VLSI Design

Syllabus

SECTION-A	
Unit I :	Introduction to VLSI: Applications of VLSI, Advantages, Integrated Circuit Manufacturing - Technology and Economics; CMOS Technology - Power consumption, Design and Testability, Reliability ; Integrated Circuit Design Techniques - Hierarchical Design, Design Abstraction and CAD; IP based design - types of IP, IP across design Hierarchy, IP Life cycle.
Unit II :	Basic HDL Constructs: VLSI Design flow, Overview of different modeling styles in VHDL, Data types, operators and data objects in VHDL, Dataflow Modeling, Behavioral Modeling, using VHDL for combinational Circuits and sequential Circuits.+`
Unit III :	Hardware Description Language: Structural Modeling, Subprograms, Packages and Libraries, Generics, Configurations, attributes. Simple Test Bench, Simulation and Synthesis issues, case study of ALU/ Sequence Detector, Comparison of various Hardware Description Languages.

SECTION-B

Unit IV :	Programmable Logic Devices: Introduction to CPLDs: Function block architecture, input/output block, switch matrix, Study of architecture of CPLDs of Altera /Xilinx. Introduction to FPGAs: Configurable logic block, input/output block and interconnect, Study of architecture of FPGAs of Xilinx /Altera.
Unit V :	CMOS Circuits: Different logic families, MOS Transistor, CMOS as an inverter, propagation delay, power consumption/ dissipation issues, simple circuits using CMOS.
Unit VI :	CMOS Processing & Digital Circuit Verification: CMOS Fabrication: Different steps of fabrication, CMOS p-well, n-Well and twin tub processes, CMOS Layout and Design rules.

What is a VLSI Circuit?

VERY LARGE SCALE INTEGRATED CIRCUIT

Technique where many circuit components and the wiring that connects them are manufactured simultaneously into a compact, reliable and inexpensive chip.

Early (circa 1977) characterization of circuit "size" before people realized that the number of components per chip was quadrupling every 24 months (Moore's Law)! This growth rate has slowed in recent years... can you guess why?

What is VLSI?

- Very-large-scale integration (VLSI) is the process of creating an integrated circuit (IC) by combining thousands of transistors into a single chip.
- VLSI began in the 1970s when complex semiconductor and communication technologies were being developed.
- The microprocessor is a VLSI device.
- Before the introduction of VLSI technology most ICs had a limited set of functions they could perform.
- An electronic circuit might consist of a CPU, ROM, RAM and other glue logic. VLSI lets IC designers add all of these into one chip.

OR

- Very large-scale integration (VLSI) is the process of integrating or embedding hundreds of thousands of transistors on a single silicon semiconductor microchip.
- VLSI technology was conceived in the late 1970s when advanced level computer processor microchips were under development.
- VLSI is a successor to large-scale integration (LSI), medium-scale integration (MSI) and small-scale integration (SSI) technologies.

VLSI Technology

VLSI is one of the most widely used technologies for microchip processors, integrated circuits (IC) and component designing.

It was initially designed to support hundreds of thousands of transistor gates on a microchip which, as of 2012, exceeded several billion. All of these transistors are remarkably integrated and embedded within a microchip that has shrunk over time but still has the capacity to hold enormous amounts of transistors.

The first 1 mega byte RAM was built on top of VLSI design principles and included more than one million transistors on its microchip dye.

Brief History

Bell Labs lays the groundwork:
1940: Ohl develops PN junction
1945: Shockley's lab established
1947: Bardeen and Brattain create point-contact transistor with two PN junctions. Gain = 18.

1951: Shockley develops junction transistor which can be manufactured in quantity.
1952: Dummer forecasts "solid block [with] layers of insulating, conducting and amplifying materials"
1954: The first transistor radio! Also, TI makes first silicon transistor (price $2.50)

1940 Transistors invented in Bell Laboratory

1950 First IC (JK-FF by Jack Kilby at TI)

1960 Early 60s Small Scale Integration (SSI) 10 transistors on a chip

Medium Scale Integration (MSI) 100s of transistors on a chip

1970 Early 70s Large Scale Integration (LSI)1000s of transistor on a chip

1980 Early 80s **VLSI** 10,000s of transistors on a chip (later 100,000s & now 1,000,000s)

1989 Ultra LSI is sometimes used for 1,000,000s

Integrated circuit classification

Name	Signification	Year	Number of Transistors	Number of Logic Gates	Example
SSI	small-scale integration	1964	1 to 10	1 to 12	Logic Gates
MSI	medium-scale integration	1968	10 to 500	13 to 99	Registers
LSI	large-scale integration	1971	500 to 20,000	100 to 9,999	uP(Microprocessor)
VLSI	very large-scale integration	1980	20,000 to 1,000,000	10,000 to 99,999	RAM, Processor
ULSI	ultra-large-scale integration	1984	1,000,000 and more	100,000 and more	Intel Processors (i3, i5 etc)

Why VLSI?

- Integration improves the design
- Lower parasitic = higher speed
- Lower power consumption
- Physically smaller
- Integration reduces manufacturing cost-(almost) no manual assembly

Why should you learn about VLSI systems?

- They are ubiquitous in our daily lives (computers/iPods/TVs/Cars/…/etc).
- It can help you understand the devices you use.
- The market for VLSI systems (and semiconductors) is worth $500 billion dollars.
- It can help you get a decent job after graduation (or you can even start your own company).

Why Make ICs

- Integration improves
  - size
  - speed
  - power
- Integration reduce manufacturing costs
  - (almost) no manual assembly

VLSI advantages:

VLSI has many advantages-

1. Reduces the Size of Circuits.
2. Reduces the effective cost of the devices.
3. Increases the Operating speed of circuits
4. Requires less power than Discrete components.
5. Higher Reliability
6. Occupies a relatively smaller area.

VLSI Applications

VLSI is an implementation technology for electronic circuitry - analogue or digital

It is concerned with forming a pattern of interconnected switches and gates on the surface of a crystal of semiconductor

- Microprocessors
- personal computers
- microcontrollers
- Memory - DRAM / SRAM
- Special Purpose Processors - ASICS (CD players, DSP applications)
- Optical Switches

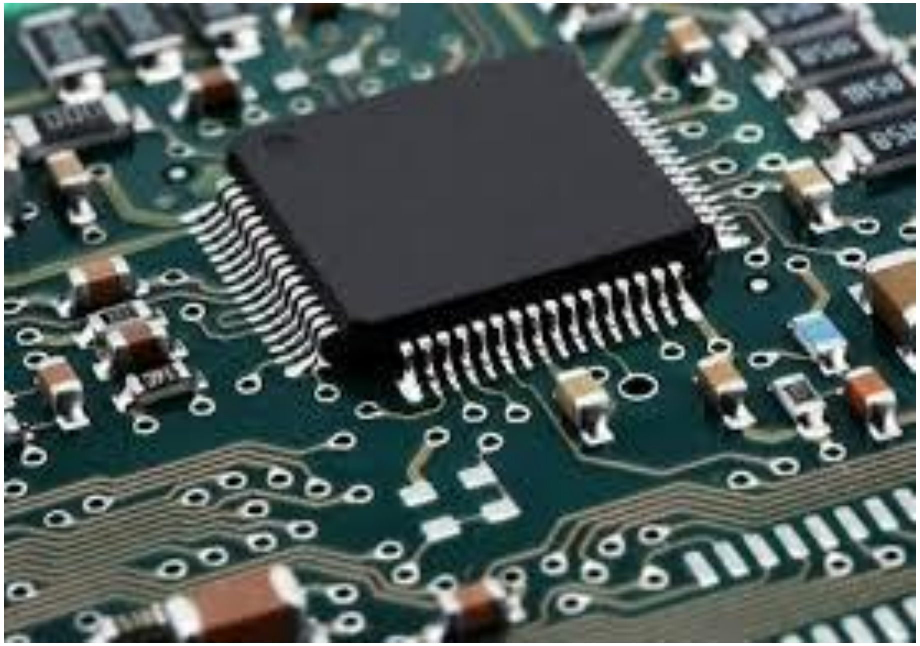
Has made highly sophisticated control systems mass-producable and therefore cheap

VLSI Applications

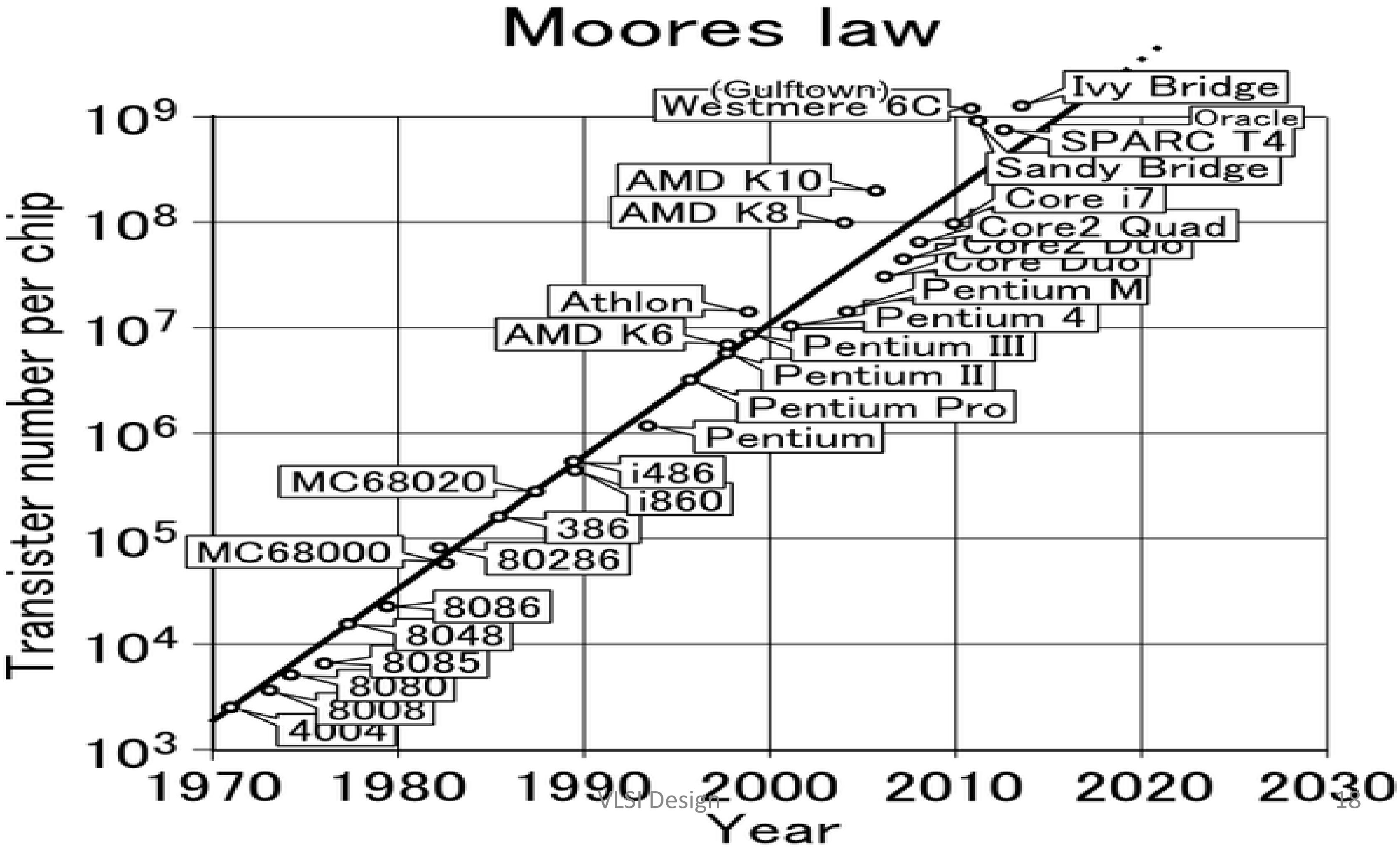
In today's world VLSI chips are widely used in various branches of Engineering like:

- Voice and Data Communication networks
- Digital Signal Processing
- Computers
- Commercial Electronics
- Automobiles
- Medicine and many more.

VLSI Chips

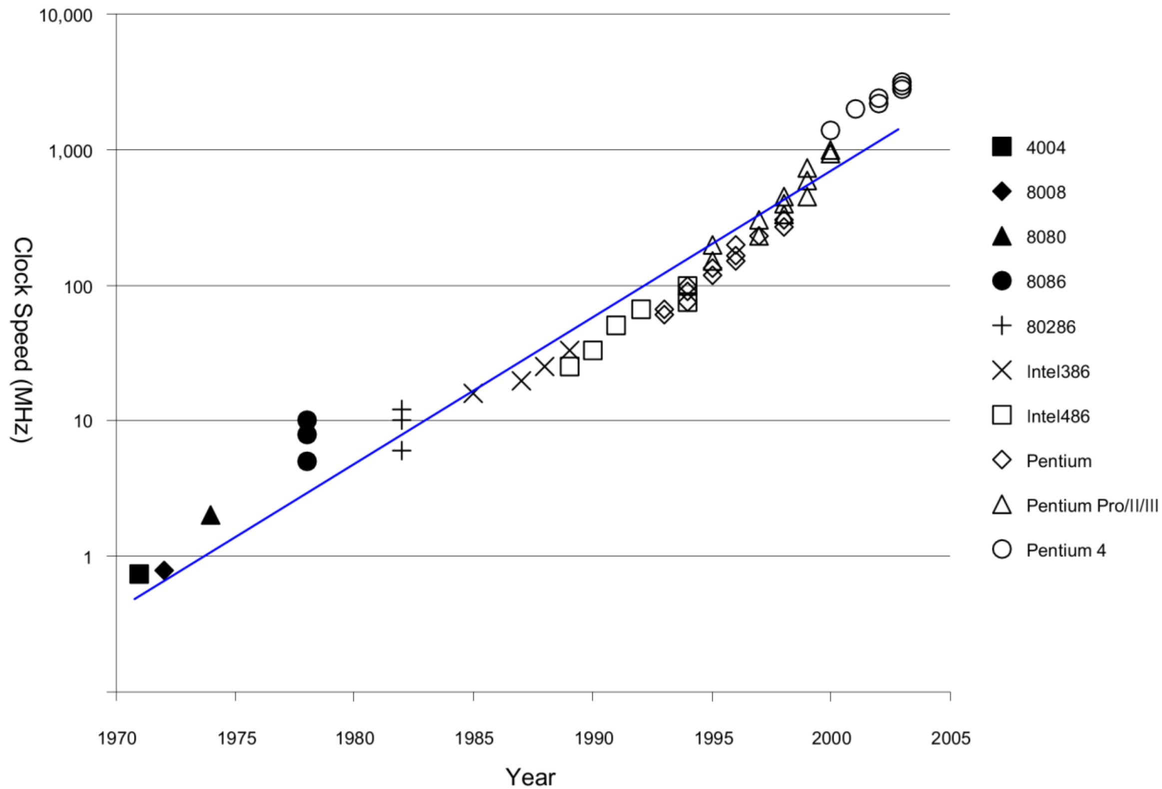


Moore's law is the observation that, over the history of computing hardware, the number of transistors on integrated circuits doubles approximately every two years (18 months).

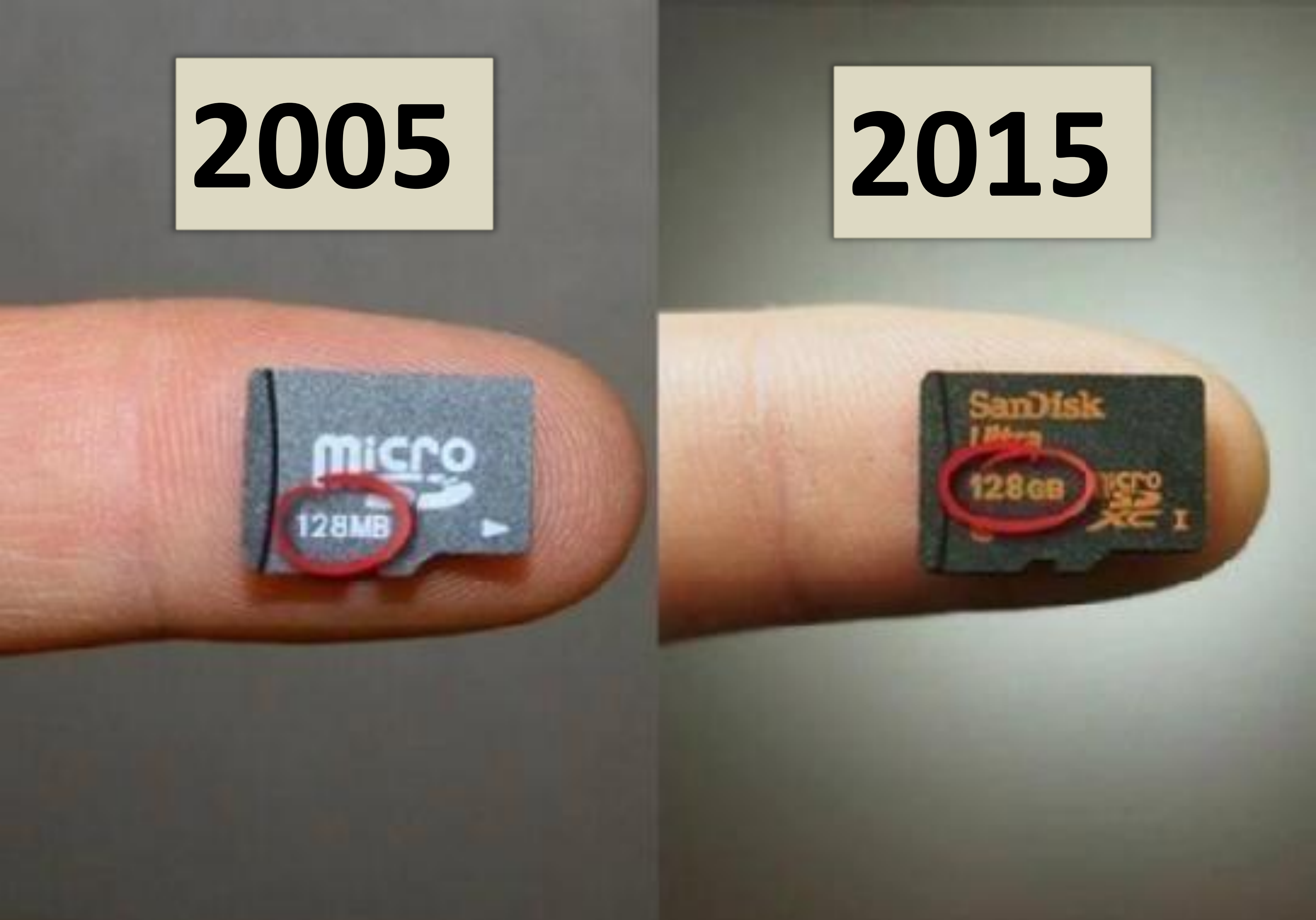


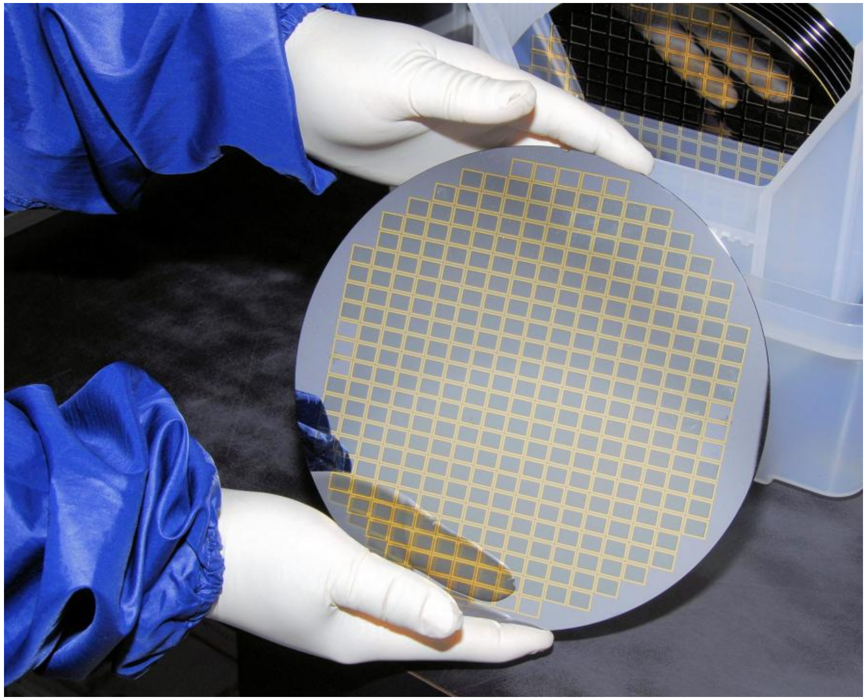
Corollaries

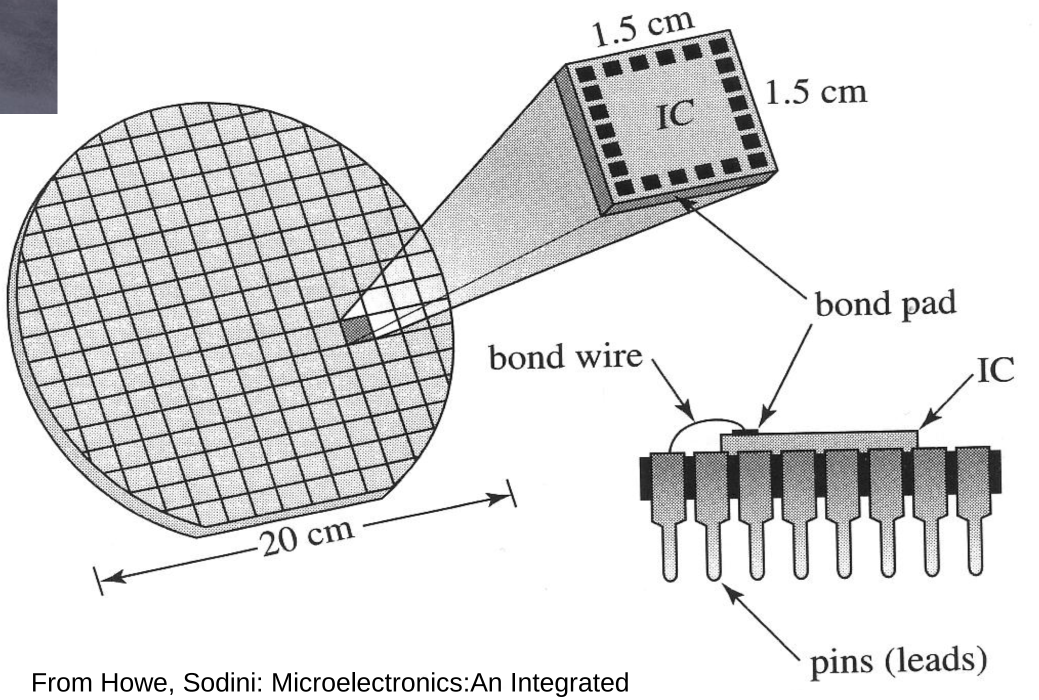
- Many other factors grow exponentially
  - Ex: clock frequency, processor performance



Feature sizes

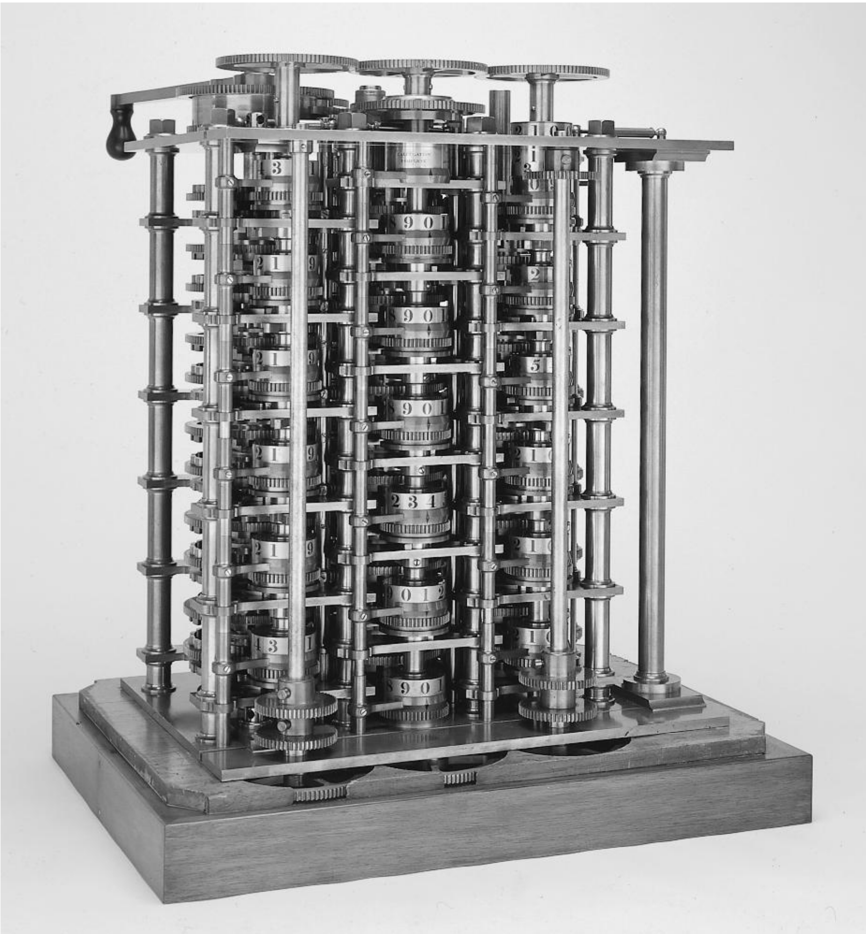

2005
micro
128MB
2015
SanDisk
128GB





From Howe, Sodini: Microelectronics:An Integrated Approach, Prentice Hall

The First Computer

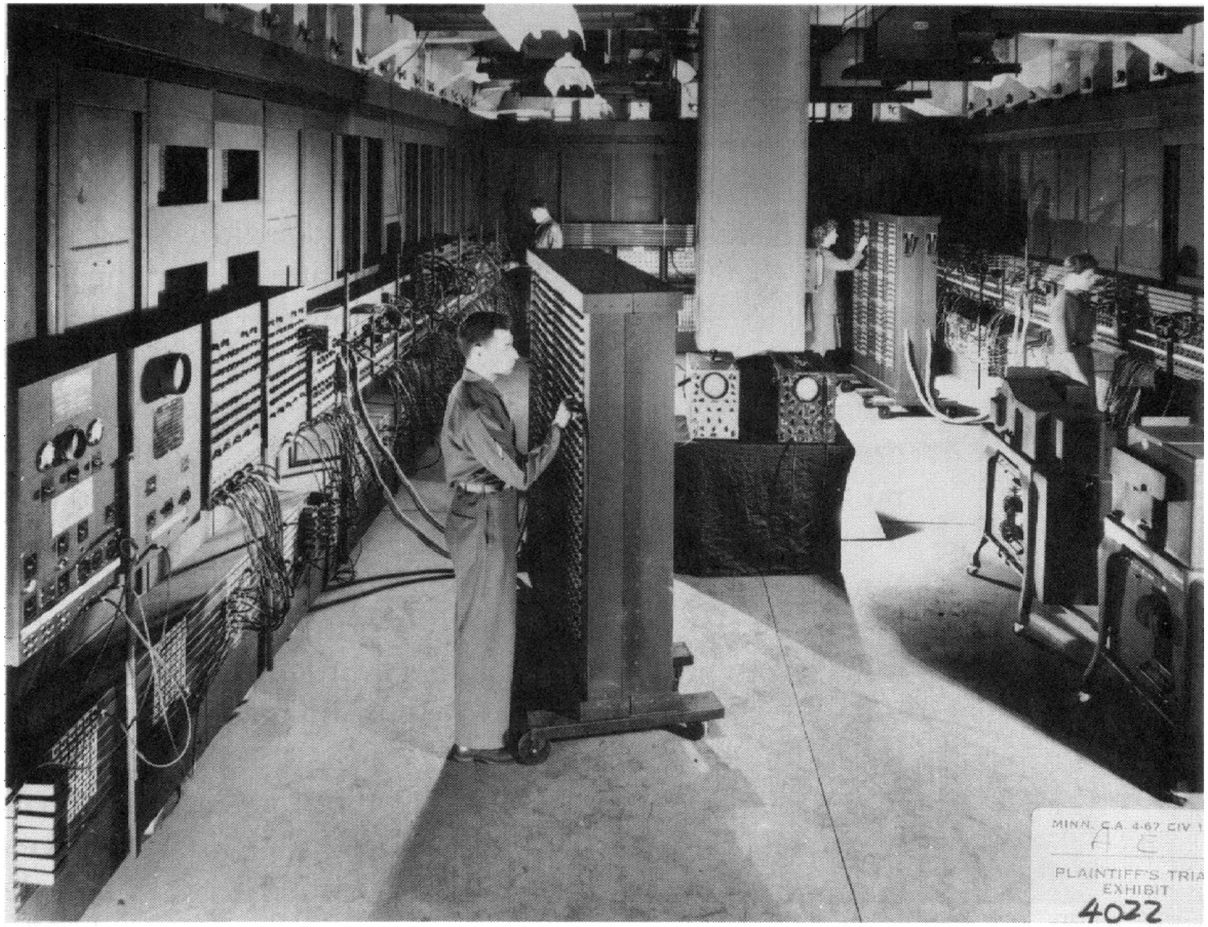


The Babbage Difference Engine (1832)

25,000 parts

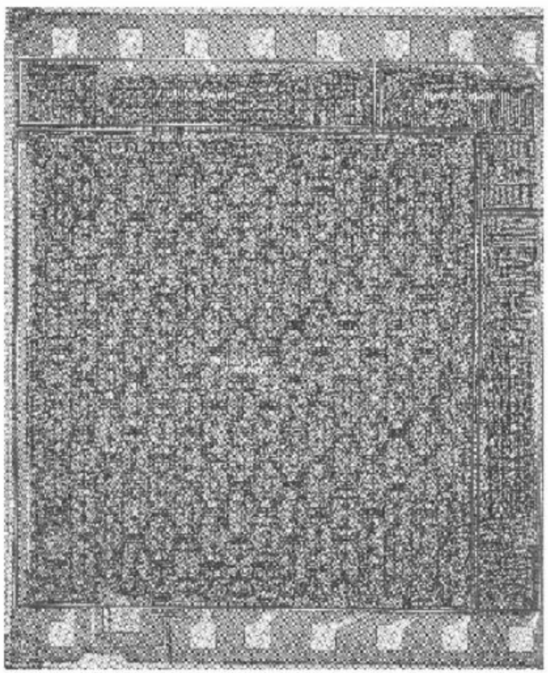
cost: £17,470

ENIAC - The first electronic computer (1946)

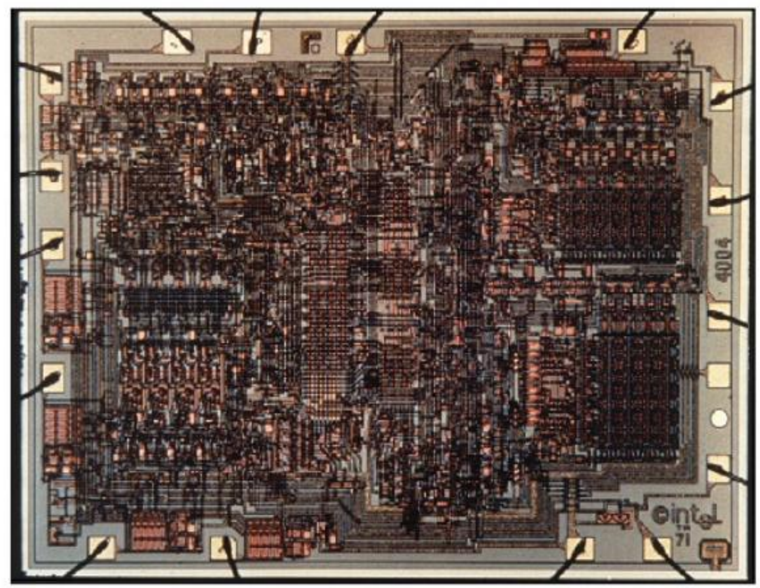


MOS Integrated Circuits

- 1970's processes usually had only nMOS transistors
  - Inexpensive, but consume power while idle
- 1980s-present: CMOS processes for low idle power



Intel 1101 256-bit SRAM



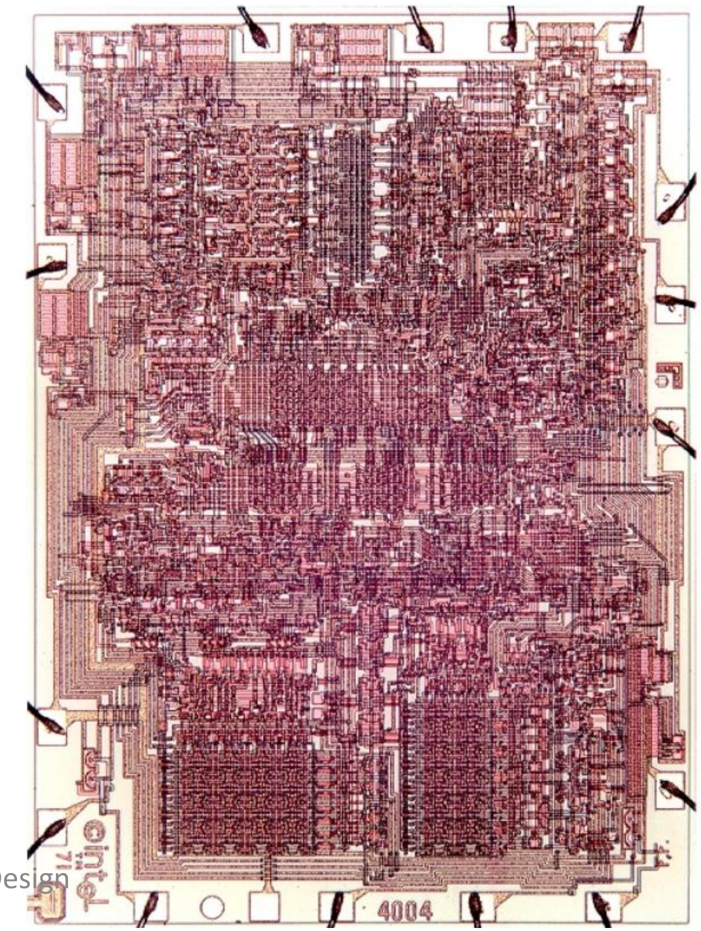
Intel 4004 4-bit μProc

Evolution of Intel Microprocessors

– Scaling from 4004 to Core i7
– Courtesy of Intel Museum

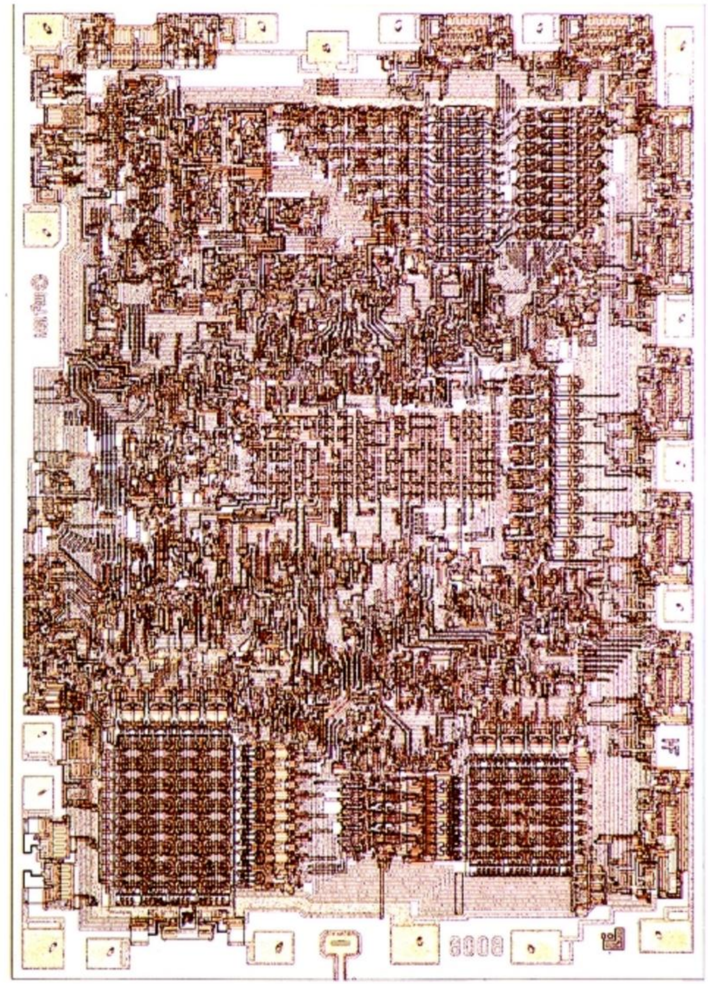
4004

- ❑ First microprocessor (1971)
  - – For Busicom calculator
- ❑ Characteristics
  - – 10 μm process
  - – 2300 transistors
  - – 400 – 800 kHz
  - – 4-bit word size
  - – 16-pin DIP package
- ❑ Masks hand cut from Rubylith
  - – Drawn with color pencils
  - – 1 metal, 1 poly (jumpers)
  - – Diagonal lines (!)



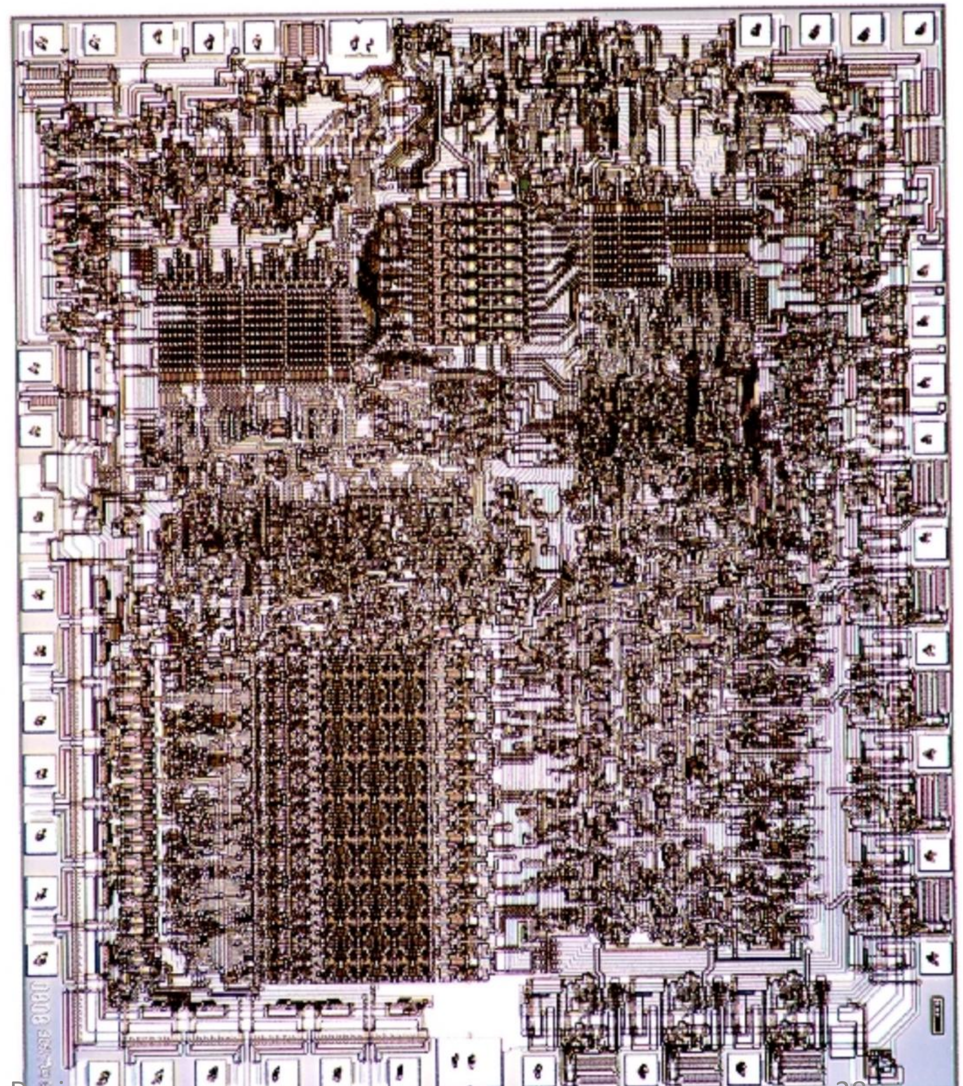
8008

- 8-bit follow-on (1972)
  - Dumb terminals
- Characteristics
  - 10 μm process
  - 3500 transistors
  - 500 – 800 kHz
  - 8-bit word size
  - 18-pin DIP package
- Note 8-bit datapaths
  - Individual transistors visible



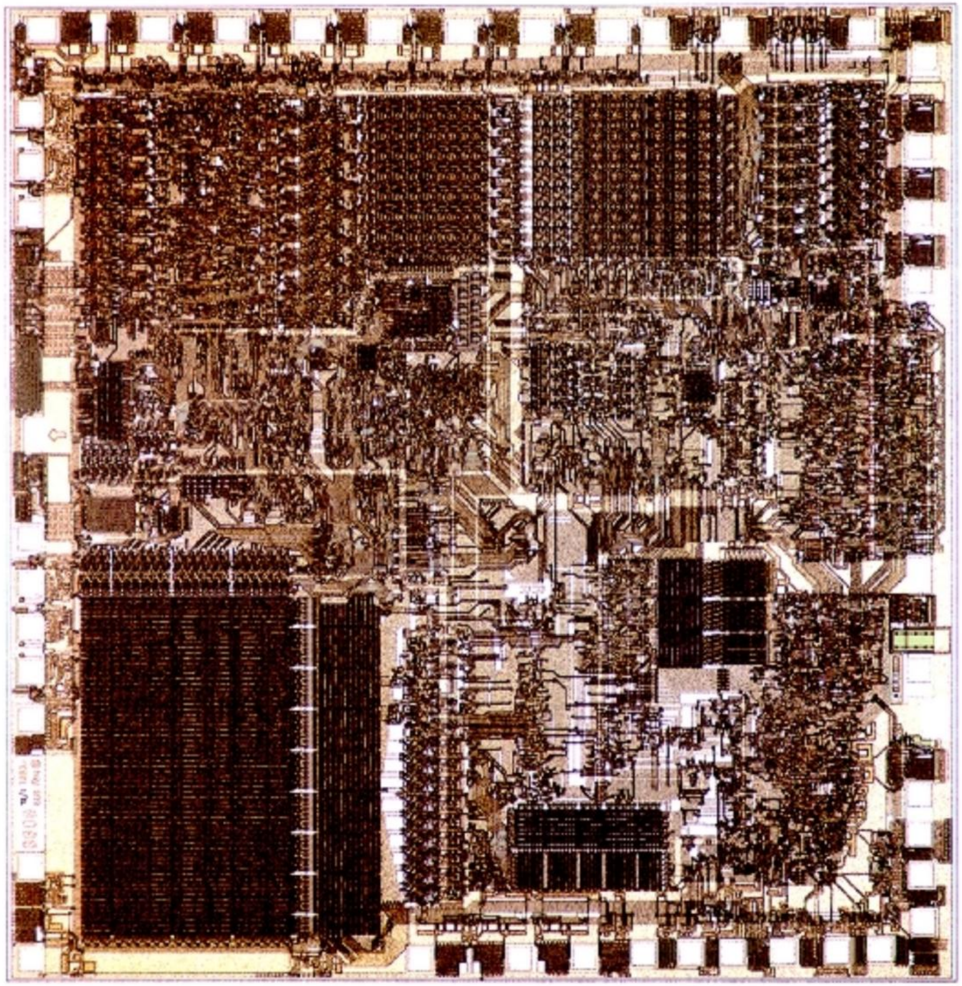
8080

- 16-bit address bus (1974)
  - Used in Altair computer
    - (early hobbyist PC)
- Characteristics
  - 6 μm process
  - 4500 transistors
  - 2 MHz
  - 8-bit word size
  - 40-pin DIP package



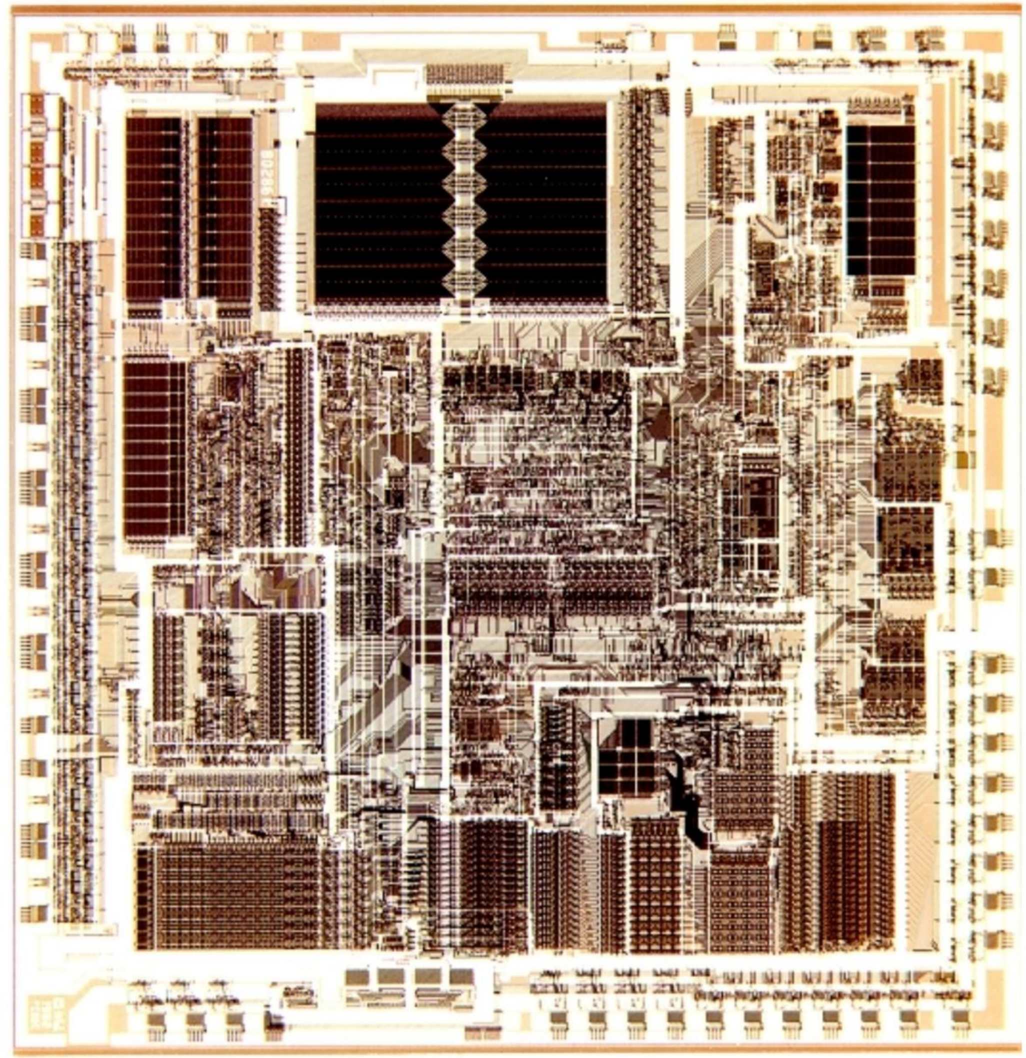
8086 / 8088

- 16-bit processor (1978-9)
  - IBM PC and PC XT
  - Revolutionary products
  - Introduced x86 ISA
- Characteristics
  - 3 μm process
  - 29k transistors
  - 5-10 MHz
  - 16-bit word size
  - 40-pin DIP package
- Microcode ROM



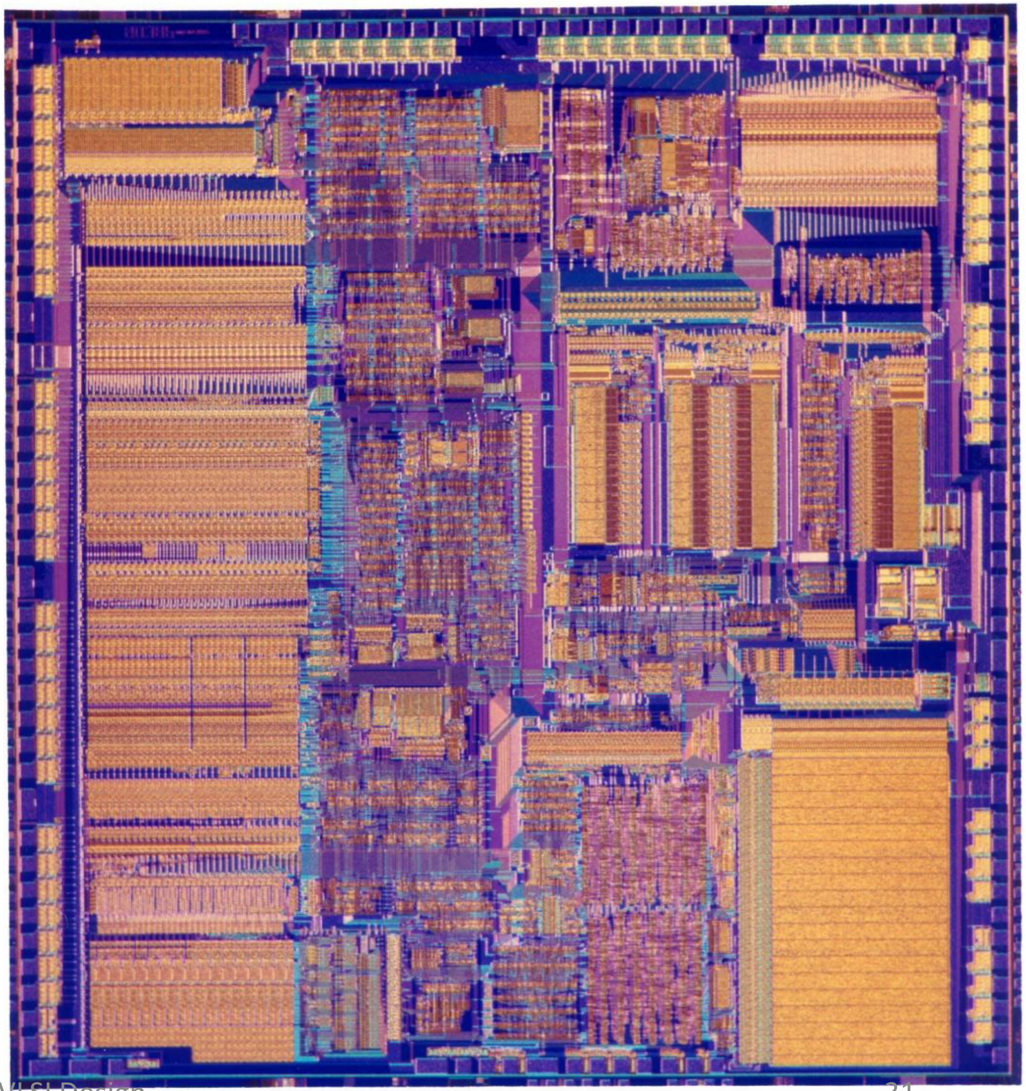
80286

- Virtual memory (1982)
  - IBM PC AT
- Characteristics
  - 1.5 μm process
  - 134k transistors
  - 6-12 MHz
  - 16-bit word size
  - 68-pin PGA
- Regular datapaths and ROMs
  Bitslices clearly visible



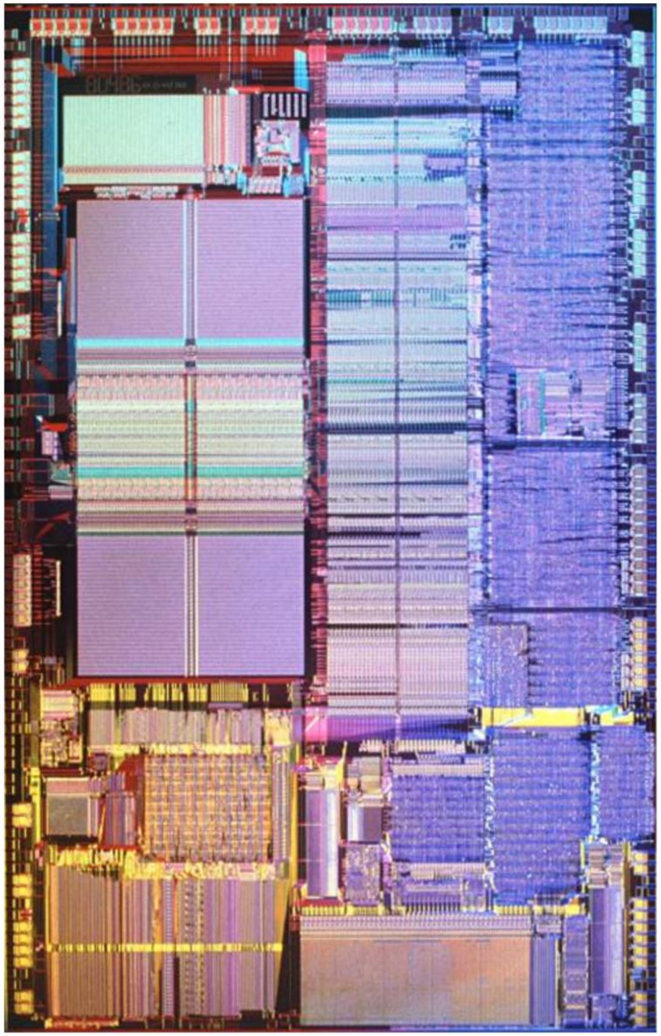
80386

- 32-bit processor (1985)
  - Modern x86 ISA
- Characteristics
  - 1.5-1 μm process
  - 275k transistors
  - 16-33 MHz
  - 32-bit word size
  - 100-pin PGA
- 32-bit datapath, microcode ROM, synthesized control



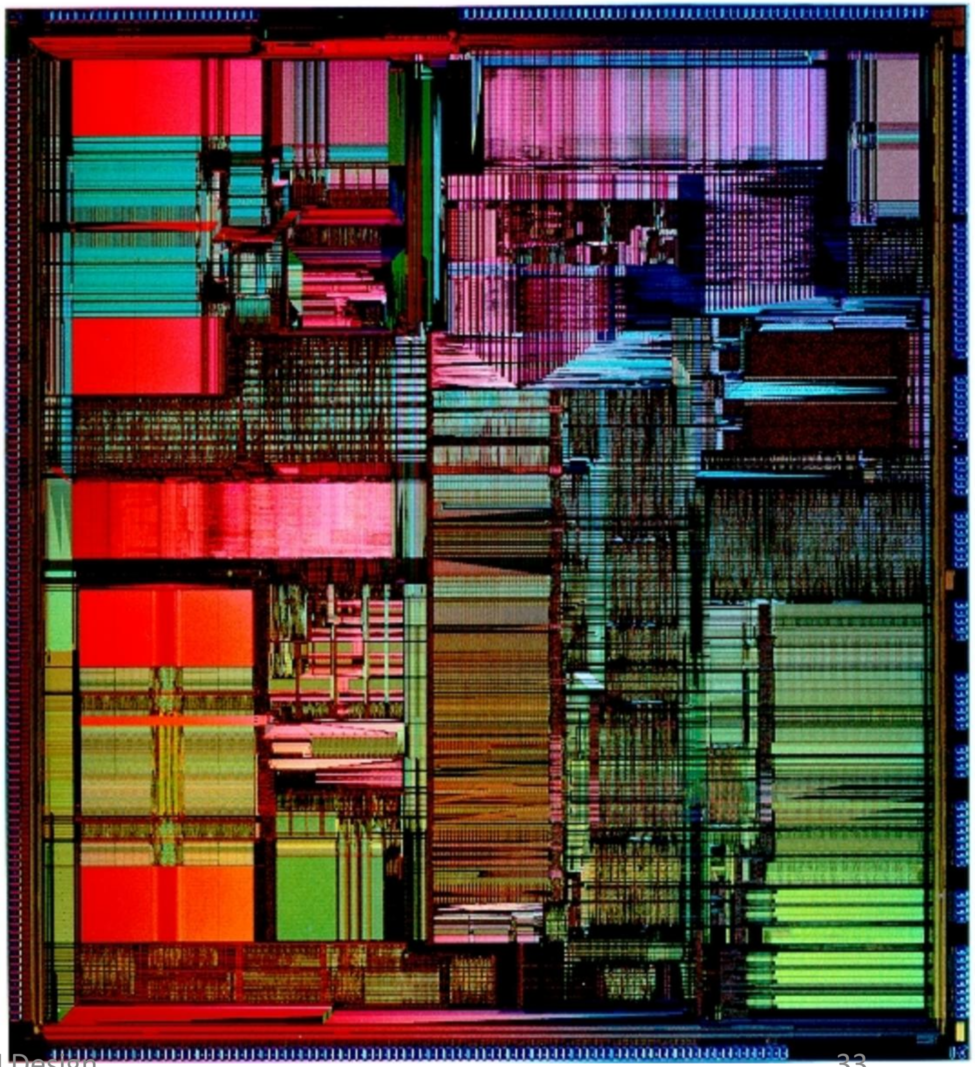
80486

- Pipelining (1989)
  - Floating point unit
  - 8 KB cache
- Characteristics
  - 1-0.6 μm process
  - 1.2M transistors
  - 25-100 MHz
  - 32-bit word size
  - 168-pin PGA
- Cache, Integer datapath, FPU, microcode, synthesized control



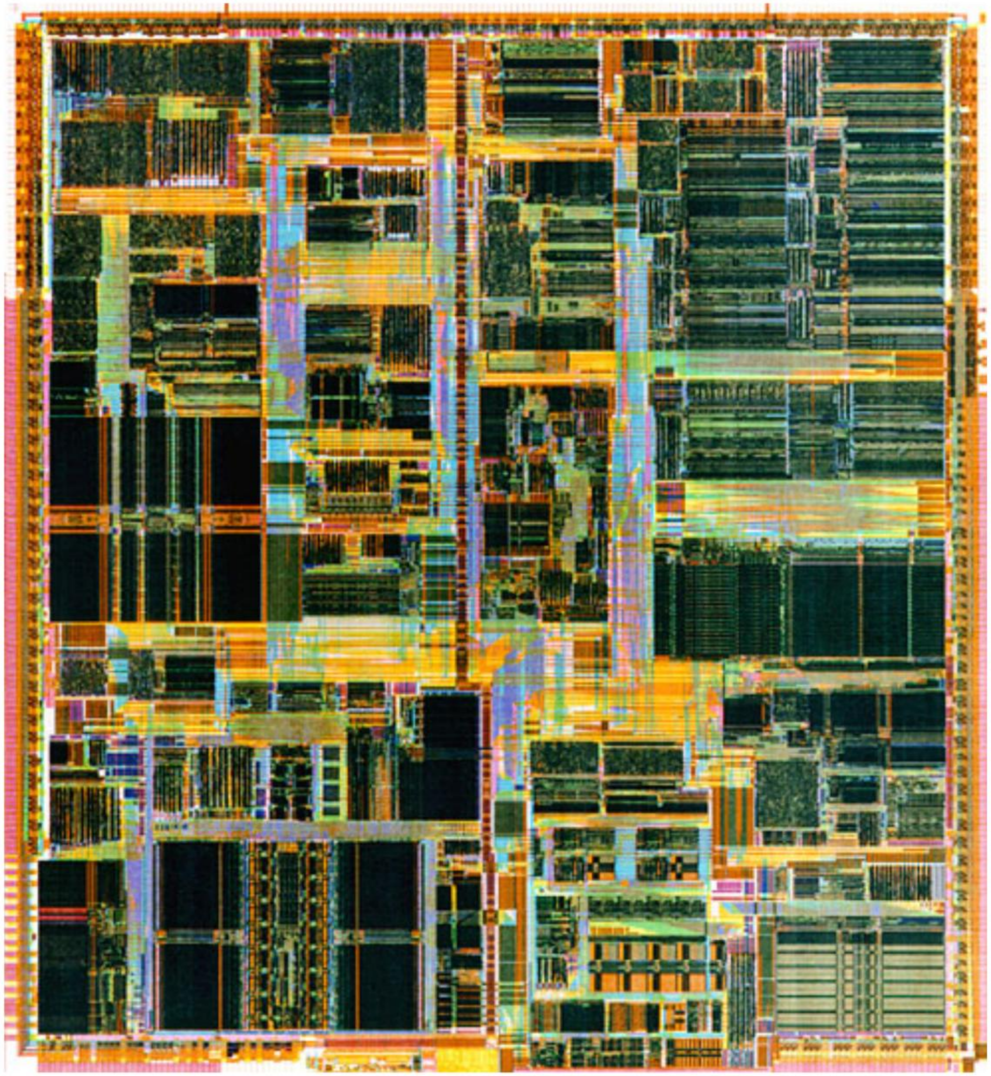
Pentium

- Superscalar (1993)
  - 2 instructions per cycle
  - Separate 8KB I$ & D$
- Characteristics
  - 0.8-0.35 μm process
  - 3.2M transistors
  - 60-300 MHz
  - 32-bit word size
  - 296-pin PGA
- Caches, datapath, FPU, control



Pentium Pro / II / III

- Dynamic execution (1995-9)
  - 3 micro-ops / cycle
  - Out of order execution
  - 16-32 KB I$ & D$
  - Multimedia instructions
  - PIII adds 256+ KB L2$
- Characteristics
  - 0.6-0.18 μm process
  - 5.5M-28M transistors
  - 166-1000 MHz
  - 32-bit word size
  - MCM / SECC

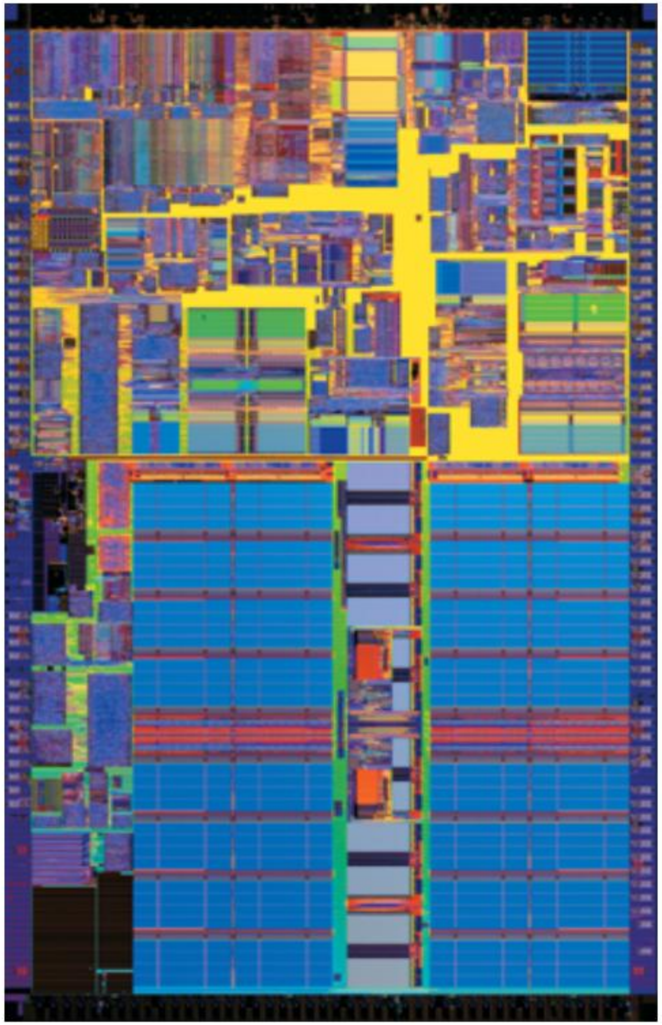


Pentium 4

- Deep pipeline (2001)
  - Very fast clock
  - 256-1024 KB L2$
- Characteristics
  - 180 – 65 nm process
  - 42-125M transistors
  - 1.4-3.4 GHz
  - Up to 160 W
  - 32/64-bit word size
  - 478-pin PGA
- Units start to become invisible on this scale

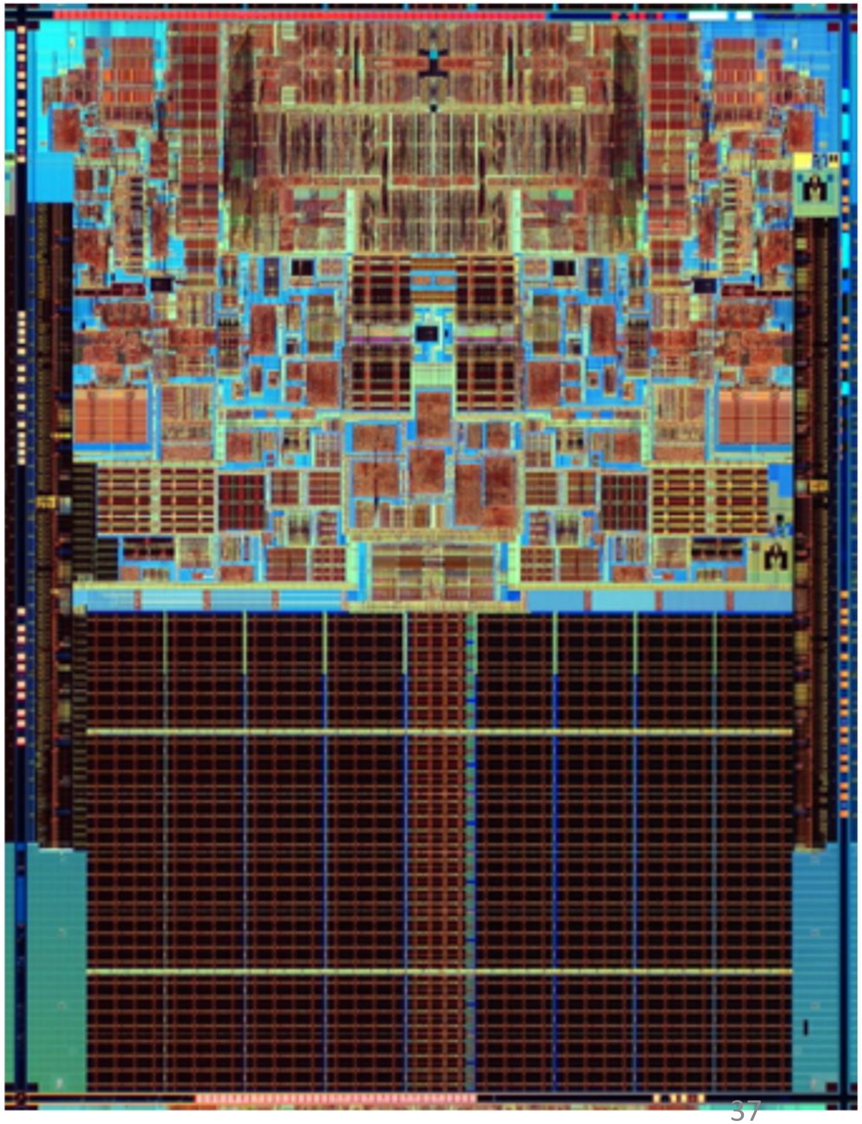
Pentium M

- Pentium III derivative
  - Better power efficiency
  - 1-2 MB L2$
- Characteristics
  - 130 – 90 nm process
  - 140M transistors
  - 0.9-2.3 GHz
  - 6-25 W
  - 32-bit word size
  - 478-pin PGA
- Cache dominates chip area



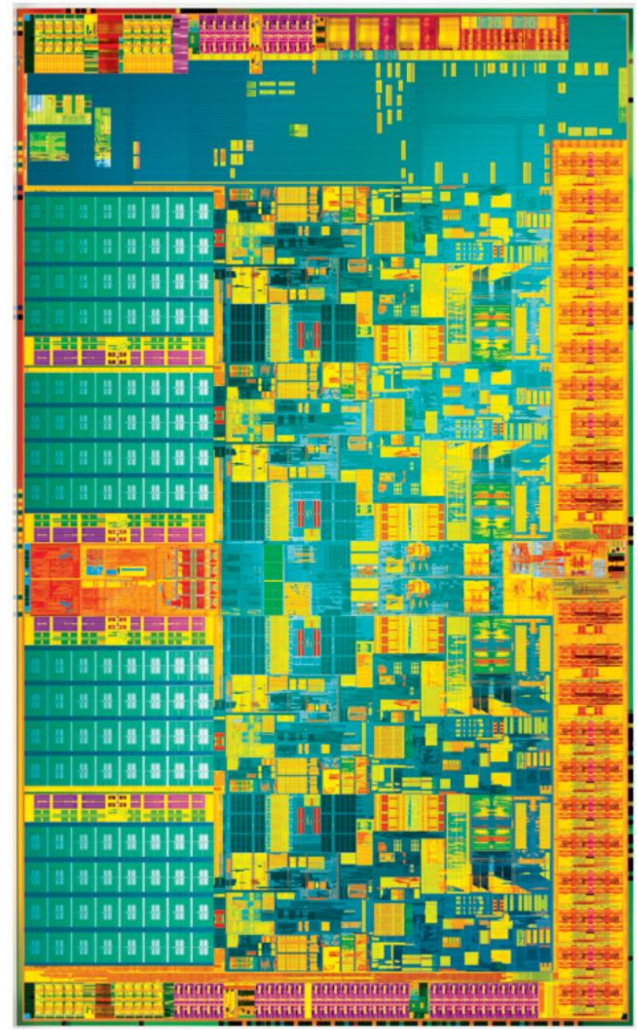
Core2 Duo

- Dual core (2006)
  - 1-2 MB L2$ / core
- Characteristics
  - 65-45 nm process
  - 291M transistors
  - 1.6-3+ GHz
  - 65 W
  - 32/64 bit word size
  - 775 pin LGA
- Much better performance/power efficiency



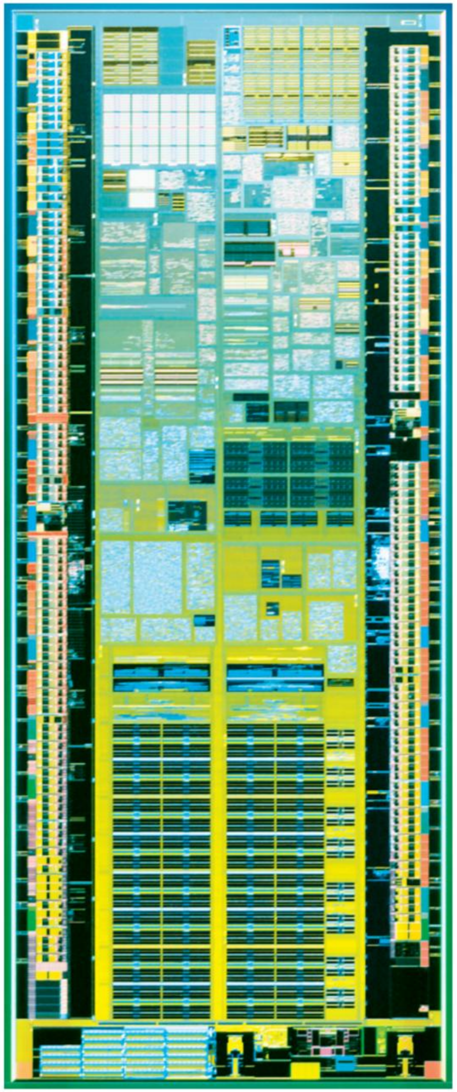
Core i7

- Quad core (& more)
  - Pentium-style architecture
  - 2 MB L3$ / core
- Characteristics
  - 45-32 nm process
  - 731M transistors
  - 2.66-3.33+ GHz
  - Up to 130 W
  - 32/64 bit word size
  - 1366-pin LGA
  - Multithreading
- On-die memory controller



Atom

- Low power CPU for netbooks
  - Pentium-style architecture
  - 512KB+ L2$
- Characteristics
  - 45-32 nm process
  - 47M transistors
  - 0.8-1.8+ GHz
  - 1.4-13 W
  - 32/64-bit word size
  - 441-pin FCBGA
- Low voltage (0.7 – 1.1 V) operation
  - Excellent performance/power



Intel Processors

- 10^4 increase in transistor count, clock frequency over 3 decades!

Processor	Year	Feature Size (μm)	Transistors	Frequency (MHz)	Word Size	Power (*W*)	Cache (L1 / L2 / L3)	Package
4004	1971	10	2.3k	0.75	4	0.5	none	16-pin DIP
8008	1972	10	3.5k	0.5–0.8	8	0.5	none	18-pin DIP
8080	1974	6	6k	2	8	0.5	none	40-pin DIP
8086	1978	3	29k	5–10	16	2	none	40-pin DIP
80286	1982	1.5	134k	6–12	16	3	none	68-pin PGA
Intel386	1985	1.5–1.0	275k	16–25	32	1–1.5	none	100-pin PGA
Intel486	1989	1–0.6	1.2M	25–100	32	0.3–2.5	8K	168-pin PGA
Pentium	1993	0.8–0.35	3.2–4.5M	60–300	32	8–17	16K	296-pin PGA
Pentium Pro	1995	0.6–0.35	5.5M	166–200	32	29–47	16K / 256K+	387-pin MCM PGA
Pentium II	1997	0.35–0.25	7.5M	233–450	32	17–43	32K / 256K+	242-pin SECC
Pentium III	1999	0.25–0.18	9.5–28M	450–1000	32	14–44	32K / 512K	330-pin SECC2
Pentium 4	2000	180–65 nm	42–178M	1400–3800	32/64	21–115	20K+ / 256K+	478-pin PGA
Pentium M	2003	130–90 nm	77–140M	1300–2130	32	5–27	64K / 1M	479-pin FCBGA
Core	2006	65 nm	152M	1000–1860	32	6–31	64K / 2M	479-pin FCBGA
Core 2 Duo	2006	65–45 nm	167–410M	1060–3160	32/64	10–65	64K / 4M+	775-pin LGA
Core i7	2008	45 nm	731M	2660–3330	32/64	45–130	64K / 256K / 8M	1366-pin LGA
Atom	2008	45 nm	47M	800–1860	32/64	1.4–13	56K / 512K+	441-pin FCBGA

IC Products

- Processors
  - CPU, DSP, Controllers
- Memory chips
  - RAM, ROM, EEPROM
- Analog
  - Mobile communication, audio/video processing
- Programmable
  - PLA, FPGA
- Embedded systems
  - Used in cars, factories
  - Network cards
- System-on-chip (SoC)

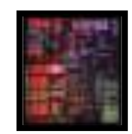
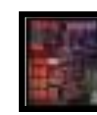
Images: amazon.com

IC Product Market Shares

Terminology

- Manufacturing node: technology at a particular channel length.
- Deep submicron technology: 250-100 nm.
- Nanometer technology: 100 nm and below.

Example: Intel Processor Sizes

Silicon Process Technology	1.5µ	1.0µ	0.8µ	0.6µ	0.35µ	0.25µ
Intel386™ DX Processor						
Intel486™ DX Processor						
Pentium® Processor						
Pentium® Pro & Pentium® II Processors						

Source: http://www.intel.com/

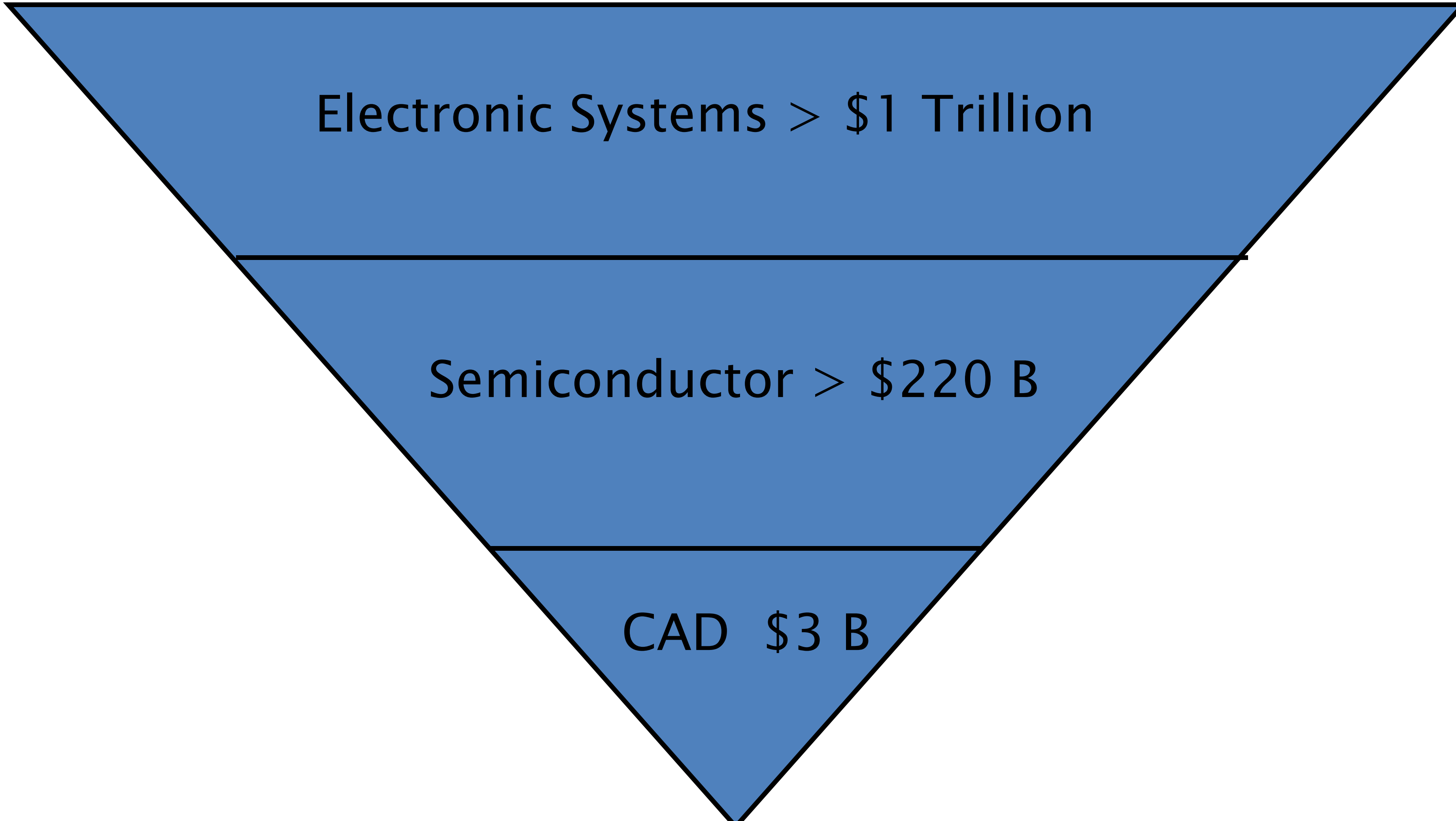
Heterogeneity on Chip

- Greater diversity of on-chip elements
  - Processors
  - Software
  - Memory
  - Analog

Heterogeneity

More transistors doing different things!

The Inverted Pyramid



[©Keutzer]

Where is the money?

- Gaps to be filled:
  - System-semiconductor gap
  - Semiconductor-CAD gap

The cost of fabrication

- Current cost: $4 billion.
- Typical fab line occupies about 1 city block, employs a few hundred people.
- Most profitable period is first 18 months-2 years.

Cost factors in ICs

- For large-volume ICs:
  – packaging is largest cost;
  – testing is second-largest cost.
- For low-volume ICs, design costs may swamp all manufacturing costs.

Cost of design

- Design cost can be significant: $20 million for a large ASIC, $500 million for a large CPU.
- Cost elements:
  - Architects, logic designers, etc.
  - CAD tools.
  - Computers the CAD tools run on.

Top 10 VLSI Companies in India

1 | Texas Instruments

Corporate office – Dallas, United State | **Establishment** –1951 | **Business** – Semiconductor | **Website** – *www.ti.com* |

Texas Instruments is world's third largest semiconductor company and a chip producer for mobile phones. The company is among the top 10 semiconductor companies in India and its product offering includes analog electronics, calculators, integrated circuits and radio frequency identification. It was founded in year 1951 and headquartered in Dallas, United states.

2 | Analog Device Inc.

Corporate office – Norwood, USA | **Establishment** – 1965 | **Business** – Semiconductor | **Website** – *www.analog.com* |

Analog Device Inc is a semiconductor design and manufacturing company which is a market leader in data conversion and signal technology. Analog device is founded in year 1965 and its design center is located in Australia, Canada, Israel, Japan, Scotland, Taiwan, Germany, UK, China, Scotland and India.

3 | Cypress Semiconductor Corporation
Corporate office – San Jose, USA | **Establishment** – 1982 | **Business** – Semiconductor | **Website** – *www.cypress.com* | Cypress semiconductor is a semiconductor manufacturing and design company established in year 1982. The US based company has total 14 design centers and more than 40 sales offices located all across the globe. Its product offering includes capacitance sensing systems, Psoc, optical sensor and wireless solution.

4 | Broadcom Corporation
Corporate office – Irvine, USA | **Establishment** – 1991 | **Business** – Semiconductor | **Website** – *www.broadcom.com* | Broad corporation is rated among the top 10 semiconductor manufacturers in India; an American company which was established in 1991 by professor and student duo Henry Samueli and Henry T Nicholas. Its product portfolio includes Integrated circuits, cable converter boxes, wireless networks, cable modems, professors, Bluetooth, VIOP, GPS, server farms, digital subscriber line.

5 | Cisco Systems

Corporate office – San Jose, USA | **Establishment** – 1984 | **Business** – Network Equipments | **Website** – *www.cisco.com* | Cisco Systems is a MNC and one of the leading design and manufacturer of networking equipment. Its major product offering includes Networking device, Optical networking, storage area networks, wireless, VOIP, IOS and NX OS software etc. It is headquartered in San Jose, USA and has employed more than 75000 people all across the globe.

6 | Bit Mapper Integration Technologies Private Limited

Corporate office – Pune, Maharashtra | **Establishment** – 1985 | **Business** – Electronic Design | **Website** – *www.bitmapper.com* | Bit Mapper is a technology company offering electronic system design using PCB and FPGA design. The company is offering design solution to various sector such as defense, aerospace, telecommunication and software. It is a leading VLSI company in India and its expertise includes PCB design, Flexible circuits, Thermal analysis, ADC based board and many more.

7 | Horizon Semiconductors
Corporate office – Bangalore, Karnataka | **Establishment** – 1815| **Business** – Semiconductor | **Website** – *www.horizonsemi.com* | Horizon Semiconductors is an integrated silicon solution provider and its product offering includes single chip cable, Satellite set-top box, dual channel HD channel, 2d & 3d graphics, Single chip Blu-ray, trans coder and encoder ICs. It is one among the top semiconductor companies in India.

8 | Einfochips limited
Corporate office – Ahmadabad, Gujarat | **Establishment** – 1994 | **Business** – Semiconductor | **Website** – *www.einfochips.com* | Among the top 10 VLSI companies in India, Einfochips is one of the most trusted brands in product engineering and semiconductor service; and serves to Aerospace & defense, energy, healthcare, retail and software sector. It is headquartered in Ahmadabad, Gujarat.

9 | Trident Tech Labs
Corporate office – New Delhi, India | **Establishment** – 2000 | **Business** – Electronic Design | **Website** – *www.tridenttechlabs.com* |
Established in year 2000, Trident Techlabs is a knowledge based technology organization which offers electronic design solution. The company is a leading computer aided engineering provider and reputed name in Very Large Scale Integration companies in India.

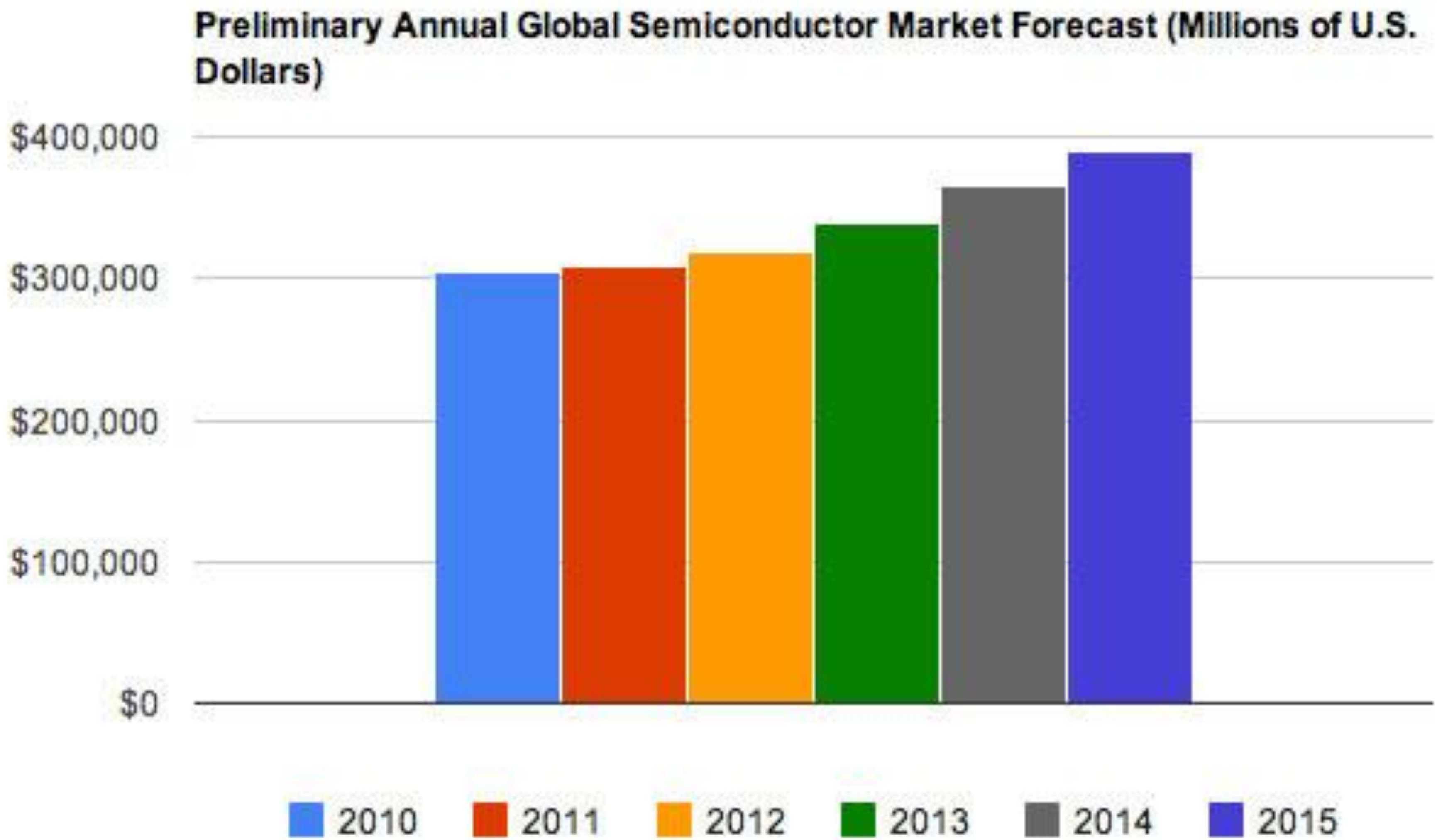
10 | HCL technologies
Corporate office – Noida, Uttar Pradesh | **Establishment** – 1991 | **Business** – IT and Software | **Website** – *www.hcltech.com*|
HCL technologies is a software, KPO and IT service provider headquartered in Noida, Uttar Pradesh. The company has office in 26 countries worldwide to provide support and consultancy to industry verticals including defense & aviation industry, energy, power, software, manufacturing, semiconductor, retail etc. It has also well known name in VLSI companies in India and its engineering & Research division provides support to semiconductor industry.

Biggest semiconductor companies

2014 Top Semiconductor R&D Spenders

2014 Rank	2013 Rank	Company	Region	IDM	FABLESS	FOUNDRY	2013 Semi Sales ($M)	2013 R&D Exp ($M)	2013 R&D/Sales (%)	2014 Semi Sales ($M)	2014 R&D Exp ($M)	2014 R&D/Sales (%)	2014/2013 % Change in R&D
1	1	Intel	Americas	•			48,321	10,611	22.0%	51,400	11,537	22.4%	9%
2	2	Qualcomm	Americas		•		17,211	3,395	19.7%	19,291	5,501	28.5%	62%
3	3	Samsung	Asia-Pac	•			34,378	2,820	8.2%	37,810	2,965	7.8%	5%
4	4	Broadcom	Americas		•		8,219	2,486	30.2%	8,428	2,373	28.2%	-5%
5	7	TSMC	Asia-Pac			•	19,935	1,623	8.1%	24,976	1,874	7.5%	15%
6	5	Toshiba	Japan	•			11,958	2,040	17.1%	11,040	1,820	16.5%	-11%
7	6	ST	Europe	•			8,014	1,816	22.7%	7,384	1,520	20.6%	-16%
8	9	Micron	Americas	•			14,294	1,487	10.4%	16,814	1,430	8.5%	-4%
9	14	MediaTek + MStar	Asia-Pac		•		5,723	1,110	19.4%	7,032	1,430	20.3%	29%
10	10	Nvidia	Americas		•		3,898	1,323	33.9%	4,348	1,362	31.3%	3%
Top 10 Total							**171,951**	**28,711**	**16.7%**	**188,523**	**31,812**	**16.9%**	**11%**

Source: Company reports, IC Insights' *Strategic Reviews* database


Preliminary Annual Global Semiconductor Market Forecast (Millions of U.S. Dollars)
$400,000
$300,000
$200,000
$100,000
$0
2010
2011
2012
2013
2014
2015

VLSI Design Challenge

Goal:

designing circuits with increasing complexity in always shorter times

- computer has to take over routine work
- deliberate the designer from unnecessary low qualification work
- shift of design activities to higher level abstract work
- computer has to support new design methods

Stronger Market Pressures

- Decreasing design window
- Less tolerance for design revisions

Time-to-market

Exponentially more complex, greater design risk, greater variety, and a smaller design window!

What does it take to design VLSI systems?

1. idea (need)

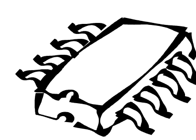
2. write specifications

3. design system

4. analyze/ model system

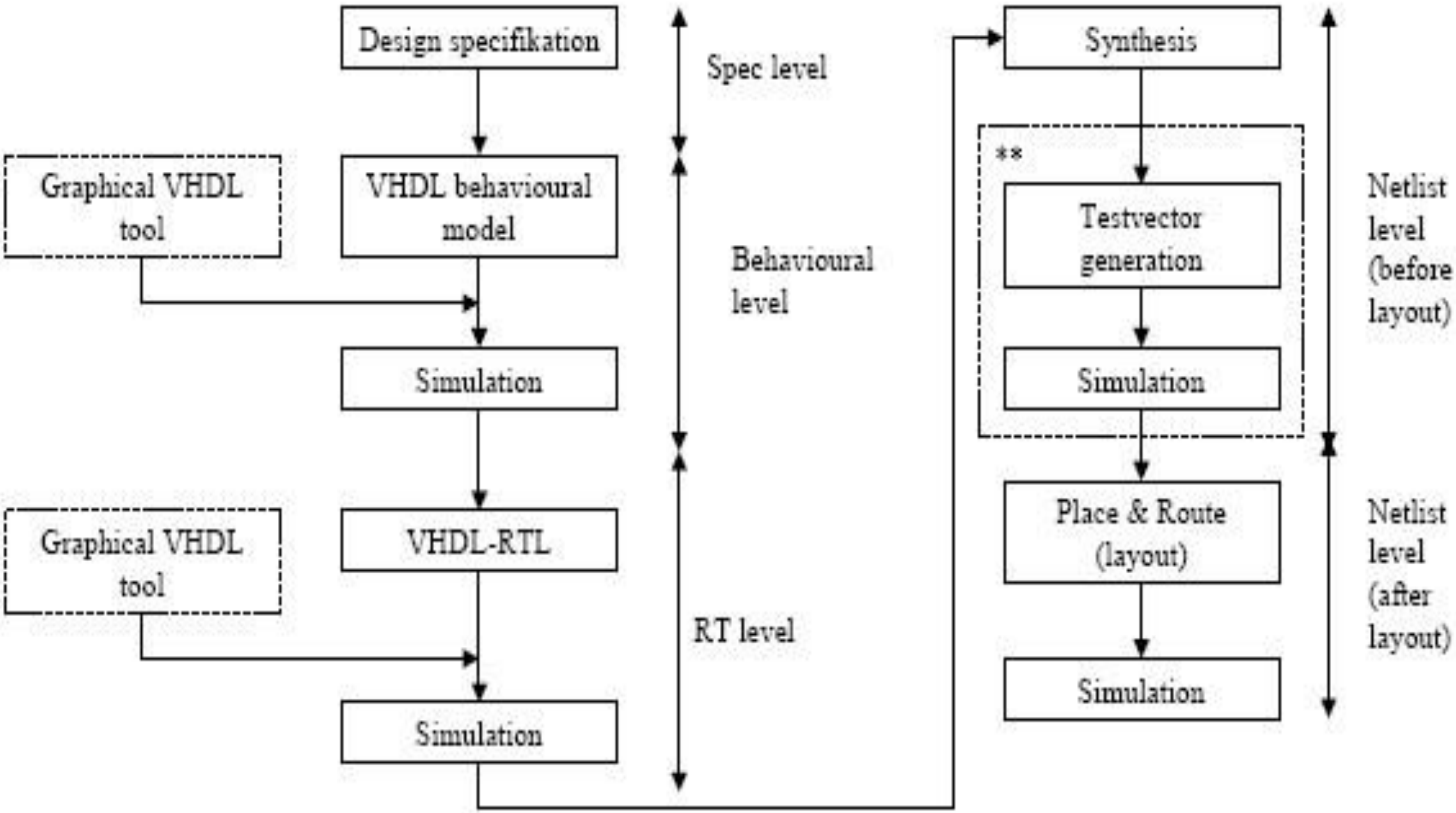
if satisfactory

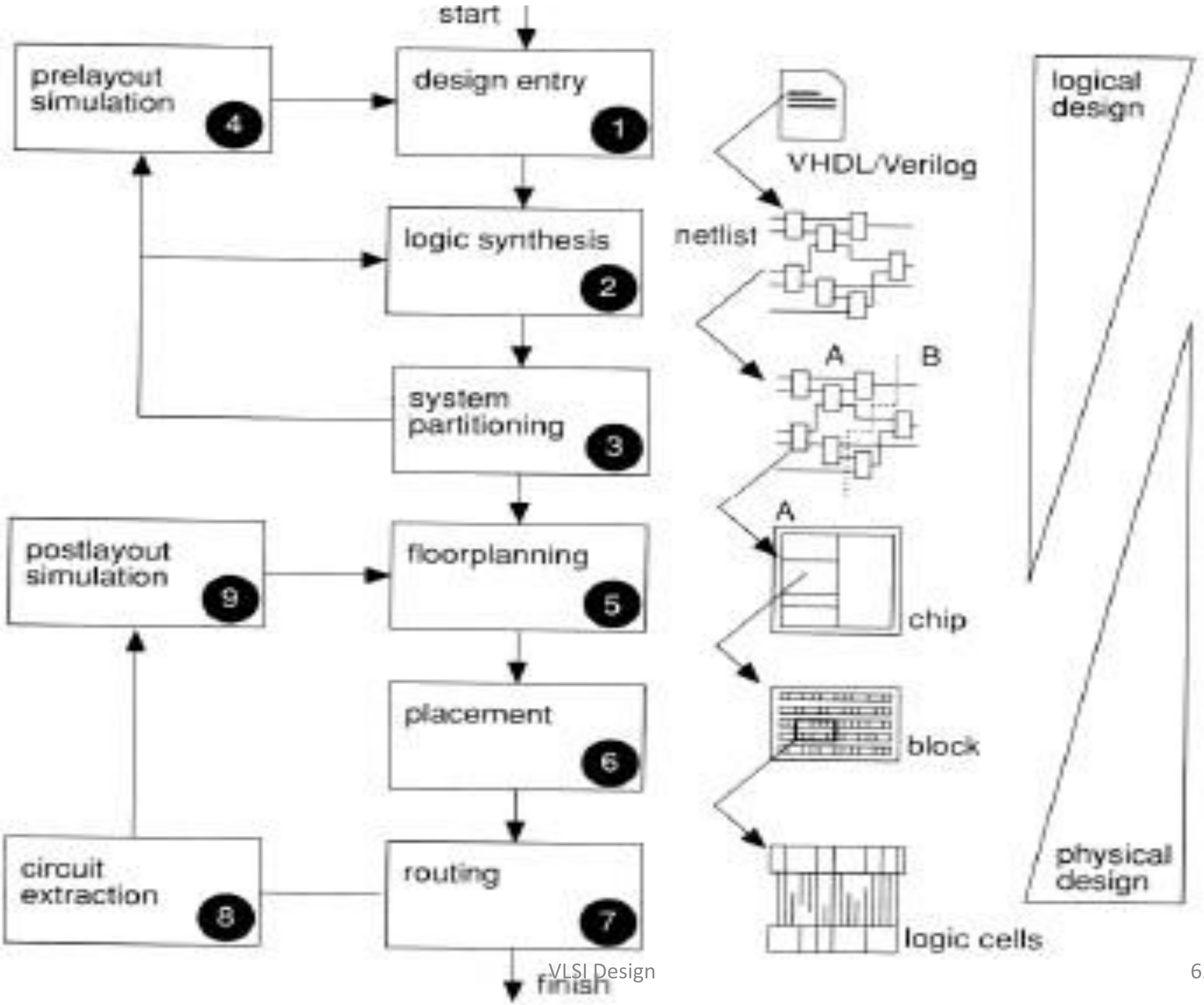
5. Fabrication

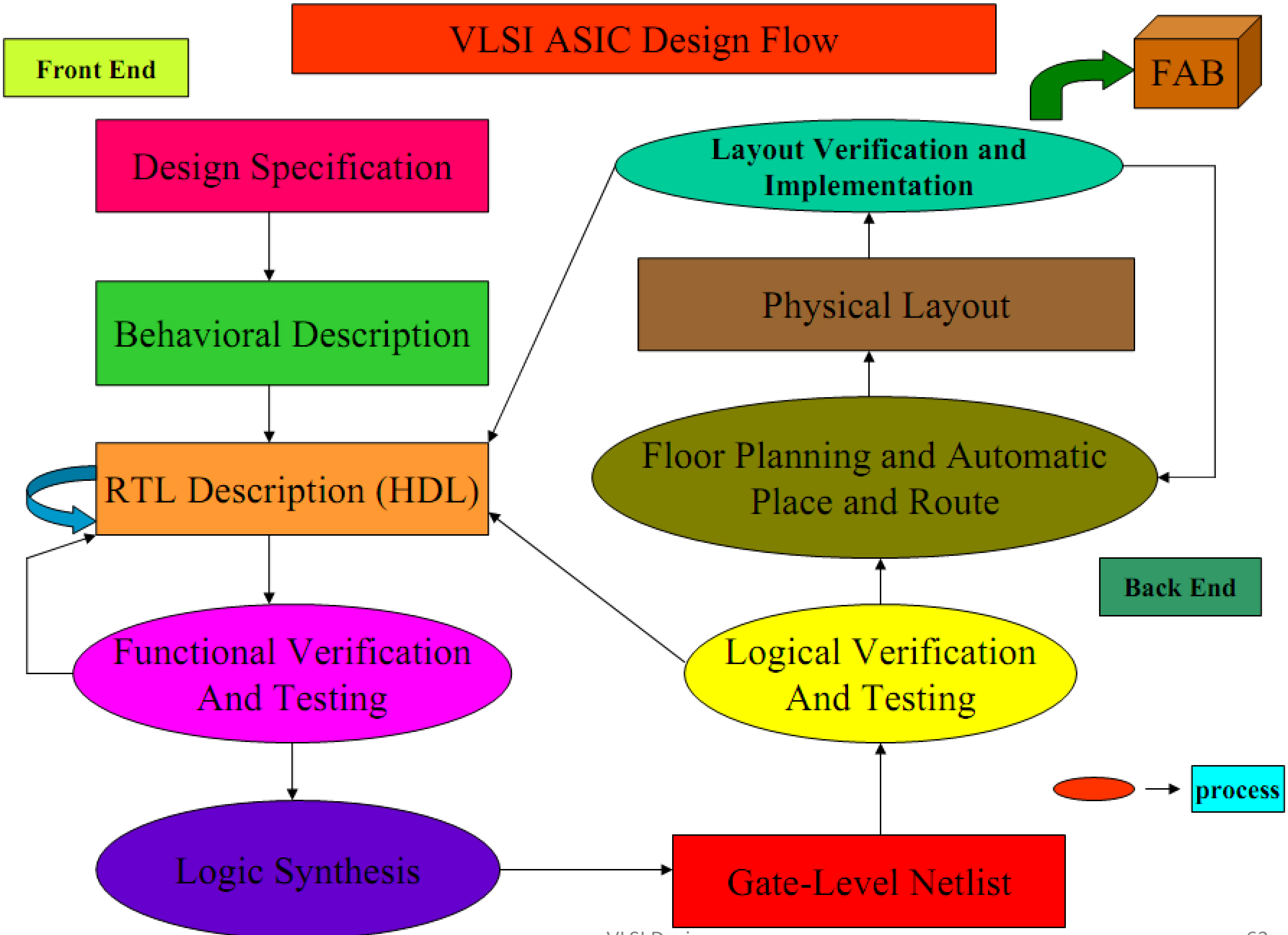


6. test / work as modeled?

Verifying the design. Design flow.




start
design entry
1
logic synthesis
2
system partitioning
3
prelayout simulation
4
floorplanning
5
placement
6
routing
7
circuit extraction
8
postlayout simulation
9
finish
VHDL/Verilog
netlist
A
B
A
chip
block
logic cells
logical design
physical design


VLSI ASIC Design Flow
Front End
FAB
Design Specification
Layout Verification and Implementation
Behavioral Description
Physical Layout
RTL Description (HDL)
Floor Planning and Automatic Place and Route
Back End
Functional Verification And Testing
Logical Verification And Testing
process
Logic Synthesis
Gate-Level Netlist

Front End Design :

The front end design consists of those steps which involves manufacturing only on software's and functionality verification. It consists of following steps :

Design Specification : According to the requirements, they describe abstractly the architecture, functionality and interface of the digital IC circuit to be designed. The object is to describe the purpose of the design including all aspects, such as the functions to be realized, timing constraints, and power dissipation requirements etc.

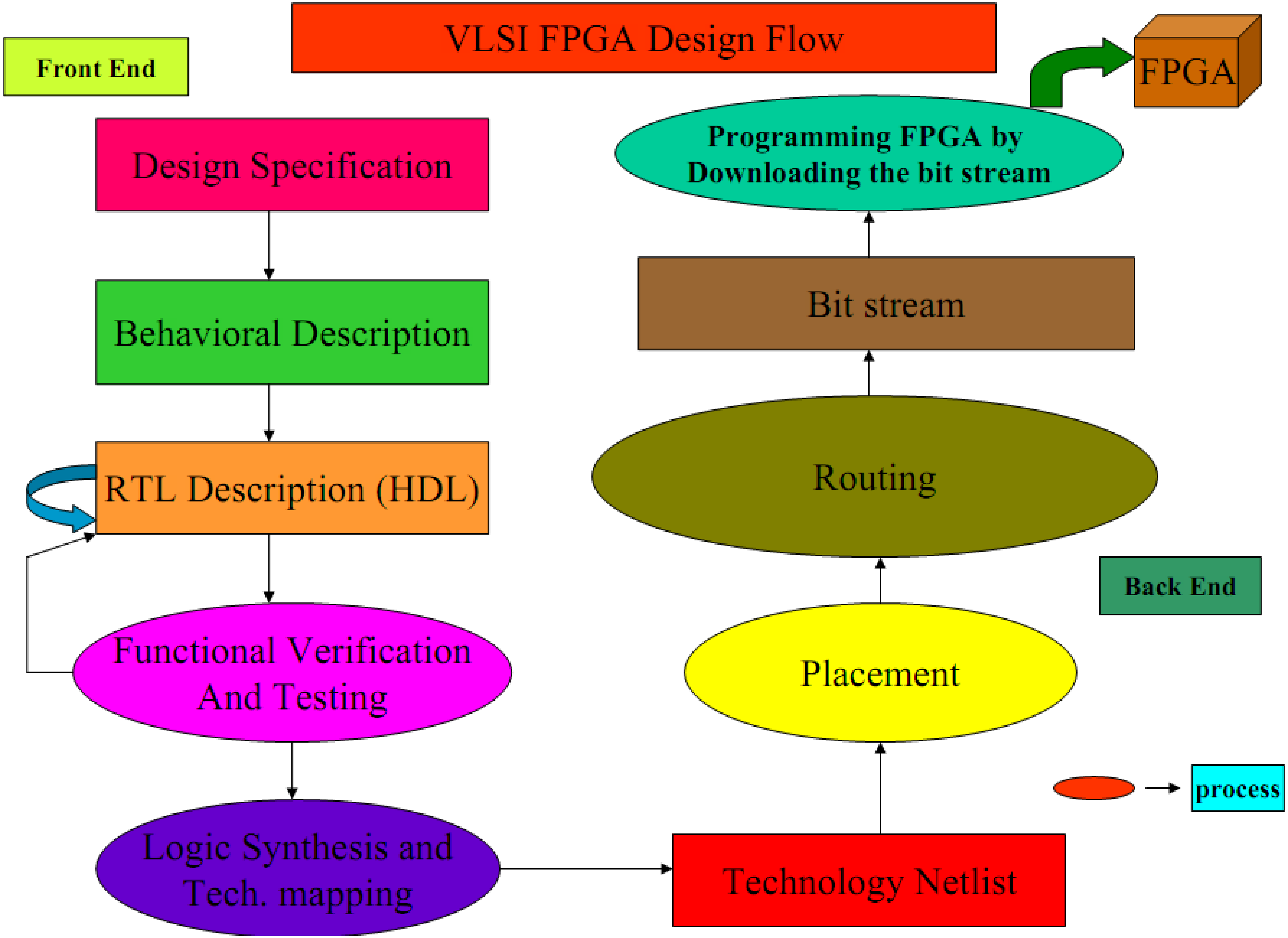
Behavioral Description : Behavioral description is then created to analyze the design in terms of functionality, performance, compliance to given standards, and other specifications.

RTL Description : RTL description is done using HDLs and simulated to test functionality. We need the help of EDA tools from here onwards. The various sub steps include verification of functionality and testing on a software. At the end, the design is synthesized using the EDA tools and various timing constraints are checked.

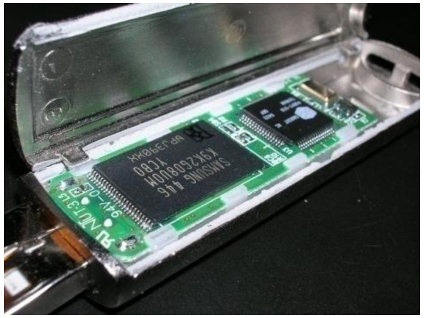
Back End Design :

Gate – level Netlist : RTL description is then converted to a gate-level netlist using logic synthesis tools. It is a description of the circuit in terms of gates and connections between them, such that they meet the timing, power and area specifications. The design is partitioned into convenient compartments or functional blocks, placed on a silicon floor and various interconnects are routed on the chip.

Physical Layout : Finally a physical layout is made, which will be verified and then sent to fabrication.


VLSI FPGA Design Flow
Front End
Design Specification
Behavioral Description
RTL Description (HDL)
Functional Verification And Testing
Logic Synthesis and Tech. mapping
Technology Netlist
Placement
Routing
Bit stream
Programming FPGA by Downloading the bit stream
FPGA
Back End
process

1. Applications / Ideas

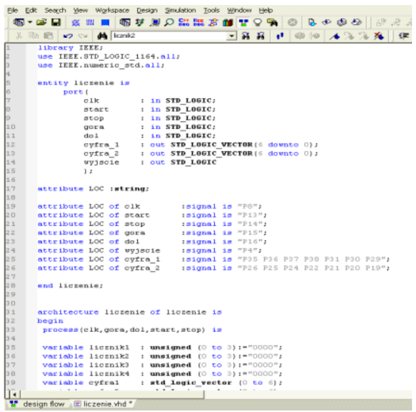


2. Specifications

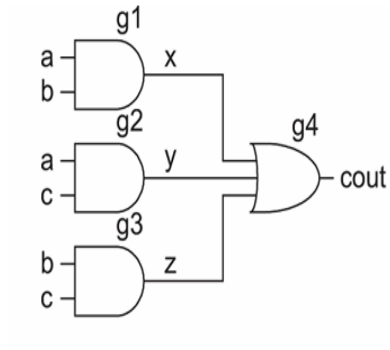
- Instruction set
- Interface (I/O pins)
- Organization of the system
- Functionality of each unit in the system, and how to communicate it to other units.

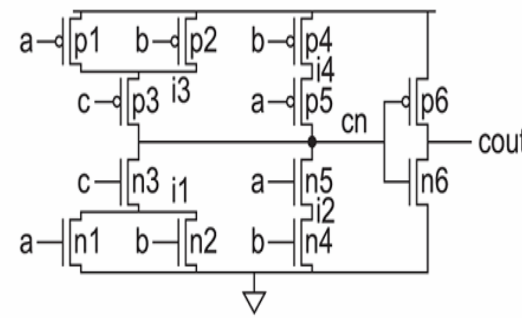
3/4. Design and Analysis

VHDL / Verilog

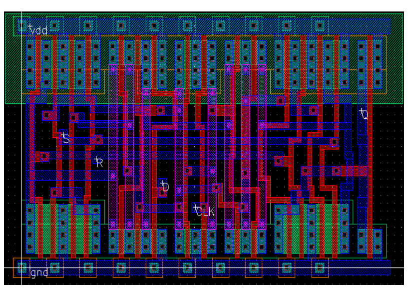


synthesis

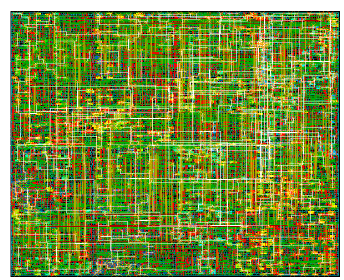




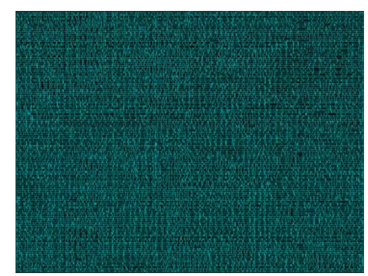
mask layout patterns



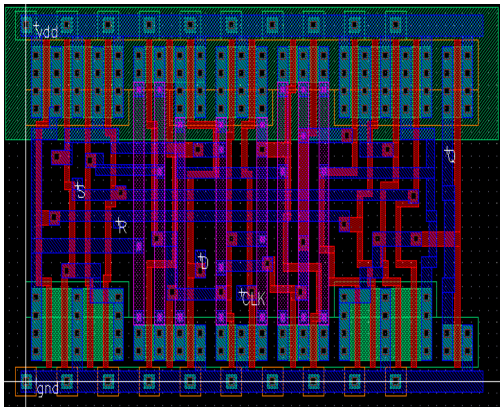
find wire routes



device layout



5. Fabrication

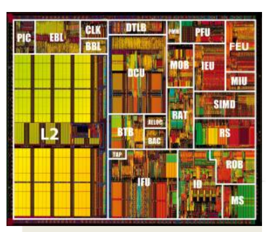


mask layout patterns

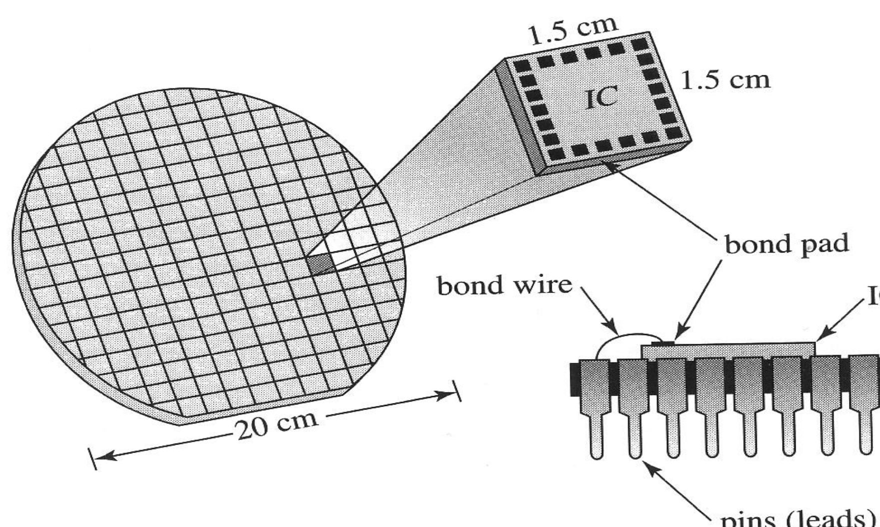
tape out

test and packaging

chip



die



From Howe, Sodini: Microelectronics:An Integrated Approach, Prentice Hall

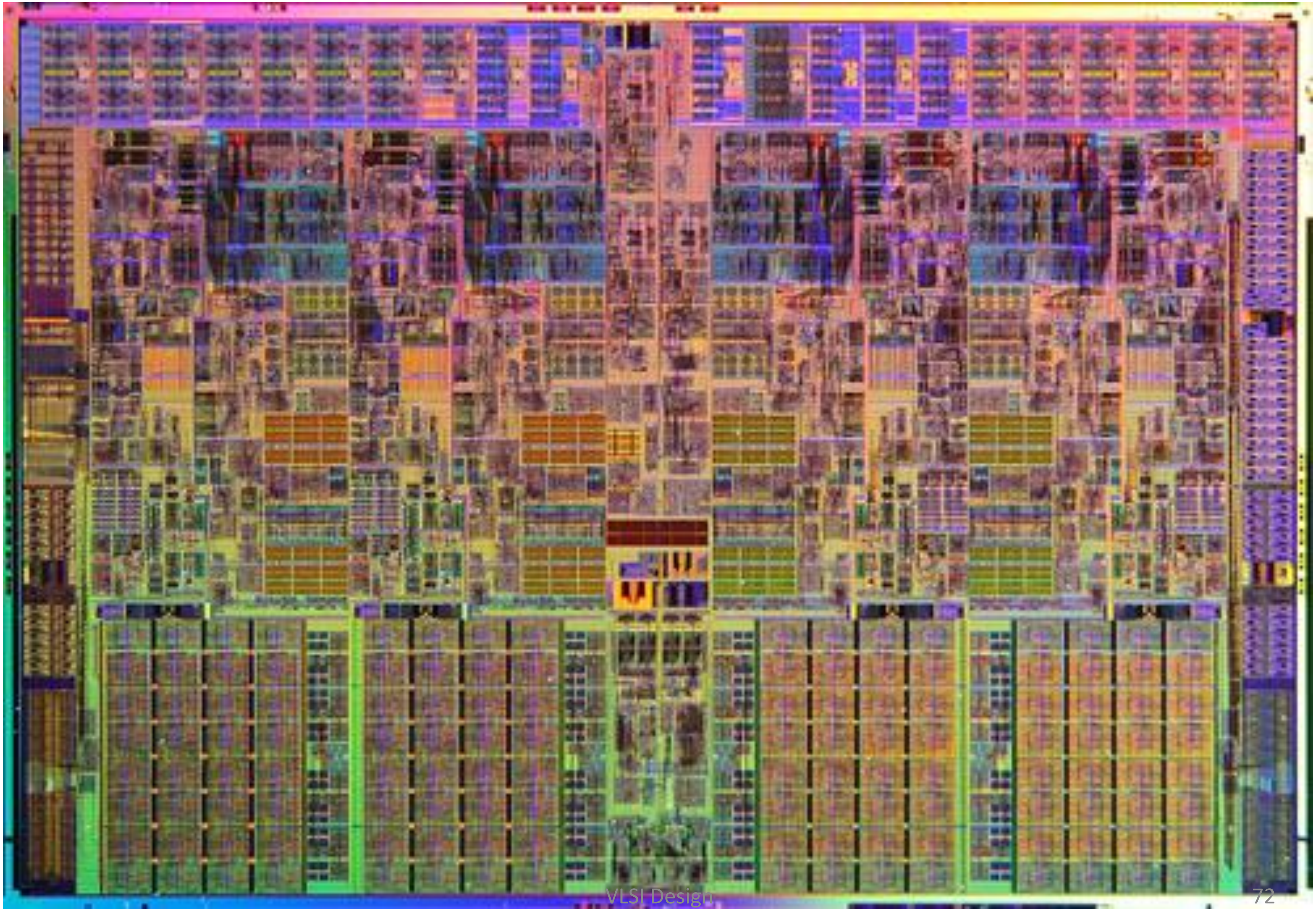
6. Evaluate design and compare to model

- Check signal integrity
- Power consumption
- Input/output behavior

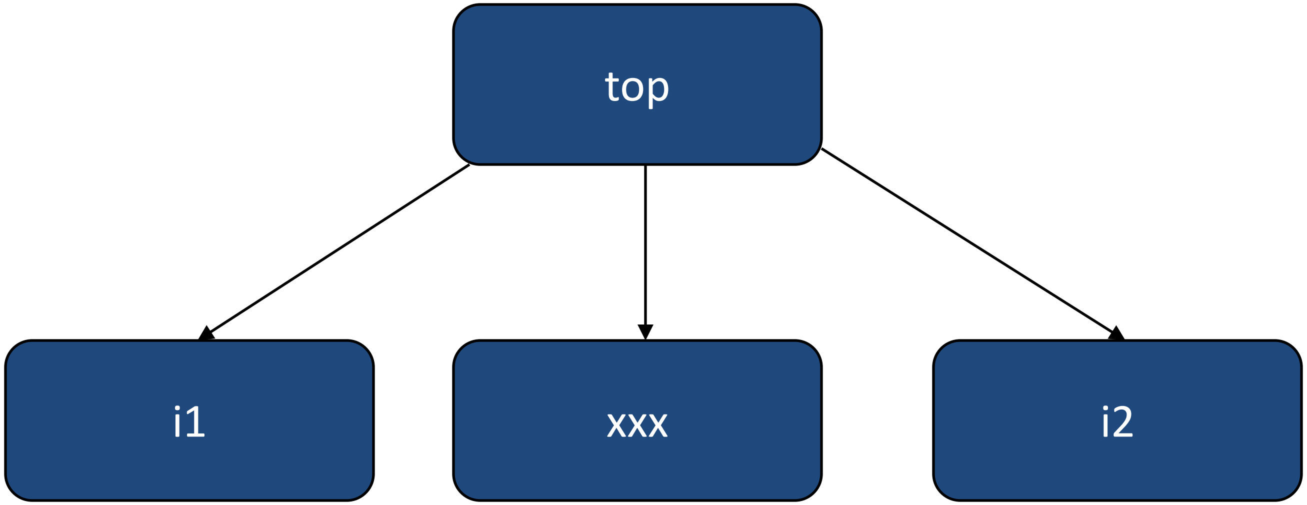
- Does the chip function as it is supposed to be?

- Does it work at desired clock frequency?

Intel core 7 processor



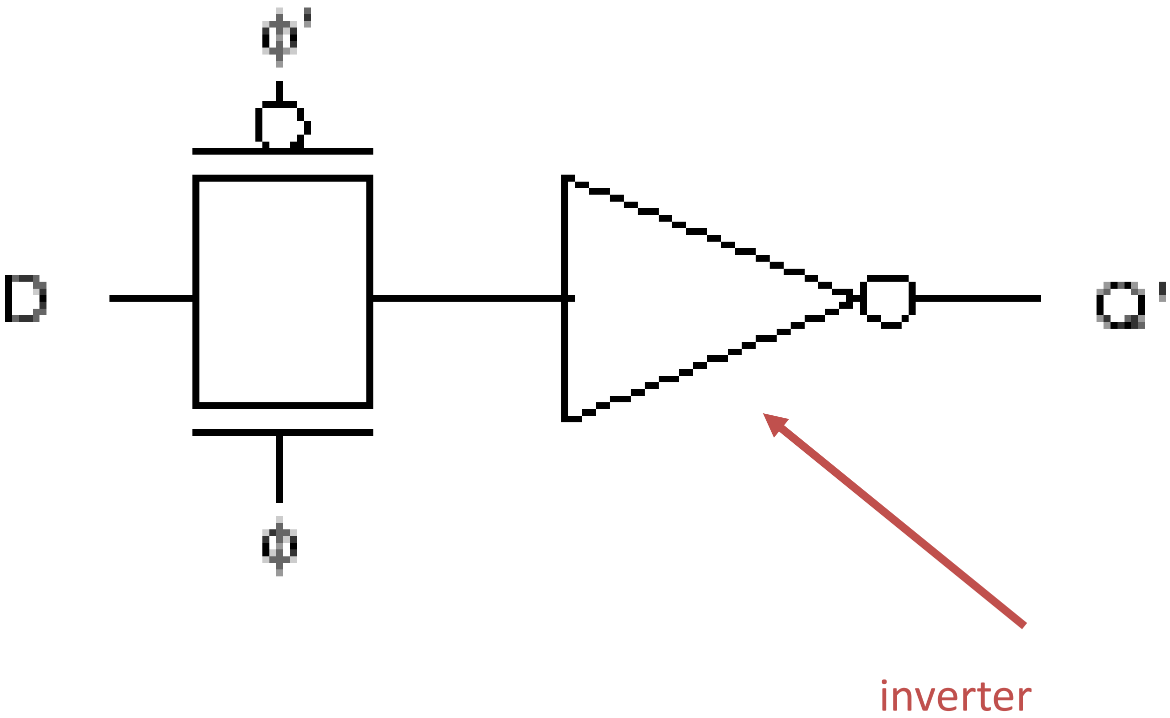
Component hierarchy



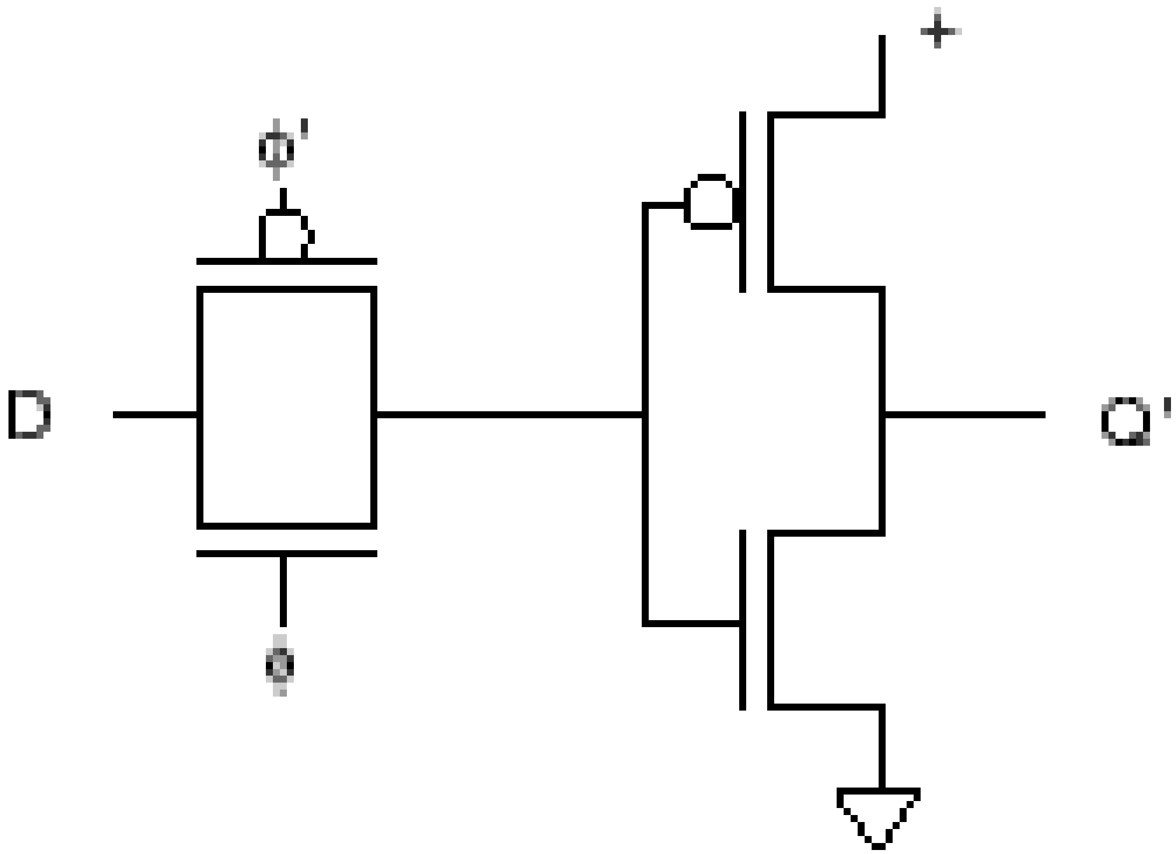
Dealing with complexity

- Divide-and-conquer: limit the number of components you deal with at any one time.
- Group several components into larger components:
  - transistors form gates;
  - gates form functional units;
  - functional units form processing elements;
  - etc.

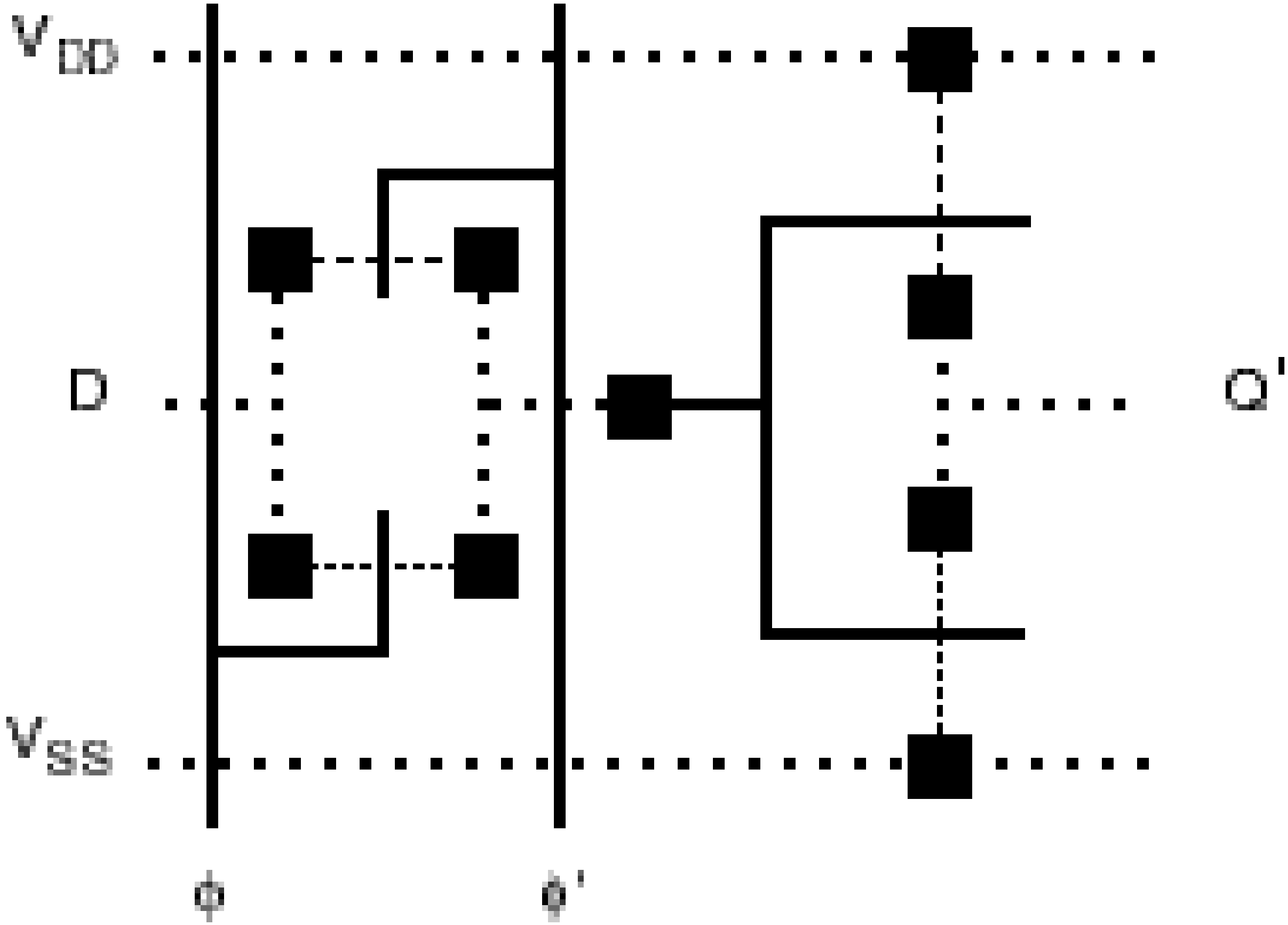
Mixed schematic



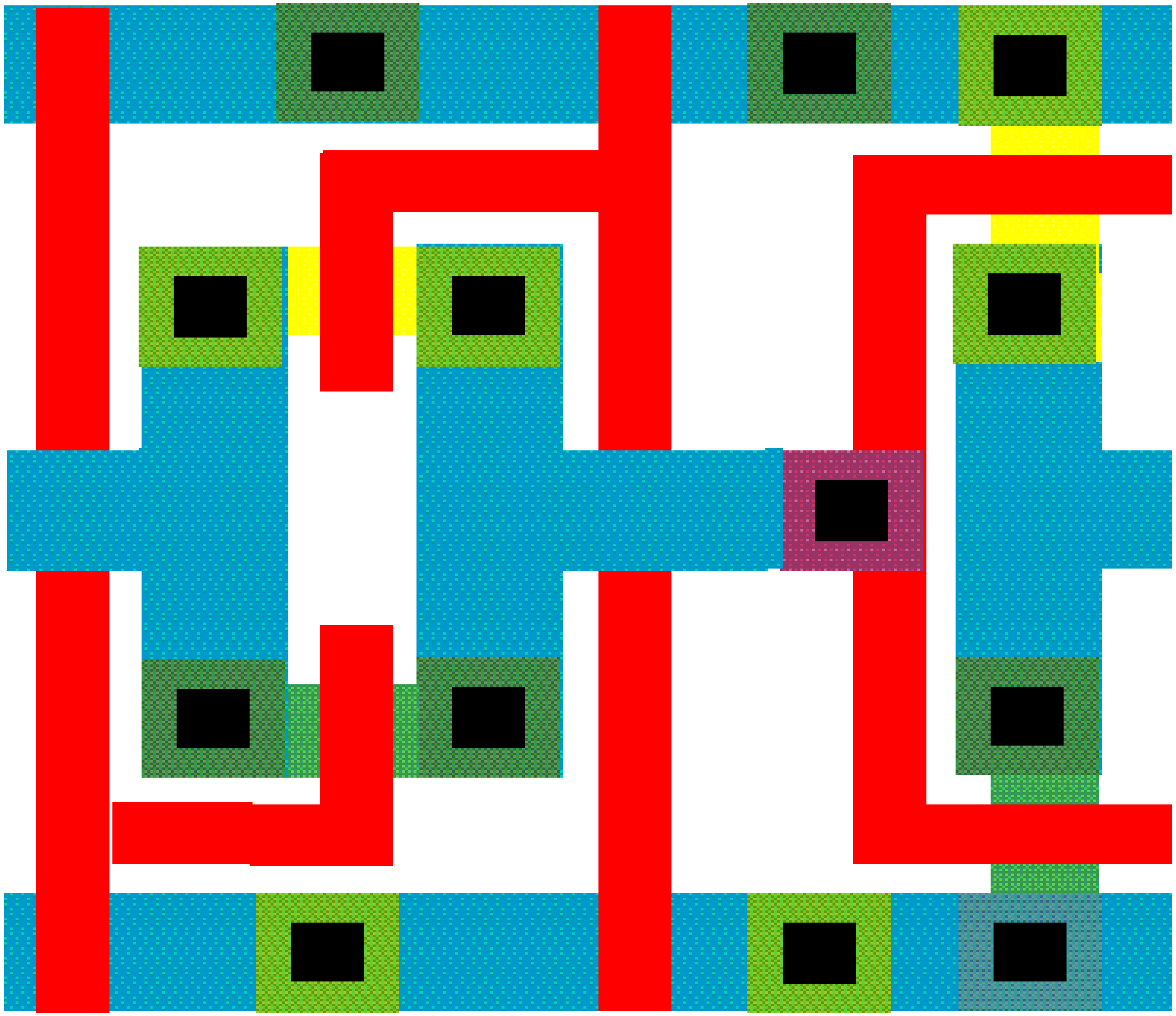
Transistor schematic



Stick diagram



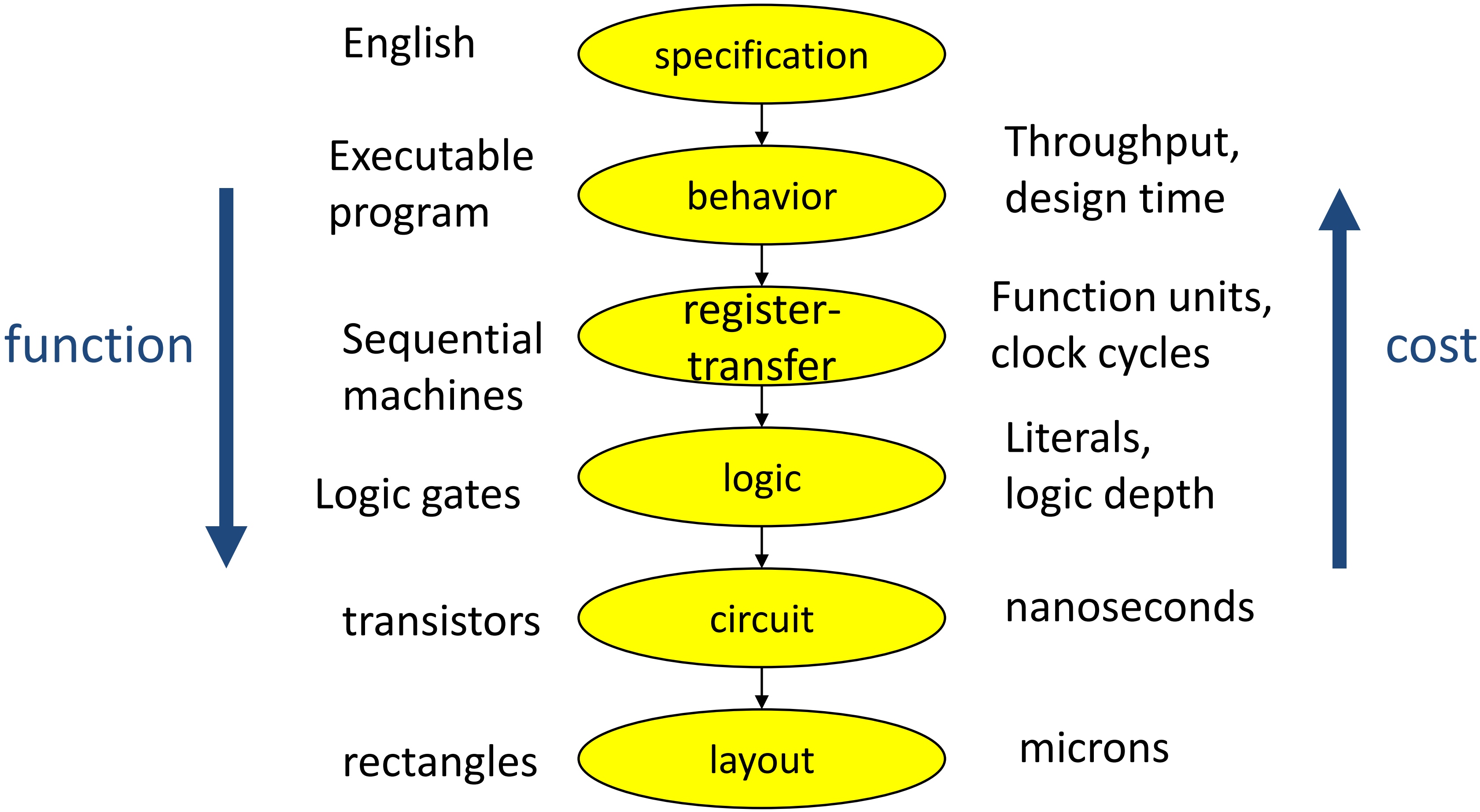
Layout and its abstractions



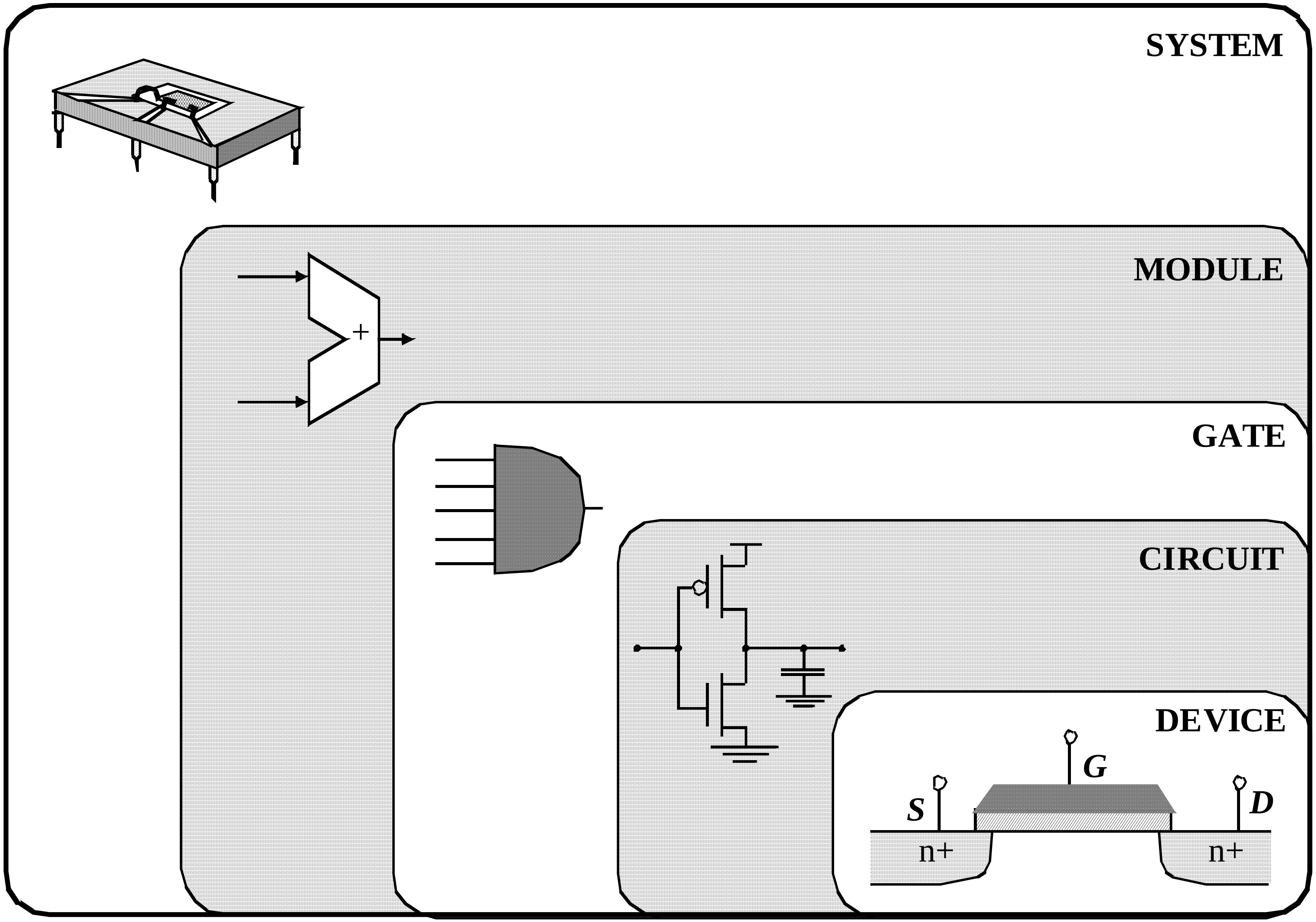
Levels of abstraction

- Specification: function, cost, etc. (Ex: Counter)
- Architecture: large blocks.
- Logic: gates + registers.
- Circuits: transistor sizes for speed, power.
- Layout: determines parasitics.

Design abstractions



Design Abstraction Levels



Help from Computer Aided Design tools

- Tools
  - Editors
  - Simulators
  - Libraries
  - Module Synthesis
  - Place/Route
  - Chip Assemblers
  - Silicon Compilers
- Experts
  - Logic design
  - Electronic/circuit design
  - Device physics
  - Artwork
  - Applications - system design
  - Architectures

New Design Methodologies

- Methodologies which are based on:
  - System Level Abstractions v.s. Device Characteristic Abstractions
    - Logic structures and circuitry change slowly over time
      - trade-offs do change, but the choices do not
  - Scalable Designs
    - Layout techniques also change slowly.
      - But the minimum feature size steadily decreases with time (also Voltage, Die Size, etc.)

VLSI Design Styles

- Full Custom
- Application-Specific Integrated Circuit (ASIC)
- Programmable Logic (PLD, FPGA)
- System-on-a-Chip

Full Custom Design

- Each circuit element carefully “handcrafted”
- Huge design effort
- High Design & NRE(Non-recurring engineering) Costs (One time cost for research) / Low Unit Cost
- High Performance
- Typically used for high-volume applications

ASIC

- Constrained design using pre-designed (and sometimes pre-manufactured) components
- Also called semi-custom design
- CAD tools greatly reduce design effort
- Low Design Cost / High NRE Cost / Med. Unit Cost
- Medium Performance

Programmable Logic (FPGA)

- Pre-manufactured components with programmable interconnect
- CAD tools greatly reduce design effort
- Low Design Cost / Low NRE Cost / High Unit Cost
- Lower Performance

System-on-chip (SOC)

- Idea: combine several large blocks
  - Predesigned custom cores (e.g., microcontroller) - "intellectual property" (IP)
  - ASIC logic for special-purpose hardware
  - Programmable Logic (PLD, FPGA)
  - Analog
- Open issues
  - Keeping design cost low
  - Verifying correctness of design

Intellectual property

- Intellectual property (IP): pre-designed components.
  - May come from outside vendors, internal sources.
- IP saves time, design cost.
- IP blocks must be designed to be reused.

IP-based design

- Almost every chip uses some form of IP:
  - Standard cell libraries.
  - Memories.
  - IP blocks.
- Designers must know how to:
  - Create IP.
  - Use IP.

Types of IP

- Hard IP:
  - Pre-designed layout.
  - Allows more detailed characterization.
- Soft IP:
  - No layout---logic synthesis, etc.
  - IP layout is created by the IP user.

Hard IP

- Must conform to many standards:
  - Layout pin placement.
  - Layer usage.
  - Transistor sizing.
- Hard IP blocks are usually qualified on a particular process.
  - Component is fabricated and tested to show that the IP works on that fab line.

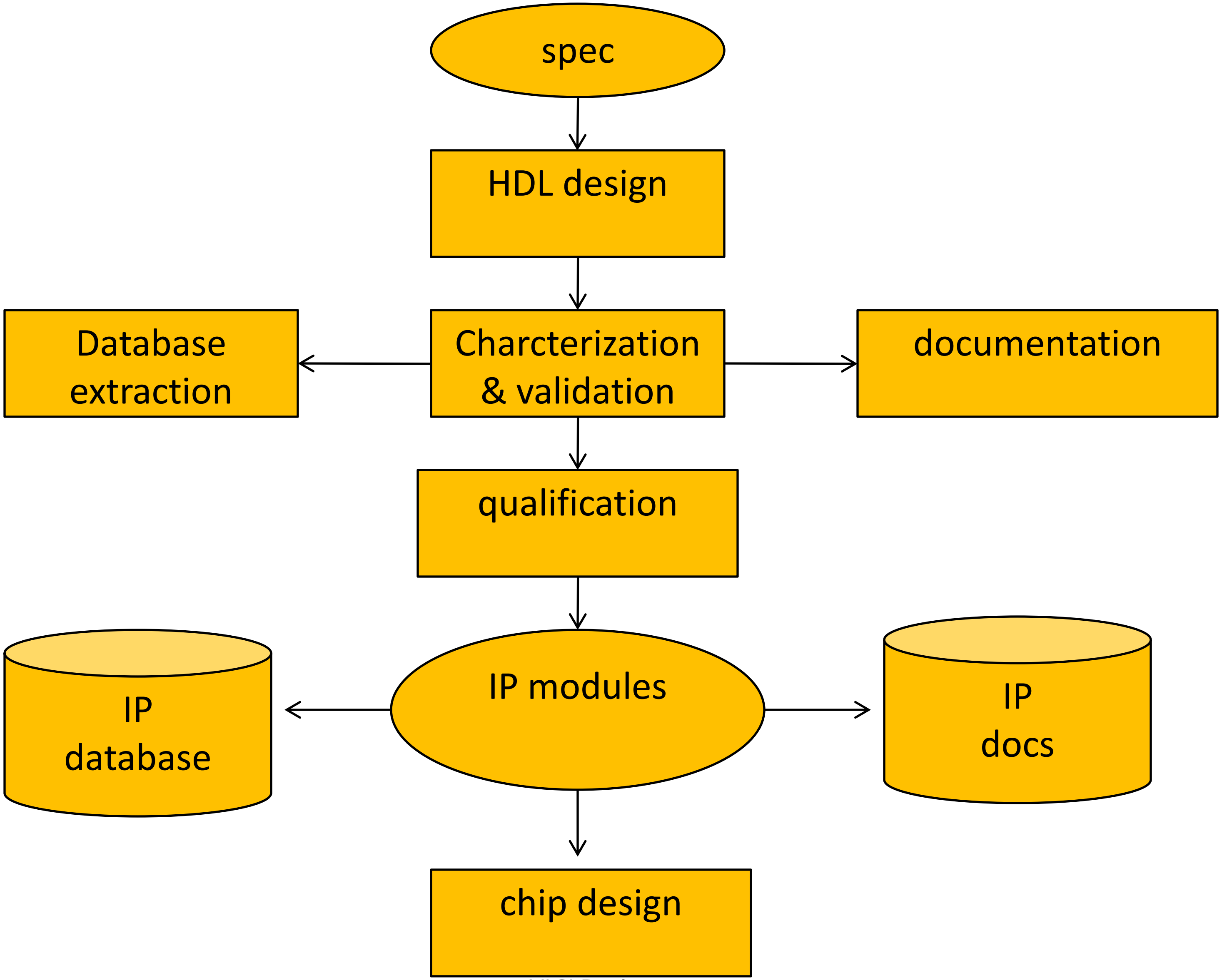
Soft IP

- Conformance of layout to local standards is easier since it is created by the user.
- Timing can only be estimated until the layout is done.
- Must conform to interface standards.
  - A <u>wrapper</u> adapts a block to a new interface.

IP across the design hierarchy

- Standard cells.
  - Pitch matched in rows, compatible drive.
- Register-transfer modules.
- Memories.
- CPUs.
- Busses.
- I/O devices.

The I/O lifecycle



Specifying IP

- Hard or soft?
- Functionality.
- Performance, including process corners.
- Power consumption.
- Special process features required.

Using IP

- May come from vendor, open source, or internal group.
- Must identify candidate IP, evaluate for suitability.
- May have to pay for IP.
- May want to qualify IP before use, particularly if it pushes analog characteristics.

VLSI

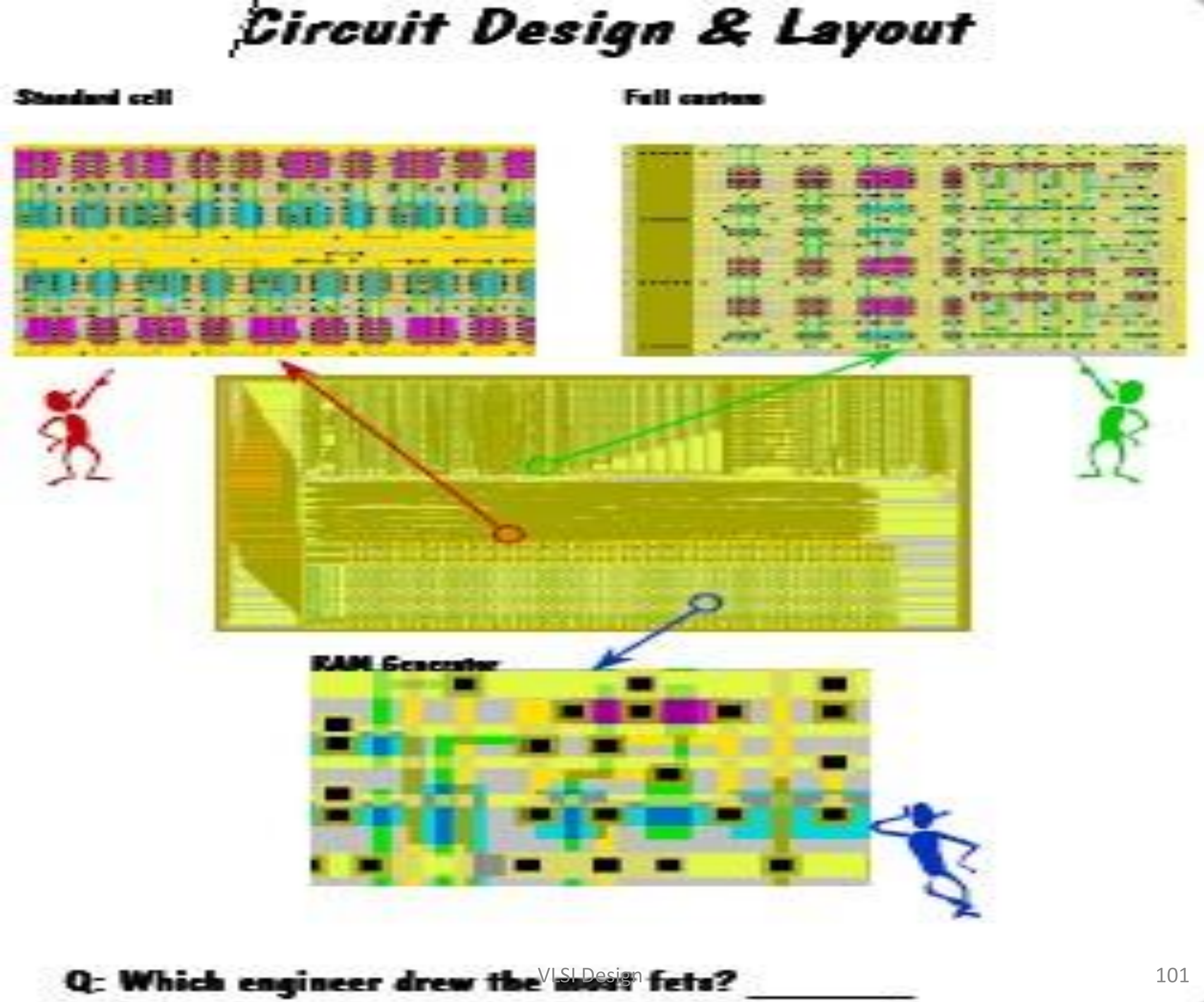
- gives the designer control over almost everything: architecture, logic design, speed, area, power, ...
- densities are increasing, costs decreasing with each passing year
- Is used by almost everyone: *"No one gets fired for building an ASIC"*
- was the enabling technology for much of the economic growth of the 80's and 90's. It will no doubt continue in its starring role for some time come.

VLSI Fact-of-Life #1:
"So much to do, so little time"

You need a *design methodology* :

- budget ($, speed, area, power, schedule, risk)
  - low-level building blocks, high-level architecture
    - behavioural design, verification
      - logic design, verification

- layout, verification


Circuit Design & Layout
Standard cell
Full custom
RAM Generator
Q: Which engineer drew the
fets?

Thank You

Any Queries ?

Assignment Questions

1 Explain design and testability for integrated circuit.
2 Explain IP life cycle.
3 Explain Advantages & Applications of VLSI.
4 Draw and explain design abstraction ladder for digital system.

Text Books:

Sr. No.	Title	Author	Publication
T-1	Principles of CMOS VLSI design	Neil H.Weste and Kamran Eshraghian	Pearson
T-2	VHDL Primer	J Bhasker	Addison Wesley
T-3	VHDL	Douglas Perry	Tata McGraw
T-4	Modern VLSI Design	Wayne Wolfe	4th Edition, PHI

Reference Books:

Sr. No.	Title	Author	Publication
R-1	VLSI Technology	Wayne Wolf	Prentice Hall
R-2	VLSI Test Principles and Architectures	Laung Terng Wang	Elsevier
R-3	Data sheet of XC95XX and sparatan 3	Xilinix	