The Semiconductor Industry Ecosystem

ELEN 4944
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Introduction

- Today we're going to be mostly non-technical
- We'll be discussing the semiconductor industry in general (and some tech insights)
- Who are the players? How do they interact?
- Why should you care?

Lay of The Land (USA)

Top S&P 500 Companies By Market Cap

Rank	1990	2024
1	IBM	Apple
2	Exxon Mobil	Nvidia
3	General Electric	Microsoft
4	Phillip Morris	Alphabet
5	Shell	Amazon
6	Bristol Myers Squibb	Meta
7	Merck	Eli Lilly
8	Walmart	Broadcom
10	AT&T	Tesla
10	Coca-Cola	JP Morgan Chase

Data courtesy of Visual Capitalist

Lay of The Land (USA)

- The tech industry dominates the US economy

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8	Walmart	Broadcom
10	AT&T	Tesla
10	Coca-Cola	JP Morgan Chase

All of these companies design or produce semiconductor devices

Data courtesy of Visual Capitalist

Lay of The Land (China)

- Similar story in China
- More representation from industrials and banking here, but also a lot of tech

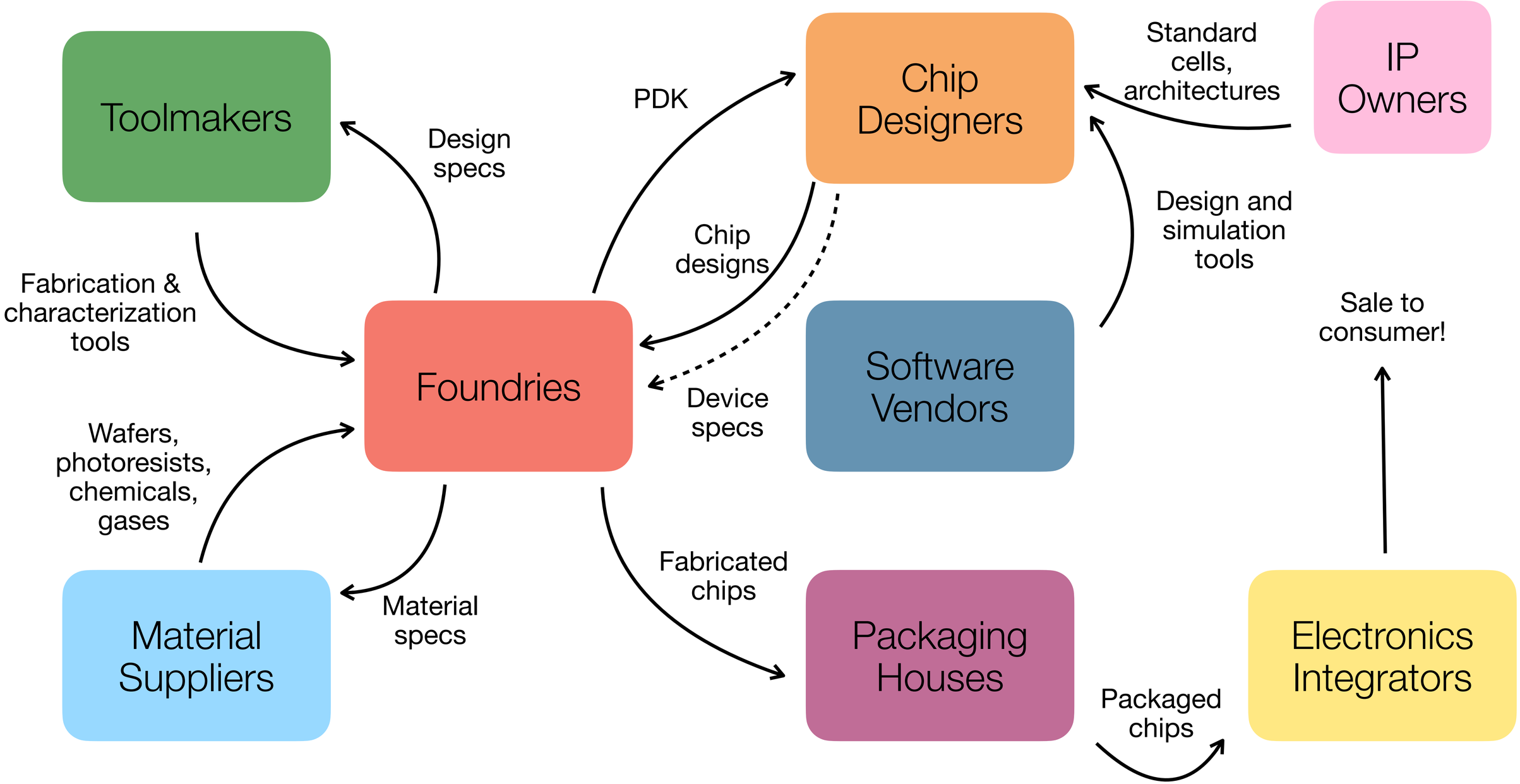
Top Companies in China
By Market Cap

Rank	2024
1	Tencent
2	Alibaba
3	ICBC
4	Kweichow Moutai
5	Agricultural Bank of China
6	China Mobile
7	China Construction Bank
8	Bank of China
10	PetroChina
10	Xiaomi

Data courtesy of Visual Capitalist

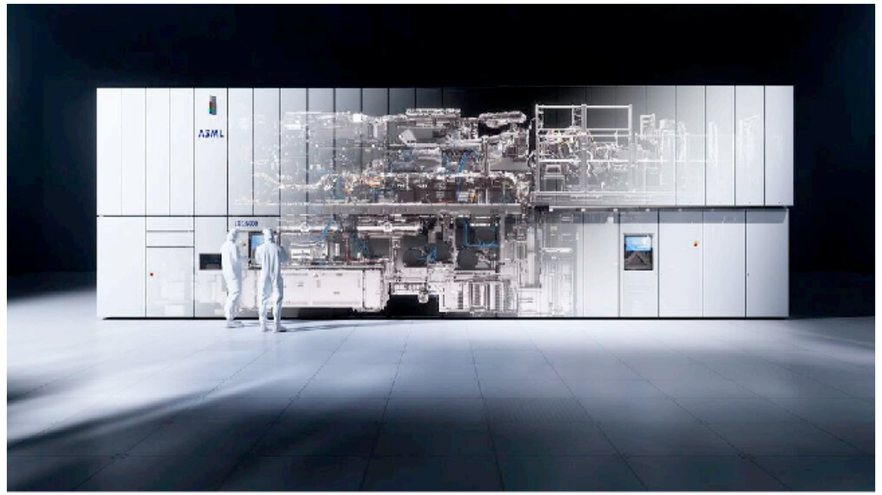
Note: some well-known companies (e.g. Huawei) are missing from this list because they are not publicly traded

The Ecosystem



Tool Suppliers

- Sell tools to the foundry
- Typically specialized into a certain part of the fabrication process (e.g. lithography, deposition, characterization)
- ASML → EUV lithography tools (Nikon and Canon also work on this, but less advanced)
- Applied Materials, Lam Research, Tokyo Electron → General fab tools. Etching, deposition, cleaning, CMP.
- Equipment costs are high (10s to 100s of millions USD) and lead times are long (years)



EUV Litho Tool - Credit: ASML

CMP Tool - Credit: Applied Materials

Materials Suppliers

- Sell materials to the foundries
- These materials may take years to develop and qualify for use in the foundry
- Chemicals (acids, solvents) → Merck
- Photoresists → JSR, Tokyo Okha Kogyo
- Bare Si wafers → Shin-Etsu, SUMCO
- Broadly, dominated by companies based in Japan

Silicon boule and wafers - Credit: Shin-Etsu Chemical Co.

Software Vendors

- Build software suites that help design chips, sell it to chip designers → “Electronic Design Automation (EDA)
- There are really only 3 players here: Cadence, Synopsys, and Siemens
- Other softwares exist for niche applications (RF, electromagnetics, etc.)
- Very few companies operating in this part of the market.
- Disruption opportunity here?

cādence

SYNOPSYS®

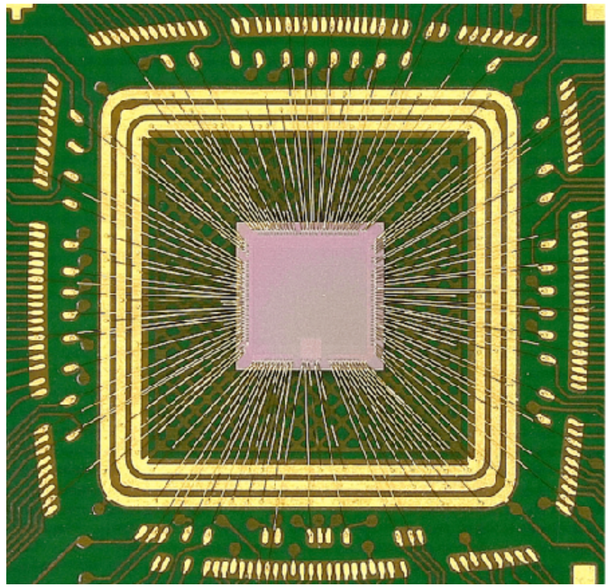
SIEMENS

Software Vendors

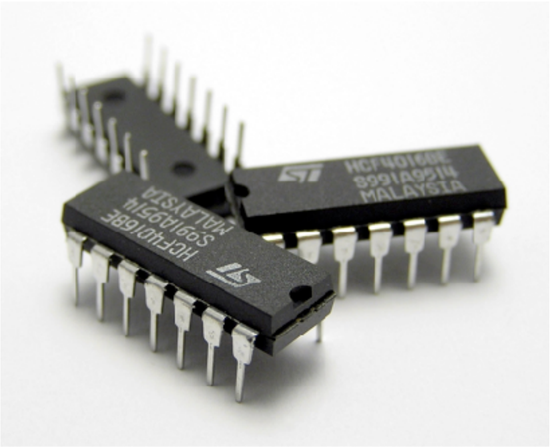
- Well, not really. Even though software is cheap to make.
- Chip designers are very “locked in” to existing solutions.
- Designers build internal tools to work with solutions they buy → Buying a new design suite means re-building tools to make them work together
- It seems like the big three EDA companies will keep collecting their licensing fees for a long time…

Packaging Houses

- Hired by foundries to take finished dies, package them into electronics people can use
- Many players in this space: ASE Technology, JCET, Powertech, Lingsen
- Primarily based in East Asia and SE Asia
- As packaging has become more complex, foundries have gotten more involved in the process



Wire bonded chip die - Credit: QP Technologies



Packaged ICs - Credit OpenPhoto

Chip Designers & IP Vendors

- Use software (from vendors) and PDK (from foundry) to design chips. Pay foundry to fabricate them.
- There are a lot of these. Think: Nvidia, Apple, AMD, Qualcomm, Broadcom
- This is the most “asset-light” part of the industry. You need software licenses and engineers to design, but no billion dollar start-up cost.
- Some design is done in-house, but some designs are also licensed from other companies.
- Certain companies (ARM is the best known) make this their entire business: design system block, sell the right to use them to other designers.

Intel Office - Credit: Getty Images

Case Study: The Fabless Revolution

Meta

Silicon Architect, Reality Labs

Redmond, WA · Reposted 1 week ago · 31 people clicked apply
Promoted by hirer · Responses managed off LinkedIn

$142K/yr - $203K/yr | Full-time

Microsoft

Principal Hardware Engineer

Austin, TX · Reposted 1 week ago · 86 people clicked apply
Promoted by hirer · Responses managed off LinkedIn

$139.9K/yr - $304.2K/yr | Hybrid | Full-time

Apply | Save

Amazon

Sr. ASIC Design Engineer, Blink/Ring ASIC Tea

Hawthorne, CA · Reposted 1 day ago · Over 100 people c
Promoted by hirer · Responses managed off LinkedIn

$143.3K/yr - $247.6K/yr | Full-time

Apply | Save

RFIC Design Engineer

San Diego, California, United States
Hardware

Work Locations (2)
San Diego, California, United States

Submit Resume

Google

CMOS Device and PPA Engineer, Silicon

San Diego, CA · Reposted 1 week ago · 55 people clicked apply
Promoted by hirer · Responses managed off LinkedIn

$183K/yr - $271K/yr | On-site | Full-time

Apply | Save

SpaceX

Physical Design Engineer (Silicon Engineering)

Sunnyvale, CA · 2 weeks ago · Over 100 people clicked apply
Promoted by hirer · Responses managed off LinkedIn

$130K/yr - $155K/yr | On-site

Apply | Save

Draper

Digital ASIC Design Engineer

Cambridge, MA · 3 days ago · Over 100 people clicked apply
Promoted by hirer · Responses managed off LinkedIn

$62.5K/yr - $125K/yr | Full-time

Apply

Volkswagen of America, Inc

Senior Hardware (Must have Modem; Infotainment; RF) Engineer

Belmont, CA · Reposted 2 weeks ago · Over 100 people clicked apply
Promoted by hirer · Responses managed off LinkedIn

$160K/yr - $190K/yr | Hybrid | Full-time

Apply | Save

Qualcomm

VLSI Design Optimization Engineer

San Diego, CA · Reposted 2 weeks ago · Over 100 people clicked apply
Promoted by hirer · Responses managed off LinkedIn

Full-time

Apply | Save

Broadcom

IC Design Engineer

Irvine, CA · Reposted 1 week ago · 86 peo
Promoted by hirer · Responses managed

$120K/yr - $192K/yr | Full-time

Apply | Save

ASIC Design Engineer Graduate (Video Silicon IP) - 2026 Start (BS/MS)

Location: San Jose
Team: Technology
Employment Type: Regular
Job Code: A47861

ByteDance

OpenAI Careers

Silicon Implementation Engineer – Custom Circuits

Hardware - San Francisco

Apply now

L3Harris Technologies

Specialist, Electrical Engineer (ASIC Engineer)

Herndon, VA · 2 hours ago · 1 person clicked apply
Promoted by hirer · Responses managed off LinkedIn

$90.5K/yr - $168.5K/yr | On-site | Full-tim

Apply | Save

AMD

CPU Cores Physical Design Engineer

Boxborough, MA · Reposted 1 week ago · Over 100 applicants
Promoted by hirer · Actively reviewing applicants

$139.4K/yr - $209K/yr | On-site | Full-time

Easy Apply | Save

NVIDIA

Senior Circuit Design Engineer

North Carolina, United States · Reposted 2 weeks ago · 78 peop
Promoted by hirer · Responses managed off LinkedIn

$136K/yr - $264.5K/yr | Hybrid | Full-time

Apply | Save

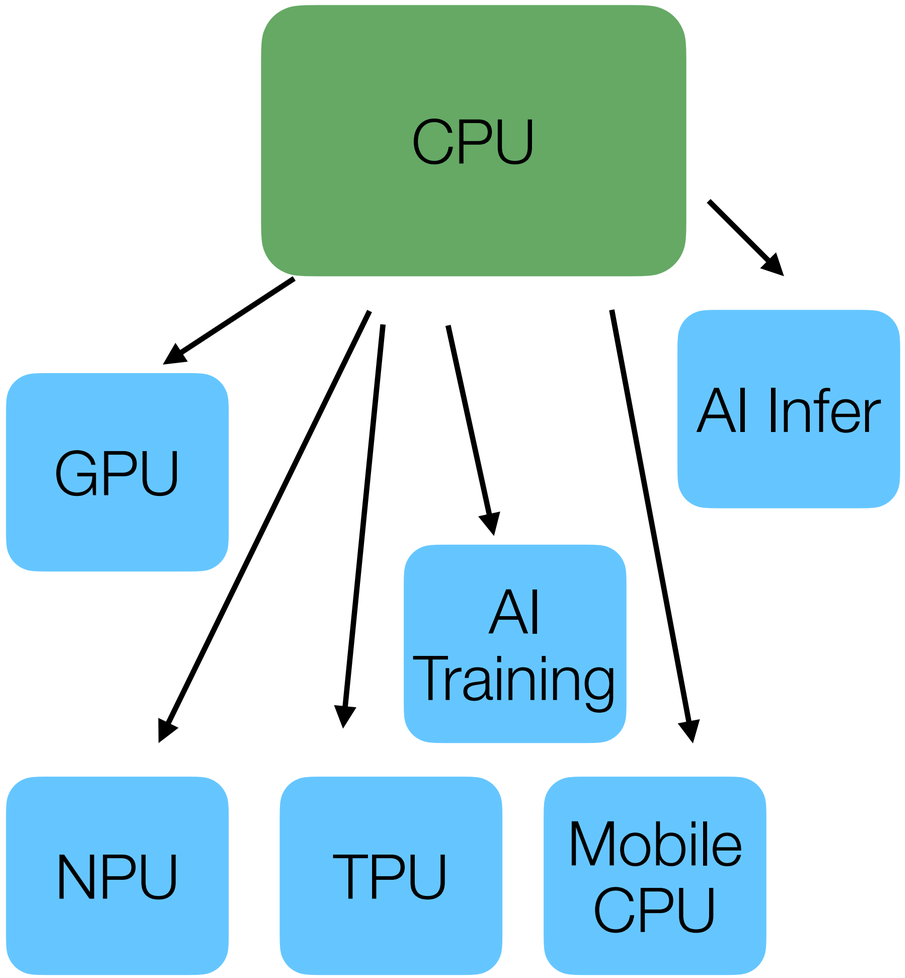
HUAWEI

Chief Engineer

R&D Family - Osaka Display Device and Module Lab

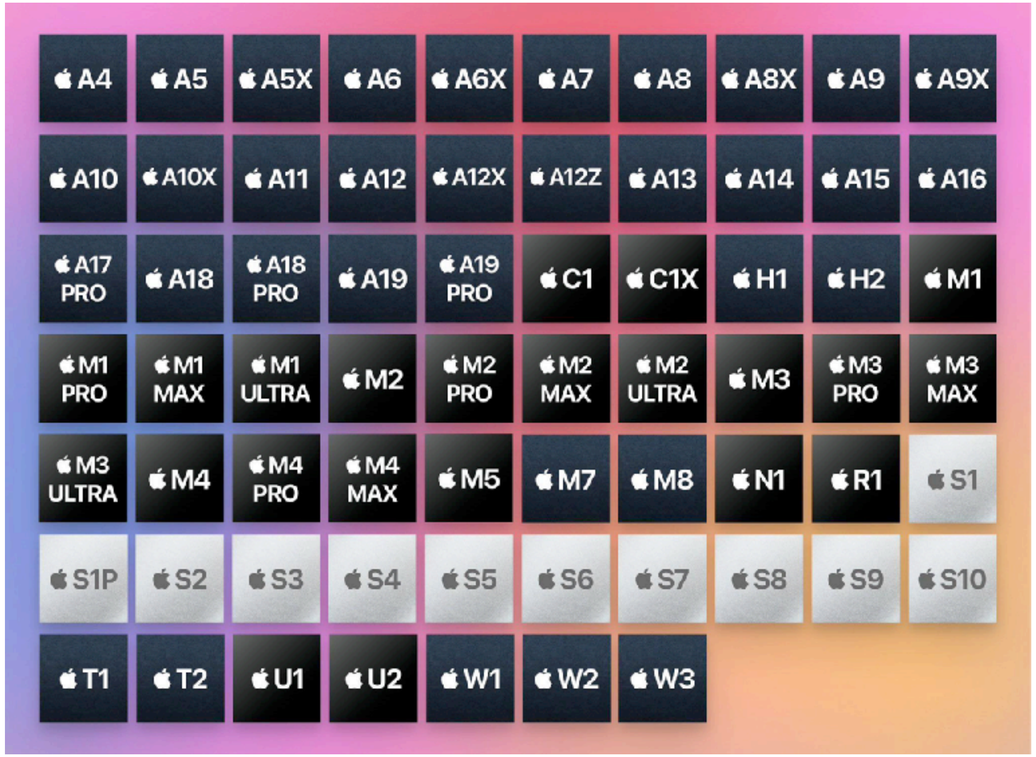
Case Study: The Fabless Revolution

- In the early days of integrated circuits, “jack of all trades” chips ruled (Intel/AMD x86 and ARM processors)
- Transistors were shrinking, and clock speeds were increasing. Hardware was getting better so fast, no one complained.
- One product serves all customers
- Some specialists existed (e.g. GPU and sound card companies) that made what we used to call “add-in boards” that would supplement CPU capabilities
- Nowadays, chips are much more specialized → “Fabless” designers plan out their own chips



Case Study: The Fabless Revolution

- Apple designed computers, buying off-the-shelf Intel CPUs
- In 2008, Apple hires Johny Srouji to lead their own custom silicon division
- In 2010, Apple releases iPhone 4 and iPad with A4 chip that they designed in house
- In 2020, Apple releases their first laptop chip. Calls it M1. M1 and following generations smash the performance-per-watt metrics of Intel/AMD competitors
- In the end, Intel and AMD lose a lot of money as their customers realize they can design a better product (for their specific purpose)



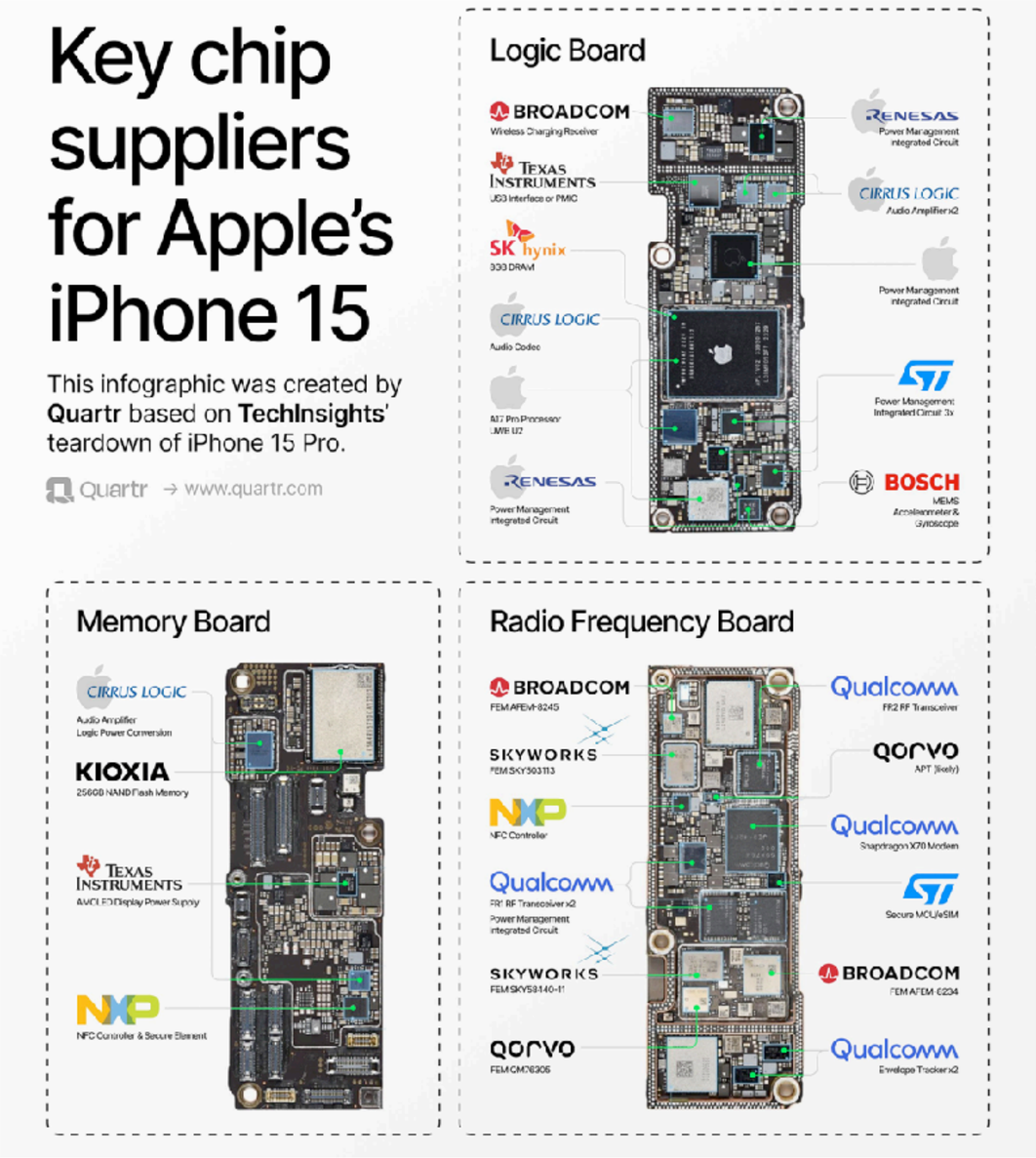
All Apple custom chips (2025)

Electronics Integrators

- These are often the companies you would buy electronics from
- Think: Sony, Dell, Apple, Samsung, Lenovo, HP, Nintendo, Xiaomi
- Basically buy existing packaged electronics, put them together into a box that people can interact with
- Some are very vertically integrated (e.g. Apple)

Electronics Integrators

One integrator may get parts from many sources!



iPhone 15 chip suppliers - Credit: quartr.com

The trend: Do more design in-house, push out "middleman" designers, capture more margin

Foundries

- This is where everything comes together
- Fabrication process is developed. Typically call this a “process node” or just “node”
- For a given node, the foundry releases a “process design kit” (PDK)
- The PDK basically a dataset that explains what devices the foundry can make, their physical layout, and their performance
- Designers access the PDK (under NDA) and design/simulate their chips

12 inch wafer fab - Credit: Taiwan Semiconductor Manufacturing Co., Ltd.

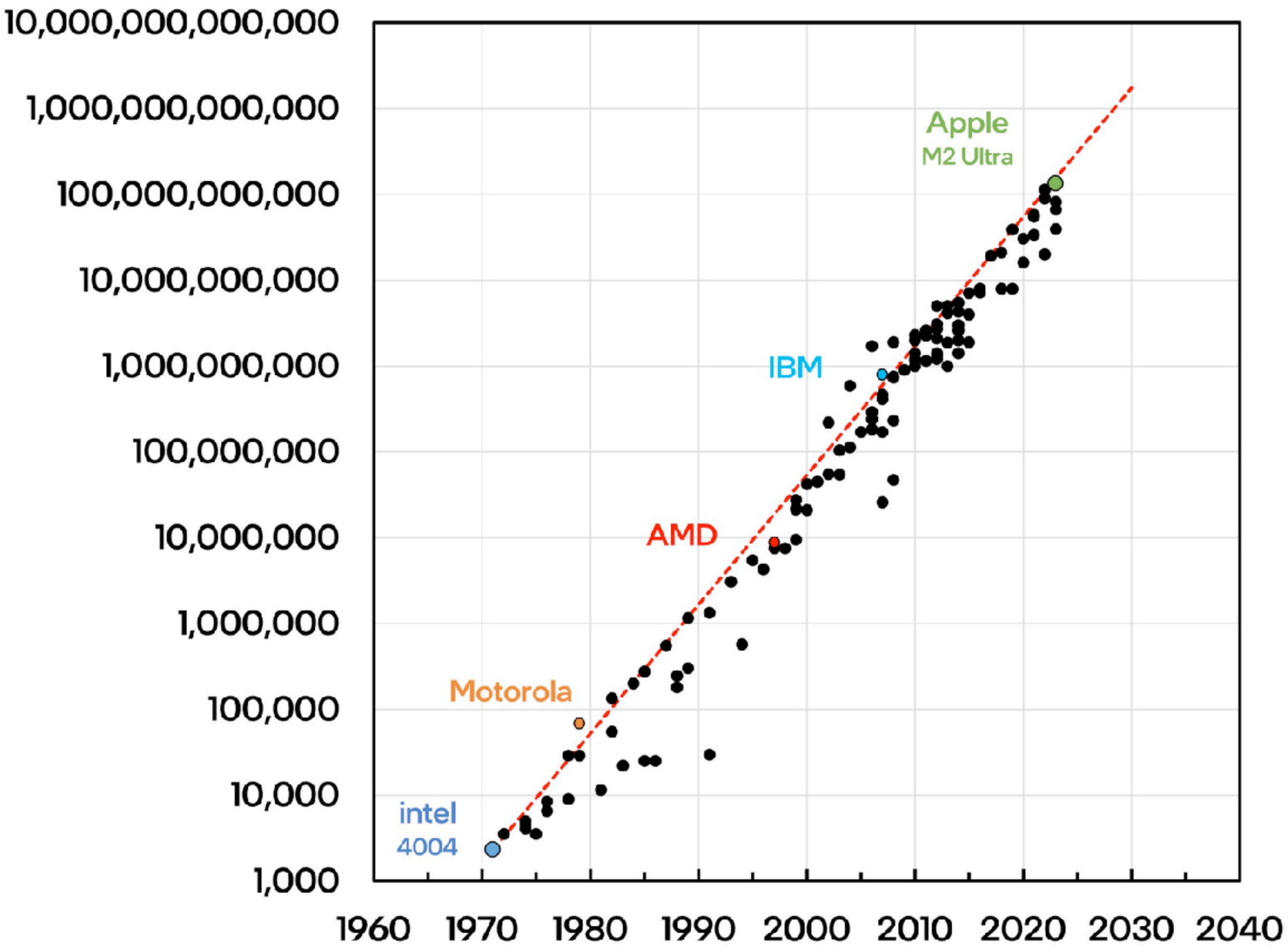
Foundries - Logic

- Different type of semiconductor device → Different manufacturing processes → Made in different foundries

- We call the foundries that focus on making chips primarily composed of transistors for computation (think CPU, GPUs, analog electronics) “logic foundries”

- Today, there are only a few of them….

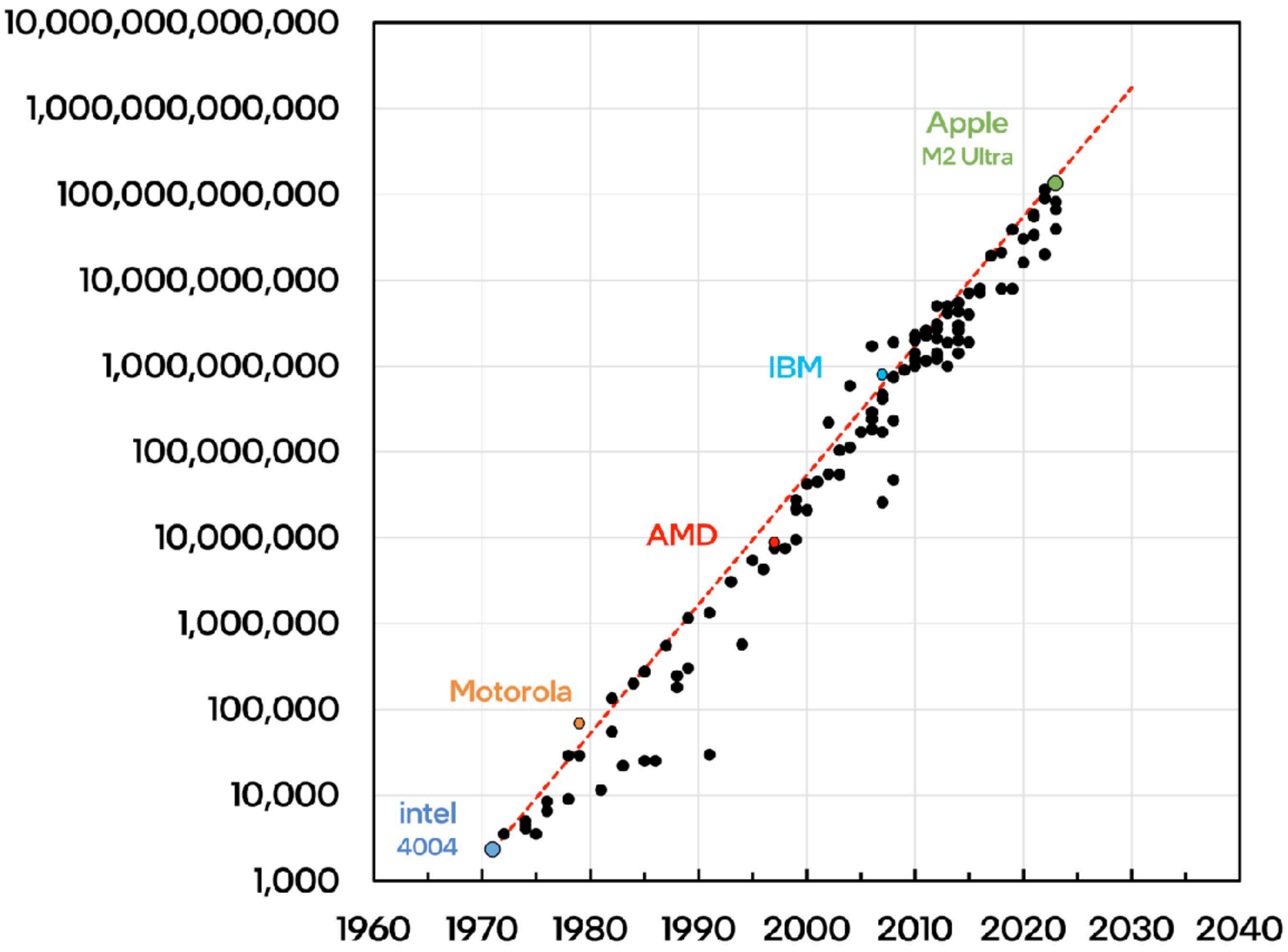
Foundries - Bleeding Edge Logic



The reason has to do with this plot.

What is it?

Foundries - Bleeding Edge Logic



- Since the 1970s, foundries have made heroic efforts to scale down transistors
- The problem? Every time they do it, it gets more expensive
- Most capital intensive business in the world ($28 billion Intel project in Ohio)
- There used to be a lot of foundries, very few remain at the “bleeding edge”

Foundries - Bleeding Edge Logic

The Last 35 Years

- 1990-1995: Intel, IBM, Texas Instruments, LSI, Motorola, UMC, TSMC, NEC, Toshiba and others → Fierce competition, many companies in many countries
- 1995-2000: Intel, IBM, TSMC, UMC → Consolidation. Mostly into USA and Taiwan
- 2000-2010: Intel, IBM, TSMC → UMC falls out of the race
- 2010-2015: Intel, TSMC, Samsung, Global Foundries → Samsung, Global Foundries enter
- 2015-2020: TSMC, Samsung → GF stops pushing leading edge, Intel has various technical problems which slow them down
- 2020-2025: TSMC → Samsung yields fall, only TSMC left
- Today and future: ? → TSMC dominant, Intel, Samsung, SMIC, Rapidus fight to regain parity

Case Study: Global Foundries

- Global Foundries is an illustrative example of foundry business dynamics. It's also our "local" fab!
- AMD (the CPU/GPU designer) originally operated both a design arm, and a foundry business → "IDM" model.
- Their main competitor, Intel, did the same. But Intel's foundry technology was better.
- Result? Tough spot for AMD. Can't sell chips because their foundry can't compete with Intel's → Can't earn enough money to upgrade foundry because they can't sell chips…

Columbia to Global Foundries HQ by car

Case Study: Global Foundries

- In 2009, AMD decides foundry is such a money sink, they sell it off.
- Investment group pays $700 million and gives AMD a 34% stake to acquire their foundry business.
- They name the new business “Global Foundries”.
- At the time, a lot of doom and gloom. But it turns out it was actually a good move.
- In 2014, IBM faces a similar issue. They only make small volumes, but foundry is really expensive to run→ IBM **pays** Global Foundries $1.4 billion to take their foundry business.
- Global Foundries quits pursuing leading edge nodes in 2018, announcing they will not attempt to develop a 7 nm process

GlobalFoundries™

Columbia to Global Foundries HQ by car

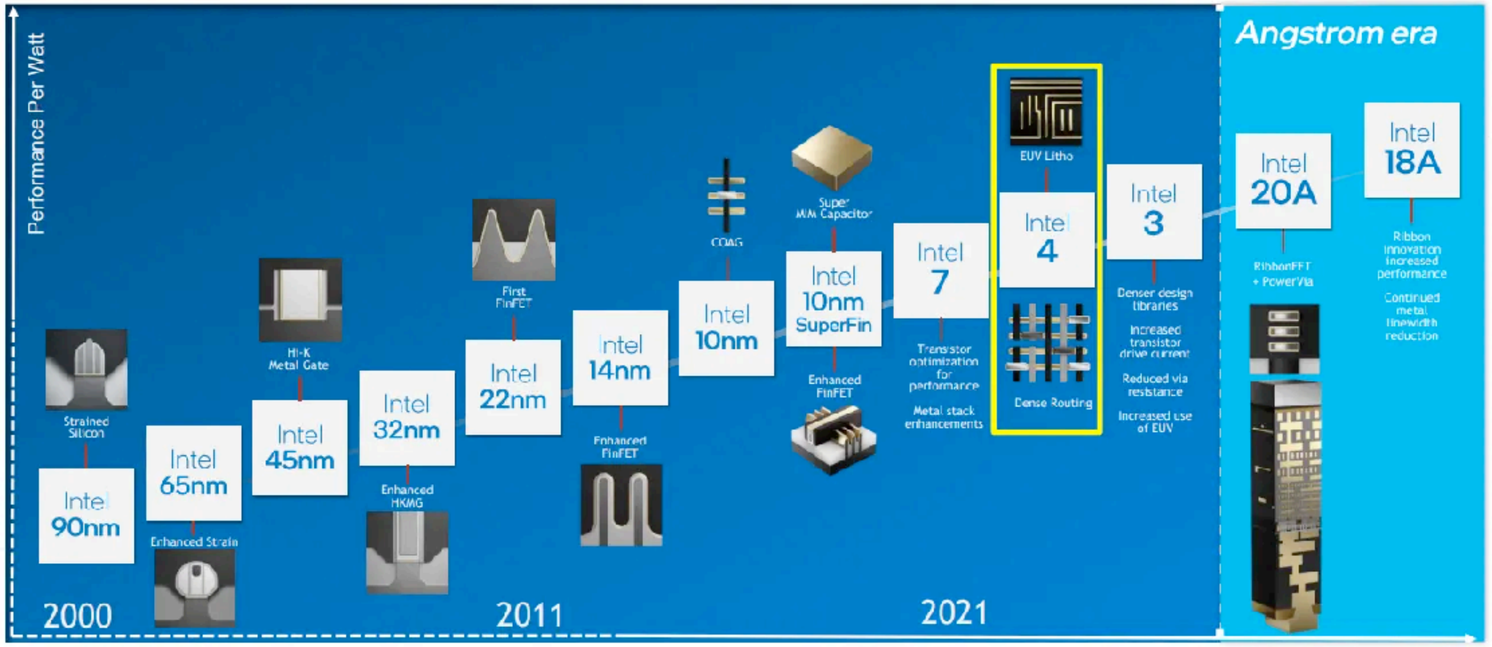
Foundries - Bleeding Edge Logic

Foundries publish “roadmaps” to show what nodes they plan to fabricate in the future.

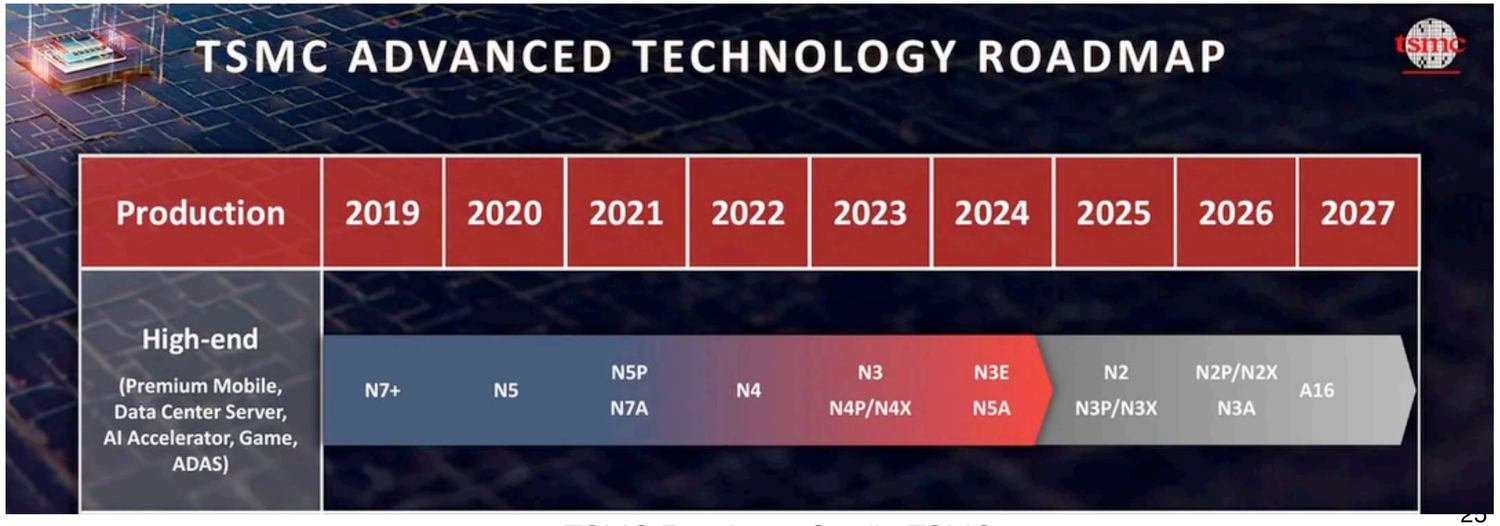
<u>Most advanced nodes:</u>

- TSMC: N2
- Intel: 18A
- Samsung: SF3
- Rapidus: 2HP

Note: none of these numbers actually mean anything…



Intel Roadmap Credit: Intel

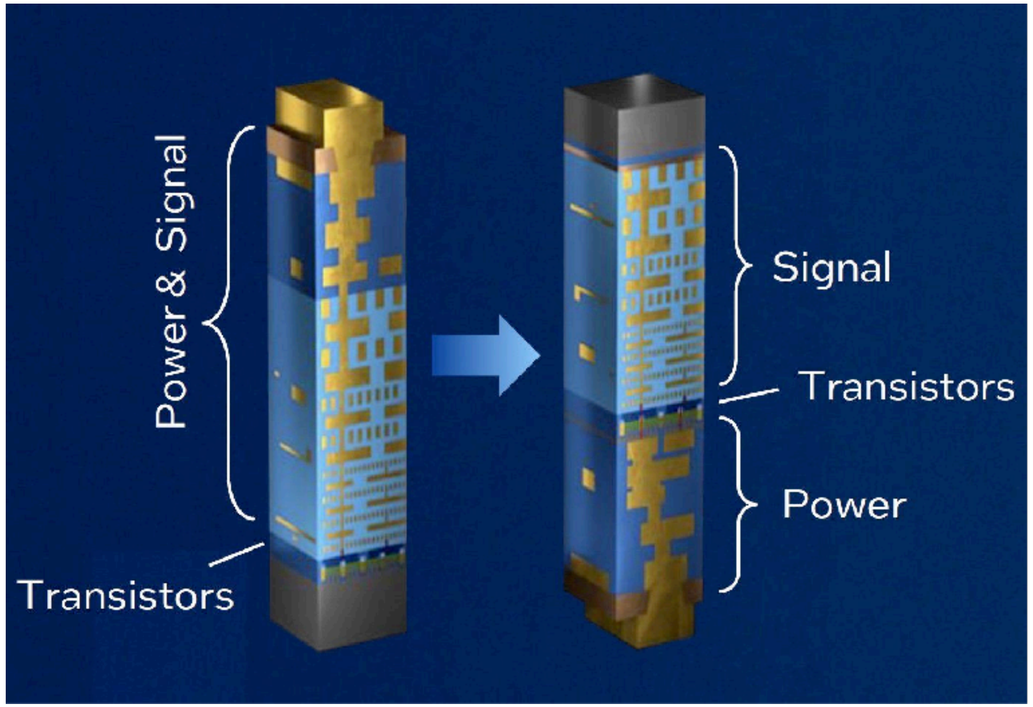


TSMC Roadmap Credit: TSMC

Foundries - Bleeding Edge Logic

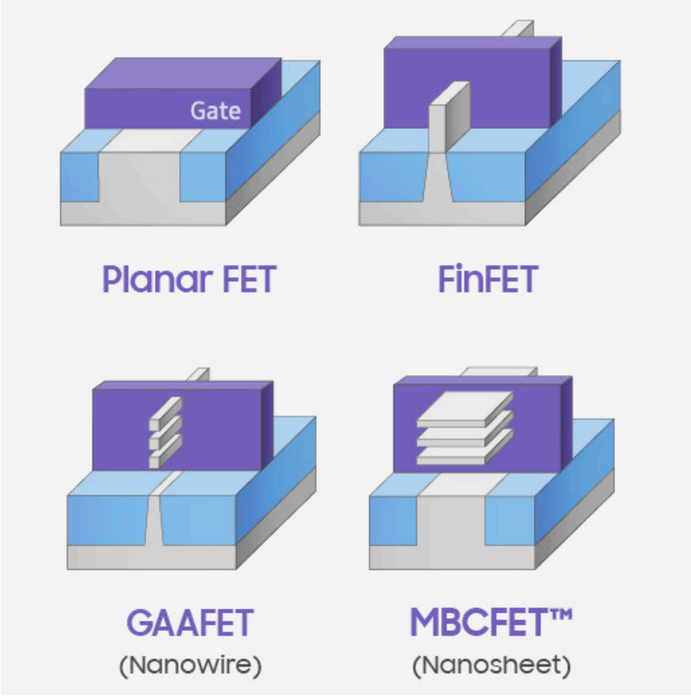
What changes are driving continued performance increase in modern logic nodes?

Backside Power Delivery



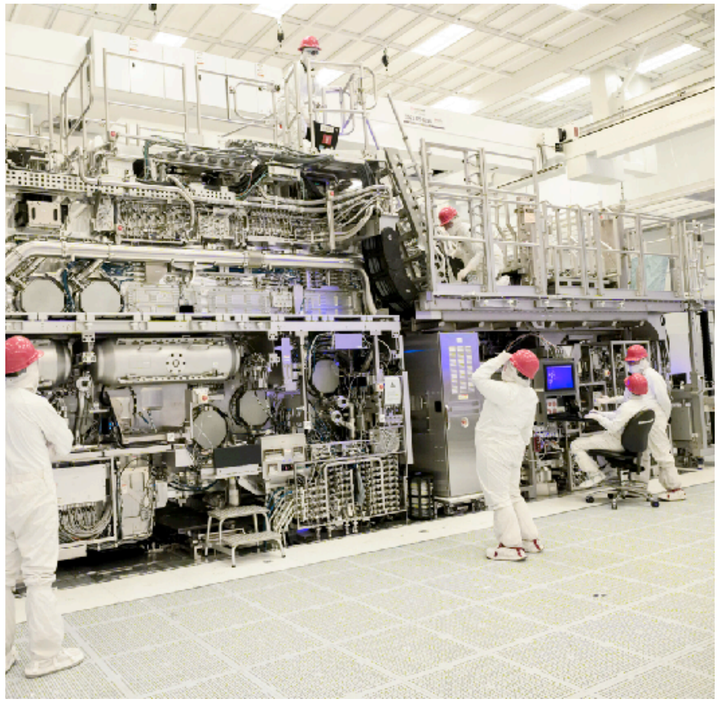
Credit: Intel via IEEE Spectrum

3D Transistor Architecture



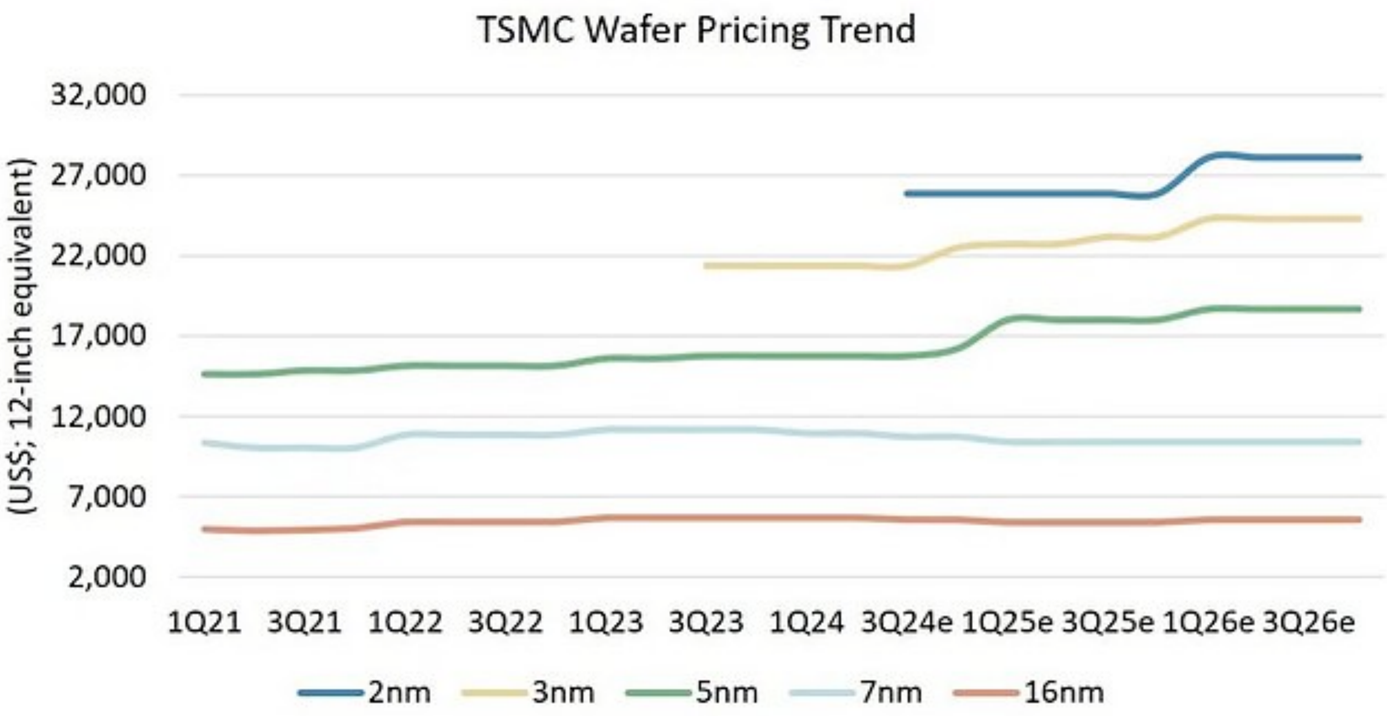
Credit: Samsung Semiconductor

High NA-EUV Litho



Credit: Intel Newsroom

Foundries - Bleeding Edge Logic



TSMC Wafer Pricing - Credit: Morgan Stanley via 3DCenter.org (rumors!)

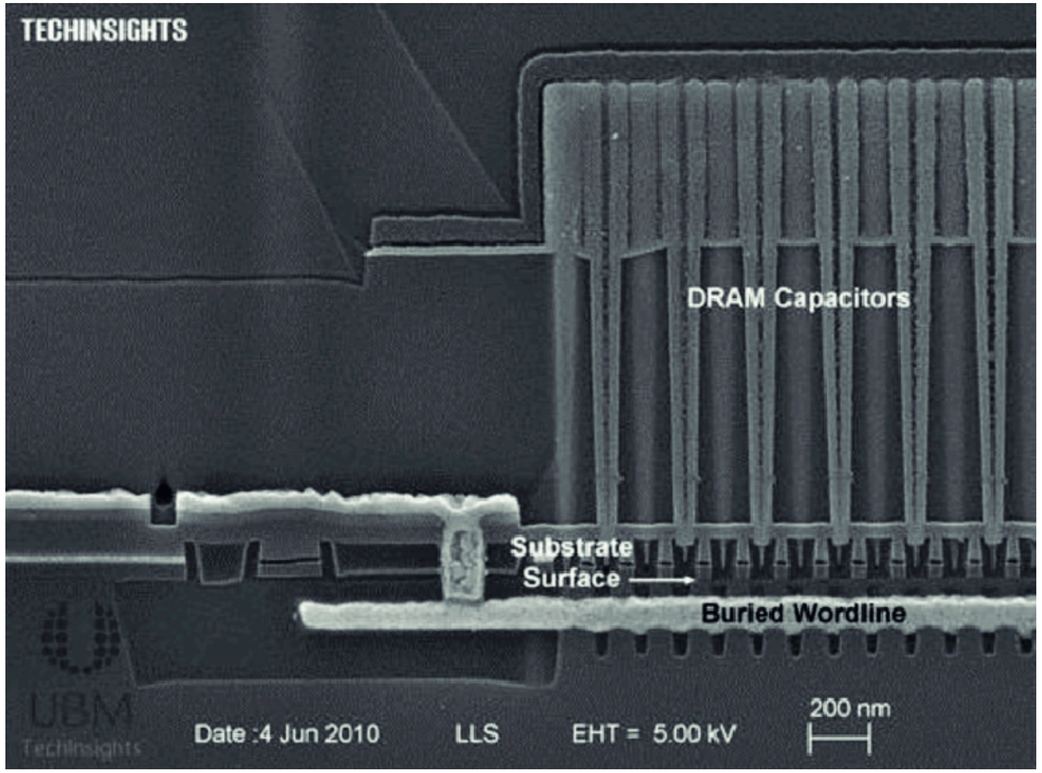
- Newer foundry nodes are dramatically more expensive than ones
- Compare TSMC 2 nm vs. 16 nm at ≈ $30k vs. ≈ $5k per wafer
- Cost per transistor is still going down, but not by as much as it used to

Foundries - Application Specific and Legacy

- Though there are only a few foundries left making the most aggressively scaled logic chips, but many other remain in niche markets
- X-FAB → Offers 110 nm node, mostly automotive and analog applications
- Tower Semiconductor → Offers 65 nm node. Analog, RF and photonics applications
- ON Semiconductor, Infineon, and Renesas → All work on power electronic devices
- Global Foundries and STMicro → Focus on SOI for military/aviation/radiation applications (but also some other mature processes)
- DB HiTek and MagnaChip → Mature large nodes

Foundries - Memory

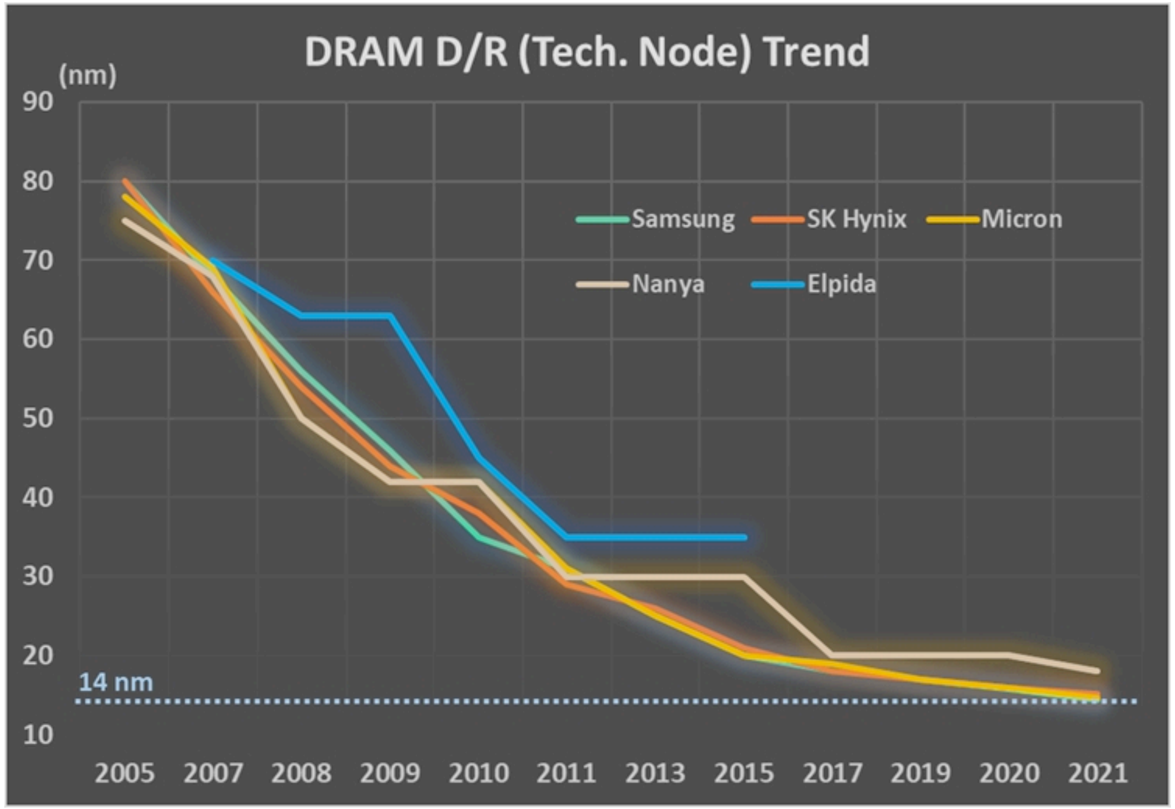
- Memory (DRAM, flash memory) are made in their own fabs which are built for this purpose
- Reason: repeated vs. varying structures, deep trench features in memory
- Three suppliers dominate the world DRAM market: SK Hynix (South Korea), Samsung (South Korea), and Micron (USA) → over 90% market share
- Their memory chips offer about the same performance, sometimes used interchangeably
- CXMT (China) is 3-5 years behind the others, but catching up quickly



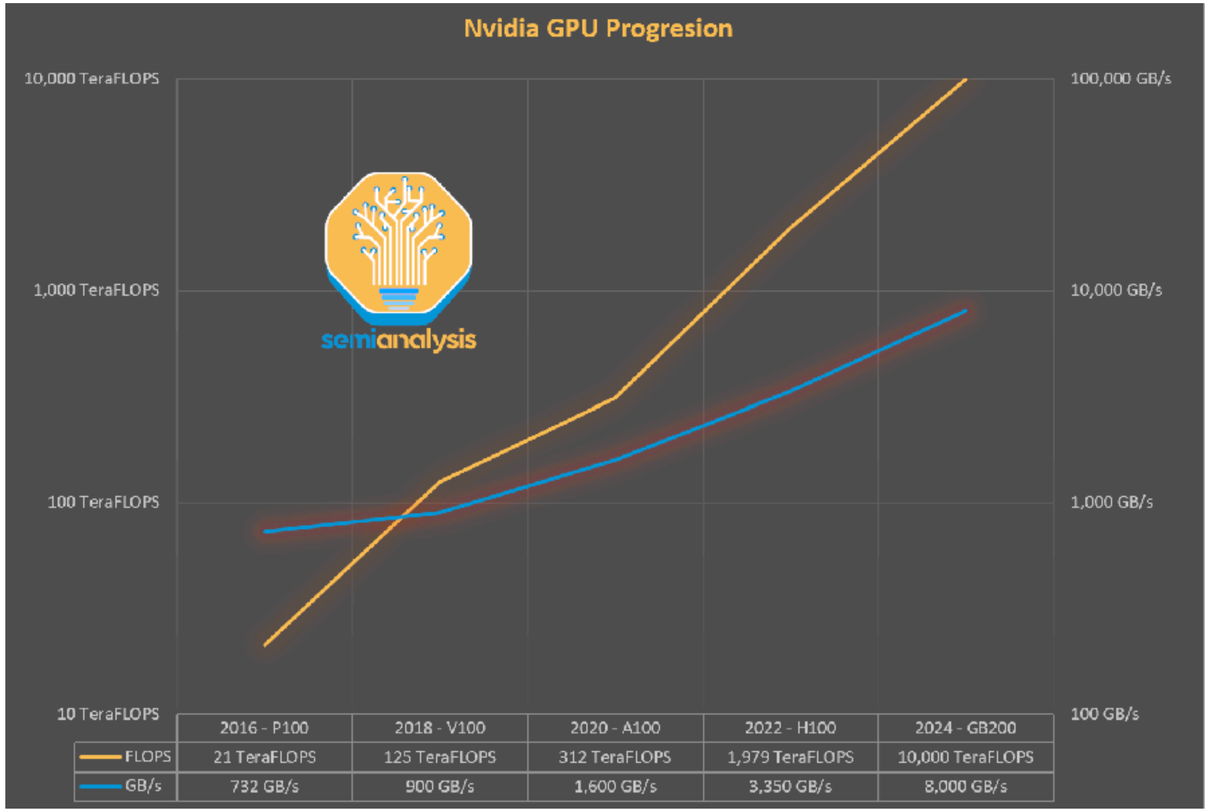
DRAM Cross Section- Credit: AspenCore

Case Study: Trends in Memory

What problem do these plots demonstrate?



DRAM node size - Credit: Semiconductor-Digest



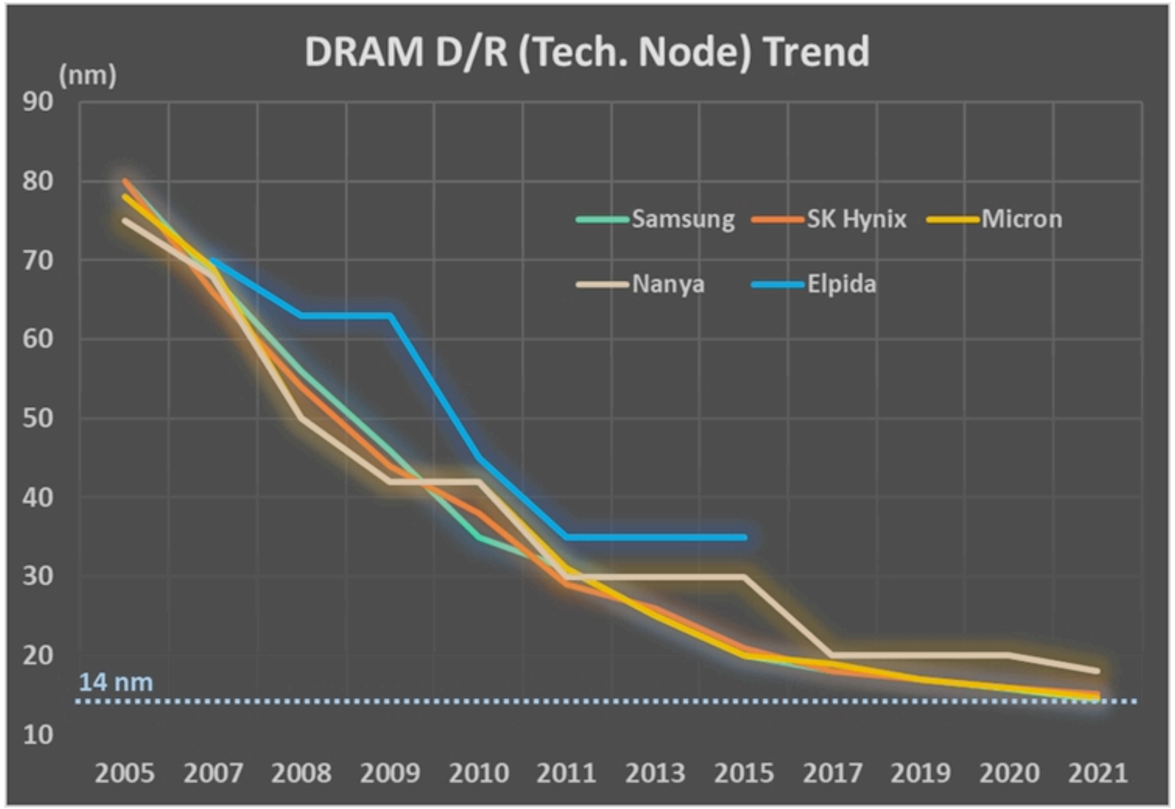
GPU compute and bandwidth over time - Credit: SemiAnalysis

Case Study: Trends in Memory

Memory scaling has stagnated, but GPU compute demands have skyrocketed

⬇

Leads to a bandwidth bottleneck between compute and memory → so-called “memory wall”



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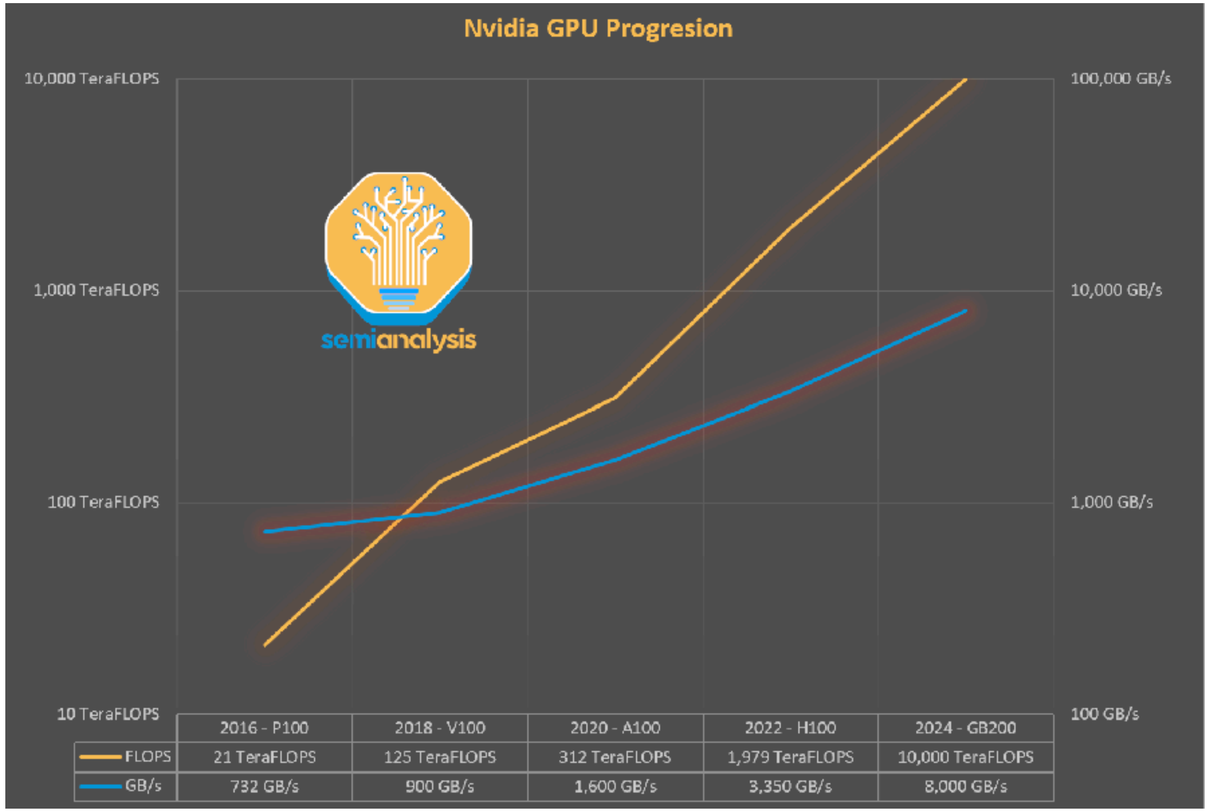
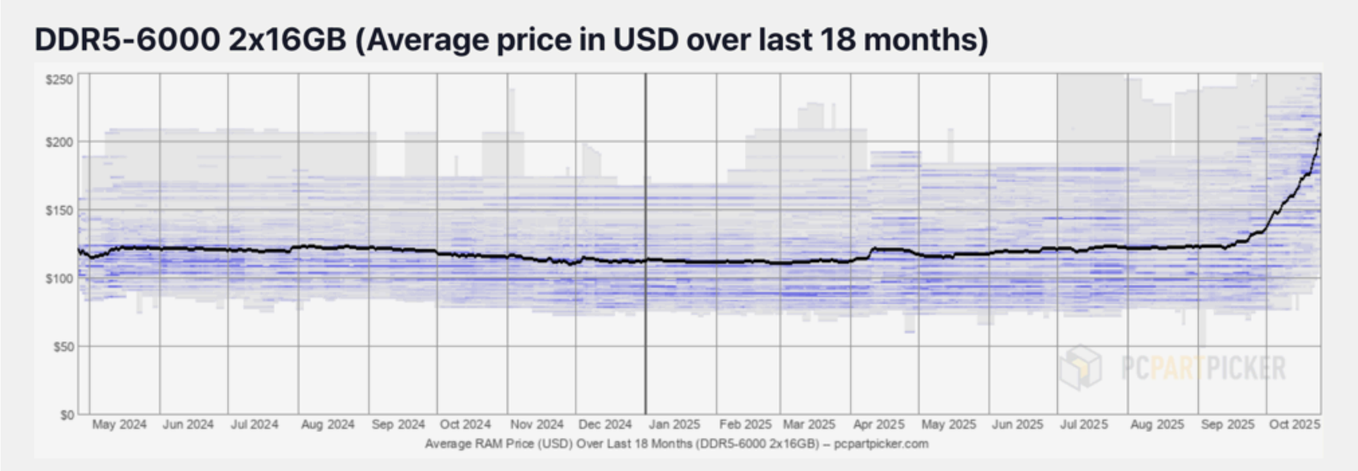
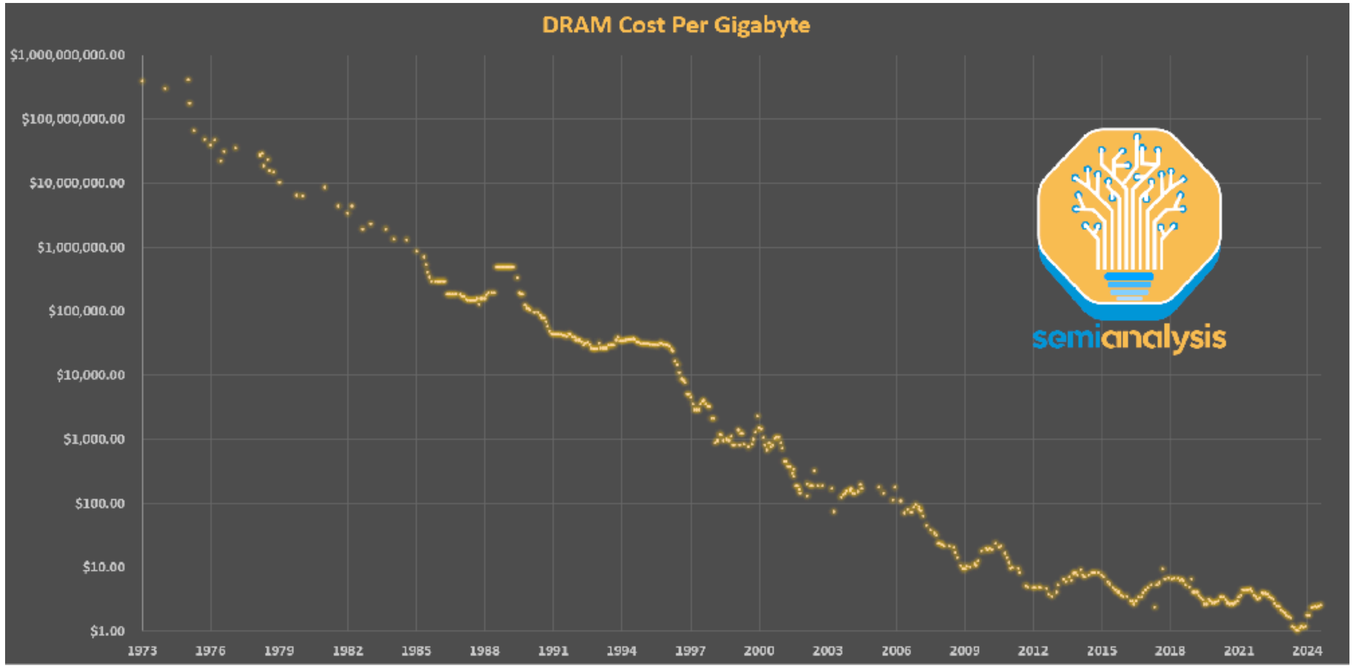


GPU compute and bandwidth over time - Credit: SemiAnalysis

Case Study: Trends in Memory



Price of 32 GB DDR5 RAM kits over time - Credit pcpartpicker



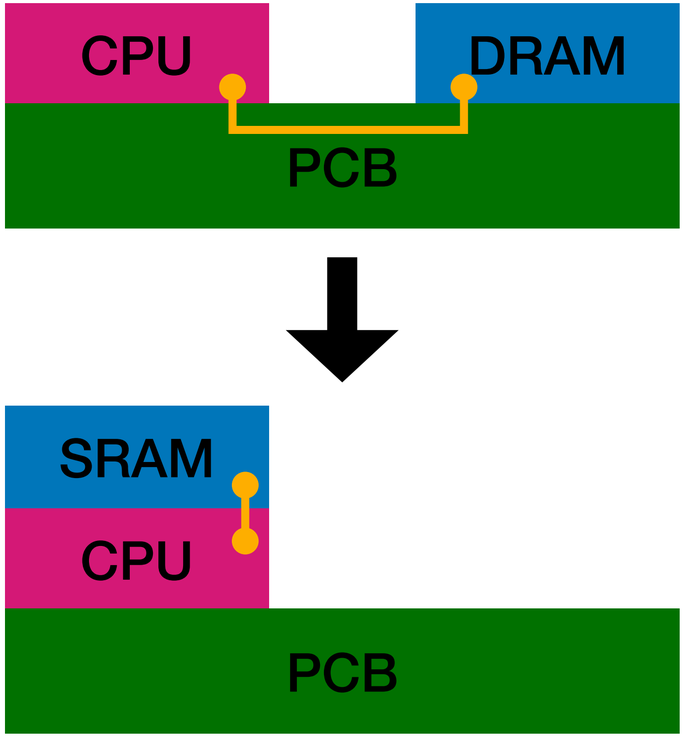
DRAM price per GB over time - Credit: SemiAnalysis

- RAM cost is volatile
- Right now it's even going up! Not what we expect electronics to do
- Basically, supply is very sticky, takes a long time to build out new fabs
- Demand spikes quickly as new tech comes to market (in this case, AI workloads requiring large memory)

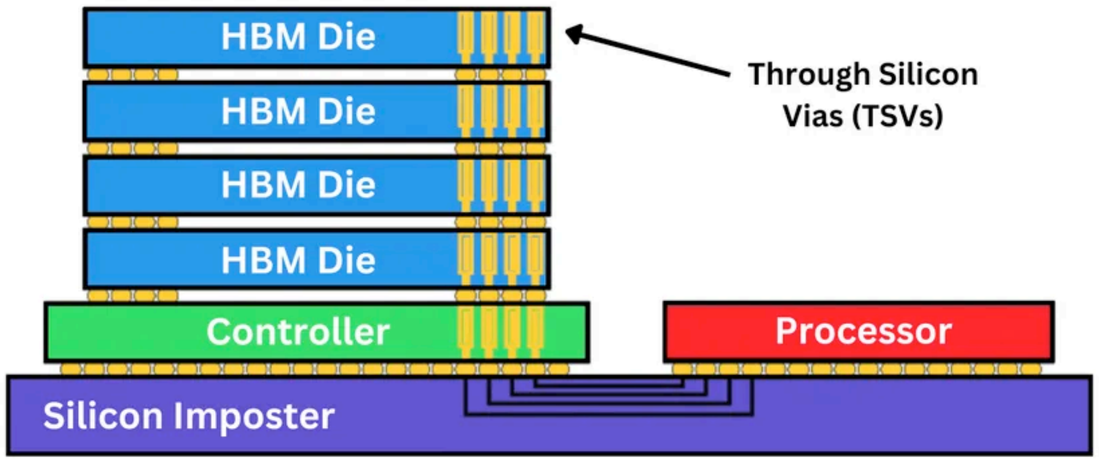
New Directions for Memory

If memory density is stalling, how are manufacturers innovating?

Advanced packaging



"High Bandwidth Memory" (HBM)



Credit: semiengineering.com

Foundries - Display

- The display fab story is a little simpler
- The short answer is:
- Virtually every OLED display is fabricated in South Korea by either Samsung or LG
- Virtually every LCD display is fabricated in China by BOE or TCL CSOT
- This story is starting to change. OLED fabrication is ramping up in China as well (especially at BOE)

42 inch TV - 2001

40 inch TV - 2025

Example: Gigabyte NVIDIA GeForce RTX 5090

- NVIDIA designs the GPU core (using software from Cadence/Synopsys/Siemens)
- TSMC fabricates it (using tools and materials from various suppliers)
- Samsung/SK Hynix/Micron supply memory chips
- Gigabyte designs PCBs, connectors, cooling solution, assembles

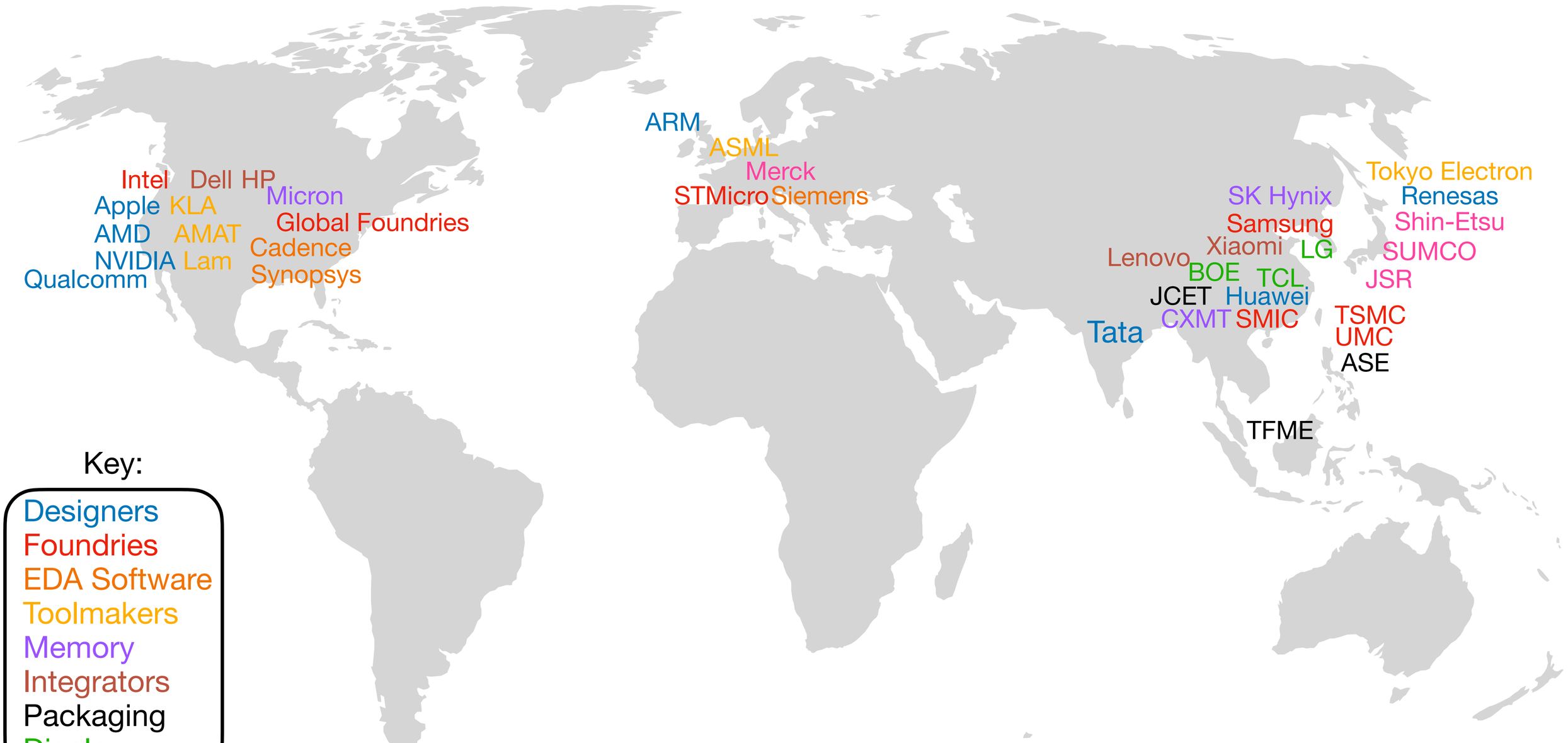
Foundries

Chip Designers

Software Vendors

Electronics Integrators

Global Picture



Key:

- Designers
- Foundries
- EDA Software
- Toolmakers
- Memory
- Integrators
- Packaging
- Display

Note: many companies perform several roles in the ecosystem

Importance of Geography (and Politics)

United States

- Dominates EDA software market
- Many (but not all) toolmakers

Japan

- Has highest quality Si wafer and photo resist suppliers
- Building foundry capability

Taiwan

- ≈65% of logic wafers below 10 nm
- ≈90% of logic wafers below 3 nm
- Clear dominance in foundry area

South Korea

- Strong in OLED
- Strong in memory
- Samsung fab is competitive

China

- Does not hold any “chokehold” in the supply chain
- Lots of investment, catching up
- Expected to reach parity in logic & memory in 5-10 years

Importance of Geography (and Politics)

- 90% of the most advanced logic chips are produced on a single island. What is the risk here?
- Governments push internally to try and on-shore parts of the supply chain → Subsidies for local companies
- Governments push externally to try and slow down the progress of others → Tariffs against foreign companies
- Long story short, each country is working to become more independent from global supply chain.
- Is this a good thing?

Balanced Rock, Arches National Park - Credit: Thomas Wolf

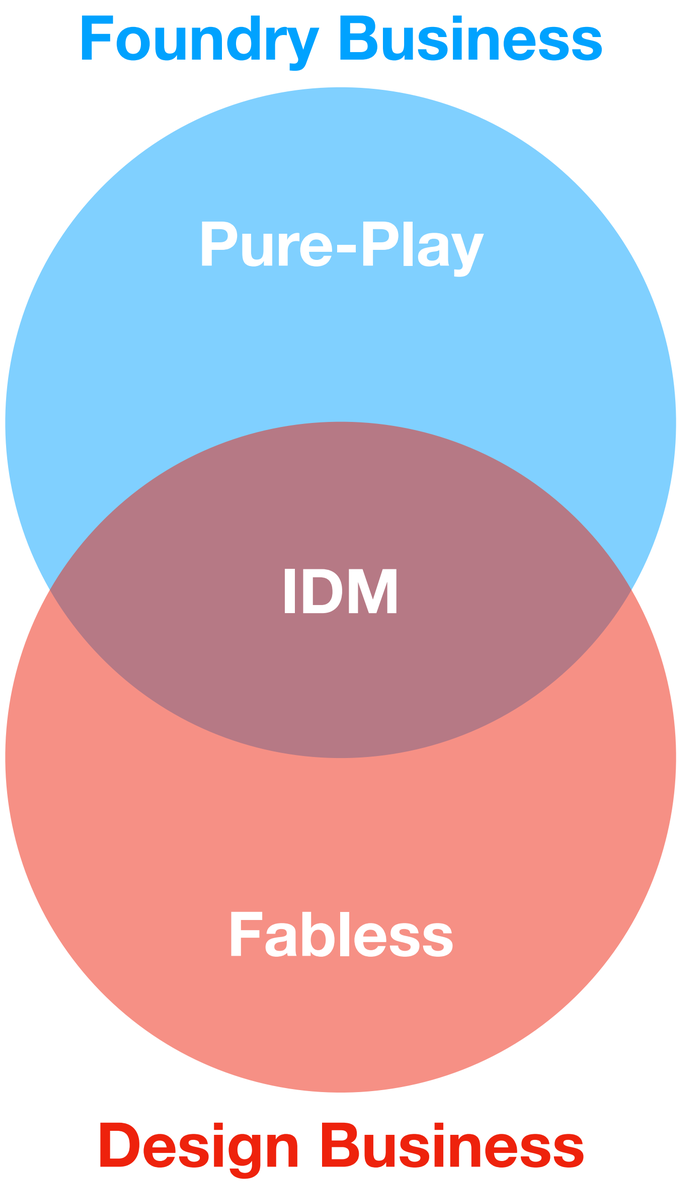
Self-Sufficiency Push

- For consumers, probably a bad thing. Tariffs and export bans make products more expensive.

- For engineers, probably a good thing. Government subsidies encourage semiconductor companies to expand operations → More jobs.

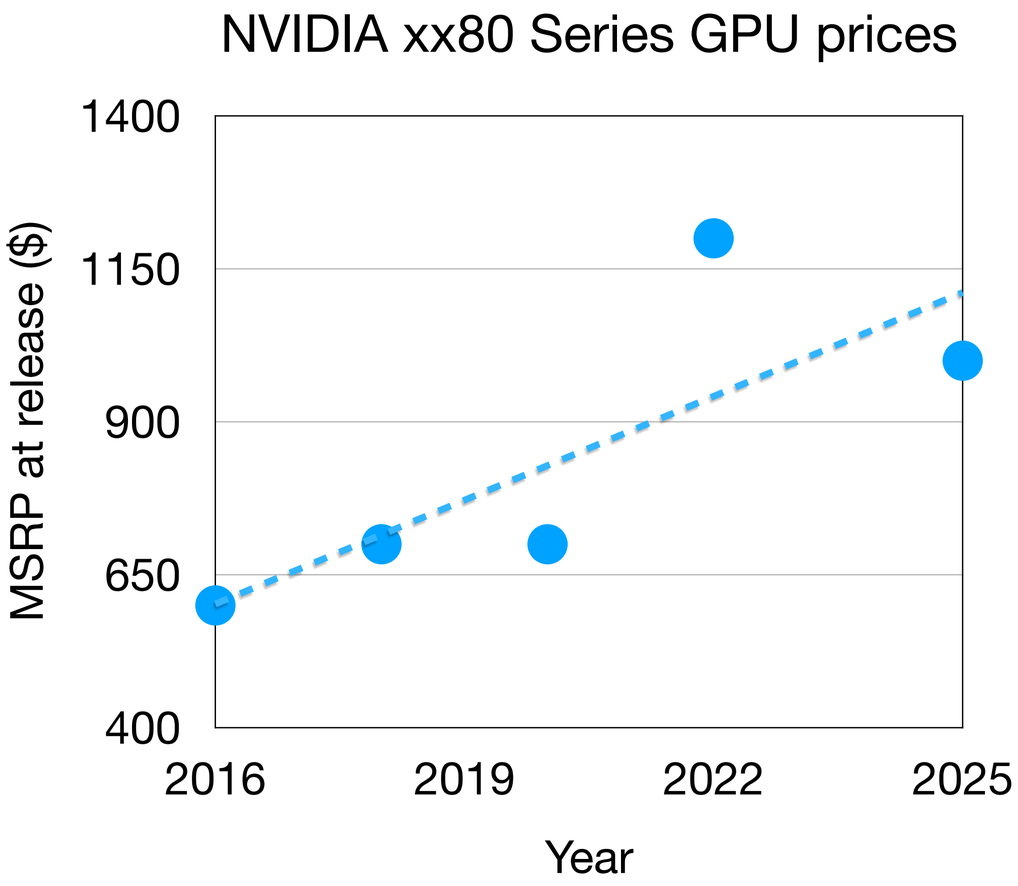
Analysis: Foundry Business Models

- There are a few words that come up a lot when describing semiconductor company business modes: "**fabless**", "**IDM**", and "**pure-play**".
- Initially, many companies operated as "Integrated Device Manufacturers" (IDMs). Now very few do.
- Foundry business is so expensive, you need to operate at enormous scale to offset R&D costs.
- In order to operate at scale, you need to make chips for external customers.
- Why don't external customers like working with IDMs? Trust Issues!
- TSMC showed why the pure-play business model works.



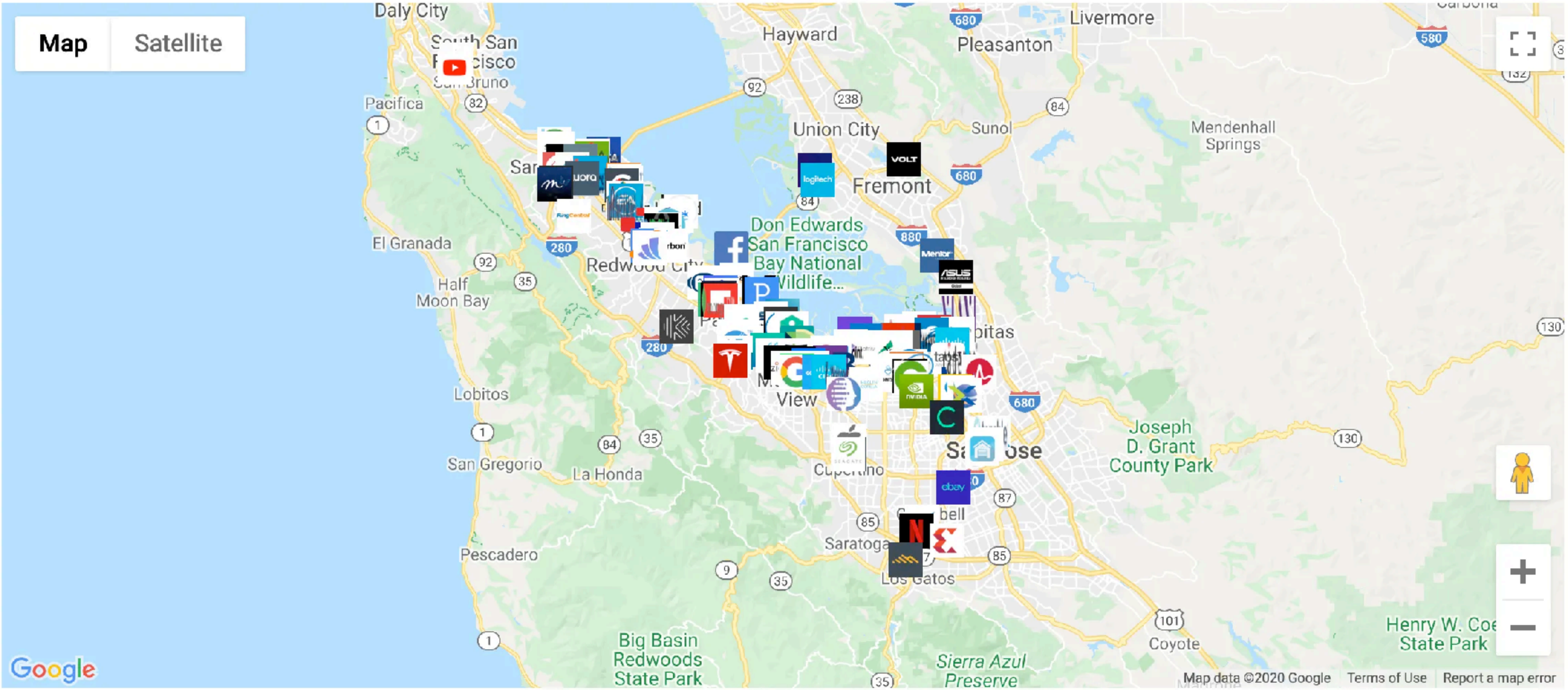
Analysis: Throughput Limit

- TSMC can only process a finite number of wafers per day/week/month/year
- Demand for advanced nodes is so high, capacity is bought **years** in advance for 3 nm and 5 nm
- TSMC 2 nm process is not in mass production yet, still final testing stages, but their production capacity is **already sold out through 2026**
- This throughput limit creates some strange dynamics
- Biggest customer (i.e. Apple) basically pays to go first. They also get input into how the tech develops.
- Why does TSMC agree to this? They basically need the pre-payment from big customers to finance R&D costs for their next node…



History: Birth of Silicon Valley

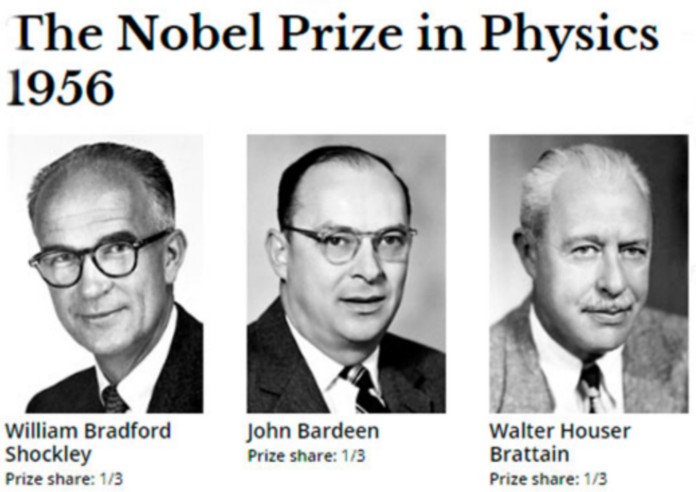
Why are so many tech companies in California?



Map of Tech Headquarters - Credit: medium.com

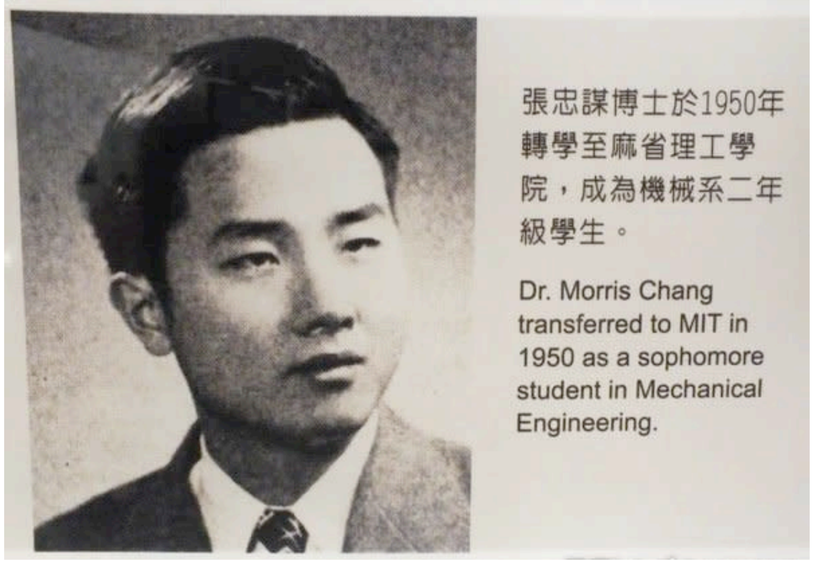
History: Birth of Silicon Valley

- World War II causes destruction across Europe, Asia, Africa, and Oceania → Industries are damaged, money is spent rebuilding
- USA is relatively unaffected but fears USSR → Diverts significant government funding to study science
- Transistor is invented at Bell Labs (New Jersey) by Bardeen, Brattain, and Shockley
- Shockley leaves Bell Labs and moves back to where he grew up in Palo Alto, CA → Starts Shockley Semiconductor Lab
- The “traitorous eight” engineers leave Shockley, start their own company → Fairchild Semiconductor
- Fairchild spins out Intel, AMD, dozens of others → ecosystem grows around them

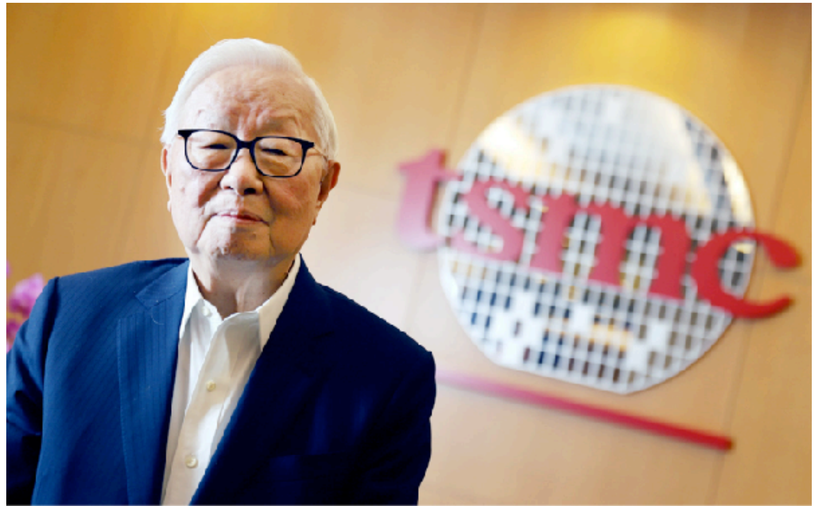


History: Morris Chang & TSMC

- 1931 - Morris Chang is born in Ningbo, China
- Studies at MIT → Gets a job at Texas Instruments (TI)
- Spends 25 years at TI, climbs the ladder to become a VP
- Government of Taiwan makes an effort to modernize economy → They recruit Chang
- In 1987 he founds a company called TSMC
- Chang breaks the existing strategic model. Instead of working as an IDM, TSMC is the first pure-play foundry
- TSMC stays neutral, serves all customers, wins the business of many customers
- Allows the fabless revolution to start and becomes world's dominant foundry



Morris Chang - Credit: Yahoo



Morris Chang - Credit: Asia.nikkei.com