

L1: 6.111 Course Overview



Courtesy of Rex Min. Used with permission.

- **Logic Design:**
 - Randy Katz, Gaetano Borriello, Contemporary Logic Design, Pearson Education, 2005

- **Verilog: there are plenty of good Verilog books and on-line resources. We recommend the book below for a basic introduction to Verilog:**
 - Samir Palnitkar, Verilog HDL, Pearson Education (2nd edition)

- **Design and Implement Complex Digital Systems**
 - Fundamentals of logic design : combinational and sequential blocks
 - System integration with multiple components (memories, discrete components, FPGAs, etc.)
 - Use a Hardware Design Language (Verilog) for digital design
 - Interfacing issues with analog components (ADC, DAC, sensors, etc.)
 - Understand different design metrics: component/gate count and implementation area, switching speed, energy dissipation and power
 - Understand different design methodologies and mapping strategies (discrete logic, FPGAs vs. custom integrated circuits)
 - Design for test
 - **Demonstrate a large scale digital or mixed-signal system**
- **Prerequisite**
 - Prior digital design experience is NOT Required
 - 6.004 is not a prerequisite!
 - Take 6.004 before 6.111 or
 - Take 6.004 after 6.111 or
 - Take both in the same term
 - Must have basic background in circuit theory
 - Some basic material might be a review for those who have taken 6.004

- **Lab 1: Basics of Digital Logic (Discrete Devices)**
 - Learn about lab equipment in the Digital Lab (38-600): oscilloscopes and logic analyzers
 - Experiment with logic gates, flip-flops, device characterization
 - Introduction to Verilog
- **Lab 2: Simple FSM (Traffic Light Controller)**
 - Design and implement simple Finite State Machines (FSM)
 - Use Verilog to program an FPGA
 - Report and its revision will be evaluated for CI-M
- **Lab 3: Simple FSM (Memory Tester)**
 - Learn how to use an SRAM and testing techniques
- **Lab 4: Complex FSM (Pong Game)**
 - Design a system with multiple FSMs (Major/Minor FSM)
 - Video interface

- **Done in groups of two or three**
- **Open ended**
- **You and the staff negotiate a project proposal**
 - **Must emphasize digital concepts, but inclusion of analog interfaces (e.g., data converters, sensors or motors) common and often desirable**
 - **Proposal Conference**
 - **Design Review(s)**
- **Design presentation in class (% of the final grade for the in-class presentation)**
- **Top projects will be considered for design awards**
- **Staff will provide help with project definition and scope, design, debugging, and testing**
- **It is extremely difficult for a student to receive an A without completing the final project.**

■ Grading Policy

□ Approximate breakdown:

- Quiz 10%
- 3 Problem Sets 3%
- 4 Lab exercises
 - Lab 1 9%
 - Lab 2 10%
 - Lab 3 7%
 - Lab 4 11%
- Writing (Lab 2 revision- part of CIM requirement) 10%
- Participation (lecture, recitation, project presentations) 3%
- Final Project 37%

■ We impose late penalties

- Labs are penalized 20% per day
- Final Project **MUST** be done on time

■ Collaboration

- Discuss labs with anyone (staff, former students, other students, etc.)
 - Then do them individually
 - Do not copy anything, including computer files, from anyone else
- Collaboration (with your partners) on the project is desirable
 - Project reports should be joint with individual authors specified for each section
 - Copy anything you want (with attribution) for your project report

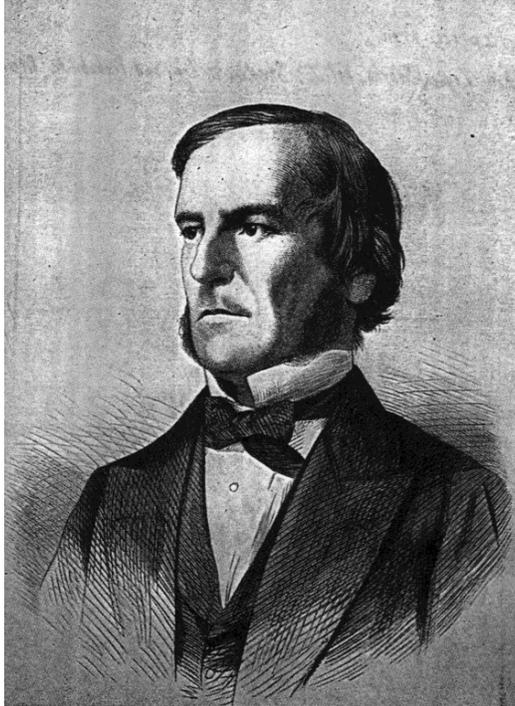
Photograph of the Babbage Difference Engine.
Image removed due to copyright restrictions

The Babbage Difference Engine (1834)

25,000 parts

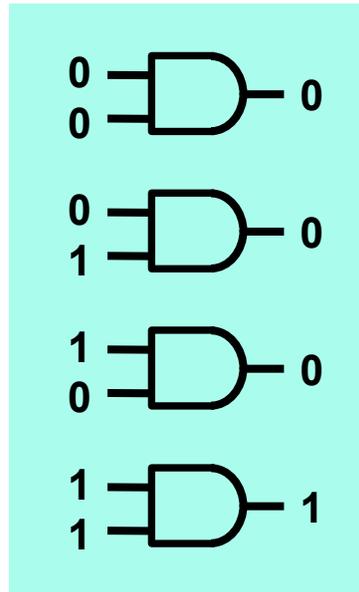
cost: £17,470

- The first digital systems were **mechanical** and used **base-10** representation.
- Most popular applications: arithmetic and scientific computation

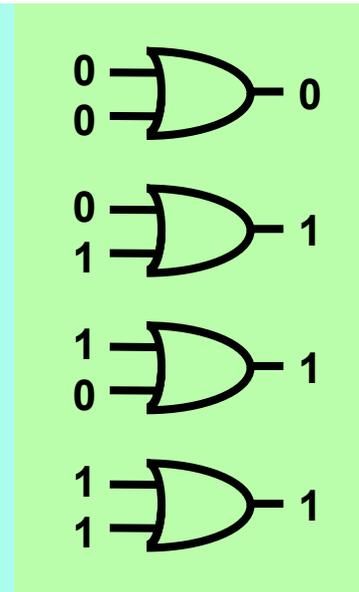


GEORGE BOOLE

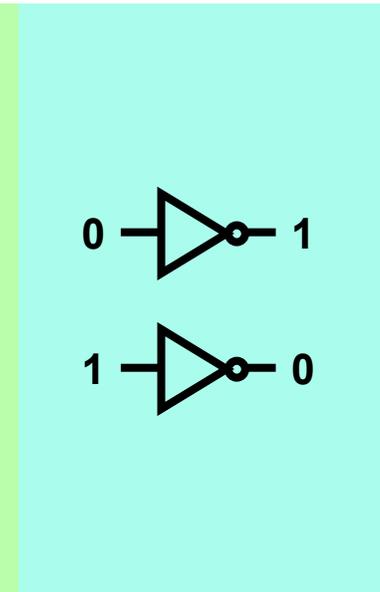
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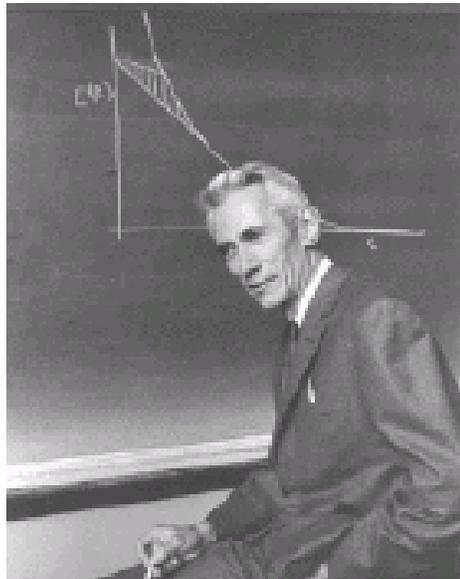
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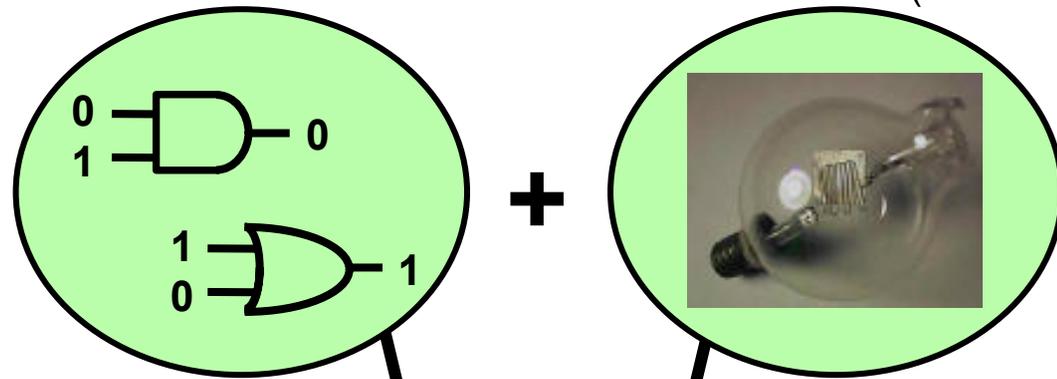
NOT



- 1854: George Boole shows that **logic** is math, not just philosophy!
- Boolean algebra: the mathematics of **binary** values



Courtesy of Jonah Sacks. Used with permission



Lee de Forest, 1906



- Despite existence of **relays** and introduction of **vacuum tube** in 1906, digital electronics did not emerge for thirty years!
- Claude Shannon notices similarities between Boolean algebra and electronic telephone switches
- Shannon's 1937 MIT Master's Thesis introduces the world to **binary digital electronics**

Vacuum Tubes

UNIVAC, 1951

1900 adds/sec

Transistors

IBM System/360, 1964

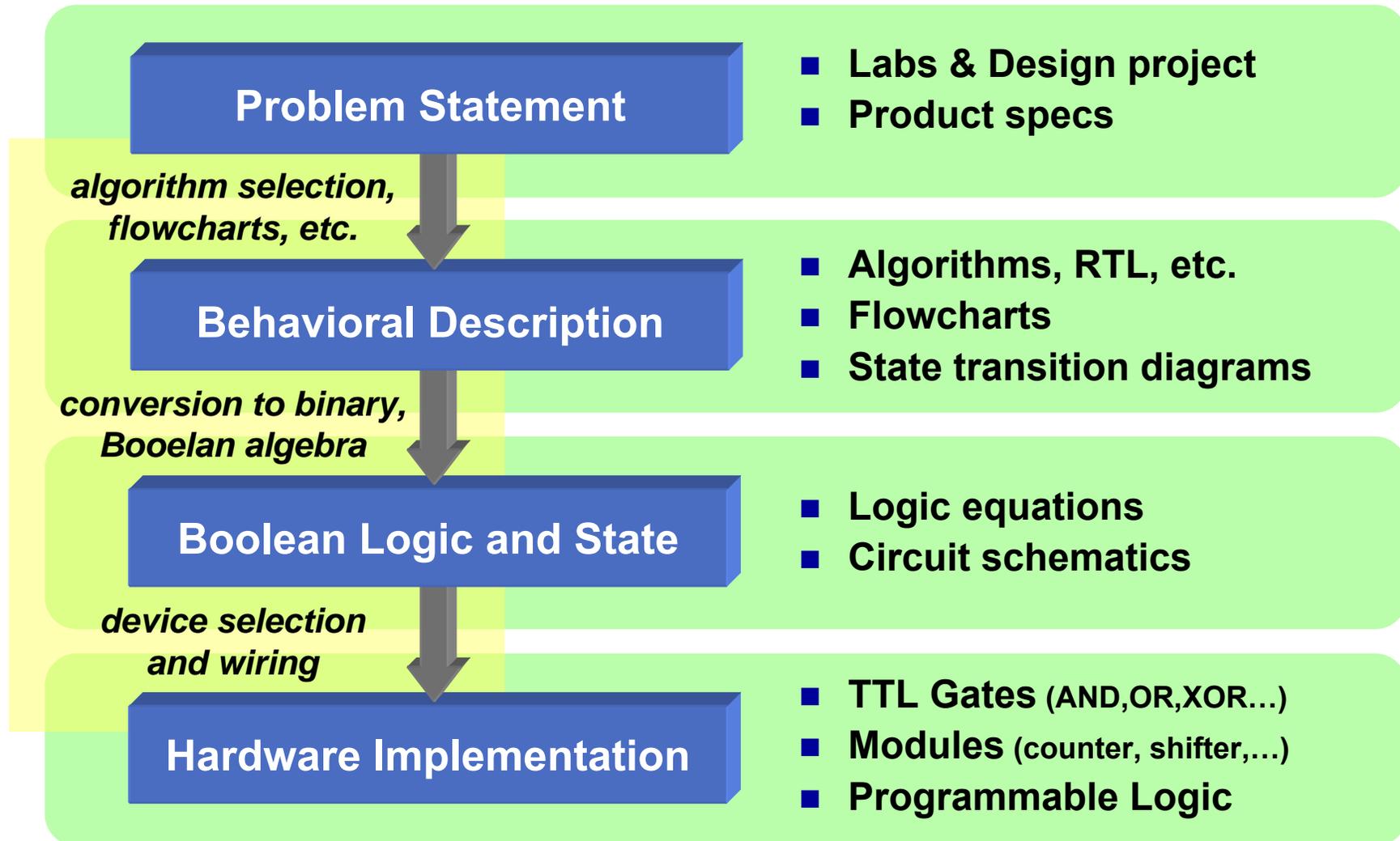
500,000 adds/sec

VLSI Circuits

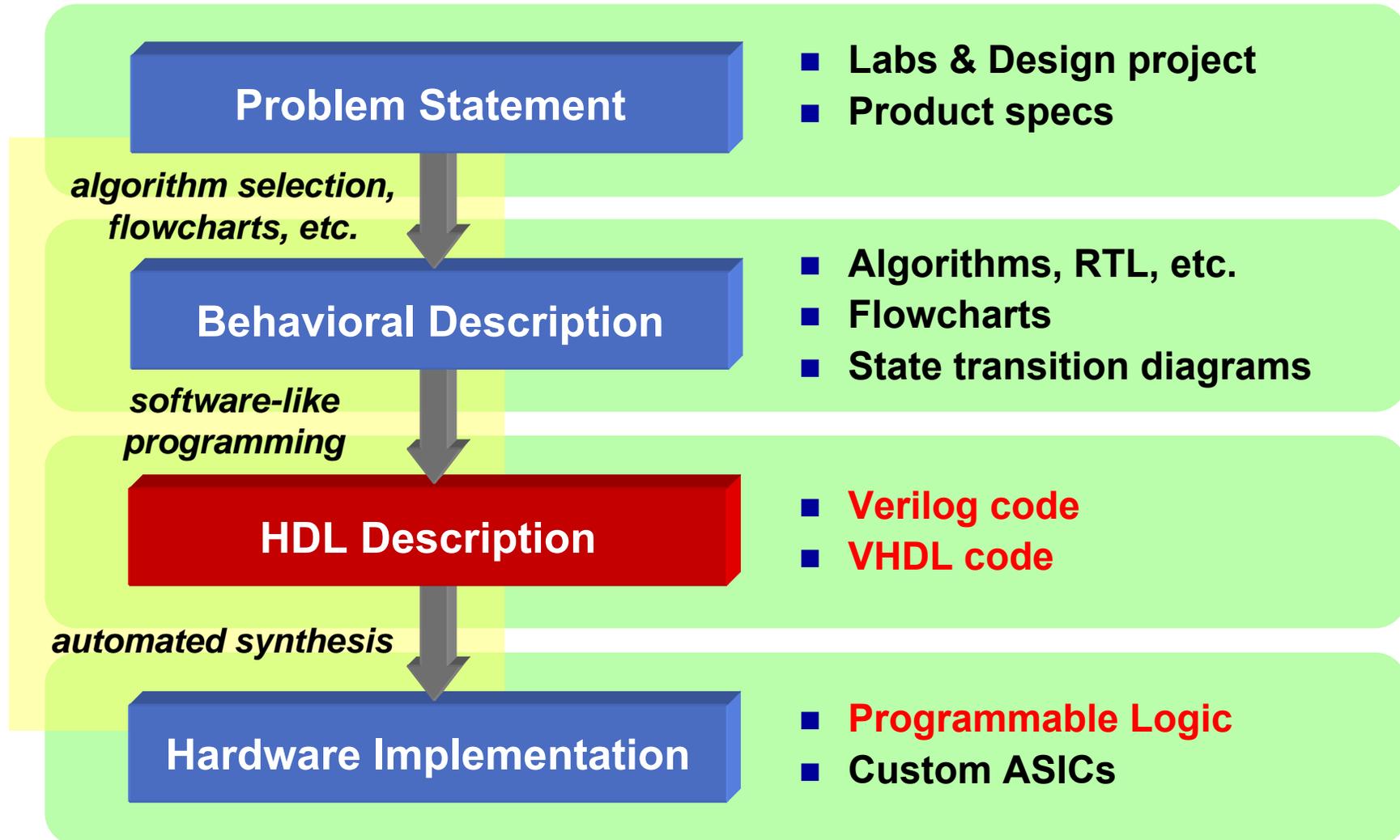
Intel Itanium, 2003

2,000,000,000
adds/sec

- **Goal of 6.111: Building binary digital solutions to computational problems**



- Logic synthesis using a Hardware Description Language (HDL) automates the most tedious and error-prone aspects of design



VHDL

- Commissioned in 1981 by Department of Defense; now an IEEE standard
- Initially created for ASIC synthesis
- Strongly typed; potential for verbose code
- Strong support for package management and large designs

Verilog

- Created by Gateway Design Automation in 1985; now an IEEE standard
- Initially an interpreted language for gate-level simulation
- Less explicit typing (e.g., compiler will pad arguments of different widths)
- No special extensions for large designs

Hardware structures can be modeled effectively in either VHDL and Verilog. Verilog is similar to c and a bit easier to learn.

- **Behavioral or Algorithmic Level**
 - Highest level in the Verilog HDL
 - Design specified in terms of algorithm (functionality) without hardware details. Similar to “c” type specification
 - Most common level of description
- **Dataflow Level**
 - The flow of data through components is specified based on the idea of how data is processed
- **Gate Level**
 - Specified as wiring between logic gates
 - Not practical for large examples
- **Switch Level**
 - Description in terms of switching (modeling a transistor)
 - No useful in general logic design – we won't use it

**A design mix and match all levels in one design is possible.
In general Register Transfer Level (RTL) is used for a
combination of Behavioral and Dataflow descriptions**

■ Misconceptions

- The coding style or clarity does not matter as long as it works
- Two different Verilog encodings that simulate the same way will synthesize to the same set of gates
- Synthesis just can't be as good as a design done by humans
 - Shades of assembly language versus a higher level language

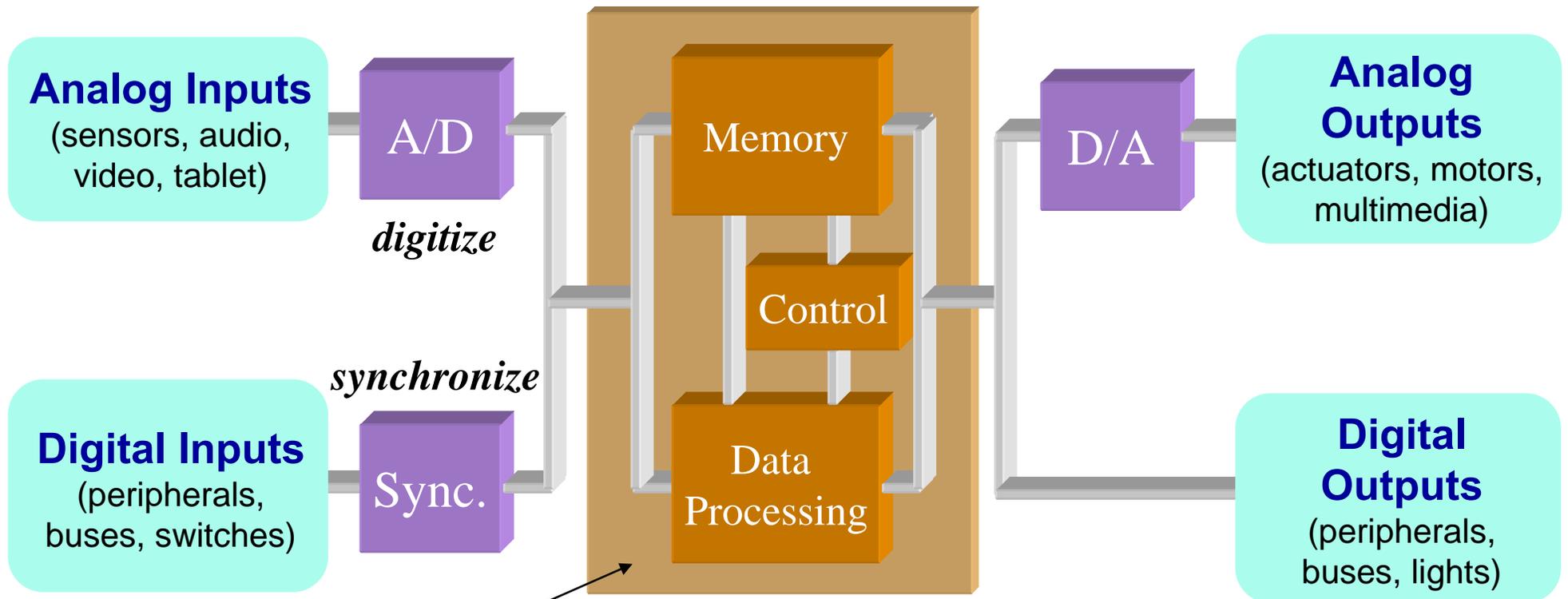
■ What can be Synthesized

- Combinational Functions
 - Multiplexors, Encoders, Decoders, Comparators, Parity Generators, Adders, Subtractors, ALUs, Multipliers
 - Random logic
- Control Logic
 - FSMs

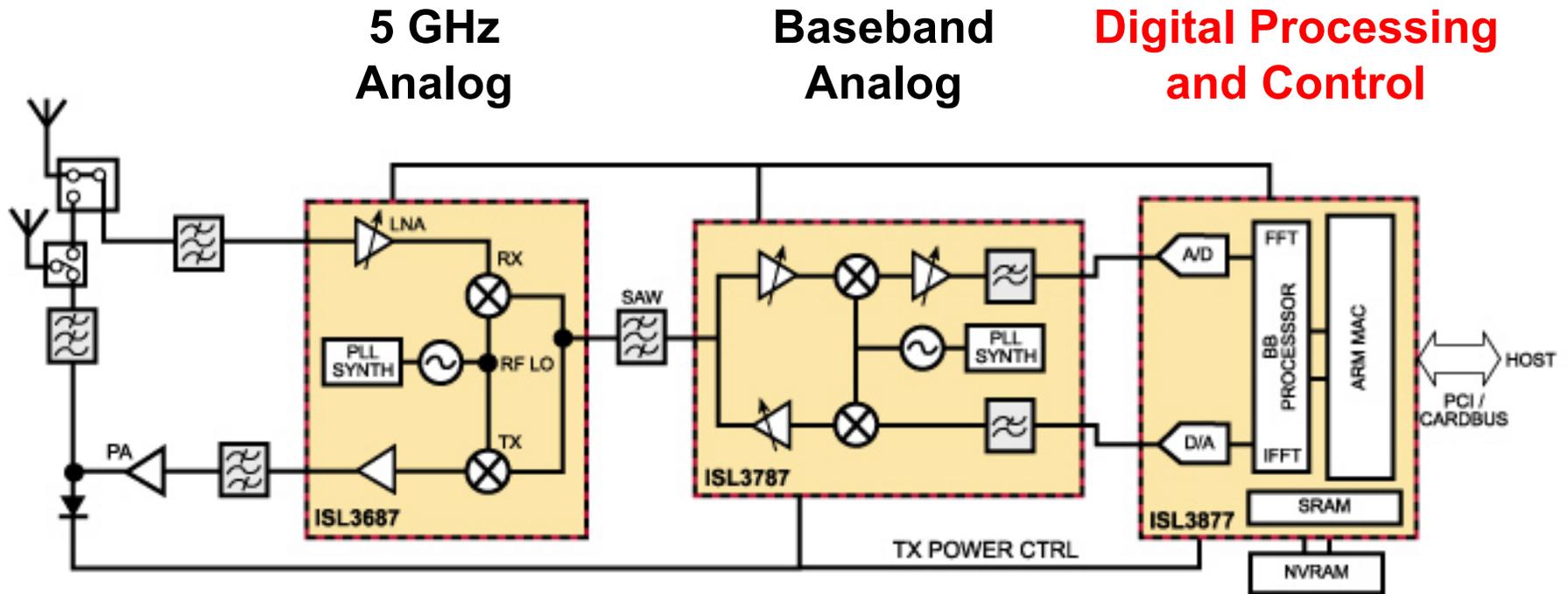
■ What can't be Synthesized

- Precise timing blocks (e.g., delay a signal by 2ns)
- Large memory blocks (can be done, but very inefficient)

**Understand what constructs are used in
simulation vs. hardware mapping**

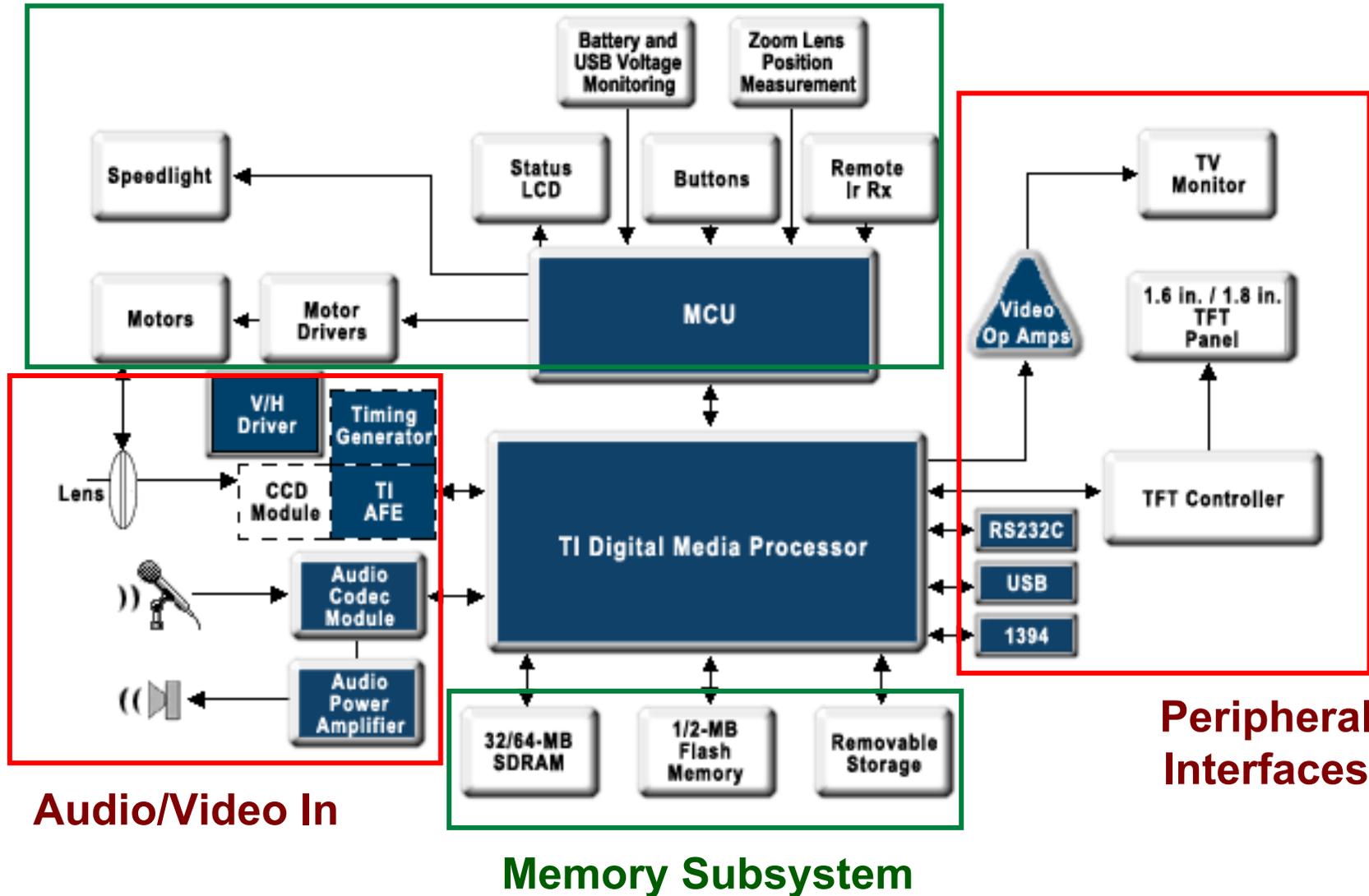


- **Digital processing systems** consist of a datapath, memory, and control. Early machines for arithmetic had insufficient memory, and often depended on users for control
- Today's digital systems are increasingly embedded into everyday places and things
- Richer interaction with the user and environment



Photograph of an Intersil 54Mbps 802.11a card. Photograph removed due to copyright restrictions

Motors and Mechanical Sensors



Cost

Speed

Energy

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commodity products

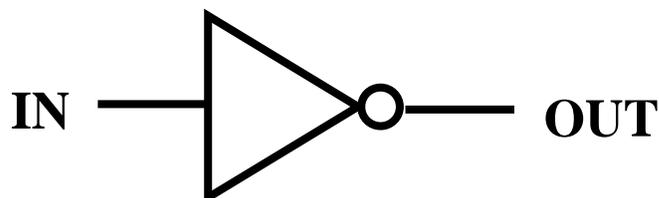
scientific computing,
simulation

portable applications

- **Commercial digital designs seek the most appropriate trade-offs for the target application...**
- **...keeping time-to-market in mind**

- Design can be fun. Verification/testing is hard work.
- Verification by simulation (and formally through test benches) is a critical part of the design process.
- The physical hardware must be tested to debug the mapping process and manufacturing defects.
- Physical realizations often do not allow access to internal signals. We will introduce formal methods to observe and control internal state.

Verification and Design for Test (DFT) are important components of digital design

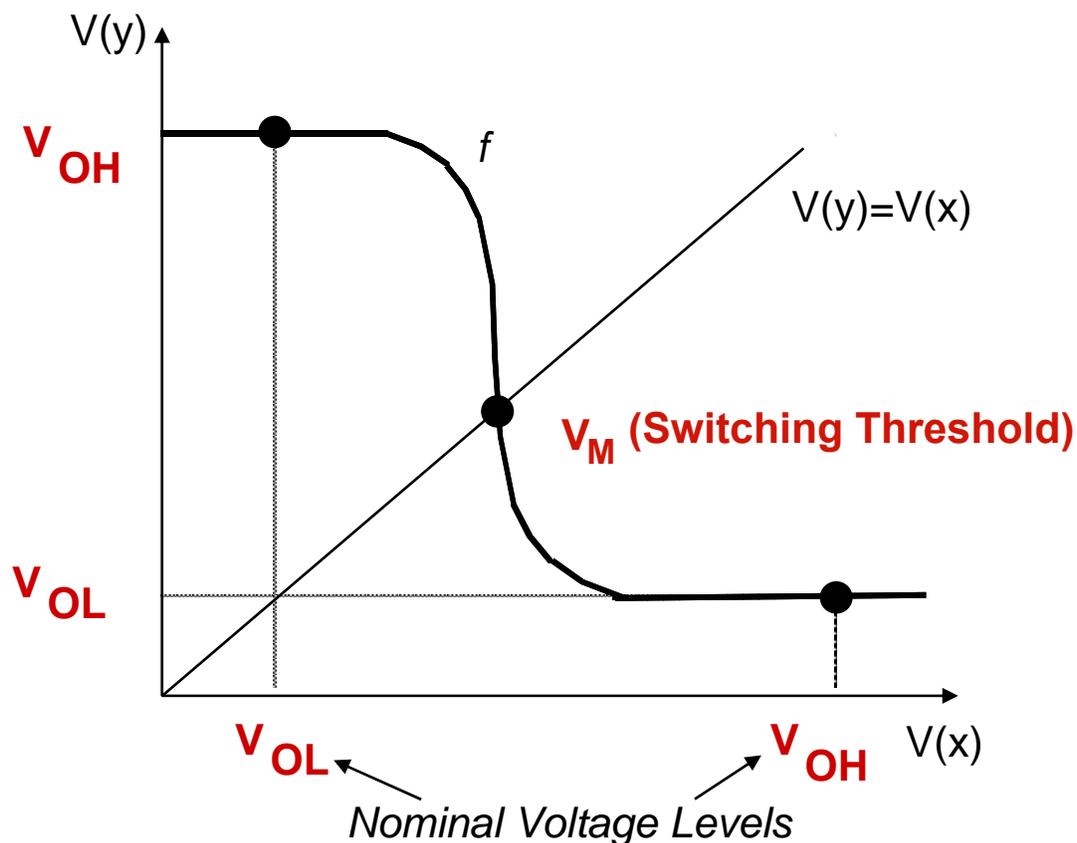


Truth Table

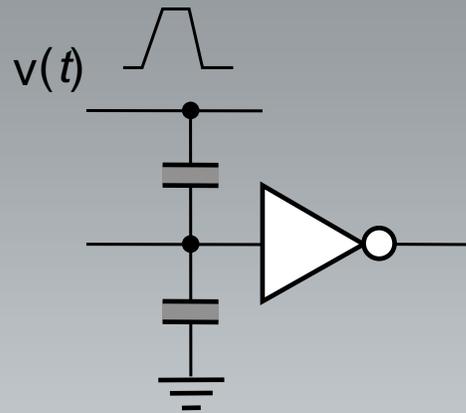
IN	OUT
0	1
1	0

Digital circuits perform operations on logical (or Boolean) variables

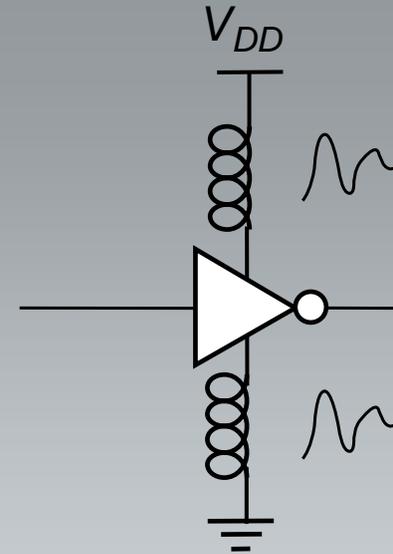
A logical variable is a mathematical abstraction. In a physical implementation, such a variable is represented by an electrical quantity



$$\begin{aligned}
 V_{OH} &= f(V_{OL}) \\
 V_{OL} &= f(V_{OH}) \\
 V_M &= f(V_M)
 \end{aligned}$$

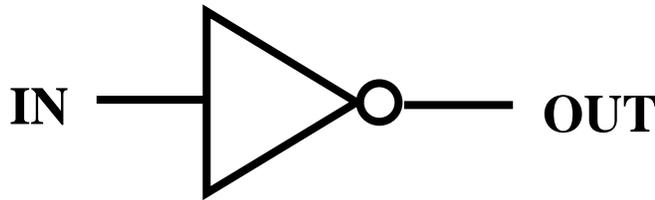


Capacitive coupling



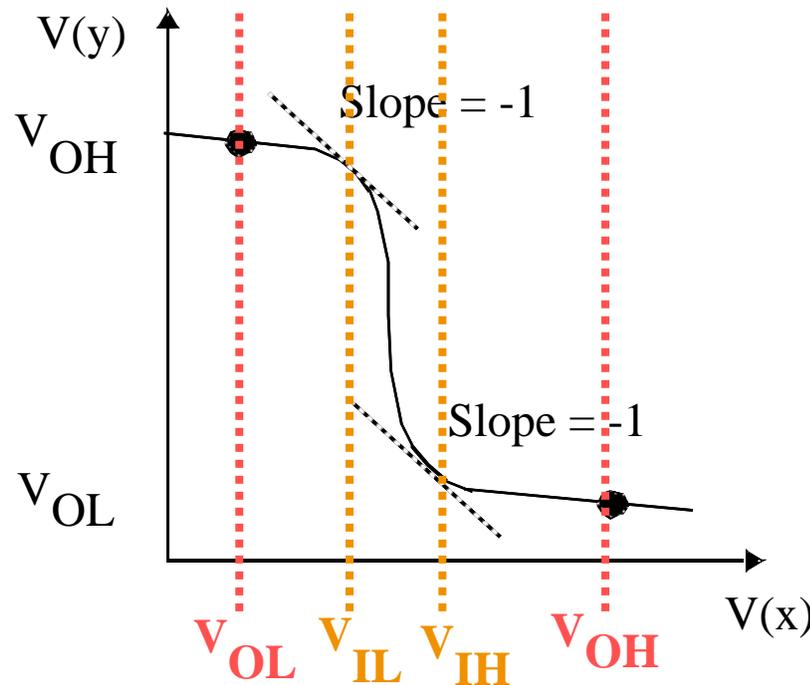
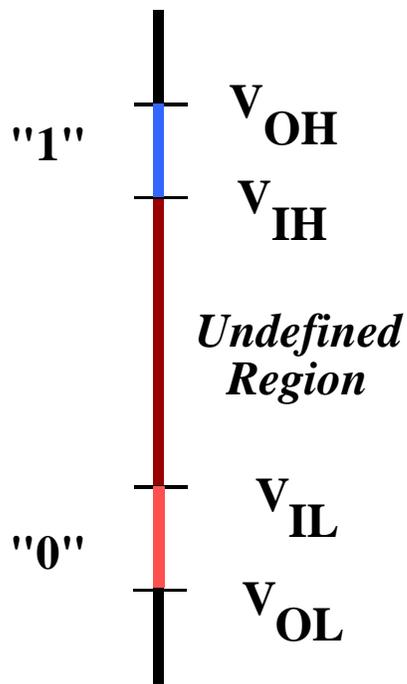
Power and ground noise

- Noise sources: coupling, cross talk, supply noise, etc.
- Digital circuits must be robust against such noise sources



Truth Table

IN	OUT
0	1
1	0

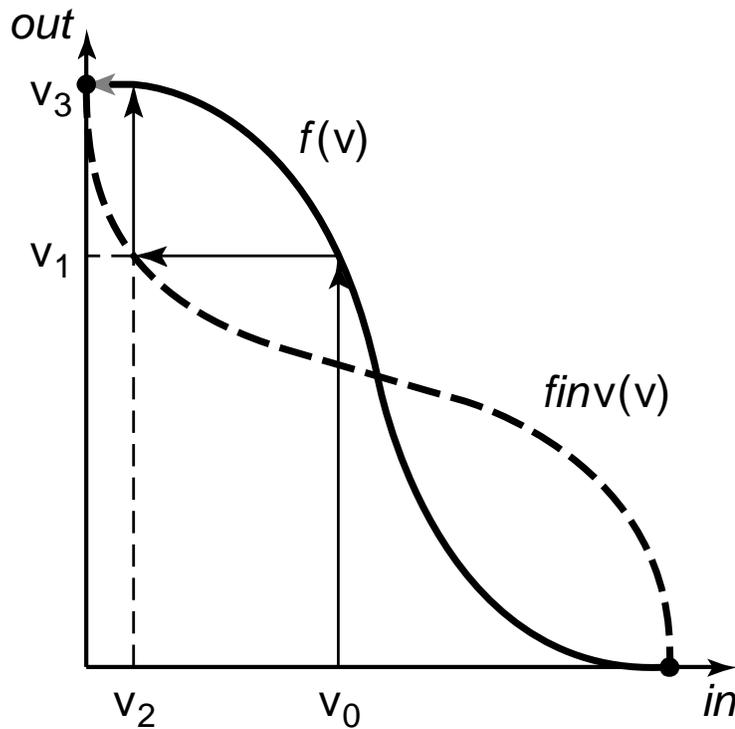
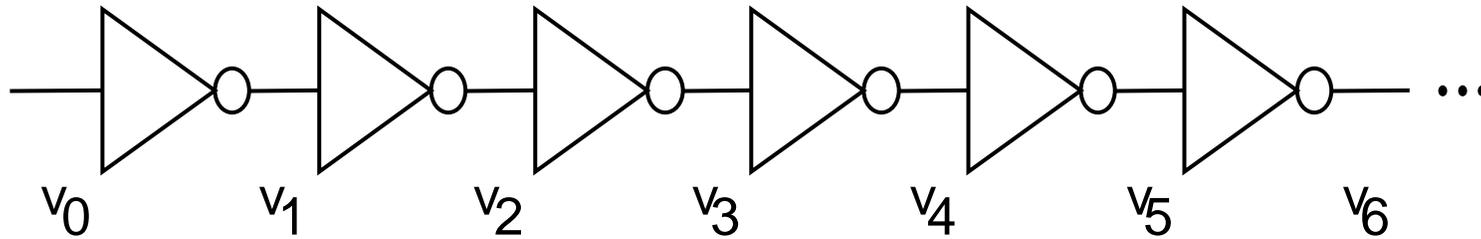


$$NM_L = V_{IL} - V_{OL}$$

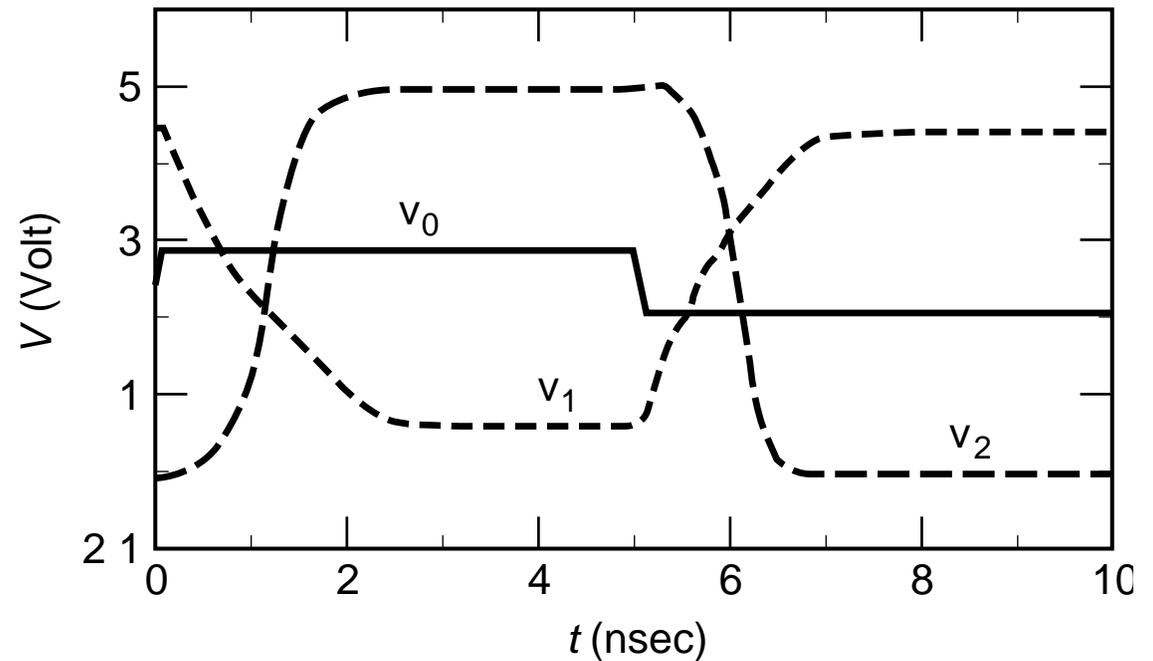
$$NM_H = V_{OH} - V_{IH}$$

- Large noise margins protect against various noise sources

A chain of inverters



Simulated response



| Voltage gain | should be > 1 between logic states

- **The normal lab hours are (please be out by the indicated time):**
 - Monday through Thursday – 9:00 AM to 11:45 PM
 - Friday – 9:00 AM to 5:15 PM
 - Saturday – CLOSED
 - Sunday – noon to 11:45 PM
 - Hours for Holidays, Spring Break, etc. is posted on the course website
- **Please do not move or reconfigure computers and other lab equipment (logic analyzers, scopes, power supplies, etc.). Please turn off the power switch for the labkit when you are done for the day.**
- **Please report any equipment malfunctions (Logic Analyzers, Computers, labkit, etc.) by tagging such equipment.**
- **We will use the following tools installed on the lab PCs (courtesy of Intel):**
 - ModelSim (powerful front-end simulator for Verilog), Xilinx ISE (software for Xilinx FPGAs), Office (Microsoft word, power point, etc.)
- **You can use WinSCP to transfer files between the lab PCs and athena**
- **Use a USB flash drive (provided with your kit) to save your work periodically**
- **On athena use 'setup 6.111'- 'setup 6.111' sources /mit/6.111/.attachrc which attaches 6.111-nfs and sources /mit/6.111-nfs/.attachrc which sets up your path and environment variables, etc.**



- **Labkit based on a state-of-the-art Xilinx FPGA (6 Million gates)**
 - Built-in audio/video interfaces, flash memory, high-speed SRAM
 - Advanced projects in audio/video, wireless, graphics, etc.
- **State-of-the-art testing equipment (logic analyzers, scopes, computers)**