Economy, Technology, and Education

SoC: A New Technology Advancement

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Economy

- Creation of Wealth
- Distribution of Wealth
Technology

- Application of Scientific Knowledge to the Solution of Practical Problems
Education

- Discovery of Knowledge
- Production of Human Resources
Economy: Creation of Wealth

- Labor Force Wealth
- Natural Resources Wealth
- Technology Wealth
Labor Force  Wealth

- Large Population
- Slaves
- Expatriates, Migrant Workers
- Sweatshops
- Steam Engine : First Industrial Revolution
Natural Resources  Wealth

- Gold, Coal, Iron, Oil,…
- Territory, Colony
- Cartels
Technology  Wealth

- Aerospace, Communication, Information, Medical,..
- Fashion, Music, Literature,..
- Knowledge
- Talents
Labor Force → Wealth

Reduction
Natural Resources → Wealth

Depletion
Technology ⇌ Wealth

Mutual Enhancement
Micro-electronic Industry
An Example of High Tech Industry

Micro-electronic Industry: US$1,000 billion
- personal computers,
- cellular phones,
- networking equipment,
- video games,
- cameras

Supported by

Semiconductor Industry: US$200 billion
- microprocessors,
- microcontrollers,
- DSPs,
- integrated chipsets
Semiconductor Industry

System specification

Design
- Tools: design simulation emulation
  - $3.4 billion

Fabrication
- Equipment
  - $16.8 billion

Packaging
- Equipment
  - $2.0 billion

Test
- Equipment
  - $5.2 billion

IC
- $200 billion
Making Sausages

Piglet → Pig → Pork → Sausages → Packaging
High Tech Industry

- Rapid advancement in technology
- Low cost products
- Unbounded market needs
- Short product life
- Capital intensive
- Brain power intensive
Rapid Advancement in Technology
Semiconductor Industry

Thickness of skin is 100 $\mu$m
Diameter of a piece of hair is 50 $\mu$m
Finger nails grow by 1 $\mu$m in 10 minutes
Rapid Advancement in Technology
Semiconductor Industry

Transistors Per Die

- Memory
- Microprocessor


\(100\) \(10^1\) \(10^2\) \(10^3\) \(10^4\) \(10^5\) \(10^6\) \(10^7\) \(10^8\)

Memory:
- 4K
- 16K
- 64K
- 256K
- 1M
- 4M
- 16M
- 64M

Microprocessor:
- 4004
- 8080
- 8086
- 80286
- i386™ CPU
- i486™ CPU
- Pentium® Pro Proc.
- Pentium® II Processor
- Pentium® II Processor
Low Cost
Semiconductor Industry

- A transistor cost $30 in 1960
- 8080 (5,000 tx) cost $150 in 1974
  - 3 cents/tx
- Pentium-II (7,500,000 tx) cost $225 in 1997
  - 0.003 cents/tx

- 1,000 fold decrease from 1960 to 1974
- 1,000,000 fold decrease from 1960 to 1997
Technology

- Rapid advancement in technology
- Miniaturization, low cost
- Cheaper, smaller, faster systems
- Greater market needs

Moore's Law
Capital Intensive
Semiconductor Industry

Million US$
Customization and Short Product Life

Complex Design Work

Short Design Cycle

Brain Power

Design Power
Brain Power: Productivity Gap
Semiconductor Industry

Chip Capacity and Designer Productivity

Complexity growth rate
58% per yr.

Productivity growth rate
21% per yr.
Headcount is growing and growing and growing

Moore’s Law also applies ...
Underlying Architecture adds yet Another Dimension

Tools & Design Methodology Are Inextricably Interwoven-like an “Electronic” DNA

Underlying Architecture adds yet Another Dimension
System-on-a-Chip  SoC

An Example of Technology Advancement

- A Microelectronic System-on-a-Chip
- It used to be
  - System-in-a-Package  Multi-chip Module
  - System-on-a-Board  Printed Circuit Board
  - System-in-a-Cabinet
  - System-in-a-Room
What does an engineer do?

Putting things together!

Integration!

\[ \int x \, dx \]
1952, 1958

Learned to Program an IBM 709 in FORTRAN
Stored Program Digital Computers

- Processor
- Memory
- IO
- Auxiliary Memories
Electronic Digital Computers

- First Generation: Vacuum Tubes
  Discrete Components

- Second Generation: Transistors
  Discrete Components

- Third Generation: Integrated Circuits
  Circuit-on-a-Chip

- Fourth Generation: Microprocessors
  Processor-on-a-Chip

- Fifth Generation: System-on-a-Chip
Processors  Speed, Size, Cost

- **Speed**: $10^3$, $10^6$, $10^9$, $10^{12}$ operations/second
  - below 1 MHz → over 1,000 MHz
- **Size**: $1\text{cm} \times 1\text{cm}$ chips
- **Cost**: a few millions dollars
  → tens of millions of dollars
  → a few hundred dollars
  → a few dollars
Memories  Speed, Size, Cost

- Magnetic Core Memory: Magnetic Cores
  Discrete Components
  Random Access, Non-Volatile

- Semiconductor Memory: Transistors
  Memory-on-a-Chip
  Random Access, Volatile

- Flash Memory: Transistors
  Memory-on-a-Chip
  Random Access, Non-Volatile

Microseconds $\rightarrow$ Nanoseconds 1,000 fold increase
4 Kilo-bytes $\rightarrow$ 64 Mbytes 16,000 fold increase
$100,000 \rightarrow$ $1$ 100,000 fold decrease
System-on-a-Chip

**Hardware**

- Digital Circuits
- Interface Circuits
- Analog Circuits
- Memories
- Input-Output Devices
- \(\mu P\)
- DSP
- MPEG
- ASIC
- FPGA
- A/D
- D/A
- RF
- PLL
- TxBx
- RAM
- ROM
- FLASH
- Sensors
- Mechanical Electrical Devices

**Software**

- Operating Systems
- Application Programs
Integration Advantages

- Improvement in Performance
- Reduction in Size
- Reduction in Cost
- Easy to Assemble
- Energy Efficient
Heterogeneity
New/Old Technical Issues

- Design Objectives
- System Integration
- Design Complexity: Reusable Components Intellectual Properties
- Hardware/Software Co-Design
- Analog and Mixed Signal Circuit and System Design
- Processing
Design Objectives

- Digital Circuits: Speed
- Memories: Density
- Mixed Signal Circuits: Compatibility
- Analog Circuits: Precision
- Input-Output Devices: Sensitivity, Size, Power
### Design Complexity:

**Reusable Components Intellectual Properties, IP**

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- **Reusable Design**
  - Subroutine
  - Algorithm
  - C++ Program
  - Binary Code

- **Hard IP**
  - Silicon Block

- **Firm IP**
  - Gate-Level Netlist

- **Soft IP**
  - HDL Description

- **Reusable IP**
  - Subroutine

- **Intellectual Properties, IP**
  - Silicon Block
IP New Design Methodology

- **Export (IP creation)**
  - implementation, documentation, test, customer support,…

- **Import (IP selection)**
  - catalog, evaluation, qualification,…

- **Compatibility**
  - protocols, interfaces,…

- **IP Protection**
  - water mark, finger printing, encryption,…

- **Design reuse cost minimization**
  - enhancements, process migration, version control,…
Hardware-Software Co-Design
New Design Methodology

- Partitioning
- Co-specification, co-analysis, co-design, co-simulation, co-verification
- Interface synthesis
Analog and Mixed Signal System and Circuits

- Design
- A/D, D/A Conversion
Processing

- Processing Technology
- Yield:

Product of Yields of Components

\[ 0.9 \times 0.9 \times 0.9 = 0.729 \]
System-on-a-Chip

New Technology Advancement

- Will push semi-conductor technology forward
- Will invigorate the economy
- Will demand human resources from universities
Concluding Remarks
Concluding Remarks

A Peaceful, Prosperous, and Happy World