Part1 :
Introduction to VLSI Circuits (Hardware)

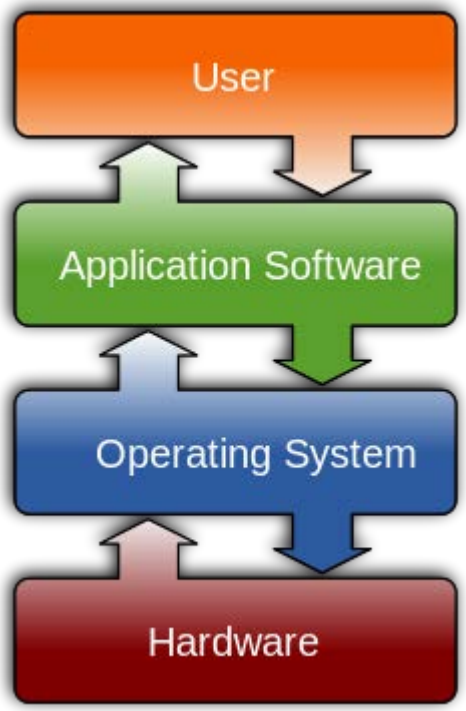
An Overview of VLSI

What's hardware

- Computer hardware is the collection of **physical components** that constitute a computer system.
- Computer hardware is the physical parts or components of a computer, such as monitor, keyboard, computer data storage, graphic card, sound card, motherboard, and so on, all of which are **tangible objects**.
- By contrast, software is instructions that can be stored and run by hardware.

Hardware and Software

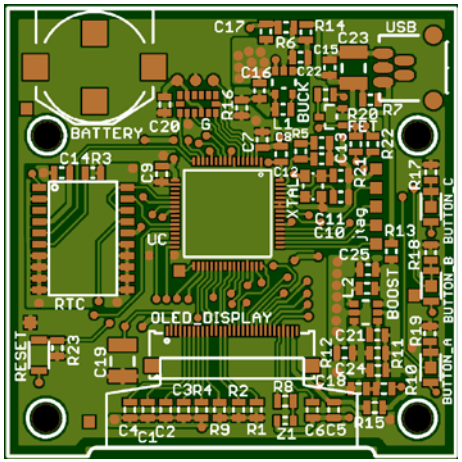
- software, is that part of a computer system that consists of **data** or computer **instructions,** in contrast to the physical hardware from which the system is built.
- In computer science and software engineering, computer software is **all information** processed by computer systems, programs and data.



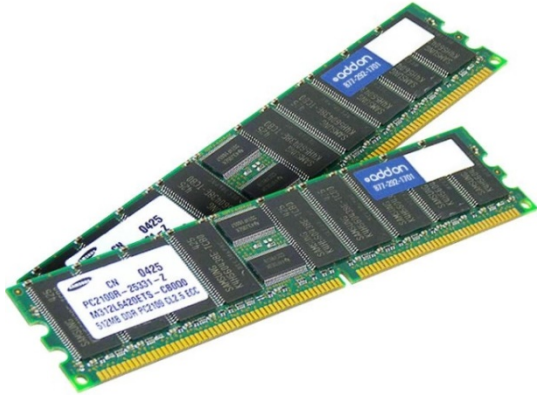
Hardware and Software

- 软件和硬件的边界是什么？
  - 效率（性价比）
- “People who are really serious about software should make their own hardware”， By Alan Kay，
  - Alan Kay：面向对象的编程方法/windowsGUI
  - 计算机从业者应当从系统的观点看待自己的工作
    - 阿里
    - 百度
    - google

Hardware's'

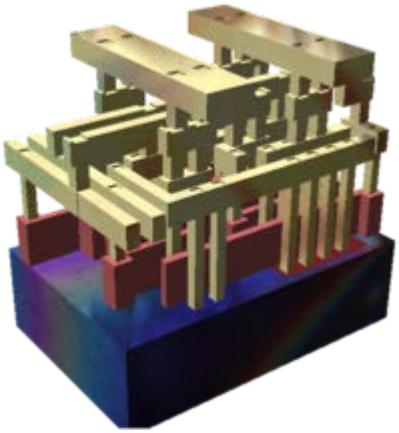

BATTERY
OLED DISPLAY
RTC
USB
BUCK
BOOST
XTAL
Jtag
RESET
BUTTON_A
BUTTON_B
BUTTON_C


intel
Xeon
processor

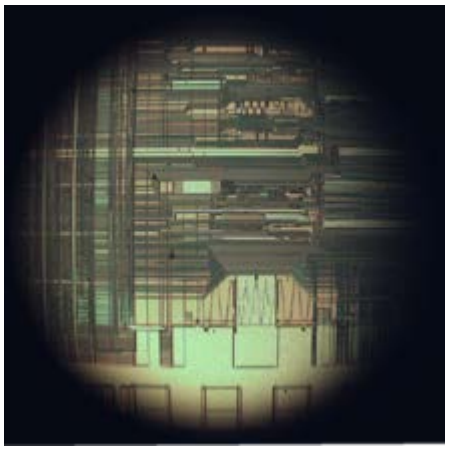


IC definition

- A circuit in which all or some of the circuit elements are inseparably associated and electrically interconnected so that it is considered to be indivisible for the purposes of construction and commerce.
  - 紧密相关
  - 电互连
  - 不可分割



3D渲染图



80486管芯照片

中国的集成电路产业

- 2014年，中国IC销售收入3015.4亿元人民币；2017年，超过5000亿人民币？；
- 2013年，中国集成电路进口金额高达2313亿美元，多年来与石油一起位列最大两宗进口商品。
- 2013年，中国生产了14.6亿部手机、3.4亿台计算机、1.3亿台彩电，但是，由于主要以整机制造为主，以集成电路和为核心的价值链核心环节缺失，致使行业平均利润仅为4.5%，低于工业平均水平1.6个百分点。

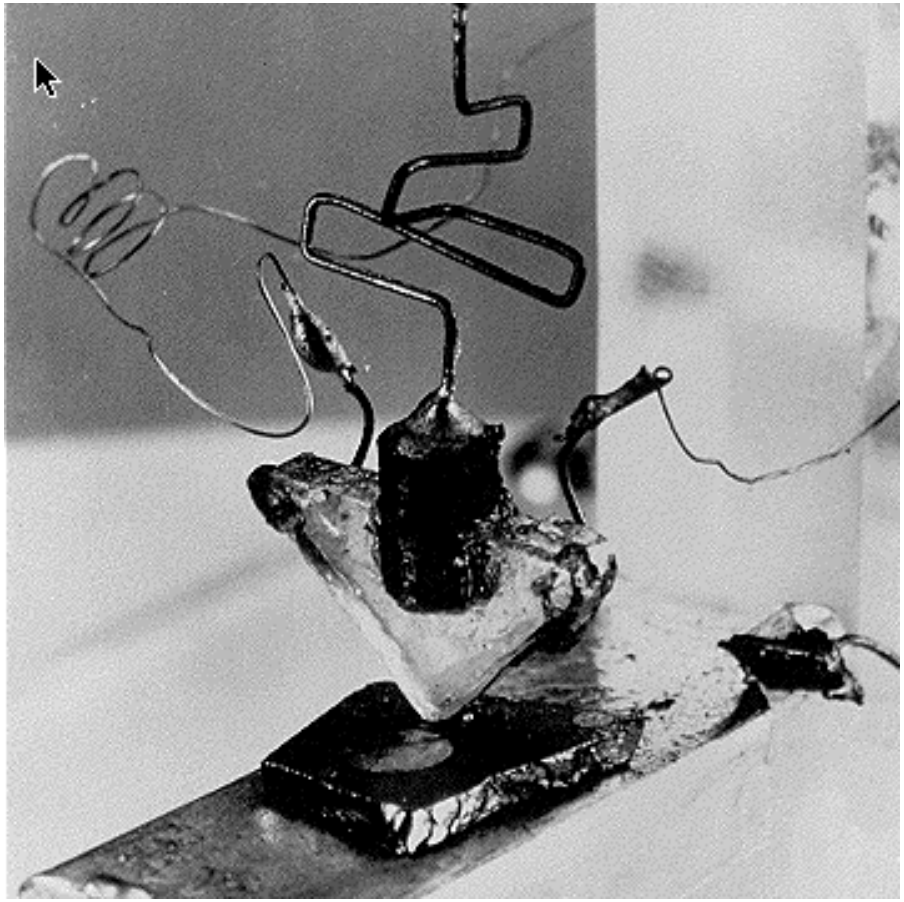
中国的集成电路产业

- 全球集成电路制造已经向中国大陆转移
- 台积电南京厂、联电厦门厂、英特尔大连厂、三星电子西安厂、力晶合肥厂
- 2014年6月，国务院印发《国家集成电路产业发展推进纲要》（下称《纲要》），提出成立国家集成电路产业投资基金（下称“大基金”）。
- 2013年，紫光以18亿美元收购在美上市的展讯，随后以9.1亿美元收购锐迪科。2014年，紫光把被收购的二者20%股份作价90亿元人民币售予英特尔。
- 2015年6月，由中芯国际、华为、IMEC（比利时微电子研究中心）、美国高通4家企业共同投资的中芯国际集成电路新技术研发公司浮出水面。
- AMD、中科曙光、海光
- 高通、贵州、计算所、华芯微电子

The history of integrated circuit

The first transistor

- On December 16, 1947 Bardeen and Brattain built the point-contact transistor（点接触晶体管）
- 1948.1 Shockley发明结型晶体管

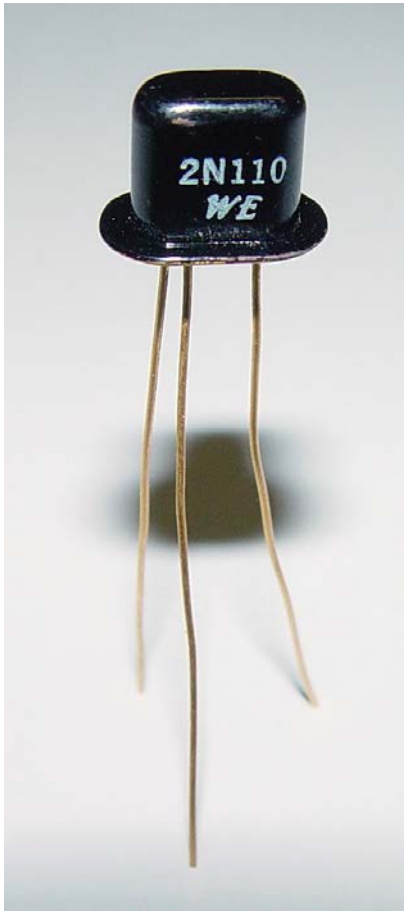


The first transistor

- Invention of the transistor by Bardeen, Brattain and Shockley unveiled by Bell Laboratories on June 30, 1948.

Sony Electronics

- Masaru Ibuka（井深大） and Akio Morita（盛田昭夫）, founded a new company named Sony Electronics that mass-produced tiny transistorized radios.
- 东京通信研究所，1946年



The Integrated Circuit

- 1959: Jack Kilby, working at TI, invented a monolithic “integrated circuit”
  - » Components connected by hand-soldered wiresand isolated by “shaping”, PN-diodes used as resistors (U.S. Patent 3,138,743)

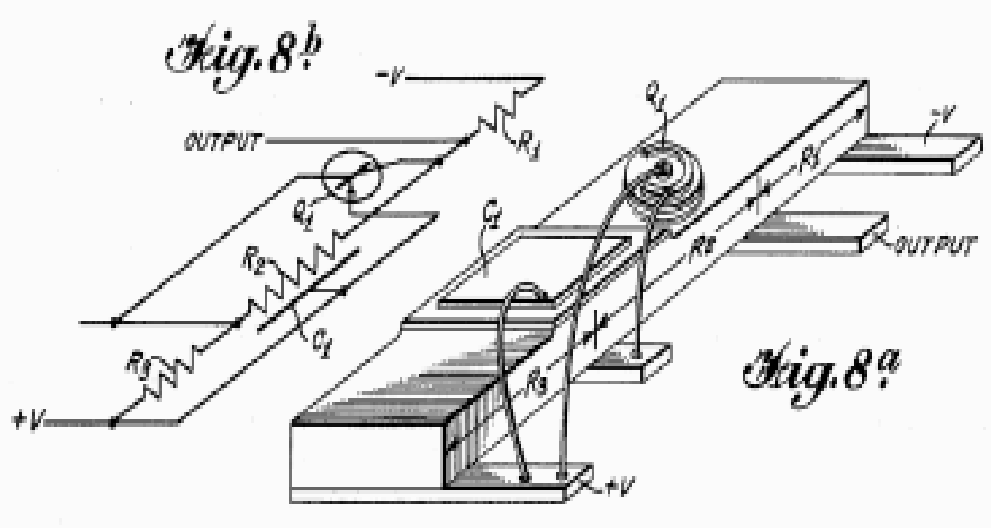


Figure 0.1 Diagram from patent application

The Integrated Circuits

- 1961: TI and Fairchild introduce the first logic ICs ($50 in quantity)
- 1962: RCA develops the first MOS transistor

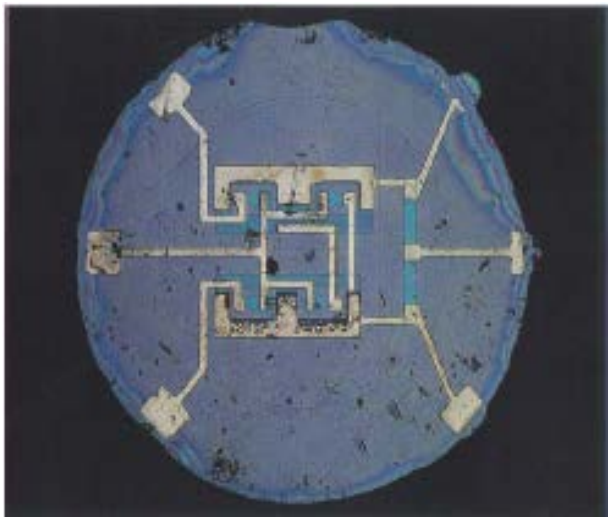


Figure 0.2 Fairchild bipolar RTL Flip-Flop

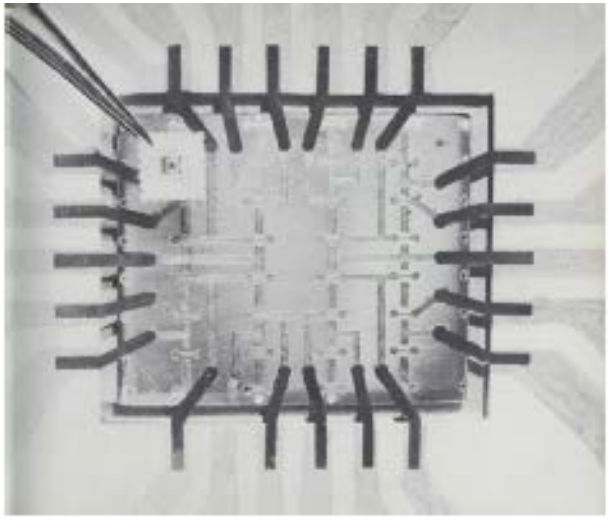
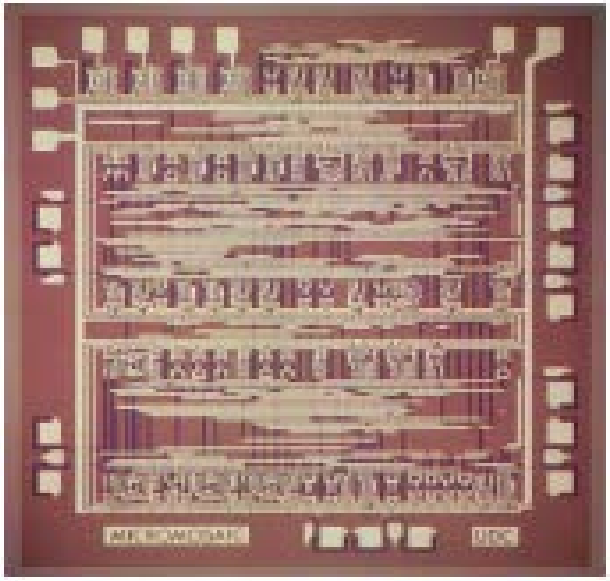


Figure 0.3 RCA 16-transistor MOSFET IC

Computer-Aided Design

- 1967: Fairchild develops the “Micromosaic” IC using CAD
  - » Final Al layer of interconnect could be customized for different applications



- 1968: Noyce, Moore leave Fairchild, start Intel

RAMs

- 1970: Fairchild introduces 256-bit Static RAMs
- 1970: Intel starts selling1K-bit Dynamic RAMs

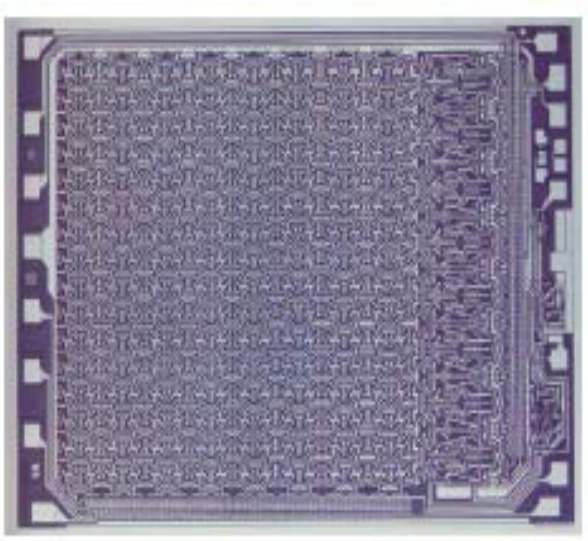


Figure 0.4 Fairchild 4100 256-bit SRAM

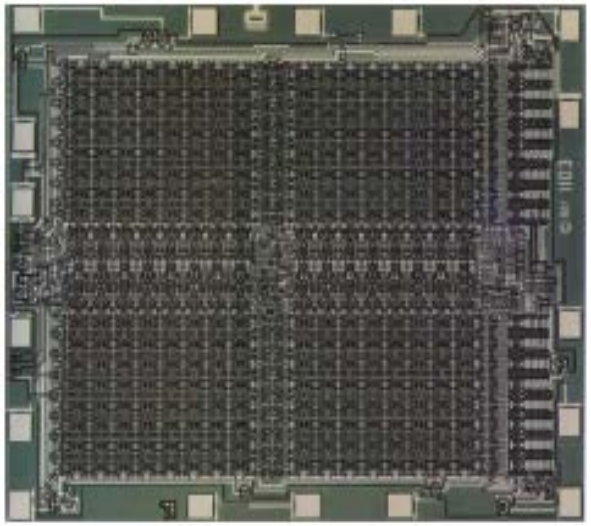


Figure 0.5 Intel 1103 1K-bit DRAM

The first microprocessor

- 1971: Intel introduces the 4004（**2,108 transistors**）
  - General purpose programmable computer instead of custom chip for Japanese calculator company

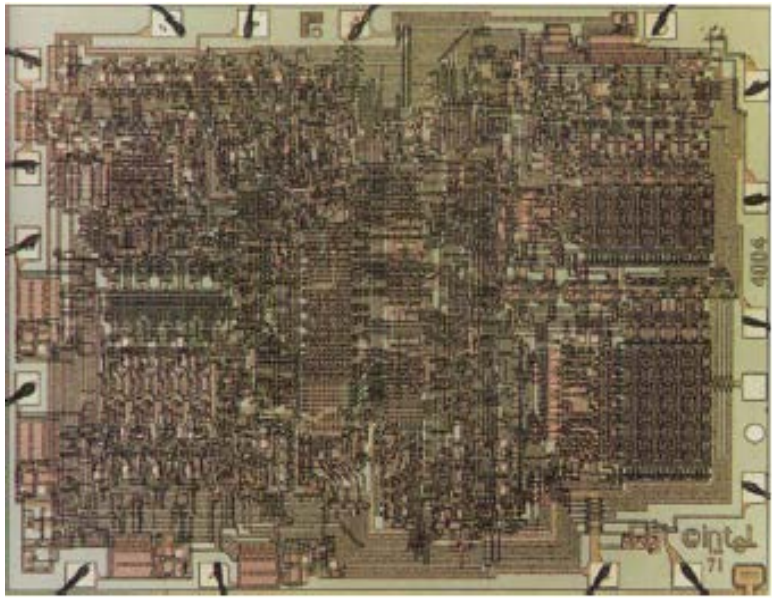
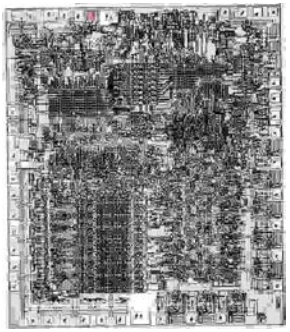
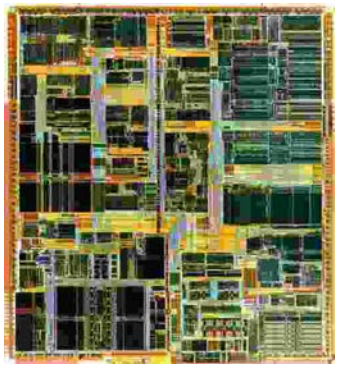


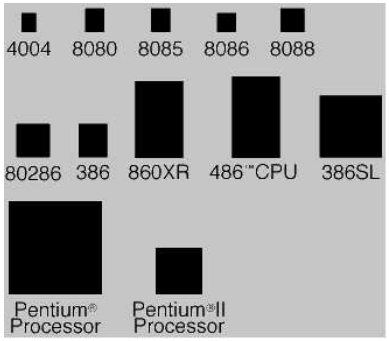
Figure 0.6 Intel 4004 Microprocessor

The first PC(4th Generation)

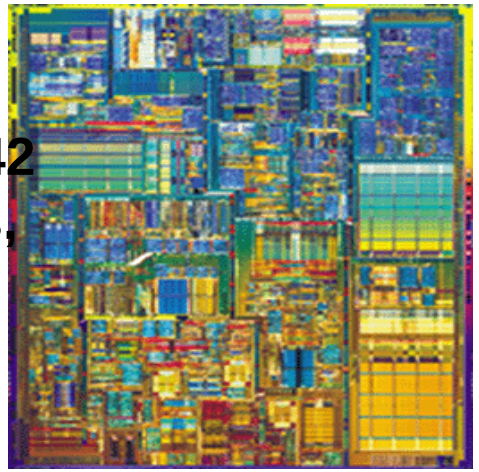
- **1974: first "PC" (the Altair), Intel 8080 microprocessor, 2MHz, 20mm²**
- **1978: IBM PC, Intel 8086/8088**
- **1997: Intel Pentium® II, 7.5 million transistors, 200-300MHz, 209mm²**







- **2000: Pentium 4, 42 million transistors, 0.18 microns, 1.5 GHz, 224mm²**

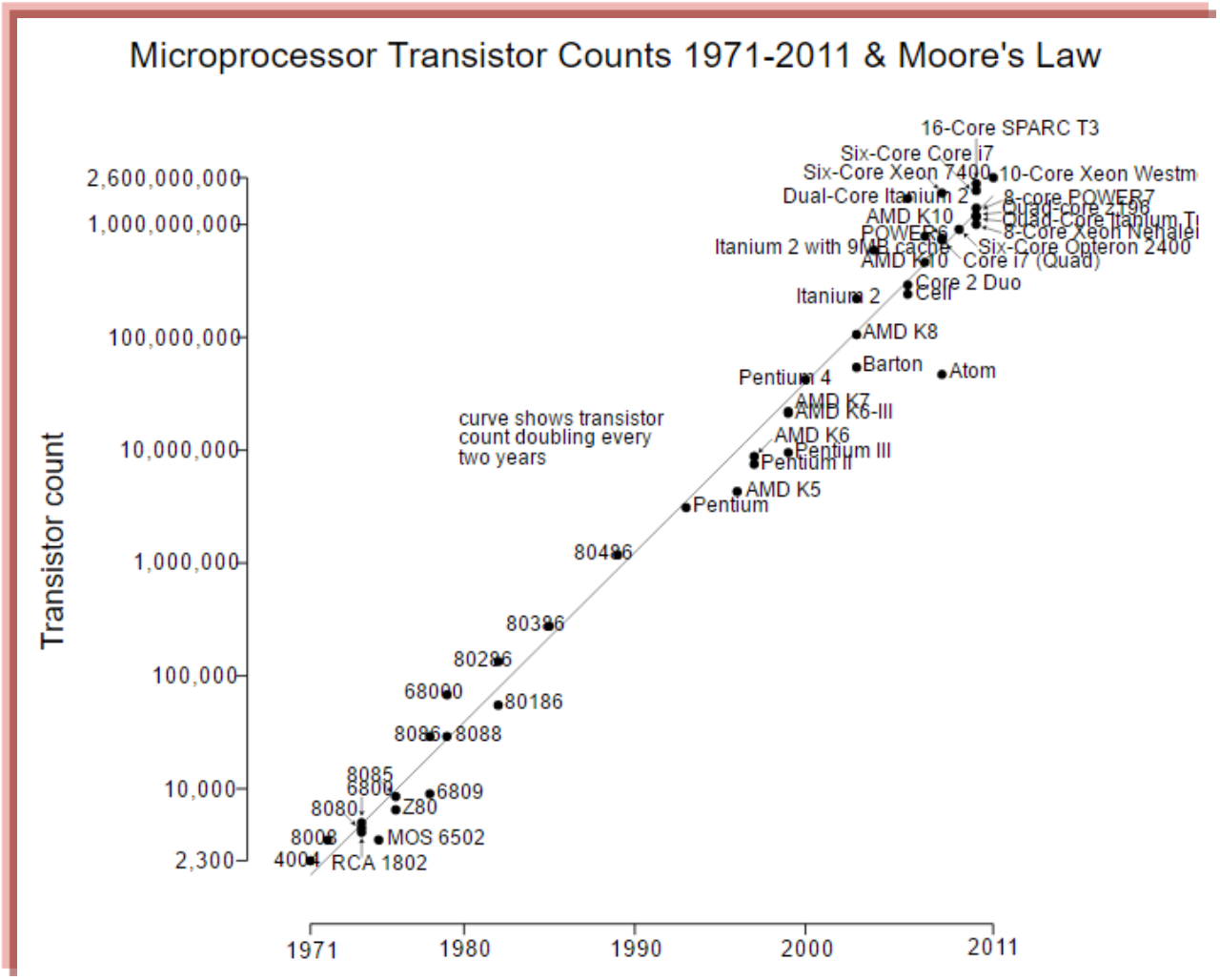


http://www.intel.com/intel/intelis/museum/exhibit/hist_micro/hof/hof_main.htm, also data from: http://www.icknowledge.com/trends/uproc.html

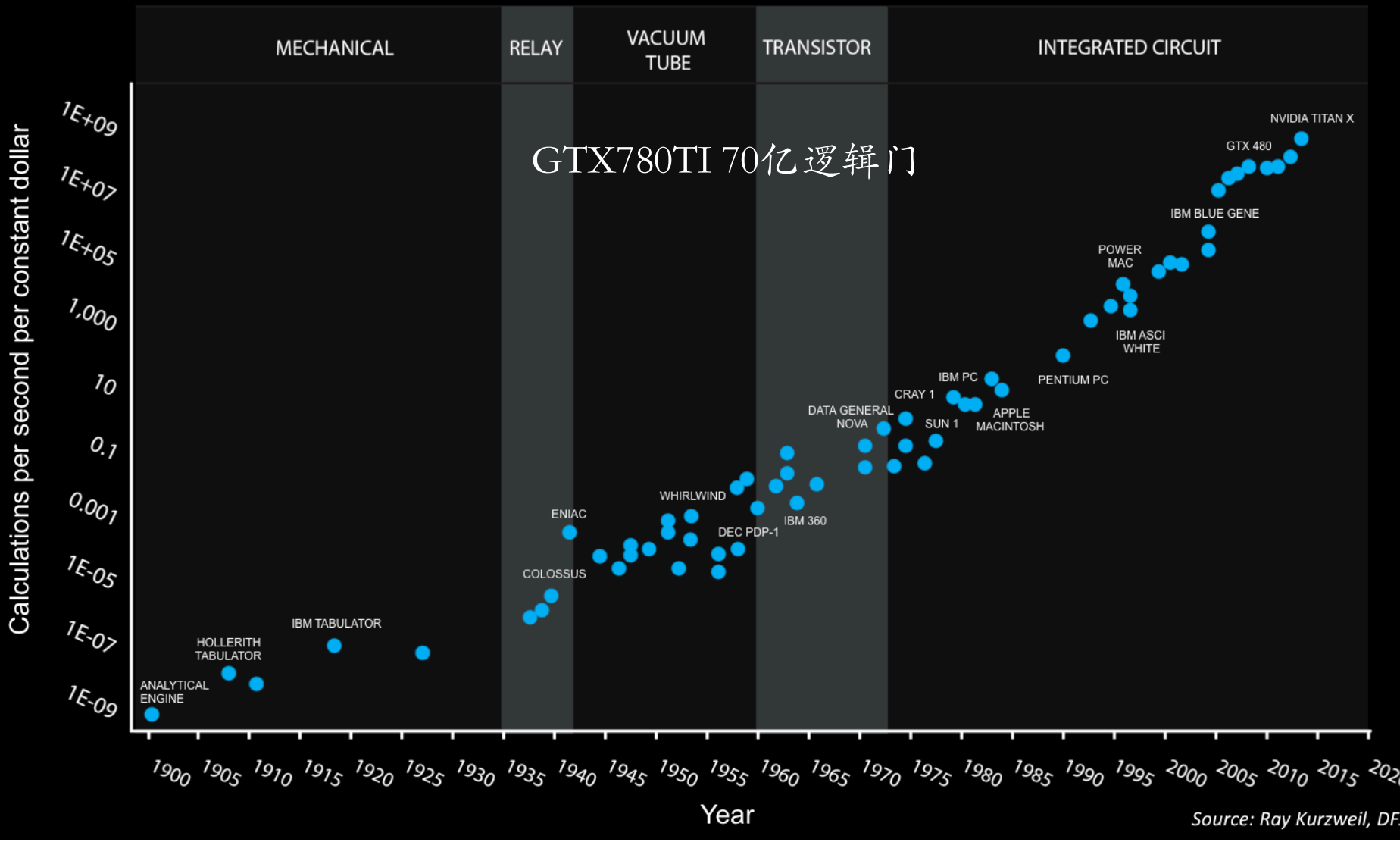
第4代：大规模集成电路机（1970年至今）

摩尔定律

- Original Moore's prediction in 1965, (Electronics, Vol. 38, No.8, April 19, 1965)
- **doubling** every year in the number of components per integrated circuit，1965
- **doubling** two year in the number of components per integrated circuit，1965
- Intel executive David House，18 months



120 Years of Moore's Law

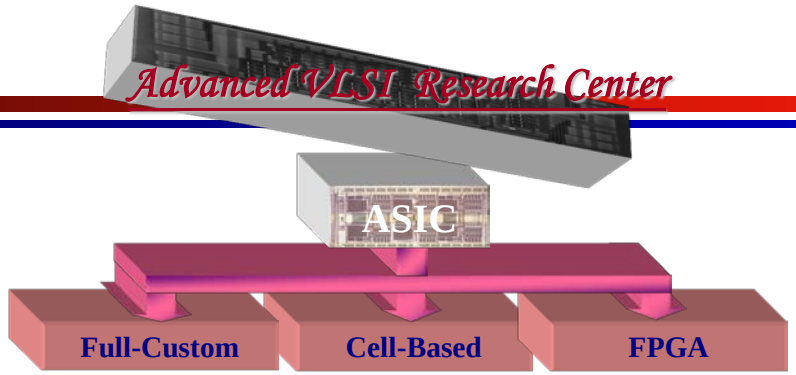


IC design methodology

Classification of IC Designs

- IC Types
  - Microprocessor/DSP
  - ASIC: Application Specific IC
  - Programmable Logic
    - Fast prototyping with FPGA or CPLD chips
  - ASIP
  - AI芯片：寒武纪、TPU
- IC Designs can be Analog or Digital
- CMOS design methods
  - Cell-based Design
    - Designs synthesized automatically from a high-level language description
  - Full-custom Design
    - Every transistor designed and laid out by hand
  - Platform-based Design
    - System on a chip

IC Design Flow



Cell Based Design Flow

Specification

System-Level Design & Sim

SPW

Matlab

BONeS

Behavior Synthesis

Visual Architect

MathWork RTW

RTL-Level Sim

Verilog-XL

Synopsys VCS

RTL Synthesis

Cell Library

Ambit

Design-Compiler

Gate-Level Sim

Cell Library Model

Synopsys VCS

Verilog-XL

Physical Verification

Apollo/Hercules

Silicon Ensemble Ultra / Dracula

RC Extraction

Star-RC

Dracula

Post-Layout Sim

TimeMill

Star-time

Star-sim

Tape Out

Full Custom Design Flow

Circuit-Level Design

Composer

Pre-Layout Circuit-Sim

Hspice

Spice Model

SBTSPICE

Physical Layout

Virtuoso

Physical Verification & RC Extraction

Dracula

Post-Layout Sim

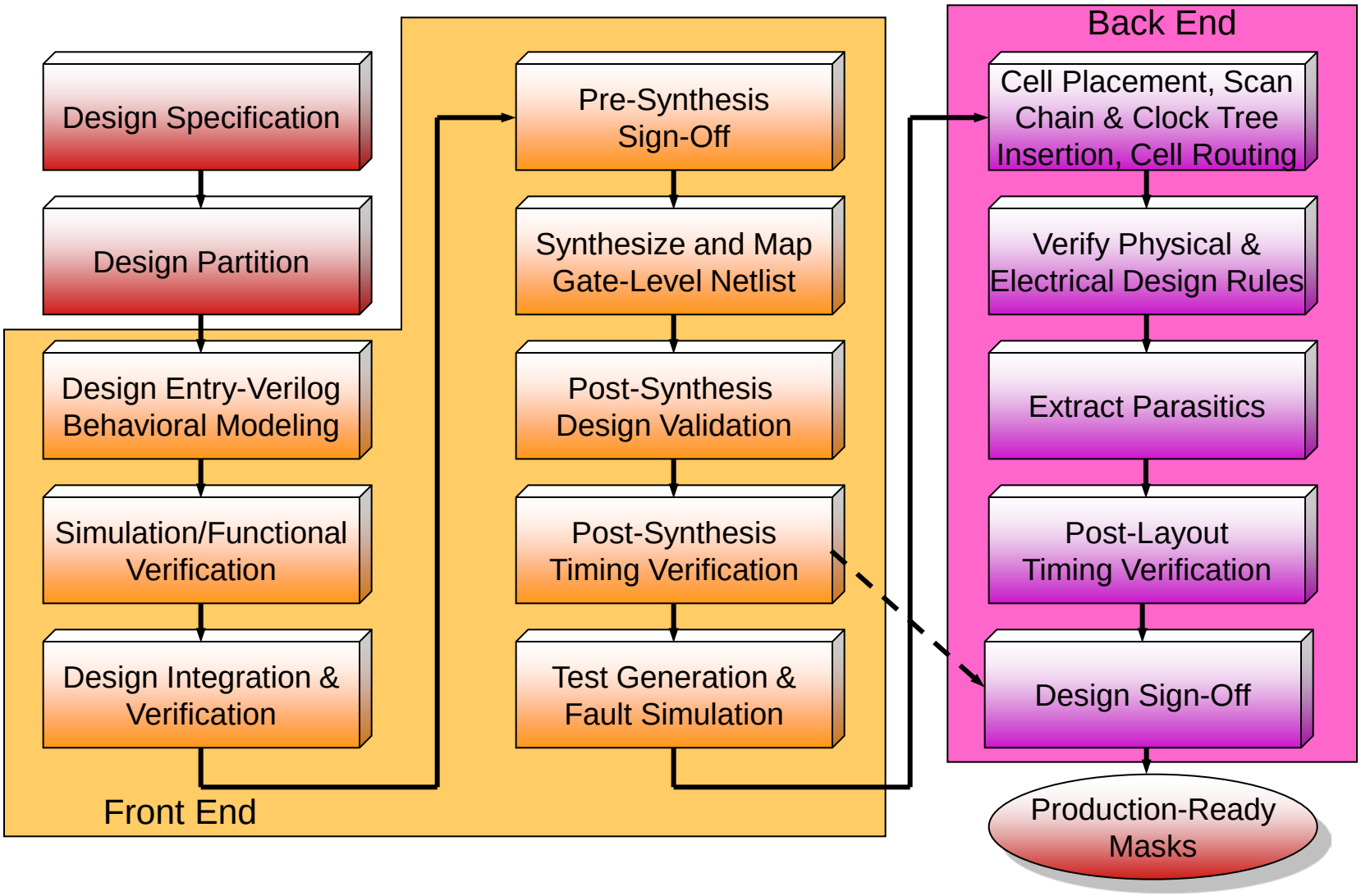
Hspice

Spice Model & RC

SBTSPICE

Tape Out

Cell Based Design Flow



Hardware Description Language

- HDL – Hardware Description Language
- Why use an HDL ?
  - Hardware is becoming very difficult to design directly
  - HDL is easier and cheaper to explore different design options
  - Reduce time and cost

Descript Levels

- Architectural / Algorithmic
- Register Transfer Logic (RTL)
- Gate
- Switch

Verilog HDL

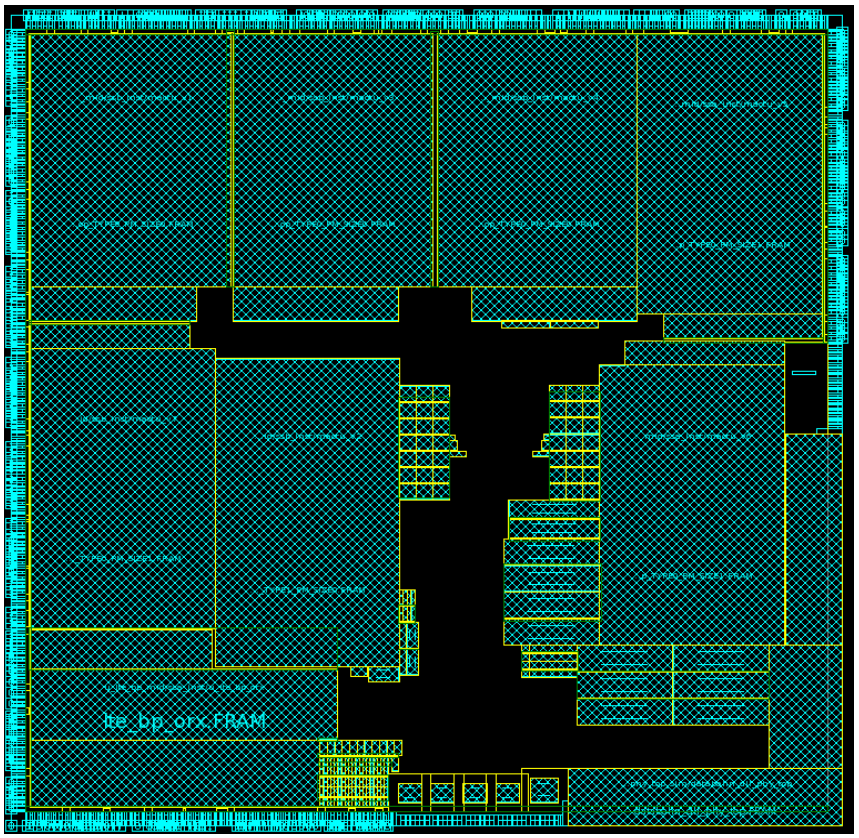
An Example: Counter

```
`timescale 1ns/1ns
   module counter;
      reg clock;                  // declare reg data type for the clock
      integer count;              // declare integer data type for the count
   initial                        // initialize things - this executes once at start
      begin
         clock = 0; count = 0;       // initialize signals
         #340 $finish;               // finish after 340 time ticks
      end
/* an always statement to generate the clock, only one statement follows the always so we don't
need a begin and an end */
   always
      #10 clock = ~ clock;                  // delay is set to half the clock cycle
/* an always statement to do the counting, runs at the same time (concurrently) as the other always
statement */
   always
      begin
         // wait here until the clock goes from 1 to 0
         @ (negedge clock);
         // now handle the counting
         if (count == 7)
            count = 0;
         else
            count = count + 1;
         $display("time = ",$time," count = ", count);
      end
   endmodule
```

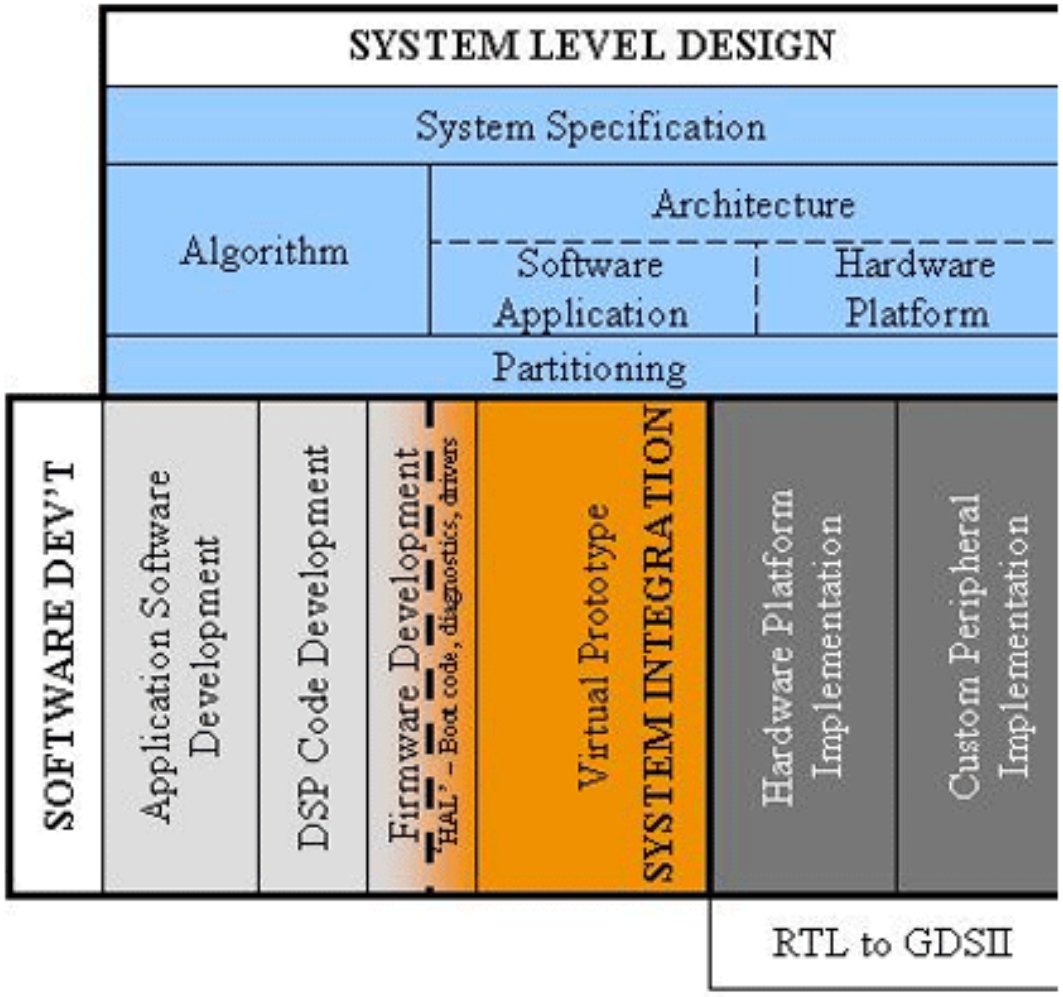
A Real Chip implemented with Verilog

4G/LTE基站芯片

- ~4000万逻辑门
- 75平方毫米
- SMIC 55nm
- 550万 Verilog HDL代码



IC design Principles



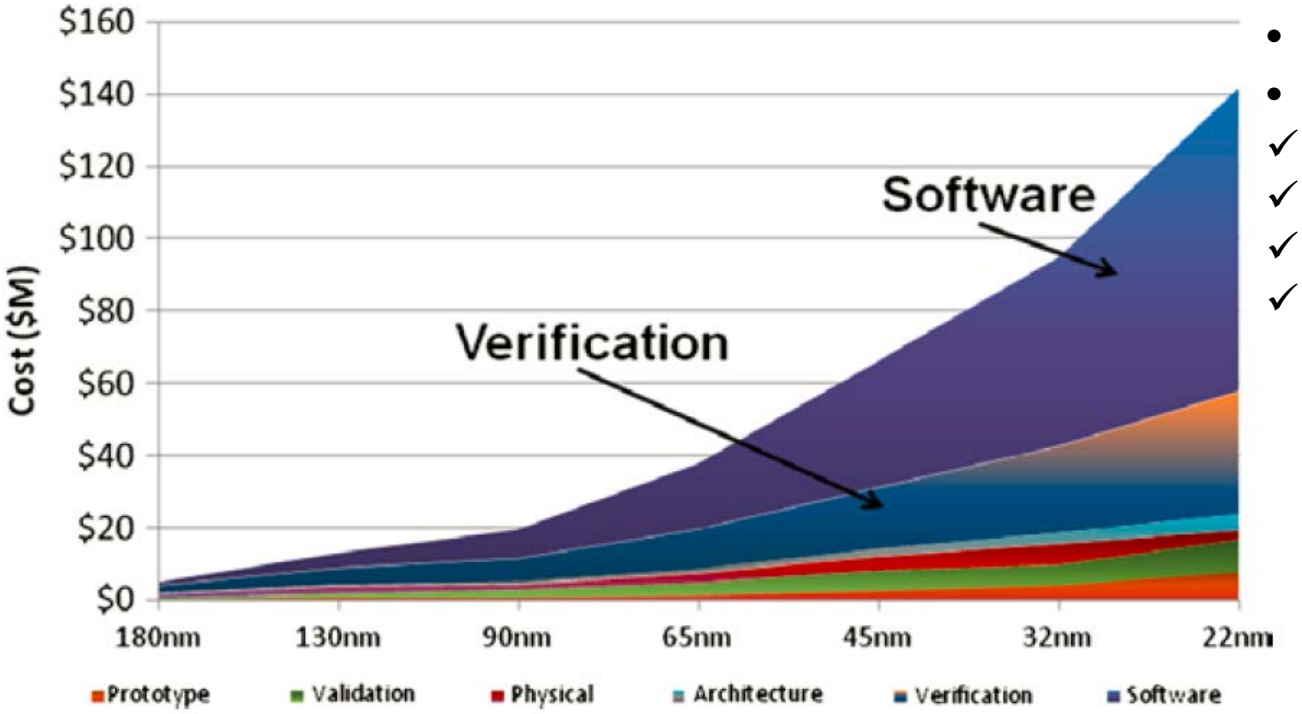
IC Design Challenges

- Functionality
  - ✓ Function (right or false)
  - ✓ RT performance (In time?)

- Efficiency
  - ✓ Power
  - ✓ Area
  - ✓ Cost (NRE, Design, Verification)
  - ✓ Time-to-Market

The Problem

Designing complex systems is becoming extremely difficult and very expensive



- Physical design is stable
- FE efficiency is stable

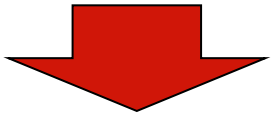
✓ 10L/30L HW/SW
✓ 3-10Gates/Line
✓ $2/Gate
✓ $30/Line

Moore Law

The result is complex SoC

Challenges in Complex SoC

- Divide and Conquer



- Tightly Coupled vs. Loosely Coupled Systems

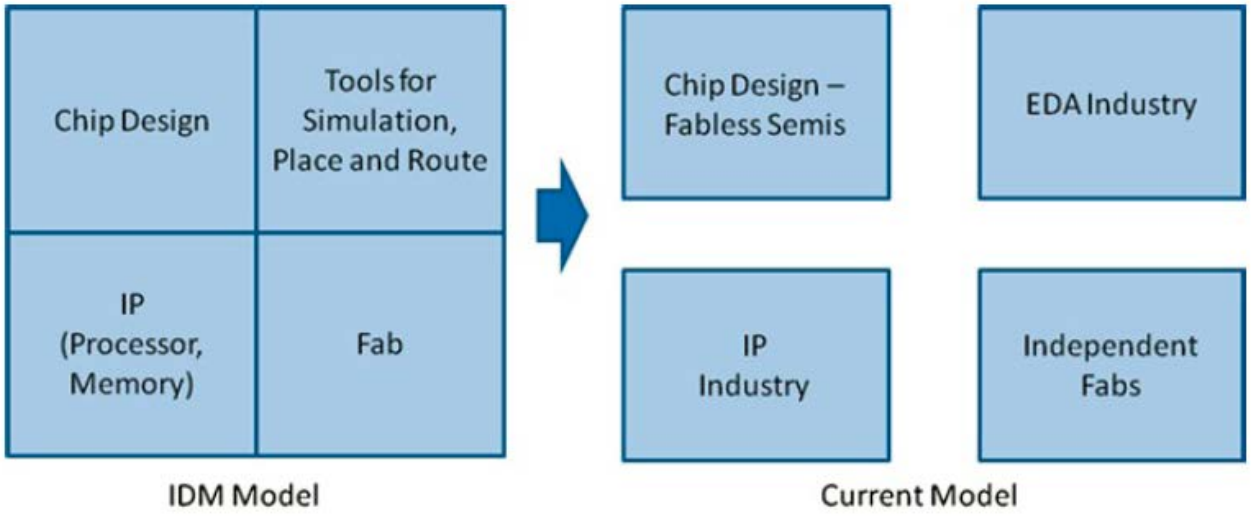
- The Challenge of Verification

Challenges in Complex SoC

◆Divide and Conquer

Divide and conquer is the key tool for solving many complex problems.

The partitioning of the system into appropriately sized components and designing good interfaces between them.



Intel, 80s LSI

Today's IC company

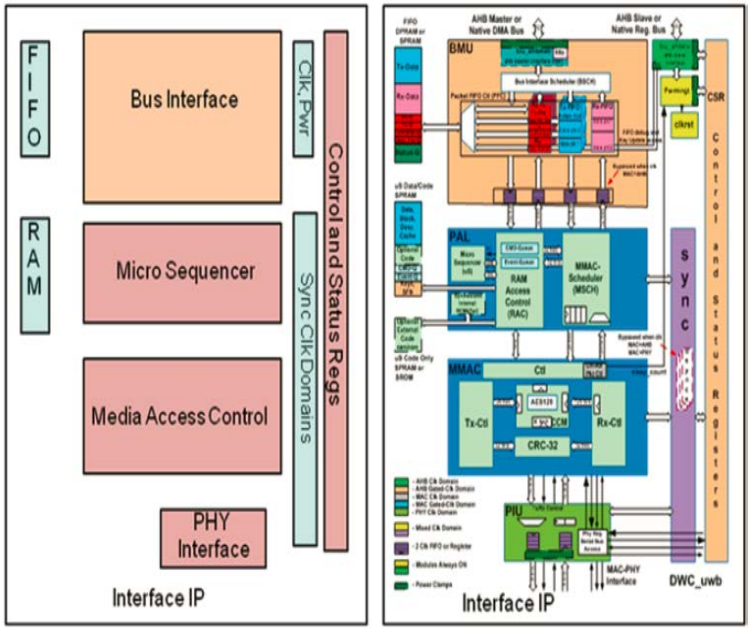
Challenges in Complex SoC

◆Divide and Conquer

- The General Model
  - ✓ Product design (the cell phone)
  - ✓ PC board design
  - ✓ SoC design
  - ✓ IP design

  At each level of design, we decompose the design problem into a set of components.

- The rule of 7
  - ✓ Psychologist's "The Magic Number Seven Plus and Minus Two"
  - ✓ in any design, at any level of hierarchy, we can at any one time understand a design of up to seven to nine blocks.



Challenges in Complex SoC

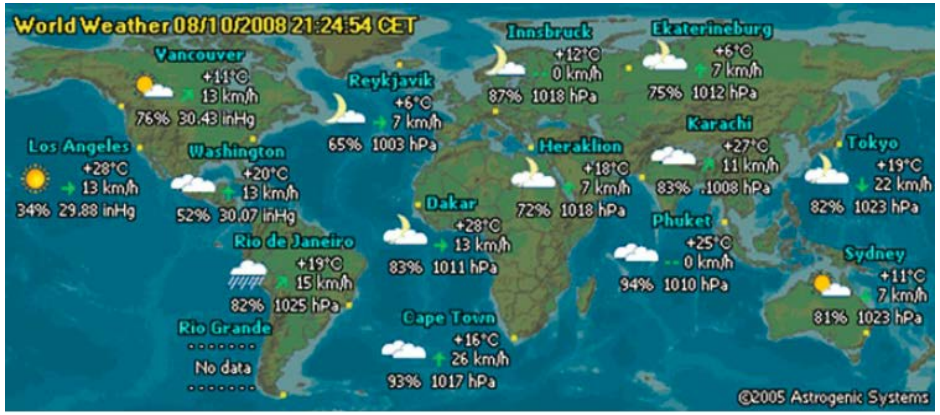
- Tightly Coupled vs. Loosely Coupled Systems

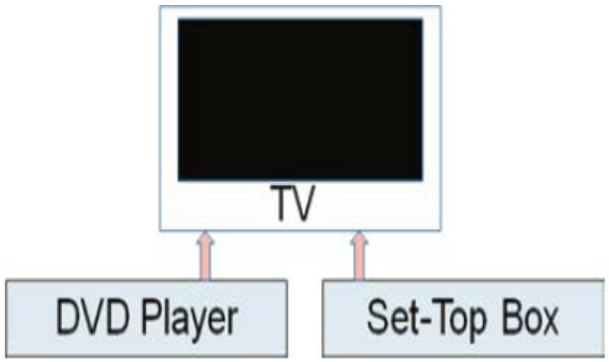
Tightly coupled system :

- ✓ more efficient than loosely coupled systems
- ✓ allow for global optimization
- ✓ harder to analyze
- ✓ local problems can become global problems

Loosely coupled system :

- ✓ more robust
- ✓ support the design of larger systems
- ✓ easier to analyze
- ✓ local problems remain local





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Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?

Challenges in Complex SoC

- Tightly Coupled vs. Loosely Coupled Systems

In SoC designs

Flatten or Hierarchical place and route

- ✓ Global optimization of the entire design, ~20% efficiency in Maotu
- ✓ ECO efforts
- ✓ Module/subsystem partitions

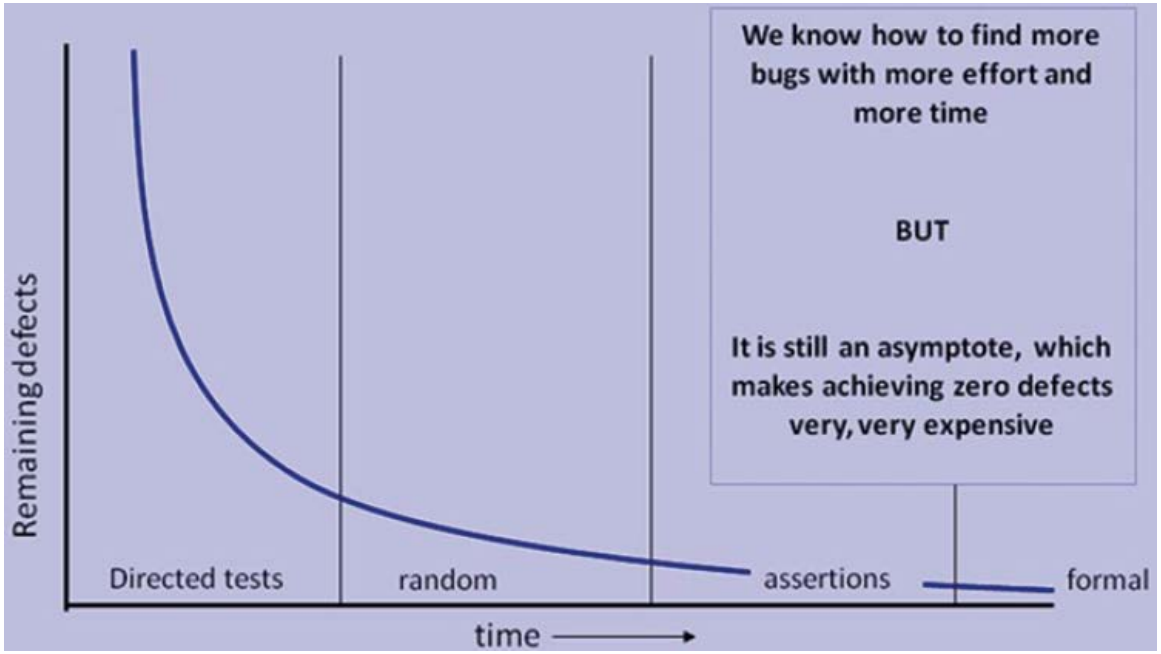
One of the keys to the good design of SoC's is to:

make sure that they are loosely coupled systems.

Challenges in Complex SoC

- The Challenge of Verification

As designs become larger and more complex,
the challenge of functional verification has become extremely difficult.



1bugs/10lines
0.5bugs/KLOC best sw
0.1bugs/KLOC best hw

Challenges in Complex SoC

- The Challenge of Verification

The statistical bugs in ES0.5: (@ 0.1 bugs/KLOC)

Module	Lines	Bugs
CGCU	2498	0.2498
EMI	6173	0.6173
HDI	375	0.0375
L1CP	42322	4.2322
LPCU	733	0.0733
MAOTU	5331164	533.1164
MID	2549	0.2549
MISC	328	0.0328
ORX	54158	5.4158
OTX	24024	2.4024
RFIU	7174	0.7174
RWU	912	0.0912
SMEM	902	0.0902
SSA	7033	0.7033
SSB	3662	0.3662
TBU	2654	0.2654
TOP	3032	0.3032
Total	5489693	548.9693

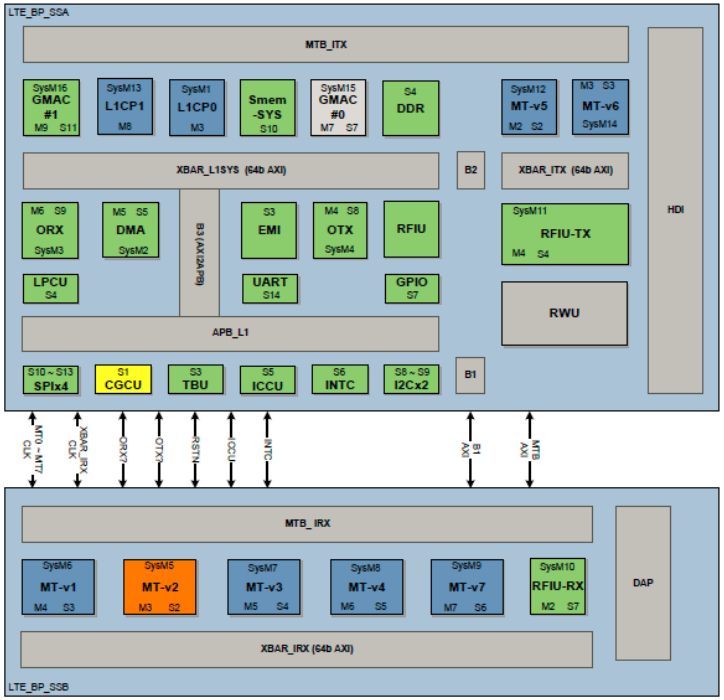
SoC design Principles

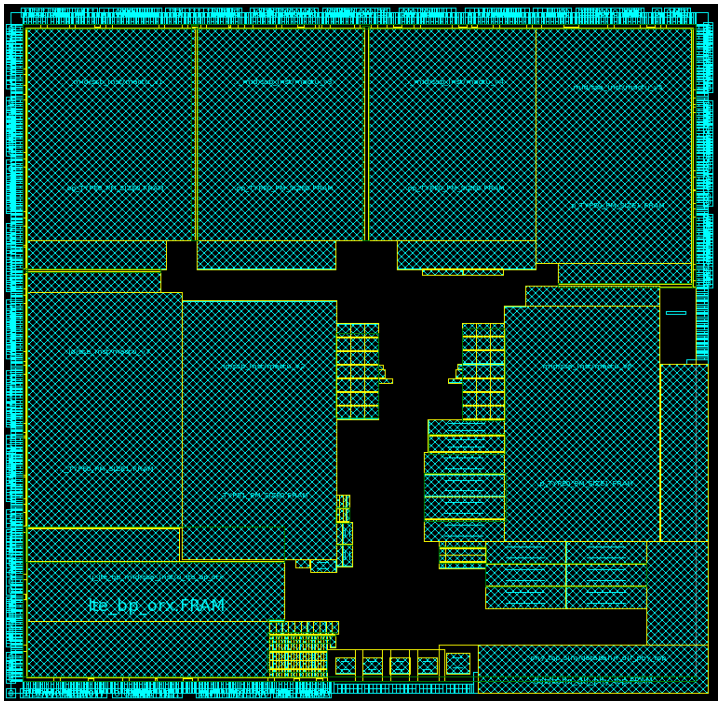
- Hierarchy: Subdivide the design into many levels of sub-modules
- Regularity: Subdivide to max number of similar sub-modules at each level
- Modularity: Define sub-modules unambiguously & well defined interfaces
- Locality: Max local connections, keeping critical paths within module boundaries

Consider ES0.5 Design

ES 0.5 Architecture

How to Divide and Conquer ?

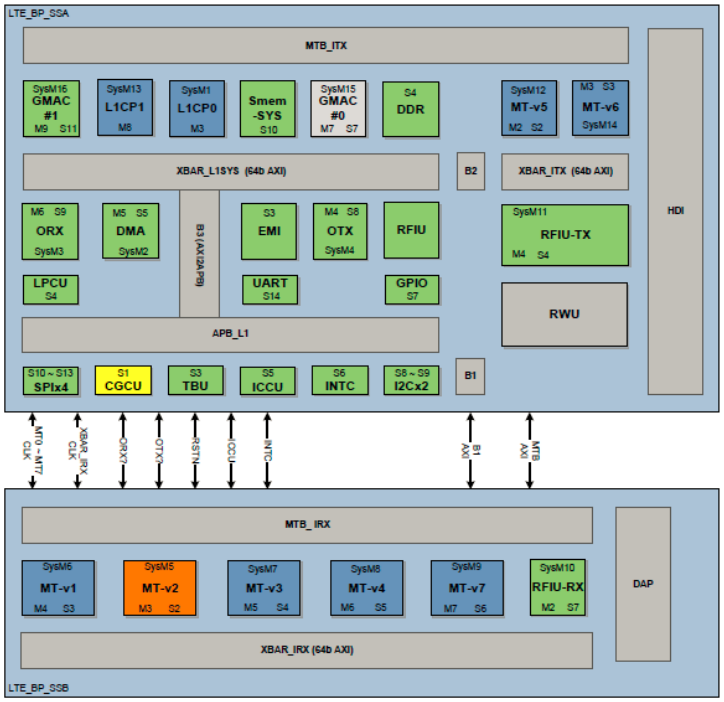


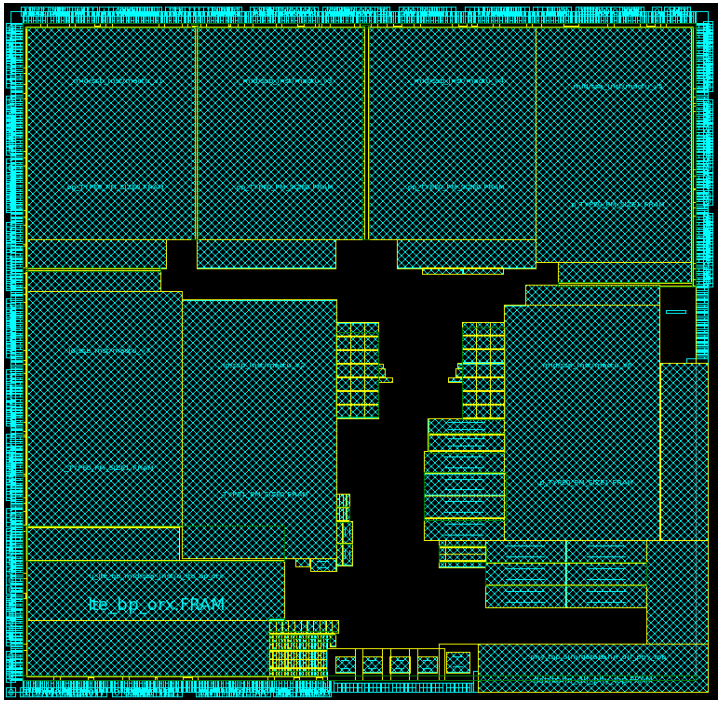


- Methodologically: SDR (Processors)
- Functionally: IRX, ITX, ORX, OTX, infra-structure
- Logically: TOP, MID, SSA, SSB, Maotu, ORX
- Schematically: ORX, Maotu x 7, DDR

ES 0.5 Architecture

“Tightly Coupled ?” OR “Loosely Coupled ?”





- AMBA Cross-bar and Bus
- On chip interrupts

MOST Loosely Coupled system?
Benefits? Penalty?

ES 0.5 Architecture

How about the Verification ?

- Methodologically consideration:
  - ✓ SDR (DSP)
  - ✓ IP re-use (DW, Opencores)

- Verification terms
  - ✓ Direct test
    - ➢ FPGA
    - ➢ RTL sim
    - ➢ GATE sim
  - ✓ Formal
    - ➢ MVRC
    - ➢ fm_shell
    - ➢ Leda/Spyglass

Do we find

548.9693

bugs?

ES 0.5 Architecture

Think more about OUR SoC Design?

Why SDR?

- ✓ benefit, penalty?
- ✓ For the TTM, Verification, and more?

Is there better system architecture?

- ✓ OCB
- ✓ Memory Arch
- ✓ HW/SW partitions

How about the verification?

- ✓ What to do in the future?

Story about IC

The origin of IC

1947, John Bardeen, William Shockley and Walter Bratta, AT&T's Bell Labs
- ✓ Transistor is first developed

1949, Werner Jacobi, Simens, German
- ✓ A patent of “IC-like” device.
- ✓ But NO commercial use.

1952, Geoffrey W.A. Dummer, Ministry of Defence, British
- ✓ IC was conceived, the idea was published.
- ✓ But the implementation was FAILD.

1958, Jack Kilby, Texas Instrument, USA
- ✓ The idea of small ceramic squares.
- ✓ July 1958, the IDEA of IC is recoded.
- ✓ 12 Sep. 1958, the first working IC was build.
- ✓ Feb. 1959, The patent was applied.

1958, Robert Noyce, Fairchild Semiconductor, USA
- ✓ Silicon IC.
- ✓ basis of all modern CMOS computer chips.

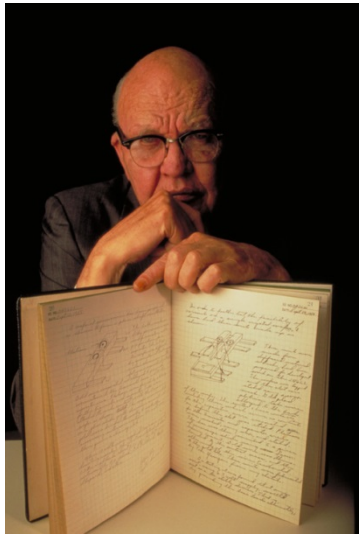
The origin of IC

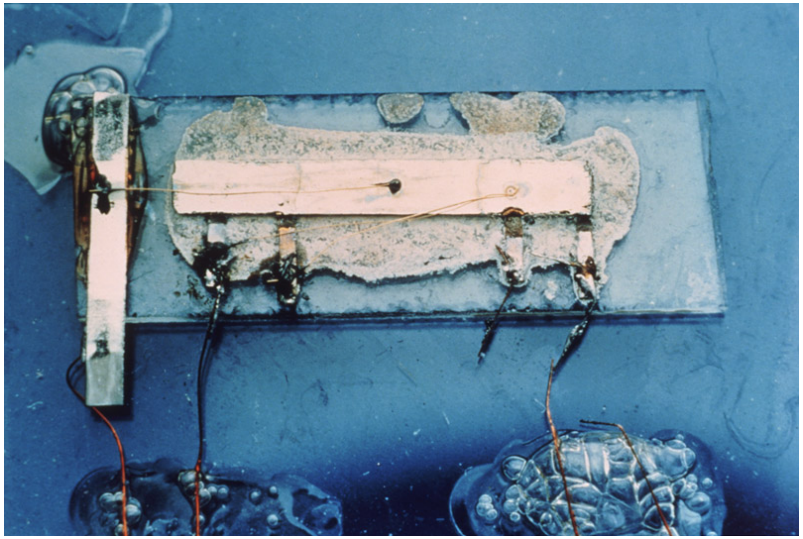
Jack Kilby defines IC as “a body of semiconductor material … wherein all the components of the electronic circuit are completely integrated.”

The first customer for the new invention was the US Air Force.

Kilby won the 2000 Nobel Prize in Physics for his part of the invention of the IC.

Kilby's work was named an IEEE Milestone in 2009.





Fairchild Semiconductor

Funded: 1957 – 1997
Products:
Integrated circuits, Signal processors, Motor controllers, Field-effect transistors

The first marketed transistor (2N697, 150$, IBM)
Creating the first silicon IC: a circuit with four transistors on a single wafer of silicon.

Funders:

William Shockley:

✓ Co-invented the transistor. Awarded the 1956 Nobel Prize in Physics.

Robert Noyce:

✓ Gave Silicon Valley its name, "The Mayor of Silicon Valley".
✓ Co-founded Intel Corporation in 1968.
✓ Credited (along with Jack Kilby) with the invention of the IC.

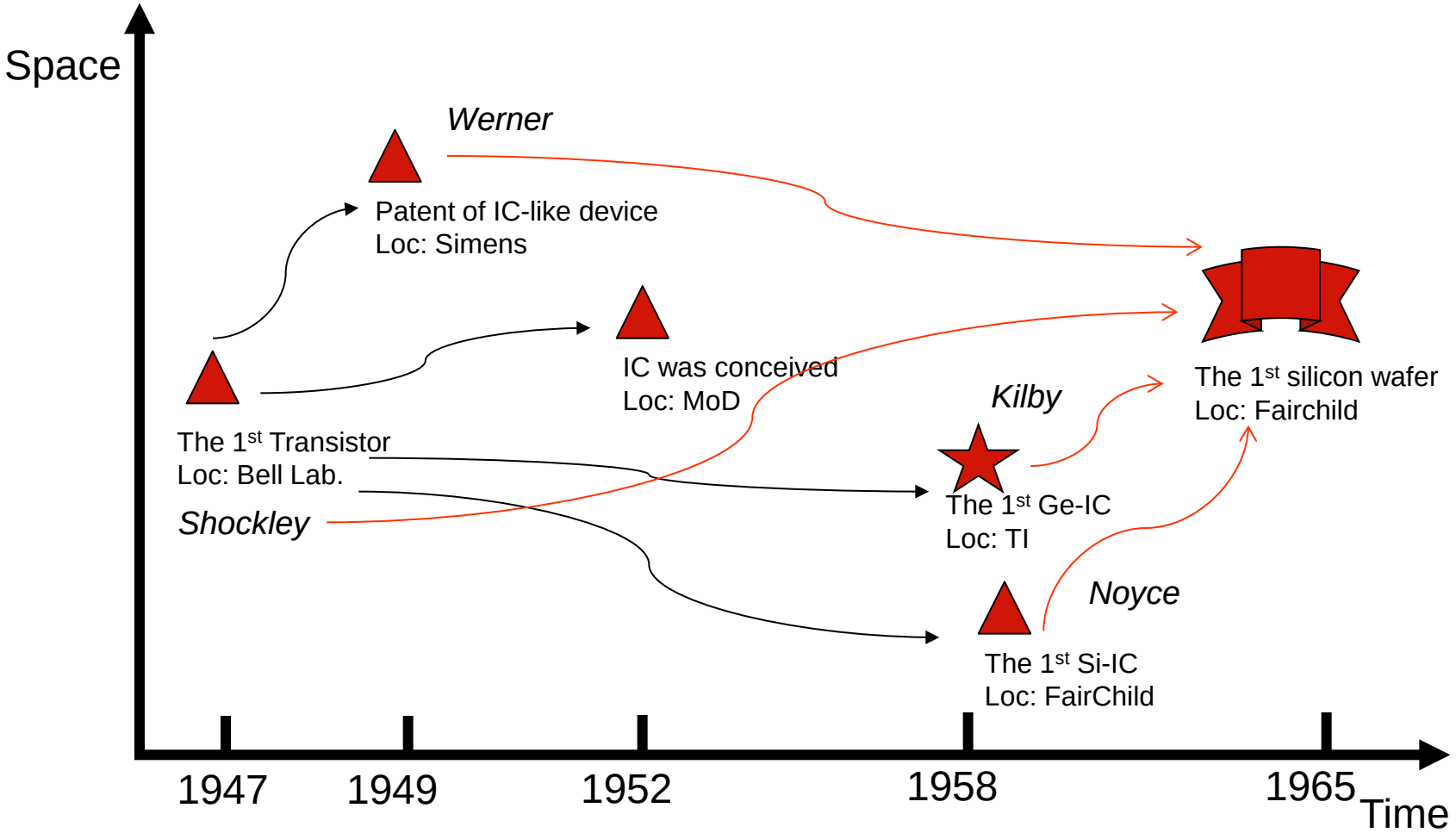
Eugene Kleiner(尤金-克莱尔):

✓ Funder of KPCB（凯鹏华盈美国最大的风险基金公司）
✓ ventures including Google, Amazon.com, Netscape, Sun Microsystems, Symantec，京东，百度，阿里

Gordon Moore:

✓ Intel

Illustration about IC comes

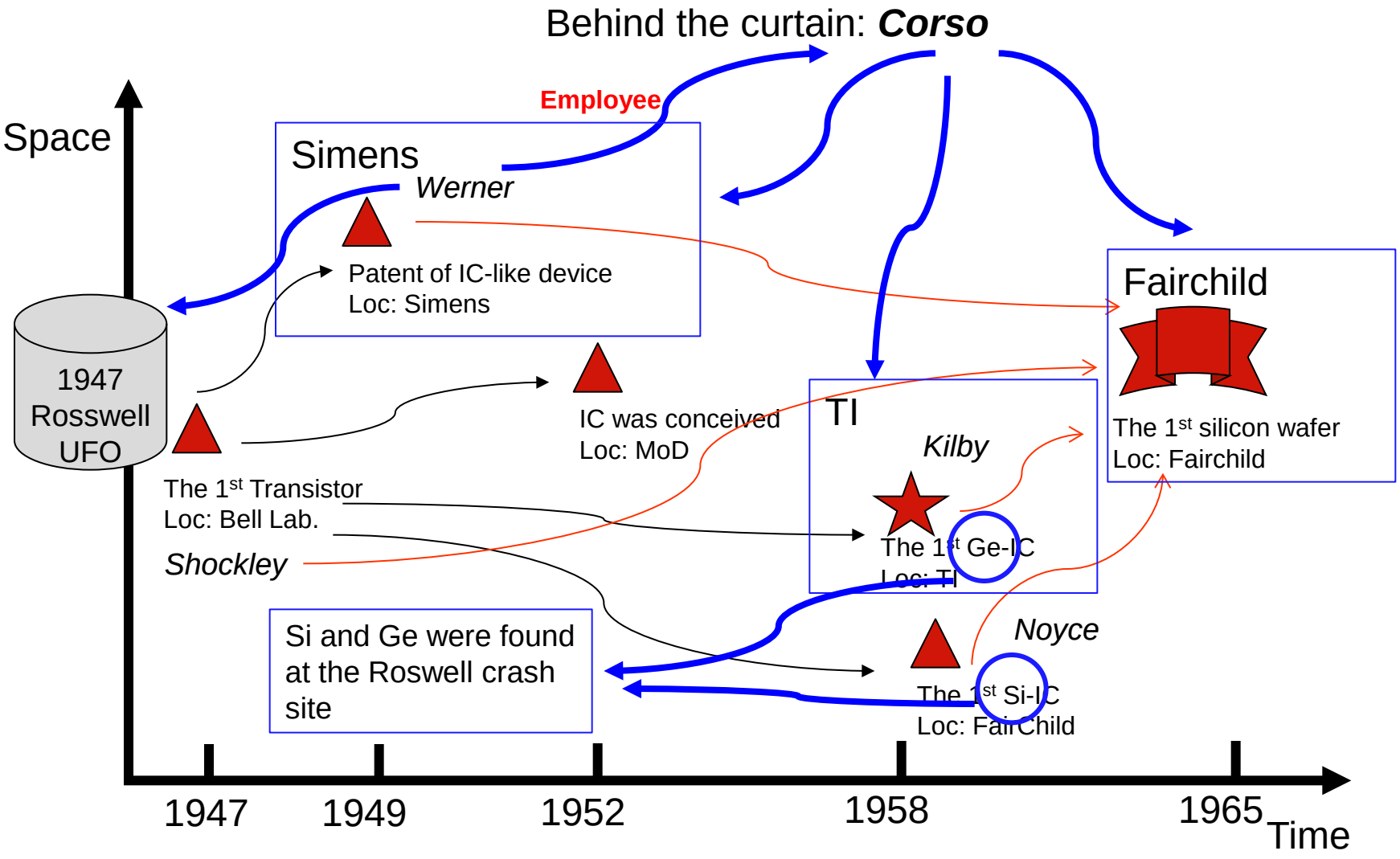


Did IC Tech Come From Aliens?

Some peoples and events:

- Roswell UFO incident:
  - ✓ 1947
  - ✓ Silicon(硅），Germanium（锗） were found at the crash
- Corso:
  - ✓ The head of the Foreign Technology Desk, R&D at the Pentagon.
  - ✓ Member of President Eisenhower's NSC (National Security Council) staff.
  - ✓ Write a book entitled "The Day After Roswell".
- Werner
  - ✓ The Vice President of Fairchild.
  - ✓ Operation Paperclip.
  - ✓ On Corso's research and development team.
- Dummer
  - ✓ Employed by Ministry of Defence, British.
  - ✓ Published the concept of IC.
- Special projects and programs in the US companies
  - ✓ TI, Fairchild, Simens

Did IC Tech Come From Aliens?



谢谢

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