EE 431: COMPUTER-AIDED DESIGN OF VLSI DEVICES

Introduction

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OVERVIEW

- Integrated circuits: many transistors on one chip.
- *Very Large Scale Integration* (VLSI)
- *Complementary Metal Oxide Semiconductor*
  - Fast, cheap, low power transistors
- Early in course (next few days): How to build your own simple CMOS chip

  - CMOS transistors

  - Building logic gates from transistors

  - Transistor layout and fabrication
- Rest of the course: How to build a good CMOS chip

A BRIEF HISTORY OF IC

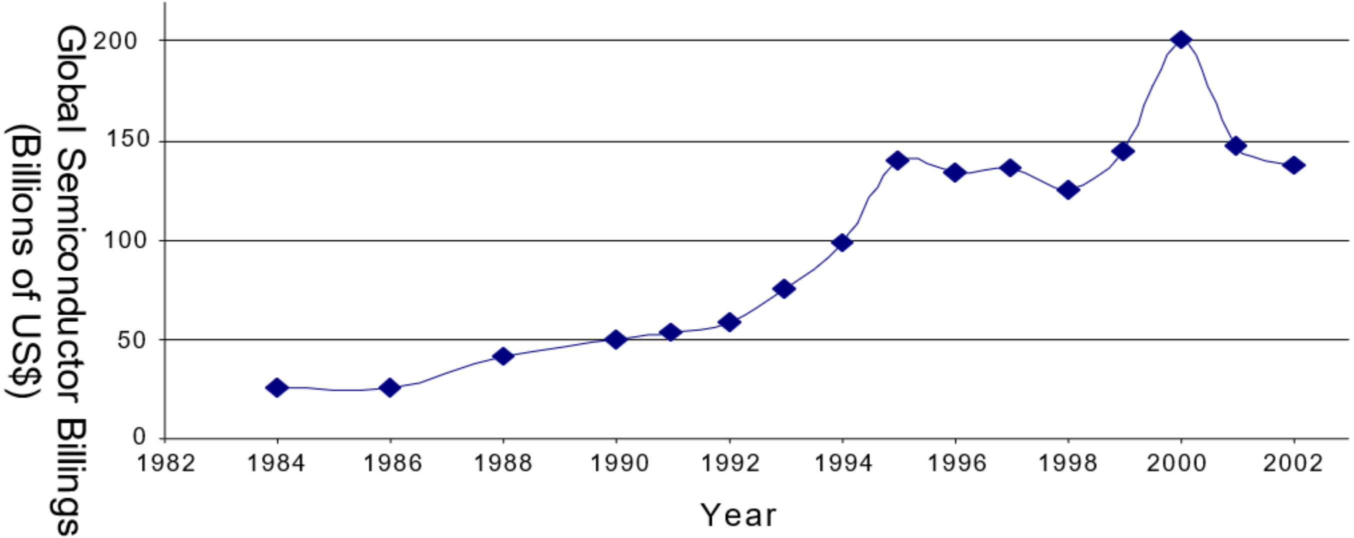
- 1958: First integrated circuit
  - Flip-flop using two transistors
  - Built by Jack Kilby at Texas Instruments
- 2003
  - Intel Pentium 4 μprocessor (55 million transistors)
  - 512 Mbit DRAM (> 0.5 billion transistors)
- 53% compound annual growth rate over 45 years
  - No other technology has grown so fast so long
- Driven by miniaturization of transistors
  - Smaller is cheaper, faster, lower in power!
  - Revolutionary effects on society

CAL POLY
SAN LUIS OBISPO

ANNUAL SALES

10^{18} transistors manufactured in 2003

- 100 million for every human on the planet



TRANSISTOR TYPES

- Bipolar Transistor

  - npn or pnp silicon structure

  - Small current into very thin base layer controls large currents between emitter and collector

  - Base currents limit integration density

- Metal Oxide Semiconductor Field Effect Transistors

  - nMOS and pMOS MOSFETS

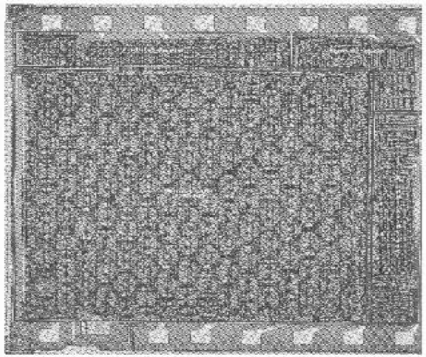
  - Voltage applied to insulated gate controls current between source and drain Low power allows very high integration

  - The workhorse of CMOS

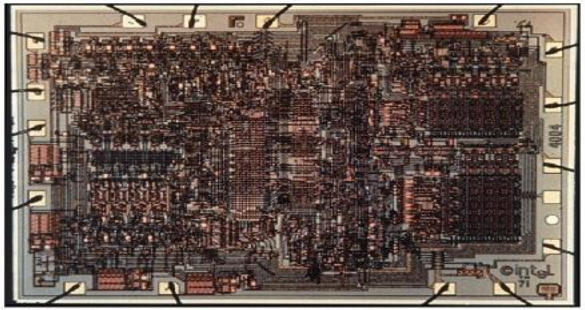
- FinFETs – MOSFET with thin vertical fin – has powered sub 20 nm fabrication

MOS INTEGRATED CIRCUIT

- 1970’s processes usually had only nMOS transistors
  - Inexpensive, but consume power while idle



Intel 1101 256-bit SRAM

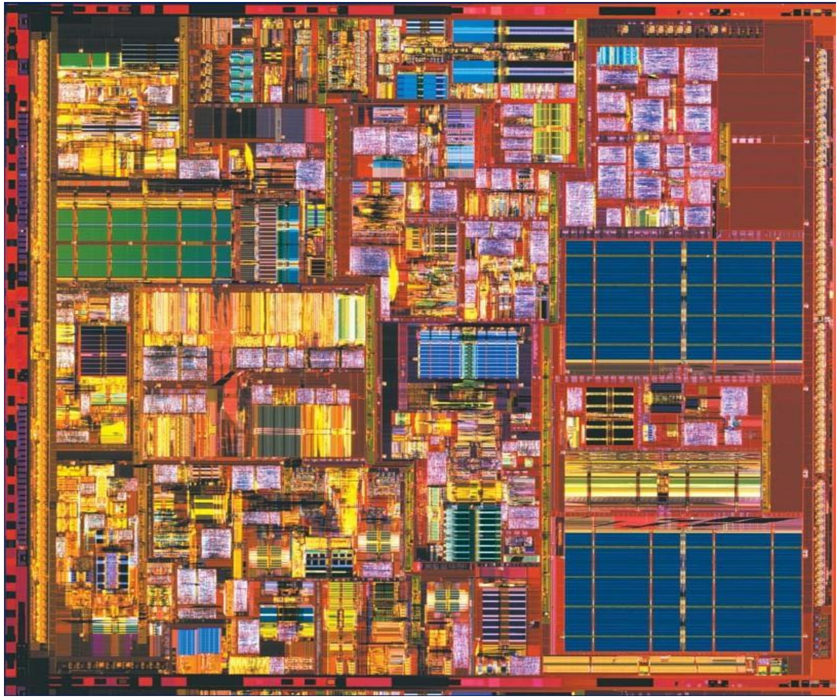


Intel 4004 4-bit µProc

- 1980s-present: CMOS processes for low idle power

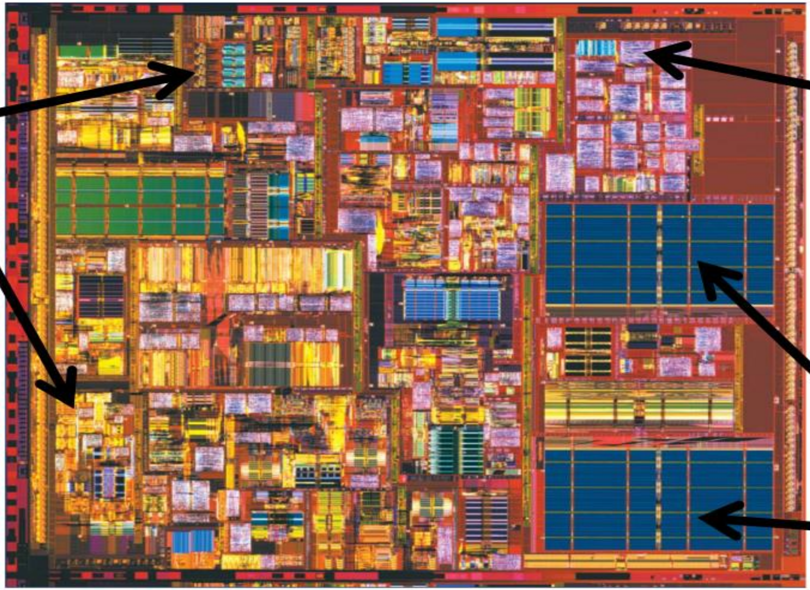
MODERN PROCESSORS

- CMOS remains the driving technology A lot of chip area is memory (cache)
- Very little is completely custom (datapath)
- Many blocks synthesized from VHDL or Verilog
- Transistor count for Pentium 4 ~50 million
- Currently implemented at 65nm technology node



MODERN PROCESSORS: A QUICK LOOK

Custom: Tightly packed but irregular regions

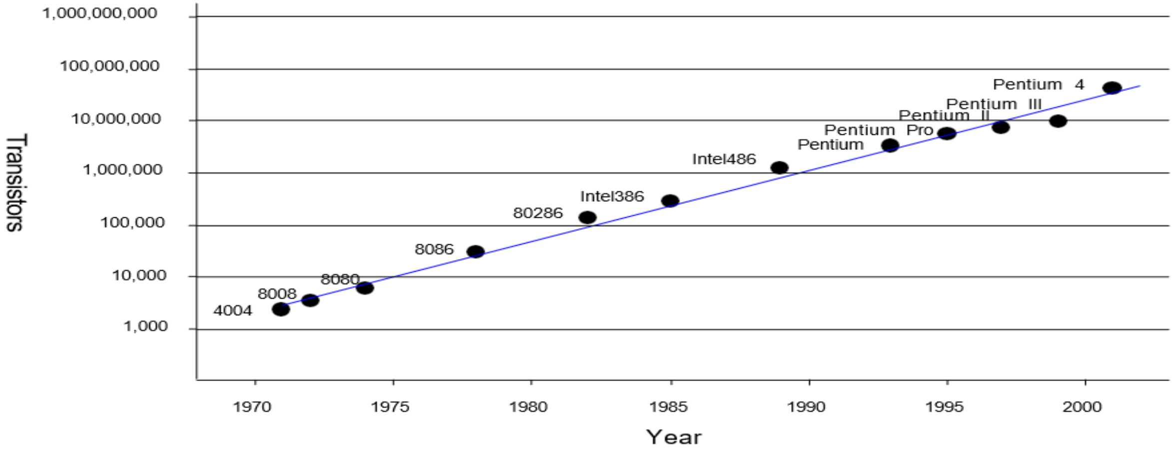


Automated: Very irregular "rats' nest" regions

Memory (very regular & dense) is custom but can easily be drawn using SKILL

MOORE'S LAW

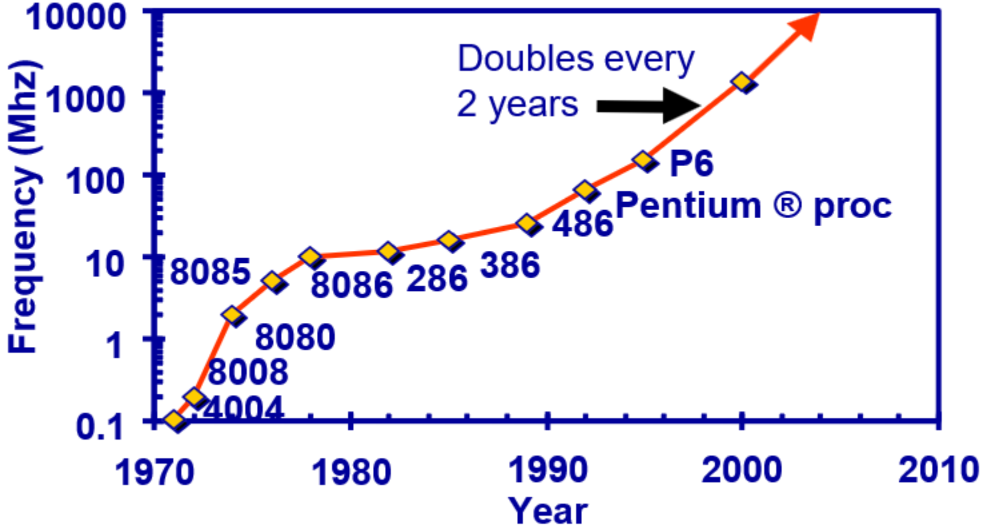
- 1965: Gordon Moore plotted transistor on each chip
  - Fit straight line on semilog scale
  - Transistor counts have doubled every 26 months



Integration Levels

SSI:	10 gates
MSI:	1000 gates
LSI:	10,000 gates
VLSI:	> 10k gates

FREQUENCY



Lead Microprocessors frequency doubles every 2 years

DIGITAL DESIGN CHALLENGES

"Microscopic Problems"

- Ultra-high speed design
- Interconnect
- Noise, Crosstalk
- Reliability, Manufacturability
- Power Dissipation
- Clock distribution.

?

"Macroscopic Issues"

- Time-to-Market
- Millions of Gates
- High-Level Abstractions
- Reuse & IP: Portability
- Predictability
- etc.

WHY SCALING?

- Technology shrinks by 0.7/generation
- Every generation can integrate 2x more functions per chip; chip cost does not increase significantly
- Cost of a function decreases by 2x
- But…
  - How to design chips with more and more functions?
  - Design engineering population does not double every two years…
- Hence, a need for more efficient design methods
  - Exploit different levels of abstraction

STRUCTURED DESIGN

Hierarchy: Divide and Conquer

- Recursively system into modules

Regularity

- Reuse modules wherever possible
- Ex: Standard cell library

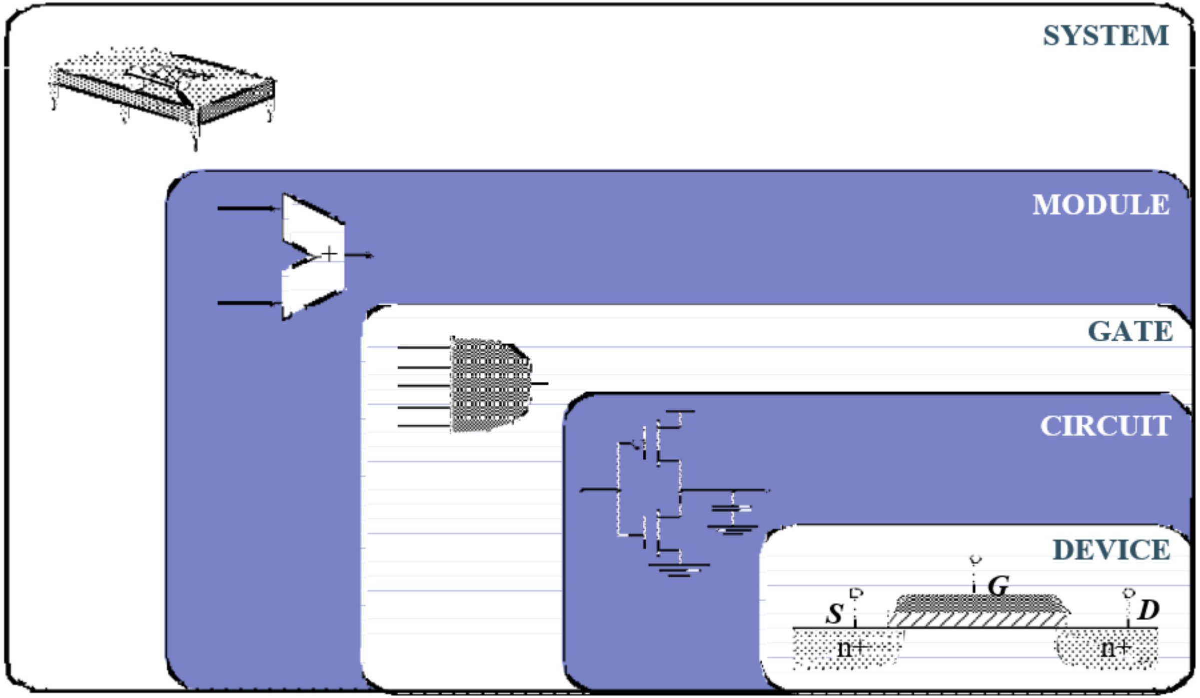
Modularity: well-formed interfaces

- Allows modules to be treated as black boxes

Locality

- Physical and temporal

DESIGN ABSTRACTION LEVEL



PERFORMANCE METRICS

How do we evaluate performance of a digital circuit (gate, block, …)?

- Cost
- Reliability
- Scalability
- Speed (delay, operating frequency)
- Power dissipation
- Energy to perform a function

SUMMARY

- VLSI design occurs at several abstraction layers
- A good designer is expert in one area but knowledgeable of many
- When you do something for the first time, it often looks ugly

Welcome... Let’s have fun designing integrated circuits!