Computer Architecture
（计算机体系结构）

Lecture 14
Introduction to Synchronous Digital Systems

2020-10-09

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www.cadetlab.cn/~courses

Don’t Let Your Power Rail Become a Fusible Link

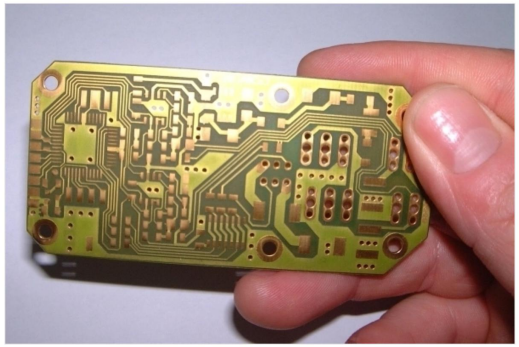


Figure 1: A small PC board similar to this one had a short, super-thin trace which acted like a fuse when hit with a 10-A surge, despite insignificant IR voltage drop. (Image Source: IBFriedrich/TARGET 3001!)

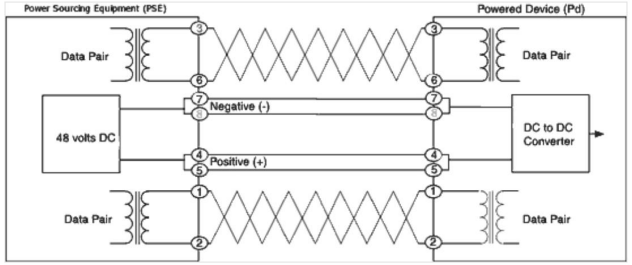
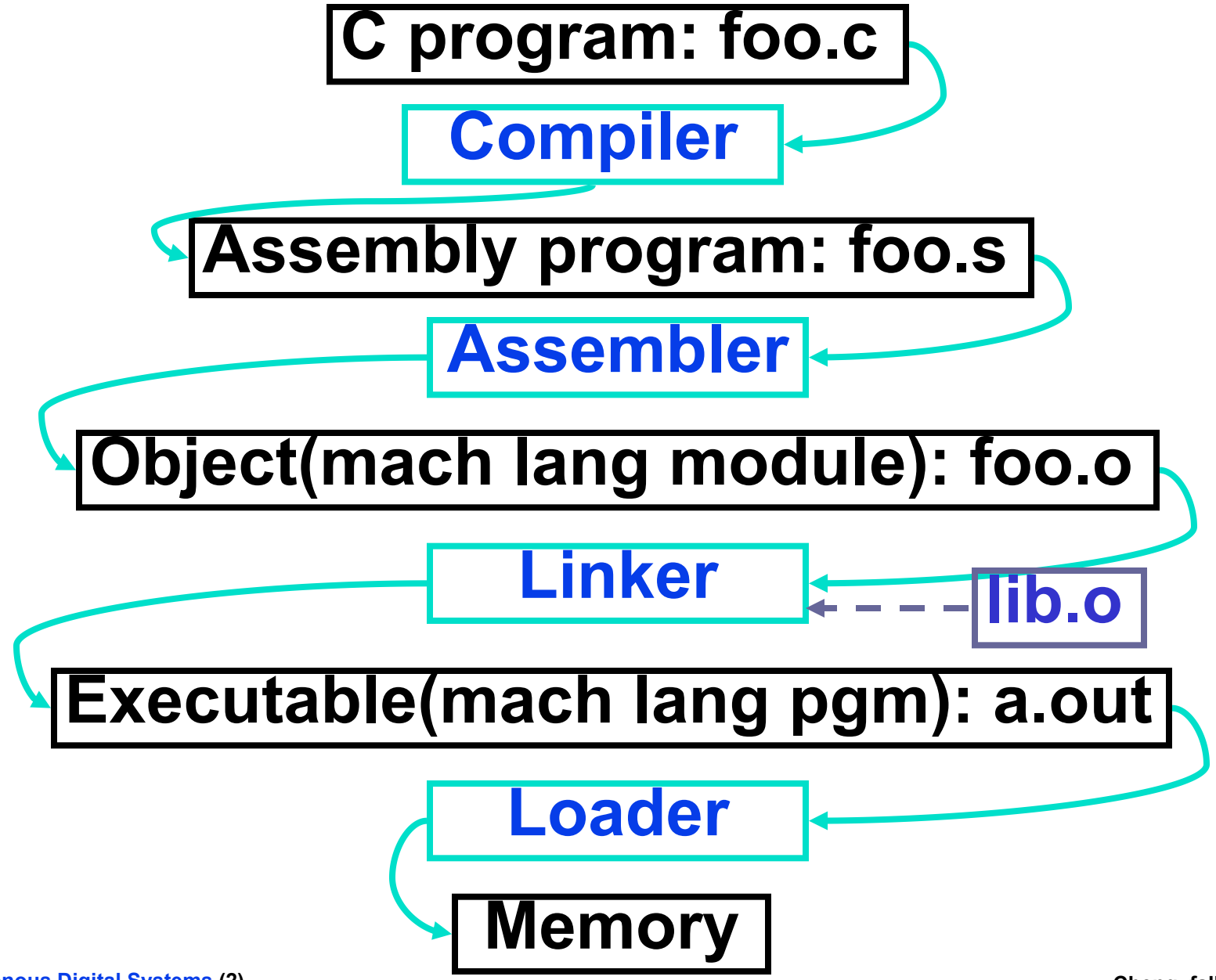
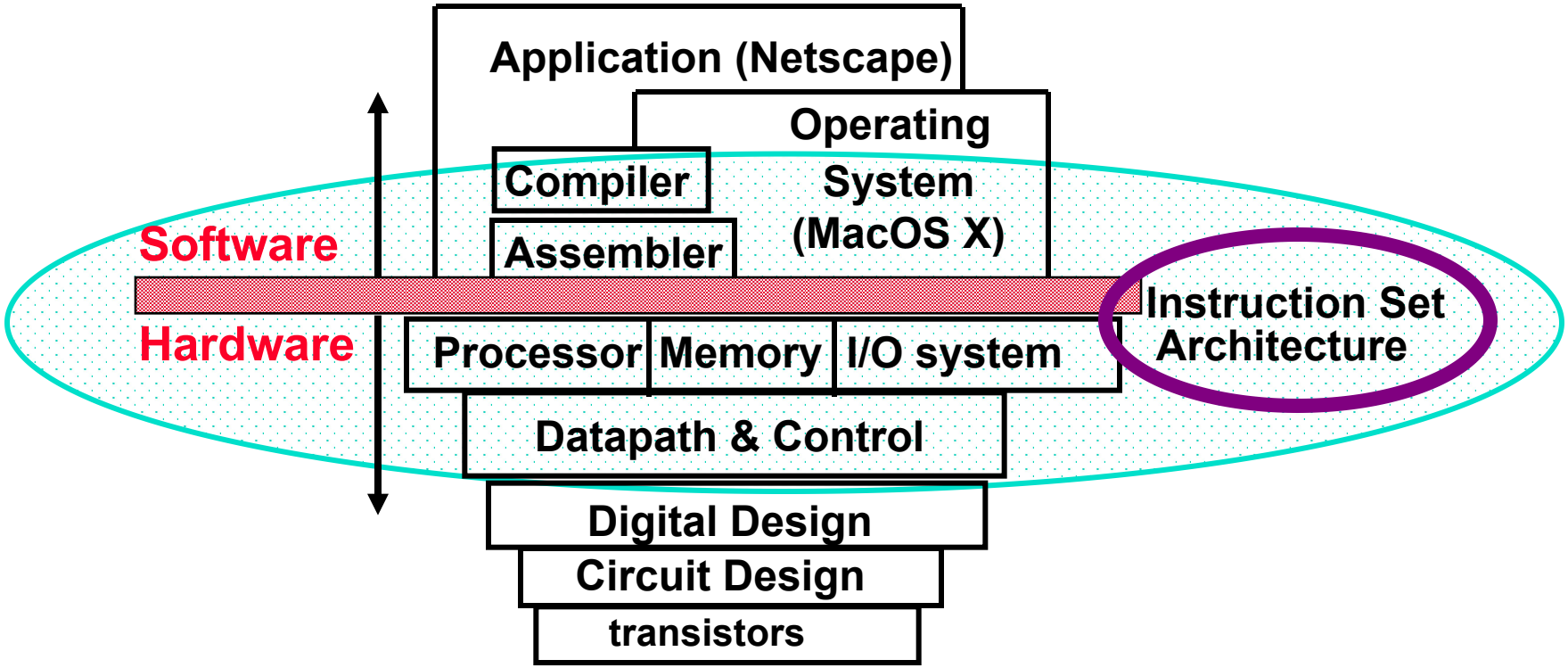


Figure 2: The recently approved third version of the Power-over-Ethernet allows for substantial power in the thin wires, which can result in excessive self-heating and performance degradation, especially in constrained installations. (Image Source: Advantech B+B SmartWorx)

Review



What are "Machine Structures"?



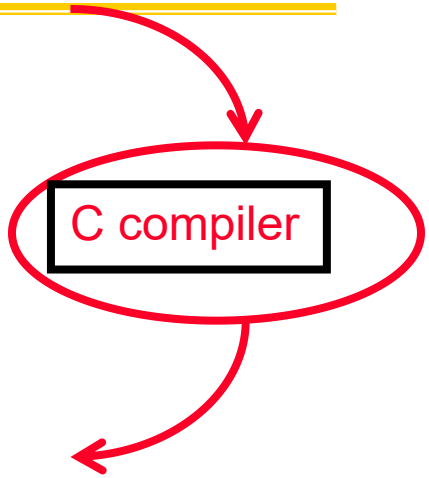
Coordination of many *levels of abstraction*

ISA is an important abstraction level: contract between HW & SW

Below the Program

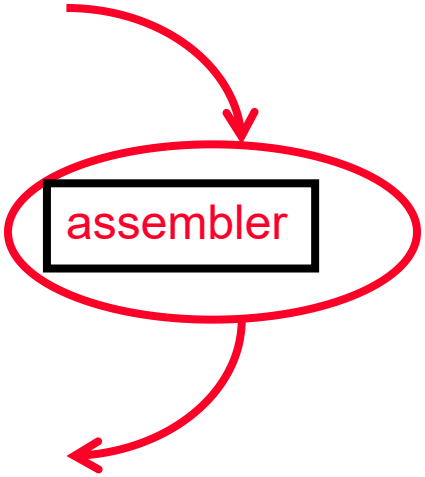
- **High-level language program (in C)**

```
swap  int v[], int k){
      int temp;
      temp = v[k];
      v[k] = v[k+1];
      v[k+1] = temp;
}
```



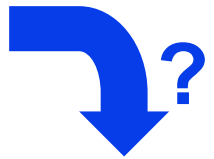
- **Assembly language program (for MIPS)**

```
swap: sll   $2, $5, 2
      add   $2, $4,$2
      lw    $15, 0($2)
      lw    $16, 4($2)
      sw    $16, 0($2)
      sw    $15, 4($2)
      jr    $31
```



- **Machine (object) code (for MIPS)**

```
000000 00000 00101 0001000010000000
000000 00100 00010 0001000000100000 . . .
```



Synchronous Digital Systems

The hardware of a processor, such as the MIPS, is an example of a Synchronous Digital System

Synchronous:

- **Means all operations are coordinated by a central clock.**
  - **It keeps the "heartbeat" of the system!**

Digital:

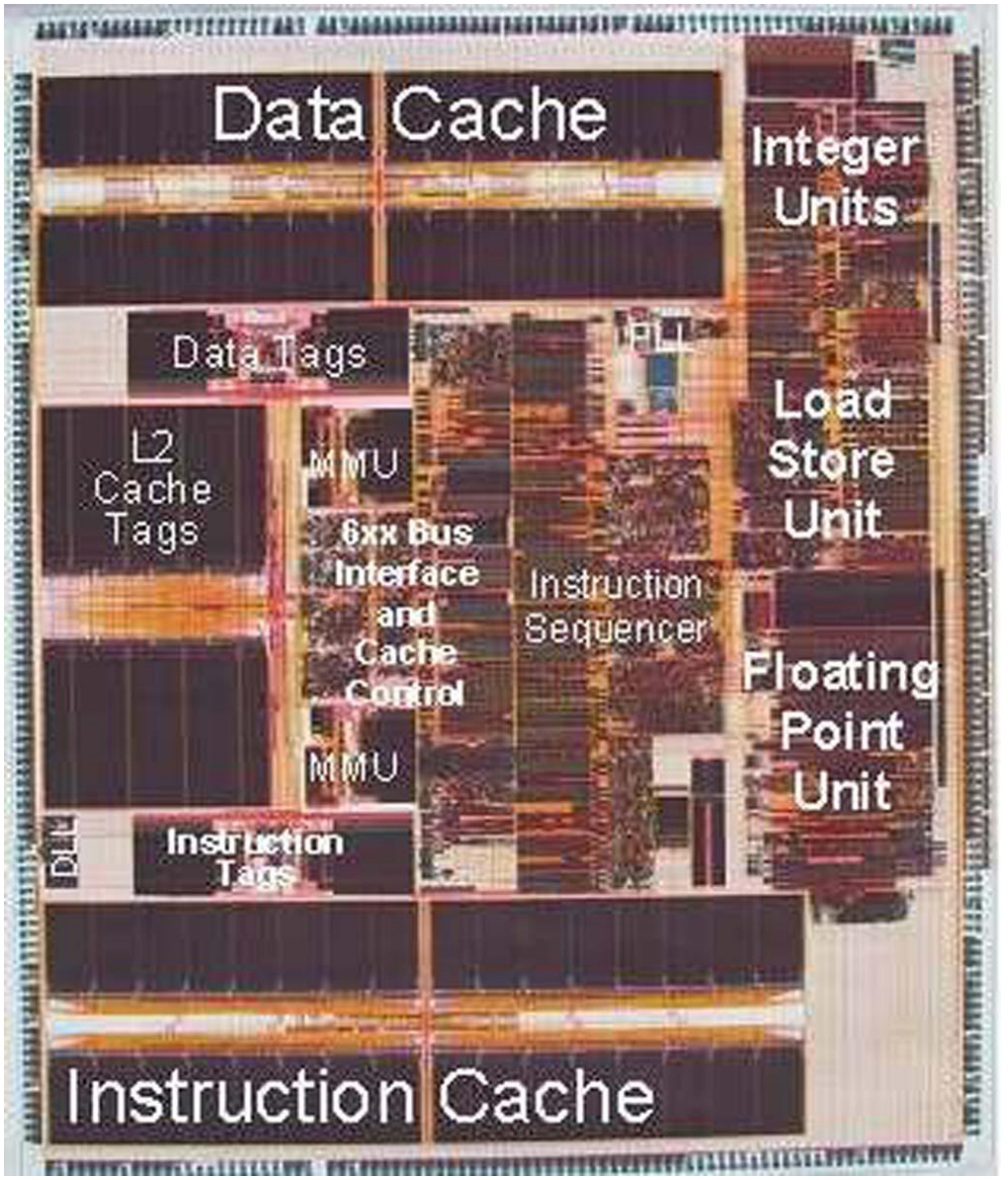
- **Mean all values are represented by discrete values**
- **Electrical signals are treated as 1's and 0's and grouped together to form words.**

Logic Design

- **Next 4 weeks: we'll study how a modern processor is built; starting with basic elements as building blocks.**
- **Why study hardware design?**
  - **Understand capabilities and limitations of hardware in general and processors in particular.**
  - **What processors can do fast and what they can't do fast (avoid slow things if you want your code to run fast!)**
  - **Background for more detailed hardware courses**
  - **There is just so much you can do with processors. At some point you may need to design your own custom hardware.**

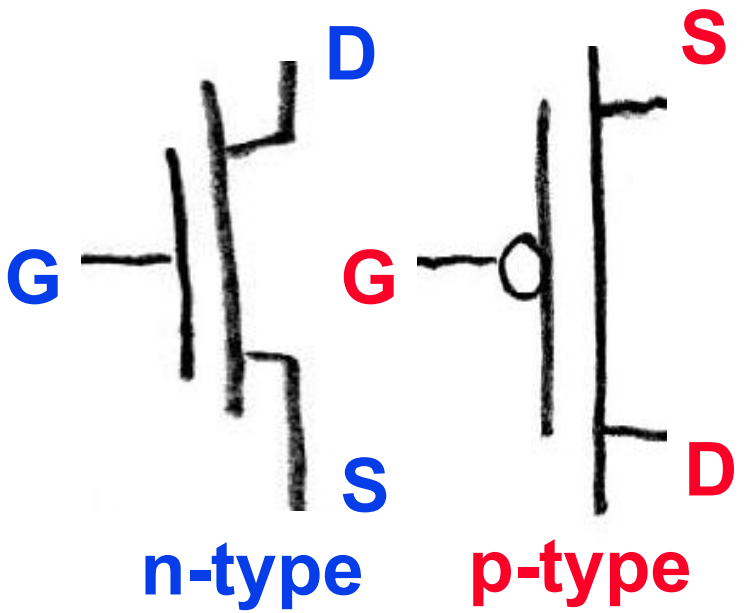
PowerPC Die Photograph

Let's look closer…

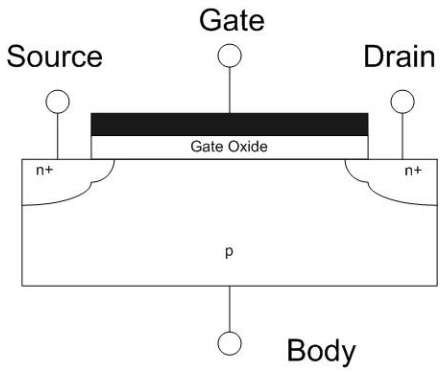


Transistors 101

- **MOSFET**
  - Metal-Oxide-Semiconductor Field-Effect Transistor
  - Come in two types:
    - n-type NMOSFET
    - p-type PMOSFET



- For n-type (p-type opposite)
  - If voltage not enough between G & S, transistor turns “off” (cut-off) and Drain-Source NOT connected
  - If the G & S voltage is high enough, transistor turns “on” (saturation) and Drain-Source ARE connected

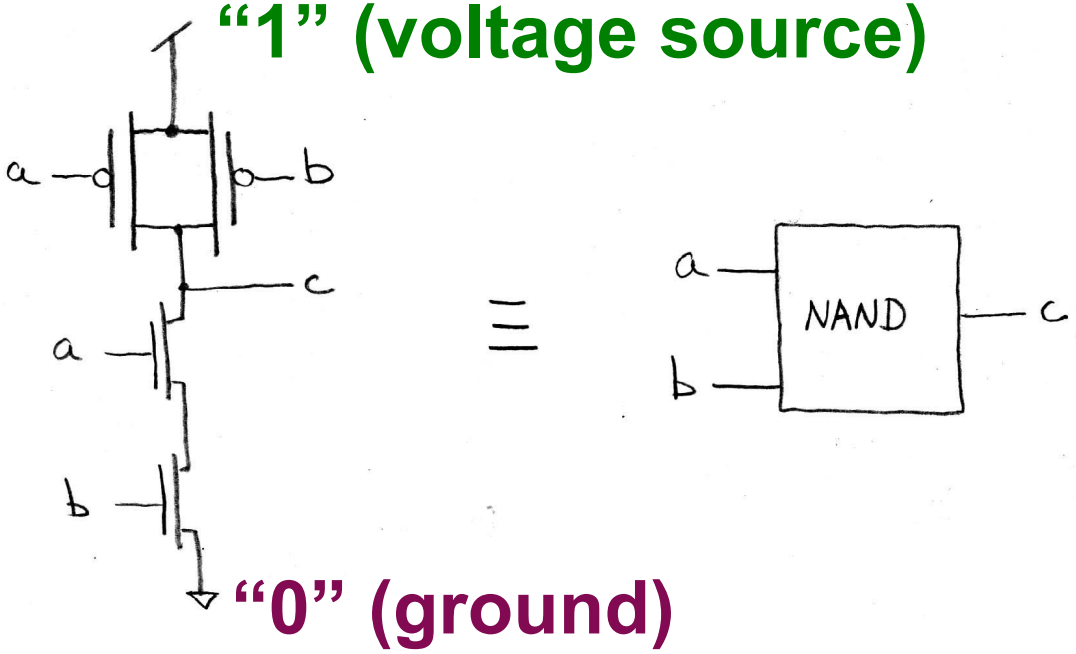


Side view

www.wikipedia.org/wiki/Mosfet

Transistor Circuit Rep. vs. Block diagram

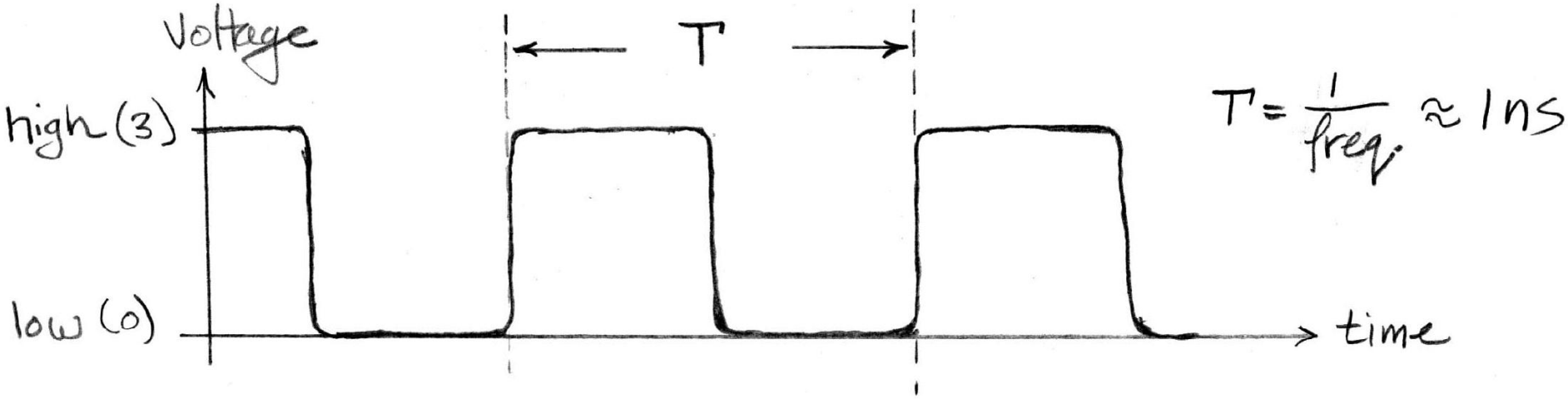
- Chips is composed of nothing but transistors and wires.
- Small groups of transistors form useful building blocks.



a	b	c
0	0	1
0	1	1
1	0	1
1	1	0

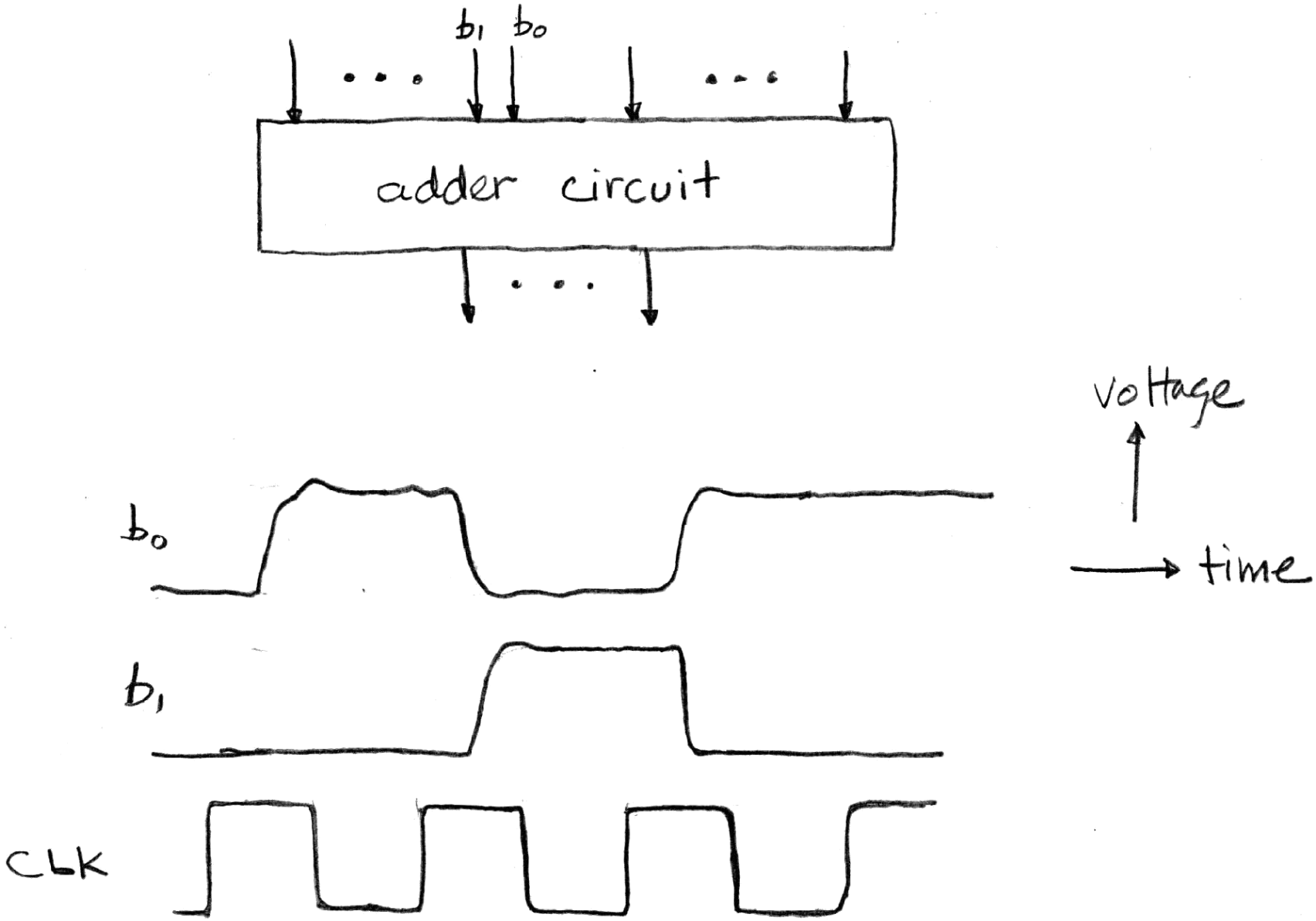
- Block are organized in a hierarchy to build higher-level blocks: ex: adders.

Signals and Waveforms: Clocks

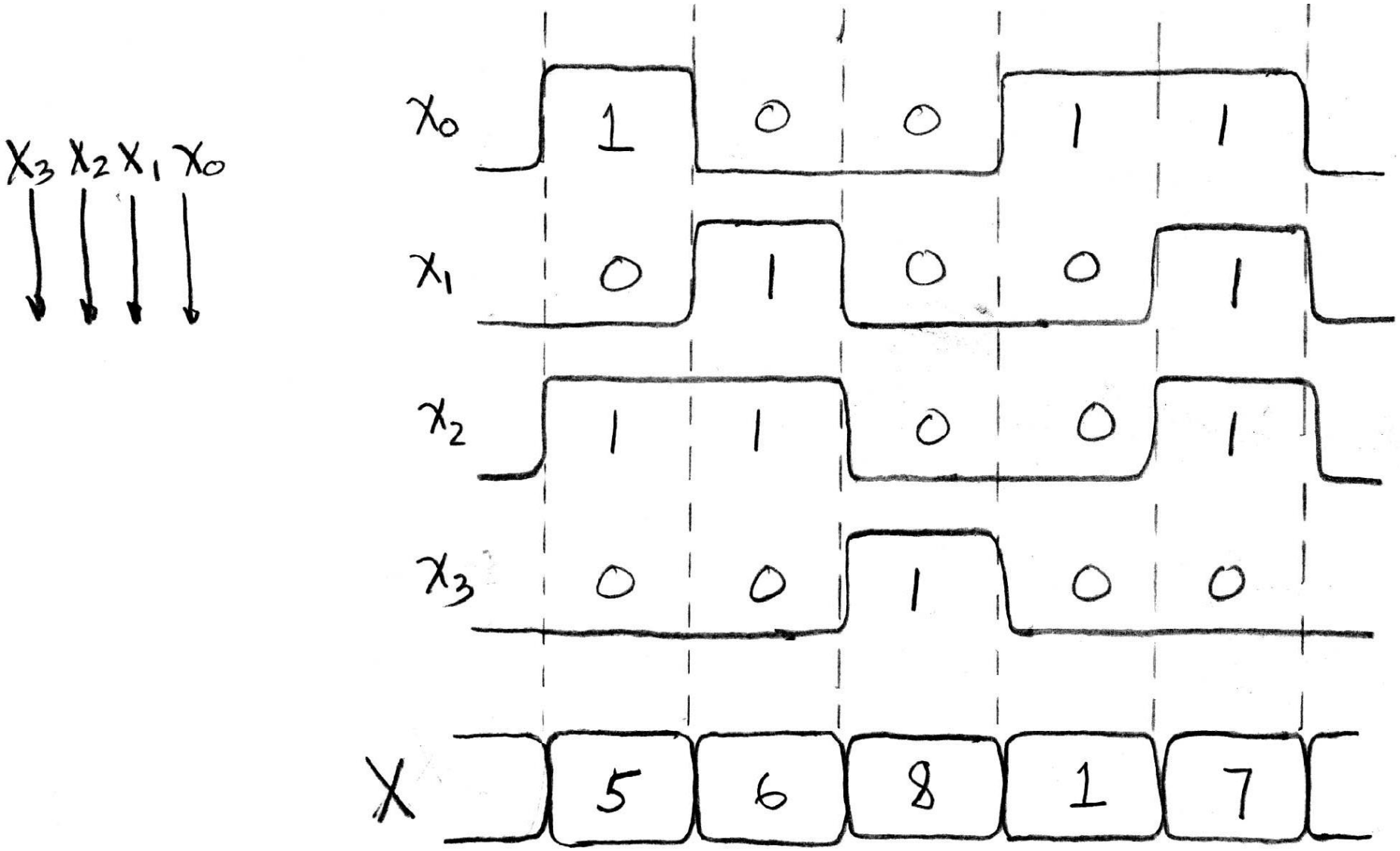


- **Signals**
  - **When digital is only treated as 1 or 0**
  - **Is transmitted over wires continuously**
  - **Transmission is effectively instant**
    - **Implies that any wire only contains 1 value at a time**

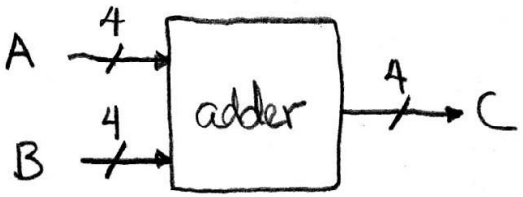
Signals and Waveforms



Signals and Waveforms: Grouping

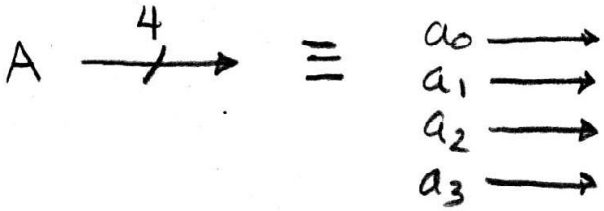


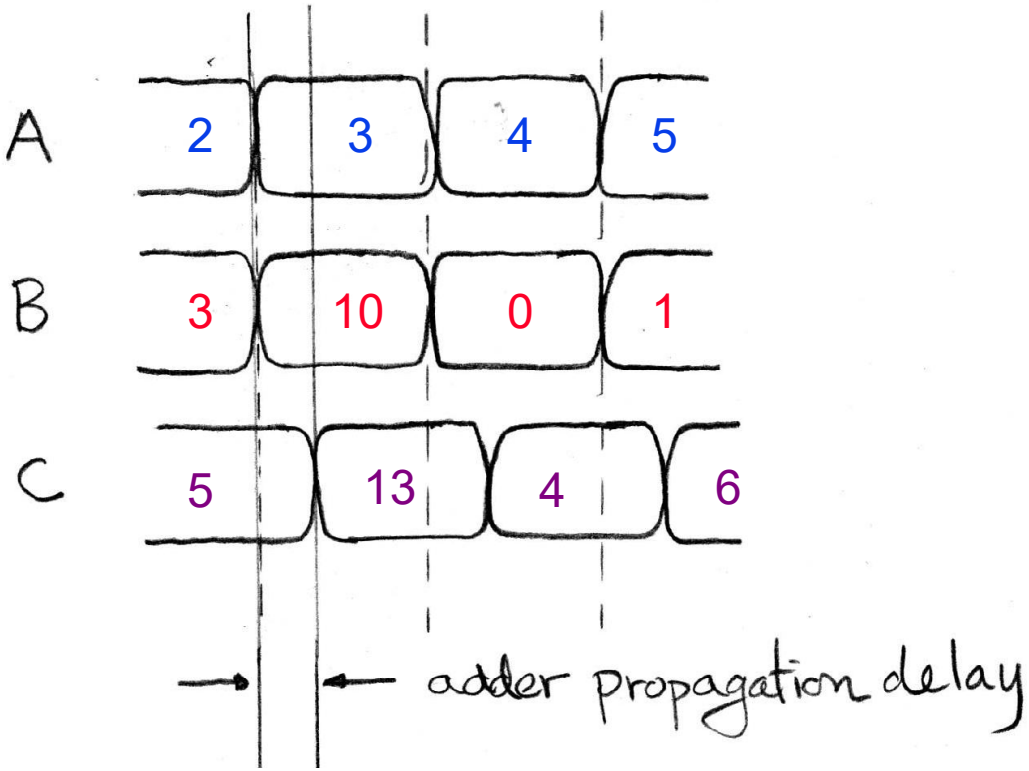
Signals and Waveforms: Circuit Delay



$A = [a_3, a_2, a_1, a_0]$

$B = [b_3, b_2, b_1, b_0]$

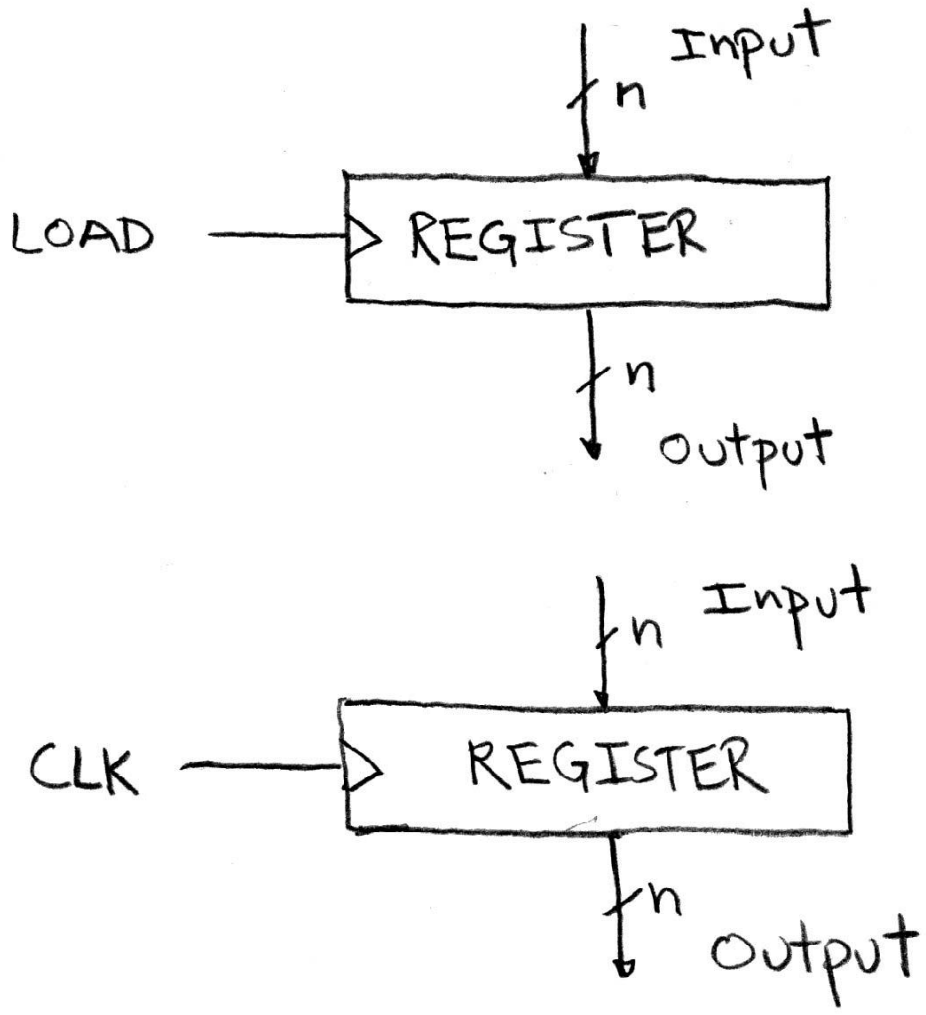




Type of Circuits

- **Synchronous Digital Systems are made up of two basic types of circuits:**
- **Combinational Logic (CL) circuits**
  - **Our previous adder circuit is an example.**
  - **Output is a function of the inputs only.**
  - **Similar to a pure function in mathematics, y = f(x). (No way to store information from one invocation to the next. No side effects)**
- **State Elements: circuits that store information.**

Circuits with STATE (e.g., register)



Peer Instruction

1) SW can peek at HW (past ISA abstraction boundary) for optimizations
2) SW can depend on particular HW implementation of ISA

	12
a)	FF
b)	FT
c)	TF
d)	TT

And in conclusion…

- ISA is very important abstraction layer
  - Contract between HW and SW
- Clocks control pulse of our circuits
- Voltages are analog, quantized to 0/1
- Circuit delays are fact of life
- Two types of circuits:
  - Stateless Combinational Logic (&,|,~)
  - State circuits (e.g., registers)

Sample Debugging Waveform