decided to tighten export restrictions on chipmaking tools.

2020年，就在美國開始對中國實施芯片禁運，將該國一些領先的技術公司剝離開美國芯片技術的時候，第二個芯片禁運開始令世界經濟部分窒息。某些類型的芯片變得很難獲得，特別是在汽車中廣泛使用的基本邏輯芯片類型。兩個芯片禁運在某種程度上互相關聯。像華為這樣的中國企業自2019年以來一直在儲備芯片，為了應對可能的未來美國制裁，而中國的晶圓廠則盡可能多地購買製造設備，以防美國決定加緊出口限制芯片製造工具。

However, Chinese stockpiling explains only part of the COVID-era chip choke. The bigger cause is vast swings in orders for chips after the pandemic began, as companies and consumers adjusted their demand for different goods. PC demand spiked in 2020, as millions of people upgraded their computers to work from home. Data centers' demand for servers grew, too, as more of life shifted online. Car companies at first cut chip orders, expecting car sales to slump. When demand quickly recovered, they found that chipmakers had already reallocated capacity to other customers. According to the American Automotive Policy Council, an industry group, the world's biggest auto companies can use over a thousand chips in each car. If even one chip is missing, the car can't be shipped. Carmakers spent much of 2021 struggling and often failing to acquire semiconductors. These firms are estimated to have produced 7.7 million fewer cars in 2021 than would have been possible had they *not* faced chip shortages, which implies a $210 billion collective revenue loss, according to industry estimates.

然而，中國的庫存只能解釋COVID時代晶片短缺的部分原因。更大的原因是疫情開始後晶片訂單的大幅波動，因為公司和消費者調整了對不同商品的需求。2020年，數百萬人升級自己的電腦以在家工作，使個人電腦(PC)的需求急速增加。數據中心的伺服器需求也隨之增長，因為更多的生活方式轉向線上。汽車公司一開始減少了晶片訂單，期望汽車銷售量下滑。當需求迅速恢復時，他們發現晶片製造商已經向

其他客戶重新分配了生產能力。據美國汽車政策委員會估計，全球最大的汽車公司每輛車可使用超過一千個晶片。如果有一個晶片缺失，車輛就無法出貨。汽車製造商在2021年大部分時間裡都在努力且經常失敗地獲得半導體。根據行業估計，這些公司在2021年生產的汽車數量比沒有晶片短缺情況下少了770萬輛，這意味著產值損失2100億美元。

The Biden administration and most of the media interpreted the chip shortage as a supply chain problem. The White House commissioned a 250-page report on supply chain vulnerabilities that focused on semiconductors. However, the semiconductor shortage wasn’t primarily caused by issues in the chip supply chain. There were some supply disruptions, like COVID lockdowns in Malaysia, which impacted semiconductor packaging operations there. But the world produced more chips in 2021 than ever before—over 1.1 trillion semiconductor devices, according to research firm IC Insights. This was a 13 percent increase compared to 2020. The semiconductor shortage is mostly a story of demand growth rather than supply issues. It’s driven by new PCs, 5G phones, AI-enabled data centers—and, ultimately, our insatiable demand for computing power.

拜登政府和大部分媒体将芯片短缺解释为供应链问题。白宫委托一份250页的关于供应链漏洞的报告，其中重点关注半导体。然而，半导体短缺并不是主要由于芯片供应链问题所导致的。虽然有一些供应中断，如马来西亚的COVID封锁，影响了那里的半导体封装作业。但根据研究机构IC Insights的数据，2021年世界上生产的芯片比以往任何时候都多——超过1.1万亿个半导体器件，这比2020年增长了13%。半导体短缺主要是需求增长的故事，而不是供应问题。它是由新的个人电脑、5G手机、AI启用的数据中心以及最终我们对计算能力的贪求驱动的。

Politicians around the world have therefore misdiagnosed the semiconductor supply chain dilemma. The problem isn’t that the chip industry’s far-flung production processes dealt poorly with COVID and the resulting lockdowns. There are few industries that sailed through the pandemic with so little disruption. Such problems that emerged, notably the shortage of auto chips, are mostly the fault of carmakers’ frantic and ill-advised cancelation of chip orders in the early days of the pandemic coupled with their just-in-time manufacturing practices that provide little margin of error. For the car industry, which suffered a several-hundred-billion-dollar hit to revenue, there's plenty of reason to rethink how they've managed their own supply chains. The semiconductor industry, however, had a banner year. Besides a massive earthquake—a low but non-zero probability risk—it's hard to imagine a more severe peacetime shock to supply chains than what the industry has survived since early 2020. The substantial increase in chip production during both 2020 and 2021 is not a sign that multinational supply chains are broken. It's a sign that they've worked.

因此，全球的政治家们误诊了半导体供应链问题。问题不在于芯片行业分散的生产过程在应对COVID和随之而来的封锁方面表现不佳。在全球受疫情影响的各行各业中，几乎没有哪个行业像芯片行业一样，受到如此少的干扰。出现的问题，尤其是汽车芯片短缺，大多是汽车制造商在疫情早期疯狂和不明智地取消了芯片订单，再加上他们的及时生产实践提供了很少的错误余地所致。对于汽车行业来说，他们受损了数千亿美元的收入，有足够的理由来重新考虑他们自己的供应链管理方式。然而，半导体行业却拥有了一个标志性的年度。除了一次大地震——这是低概率但不为零的风险外，很难想象行业自2020年初以来经受了比这更严重的和平时期冲击的供应链。芯片产量在2020年和2021年都有了显著增加，这不是多国供应链破裂的迹象，而是它们已经起作用的迹象。

Nevertheless, governments should think harder about semiconductor supply chains than they used to. The real supply chain lesson of the past few years is not about fragility but about profits and power. Taiwan's extraordinary ascent shows how one company—with a vision and with government financial support—can remake an entire industry. Meanwhile, U.S. restrictions on China's access to chip technology demonstrate just how powerful the chip industry's choke points are. The rise of China's semiconductor industry over the past decade, however, is a reminder that these choke points are not infinitely durable. Countries and governments can often find ways around choke points, though doing so is time-consuming and expensive, sometimes extraordinarily so. Technological shifts can erode the efficacy of choke points, too.

然而，政府應更加深入地思考半導體供應鏈，而不是以往的方式。過去幾年來真正的供應鏈教訓不是關於脆弱性，而是關於利潤和權力。台灣的非凡崛起展示了一家公司如何通過願景和政府財政支持重塑整個行業。與此同時，美國對中國獲取芯片技術的限制表明了芯片行業的突破點有多麼強大。然而，中國半導體行業在過去十年的崛起提醒人們，這些突破點並不是無限耐用的。國家和政府通常可以找到解決突破點的方法，但這樣做往往耗時費力，有時甚至是非常昂貴的。技術變革也可以削弱突破點的效力。

These choke points only work if they're controlled by a couple of companies, and ideally only by one. Although the Biden administration has promised to work "with industry, allies, and partners," the U.S. and its allies aren't completely aligned when it comes to the future of the chip industry. The U.S. wants to reverse its declining share of chip fabrication and retain its dominant position in semiconductor design and machinery. Countries in Europe and Asia, however, would like to grab a bigger share of the high-value chip design market. Taiwan and South Korea, meanwhile, have no plans to surrender their market-leading positions fabricating advanced logic and memory chips. With China viewing expansion of its own fabrication capacity as a national security necessity, there's a limited amount of future chip fabrication business that can be shared between the U.S., Europe, and Asia. If the U.S. wants to increase its market share, some other country's market share must decrease. The U.S. is implicitly hoping to grab market share from one of the other areas with modern chipmaking facilities. Yet outside China, all the world's advanced chip fabs are in countries that are U.S. allies or close friends.

這些瓶頸只有在由幾家公司控制，最理想的是只有一家公司控制的情況下才能發揮作用。儘管拜登政府承諾將與行業、盟友和合作夥伴合作，但美國及其盟友在晶片產業未來方向上並非完全一致。美國希望扭轉其晶片製造市場份額下降的趨勢，並保持其在半導體設計和製造設備上的龍頭地位。然而，歐洲和亞洲國家希望分一杯羹，爭取更大的高價值晶片設計市場份額。同時，台灣和韓國並沒有計劃放棄自己在先進邏輯和記憶體晶片製造市場的領先地位。中國認為擴大自己的製造能力對國家安全是必要的，因此美國、歐洲和亞洲之間能分享的未來晶片製造業務有限。如果美國想增加其市場份額，就必須減少其他國家的市場份額。美國隱含地希望從現代晶片製造設施的其他地區

中搶占市場份額。然而，除了中國，全世界所有的先進晶片製造工廠都位於美國的盟友或親密的朋友之中。

South Korea, however, plans to retain its leading position in making memory chips while trying to expand its role in making logic chips. “Rivalries among semiconductor businesses have now begun to draw in countries,” South Korean president Moon Jae-in has noted. “My administration will also work with business as one team so Korea stays a semiconductor powerhouse.” The Korean government has poured money into a city called Pyeongtaek, formerly home to a U.S. military base but now the site of a major Samsung facility. All the major chipmaking equipment companies, from Applied Materials to Tokyo Electron, have opened offices in the city. Samsung has said it plans to spend over $100 billion by 2030 on its logic chip business in addition to investing comparable sums in memory chip production. The grandson of Samsung’s founder, Lee Jay-yong, was paroled from prison in 2021, where he was serving a sentence for bribery. Korea’s Justice Ministry cited “ economic factors” in justifying his release, including, media reports suggested, expectations that he will help the company make major semiconductor investment decisions.

然而，韩国计划在保持制造存储芯片的领先地位的同时，试图扩大在制造逻辑芯片方面的作用。“半导体企业之间的竞争现在已经开始涉及到国家”，韩国总统文在寅指出，“我的政府将与企业一起作为团队合作，以使韩国始终保持半导体强国的地位。”韩国政府已经向一个名为平泽的城市注入资金，该城市曾经是美国军事基地的所在地，现在是三星重要设施的所在地。所有主要的芯片制造设备公司，从应用材料到东京电子，在该市设立了办事处。三星表示，除了在存储芯片生产上投资相当的资金外，它计划在2030年之前在逻辑芯片业务上投资1000亿美元以上。三星的创始人孙子李在亨于2021年出狱，他因受贿被判刑。韩国司法部称其释放是基于“经济因素”，其中包括媒体报道暗示的预期，即他将帮助公司作出重大的半导体投资决策。

Samsung and its smaller Korean rival SK Hynix benefit from the support of the Korean government but are stuck between China and the U.S., with each country trying to cajole South Korea’s chip giants to build more manufacturing in their countries. Samsung recently announced plans to expand and upgrade its facility for producing advanced logic chips in Austin, Texas, for example, an investment estimated to cost $17 billion. Both companies face scrutiny from the U.S. over proposals to upgrade their facilities in China, however. U.S. pressure to restrict the transfer of EUV tools to SK Hynix's facility in Wuxi, China, is reportedly delaying its modernization—and presumably imposing a substantial cost on the company.

三星和其规模较小的韩国竞争对手SK海力士得到了韩国政府的支持，但它们陷于中美之间，每个国家都试图说服韩国芯片巨头在其国内建立更多制造业。例如，三星最近宣布了在德克萨斯州奥斯汀扩建和升级生产先进逻辑芯片的设施的计划，投资估计将达到170亿美元。然而，这两家公司在向中国升级设施的提议方面面临来自美国的审查。报道称，美国限制EUV工具向SK海力士在中国无锡的工厂转移，这可能会延迟其现代化，并向公司施加巨大的成本压力。

South Korea isn't the only country where chip companies and the government work as a "team," to use President Moon's phrase. Taiwan's government remains fiercely protective of its chip industry, which it recognizes as its greatest source of leverage on the international stage. Morris Chang, now ostensibly fully retired from TSMC, has served as a trade envoy for Taiwan. His primary interest—and Taiwan's—remains ensuring that TSMC retains its central role in the world's chip industry. The company itself plans to invest over $100 billion between 2022 and 2024 to upgrade its technology and expand chipmaking capacity. Most of this money will be invested in Taiwan, though the company plans to upgrade its facility in Nanjing, China, and to open a new fab in Arizona. Neither of these new fabs will produce the most cutting-edge chips, however, so TSMC's most advanced technology will remain in Taiwan. Chang continues to call for "free trade" in the semiconductor industry, threatening that otherwise "costs will go up, technology development will slow down." Meanwhile, Taiwan's government has repeatedly intervened to support TSMC through such measures as keeping Taiwan's currency undervalued to make Taiwanese exports more competitive.

韓國不是唯一一個讓晶片公司和政府一起合作的國家，使用文在寅總統的話說就是「一夥人」。台灣政府仍然強烈保護其晶片產業，因為它認為這是其在國際舞台上最大的籌碼。現在已完全退休的張忠謀擔任了台灣的貿易特使。他和台灣的主要利益在於確保台積電保持其在

全球晶片產業中的核心地位。該公司計劃在2022年至2024年之間投資1000億美元升級技術和擴大晶片生產能力。大部分資金將投資於台灣，但公司計劃升級在中國南京的設施，並在亞利桑那州開設一個新的晶圓廠。然而，這些新的晶圓廠都不會生產最尖端的晶片，所以台積電最先進的技術仍將留在台灣。張繼續呼籲晶片產業要實現「自由貿易」，並威脅否則「成本會上升，技術開發將放緩」。與此同時，台灣政府多次干預，以支持台積電，例如保持台灣貨幣貶值，使台灣出口更具競爭力。

Europe, Japan, and Singapore are three other regions looking for new semiconductor investments. Some European Union leaders have suggested the continent can "invest massively" and produce 3nm or 2nm chips, putting European fabs near the cutting edge. Given the continent's low market share in advanced logic, this is unlikely. More plausible is that Europe will convince a big foreign chip firm, like Intel, to build a new facility providing a stable source of supply for European automakers. Singapore continues to provide substantial incentives for chipmaking, recently winning a $4 billion investment from U.S.-based GlobalFoundries for a new fab. Japan, meanwhile, is heavily subsidizing TSMC to build a new chipmaking facility in partnership with Sony. Japan has lost much of its chipmaking in the decades since executives like Akio Morita left the scene, but Sony still retains a sizeable and profitable business making semiconductors that can sense images and which are used in the cameras in many consumer devices. Japan's decision to subsidize a new TSMC facility, though, wasn't primarily to help Sony. Japan's government feared that if manufacturing kept shifting offshore, the parts of the supply chain in which Japan retains a strong position, like machine tools and advanced materials, would shift abroad, too.

歐洲、日本和新加坡是另外三個正在尋求新半導體投資的地區。一些歐盟領導人建議歐洲可以"大規模投資"生產3納米或2納米芯片，使歐洲的製造廠進入前沿。考慮到歐洲在先進邏輯市場份額較低，這是不太可能的。更有可能的是，歐洲將說服像英特爾這樣的大型外國芯片公司建立一個新設施，為歐洲汽車製造商提供穩定的供應源。新加坡繼續提供重大激勵措施進行芯片製造，最近獲得了總值40億美元的美國環球封裝的新製造廠投資。與此同時，日本正在大力補貼台積電和索尼合作建設新的芯片製造設施。自秦淮光等高管離去以來，日本在數十年中失去了大部分的晶圓製造，但索尼仍然擁有一個規模不小而

且獲利豐厚的製造半導體業務，這些芯片可以感應圖像，並用於許多消費者設備的相機中。然而，日本補貼建立新的台積電設施的決定，並不是主要是為了幫助索尼。日本政府擔心如果製造業繼續向海外轉移，日本在機器工具和先進材料等保持強勁地位的供應鏈中，也會轉移到海外。

While Japan could use a new Akio Morita, the United States is in desperate need of a new Andy Grove. America still has an enviable position in the chip industry. Its control over many of the industry's choke points, including software and machinery, is as strong as ever. Companies like Nvidia look likely to play a foundational role in the future of computing trends like artificial intelligence. Moreover, after a decade in which chip startups were out of fashion, in the past few years Silicon Valley has poured money into fabless firms designing new chips, often focused on new architectures that are optimized for artificial intelligence applications.

雖然日本可能需要一位新的盛田昭夫，但美國迫切需要一位新的安迪·葛羅夫。美國仍然在晶片行業中處於令人羨慕的地位。其對許多行業的瓶頸，包括軟件和機械的控制，仍然非常強大。像英偉達這樣的公司似乎有望在人工智能等計算趨勢的未來發揮基礎性作用。此外，經過了十年不受歡迎的晶片初創企業，在過去幾年中，硅谷已經投入了大量的資金到設計新芯片的無廠設計公司，通常是專注於為人工智能應用優化的新架構。

When it comes to making these chips, however, the U.S. currently lags behind. The primary hope for advanced manufacturing in the United States is Intel. After years of drift, the company named Pat Gelsinger as CEO in 2021. Born in small-town Pennsylvania, Gelsinger started his career at Intel and was mentored by Andy Grove. He eventually left to take on senior roles at two cloud computing companies before he was brought back to turn Intel around. He's set out an ambitious and expensive strategy with three prongs. The first is to regain manufacturing leadership, overtaking Samsung and TSMC. To do this, Gelsinger has cut a deal with ASML to let Intel acquire the first next-generation EUV machine, which is expected to be ready in 2025. If Intel can learn how to use these new tools before rivals, it could provide a technological edge.

然而，在生产这些芯片方面，美国目前落后于其他国家。在美国，领先的高级制造商是英特尔。在漂泊了多年之后，该公司在2021年任命帕特·盖尔辛格（Pat Gelsinger）为首席执行官。盖尔辛格出生在宾夕法尼亚州的一个小镇，并在英特尔开始了自己的职业生涯。他是安迪·格鲁夫（Andy Grove）的门徒。后来，他离开了英特尔，担任了两家云计算公司的高级职务，然后被重新聘用来领导英特尔的转型。他明确了三个雄心勃勃且昂贵的战略目标。第一个目标是重新夺回生产领导地位，超过三星和台积电。为了实现这个目标，盖尔辛格与ASML达成了协议，允许英特尔收购第一台下一代EUV机器，该机器预计将于2025年投入使用。如果英特尔能够在竞争对手之前学会如何使用这些新工具，那么将为其提供技术优势。

The second prong of Gelsinger’s strategy is launching a foundry business that will compete directly with Samsung and TSMC, producing chips for fabless firms and helping Intel win more market share. Intel’s spending heavily on new facilities in the U.S. and Europe to build capacity that potential future foundry customers will require. However, making the foundry business financially viable will likely require winning some customers who are producing at the technological cutting edge—meaning that Intel’s foundry business will only work if the company can reduce its technological lag with Samsung and TSMC. Intel’s foundry pivot comes as its market share in data center chips continues to decline, both because of competition from AMD and Nvidia and because cloud computing companies like Amazon Web Services and Google are designing their own chips.

吉尔辛格战略的第二个支柱是推出一家铸造公司，直接竞争三星和台积电，为无晶圆厂公司生产芯片并帮助英特尔赢得更多市场份额。英特尔正在美国和欧洲大力投资新设施，以建立潜在未来铸造客户所需的能力。然而，要使铸造业务在财务上可行，可能需要赢得一些在技术领域处于领先地位的客户 - 这意味着英特尔的铸造业务只有在公司能够缩小与三星和台积电的技术差距时才能运作。英特尔的铸造业务转变正值其数据中心芯片市场份额持续下降之际，这既归因于AMD和Nvidia的竞争，也归因于像亚马逊网络服务和Google这样的云计算公司正在设计自己的芯片。

Whether Intel succeeds or fails will depend on whether it can execute Gelsinger’s strategy and whether Samsung or TSMC slip up. Moore’s Law requires these companies to roll out new technologies every few years, so one or both of Intel's competitors could easily face major delays. Yet Intel's strategy has an uncomfortable third prong: get help from TSMC. Publicly, Intel is encouraging a new wave of chip nationalism and nervousness about reliance on production in Asia. It's trying to extract subsidies from both the U.S. and European governments to build fabs at home. "The world needs a more balanced supply chain," Gelsinger argues. "God decided where the oil reserves are, we get to decide where the fabs are." Yet while Intel tries to sort out its in-house chip fabrication, it is outsourcing production of a growing share of its advanced chip designs to TSMC's most advanced facilities in Taiwan.

英特爾的成功或失敗，將取決於它是否能執行吉爾辛格的策略，以及三星或台積電是否犯了錯誤。摩爾定律要求這些公司每幾年推出新技術，因此英特爾的一個或兩個競爭對手可能會遭遇重大延遲。然而，英特爾的策略還有一個尷尬的第三個要素：得到台積電的幫助。英特爾公開鼓勵新一波晶片民族主義，以及對亞洲生產依賴的不安。它正在試圖從美國和歐洲政府獲得補貼來在本土建立晶圓廠。吉爾辛格辯稱："世界需要更平衡的供應鏈。上帝決定了油藏的位置，我們可以決定晶圓廠的位置。"然而，當英特爾試圖處理其內部晶片製造時，它正在外包越來越多的先進晶片設計生產到台灣台積電最先進的設施中。

As it began to reckon with the concentration of advanced chipmaking in East Asia, the U.S. government convinced both TSMC and Samsung to open new facilities in the U.S., with TSMC planning a new fab in Arizona and Samsung expanding a facility near Austin, Texas. These fabs are partially intended to appease American politicians, though they will also produce chips for defense and other critical infrastructure that the U.S. would prefer to fabricate onshore. However, both companies plan to keep the vast majority of their production capacity—and their most advanced technology—at home. Even promises of subsidies from the U.S. government are unlikely to change this.

當美國開始面對在東亞的晶片製造集中問題時，政府說服台積電和三星在美國開設新工廠，其中台積電計劃在亞利桑那州建造新的晶圓廠，而三星則擴建了在德克薩斯州奧斯汀附近的工廠。這些工廠部分旨在取悅美國政治家，但它們也將生產用於國防和其他美國希望在本

土製造的關鍵基礎設施芯片。然而，這兩家公司計劃保留絕大部分生產能力和最先進的技術在本土。即使美國政府承諾提供補貼，也不太可能改變這一點。

Among American national security officials, there is growing discussion about whether to use threats of export controls on chip design software and manufacturing equipment to pressure TSMC to roll out its newest process technologies simultaneously in the U.S. and in Taiwan. Alternatively, TSMC could be pressed to commit that every dollar of capital expenditure in Taiwan will be matched, for example, by a dollar of capital expenditure at one of TSMC's new facilities in Japan, Arizona, or Singapore. Such moves might begin to reduce the world's reliance on chipmaking in Taiwan. But for now, Washington is unwilling to exert the pressure that would be required. The entire world's dependence on Taiwan, therefore, continues to grow.

在美国国家安全官员中，越来越多地讨论使用威胁出口管制芯片设计软件和制造设备的方式来施压TSMC，在美国和台湾同时推出其最新的工艺技术。或者，可以督促TSMC承诺在台湾的每一美元资本支出都将与日本、亚利桑那州或新加坡其中一个新设施的一美元资本支出相匹配。这些举措可能会开始减少世界对台湾芯片制造的依赖。但目前，华盛顿不愿施加所需的压力。因此，整个世界对台湾的依赖仍然在不断增加。

CHAPTER 54 The Taiwan Dilemma

“ A re your customers concerned,” one financial analyst asked TSMC chairman Mark Liu, when China from time to time threatens “a war against Taiwan?” CEOs are used to tough questions on quarterly earnings calls, but they’re usually about missed profit targets or product launches gone wrong. At the time of this call, July 15, 2021, TSMC’s financials looked fine. The company had weathered the sanctioning of its second-largest customer, Huawei, with scarcely any impact on its performance. TSMC’s share price was near a record high. The global semiconductor shortage had made its business even more lucrative. For a time in 2021, it was the most valuable publicly traded company in Asia, one of the ten most valuable publicly traded companies in the world.

當中國時不時威脅“對台灣開戰”時，一位金融分析師問TSMC主席劉德音，“您的客戶是否感到擔憂？” CEO一直習慣於在季度盈利電話會議上回答嚴肅的問題，但通常是關於未達成盈利目標或產品推出失敗的問題。在2021年7月15日的電話會議上，TSMC的財務狀況看起來不錯。該公司已經成功度過對第二大客戶華為的制裁，對其業績幾乎沒有任何影響。TSMC的股價接近創紀錄高點。全球晶片短缺使其業務更加有利可圖。在2021年的某個時候，它是亞洲最有價值的上市公司之一，是全球最有價值的十家上市公司之一。

Yet the more indispensable TSMC has become, the more risk has risen—not to TSMC’s financials, but to its facilities. Even investors who for years chose to ignore the severity of the U.S.-China antagonism began looking nervously at the map of TSMC’s chip fabs, arrayed along the western coast of the Taiwan Strait. TSMC’s chairman insisted that there was no reason for concern. “As to the invasion of China, let me tell you,” he declared, “everybody wants to have a peaceful Taiwan Strait.” Taipei-born, Berkeley-educated, and Bell Labs−trained, Liu has an impeccable chipmaking record. His skill in assessing the risk of war, however, has yet to be tested. Peace in the Taiwan Strait “is to every country’s benefit,” he argued, given the world’s reliance on “the semiconductor supply chain in Taiwan. No one wants to disrupt it.”

然而，TSMC变得越来越不可或缺，风险也随之增加，而这种风险不是针对TSMC的财务状况，而是针对其设施的。即使是多年来一直选择忽视中美对抗严重性的投资者，现在也开始紧张地看着分布在台湾海峡西岸的TSMC芯片工厂地图。TSMC董事长坚称没有理由担心。他说，“至于中国的入侵，让我告诉你，每个人都希望台湾海峡和平。”刘在台湾出生，在伯克利接受教育，在贝尔实验室接受训练，具备无可挑剔的芯片制造记录。然而，他对战争风险的评估能力尚未得到检验。他辩称，由于全球对“台湾的半导体供应链”有着重要依赖，因此维持台湾海峡的和平对每个国家都有益处。他表示，“没有人希望破坏它。”

The next day, July 16, dozens of People’s Liberation Army Type 05 amphibious armored vehicles stormed off the Chinese coast into the ocean. Though they look like tanks, these vehicles are equally capable of driving on beaches as they are of speeding through the water like small boats. They’d be instrumental in any PLA amphibious assault. After motoring into the ocean, dozens of these vehicles approached landing ships stationed offshore, driving from the water up onto the ships, where they prepared for “a long-distance sea-crossing,” Chinese state media reported. The landing ships steamed toward their target. Upon arrival, wide doors in the ships’ bows swung open and amphibious vehicles streamed off into the water, making their way to the beach and firing their guns as they went.

7月16日，数十辆中国人民解放军05式两栖装甲车冲出中国海岸进入海洋。尽管它们看起来像坦克，但这些车辆既能在海滩上行驶，也能像小艇一样迅速驶过水面。它们将在任何解放军两栖攻击中发挥关键作用。在驶入海洋后，数十辆这些车辆接近停泊在离岸处的登陆舰，从水中驶上船上，准备进行“长距离海上渡海行动”，中国官方媒体报道。登陆舰驶向目标。抵达后，船首的宽敞门打开，两栖车辆朝水中涌去，一边前进一边开火。

This time, it was just an exercise. Over the next few days, the PLA launched other drills near the north and south entrances to the Taiwan Strait. “We must train hard under scenarios just like those in real battles, be combat-ready at all times and resolutely safeguard national sovereignty and territorial integrity,” China’s *Global Times* newspaper quoted one battalion commander as saying. The newspaper pointedly noted that the exercises took place only three hundred kilometers from Pratas Island, a tiny atoll equidistant between Hong Kong and Taiwan and administered by the latter.

這次只是一個演習。在接下來的幾天裡，中國人民解放軍在台灣海峽北方和南方入口附近進行了其他演練。 "我們必須在像真正戰役一樣的情況下進行艱苦的訓練，隨時準備戰鬥，堅決捍衛國家主權和領土完整，" 中國的《環球時報》援引一名營長的話說。該報特別指出，這些演習發生在距離中港台之間的小環礁--東沙群島普陀洲僅有300公里的地方。

There are many ways a war over Taiwan could begin, but some defense planners think a ramped-up dispute over isolated Pratas Island is the most likely. One recent war game organized by American defense experts envisioned Chinese troops landing on the island and seizing the small Taiwanese garrison there without firing a shot. Taiwan and the U.S. would face the difficult choice of starting a war over an irrelevant atoll or establishing a precedent that China can slice off chunks of Taiwanese territory like pieces of soft salami. “Moderate” responses would include stationing large numbers of U.S. troops in Taiwan or launching cyberattacks on China, both of which could easily escalate into a full-blown conflict.

開戰台灣的方式有很多種，但一些防衛規劃人員認為，對孤立的東沙群島争端升级是最有可能的。美國防衛專家組織的一個最近的戰爭遊戲展示了中國軍隊登陸該島並沒收那裡的臺灣駐軍，而不用開一槍。臺灣和美國將面臨一個艱難的選擇，是就一個無關緊要的環礁發起一場戰爭，還是確立中國可以像軟色拉葉子一樣地割下臺灣領土的先例。"適度"的回應包括在臺灣部署大量美國軍隊或對中國發動網絡攻擊，這兩種回應都很容易升級成全面衝突。

The Pentagon’s public reports on Chinese military power have identified multiple ways China could use force against Taiwan. The most straightforward—but most unlikely—is a D-Day style invasion, with hundreds of Chinese ships steaming across the Strait and landing thousands of PLA infantrymen on shore. The history of amphibious invasions is littered with disasters, however, and the Pentagon judges that such an operation would “strain” the PLA’s capabilities. China would have little difficulty in knocking out Taiwan’s airfields and naval facilities as well as electricity and other critical infrastructure before any assault, but even still, it would be a tough fight.

五角大楼就中国军事力量发布的公开报告，已经确定中国有多种攻台方式。最直接、但最不可能的是像D-Day一样入侵，数百艘中国船舶横渡海峡，将数千个中国解放军士兵登陆岸边。但是，两栖入侵的历史充满了灾难，而五角大楼认为这样的行动会“紧张”中国人民解放军的能力。在袭击前，中国将很容易击败台湾的机场、海军设施以及电力和其他关键基础设施，但即使如此，这仍将是一场艰苦的战斗。

Other options would be easier for the PLA to implement, in the Pentagon’s judgment. A partial air and maritime blockade would be impossible for Taiwan to defeat on its own. Even if the U.S. and Japanese militaries joined Taiwan to try and break the blockade, it would be difficult to do. China has powerful weapons systems arrayed along its shores. A blockade wouldn’t need to be perfectly effective to strangle the island’s trade. Ending a blockade would require Taiwan and its friends—mainly, the U.S.—to disable hundreds of Chinese military systems sitting on Chinese territory. A blockade-busting operation could easily spiral into a bloody great power war.

根據五角大廈的判斷，其他選擇對於解放軍實施起來會容易得多。部分航空和海上封鎖是台灣無法自行擊敗的。即使美國和日本軍隊加入台灣嘗試打破封鎖，也會很困難。中國在沿海地區擁有強大的武器系統。封鎖不必完全有效就可以掐死該島的貿易。解除封鎖需要台灣及其朋友主要是美國將存在於中國領土的數百個軍事系統停用。破解封鎖行動可能會很快蔓延成為一場血腥的大國之間的戰爭。

Even without a blockade, a Chinese air and missile campaign alone could defang Taiwan’s military and shut down the country’s economy without placing a single pair of Chinese boots on the ground. In a couple days, absent immediate U.S. and Japanese aid, Chinese air and missile forces could probably disarm key Taiwanese military assets—airfields, radar facilities, communications hubs, and the like—without severely impacting the island’s productive capacity.

TSMC's chairman is certainly right that no one wants to "disrupt" the semiconductor supply chains that crisscross the Taiwan Strait. But both Washington and Beijing would like more control over them. The idea that China would simply destroy TSMC's fabs out of spite doesn't make sense, because China would suffer as much as anyone, especially since the U.S. and its friends would still have access to Intel's and Samsung's chip fabs. Nor has it ever been realistic that Chinese forces could invade and straightforwardly seize TSMC's facilities. They'd soon discover that crucial materials and software updates for irreplaceable tools must be acquired from the U.S., Japan, and other countries. Moreover, if China were to invade, it's unlikely to capture all TSMC employees. If China did, it would only take a handful of angry engineers to sabotage the entire operation. The PLA's proven it can seize Himalayan peaks from India on the two countries' disputed border, but grabbing the world's most complex factories, full of explosive gases, dangerous chemicals, and the world's most precise machinery—that's a different matter entirely.

即使没有封锁，单靠中国的空袭和导弹攻击就足以使台湾军队失去战斗力，并关闭该国的经济，而且不用在台湾地面上派遣一双中国军靴。几天内，如果美国和日本不能立即提供援助，中国的空军和导弹部队可能就能够瘫痪台湾的关键军事设施，如机场、雷达设施、通讯中心等，而不会严重影响该岛的生产能力。 TSMC的董事长肯定是正确的，没有人希望"扰乱"穿越台湾海峡的半导体供应链。但华盛顿和北京都希望对它们拥有更多的控制权。中国简单地摧毁TSMC的晶圆厂是没有意义的，因为中国将会遭受与任何其他人一样的后果，尤其是因为美国及其盟友仍将有机会使用英特尔和三星的芯片制造厂。而且，中国部队入侵并直接夺取TSMC的设施的想法从来就不现实。他们很快就会发现，对于不可替代的工具，关键的材料和软件更新必须从美国、日本和其他国家获得。此外，如果中国发动入侵，它不太可能俘获所有的TSMC员工。如果中国这么做了，只需要一小撮愤怒的工程师就可以破坏整个操作。中国军队证明过，他们可以从印度亚喀巴进攻两国在边界争议地区的喜马拉雅山峰，但是抓住世界上最复杂的工厂，那些充满易爆气体、危险化学物质和世界上最精密的机器，这完全是另一回事。

However, it's easy to imagine a way that an accident, like a collision in air or at sea, could spiral into a disastrous war that neither side wants. It's also perfectly reasonable to think China might conclude that military pressure without a full-scale invasion could decisively undermine America’s implicit security guarantee and fatally demoralize Taiwan. Beijing knows that Taiwan’s defense strategy is to fight long enough for the U.S. and Japan to arrive and help. The island is so small relative to the cross-strait superpower that there’s no realistic option besides counting on friends. Imagine if Beijing were to use its navy to impose customs checks on a fraction of the ships sailing in and out of Taipei. How would the U.S. respond? A blockade is an act of war, but no one would want to shoot first. If the U.S. did nothing, the impact on Taiwan’s will to fight could be devastating. If China then demanded that TSMC restart chip fabrication for Huawei and other Chinese companies, or even to transfer critical personnel and know-how to the mainland, would Taiwan be able to say no?

然而，可以想象一种方式，即事故，例如空中或海上碰撞，可能会演变成双方都不想要的灾难性战争。同样合理的是，中国可能会得出结论，军事压力无需全面入侵即可决定性地削弱美国的隐含安全保障，并使台湾陷入绝望。北京知道台湾的防御战略是要战斗足够长的时间，使美国和日本来到并提供帮助。相对于跨海超级大国，该岛太小了，除了依靠朋友，没有真正的选择。想象一下，如果北京使用其海军对出入台北的一小部分船只实施海关检查，美国将如何回应？封锁是一种战争行为，但是没有人想要先开枪。如果美国什么也不做，对台湾打击意志的影响可能是毁灭性的。如果中国随后要求台积电恢复向华为和其他中国公司制造芯片，甚至将关键人员和专业知识转移到中国大陆，台湾能否说不？

Such a series of moves would be risky for Beijing, but they wouldn’t be unthinkable. China’s ruling party has no higher goal than asserting control over Taiwan. Its leaders constantly promise to do so. The government has passed an “Anti-Secession Law” envisioning the potential use of what it calls “non-peaceful means” in the Taiwan Strait. It’s invested heavily in the type of military systems, like amphibious assault vehicles, needed for a cross-strait invasion. It exercises these capabilities regularly. Analysts uniformly agree that the military balance in the Strait has shifted decisively in China’s direction. Long gone are the days, as during the 1996 Taiwan Strait crisis, that the U.S. could simply sail an entire aircraft carrier battlegroup through the Strait to force Beijing to stand down. Now such an operation would be fraught with risk for the U.S. warships. Today Chinese missiles threaten not only U.S. ships around Taiwan but also bases as far away as Guam and Japan. The stronger the PLA gets, the less likely the U.S. is to risk war to defend Taiwan. If China were to try a campaign of limited military pressure on Taiwan, it’s more likely than ever that the U.S. might look at the correlation of forces and conclude that pushing back isn’t worth the risk.

这样一系列的行动对北京来说是有风险的，但也不是不可想象的。中国执政党的最高目标就是对台湾实施控制。它的领导人经常承诺要这样做。政府通过了一个《反分裂国家法》，设想在台湾海峡可能使用所谓的“非和平手段”。它大量投资于像两栖突击车这样的军事系统，需要进行跨海峡入侵。它经常锻炼这些能力。分析人士普遍认为海峡的军事平衡已经明显向中国倾斜。已经过去了像1996年台湾海峡危机期间的日子，当时美国可以简单地通过海峡驶过整个航空母舰战斗群来迫使北京放弃。现在，这样的操作对美国军舰而言充满了风险。今天，中国的导弹不仅威胁着围绕台湾的美国舰艇，还威胁着远至关岛和日本的基地。中国人民解放军变得越强大，美国就越不愿冒险保卫台湾。如果中国试图对台湾施加有限军事压力的行动，美国可能会考虑兵力对比，并得出结论，反击不值得冒险。

If China were to succeed in pressuring Taiwan into giving Beijing equal access—or even preferential access—to TSMC’s fabs, the U.S. and Japan would surely respond by placing new limits on the export of advanced machinery and materials, which largely come from these two countries and their European allies. But it would take years to replicate Taiwan’s chipmaking capacity in other countries, and in the meantime we’d still depend on Taiwan. If so, we’d find ourselves not only reliant on China to assemble our iPhones. Beijing could conceivably gain influence or control over the only fabs with the technological capability and production capacity to churn out the chips we depend on.

如果中國成功施壓台灣讓北京取得跟台積電一樣的平等甚至優先使用權，美國和日本肯定會針對這件事情對進口先進設備以及原材料實施新限制，而這些東西大多數都是來自這兩個國家以及歐洲盟友。但在其他國家複製台灣的晶片製造能力可能需要數年的時間，在此期間我們仍然依賴台灣。如果這樣的話，不僅仍然依賴中國來組裝我們的

iPhone，北京還有可能獲得對我們所依賴的唯一具有技術能力和生產能力的晶片製造廠的影響力或控制權。

Such a scenario would be disastrous for America's economic and geopolitical position. It would be even worse if a war knocked out TSMC's fabs. The world economy and the supply chains that crisscross Asia and the Taiwan Strait are predicated on this precarious peace. Every company that's invested on either side of the Taiwan Strait, from Apple to Huawei to TSMC, is implicitly betting on peace. Trillions of dollars are invested in firms and facilities within easy missile shot of the Taiwan Strait, from Hong Kong to Hsinchu. The world's chip industry, as well as the assembly of all the electronic goods chips enable, depends more on the Taiwan Strait and the South China coast than on any other chunk of the world's territory except Silicon Valley.

這樣的情況對美國的經濟和地緣政治地位將是災難性的。如果戰爭摧毀了台積電的fabs，情況將更糟。世界經濟和縱橫交錯的亞洲和台灣海峽供應鏈是建立在這種不穩定的和平基礎上的。從蘋果到華為再到台積電，投資於台灣海峽兩岸的每家公司都在暗示著和平。數萬億美元的投資在容易受到台灣海峽導彈攻擊的公司和設施裡面，從香港到新竹。除了硅谷以外，全球芯片產業以及所有電子產品芯片的組裝都更加依賴台灣海峽和南中國海岸這塊地區。

Business as usual is not nearly as fraught in California's tech epicenter. Much of Silicon Valley's knowledge could be easily relocated in case of war or earthquake. This was tested during the pandemic, when almost all the region's workers were told to sit at home. Big tech firms' profits even went up. If Facebook's fancy headquarters were to sink into the San Andreas Fault, the company might barely notice.

If TSMC's fabs were to slip into the Chelungpu Fault, whose movement caused Taiwan's last big earthquake in 1999, the reverberations would shake the global economy. It would only take a handful of explosions, deliberate or accidental, to cause comparable damage. Some back-of-the-envelope calculations illustrate what's at stake. Taiwan produces 11 percent of the world's memory chips. More important, it fabricates 37 percent of the world's logic chips. Computers, phones, data centers, and most other electronic devices simply can't work without them, so if Taiwan's fabs were knocked offline, we'd produce 37 percent less computing power during the following year.

加州的科技中心并没有像其他地方那样充满危机感。在战争或地震的情况下，硅谷的许多知识可以很容易地转移。在疫情期间，几乎所有该地区的工人都被告知呆在家里，但大型科技公司的利润甚至上升了。如果Facebook高端的总部沉入圣安德烈亚斯断层，公司可能几乎察觉不到。 如果台积电的制造工厂滑入导致1999年台湾大地震的彰隆断层中，这将引起全球经济的震荡。只需要几次意外或故意的爆炸，就可以造成类似的损失。一些草率的计算说明了风险。台湾生产了全球11％的存储芯片。更重要的是，它制造了全球37％的逻辑芯片。电脑、手机、数据中心和大多数其他电子设备都离不开它们，因此，如果台湾的制造工厂宕机，我们在接下来的一年内将产生37％的计算能力下降。

The impact on the world economy would be catastrophic. The post-COVID semiconductor shortage was a reminder that chips aren't only needed in phones and computers. Airplanes and autos, microwaves and manufacturing equipment—products of all types would face devastating delays. Around one-third of PC processor production, including chips designed by Apple and AMD, would be knocked offline until new fabs could be built elsewhere. Growth in data center capacity would slow dramatically, especially for servers focused on AI algorithms, which are more reliant on Taiwan-manufactured chips from companies like Nvidia and AMD. Other data infrastructure would be hit harder. New 5G radio units, for example, require chips from several different firms, many of which are made in Taiwan. There'd be an almost complete halt to the rollout of 5G networks.

對世界經濟的影響將是災難性的。COVID後的半導體短缺提醒人們，晶片不僅在手機和電腦中需要。飛機和汽車、微波爐和製造設備——所有類型的產品都將面臨毀滅性的延誤。其中約三分之一的PC處理器生產，包括由蘋果和AMD設計的晶片，將在新晶片工廠建成之前暫停生產。數據中心容量的增長將急劇放緩，特別是專注於AI算法的服務器，這些服務器更依賴於台灣製造的顯示卡公司Nvidia和AMD的晶片。其他數據基礎設施將受到更大的衝擊。例如，新的5G無線電單元

需要來自幾家不同公司的晶片，其中許多晶片都是在台灣製造的。5G網絡的部署將幾乎完全停止。

It would make sense to halt cell phone network upgrades because it would be extremely difficult to buy a new phone, too. Most smartphone processors are fabricated in Taiwan, as are many of the ten or more chips that go into a typical phone. Autos often need hundreds of chips to work, so we'd face delays far more severe than the shortages of 2021. Of course, if a war broke out, we'd need to think about a lot more than chips. China's vast electronics assembly infrastructure could be cut off. We'd have to find other people to screw together whatever phones and computers we had components for.

停止手机网络升级是有意义的，因为购买新手机也会变得极其困难。大多数智能手机处理器都是在台湾制造的，许多典型手机所需的10个或更多芯片也是如此。汽车通常需要数百个芯片才能正常工作，所以我们将面临比2021年短缺更严重的延迟。当然，如果爆发战争，我们需要考虑的不仅仅是芯片问题。中国庞大的电子组装基础设施可能会受到切断。我们必须找到其他人来组装我们所拥有的组件的任何手机和电脑。

Yet it would be far easier to find new assembly workers—as difficult as that would be—than to replicate Taiwan's chipmaking facilities. The challenge wouldn't simply be building new fabs. Those facilities would need trained personnel, unless somehow many TSMC staff could be exfiltrated from Taiwan. Even still, new fabs must be stocked with machinery, like tools from ASML and Applied Materials. During the 2021–2022 chip shortage, ASML and Applied Materials both announced they were facing delays in producing machinery because they couldn't acquire enough semiconductors. In case of a Taiwan crisis, they'd face delays in acquiring the chips their machinery requires.

然而，找到新的裝配工人會比複製台灣的晶片製造設施容易得多——儘管這本身也很困難。挑戰不僅在於建造新的晶圓廠。這些設施需要受過培訓的人員，除非能某種方式從台灣帶走很多台積電的員工。即使如此，新的晶圓廠也必須裝備機器設備，如來自ASML和Applied Materials的工具。在2021-2022年晶片短缺期间，ASML和Applied Materials均宣布他們面臨生產機器的延誤，因為他們無法獲得足够的

半導體。在台灣危機的情況下，他們將面臨獲取機器所需芯片的延誤。

After a disaster in Taiwan, in other words, the total costs would be measured in the trillions. Losing 37 percent of our production of computing power each year could well be more costly than the COVID pandemic and its economically disastrous lockdowns. It would take at least half a decade to rebuild the lost chipmaking capacity. These days, when we look five years out we hope to be building 5G networks and metaverses, but if Taiwan were taken offline we might find ourselves struggling to acquire dishwashers.

在台灣發生災難之後，換句話說，其總成本將以數萬億計算。每年損失37％的計算能力生產很可能比COVID大流行及其經濟毀滅性的封鎖措施更為昂貴。重建失去的晶片生產能力至少需要半個世紀。如今，當我們展望五年後，希望建立5G網絡和虛擬現實，但如果台灣斷電，我們可能會發現自己在設法獲取洗碗機上掙扎。

Taiwan's president Tsai Ing-wen recently argued in *Foreign Affairs* that the island's chip industry is a "'silicon shield' that allows Taiwan to protect itself and others from aggressive attempts by authoritarian regimes to disrupt global supply chains." That's a highly optimistic way of looking at the situation. The island's chip industry certainly forces the U.S. to take Taiwan's defense more seriously. However, the concentration of semiconductor production in Taiwan also puts the world economy at risk if the "silicon shield" doesn't deter China.

台灣總統蔡英文最近在《外交事務》雜誌中表示，該島的芯片產業是一個"矽盾"，使台灣能夠保護自己和其他國家免於遭到專制政權的侵害，並維護全球供應鏈的穩定。這是一種非常樂觀的看法。該島的芯片產業確實迫使美國更加重視對台灣的防禦。然而，如果"矽盾"無法阻止中國，芯片產業在台灣的集中生產也會使全球經濟面臨風險。

In a 2021 poll, most Taiwanese reported thinking that a war between China and Taiwan was either unlikely (45 percent) or impossible (17 percent). The Russian invasion of Ukraine, however, is a reminder that just because the Taiwan Strait has been mostly peaceful for the past few decades, a war of conquest is far from unthinkable. The Russia-Ukraine War also illustrates the extent to which any large conflict will be determined in part by a country's position in the semiconductor supply chain, which will shape its ability to wield military and economic power.

在2021年的一次民調中，大多數台灣人報告認為中國和台灣之間的戰爭要麼不太可能（45%），要麼根本不可能（17%）。然而，俄羅斯對烏克蘭的入侵提醒人們，即使過去幾十年中，台灣海峽一直相對和平，征服戰爭仍然並非不可想象。俄烏戰爭還說明了任何大型衝突都將在一定程度上取決於一個國家在半導體供應鏈中的地位，這將決定其在軍事和經濟方面行使權力的能力。

Russia's chip industry, which lagged behind Silicon Valley since the days of Soviet minister Shokin and the founding of Zelenograd, had decayed since the Cold War ended, as most Russian customers chose to stop buying from domestic chipmakers and outsourced production to TSMC. The only remaining customers were Russia's defense and space industries, which were not big enough buyers of chips to fund advanced chipmaking at home. As a result, even high priority defense projects in Russia struggled to acquire the chips they needed. Russia's equivalent of GPS satellites, for example, have faced wrenching delays due to problems sourcing semiconductors.

俄罗斯的芯片行业自苏联时期的 Shokin 部长和 Zelenograd 成立以来一直落后于硅谷，并在冷战结束后走向衰落，因为大多数俄罗斯客户选择停止从国内芯片制造商购买，并将生产外包给 TSMC。唯一留下的客户是俄罗斯的国防和航天工业，它们的芯片采购量不足以支持本土先进芯片制造。因此，即使在俄罗斯，优先级较高的国防项目也难以获得所需的芯片。例如，俄罗斯的 GPS 卫星等价物因为在采购半导体方面遇到了问题而面临严重的延误。

Russia's ongoing difficulties with fabricating and acquiring chips explains why the country's drones shot down over Ukraine are full of foreign microelectronics. It also explains why Russia's military continues to rely extensively on non-precision-guided munitions. A recent analysis of Russia's war in Syria found that up to 95 percent of munitions dropped were unguided. The fact that Russia faced shortages of guided cruise missiles within several weeks of attacking Ukraine is also partly due to the sorry state of its semiconductor industry. Meanwhile, Ukraine has received huge stockpiles of guided munitions from the West, such as Javelin anti-tank missiles that rely on over 200 semiconductors each as they home in on enemy tanks.

俄罗斯目前在编造和获取芯片方面遇到的困难说明了该国在乌克兰领空遭击落的无人机中充斥着外国微电子的原因。这也解释了为什么俄罗斯军队继续大量依赖非精确制导弹药。最近对俄罗斯在叙利亚战争的分析表明，高达95％的弹药是非制导的。俄罗斯在攻击乌克兰数周后面临制导巡航导弹短缺的原因，部分原因也归因于半导体行业的状况。与此同时，乌克兰从西方获得了大量制导弹药库存，例如Javelin反坦克导弹，每个导弹需要使用200多个半导体对敌方坦克进行跟踪。

Russia’s dependence on foreign semiconductor technology has given the United States and its allies a powerful point of leverage. After Russia invaded, the U.S. rolled out sweeping restrictions on the sale of certain types of chips across Russia’s tech, defense, and telecoms sectors, which was coordinated with partners in Europe, Japan, South Korea, and Taiwan. Key chipmakers from America’s Intel to Taiwan’s TSMC have now cut off the Kremlin. Russia’s manufacturing sector has faced wrenching disruptions, with a substantial portion of Russian auto production knocked offline. Even in sensitive sectors like defense, Russian factories are taking evasive maneuvers such as deploying chips intended for dishwashers into missile systems, according to U.S. intelligence. Russia has little recourse other than to cut its consumption of chips, because its chipmaking capabilities today are even weaker than during the heyday of the space race.

俄羅斯對外國半導體技術的依賴給了美國及其盟友一個強大的籌碼。在俄羅斯入侵之後，美國在歐洲、日本、韓國和台灣等合作夥伴的協調下，對俄羅斯的技術、國防和電信等行業的某些類型的晶片銷售實行了全面限制。美國的英特爾和台灣的台積電等關鍵芯片生產商現在已經斷絕了與克里姆林宮的聯繫。俄羅斯的製造業面臨著劇烈的干擾，其中相當一部分俄羅斯汽車生產已經停擺。即使在像國防這樣敏感的領域，美國情報機構稱，俄羅斯工廠也正在採取迴避漏洞，如將用於洗碗機中的晶片部署到導彈系統中。俄羅斯沒有其他選擇，除了削減對晶片的消費，因為現今俄羅斯的芯片制造能力比太空競賽鼎盛期還要弱。

The emerging Cold War between the U.S. and China, however, will be a less lopsided match when it comes to semiconductors, given Beijing's investment in the industry and given that much of the chipmaking capacity America relies on is within easy range of PLA missiles. It would be naïve to assume that what happened in Ukraine couldn't happen in East Asia. Looking at the role of semiconductors in the Russia-Ukraine War, Chinese government analysts have publicly argued that if tensions between the U.S. and China intensify, " we must seize TSMC."

然而，随着美国和中国之间新兴的冷战，就半导体而言，这将是一场较少一边倒的竞争，考虑到北京在该行业的投资，以及美国所依赖的大部分芯片制造能力都在PLA导弹的易射程之内。假设在乌克兰所发生的事情在东亚不会发生是天真的。在俄罗斯与乌克兰战争中，若关系紧张，中国政府分析师公开争论："我们必须抢夺台积电(TSMC)"。

Cold War I had its own standoffs over Taiwan, in 1954 and again in 1958, after Mao Zedong's military barraged Taiwanese-held islands with artillery. Today Taiwan is within range of far more destructive Chinese forces—not only an array of short- and medium-range missiles but also aircraft from the Longtian and Huian airbases on the Chinese side of the Strait, from which it's only a seven-minute flight to Taiwan. Not coincidentally, in 2021, these airbases were upgraded with new bunkers, runway extensions, and missile defenses. A new Taiwan Strait crisis would be far more dangerous than the crises of the 1950s. There'd still be the risk of nuclear war, especially given China's growing atomic arsenal. But rather than a standoff over an impoverished island, this time the battleground would be the beating heart of the digital world. What's worse is that unlike in the 1950s, it's not clear the People's Liberation Army would eventually back down. This time, Beijing might wager that it could well win.

冷戰一期曾經爆發過兩次有關台灣的對峙，分別於1954年和1958年。當時，毛澤東的軍隊用炮火洶湧攻擊台灣防守的小島。如今，台灣已經處於更為破壞性的中國武裝力量範圍之內，不僅面臨著各種短中程導彈的威脅，還受到了來自廈門和龍田空軍基地的飛機威脅。從中國海峽對岸起飛，只需不到七分鐘，便可抵達台灣。一不做二不休，這兩座基地在2021年進行了升級，新建了掩體、擴建了跑道，並加強了對導彈的防禦。假如在現今的亞洲地區爆發新的台灣海峽危機，其危

險程度將遠勝於20世紀50年代的危機。雖然仍然存在核戰爭的風險，尤其是考慮到中國逐漸擴大的核武庫存，但這一次，戰場不再是一個貧困的島嶼，而是全球數字世界的中心。更糟糕的是，和1950年代不同的是，人民解放軍不確定是否會最終做出妥協。中國可能會賭上一切，認為自己可以贏得這場戰爭。

Conclusion

I t was only five days after People's Liberation Army forces began shelling the Taiwanese-held Quemoy Island in 1958 that, amid the sweltering Dallas summer, Jack Kilby demonstrated to his colleagues that all the components of a circuit—transistors, resistors, and capacitors—could be made from semiconductor materials. Four days after that, Jay Lathrop pulled into the Texas Instruments parking lot for the first time. He'd already filed for a patent on the process of making transistors via photolithography but had yet to receive the Army prize that enabled him to buy a new station wagon. Several months earlier, Morris Chang had left his job at a Massachusetts electronics firm and moved to Texas Instruments, earning a reputation for a nearly magical ability to eliminate errors from TI's semiconductor fabrication processes. That same year, Pat Haggerty was named president of Texas Instruments, with the board of directors betting that his vision of building electronics for military systems was a better business than producing the oil exploration instruments that the company had been founded to create. Haggerty had already assembled a talented team of engineers like Weldon Word, who were building the electronics needed for "smart" weapons and accurate sensors.

在1958年解放军开始炮轰台湾控制的金门岛仅五天后，杰克·基尔比就在炎热的达拉斯夏天向同事展示了一个电路的所有组件，包括晶体管、电阻器和电容器，都可以用半导体材料制造。四天后，杰伊·拉思罗普第一次驶入德州仪器公司的停车场。他已经申请了通过光刻制造晶体管的专利，但还没有获得军队奖励以购买新的旅行车。几个月前，莫里斯·张离开了马萨诸塞州的一家电子公司，搬到德州仪器公司，在消除TI半导体制造过程中的错误的神奇能力方面赢得声誉。同年，帕特·哈格蒂被任命为德州仪器公司的总裁，董事会打赌他建立电子军事系统的愿景比创造该公司创立的油气勘探仪器更好的业务。哈格蒂已经组建了像韦尔顿·沃德这样的工程师团队，为“智能”武器和精确传感器所需的电子产品打造了基础。

Texas was on the opposite side of the world from Taiwan, but it wasn't a coincidence that Kilby invented his integrated circuit amid a U.S.-China crisis. Defense dollars were flowing into electronics firms. The U.S. military was relying on technology to preserve its edge. With Soviet Russia and Communist China building industrial-scale militaries, the U.S. couldn't count on fielding bigger armies or more tanks. It *could* build more transistors, more precise sensors, and more effective communications equipment, all of which would eventually make American weapons far more capable.

德克薩斯州與臺灣相距遙遠，但基爾比在美中危機時期發明集成電路並非巧合。防衛資金源源不斷地流入電子公司。美國軍方依賴技術來保持優勢。由於蘇聯和中國共產黨建立了工業化軍隊，美國不能指望展開更大規模的軍事行動或擁有更多的坦克。它可以生產更多的晶體管、更精確的感應器和更有效的通訊設備，所有這些最終都會使美國的武器能力更強大。

Nor was it a coincidence that Morris Chang was seeking work in Texas rather than, say, Tianjin. For an ambitious child of an upper-class family, staying in China risked harassment or even death. Amid Cold War chaos and the disruptions of decolonization that swept the world, the best and the brightest from many countries tried to make their way to the United States. John Bardeen and Walter Brattain invented the first transistor, but it was their Bell Labs colleagues Mohamed Atalla and Dawon Kahng who devised a transistor structure that could be mass-produced. Two of the "traitorous eight" engineers who founded Fairchild Semiconductor with Bob Noyce were born outside the United States. A few years later, a sharp-elbowed Hungarian émigré formerly known as Andras Grof helped Fairchild optimize the use of chemicals in the company's chipmaking processes and set himself on a path to becoming CEO.

莫里斯·張(Morris Chang)在德克薩斯州尋求工作，而不是天津，這也並非巧合。對於一個上層階級家庭中充滿野心的孩子而言，留在中國可能會面臨騷擾甚至死亡的風險。在冷戰混亂和全球脫殖民化的混亂中，來自許多國家的最優秀的人才試圖前往美國。約翰·巴丁(John Bardeen)和沃爾特·布拉丁(Walter Brattain)發明了第一個晶體管，但是他們的貝爾實驗室同事穆罕默德·阿特拉(Mohamed Atalla)和多恩·卡恩(Dawon Kahng)設計出了一個可大量生產的晶體管結構。創立Fairchild

半導體公司的“叛逆的八個”工程師中有兩個出生在美國以外的地方。幾年之後，一個又一個精明能幹的匈牙利移民，原名安德拉斯·格羅夫 (Andras Grof) 的人協助Fairchild優化了公司的芯片製造工藝的化學物質的使用，並開啟了成為CEO的道路。

At a time when most of the world had never heard of silicon chips, and still fewer understood anything about how they worked, America’s centers of semiconductor production were drawing the world’s most brilliant minds to Texas, Massachusetts, and above all to California. These engineers and physicists were driven by the belief that miniaturizing transistors could quite literally change the future. They were proven right far beyond their wildest dreams. Visionaries like Gordon Moore and Caltech professor Carver Mead saw decades ahead, but Moore’s prediction from 1965 of “home computers” and “personal portable communications equipment” barely begins to describe the centrality of chips in our lives today. The idea that the semiconductor industry would eventually produce more transistors each day than there are cells in the human body was something the founders of Silicon Valley would have found inconceivable.

在世界大多数人还没有听说过硅芯片，更不了解它的工作原理时，美国半导体制造中心吸引了世界上最聪明的头脑到德克萨斯、马萨诸塞州和加利福尼亚州。这些工程师和物理学家被信念驱动，认为微型化晶体管可能会改变未来。他们的想法远远超越了他们最狂野的梦想。像戈登·摩尔和卡尔特克教授卡弗·米德这样的先见之士看得比较远，但是摩尔在1965年对“家用电脑”和“个人便携式通讯设备”的预测几乎无法描述芯片在我们生活中的重要性。硅谷创始人们认为半导体行业将最终每天生产比人体细胞还多的晶体管，这在他们看来是难以想象的。

As the industry’s scaled up, and transistors have scaled down, the need for vast, global markets is more important than ever. Today, even the Pentagon’s $700 billion budget isn’t big enough to afford facilities for building cutting-edge chips for defense purposes on U.S. soil. The Defense Department has dedicated shipyards for billion-dollar submarines and ten-billion-dollar aircraft carriers, but it buys many of the chips it uses from commercial suppliers, often in Taiwan. Even the cost of *designing* a leading-edge chip, which can exceed $100 million, is getting too expensive for the Pentagon. A facility to fabricate the most advanced logic chips costs twice as much as an aircraft carrier but will only be cutting-edge for a couple of years.

隨著產業的擴大和晶體管的縮小，需求全球龐大市場的必要性比以往任何時候都更加重要。現今，即便是五角大樓的 7000 億美元預算也不足以在美國本土建造製造最新芯片的設施。國防部為十億美元的潛艇和數十億美元的航空母艦保留了造船廠，但它購買的許多芯片卻來自商業供應商，常常是台灣。即使領先芯片的設計成本超過 1 億美元，這也對於國防部來說變得太過昂貴。製造最先進的邏輯芯片的設施成本是航空母艦的兩倍，但使用期只有幾年。

The staggering complexity of producing computing power shows that Silicon Valley isn't simply a story of science or engineering. Technology only advances when it finds a market. The history of the semiconductor is also a story of sales, marketing, supply chain management, and cost reduction. Silicon Valley wouldn't exist without the entrepreneurs who built it. Bob Noyce was an MIT-trained physicist, but he made his mark as a businessman, perceiving a vast market for a product that didn't yet exist. Fairchild Semiconductor's ability to "cram more components onto integrated circuits"—as Gordon Moore put it in his famous 1965 article—depended not only on the company's physicists and chemists, but also on hard-driving manufacturing bosses like Charlie Sporck. Pursuing union-free fabs and offering stock options to most employees drove productivity relentlessly higher. Transistors today cost far less than a millionth of their 1958 price thanks to the spirit expressed by the now-forgotten Fairchild employee who wrote on his exit survey when leaving the company: "I… WANT… TO… GET… RICH."

生產計算能力的驚人複雜性表明，硅谷不僅僅是科學或工程學的故事。技術只有在找到市場時才會進步。半導體的歷史也是一個關於銷售、市場推廣、供應鏈管理和成本降低的故事。沒有建立它的企業家，硅谷就不會存在。鮑勃·諾伊斯是一名麻省理工學院訓練有素的物理學家，但他以商人的身分留下了自己的印記，認識到一個還不存在的產品的廣泛市場。費爾德半導體公司"將更多元件集成到集成電路中"——正如戈登·摩爾在他1965年著名的文章中所說的那樣，這不僅取決於公司的物理學家和化學家，還取決於像查理·斯波克這樣的拼命製造老板。追求無工會製造和向大多數員工提供股票期權驅使生產力

不斷提高。由於那位現已被遺忘的費爾德員工在離開公司時在他的離職調查表上寫道：“我……要……發……財。”，現在的晶體管價格比1958年還要便宜幾乎百萬分之一。

On reflection, it’s too simple to say that the chip made the modern world, because our society and our politics have structured how chips were researched, designed, produced, assembled, and used. For example, DARPA, the Pentagon’s R&D unit, has literally shaped the semiconductor by funding crucial research into the 3D transistor structures, called FinFETs, used in the most advanced logic chips. And in the future China’s deluge of subsidies will profoundly reshape the semiconductor supply chain, whether China achieves its goal of semiconductor supremacy or not.

反思之后，断言芯片使现代世界变得太过简单，因为我们的社会和政治构建了芯片的研究、设计、生产、组装和使用。例如，五角大楼的研发单位DARPA通过资助关键的研究，如用于最先进的逻辑芯片中的3D晶体管结构FinFETs，实际上塑造了半导体行业。未来，中国的大量补贴将彻底重塑半导体供应链，无论中国是否实现半导体霸权。

There’s no guarantee, of course, that chips will remain as important as they’ve been in the past. Our demand for computing power is unlikely ever to diminish, but we *could* run out of supply. Gordon Moore’s famous law is only a prediction, not a fact of physics. Industry luminaries from Nvidia CEO Jensen Huang to former Stanford president and Alphabet chairman John Hennessy have declared Moore’s Law dead. At some point, the laws of physics will make it impossible to shrink transistors further. Even before then, it could become too costly to manufacture them. The rate of cost declines has already significantly slowed. The tools needed to make ever-smaller chips are staggeringly expensive, none more so than the EUV lithography machines that cost more than $100 million each.

當然，並沒有保證晶片仍能像過去一樣重要。我們對於計算能力的需求不可能減少，但供應可能會枯竭。戈登·摩爾的著名定律只是一個預測，而非物理事實。從 Nvidia CEO Jensen Huang 到前 Stanford 總統兼 Alphabet 主席 John Hennessy 等行業專家都宣布摩爾定律已死亡。在某些時候，物理定律將使得進一步縮小晶體管變得不可能。在此之前，它的製造成本可能會太高。成本的降低率已經顯著減緩。製造越來越

小的晶片需要投入巨額資金，其中最昂貴的是耗資逾一億美元的 EUV 光刻機。

The end of Moore’s Law would be devastating for the semiconductor industry—and for the world. We produce more transistors each year only because it’s economically viable to do so. This isn’t the first time, though, that Moore’s Law has been declared near dead. In 1988, Erich Bloch, an esteemed expert at IBM and later head of the National Science Foundation, declared that Moore’s Law would stop working when transistors shrank to a quarter of a micron—a barrier that the industry bashed through a decade later. Gordon Moore worried in a 2003 presentation that “business as usual will certainly bump up against barriers in the next decade or so,” but all these potential barriers were overcome. At the time, Moore thought a 3D transistor structure was a “radical idea,” but less than two decades later, we’ve already produced trillions of these 3D FinFET transistors. Carver Mead, the Caltech professor who coined the phrase “Moore’s Law,” shocked the world’s semiconductor scientists with his prediction half a century ago that chips might eventually contain 100 million transistors per square centimeter. Today, the most advanced fabs can squeeze a hundred times as many transistors on a chip than even Mead thought possible.

摩尔定律的终结将对半导体行业及全球造成毁灭性影响。之所以每年能够生产更多晶体管，是因为这样做在经济上是可行的。然而，这并不是第一次宣布摩尔定律濒临死亡。1988年，IBM著名专家、后来的美国国家科学基金会主席Erich Bloch曾宣布，当晶体管缩小到四分之一微米时，摩尔定律将停止发挥作用——而十年后，该行业击穿了这一障碍。2003年，戈登·摩尔在一次演讲中担心“惯常商业活动将肯定在接下来的十年或这样碰到障碍”，但所有这些潜在障碍都被克服了。当时，摩尔认为3D晶体管结构是一个“激进的想法”，但不到两十年后，我们已经生产了数万亿个这样的3D FinFET晶体管。卡弗·米德（Carver Mead）是发明“摩尔定律”一词的加州理工学院教授，他在半个世纪前预测，芯片最终可能包含每平方厘米1亿个晶体管，震惊了全球半导体科学家。如今，最先进的晶圆厂可以在一块芯片上挤入比米德认为可能的晶体管数量多100倍的晶体管。

The durability of Moore’s Law, in other words, has surprised even the person who it’s named after and the person who coined it. It may well surprise today’s pessimists, too. Jim Keller, the star semiconductor designer who’s widely credited for transformative work on chips at Apple, Tesla, AMD, and Intel, has said he sees a clear path toward a fifty times increase in the density with which transistors can be packed on chips. First, he argues, existing fin-shaped transistors can be printed thinner to allow three times as many to be packed together. Next, fin-shaped transistors will be replaced by new tube-shaped transistors, often called “gate-all-around.” These are wire-shaped tubes that let an electric field be applied from all directions—top, sides, and bottom—providing better control of the “switch” to cope with challenges as transistors shrink. These tiny wires will double the density at which transistors can be packed, Keller argues. Stacking these wires on top of each other can increase density eight times further, he predicts. This adds up to a roughly fifty times increase in the number of transistors that can fit on a chip. “We’re not running out of atoms,” Keller has said. “We know how to print single layers of atoms.”

摩尔定律的耐久性甚至出乎命名人和创造者的预料。今天的悲观主义者也许会感到惊讶。被广泛认为在苹果、特斯拉、AMD和英特尔等公司进行了变革性的芯片工作的明星半导体设计师吉姆·凯勒表示，他看到了在芯片上打包晶体管的密度可以增加50倍的明显路径。首先，他认为现有的鳍形晶体管可以印刷得更薄，以便将三倍的晶体管打包在一起。其次，鳍形晶体管将被新的管形晶体管取代，通常称为“全环门”晶体管。这些是线状管，可从上、侧和下方施加电场，提供更好的“开关”控制，以适应随着晶体管缩小而带来的挑战。凯勒认为，这些微小的导线将使晶体管的密度加倍。将这些导线叠放在彼此上方可以进一步增加8倍的密度，他预测。这相当于晶体管数量约增加50倍。“我们没有原子耗尽的问题，”凯勒曾表示。“我们知道如何印刷单层原子。”

For all the talk of Moore’s Law ending, there’s more money than ever before flowing into the chip industry. Startups designing chips optimized for AI algorithms have raised billions of dollars in the past few years, each hoping that they can become the next Nvidia. Big tech firms—Google, Amazon, Microsoft, Apple, Facebook, Alibaba, and others—are now pouring money into designing their own chips. There’s clearly no deficit of innovation.

The best argument in favor of the thesis that Moore’s Law is ending is that all this new activity in chips for specific purposes, or even for individual companies, is displacing the improvements in “general-purpose” computing that Intel’s regular cadence of ever-more-powerful microprocessors provided for the past half century. Neil Thompson and Svenja Spanuth, two researchers, have gone so far as to argue that we’re seeing a “decline of computers as a general purpose technology.” They think the future of computing will be divided between “‘fast lane’ applications that get powerful customized chips and ‘slow lane’ applications that get stuck using general-purpose chips whose progress fades.”

盡管外界纷纷表示摩尔定律即将结束，但芯片产业正迎来前所未有的投资。过去几年，专门设计优化AI算法的初创公司已筹集了数十亿美元的资金，每个公司都希望成为下一个英伟达。谷歌、亚马逊、微软、苹果、Facebook、阿里巴巴等大型科技公司都在大举投资设计自己的芯片。可以明显看出，这一行业并未缺乏创新意识。 摩尔定律即将结束的最有力证据是，针对特定目的甚至个别公司专门设计芯片的新活动正在取代英特尔过去半个世纪中提供的“通用计算”改进，即不断提高微处理器的计算能力。两位研究者Neil Thompson和Svenja Spanuth甚至认为，我们正在见证计算机作为通用技术的“衰退”，未来计算机将被分为“快车道”应用程序和“慢车道”应用程序。前者能够获得功能强大的定制芯片，而后者则只能使用进展缓慢的通用芯片。

It’s undeniable that the microprocessor, the workhorse of modern computing, is being partially displaced by chips made for specific purposes. What’s less clear is whether this is a problem. Nvidia’s GPUs are not general purpose like an Intel microprocessor, in the sense that they’re designed specifically for graphics and, increasingly, AI. However, Nvidia and other companies offering chips that are optimized for AI have made artificial intelligence far cheaper to implement, and therefore more widely accessible. AI has become a lot more “general purpose” today than was conceivable a decade ago, largely thanks to new, more powerful chips.

不可否认的是，现代计算机的工作马力微处理器正被为特定目的而制造的芯片所部分取代。不过问题的关键是，这是否为问题。Nvidia的GPU不像英特尔微处理器那样是通用的，因为它们被专门设计用于图形和越来越多的人工智能。然而，优化用于人工智能的芯片的Nvidia

和其他公司已经使人工智能的实现成本大大降低，因此更加普及。如今的人工智能比十年前更加“通用”，这在很大程度上要感谢新的，更强大的芯片。

The recent trend of big tech firms like Amazon and Google designing their own chips marks another change from recent decades. Both Amazon and Google entered the chip design business to improve the efficiency of the servers that run their publicly available clouds. Anyone can access Google's TPU chips on Google's cloud for a fee. The pessimistic view is to see this as a bifurcation of computing into a "slow lane" and a "fast lane." What's surprising though, is how easy it is for almost anyone to access the fast lane by buying an Nvidia chip or by renting access to an AI-optimized cloud.

近年來Amazon和Google等大型科技公司開始設計自己的晶片，這標誌著另一個近幾十年的變化。Amazon和Google都進入了晶片設計行業，以提高運行其公開可用雲端的服務器的效率。任何人都可以付費使用Google雲端上的TPU晶片。悲觀的看法是將其視為計算分為“慢車道”和“快車道”的二元分化。但是，讓人驚訝的是，通過購買Nvidia晶片或租用AI優化的雲端，幾乎任何人都可以輕鬆地進入快車道。

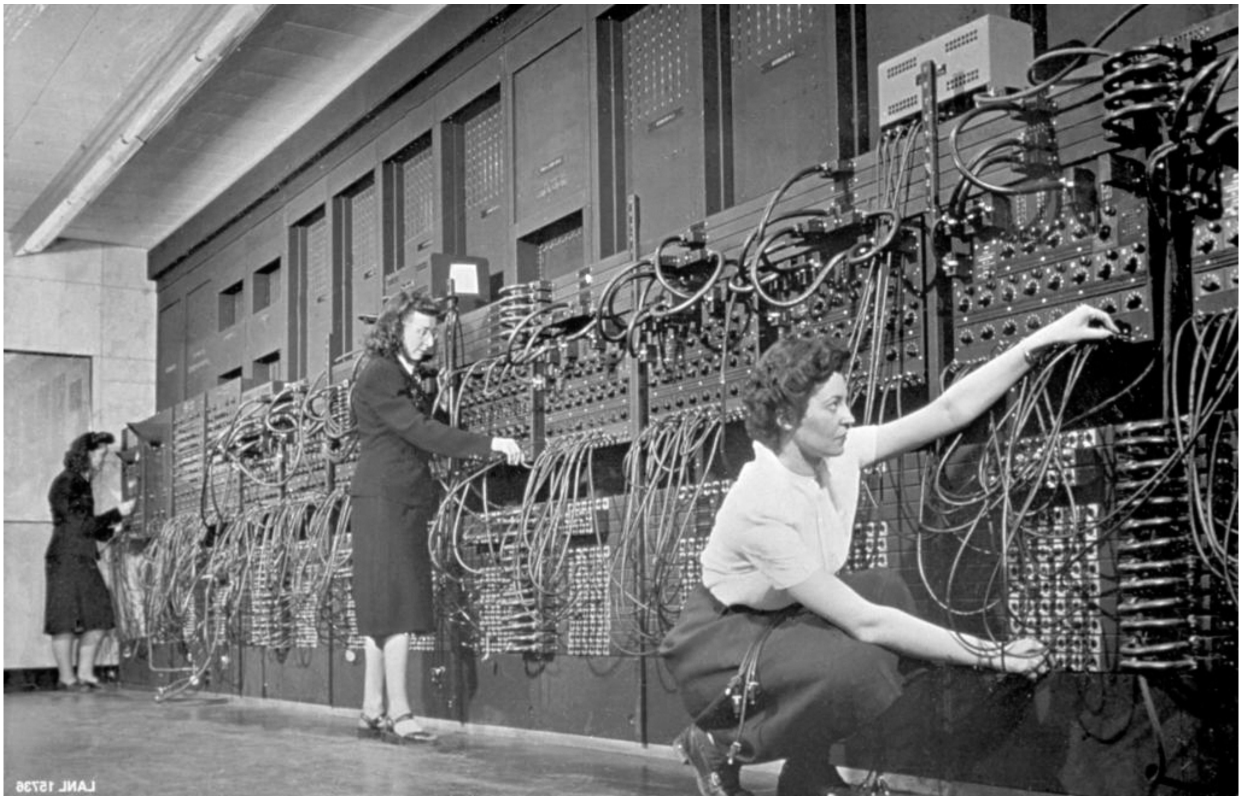
Moreover, it's easier than ever before to combine different types of chips. In the past, a device would often have a single processor chip. Now it might have multiple processors, some focused on general operations, with others optimized to manage specific features like a camera. This is possible because new packaging technologies make it easier to connect chips efficiently, letting companies easily swap certain chips in or out of a device as processing requirements or cost considerations change. Big chipmakers are now putting more thought than ever before into the systems in which their chips will operate. So the important question isn't whether we're finally reaching the limits of Moore's Law as Gordon Moore initially defined it—exponential increase in the number of transistors per chip—but whether we've reached a peak in the amount of computing power a chip can cost-effectively produce. Many thousands of engineers and many billions of dollars are betting not.

此外，现在比以往任何时候都更容易组合不同类型的芯片。过去，一个设备通常只有一个处理器芯片。现在可能有多个处理器，其中有些

专注于通用操作，而其他优化以处理特定功能，如相机。这是可能的，因为新包装技术使连接芯片更加高效，使公司能够轻松地交换某些芯片进出设备，以适应处理要求或成本考虑的变化。大型芯片制造商现在比以往任何时候都更加深入地考虑其芯片将运行的系统。因此，重要的问题不是我们是否最终达到了戈登·摩尔最初定义的每个芯片晶体管数量的指数增长的极限，而是我们是否已经达到了一个芯片可以以费用效益的方式产生的计算能力峰值。许多数千名工程师和数十亿美元正在进行投注。

Back in December 1958—the same year that saw Morris Chang, Pat Haggerty, Weldon Word, Jay Lathrop, and Jack Kilby all assembled at Texas Instruments—an electronics conference took place in a wintry Washington, D.C. Attending that day were Chang, Gordon Moore, and Bob Noyce, who all went out for beers and then, in the day's waning hours, meandered back to their hotel, young and excited, singing amid the snowdrifts. No one they passed in the street would have guessed these were three future titans of technology. Yet they've left an enduring imprint not only on billions of silicon wafers but on all our lives. The chips they invented and the industry they built provide the hidden circuitry that's structured our history and will shape our future.

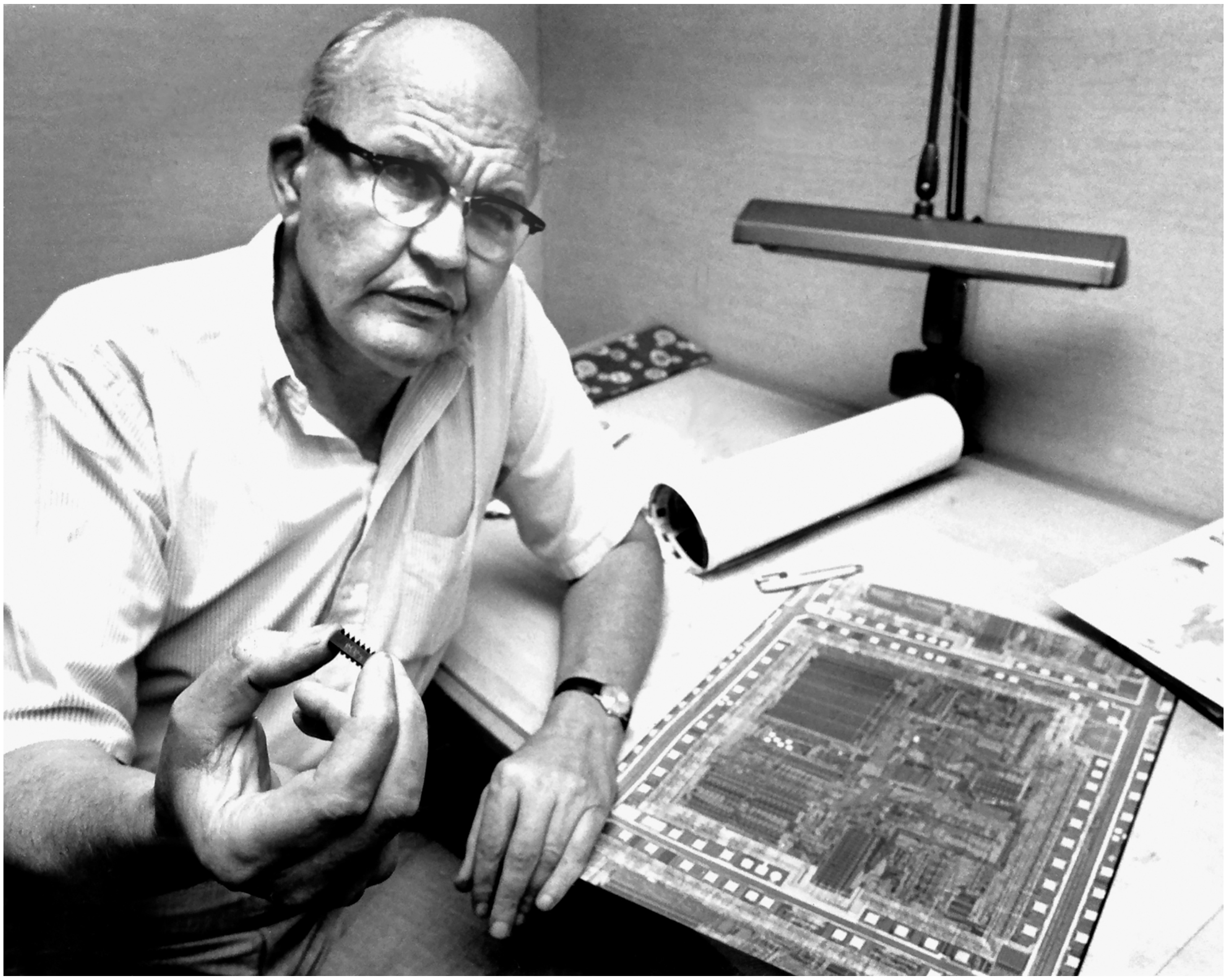
回到1958年12月——同年莫里斯·張、帕特·哈格蒂、韋爾登·華德、傑·拉思羅普和傑克·基爾比都在德州儀器公司聚集时——在一个寒冷的華盛頓特區，一場電子學會議舉行。當天出席的有張忠謀、戈登·摩爾和鮑勃·諾伊斯，他們一起喝啤酒，然後在日漸消逝的夜晚裡漫步回到自己的旅館，年輕而興奮，在積雪中歌唱。走在街上的人都不會猜到這三個未來的科技巨頭。然而，他們不僅在數十億個矽晶圓上留下了持久的印記，也改變了我們所有人的生活。他們發明的晶片和他們建立的行業，提供了結構化我們歷史的隱藏電路，將影響我們的未來。



Today’s computers and smartphones run on chips containing billions of microscopic transistors, the tiny electric switches that flip on and off to represent information. As such, they are unfathomably more capable than the U.S. Army’s ENIAC computer, which was state of the art for 1945. That device contained a mere 18,000 “switches.” (Getty Images)

Bob Noyce (*center*) cofounded Fairchild Semiconductor in 1957 with the goal of building silicon transistors. Also pictured is Noyce's longtime partner Gordon Moore (*far left*) as well as Eugene Kleiner (*third from left*), who later founded Kleiner Perkins, America's most powerful venture capital firm. (Wayne Miller/Magnum Photos)

現今的電腦和智慧型手機搭載了數十億個微小的晶體管晶片，這些微小的開關可以表示資訊的打開和關閉。因此，它們比美國陸軍的ENIAC電腦強大得難以想像，而該電腦在1945年是當時的頂尖裝備，只有18,000個“開關”。（Getty Images）鮑勃·諾伊斯（Bob Noyce）（中）在1957年創立了費爾柴爾德半導體公司，旨在建造矽晶體管。圖中還有諾伊斯的長期合作夥伴戈登·摩爾（Gordon Moore）（最左）、和後來創立了美國最強大的風險投資公司——克萊納·帕金斯（Kleiner Perkins）的尤金·克萊納（Eugene Kleiner）（最左第三個）。（韋恩·米勒/馬格南照片）



In 1958, Jack Kilby at Texas Instruments built multiple electronic components on a single block of semiconductor material—the first “integrated circuit,” or “chip.” (*Dallas Morning News*)

Bob Noyce realized it was the civilian computer market, not the military, that would drive chip demand. He aggressively cut prices so that chips could be plugged into civilian computers, fueling the industry's growth. (Ted Streshinsky/Getty Images)

The first major order for Texas Instruments' chips was for the guidance computer on the Minuteman II missile, pictured here. (Dave Fields)

1958年，德州儀器公司的傑克·基爾比在一塊半導體材料上建造了多個電子元件，這是第一個“集成電路”或“晶片”。（達拉斯晨報） 鮑勃·諾伊斯意識到民用計算機市場而不是軍方將推動晶片需求。他積極降價以便晶片能夠插入民用計算機，推動了產業的增長。(泰德·斯特雷辛斯基/盖蒂图片社) 德州儀器公司晶片的第一個主要訂單是用於圖中的Minuteman II導彈的制導計算機。(戴夫·菲爾茲)

KGB spies Alfred Sarant and Joel Barr, both of whom grew up in New York, defected to the USSR to help build the Soviet computer industry. Despite the Soviets’ pilfering, they failed to find the cutting edge. (Barr Papers/Steven Usdin)

At Texas Instruments, Weldon Word used microelectronics to build the first laser-guided bomb, which was first used to strike a bridge in Vietnam that had previously been missed by hundreds of “dumb” bombs. (Mark Perlstein/Getty Images)

In the 1980s Japan challenged the U.S. for semiconductor dominance. Akio Morita and Masaru Ibuka, cofounders of Sony, pioneered transformative products like the Sony Walkman, which proved that Asian firms could not only manufacture effectively but also win lucrative consumer markets. (Sony)

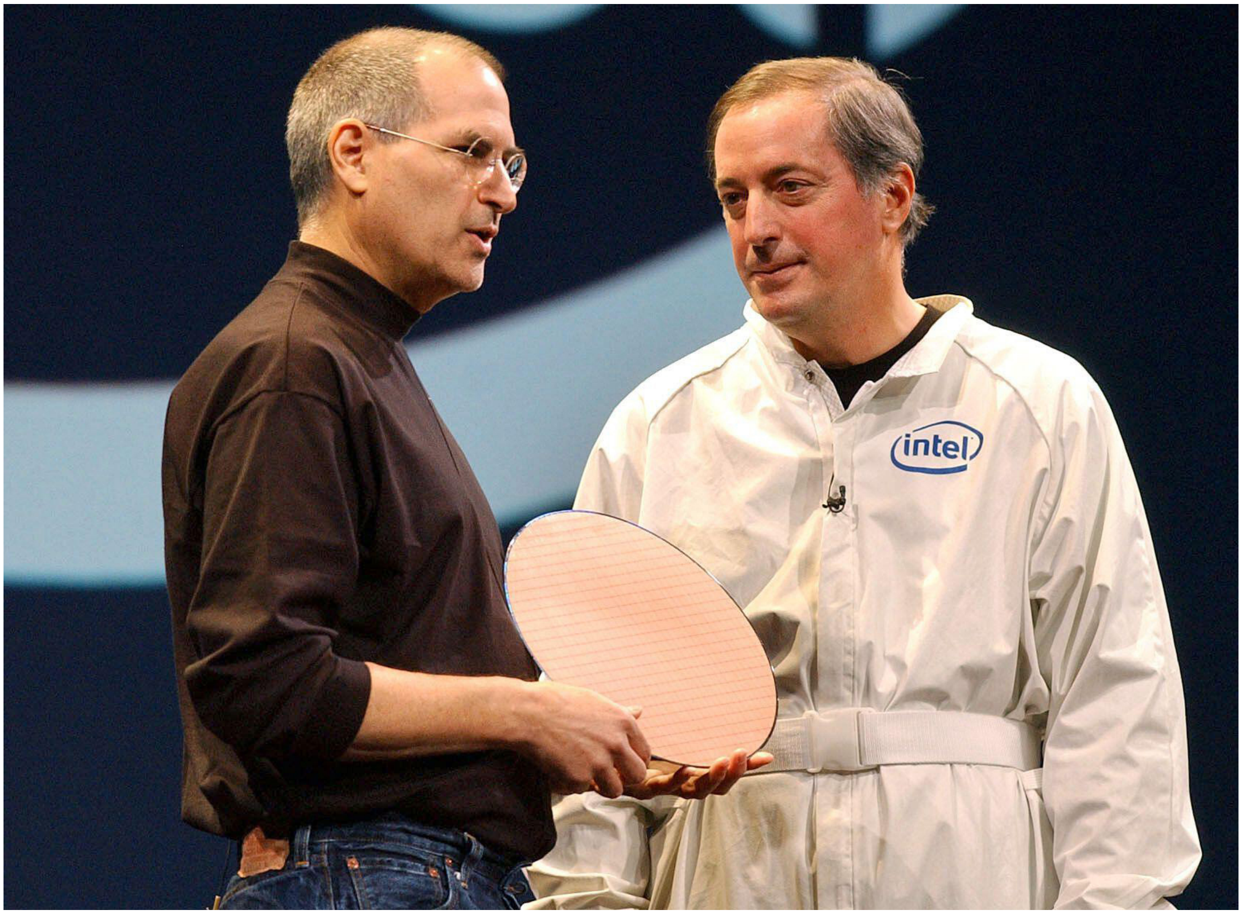
KGB特務阿爾弗雷德·薩倫特和喬爾·巴爾兩人都在紐約長大，叛逃到蘇聯幫助建立蘇聯計算機產業，儘管蘇聯曾盜取技術，但未能找到前沿技術。（巴爾文件/史蒂芬·厄斯丁） 威爾登·沃德在德州儀器公司（Texas Instruments）利用微電子學建造了第一枚激光制導炸彈，首次用於越南轟炸那座先前被數百枚“笨炸彈”錯過的橋樑。（馬克·蓬恩斯坦/蓋蒂图片社） 1980年代，日本挑戰美國在半導體領域的主導地位。索尼的創始人盛田昭夫和井深大統一率先開創了變革性產品，如Sony Walkman，證明亞洲公司不僅能有效製造，而且還能贏得有利可圖的消費市場。（索尼）

American semiconductor assembly plants across Asia provided thousands of jobs for America’s allies. Pictured here are women at an Intel facility in Penang, Malaysia, that opened in 1972. “The workers were predominantly women,” Intel explained, “because they performed better on dexterity tests.” (Intel)

When Morris Chang was passed over for the CEO job at Texas Instruments, he moved to Taiwan where he founded Taiwan Semiconductor Manufacturing Company and built the country’s chip industry. TSMC is one of Asia’s most valuable companies. (Bloomberg/Getty Images)

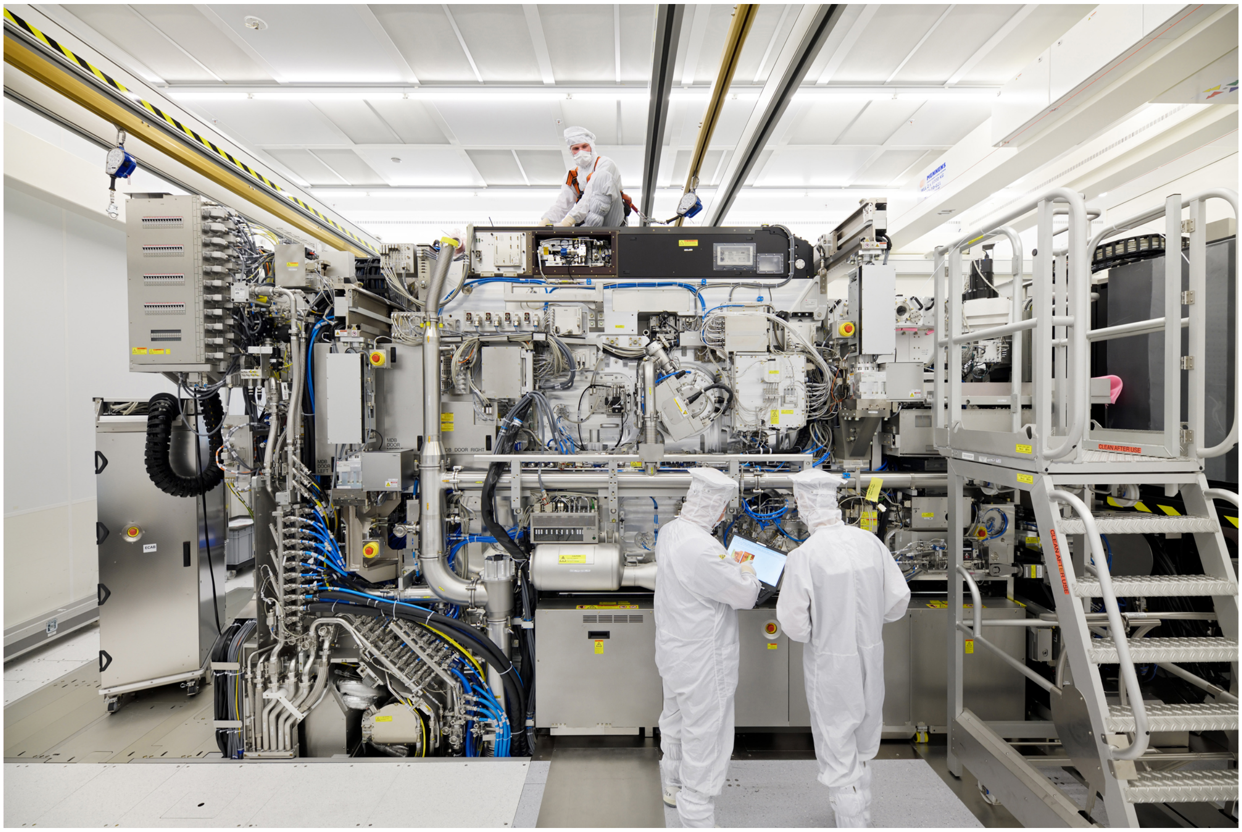
美國在亞洲的半導體裝配廠提供了數千個工作機會給美國的盟友。這裡展示的是1972年在馬來西亞檳城成立的英特爾工廠的女性工人。英特爾解釋說，“工人主要是女性，因為她們在靈巧測試方面表現更好。”（英特爾） 當莫里斯·張在得州儀器公司的首席執行官職位上被忽視時，他移居台灣，在那裡創立了台灣積體電路製造公司，建立了該國的芯片產業。台積電是亞洲最有價值的公司之一。（彭博社/盖蒂图片社）

Facing competition from Asia, American chipmakers competed on innovation. Intel's Andy Grove, who took over as CEO after Gordon Moore, forged an alliance with Bill Gates. Forty years later, Microsoft's Windows software and Intel's x86 chips continue to dominate the PC business. (AP Photo/Paul Sakuma)

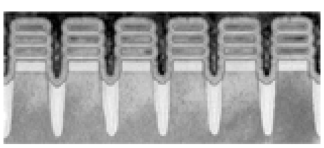


In what proved to be a colossally bad decision, Intel turned down Steve Jobs's proposal to build chips for Apple's mobile phones. "I couldn't see it," Intel CEO Paul Otellini would later say. (Karl Mondon/Abaca Press)

面对来自亚洲的竞争，美国芯片制造商竞争创新。在戈登·摩尔之后担任CEO的英特尔的安迪·格鲁夫与比尔·盖茨结盟。四十年后，微软的Windows软件和英特尔的x86芯片仍然主导着PC业务。（美联社照片/保罗·萨库马） 证明是一个巨大的错误决定，英特尔拒绝了史蒂夫·乔布斯为苹果手机建造芯片的提议。“我看不到它，”英特尔首席执行官保罗·奥特里尼后来会说。（Karl Mondon / Abaca Press）

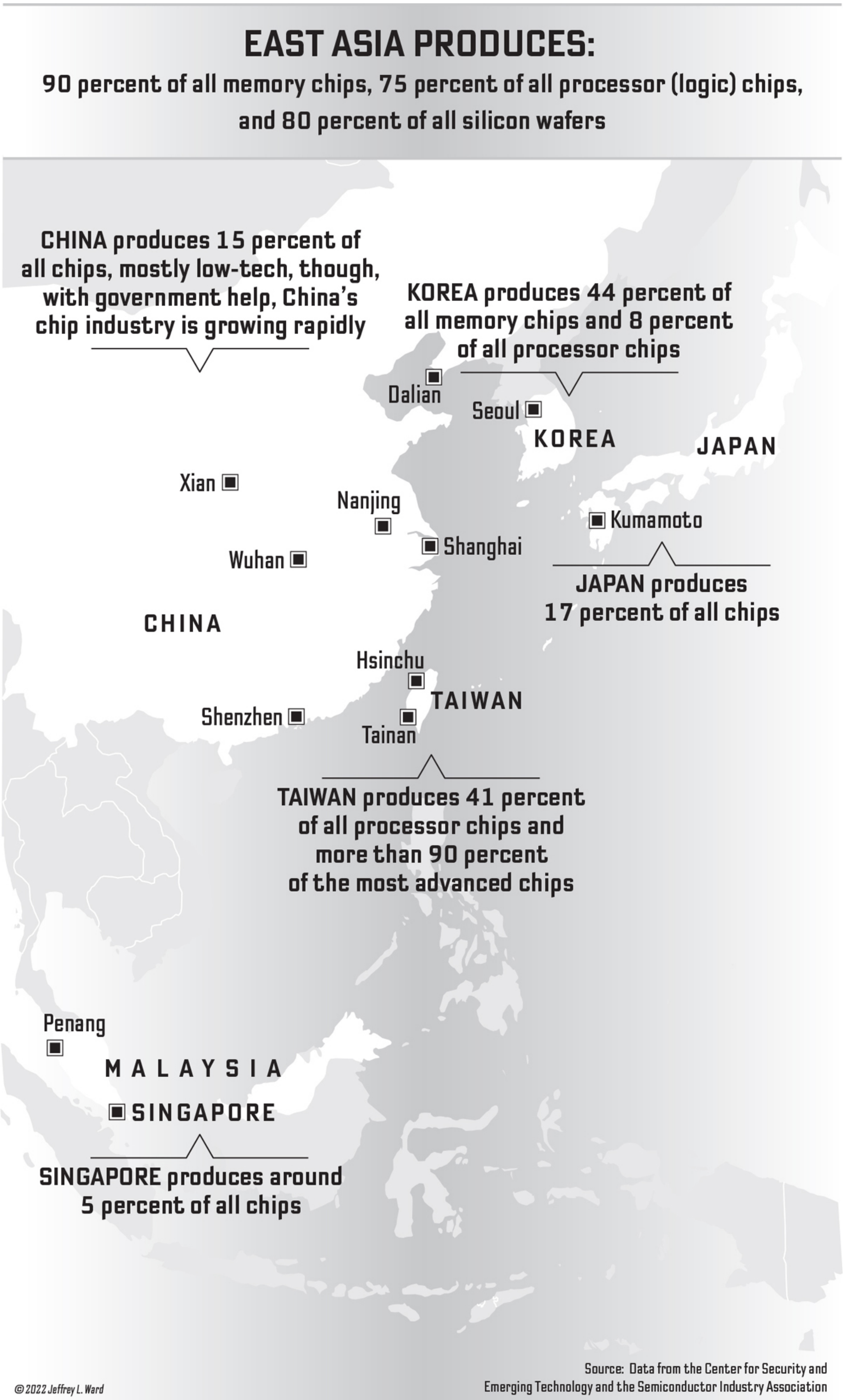


The most advanced lithography machines, which are used to pattern millions of microscopic transistors, each far smaller than a human cell, are made by ASML in the Netherlands. Each machine costs well over $100 million dollars and is built from hundreds of thousands of components. (ASML)



Today, advanced chips possess tiny, three-dimensional transistors, each smaller than a coronavirus, measuring a handful of nanometers (billionths of a meter) wide. (IBM)

最先進的光刻機，用於製作數百萬個微小過電晶體的圖案，每個晶體比人體細胞還要小，在荷蘭由ASML製造。每台機器的成本遠遠超過1億美元，由數十萬個零件組成。(ASML) 今天，先進的晶片擁有微小的三維過電晶體，每個比冠狀病毒還要小，寬度僅數十納米（十億分之一米）。(IBM)


EAST ASIA PRODUCES:
90 percent of all memory chips, 75 percent of all processor (logic) chips, and 80 percent of all silicon wafers
CHINA produces 15 percent of all chips, mostly low-tech, though, with government help, China's chip industry is growing rapidly
KOREA produces 44 percent of all memory chips and 8 percent of all processor chips
Dalian
Seoul
KOREA
JAPAN
Xian
Nanjing
Kumamoto
Shanghai
Wuhan
JAPAN produces 17 percent of all chips
CHINA
Hsinchu
TAIWAN
Shenzhen
Tainan
TAIWAN produces 41 percent of all processor chips and more than 90 percent of the most advanced chips
Penang
MALAYSIA
SINGAPORE
SINGAPORE produces around 5 percent of all chips
Source: Data from the Center for Security and Emerging Technology and the Semiconductor Industry Association
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Acknowledgments

Fabricating a cutting-edge chip involves hundreds of process steps and a supply chain that stretches across multiple countries. Writing this book was only slightly less complex than making a chip. I'm grateful to the many people, in many countries, who have helped along the way.

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Notes

Introduction

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