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CSCI 150
Introduction to Digital and Computer System Design
Lecture 1: Digital Information Representations I

Jetic Gū

Overview

- Focus: Number Systems
- Architecture: Digital Circuits
- Textbook v4: Ch1 1.1, 1.2; v5: Ch1 1.1, 1.3
- Core Ideas:
  1. How information is represented in digital circuits

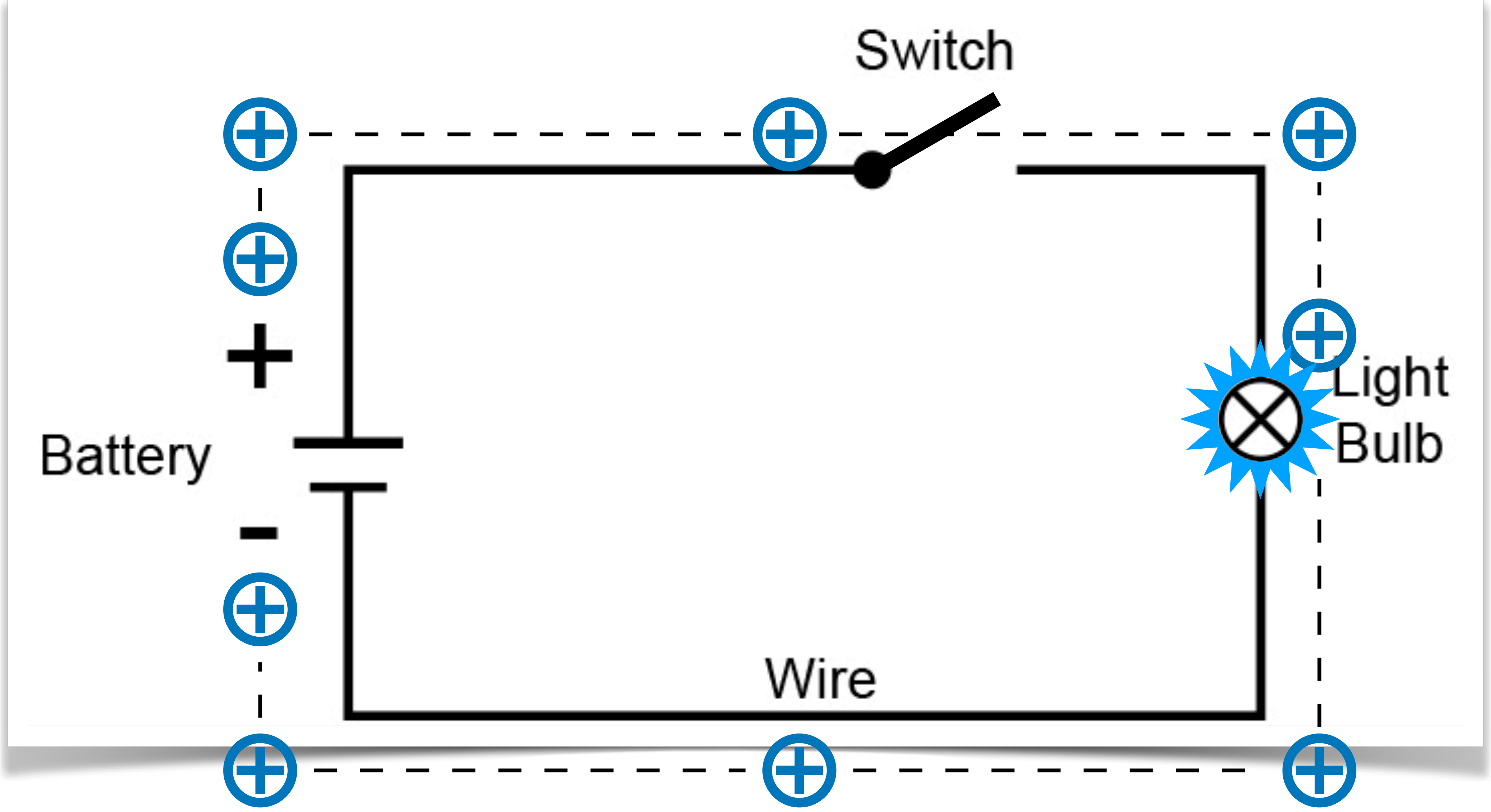
Basics

Analog vs Digital circuits;
Modern computer architectures;
Embedded systems;

P1
Basics

Circuits

- Circuits
  - Loop of conductive material
  - Charge carriers flow continuously within

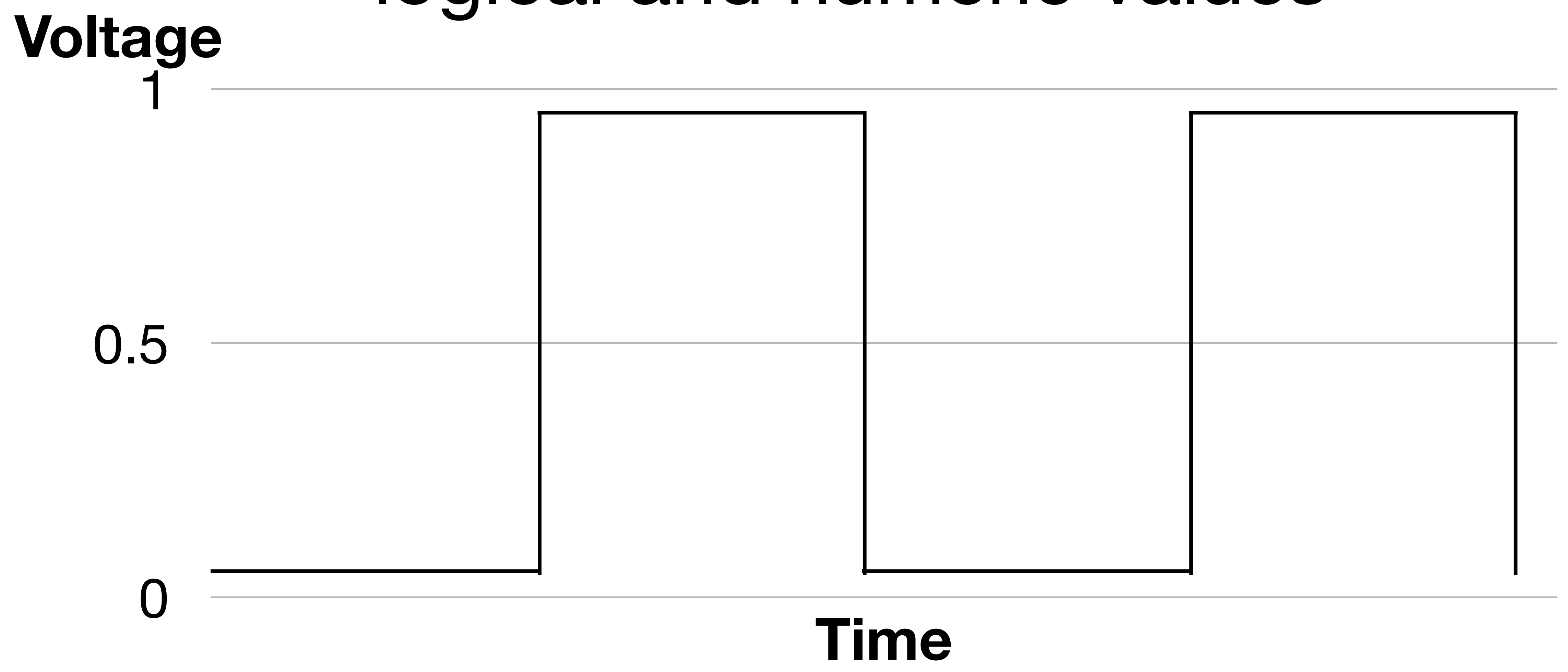


Concept

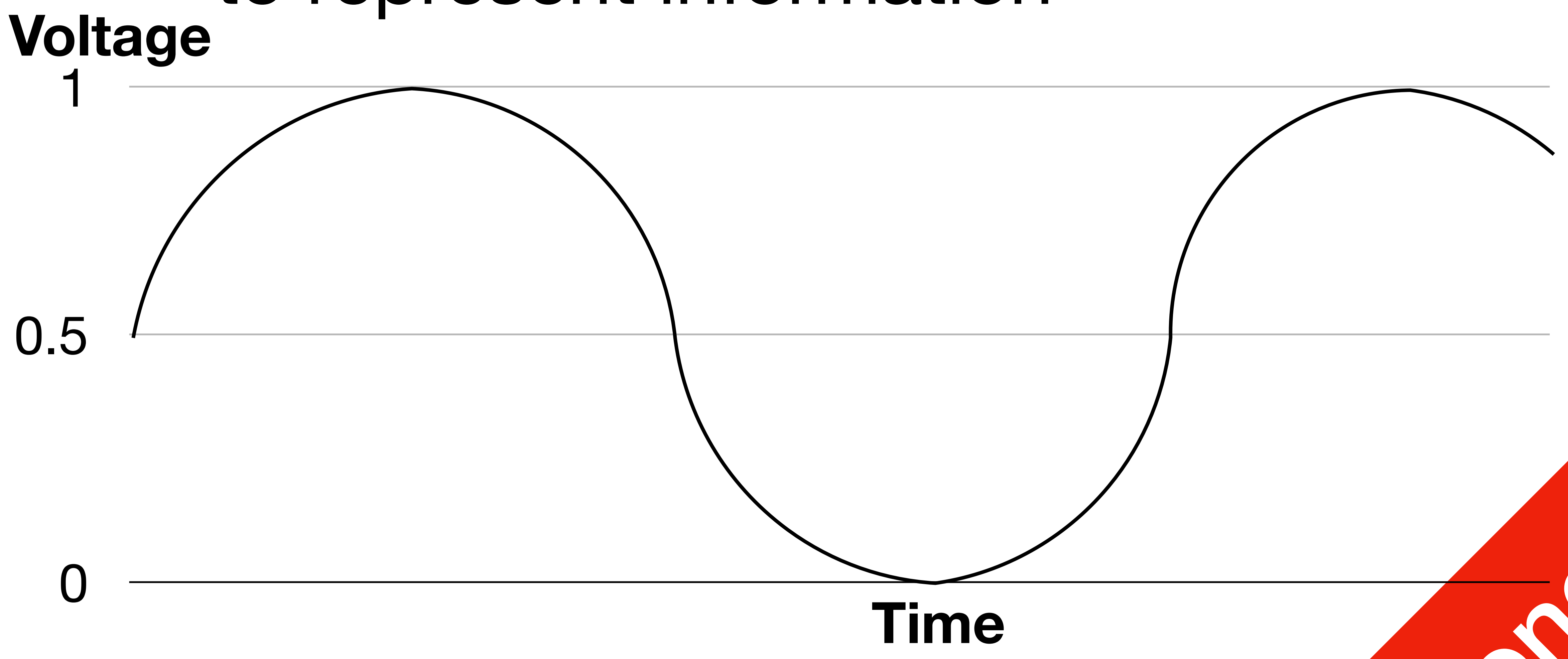
P1
Basics

Circuits

- Digital Circuits
  - Process digital signals
  - Current/Voltage represent discrete logical and numeric values



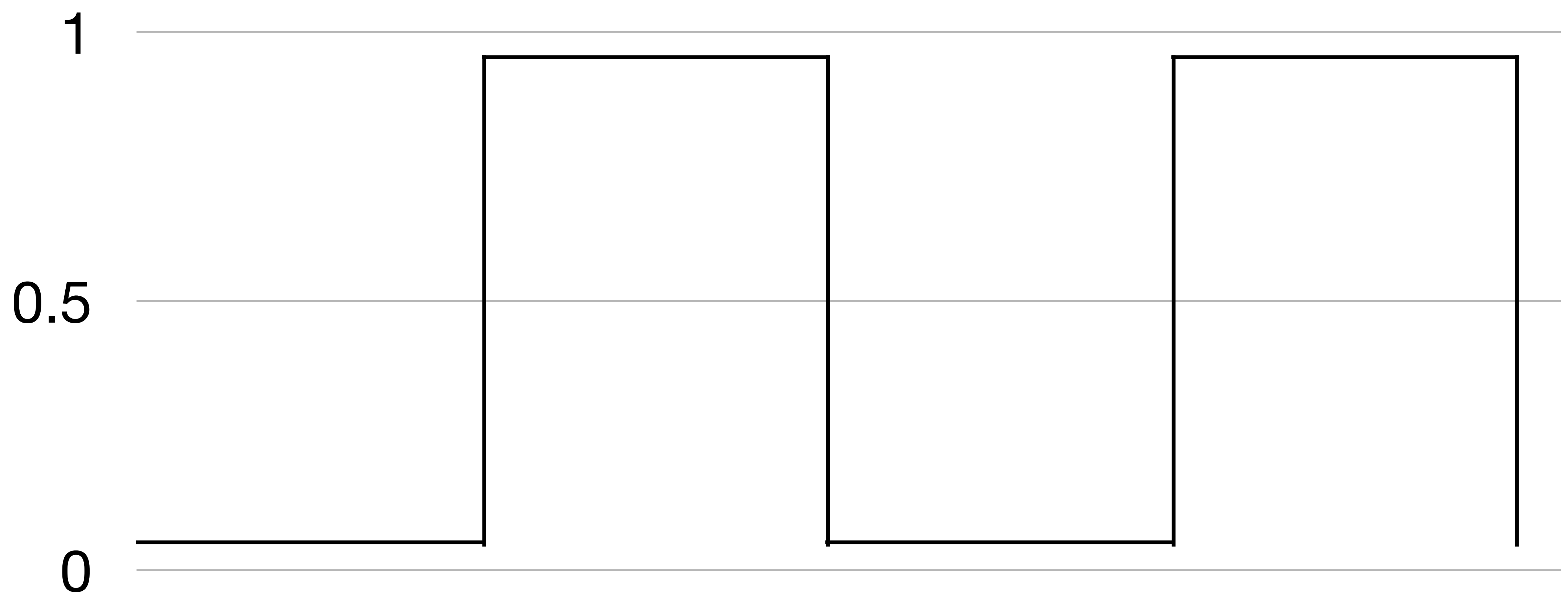
- Analog Circuits
  - Process analog signals
  - Current/Voltage vary continuously to represent information



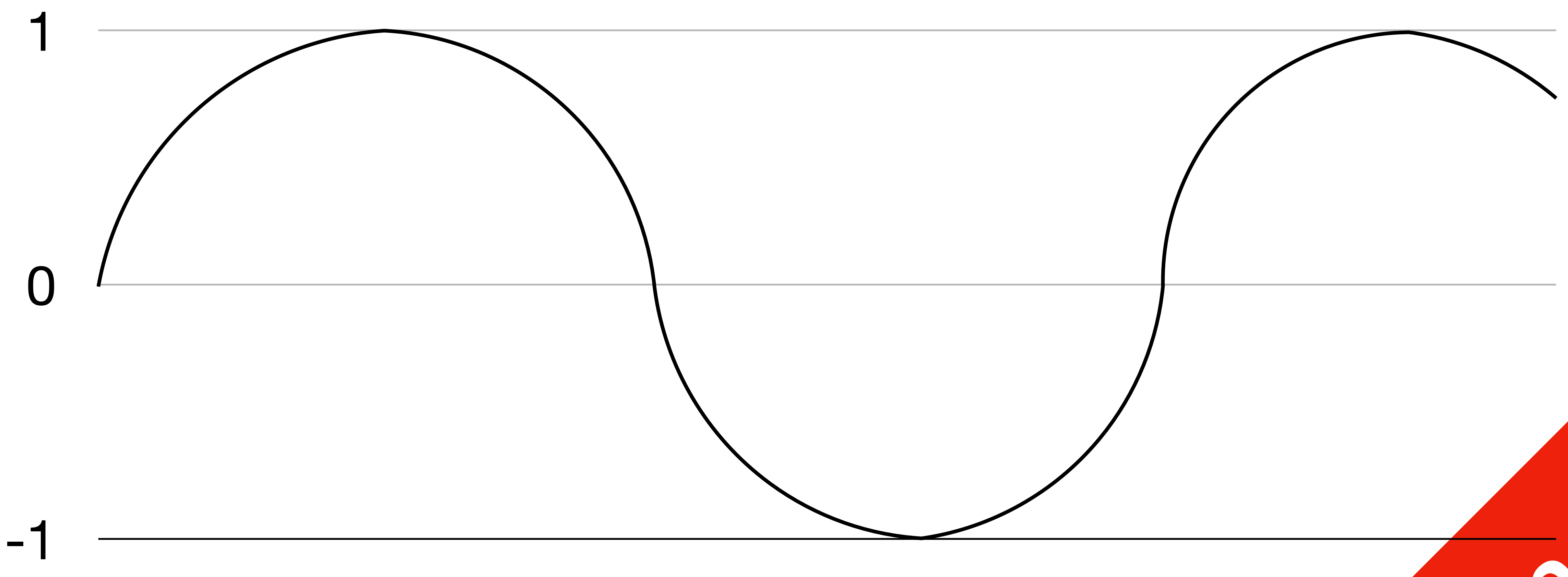
Concept

Circuits

- Digital Circuits
  - Computers
  - Blu-Ray Players



- Analog Circuits
  - Vinyl records
  - Radio

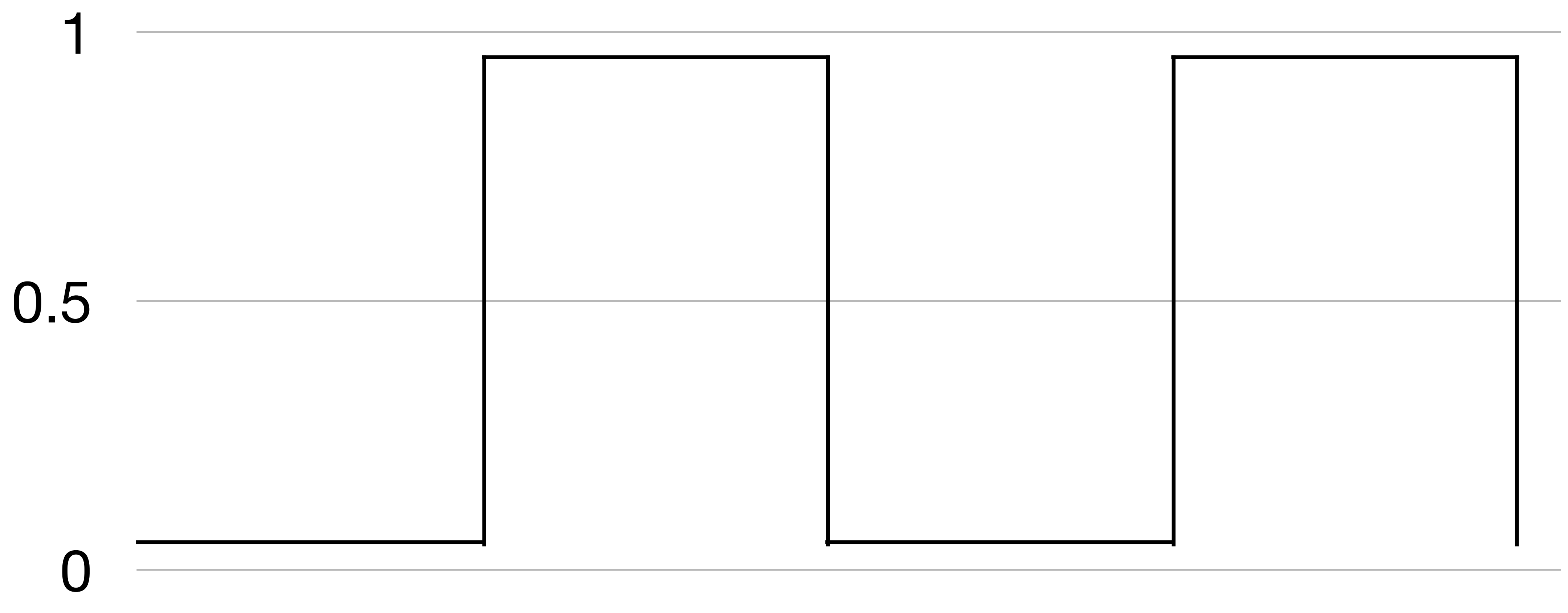


Concept

P1
Basics

Digital/Logical Circuits

- Basic signals
  - High/Low; On/Off; True/False; 1/0;



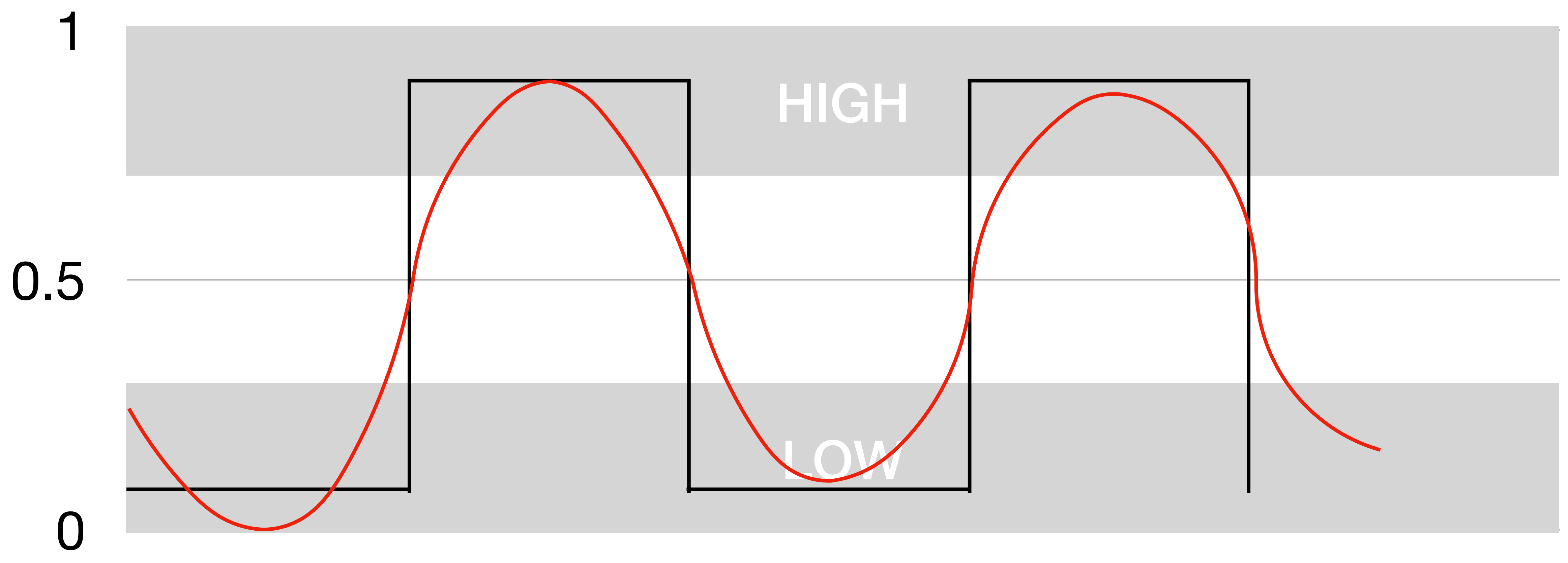
- Voltage is still continuous in digital circuits

Concept

P1
Basics

Digital/Logical Circuits !

- Basic signals
  - High/Low; On/Off; True/False; 1/0;



- Voltage is still continuous in digital circuits

Concept

P1
Basics

Digital/Logical Circuits !

- Basic signals
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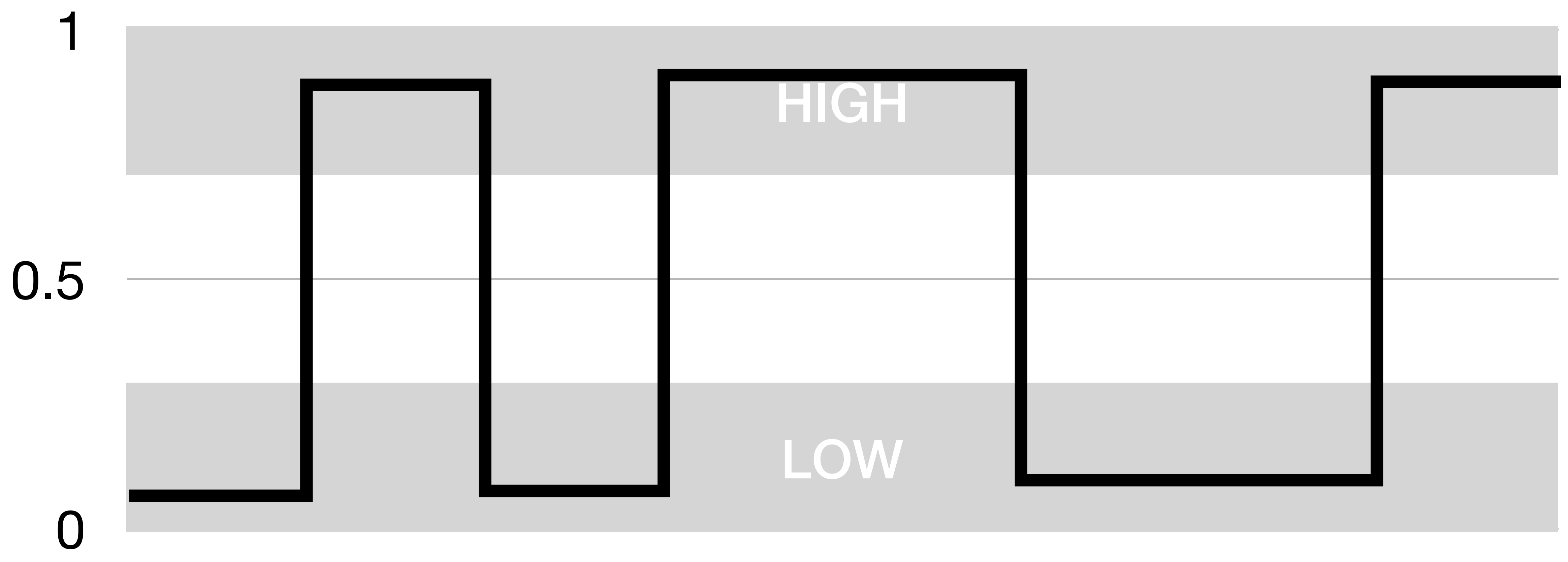


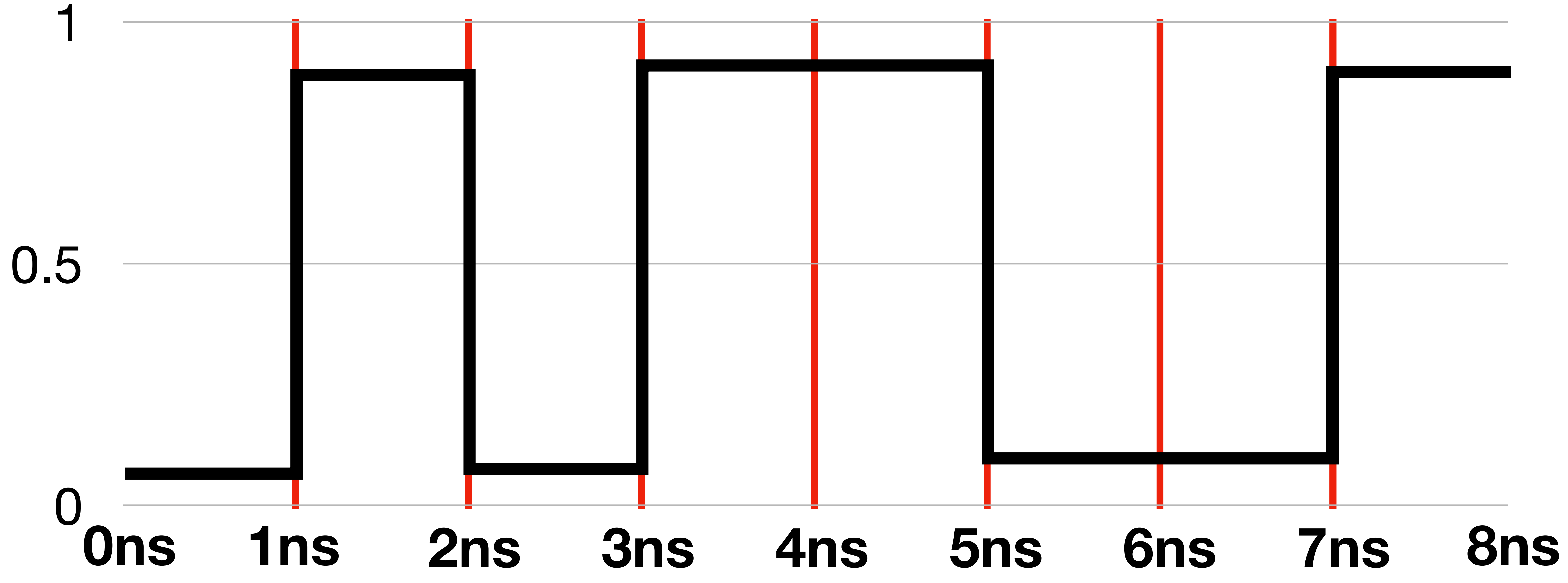
- Voltage is still continuous in digital circuits
- Approximation
- What is this signal?

Concept

P1
Basics

Digital/Logical Circuits !

- Basic signals
  - High/Low; On/Off; True/False; 1/0;

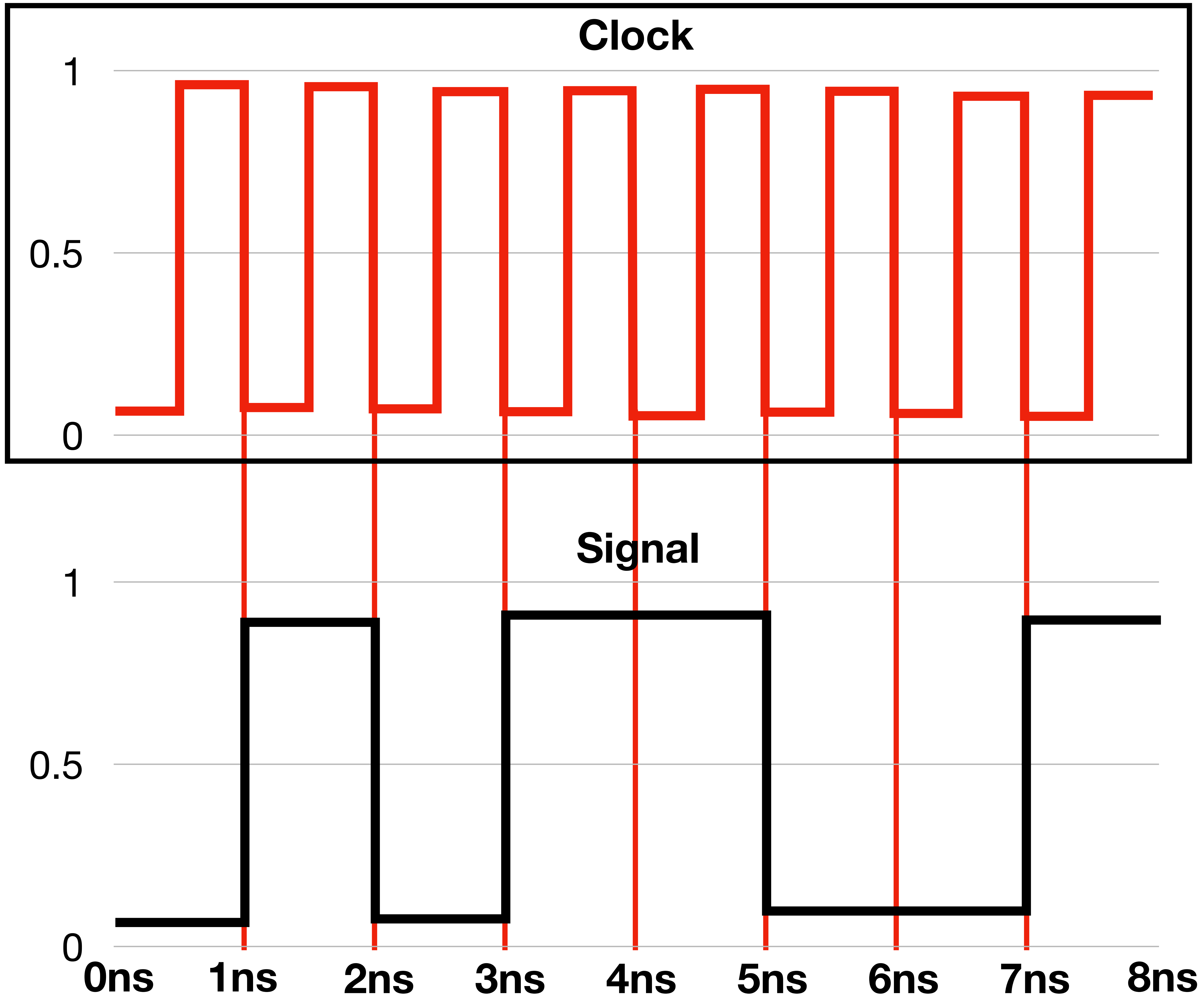


- Voltage is still continuous in digital circuits
- Approximation
- What is this signal?
  - You can fix the **sample (signal) rate**!
    e.g. every 1ns[1] is 1bit of info
    that's 10^9 samples/signals per sec

1. ns = nanosecond

Concept

Digital/Logical Circuits

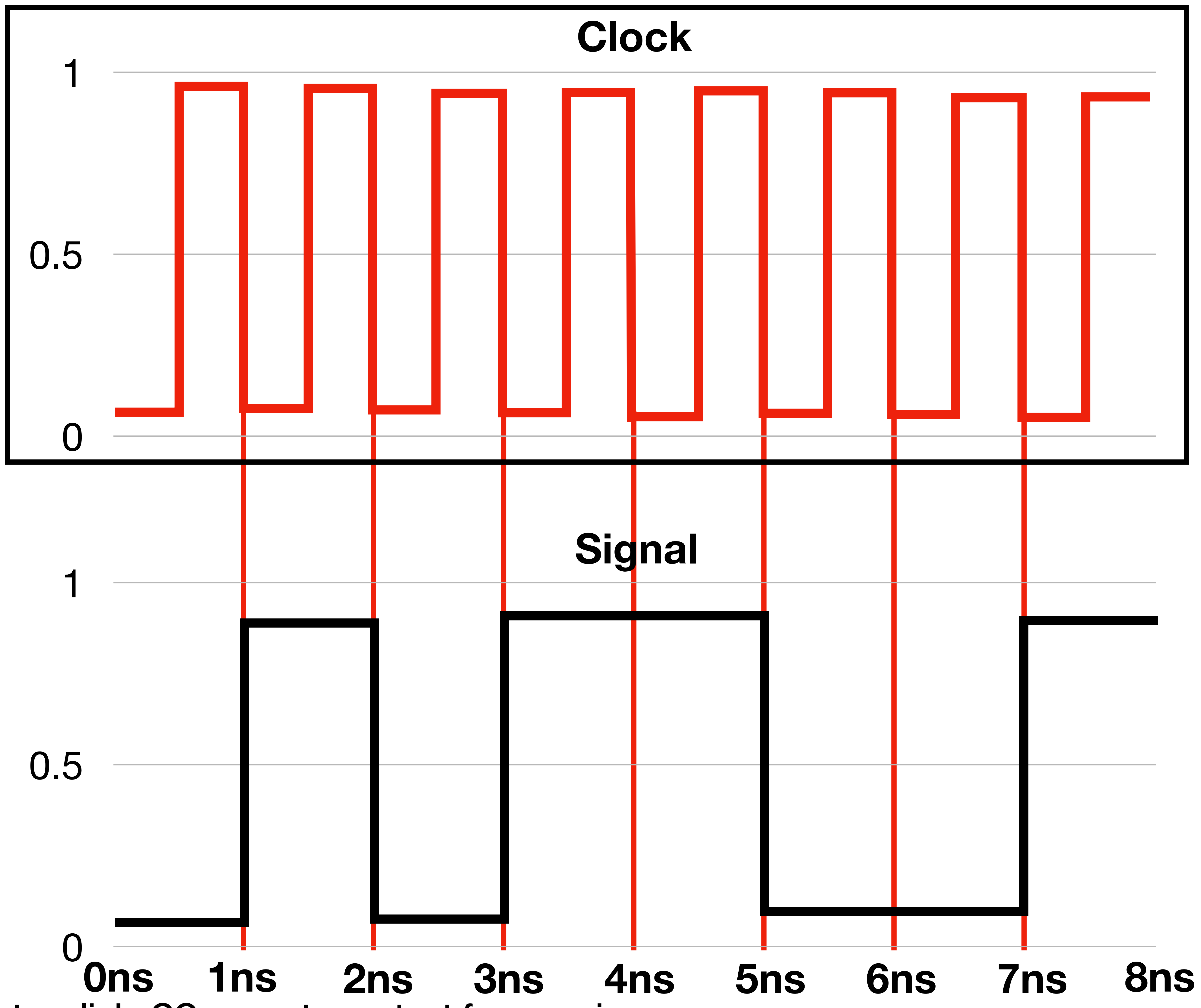


- In computers, this is controlled using a **Clock** (also called **CLK**)
- Clocks can run at:
  1) **constant** frequencies (clock speeds); or
  2) **variable** frequencies (clock speeds)
- Clock speed is measured by **Herz** (**Hz**): number of repetitions per second
- Left: 1ns per sample/signal
  10^9 samples/signals per sec
  10^9 Hz = 10^6 KHz = 10^3 MHz = 1GHz

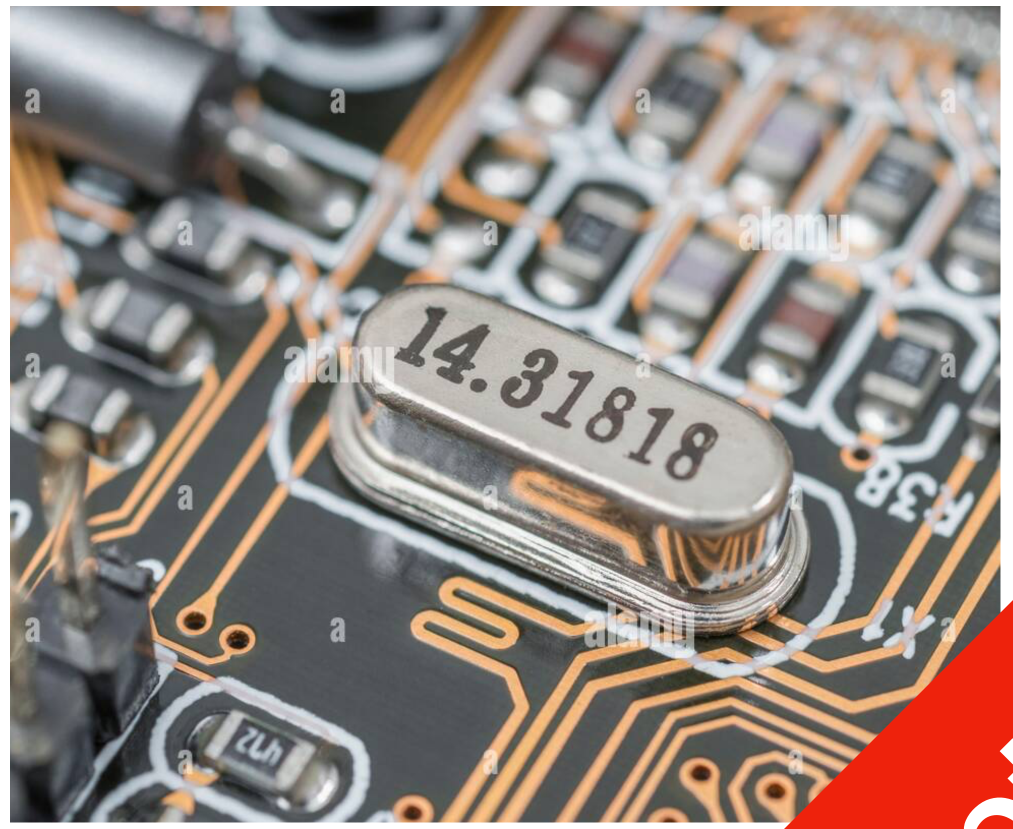
Concept

P1
Basics

Digital/Logical Circuits



- Where are the clocks?
  - **Crystal Oscillators**[1] on motherboards
    - This one runs at 14.31818 MHz
  - **VCOs**[2] in CPU, GPU, etc.

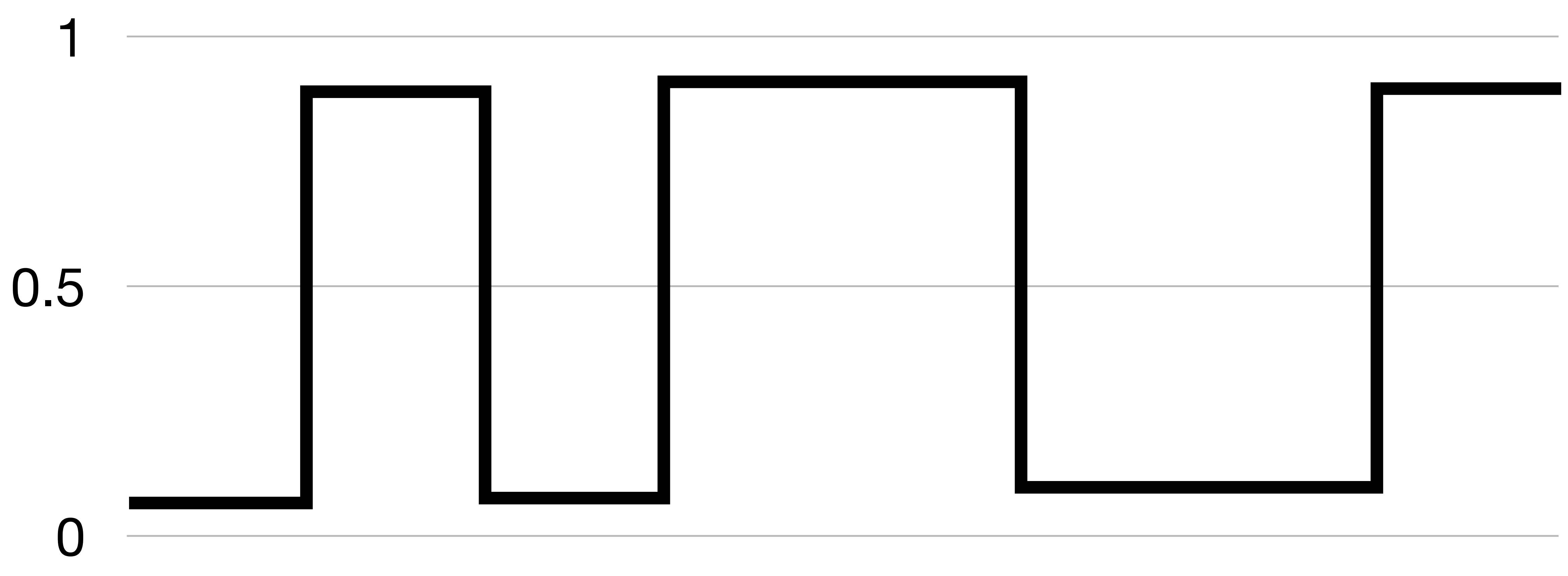


1. Picture link, COs run at constant frequencies
2. Voltage Controlled Oscillators, these can run at variable frequencies, they use COs as references

Concept

Digital/Logical Circuits

- Basic signals
  - High/Low; On/Off; True/False; 1/0;

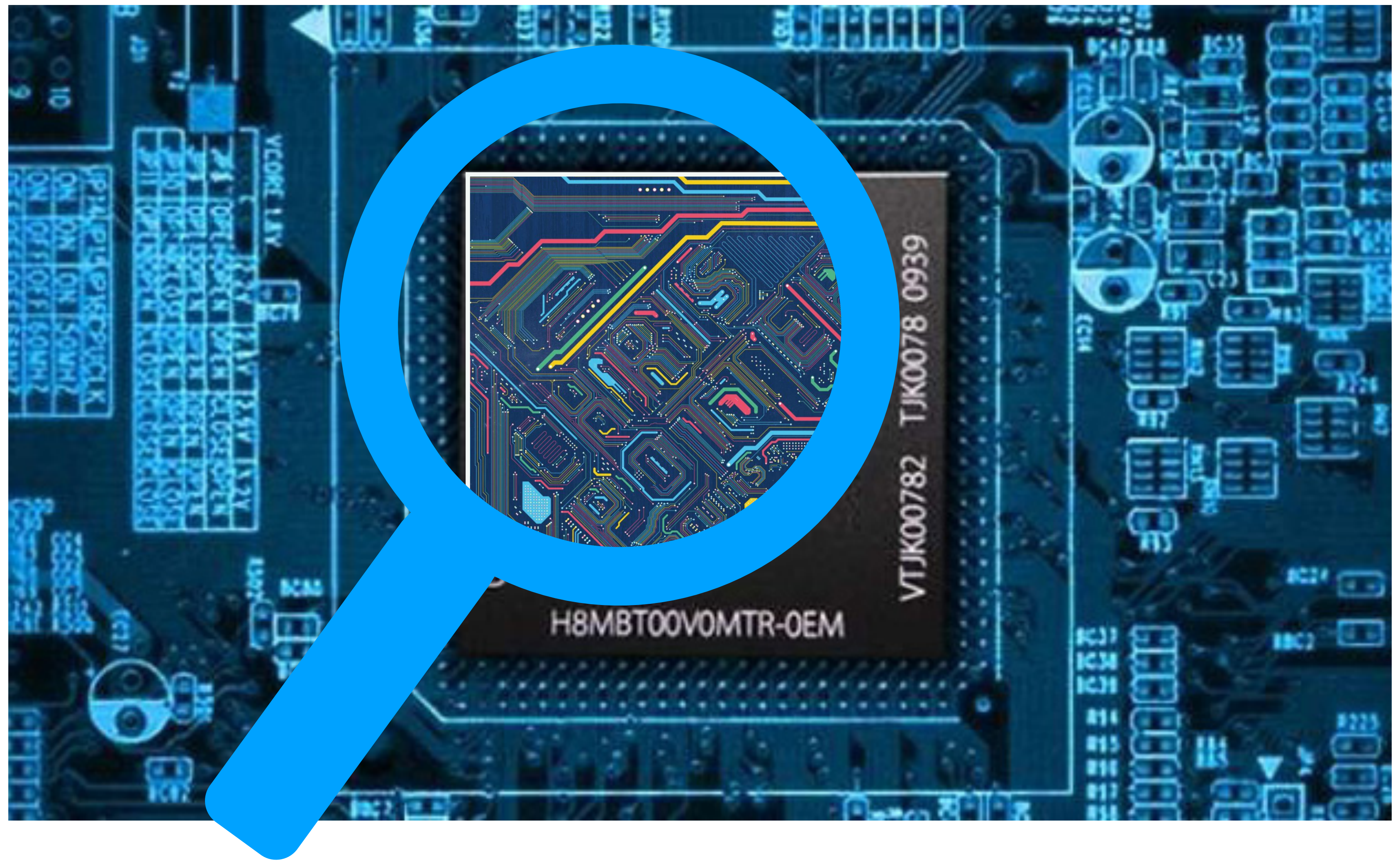


- Why might it be better than analog?
  - Resistant to noise
  - High precision
  - Faster
- Important Concept: Sample rate

Concept

Digital Integrated Circuits

- A "small" chip
  - filled with tiny components: transistors, logical gates, etc.
  - The scale of integration determined by the amount of these components
  - Inseparably associated and electrically interconnected

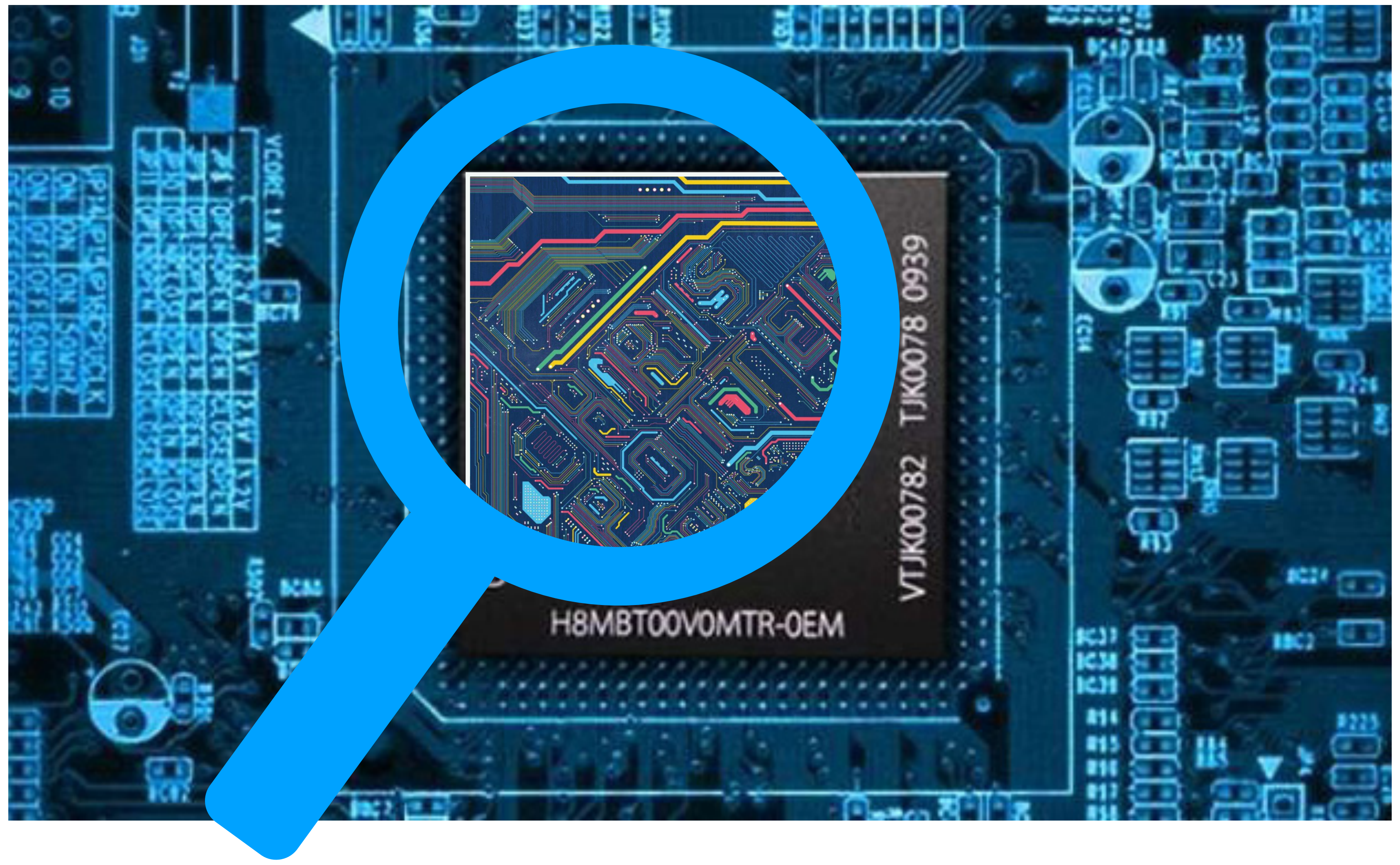


1. https://www.jedec.org/standards-documents/dictionary/terms/integrated-circuit-ic

Concept

Digital Integrated Circuits

- SSI (Small Scale Integration)
  <100 components / <10 gates
- MSI (Medium Scale Integration)
  [100, 500) components / [10, 100) gates
- In LSI (Large Scale Integration)
  [500, 300000) components / <100 gates
- VLSI, ULSI, GSI
- *exact definition varies

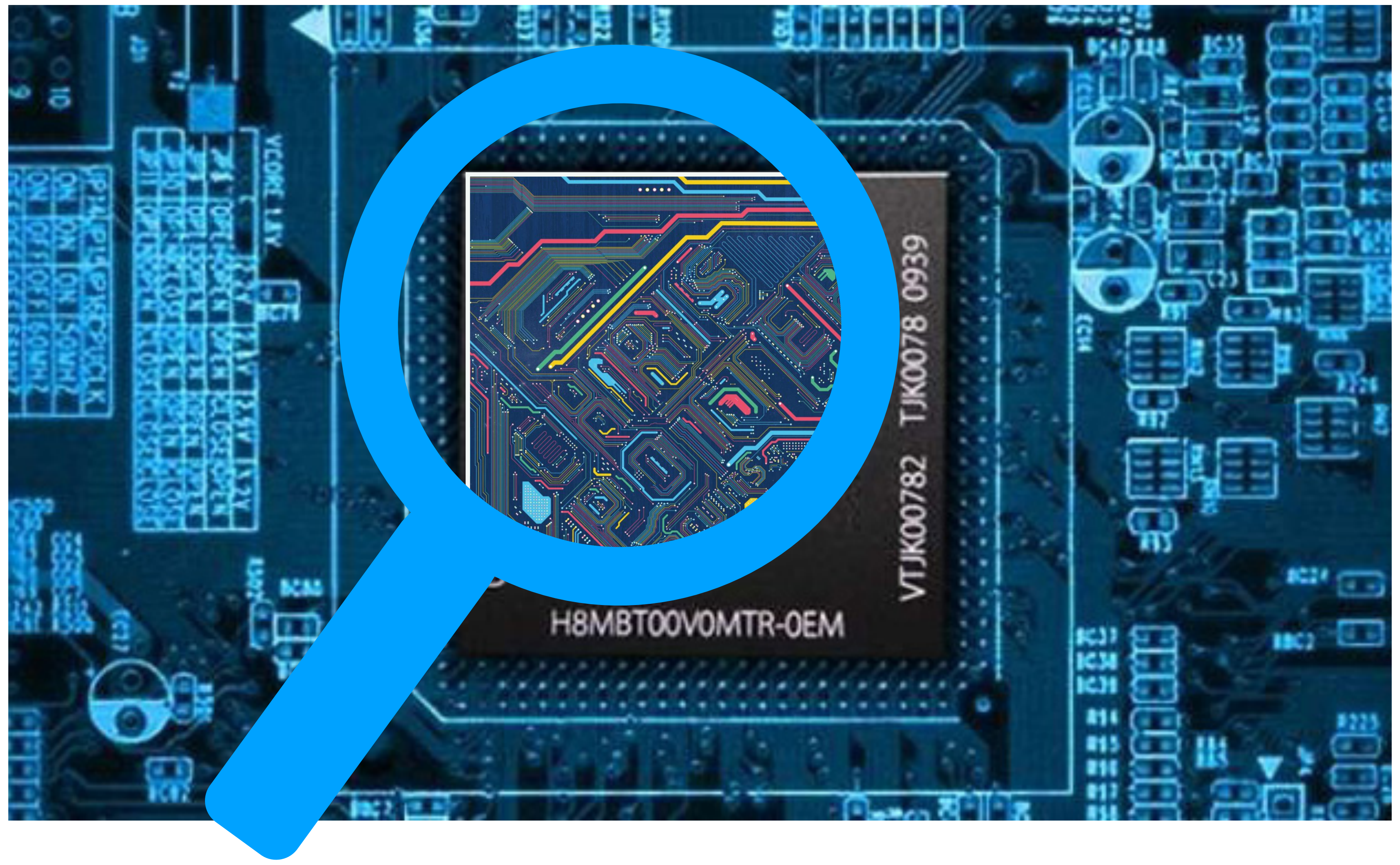


1. https://www.daenotes.com/electronics/devices-circuits/integrated-circuits-ic

Concept

Digital Integrated Circuits

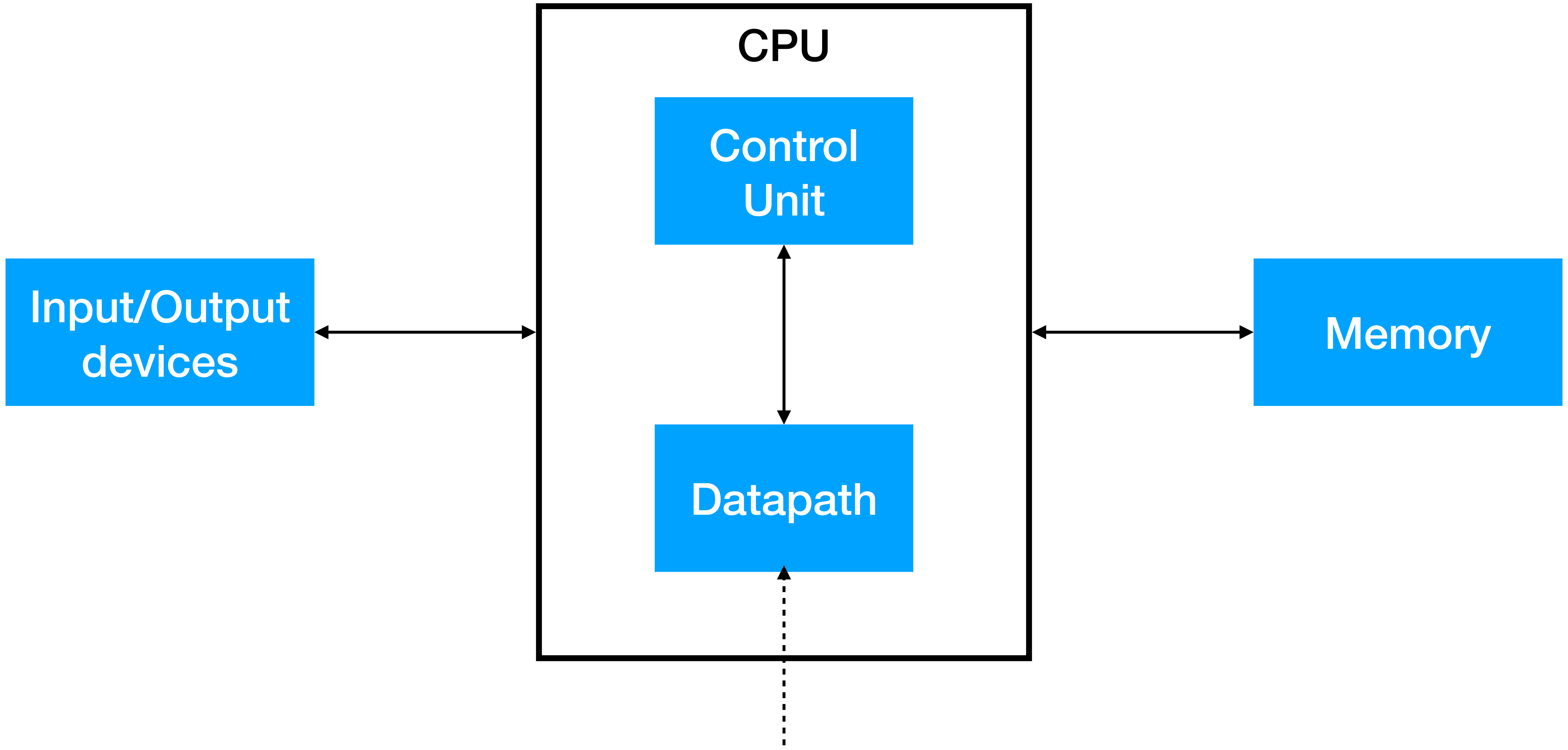
- **SSI (Small Scale Integration)**
  <100 components / <10 gates
- **MSI (Medium Scale Integration)**
  [100, 500) components / [10, 100) gates
- In LSI (Large Scale Integration)
  [500, 300000) components / <100 gates
- VLSI, ULSI, GSI
- *exact definition varies



Concept

1. https://www.daenotes.com/electronics/devices-circuits/integrated-circuits-ic

Computer

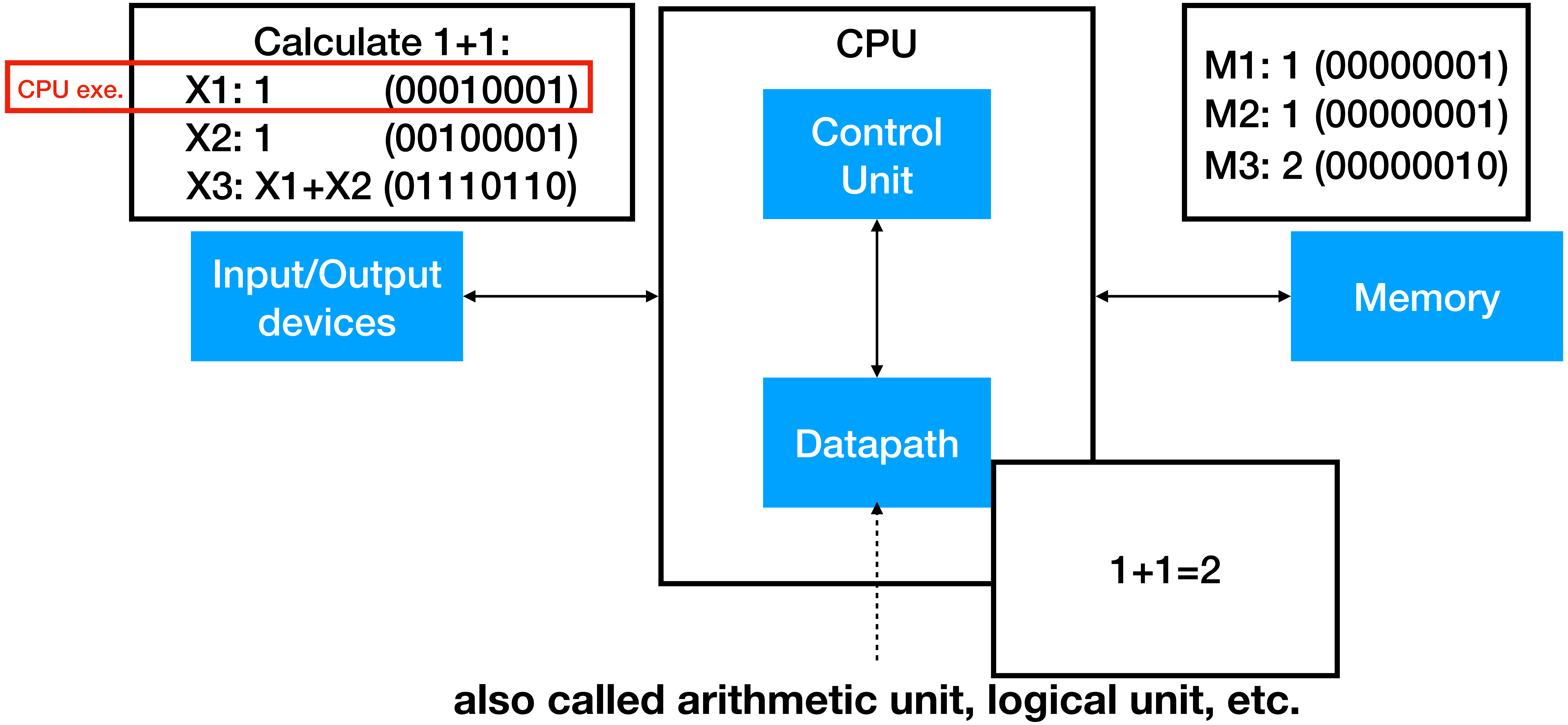


also called arithmetic unit, logical unit, etc.

1. Von Neumann Architecture

Computer

A very rough example



1. Von Neumann Architecture

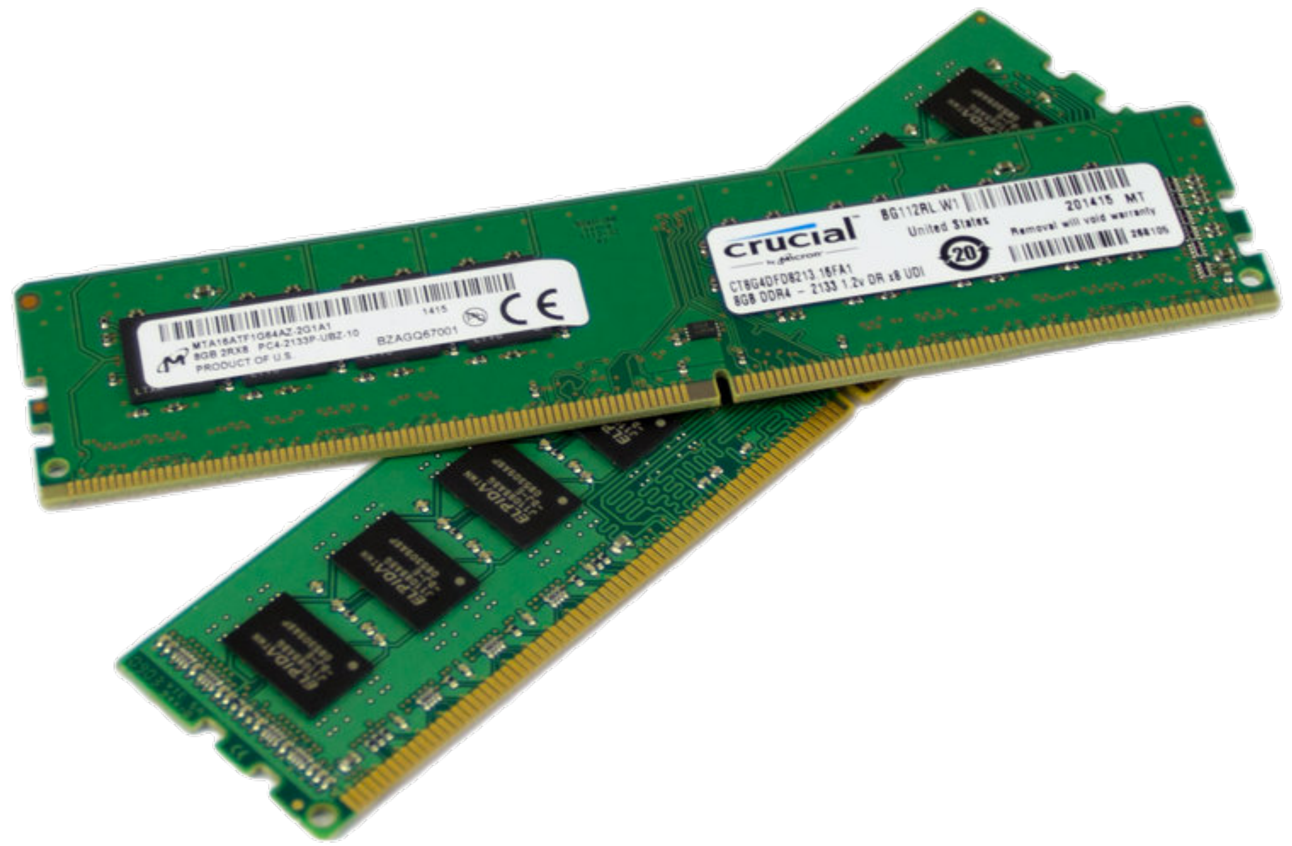
Computer

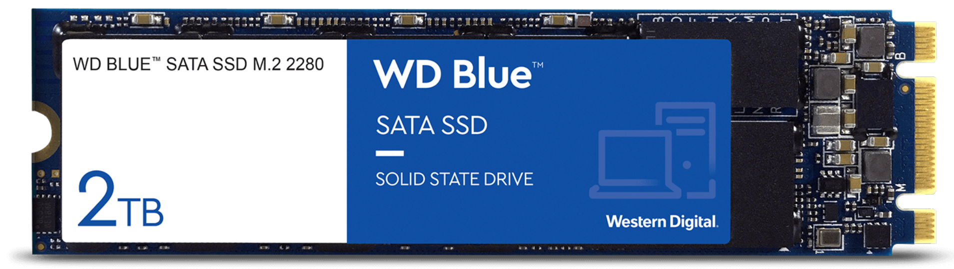
What's it like compared to a human?

- Input/Output devices
  - Interaction (Mouth, hands and feet, eyes, etc.)
- CPU + Memory
  - Processing information, thinking (Brain, short-term memory)
- Storage?
  - Part of I/O devices (Books, long-term memory)

Concept

Memory in Computers

- von Neumann Memory
  - RAM (Random Access Memory)
  - Usually smaller capacity
  - 

- Storage Device (Part of I/O Device)
  - ROM (Read-Only Memory)
  - Usually larger capacity
  - 


Concept

Embedded Systems

- Similar to computers: processes information
- Difference
  - Function is usually simpler, and very very specific
  - Not programmable

P1
Basics

Embedded Systems

- Example:
  - USB devices, such as USB sticks
    - USB is a complex protocol
    - Data Transfer stages: Synchronisation; Packet transfer; Termination

Concept

Embedded Systems

- Example:
  - Coprocessors for streaming media
  - Modern media comes compressed
    - Older computer uses software packages to perform decoding (decompression and output pixels/analog acoustics)
    - Modern computers have dedicated embedded chips to perform decoding (e.g. H264 codec)

Summary

- Circuits
  - Digital and Analog
- Integrated systems
  - Von Neumann computers
  - Embedded systems

Number Systems

Binary, Octal and Hexadecimal Numbers;
Number Ranges

Summary

Decimal System

7	2	4	.	0	5
2	1	0		−1	−2

- Numbers as strings of digits, each ranging from 0-9
- The decimal system is of base(radix) 10

Review

Decimal System

$$\underset{2}{7}\;\underset{1}{2}\;\underset{0}{4}.\underset{-1}{0}\;\underset{-2}{5}$$

$$= 7 \times 10^{2} + 2 \times 10^{1} + 4 \times 10^{0} + 0 \times 10^{-1} + 5 \times 10^{-2}$$

- Numbers as strings of digits, each ranging from 0-9
- The decimal system is of base(radix) 10

Review

Numbers of base N

- Default base: 10
- When there are numbers represented in different bases, attach base
  - Decimal: 754.05 -> $(754.05)_{10}$
  - e.g. Base 5: $(432.1)_5$ = ?

$$= 4 \times 5^2 + 3 \times 5^1 + 2 \times 5^0 + 1 \times 5^{-1} = (117.2)_{10}$$

Concept

Numbers of base N

- ALWAYS write down the base if not decimal!
  - Avoid confusion

Concept

Numbers of base N

- Convert binary number $(10100)_2$ to decimal

2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
256	128	64	32	16	8	4	2	1

(1 0 1 0 0 $)_2$

16 x 1 + 8 x 0 + 4 x 1 + 2 x 0 + 1 x 0 = 20

Example

Numbers of base N

- Convert decimal number 134 to binary

2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
256	128	64	32	16	8	4	2	1

134 = 128 + 4 + 2

128 remain (6)

+ 4 remain (2)

+ 2 remain (0)

1 0 0 0 0 1 1 0

$= (10000110)_2$

Example

Numbers of base N

- Convert decimal number 134 to binary

2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
256	128	64	32	16	8	4	2	1

- Make sure the largest number in the table is greater than your target decimal number

- Don’t forget to include trailing zeroes

Example

P2
Number Systems

Octal and Hexadecimal Systems

Decimal (Base 10)	Binary (Base 2)	Octal (Base 8)	Hexadecimal (Base 16)
00	0000	00	0
01	0001	01	1
02	0010	02	2
03	0011	03	3
04	0100	04	4
05	0101	05	5
06	0110	06	6
07	0111	07	7
08	1000	10	8
09	1001	11	9
10	1010	12	A
11	1011	13	B
12	1100	14	C
13	1101	15	D
14	1110	16	E
15	1111	17	F

Concept

Octal and Hexadecimal Systems

- Binary Number: $(1100\ 1101\ 0110)_2$
  - Convert to Hex
    - $(1100)_2 = (C)_{16} =$ Ch; $(1101)_2 = (D)_{16} =$ Dh; $(0110)_2 = (6)_{16} =$ 6h;
    - $(1100\ 1101\ 0110)_2 = (CD6)_{16} =$ CD6h

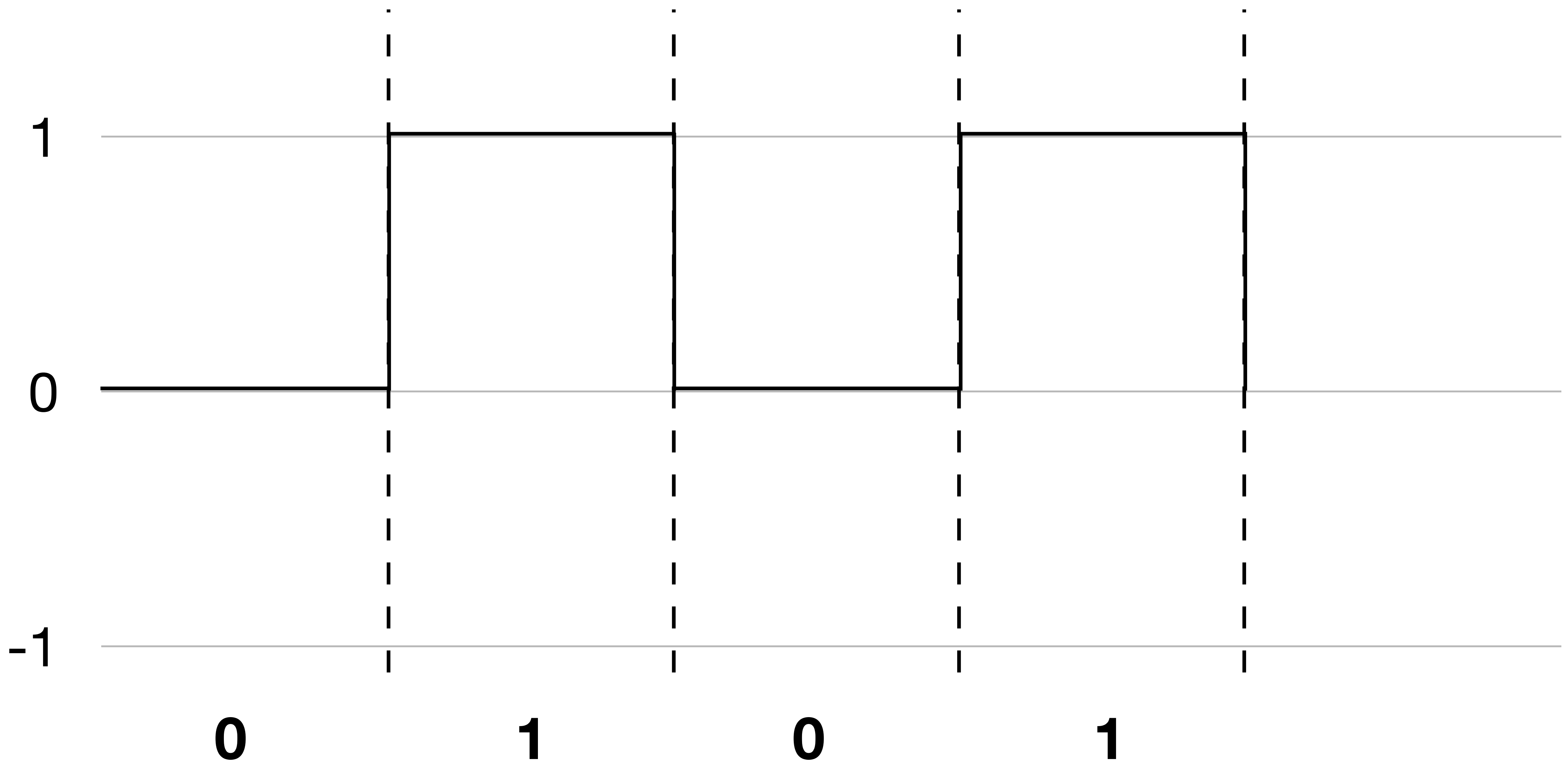
Concept

Numbers of base N

- Conversion exercises
  - decimal to binary; binary to decimal
  - hexadecimal to binary; binary to hexadecimal
  - hexadecimal <--> decimal (through binary)

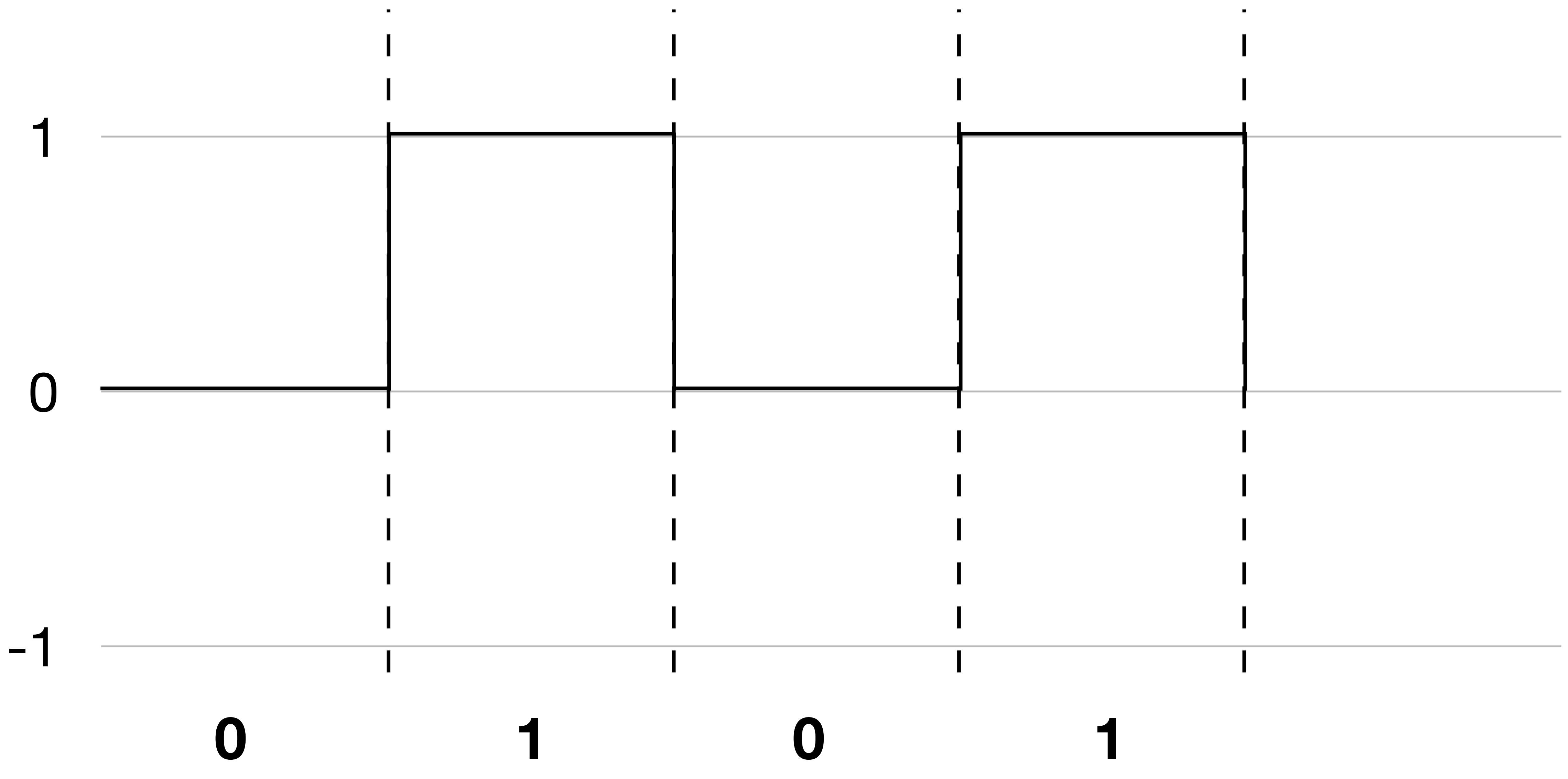
Example

Binary System



- Base 2 system
- A number is represented with a string of 1s and 0s, each called a *bit*
- $(0101)_2 = 5$

Binary System

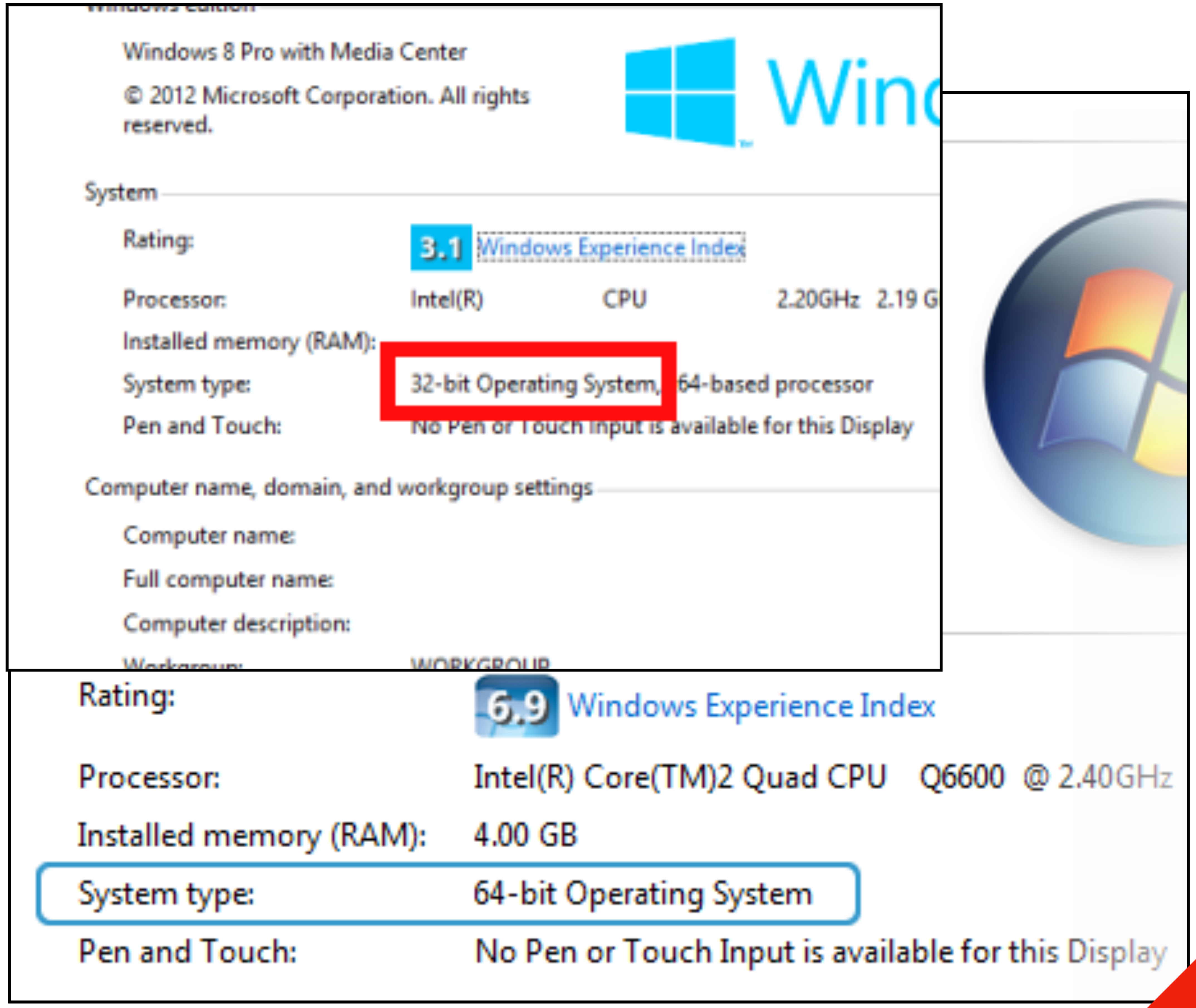


- Is it possible to use different bases in a digital circuit?
- If it is possible, why haven't we seen it very often?

Technical

Binary Systems in Computers

- Every 8bit is called a Byte
- 32bit OS
  - A single number is represented by 32bits
  - Range (int): 0 - 4,294,967,295
- OS vs Processor?
  - Compatibility mode



Concept

Binary Systems in Computers

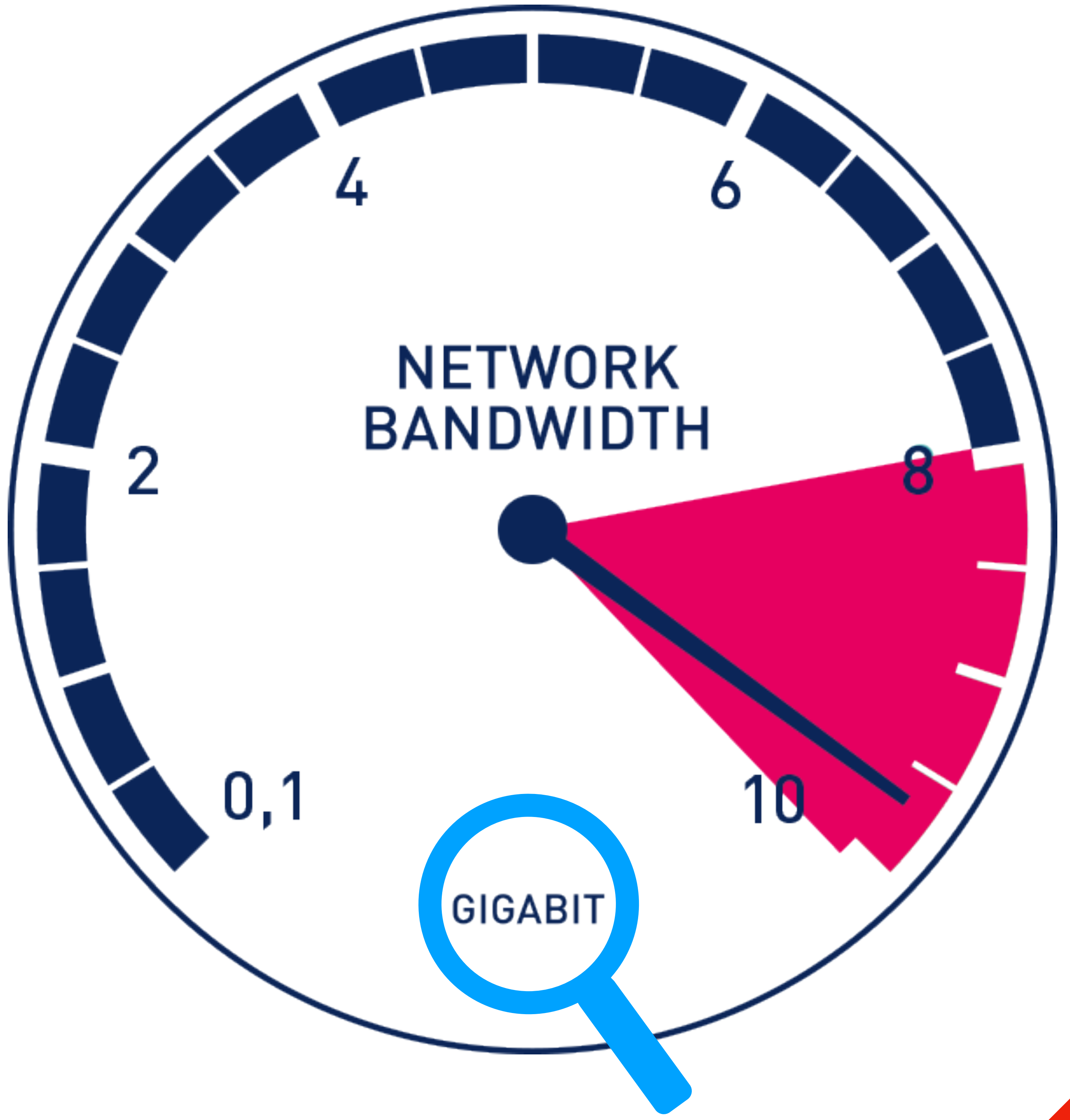
- Every 8bit is called a Byte
- 1,024 = 2^{10} is called K (Kilo)
- 1,024 x 1,024 = 2^{20} is called M (Mega)
- 1,024 x 1,024 x 1,024 = 2^{40} is called G (Giga)
- Tera, Peta, Exa, Zetta, Yotta

Concept

P2 Number Systems

Binary Systems in Computers

- What is the difference between MBps and Mbps?
  - MegaBytes per second vs MegaBits per second
  - 8x difference!



Concept

Binary Systems in Computers

- Every 8bit is called a Byte
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Concept

Octal and Hexadecimal Systems

- Octal: base 8
  - digits: 0-7
- Hexadecimal: base 16
  - digits: 0-9, A-F (10-15)

Octal and Hexadecimal Systems

Decimal (Base 10)	Binary (Base 2)	Octal (Base 8)	Hexadecimal (Base 16)
00	0000	00	0
01	0001	01	1
02	0010	02	2
03	0011	03	3
04	0100	04	4
05	0101	05	5
06	0110	06	6
07	0111	07	7
08	1000	10	8
09	1001	11	9
10	1010	12	A
11	1011	13	B
12	1100	14	C
13	1101	15	D
14	1110	16	E
15	1111	17	F

Concept

Summary

- Number systems of base N
- Binary systems
- Octal and Hexadecimal systems