Lecture 1.1

• Introduction and context for the course
  – Moore’s Law and system-level integration
  – SoCs: What & Why?
  – Key design issues
A 3,000,000,000 fold increase in 55 years
Moore’s Law

Microprocessor Transistor Counts 1971-2011 & Moore’s Law

• An empirical observation (and prediction) of the growth in number of transistors in integrated circuits over time

Source: intel.com
Moore’s Law ... in his own words

The future of integrated electronics is the future of electronics itself. The advantages of integration will bring about a proliferation of electronics, pushing this science into many new areas. Integrated circuits will lead to such wonders as home computers – or at least terminals connected to a central computer – automatic controls for automobiles, and personal portable communications equipment.

....

Cramming more components onto integrated circuits

With unit cost falling as the number of components per circuit rises, by 1975 economics may dictate squeezing as many as 65,000 components on a single silicon chip

By Gordon E. Moore

Director, Research and Development Laboratories, Fairchild Semiconductor
division of Fairchild Camera and Instrument Corp.

The future of integrated electronics is the future of electronics itself. The advantages of integration will bring about a proliferation of electronics, pushing this science into many new areas.

Integrated circuits will lead to such wonders as home computers—or at least terminals connected to a central computer—automatic controls for automobiles, and personal portable communications equipment. The electronic wristwatch needs only a display to be feasible today.

But the biggest potential lies in the production of large systems. In telephone communications, integrated circuits in digital filters will separate channels on multiplex equipment. Integrated circuits will also switch telephone circuits and perform data processing.

Computers will be more powerful, and will be organized in completely different ways. For example, memories built of integrated electronics may be distributed throughout the machine instead of being concentrated in a central unit. In addition, the improved reliability made possible by integrated circuits will allow the construction of larger processing units. Machines similar to those in existence today will be built at lower costs and with faster turn-around.

Present and future

By integrated electronics, I mean all the various technologies which are referred to as microelectronics today as well as any additional ones that result in electronics functions supplied to the user as irremediable units. These technologies were first investigated in the late 1950’s. The object was to miniaturize electronics equipment to include increasingly complex electronic functions in limited space with minimum weight. Several approaches evolved, including microassembly techniques for individual components, thin-film structures and semiconductor integrated circuits.

Each approach evolved rapidly and converged so that each borrowed techniques from another. Many researchers believe the way of the future to be a combination of the various approaches.

The advocates of semiconductor integrated circuitry are already using the improved characteristics of thin-film resistors by applying such films directly to an active semiconductor substrate. Those advocating a technology based upon films are developing sophisticated techniques for the attachment of active semiconductor devices to the passive film arrays.

Both approaches have worked well and are being used in equipment today.

The author

Dr. Gordon E. Moore is one of the new breed of electronic engineers, schooled in the physical sciences rather than in electronics. He earned a B.S. degree in chemistry from the University of California and a Ph.D. degree in physical chemistry from the California Institute of Technology. He was one of the founders of Fairchild Semiconductor and has been director of the research and development laboratories since 1969.
Moore’s Law ... in his own words

Reduced cost is one of the big attractions of integrated electronics.

For simple circuits, the cost per component is nearly inversely proportional to the number of components, the result of the equivalent piece of semiconductor in the equivalent package containing more components. But as components are added, decreased yields more than compensate for the increased complexity, tending to raise the cost per component. Thus there is a minimum cost at any given time in the evolution of the technology.
Moore’s Law ... in his own words

The complexity for minimum component costs has increased at a rate of roughly a factor of two per year (see graph). Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65,000.
Moore's Law is Based on the Concept of "Learning Curve"

- Cost per unit decreases by a fixed percent every time total cumulative volume doubles
- Applies to all free market products and services (over centuries) when measured in constant currency
- Used to predict future costs
  - Aircraft industry
  - Semiconductor industry
- Also true for subsystem or component costs and improvements in reliability, quality, yield, etc.

Source: Walden Rhines, Keynote presentation, VLSI Design Conference 2010
Learning Curve for Japanese Beer

Source: Boston Consulting Group
Learning Curve for Integrated Circuits

http://scalometer.wikispaces.com/singularity

Source: Intel
Hooray, we’re drowning in.... Transistors!

- \(1.2 \times 10^{21}\) (1.2 sextillion)
  - The number of transistors in 2014!
  - Transistors > grains of rice harvested in 2004
  - \(10^6\) times estimated number of ants on earth

Sources: “A Law of Continuing Returns”, Los Angeles Times, April 17 2005
ISSCC 2004 Keynote, Gordon Moore
What do we do with all the transistors?

- Scaling option #1 (component-driven scaling)
  - Microprocessors, GPUs
    - Pre-2005: Deeper pipelines, more complex logic for instruction-level parallelism, more cache
    - 2005- : More cores, more cache
  - Memory chips
    - Easy – just keep increasing capacity
What do we do with all the transistors?

- Scaling option #2 (system-driven scaling)
  - Integrate more and more system functions onto a chip

Benefits of integration:
- Size (miniaturization)
- Cost
- Power
- Performance

98% of “computing” systems are embedded
What are Systems-on-chip?

- Direct consequence of increasing scales of integration (Moore’s Law)
  - Integrate all or most system components into a single chip
  - Benefits: cost, size, power consumption, performance

Infineon E-GOLDVoice “Phone-on-a-chip”

Intel EP80579 SoC for embedded systems (security, communications, storage)

NVIDIA Tegra2 SoC for tablets, smartphones, cars, set-top boxes
SoCs are a growing market

- Large and growing market - $35B in 2007, ~20% CAGR
SoCs are a growing market
Benefits of SoC Integration: Size

• Impact of SoCs on mobile phones

Source: Hermann Eul, Infineon

Benefits of SoC Integration: Cost

• “Single-chip” cell phone

Munich, Germany and Barcelona, Spain – February 13, 2006

“....
The latest chip from Infineon Technologies AG (FSE/NYSE: IFX) reduces the number of electronic components in a basic mobile phone from about 100 to fewer than 50.

... Infineon’s E-GOLDvoice™ single-chip solution combines a baseband processor, radio frequency transceiver, power management unit and RAM in a footprint measuring just 8 mm x 8 mm, achieving a new record level of silicon integration for mobile communications...

Source: TI, Nokia, Infineon

Spice Mobile has launched a “people’s phone” for under $20...

Globally, over 20% of the mobile phone market is represented by the ultra low cost segment.

Source: TI, Nokia, Infineon
Benefits of Integration: Size/Cost

- Extreme size constraints
  - Integrated sensors for structural (building, bridge, aircraft) monitoring
  - Biomedical implants
Benefits of Integration: Performance/Power

- Integration converts off-chip traffic into on-chip traffic
  - Off-chip communication: ~1-10GB/s, ~1nJ/bit
  - On-chip communication: ~100GB/s-10TB/s, 0.1-1 pJ/bit

PC system-level bus trends

On-chip wire delay and power in 65nm technology (Source: Intel)