DNA
Fundamentals of Digital Logic

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Goals

- Understand basics of digital circuits
  - transistors
  - boolean logic → logic gates
  - gates → integrated circuits
  - counters
  - feedback – keeping bits in check

Background

- Voltage: difference of potentials.
  - Vcc – ground (=0).
  - Volts (V)
- Current: flow of electrons.
  - Amperes (A)
- Ohm’s law: $U = RI$
- Dissipated power: $P = UI = RI^2 = U^2/R$

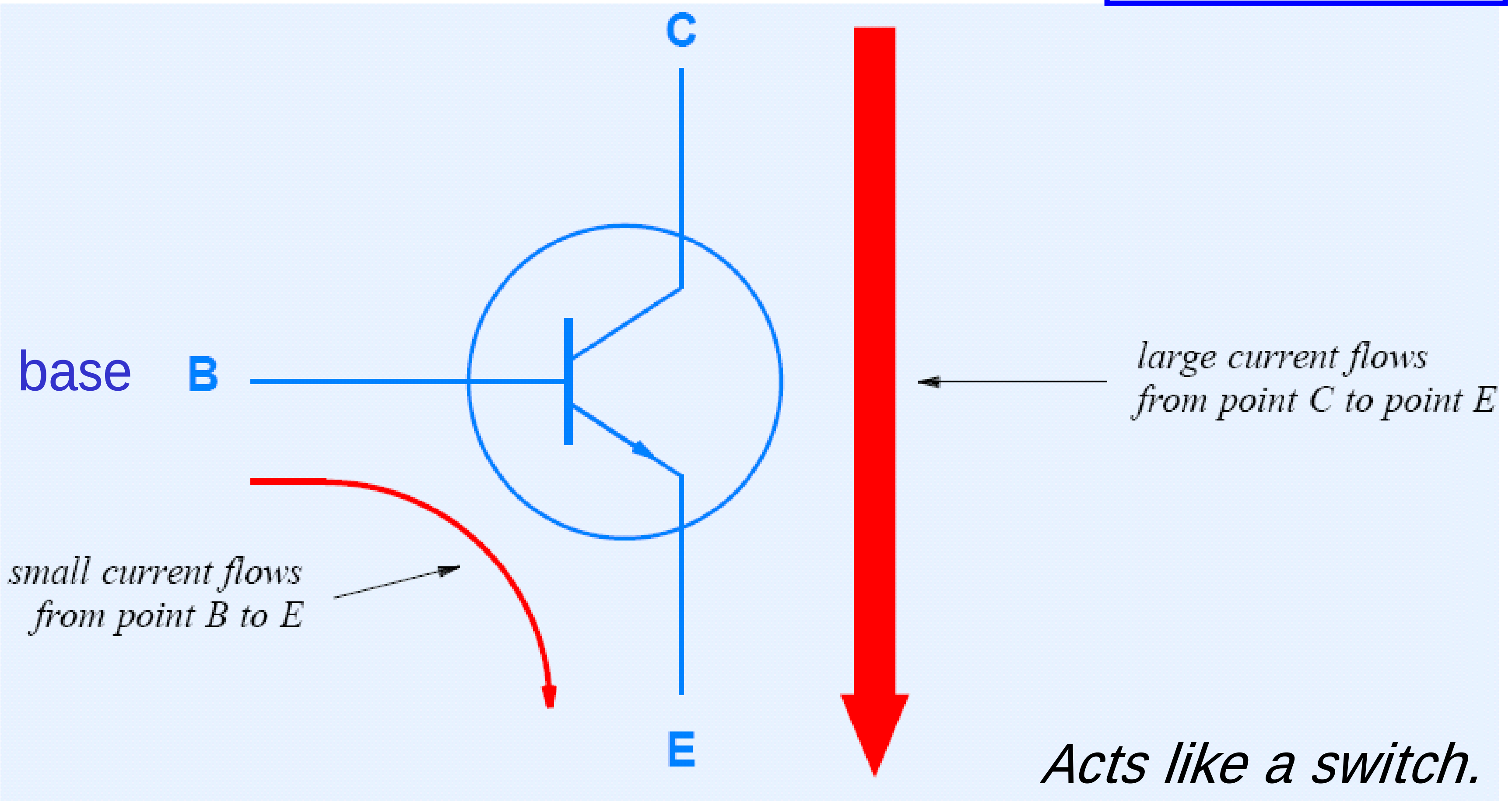
Typical Chips

- Operate on low voltage (5V, less for processors) – see power dissipation.
- Always 2 lines
  - ground (0V)
  - power (5V)
- Diagrams usually omit ground and power.

Transistor

Basic building block of digital circuits

collector



Acts like a switch.

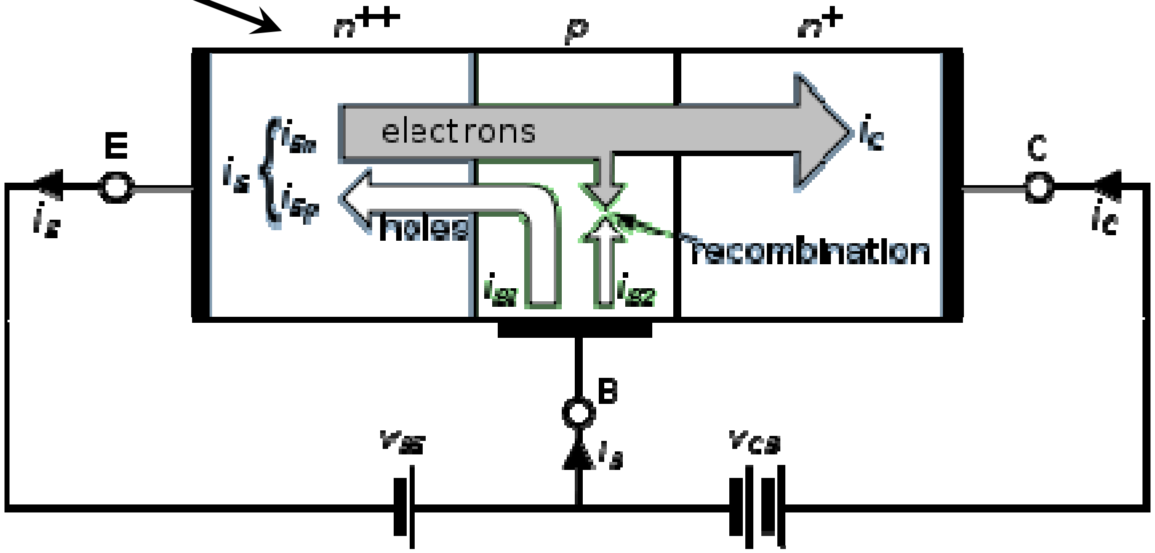
emitter

Transistor (NPN)

N doped silicon
surplus of electrons
cathode

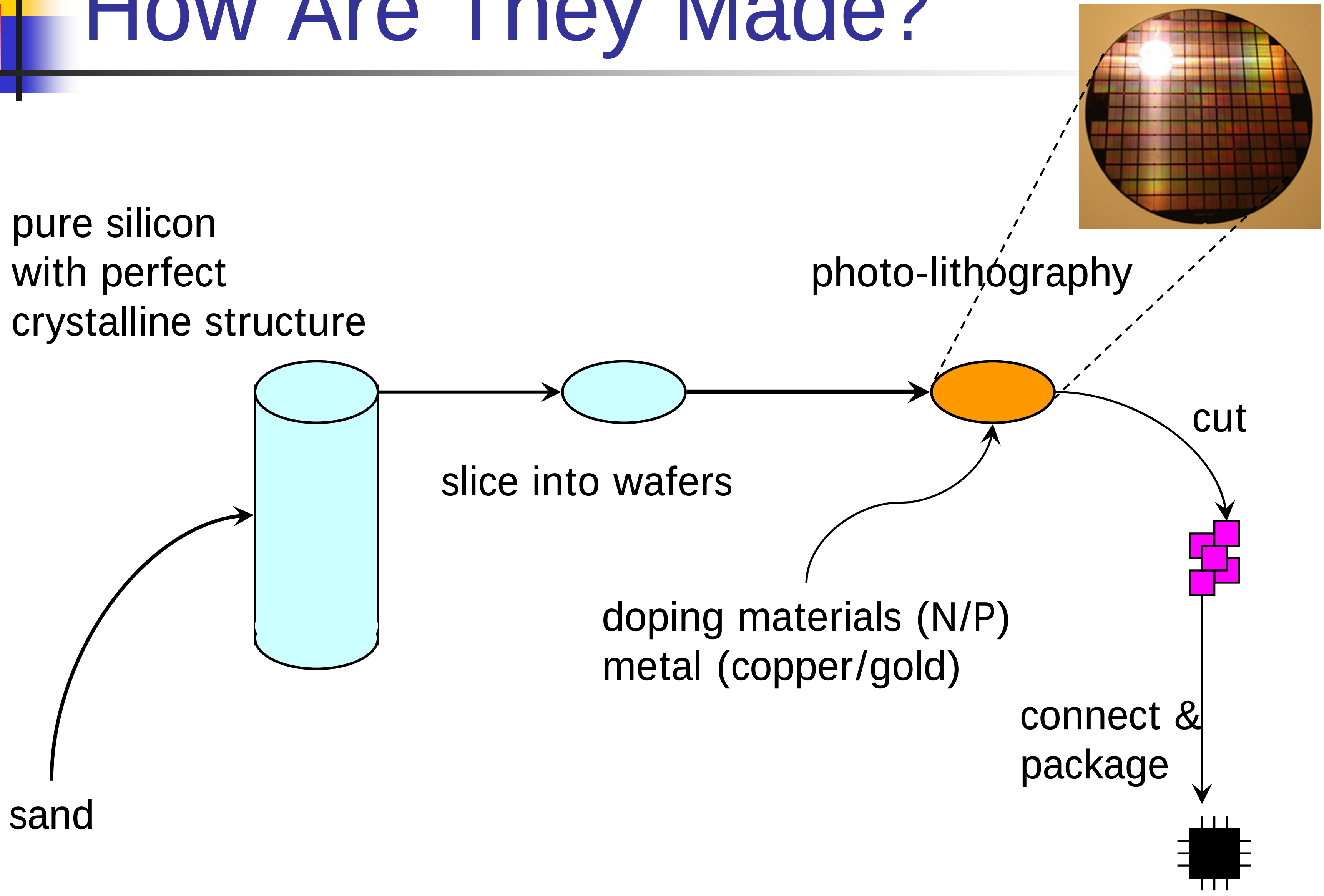
P doped silicon
electron “holes”
anode

Different technologies based on the same basic principle.



(wikipedia fig.)

How Are They Made?



pure silicon
with perfect
crystalline structure

slice into wafers

photo-lithography

doping materials (N/P)
metal (copper/gold)

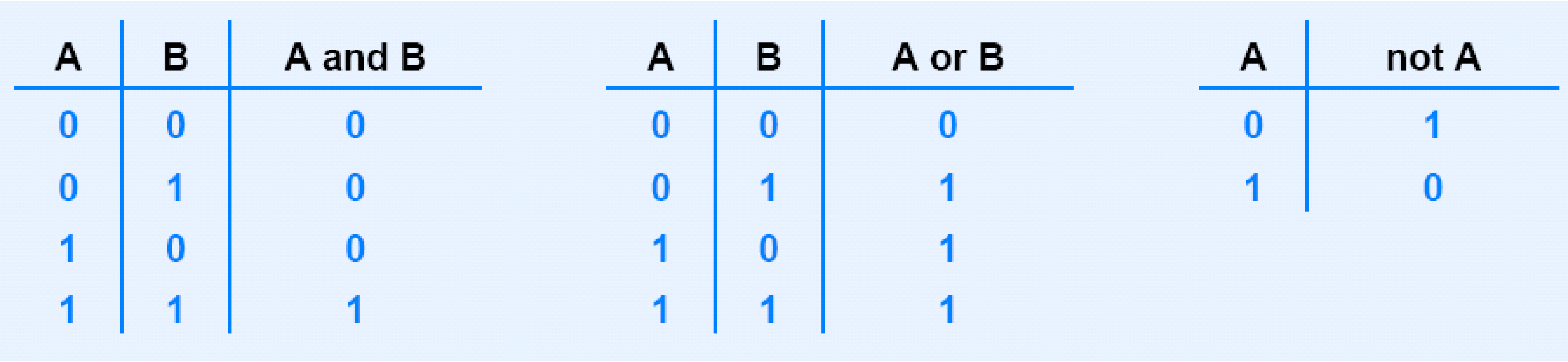
cut

connect &
package

sand

Boolean Algebra

- Mathematical basis for digital circuits.
- From boolean functions to gates.
- Basic functions: and, or, not.
- In practice, cheaper to have nand & nor.

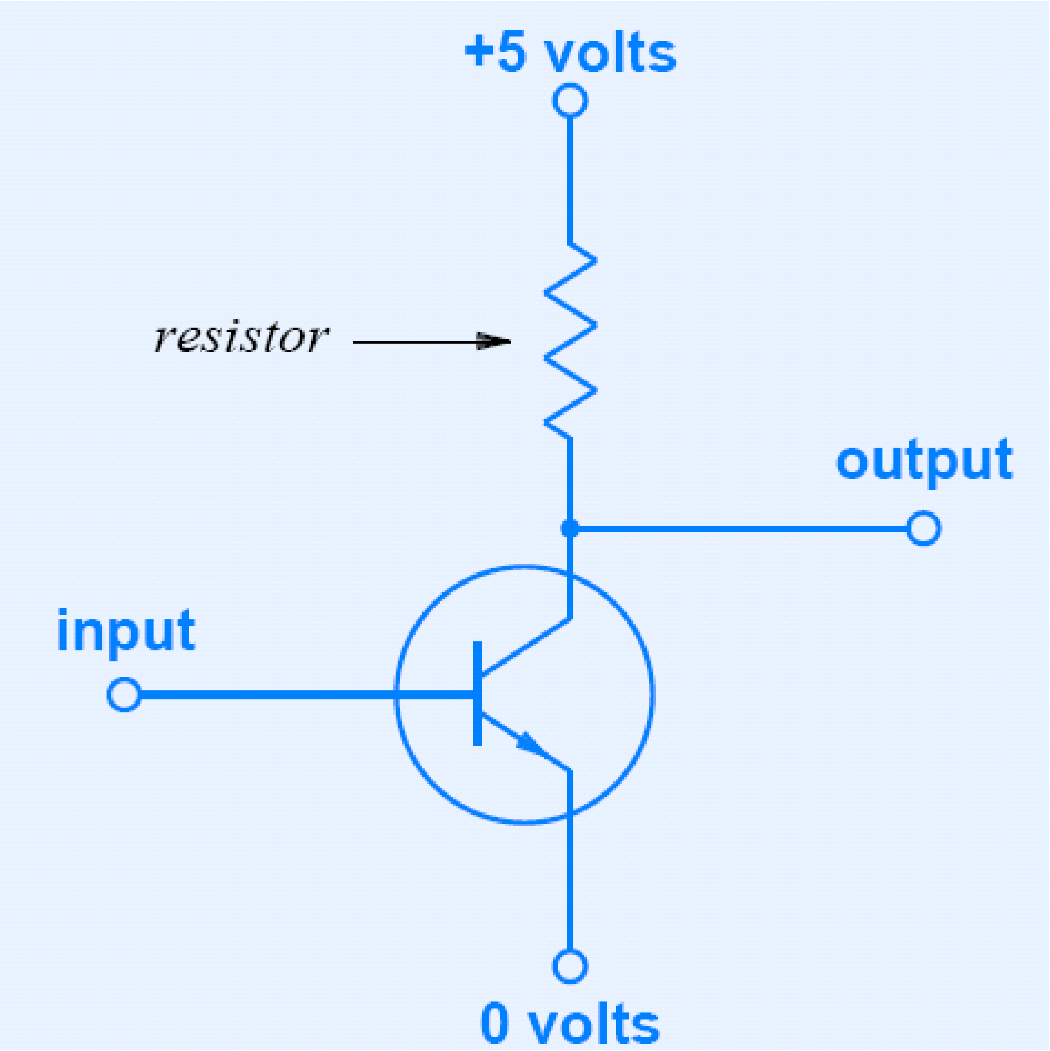


A	B	A and B
0	0	0
0	1	0
1	0	0
1	1	1

A	B	A or B
0	0	0
0	1	1
1	0	1
1	1	1

A	not A
0	1
1	0

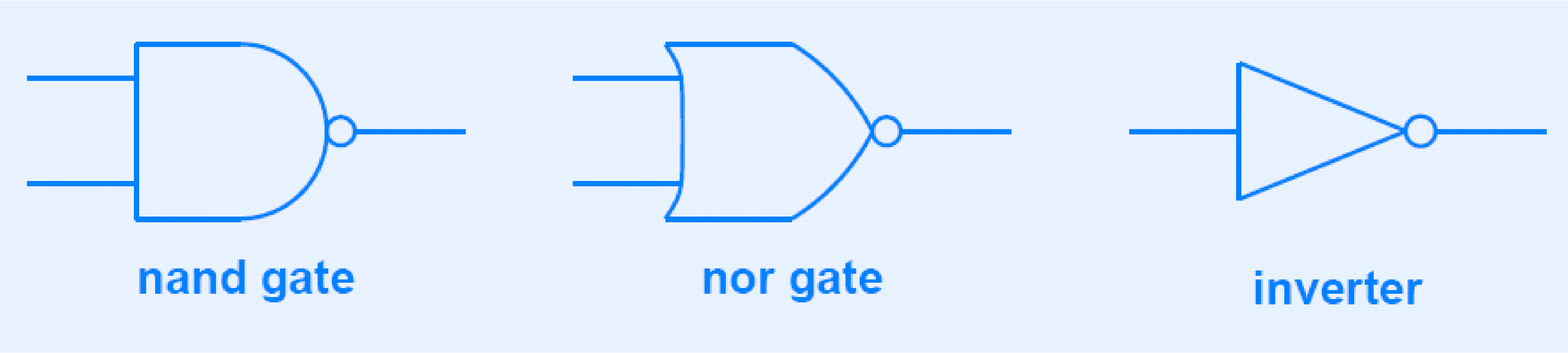
Example: Not



You also have *nor* in the book.

Gates

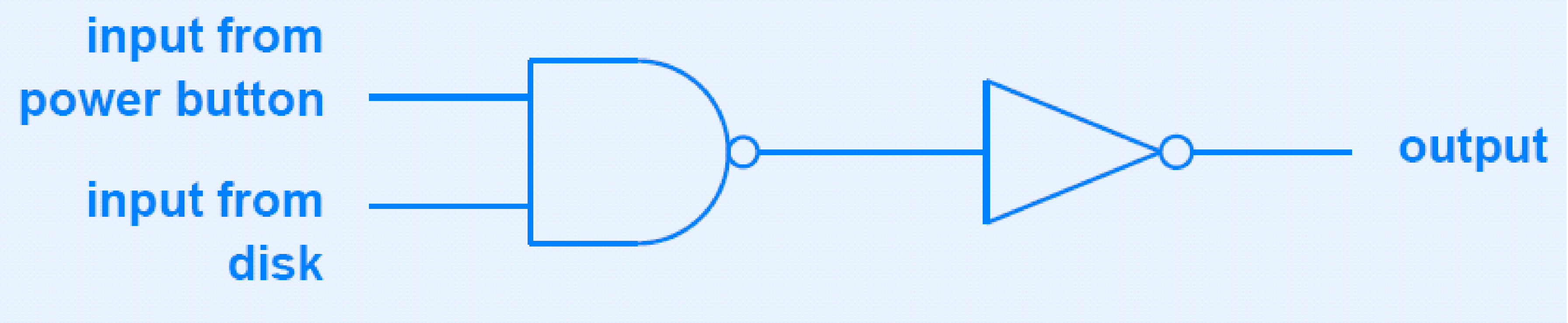
- Primitive boolean functions.
- Level of abstraction on IC.



Symbols used in circuits.

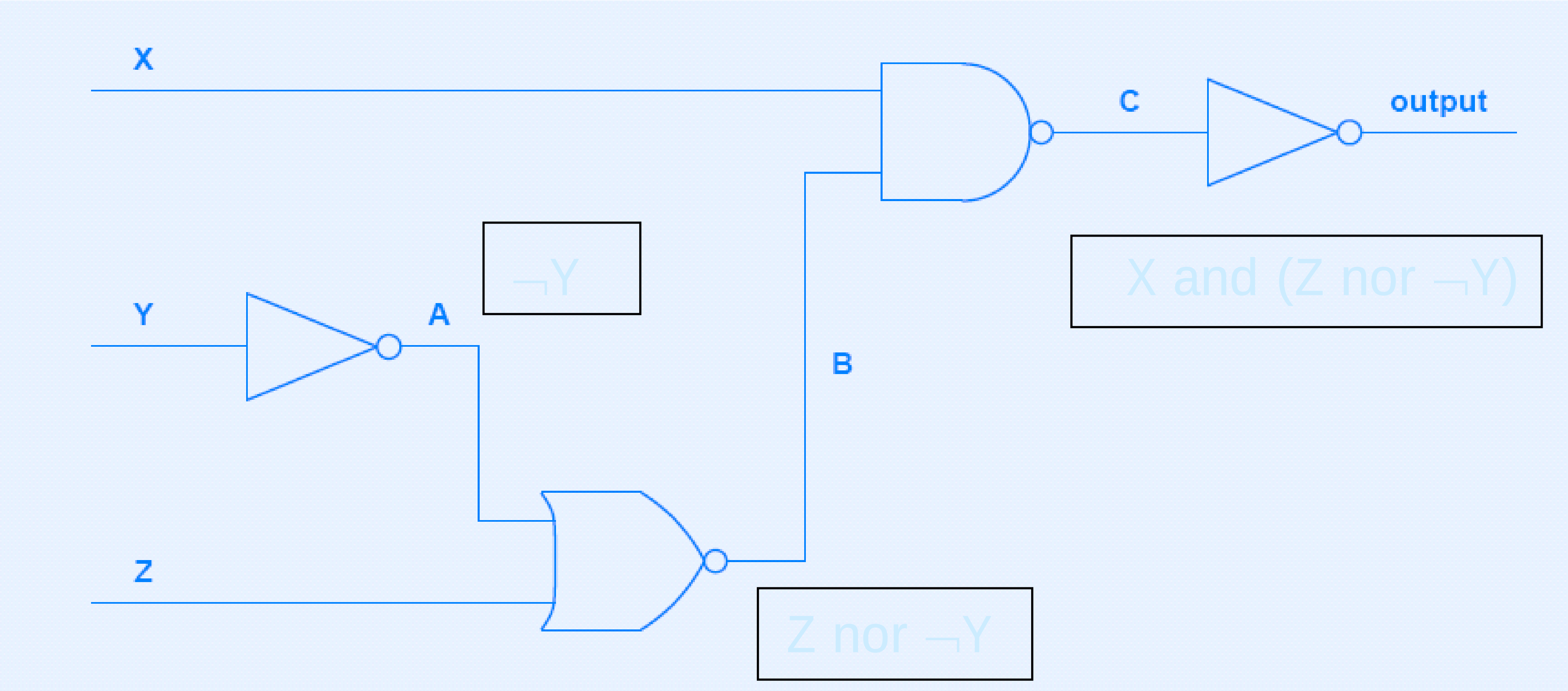
Logic Gate Technology

- Transistor-transistor technology (TTL)
  - connect directly gates together to form boolean functions



and function

Example



¬Y

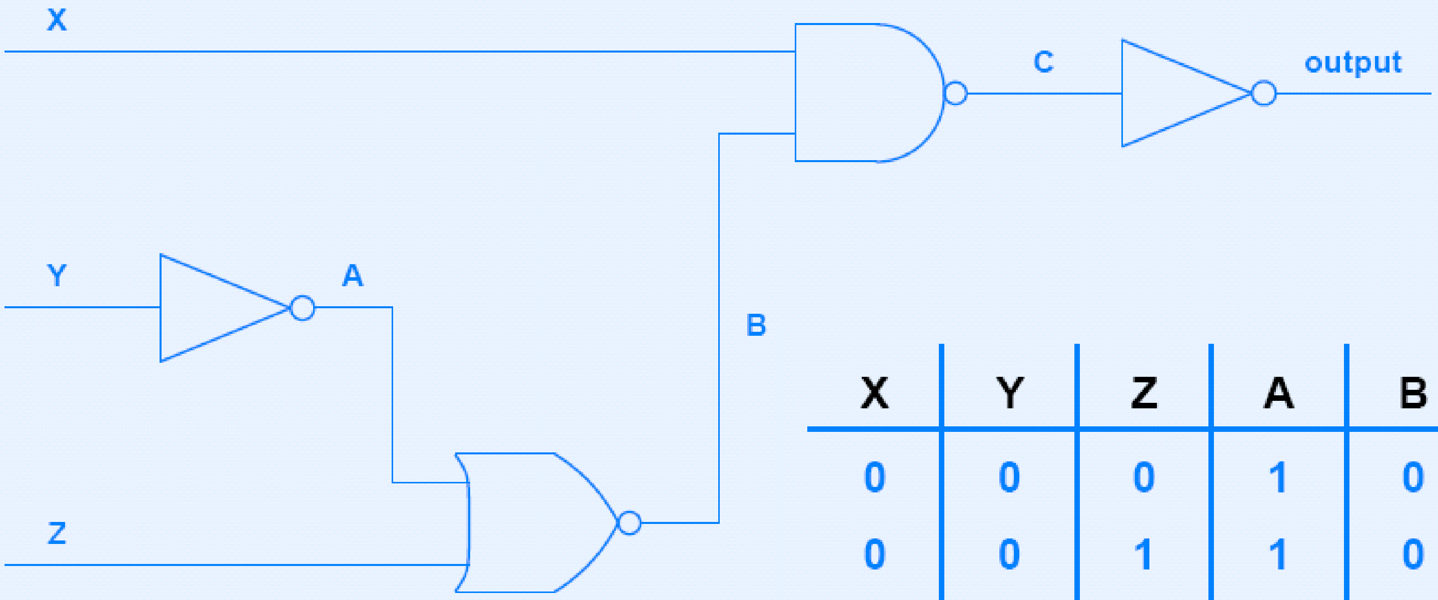
X and (Z nor ¬Y)

Z nor ¬Y

Design of Functions

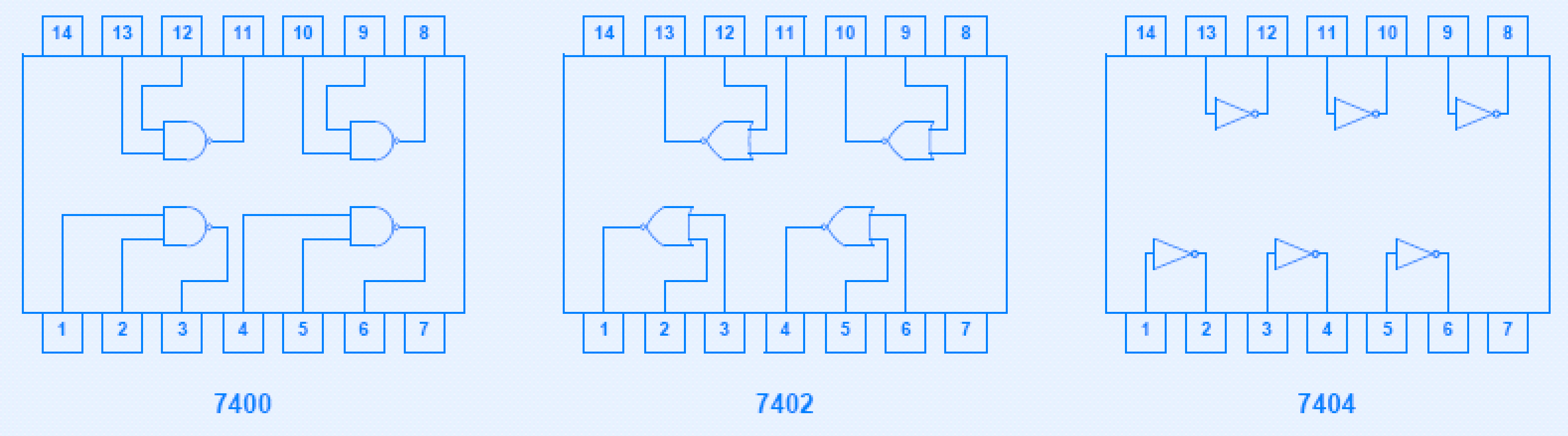
- Find a boolean expression that does what you need
  - and feed it to a tool that optimizes it to minimize the number of gates.
- Come up with the truth table of your function
  - which is converted to a boolean function.

Truth Table



X	Y	Z	A	B	C	output
0	0	0	1	0	1	0
0	0	1	1	0	1	0
0	1	0	0	1	1	0
0	1	1	0	0	1	0
1	0	0	1	0	1	0
1	0	1	1	0	1	0
1	1	0	0	1	0	1
1	1	1	0	0	1	0

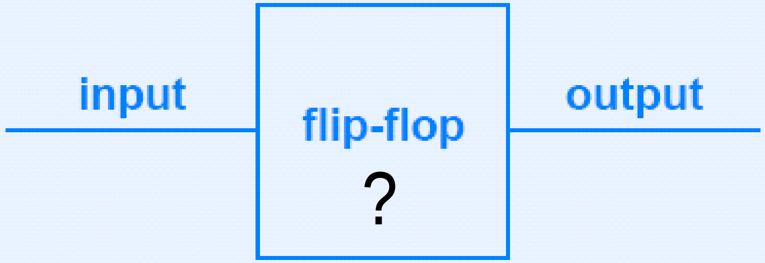
Combinatorial Circuits



- Outputs = function(inputs)
  - change outputs only when inputs changes
  - need states to perform sequences of operations without sustained inputs
    - maintain states
    - use a clock

Maintaining States

Flip-flop example



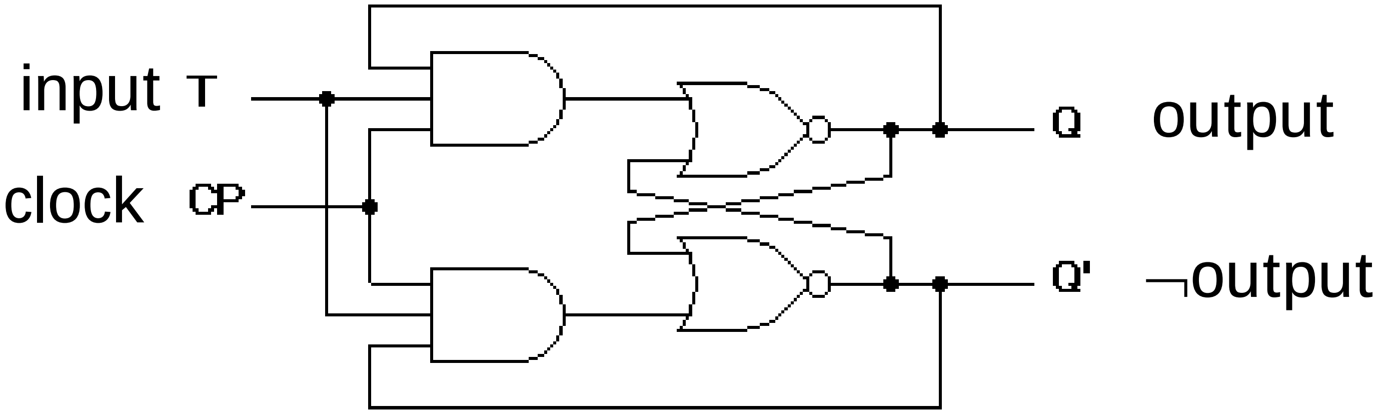
in:	0	0	1	0	1	1	0	0	0	0	1	0	1	0	1	0
out:	0	0	1	1	0	0	0	0	0	0	1	1	0	0	1	1

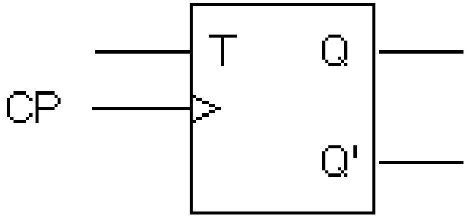
time increases

Note: output only changes when input makes a transition from zero to one

T-Flip-Flop

Key: feedback





symbol

Q	T	Q(t+1)
0	0	0
0	1	1
1	0	1
1	1	0

truth table

To Know

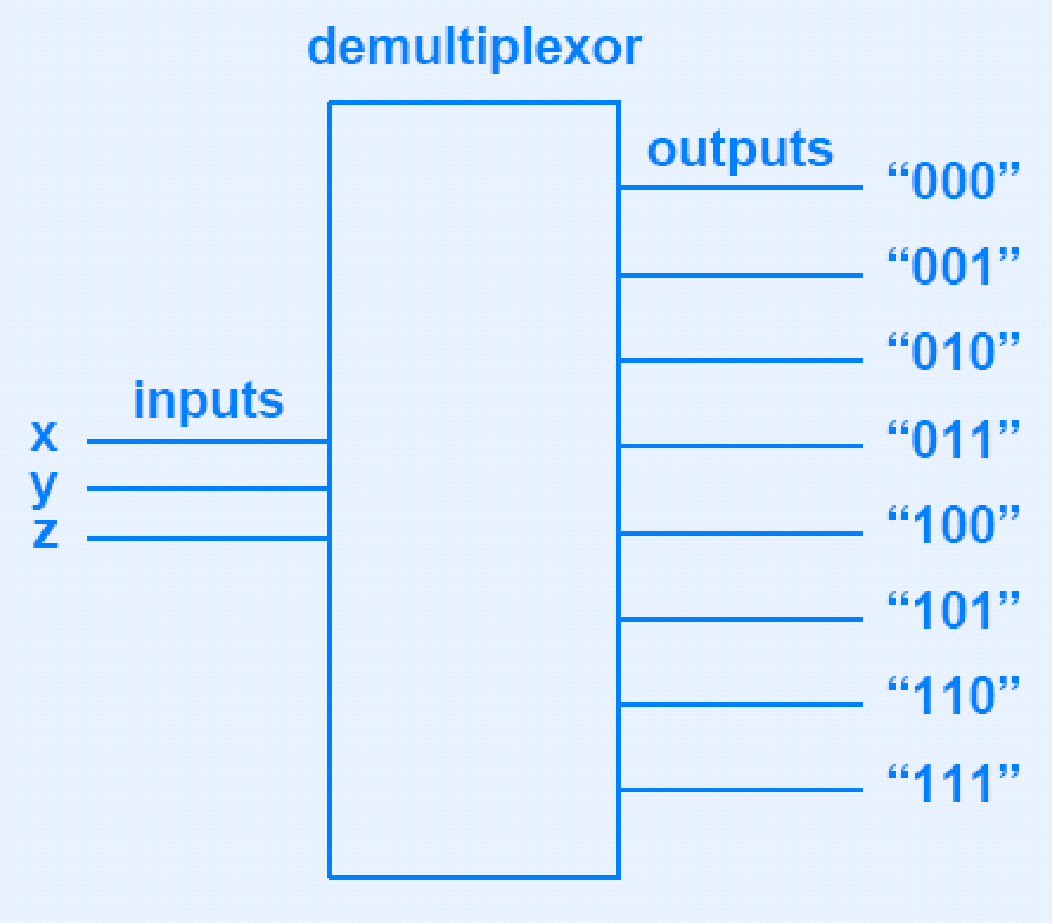
- Can occur on leading or falling edge of the clock signal.
- Variants of flip-flops.
- Transition diagrams used to visualize the function.
- Key: feedback to “keep” the bits.
- Simple not loop = base for memory bit (cache).
    - RAM: simpler with a “condensator”
        - more compact but needs to be refreshed

Binary Counters

- Count input pulses.
- Output = binary number.
- The IC keeps previous states
  - → combines with new inputs to get new output
  - → combination = boolean function

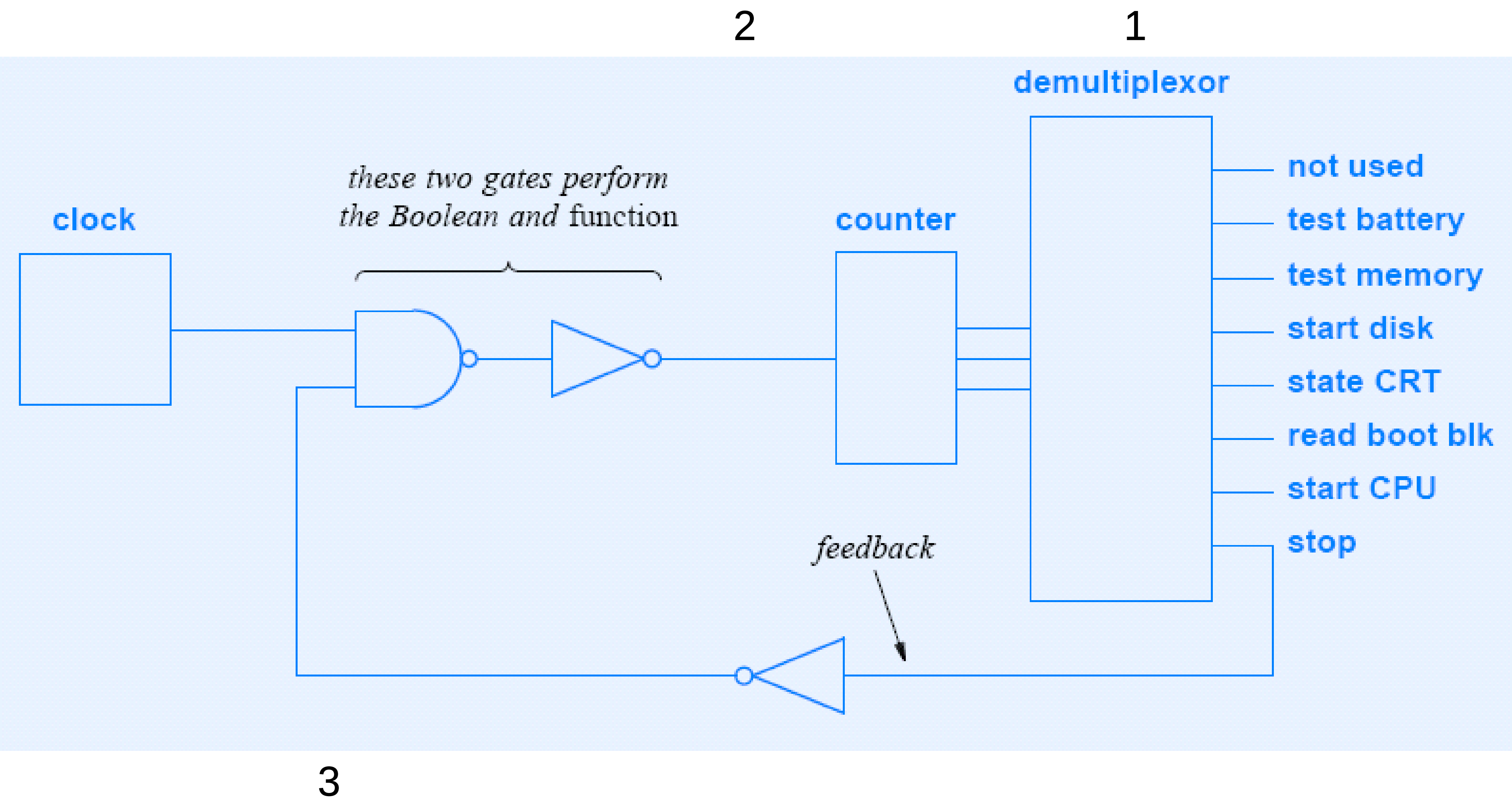
Clocks and Sequences

Input: coded binary n.



Output: line n is set.

Clocks and Sequences



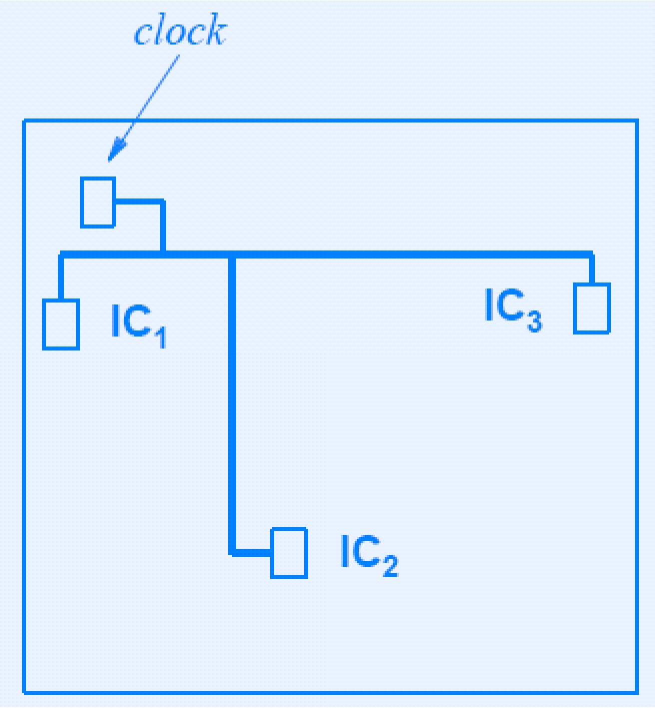
Software vs. Hardware

- Software: iterations common.
  - Avoid replication.
- Hardware: replication easier & faster.
  - Iteration clumsier.
- Major difference: parallelism.

Practical Concerns

- Power
  - consumption: how to feed
  - dissipation $P=CFV^2$ (C: capacitance, F: frequency) how not to burn
- Timing – gates need time to settle.
- Clock synchronization.

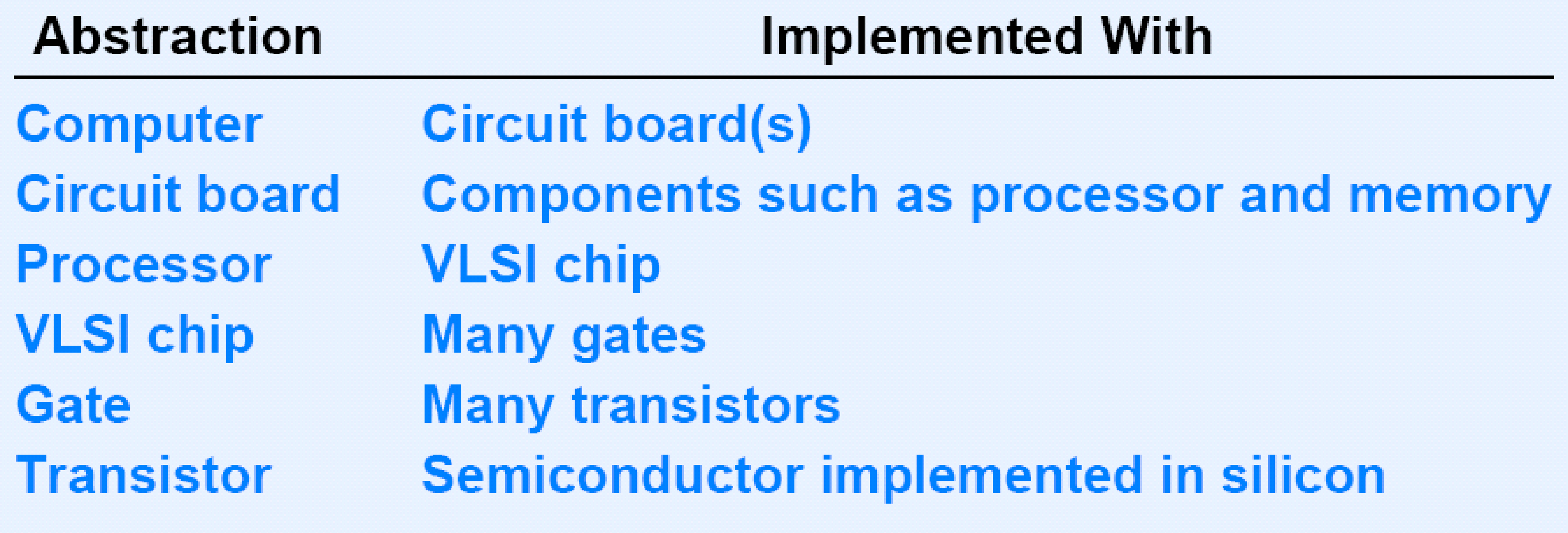
Clock Skew



Signals need time to propagate. Local clocks are used on larger systems → need to synchronize them.

The speed of light is too slow.

Levels of Abstraction



Abstraction	Implemented With
Computer	Circuit board(s)
Circuit board	Components such as processor and memory
Processor	VLSI chip
VLSI chip	Many gates
Gate	Many transistors
Transistor	Semiconductor implemented in silicon