Lecture 1: VLSI Overview

CSCE 6730
Advanced VLSI Systems

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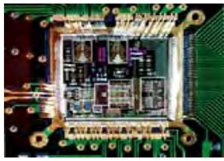
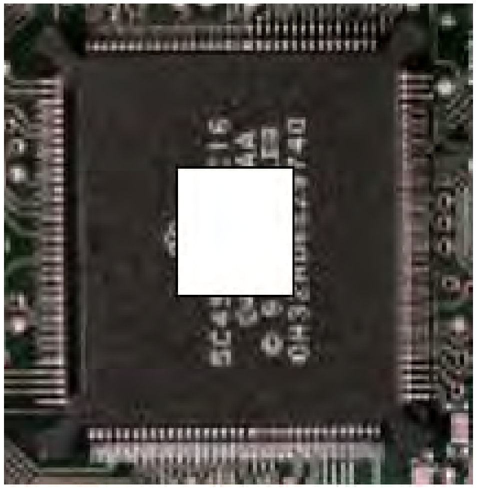
NOTE: The figures, text etc included in slides are borrowed from various books, websites, authors pages, and other sources for academic purpose only. The instructor does not claim any originality.

What is an Integrated Circuit ?

- An integrated circuits is a silicon semiconductor crystal containing the electronic components for digital gates.
- Integrated Circuit is abbreviated as IC.
- The digital gates are interconnected to implement a Boolean function in a IC .
- The crystal is mounted in a ceramic/plastic material and external connections called “pins” are made available.
- ICs are informally called chips.

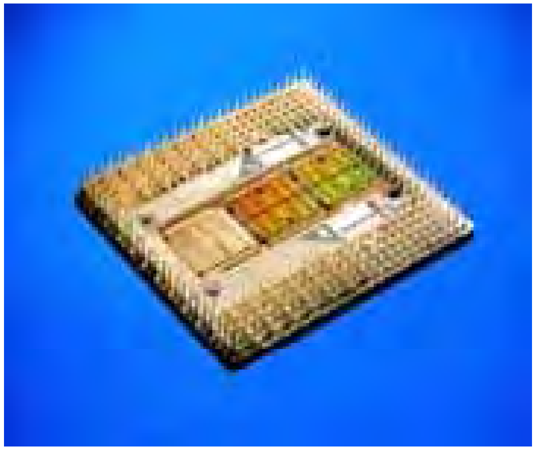


How does a chip look like?

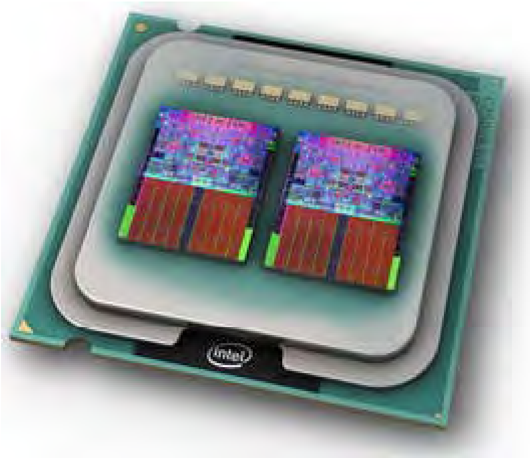


(1) ASIC

(2) Sun UltraSparc



(3) PentiumPro



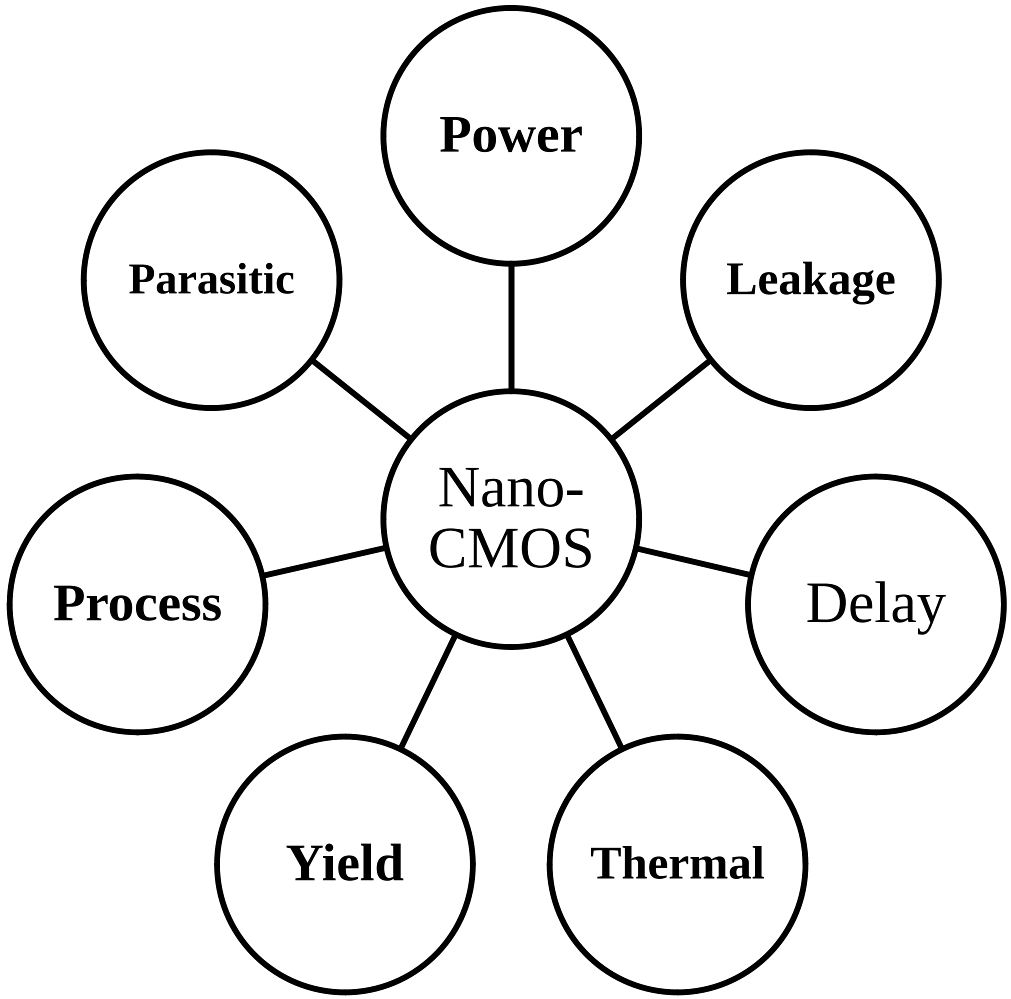
Core 2 Quad: (2006)

Different Attributes of an IC or chip

- Transistor count of a chip
- Operating frequency of a chip
- Power consumption of a chip
- Power density in a chip
- Size of a device used in chip

NOTE: Chip is informal name for IC.

Issues in Nano-CMOS

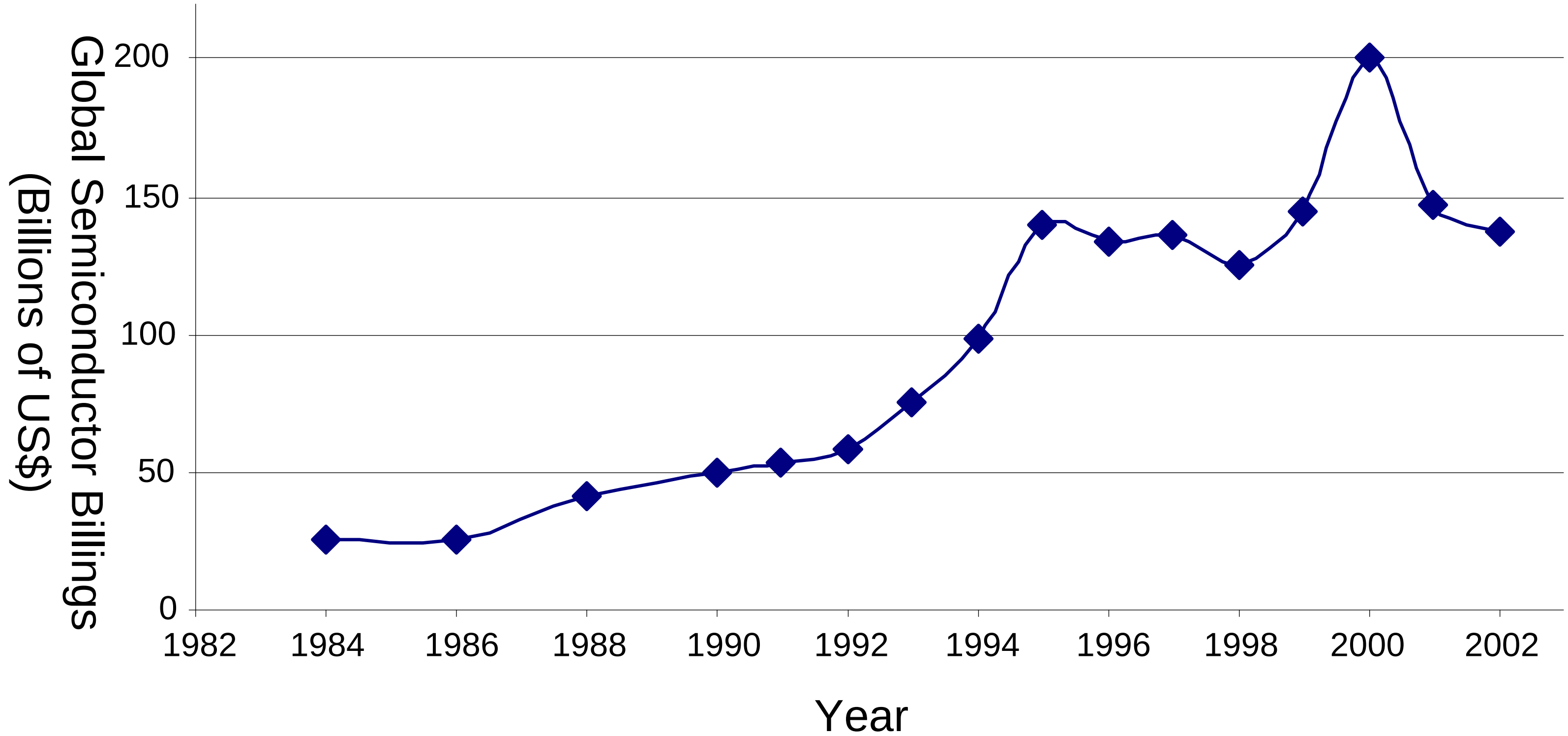


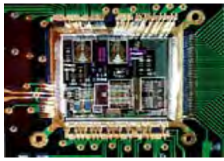
VLSI Technology: Highest Growth in History

- 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

VLSI Industry : Annual Sales

- 10^{18} transistors manufactured in 2003
  - 100 million for every human on the planet
- 340 Billion transistors manufactured in 2006. (World population 6.5 Billion!)





Invention of the Transistor

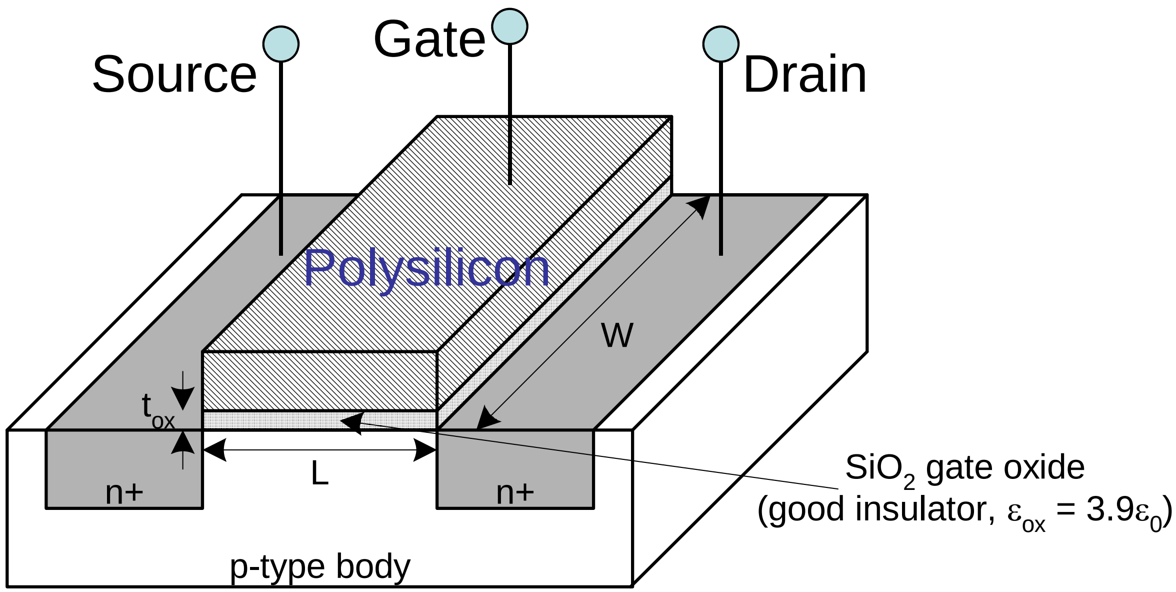
- Invention of transistor is the driving factor of growth of the VLSI technology
- Vacuum tubes ruled in first half of 20th century Large, expensive, power-hungry, unreliable
- 1947: first point contact transistor
  - John Bardeen and Walter Brattain at Bell Labs
  - Earned Nobel prize in 1956

Transistor Types

- Bipolar transistors
  - n-p-n or p-n-p 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 (MOSFET)
  - nMOS and pMOS MOSFETS
  - Voltage applied to insulated gate controls current between source and drain
  - Low power allows very high integration

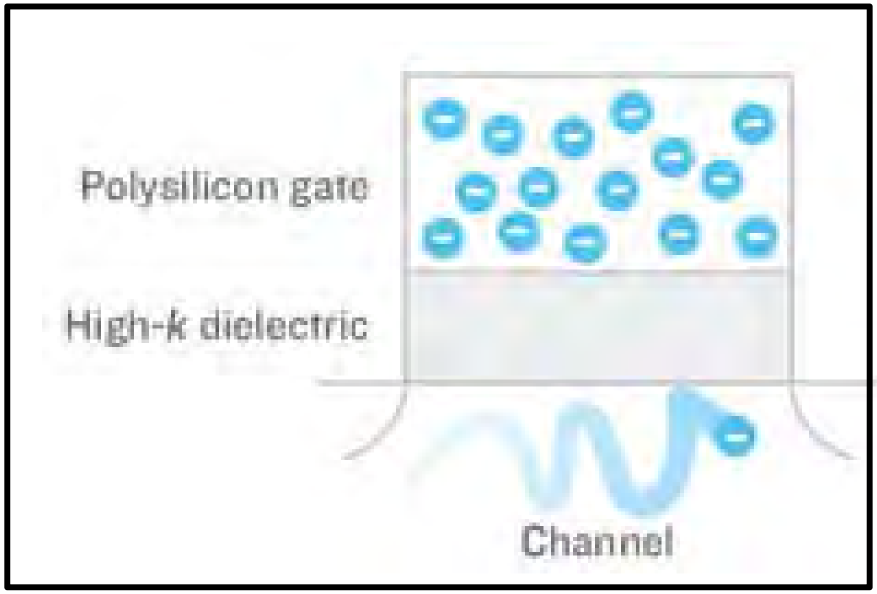
Conventional MOS Transistor: Poly Gate

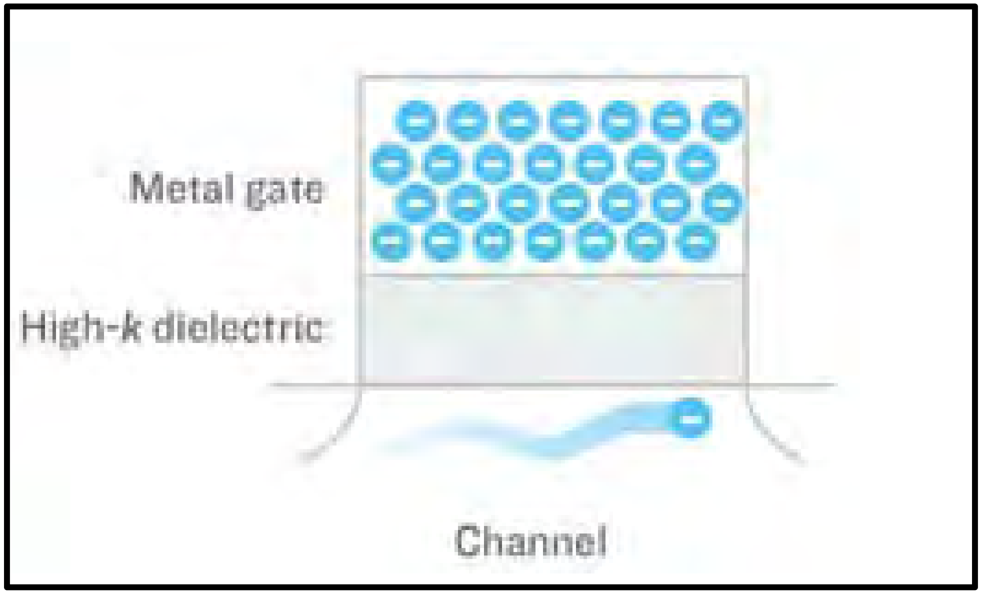
- Four terminals: gate, source, drain, body (bulk, or substrate)
- Gate – oxide – body stack looks like a capacitor
  - Gate and body are conductors
  - SiO_2 (oxide) is a very good insulator
  - Called metal – oxide – semiconductor (MOS) capacitor
  - Even though gate is no longer made of metal



Refer for use of poly: Vasdaz, L.L., Grove, A. S., Rowe, T. A., Moore, G. E. "Silicon Gate Technology," *IEEE Spectrum,* Vol. 6 No. 10 (October 1969) pp. 28-35.

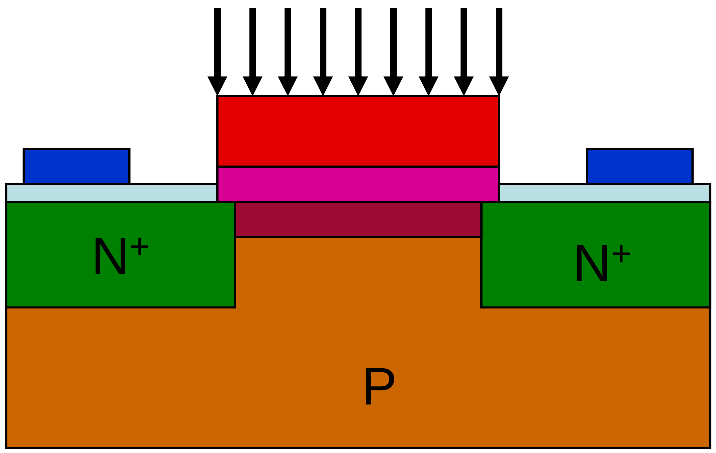
MOS Devices: High-κ



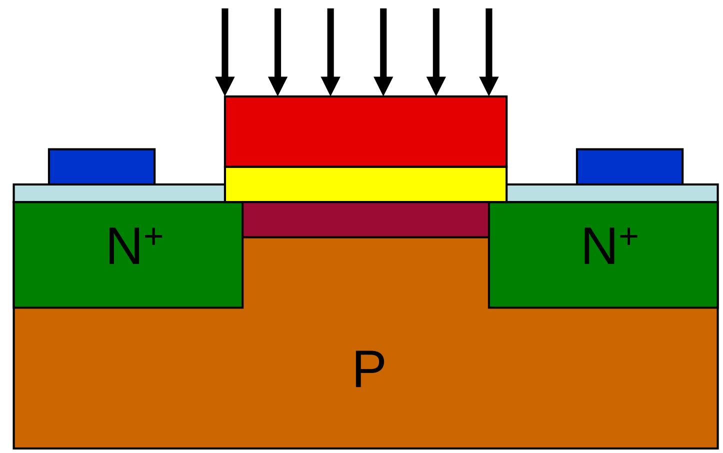


Source: IEEE Spectrum October 2007.

MOS Devices: Classical Vs Nonclassical

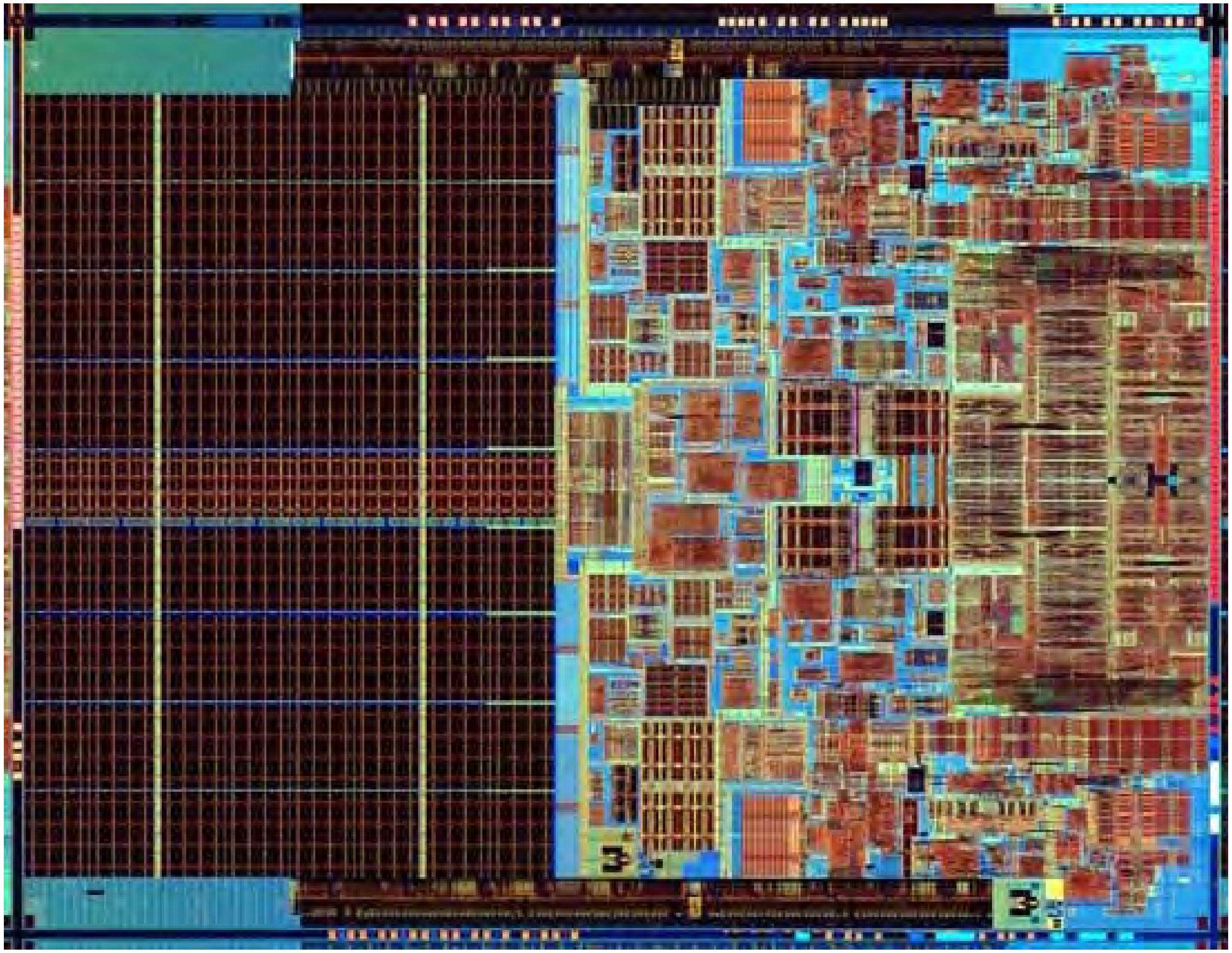


Low K_{gate} → Larger I_{gate} , Smaller delay



High K_{gate} → Smaller I_{gate} , Larger delay

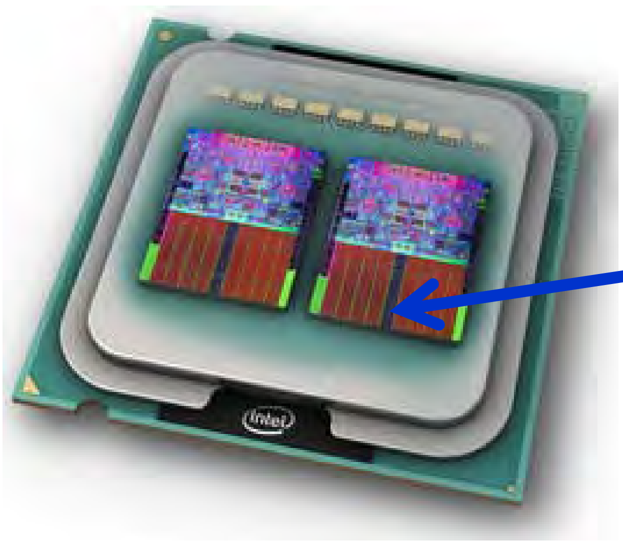
Core 2 Duo: 291M Transistors (2006)

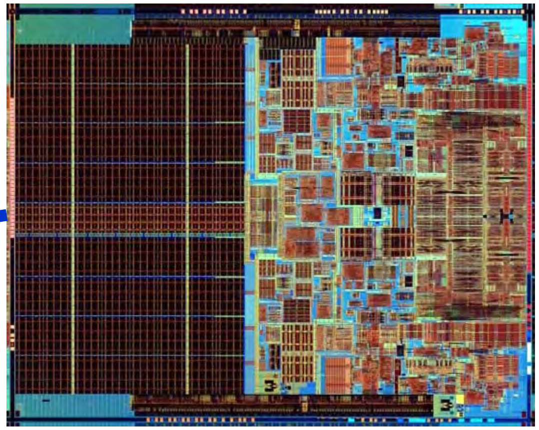


Core 2 Duo T5000/T7000 series mobile processors, called Penryn uses 800M of 45 nanometer devices (2007).

VLSI Trend : CPU

- Core 2 Duo has 291M transistors (2006).
- Core 2 Duo T5000/T7000 series mobile processors, called Penryn uses 800M of 45 nanometer devices (2007).





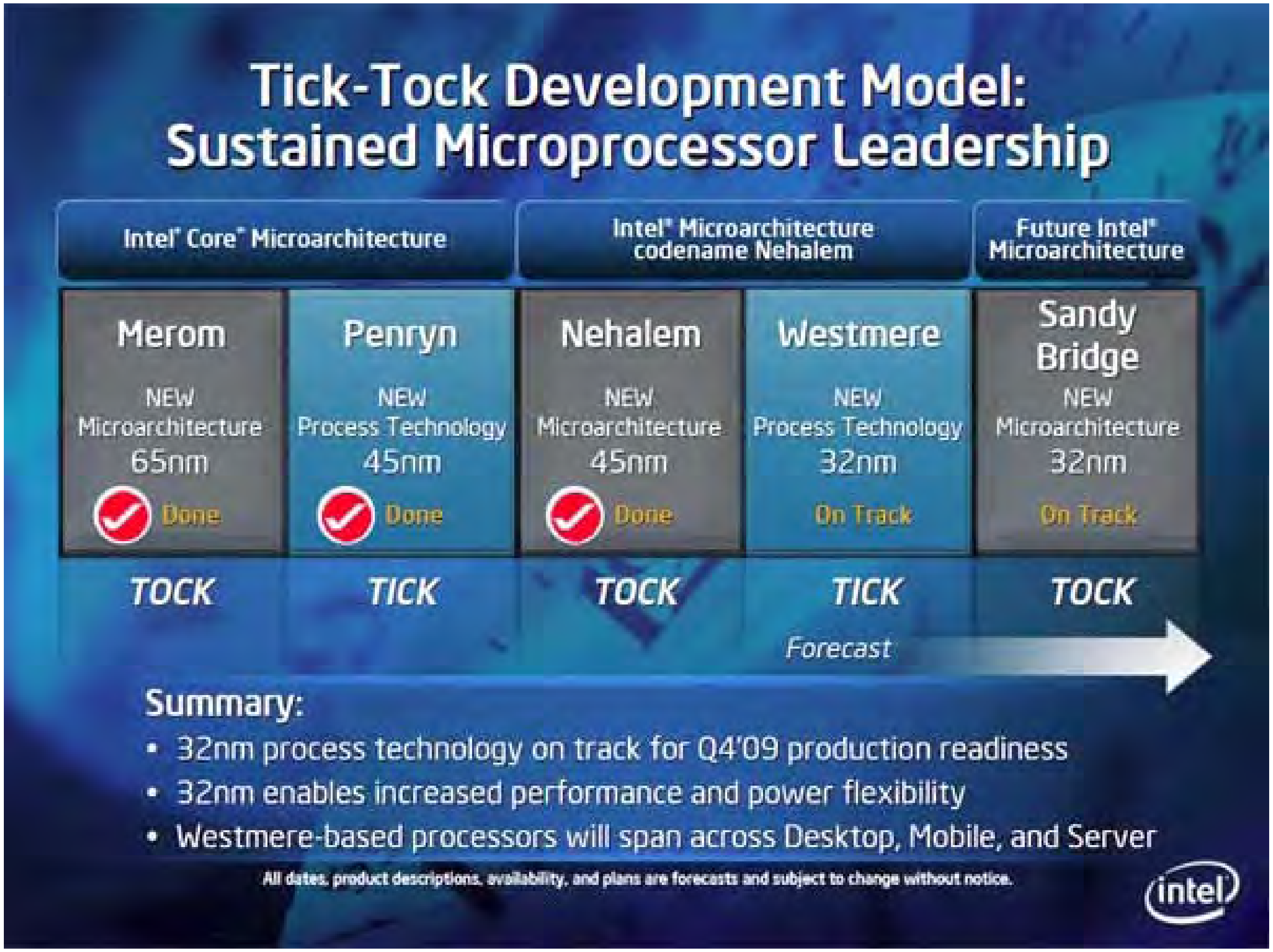
Core 2 Quad: (2006)

Source: http://www.gearfuse.com/

VLSI Trend: 32nm

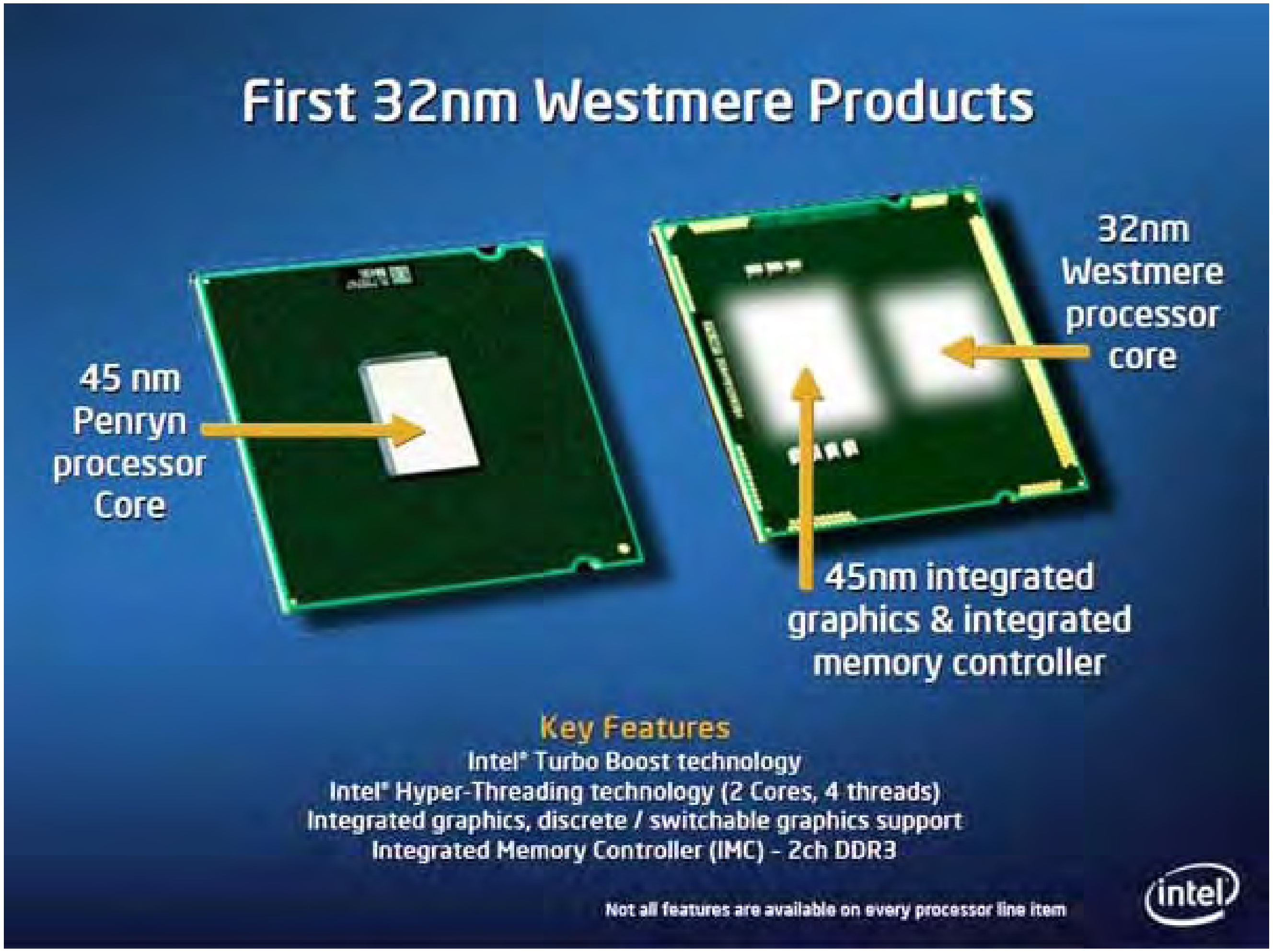
Source: Ryan Shrout, PC Perspective, http://www.pcper.com/

VLSI Trend: 32nm



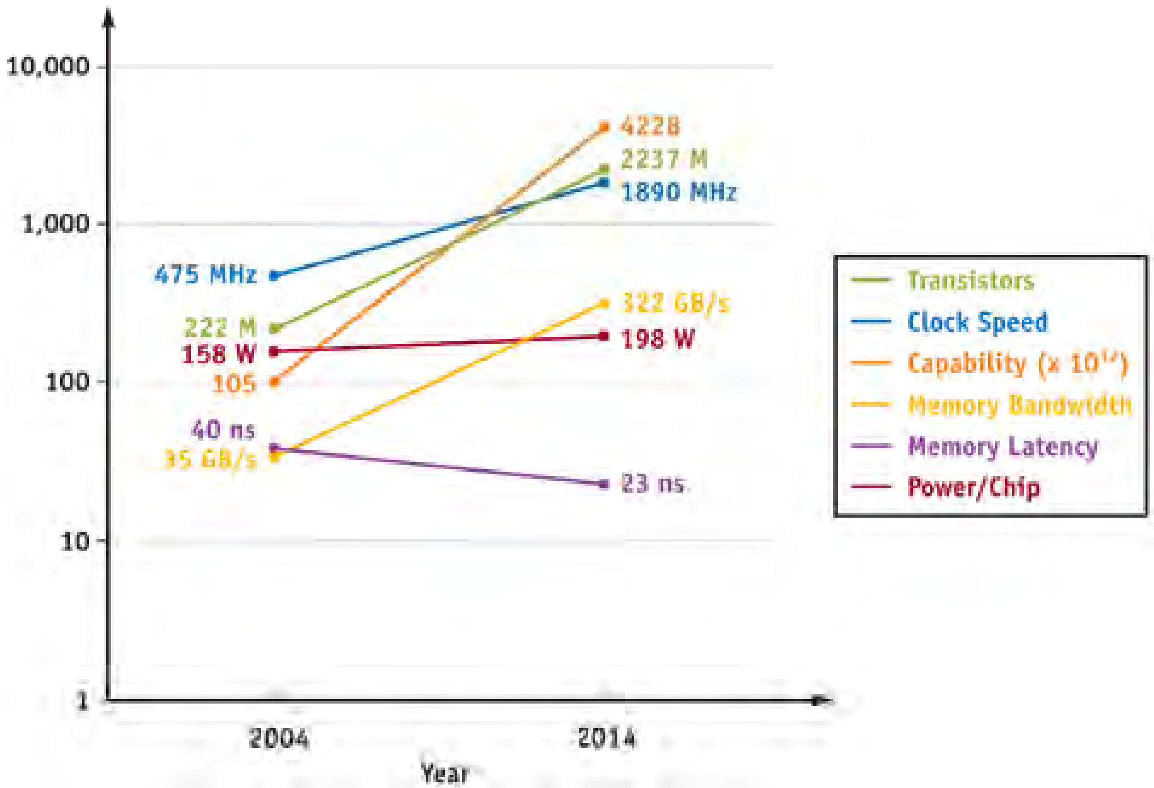
Source: Ryan Shrout, PC Perspective, http://www.pcper.com/

VLSI Trend: 32nm



Source: Ryan Shrout, PC Perspective, http://www.pcper.com/

VLSI Trend : GPU



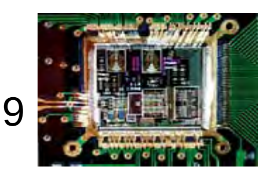
GeForce 6800

Source: GPU Gems 2

VLSI Trend : Salient Points

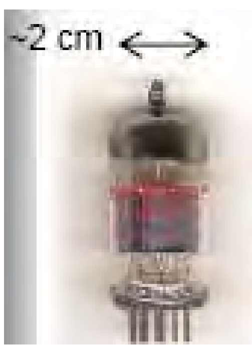
- **Increased Complexity**: 340 Billion transistors manufactured in 2006.

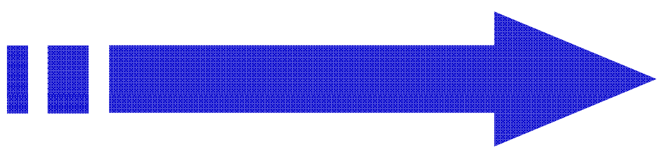
  (World population 6.5 Billion!)
- **High Power Dissipation**: Power dissipation per transistor has reduced, but power dissipation of overall chip increasing.
- **Increased Parallelism with Multicore Architecture**: To archive highest performance multiples have been put together in the same die.
- **Smaller Process Technology**: Use of smaller nanoscale CMOS technology, 32*nm* node and high-κ CMOS.
- **Reduced Time-to-market**: For competitiveness and profit.



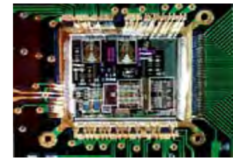
Why Technology Scaling?

- Technology shrinks by 0.7/generation
- With every generation can integrate 2x more functions per chip; chip cost does not increase significantly
- Cost of a function decreases by 2x
- However …
  - 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





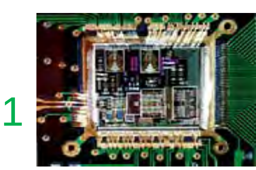
VLSI technology is the fastest growing technology in human history.



Integrated Circuits Categories

There are many different types of ICs as listed below.

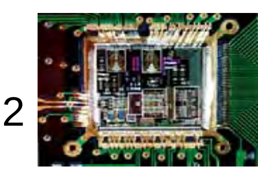
IC Categories	Functions
Analog ICs	Amplifiers
	Filters
Digital ICs	Boolean Gates
	Encoders/Decoders
	Multiplexers / Demultiplexers
	Flip-flops
	Counters
	Shift Registers
Hybrid ICs	Mixed Signal Processors
Interface ICs	Analog-Digital Converters
	Digital-Analog Converters



Levels of Integration (Chip Complexity)

Categorized by the number of gates contained in the chip.

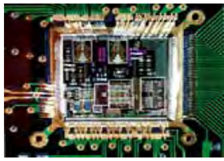
IC Complexity	Number of Gates	Functional Complexity	Examples
SSI	<10	Basic gates	Inverters, AND gates, OR gates, NAND gates, NOR gates
MSI	10-100	Basic gates	Exclusive OR/NOR
		Sub-modules	Adders, subtractors, encoders, decoders, multiplexers, demultiplexers, counters, flip-flops
LSI	100-1000s	Functional modules	Shift registers, stacks
VLSI	1000s-100,000	Major building blocks	Microprocessors, memories
ULSI	>100,000	Complete systems	Single chip computers, digital signal processors
WSI	>10,000,000	Distributed systems	Microprocessor systems



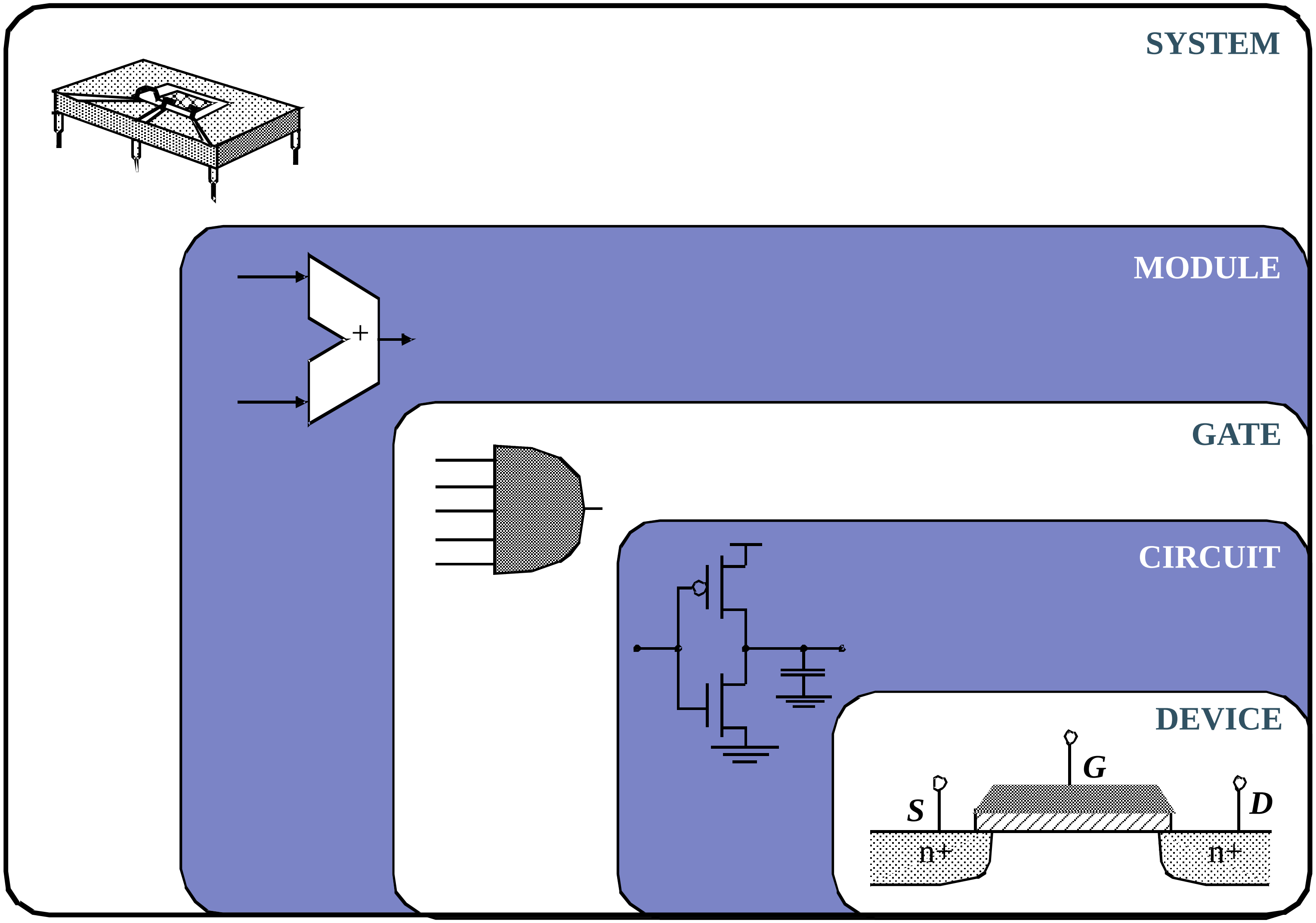
Digital Logic Families

- Various circuit technology used to implement an IC at lower level of abstraction.
- The circuit technology is referred to as a digital logic family.

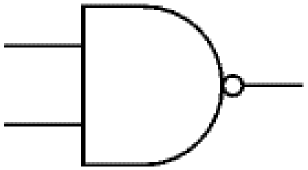
RTL - Resistor-transistor Logic	obsolete
DTL - Diode-transistor logic	obsolete
TTL - Transistor-transistor logic	not much used
ECL - Emitter-coupled logic	high-speed ICs
MOS - Metal-oxide semiconductor	high-component density
CMOS - Complementary Metal-oxide semiconductor	widely used, low-power high-performance and high-packing density IC
BiCMOS - Bipolar Complementary Metal-oxide semiconductor	high current and high-speed
GaAs - Gallium-Arsenide	very high speed circuits



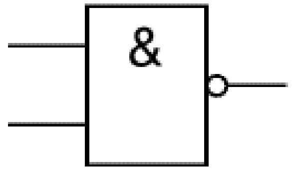
Design Abstraction Levels



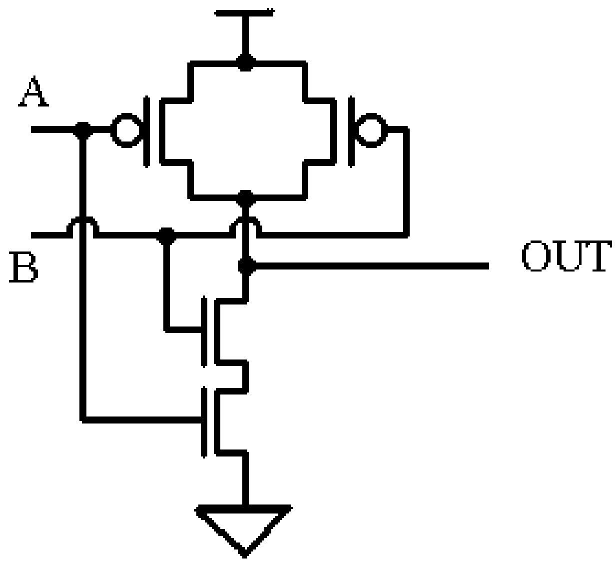
Digital Circuits : Logic to Device



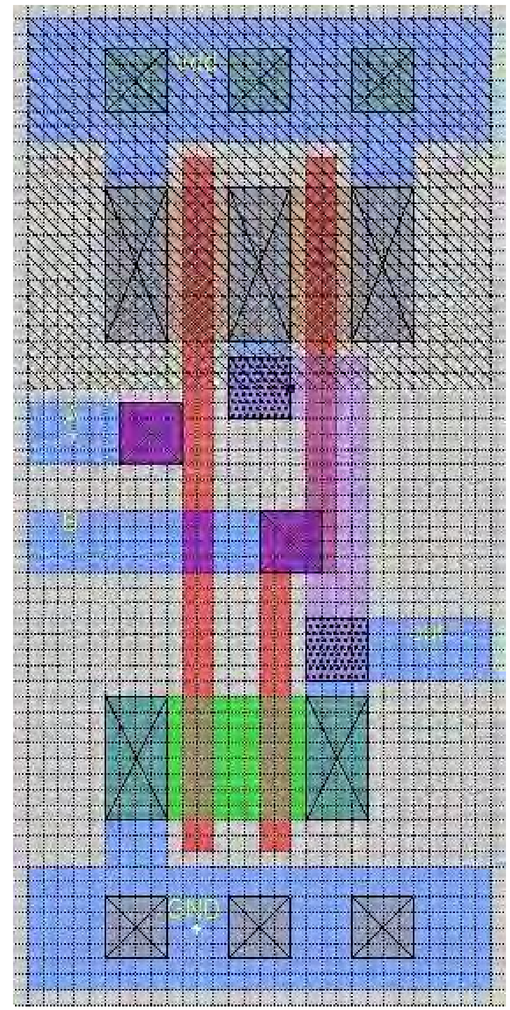
(NAND Gate)



(IEC Symbol)

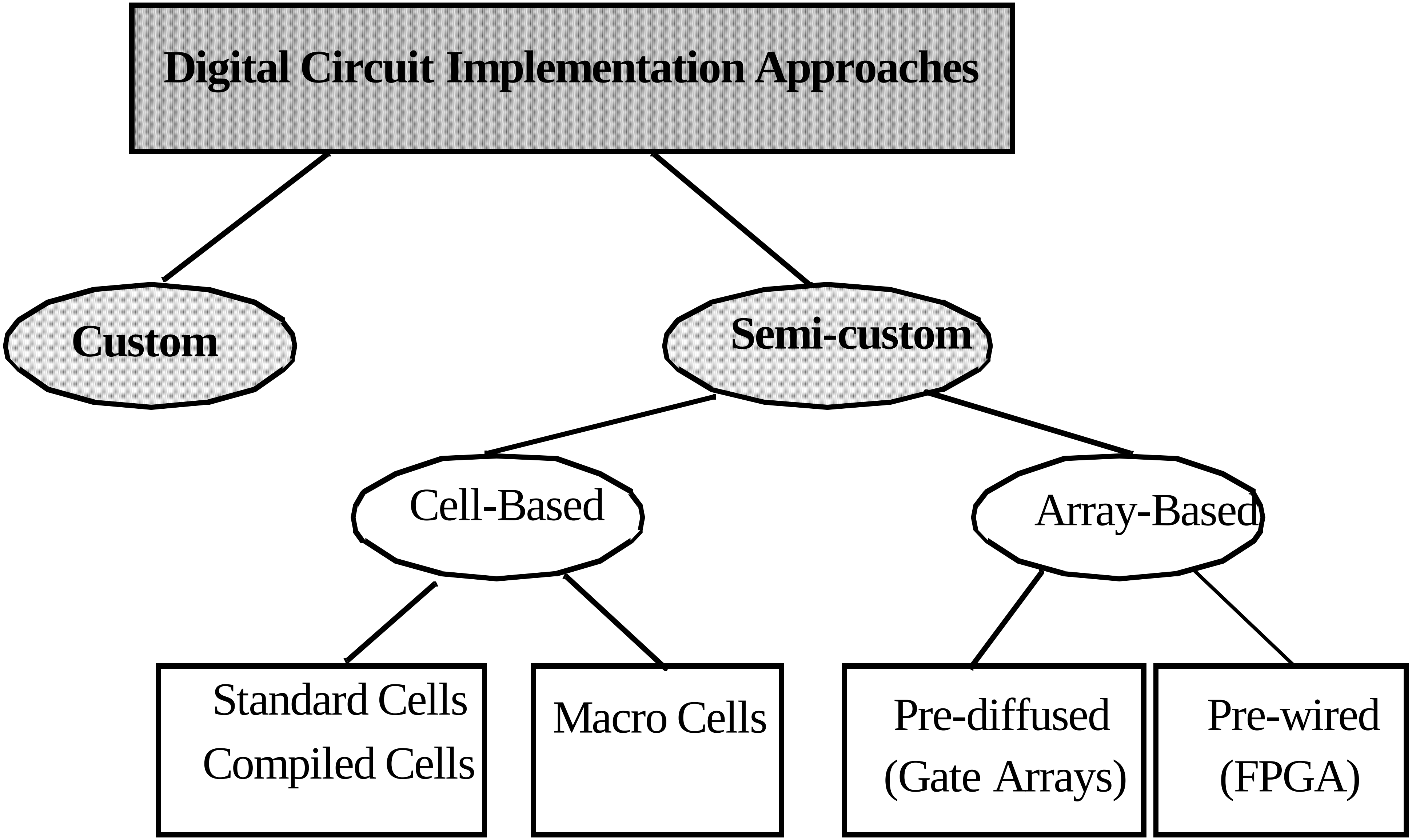


(Transistor Diagram)

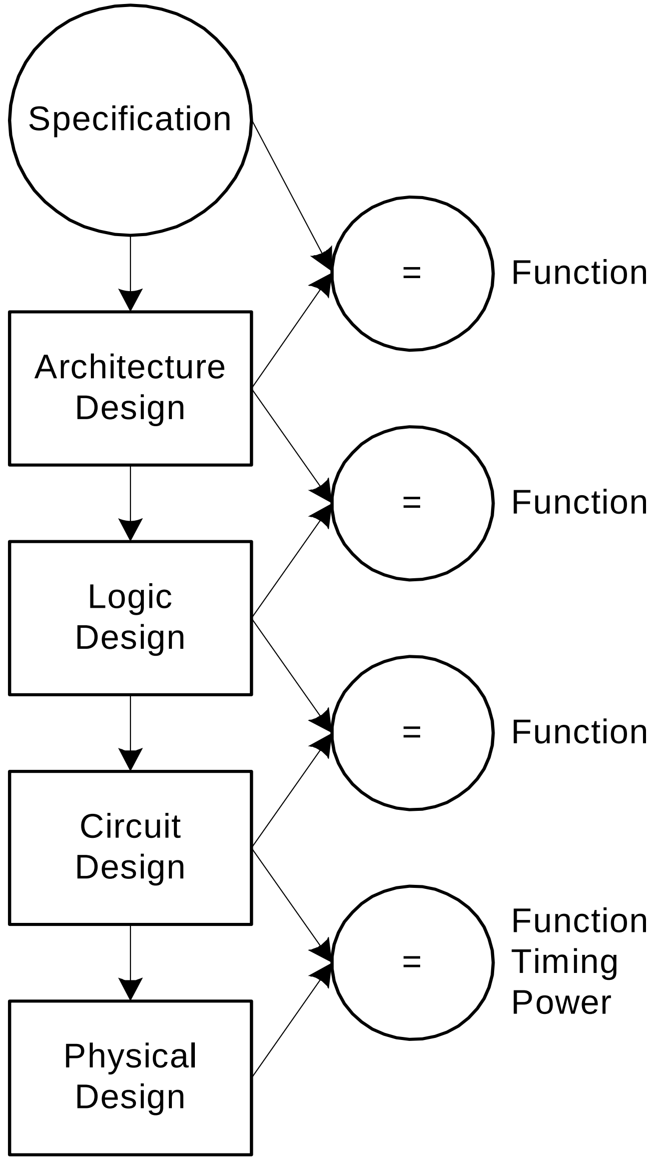


(Layout Diagram)

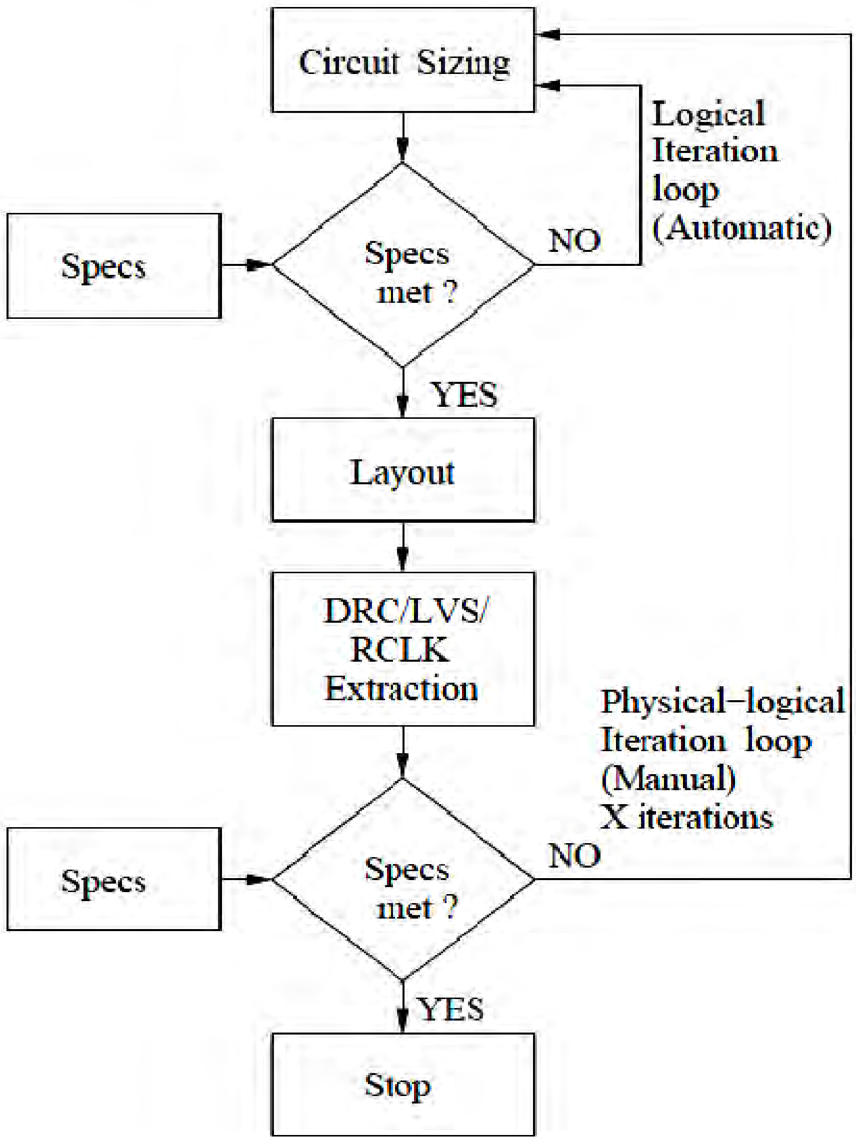
Implementation Approaches for Digital ICs



Digital Design Abstractions

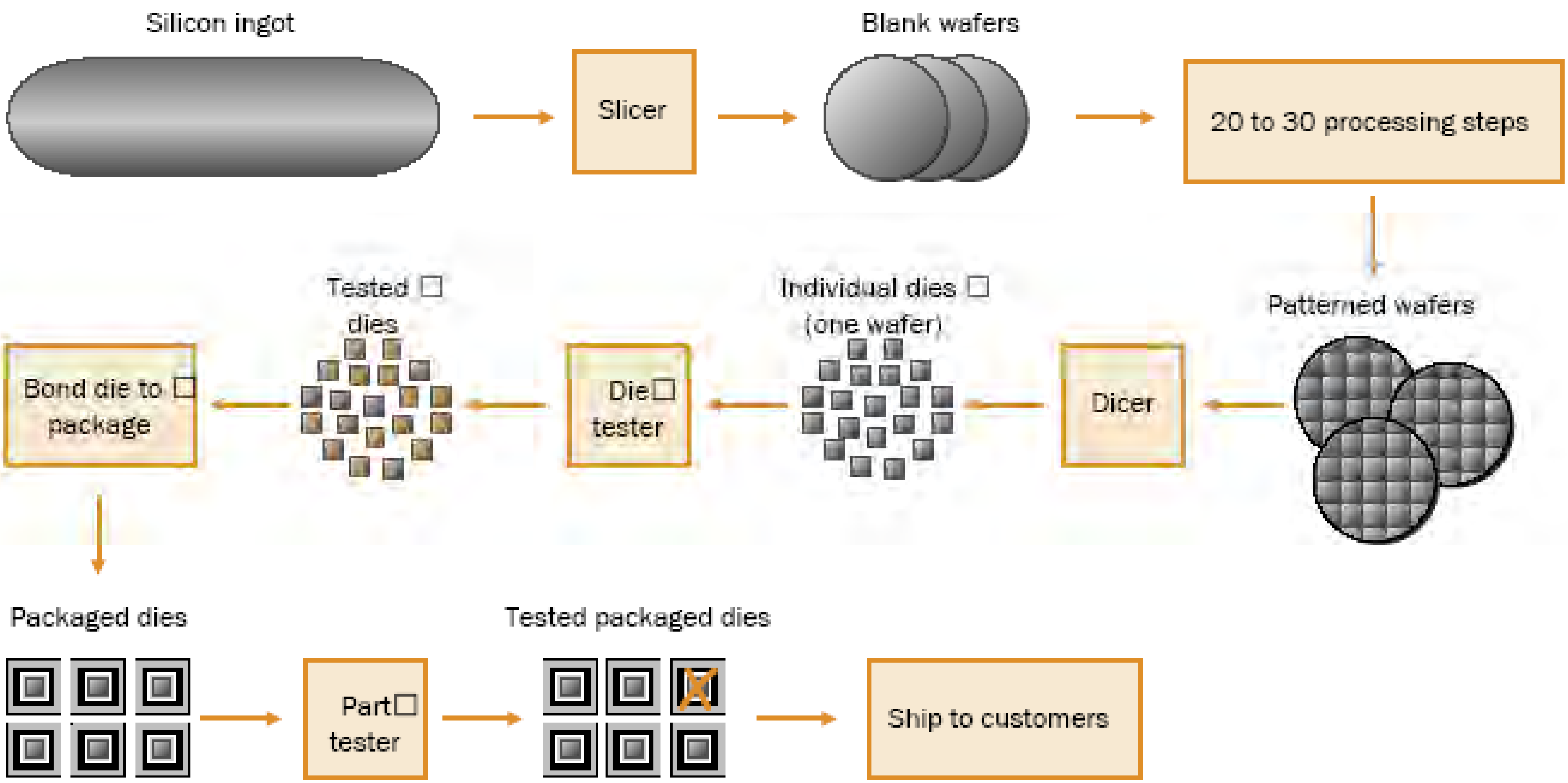


Standard Custom IC Design Flow



- Standard RFIC design flow requires multiple (X) manual iterations on the back-end layout to achieve parasitic closure between front-end circuit and back-end layout.

Digital IC Fabrication Flow



25 Historic Chips …

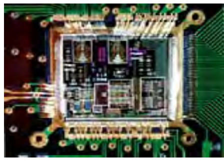
1. Signetics NE555 Timer (1971) : IC that functions as a timer or an oscillator which is used in everywhere from kitchen appliances, to toys, to spacecraft.
2. Texas Instruments TMC0281 Speech Synthesizer (1978) : The first single-chip speech synthesizer.
3. MOS Technology 6502 Microprocessor (1975) : An 8-bit microprocessor developed by MOS Technology for Apple I.
4. Texas Instruments TMS32010 Digital Signal Processor (1983) : Fastest DSP.
5. Microchip Technology PIC 16C84 Microcontroller (1993) : Used EEPROM (electrically erasable programmable read-only memory) for easy changing of code, which is used in everywhere as an industrial controllers.
6. Fairchild Semiconductor µA741 Op-Amp (1968) : Used in audio and video preamplifiers, voltage comparators, precision rectifiers, etc.
7. Intersil ICL8038 Waveform Generator (circa 1983) : Generates sine, square etc.
8. Western Digital WD1402A UART (1971) : Parallel from/to serial conversion.
9. Acorn Computers ARM1 Processor (1985) : 32-bit RISC processor.
10. Kodak KAF-1300 Image Sensor (1986) : 1.3 megapixels CCD sensor (Kodak camera was $13,000).

Source: IEEE Spectrum May 2009.

25 Historic Chips …

11. IBM Deep Blue 2 Chess Chip (1997) : 480 chess-chips each containing 1.5M transistors, won the chess match.
12. Transmeta Corp. Crusoe Processor (2000) : Software translated x86 instructions on the fly into Crusoe's machine code to save time and power.
13. Texas Instruments Digital Micromirror Device (1987) : Digital light-processing (DLP) used in theaters, rear-projection TVs, and projectors.
14. Intel 8088 Microprocessor (1979) : The 16-bit CPU used in IBM PCs.
15. Micronas Semiconductor MAS3507 MP3 Decoder (1997) : A RISC-based DSP with an instruction set optimized for audio compression and decompression.
16. Mostek MK4096 4-Kilobit DRAM (1973) : Used address multiplexing so that DRAM wouldn't require more pins as memory density increased.
17. Xilinx XC2064 FPGA (1985) : Field-programmable chip.
18. Zilog Z80 Microprocessor (1976) : A simple single-chip cheap microcontroller.
19. Sun Microsystems SPARC Processor (1987) : A 32-bit RISC processor called SPARC (for Scalable Processor Architecture).
20. Tripath Technology TA2020 AudioAmplifier (1998) : A solid-state amplifier produced high-quality sound.

Source: IEEE Spectrum May 2009.



25 Historic Chips

21. Amati Communications Overture ADSL Chip Set (1994) : DSL chip set.
22. Motorola MC68000 Microprocessor (1979) : Hybrid 16-bit/32-bit microprocessor.
23. Chips & Technologies AT Chip Set (1985) : C&T developed 5 chips that performed the functionality of the AT motherboard that used ~100 chips.
24. Computer Cowboys Sh-Boom Processor (1988) : Sh-Boom was operated faster than the clock on the circuit board that drove the rest of the computer while still staying synchronized with the rest of the computer. This is of course the typical scenario!
25. Toshiba NAND Flash Memory (1989) : The flash chip based on NAND technology is present in every gadget, such as cell phones, digital cameras, music players, and USB drives.

Source: IEEE Spectrum May 2009.