*Master of International Business and Entrepreneurship*

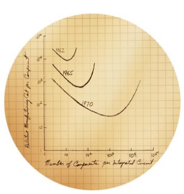
# Hardware Core Concepts

Information Systems for Managers

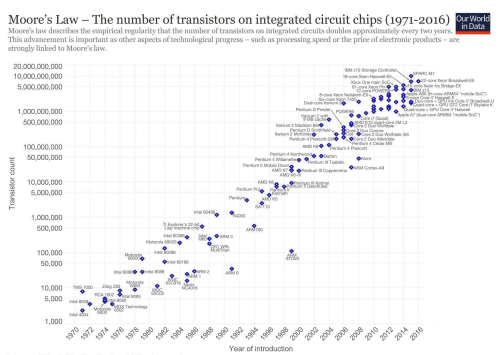
# Learning Objectives

- Understand the basic representation model that computers use.
- Understand the link between Moore's Law and CPU performance.
- Be able to describe the von Neumann computing architecture and understand the design of a general purpose machine.
- Understand and be able to describe the stored program concept.
- Be aware of, and be able to use, the appropriate technical terminology when talking about computer hardware.

# Moore's Law

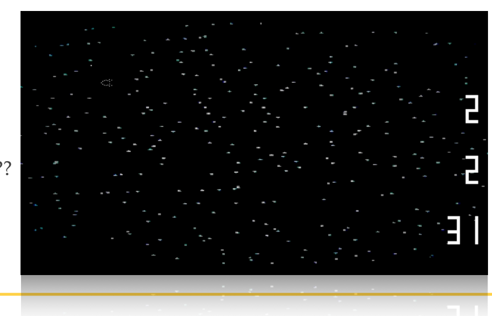


http://en.wikipedia.org/wiki/Moore%27s_law




# Moore's Law: Implications

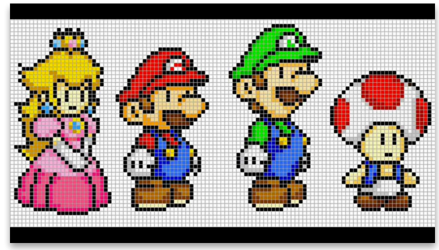
- Why?
- What is the relationships between transistors and computing power?
- And what is computing power anyway??



# Digital Technology

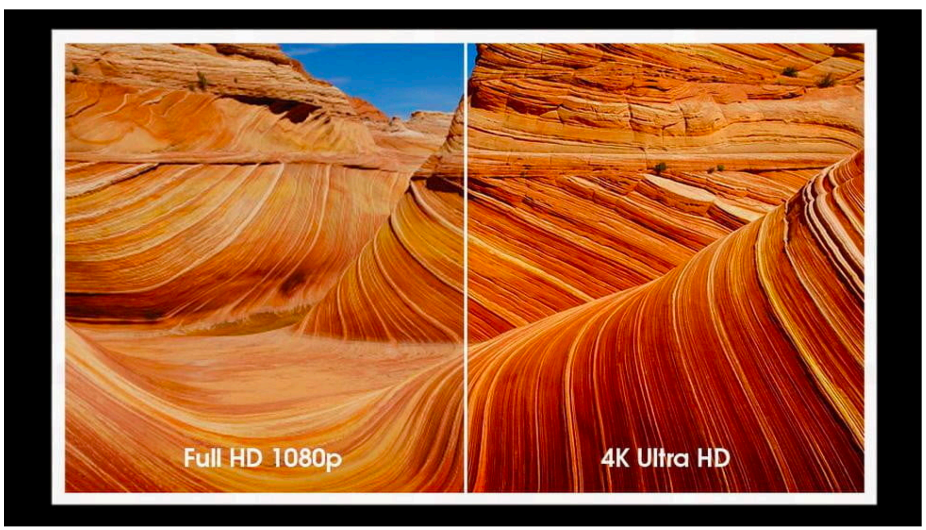
- Digital: From the Latin *Digitus* (Finger).
- Digit:
  - a finger (including the thumb) or toe.
  - any of the numerals from 0 to 9, especially when forming part of a number.
- Digital: Using digits, or made of digits (i.e., discrete).
- Digital signal: Is a codified message represented as a sequence of discrete values.
- Analog signal: Is a codified message represented as a continuous time varying variable that changes as a function of the quantity it encodes - its analogue.
- Digital electronics: Electronic equipment and components that manipulate digital signals.


# Digital vs Analog



**What's the "resolution" of your computer screen?**

**What does that number mean?**




# Binary Representation

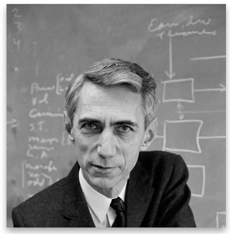

Bit → $\boxed{\phantom{0}}$

One bit: $2^1$ → $\left\{ \begin{array}{l} \boxed{0} \\ \boxed{1} \end{array} \right.$

Two bits: $2^2$ → $\left\{ \begin{array}{ll} \boxed{0} & \boxed{0} \\ \boxed{0} & \boxed{1} \\ \boxed{1} & \boxed{0} \\ \boxed{1} & \boxed{1} \end{array} \right.$

# Bit: Binary digIT

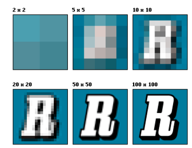
“If the base 2 is used the resulting units may be called binary digits, or more briefly bits [...]. A device with two stable positions, such as a relay or a flip-flop circuit, can store one bit of information. N such devices can store N bits.”

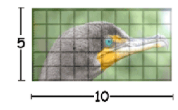


*Claude Shannon*, *father of Information Theory*

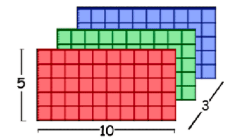
Reprinted: Shannon, C. E. (2001). A mathematical theory of communication. ACM SIGMOBILE Mobile Computing and Communications Review, 5(1), 3-55.

# Digital Encoding



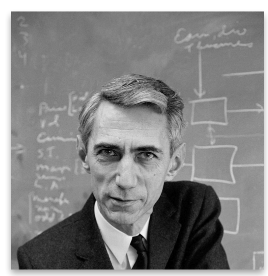

Original Color Image




Matlab RGB Matrix

| Decimal | Binary | Octal | Hex | ASCII | Decimal | Binary | Octal | Hex | ASCII | Decimal | Binary | Octal | Hex | ASCII | Decimal | Binary | Octal | Hex | ASCII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 00000000 | 000 | 00 | NUL | 32 | 00100000 | 040 | 20 | SP | 64 | 01000000 | 100 | 40 | @ | 96 | 01100000 | 140 | 60 | ` |
| 1 | 00000001 | 001 | 01 | SOH | 33 | 00100001 | 041 | 21 | ! | 65 | 01000001 | 101 | 41 | A | 97 | 01100001 | 141 | 61 | a |
| 2 | 00000010 | 002 | 02 | STX | 34 | 00100010 | 042 | 22 | " | 66 | 01000010 | 102 | 42 | B | 98 | 01100010 | 142 | 62 | b |
| 3 | 00000011 | 003 | 03 | ETX | 35 | 00100011 | 043 | 23 | # | 67 | 01000011 | 103 | 43 | C | 99 | 01100011 | 143 | 63 | c |
| 4 | 00000100 | 004 | 04 | EOT | 36 | 00100100 | 044 | 24 | $ | 68 | 01000100 | 104 | 44 | D | 100 | 01100100 | 144 | 64 | d |
| 5 | 00000101 | 005 | 05 | ENQ | 37 | 00100101 | 045 | 25 | % | 69 | 01000101 | 105 | 45 | E | 101 | 01100101 | 145 | 65 | e |
| 6 | 00000110 | 006 | 06 | ACK | 38 | 00100110 | 046 | 26 | & | 70 | 01000110 | 106 | 46 | F | 102 | 01100110 | 146 | 66 | f |
| 7 | 00000111 | 007 | 07 | BEL | 39 | 00100111 | 047 | 27 | ' | 71 | 01000111 | 107 | 47 | G | 103 | 01100111 | 147 | 67 | g |
| 8 | 00001000 | 010 | 08 | BS | 40 | 00101000 | 050 | 28 | ( | 72 | 01001000 | 110 | 48 | H | 104 | 01101000 | 150 | 68 | h |
| 9 | 00001001 | 011 | 09 | HT | 41 | 00101001 | 051 | 29 | ) | 73 | 01001001 | 111 | 49 | I | 105 | 01101001 | 151 | 69 | i |
| 10 | 00001010 | 012 | 0A | LF | 42 | 00101010 | 052 | 2A | * | 74 | 01001010 | 112 | 4A | J | 106 | 01101010 | 152 | 6A | j |
| 11 | 00001011 | 013 | 0B | VT | 43 | 00101011 | 053 | 2B | + | 75 | 01001011 | 113 | 4B | K | 107 | 01101011 | 153 | 6B | k |
| 12 | 00001100 | 014 | 0C | FF | 44 | 00101100 | 054 | 2C | , | 76 | 01001100 | 114 | 4C | L | 108 | 01101100 | 154 | 6C | l |
| 13 | 00001101 | 015 | 0D | CR | 45 | 00101101 | 055 | 2D | - | 77 | 01001101 | 115 | 4D | M | 109 | 01101101 | 155 | 6D | m |
| 14 | 00001110 | 016 | 0E | SO | 46 | 00101110 | 056 | 2E | . | 78 | 01001110 | 116 | 4E | N | 110 | 01101110 | 156 | 6E | n |
| 15 | 00001111 | 017 | 0F | SI | 47 | 00101111 | 057 | 2F | / | 79 | 01001111 | 117 | 4F | O | 111 | 01101111 | 157 | 6F | o |
| 16 | 00010000 | 020 | 10 | DLE | 48 | 00110000 | 060 | 30 | 0 | 80 | 01010000 | 120 | 50 | P | 112 | 01110000 | 160 | 70 | p |
| 17 | 00010001 | 021 | 11 | DC1 | 49 | 00110001 | 061 | 31 | 1 | 81 | 01010001 | 121 | 51 | Q | 113 | 01110001 | 161 | 71 | q |
| 18 | 00010010 | 022 | 12 | DC2 | 50 | 00110010 | 062 | 32 | 2 | 82 | 01010010 | 122 | 52 | R | 114 | 01110010 | 162 | 72 | r |
| 19 | 00010011 | 023 | 13 | DC3 | 51 | 00110011 | 063 | 33 | 3 | 83 | 01010011 | 123 | 53 | S | 115 | 01110011 | 163 | 73 | s |
| 20 | 00010100 | 024 | 14 | DC4 | 52 | 00110100 | 064 | 34 | 4 | 84 | 01010100 | 124 | 54 | T | 116 | 01110100 | 164 | 74 | t |
| 21 | 00010101 | 025 | 15 | NAK | 53 | 00110101 | 065 | 35 | 5 | 85 | 01010101 | 125 | 55 | U | 117 | 01110101 | 165 | 75 | u |
| 22 | 00010110 | 026 | 16 | SYN | 54 | 00110110 | 066 | 36 | 6 | 86 | 01010110 | 126 | 56 | V | 118 | 01110110 | 166 | 76 | v |
| 23 | 00010111 | 027 | 17 | ETB | 55 | 00110111 | 067 | 37 | 7 | 87 | 01010111 | 127 | 57 | W | 119 | 01110111 | 167 | 77 | w |
| 24 | 00011000 | 030 | 18 | CAN | 56 | 00111000 | 070 | 38 | 8 | 88 | 01011000 | 130 | 58 | X | 120 | 01111000 | 170 | 78 | x |
| 25 | 00011001 | 031 | 19 | EM | 57 | 00111001 | 071 | 39 | 9 | 89 | 01011001 | 131 | 59 | Y | 121 | 01111001 | 171 | 79 | y |
| 26 | 00011010 | 032 | 1A | SUB | 58 | 00111010 | 072 | 3A | : | 90 | 01011010 | 132 | 5A | Z | 122 | 01111010 | 172 | 7A | z |
| 27 | 00011011 | 033 | 1B | ESC | 59 | 00111011 | 073 | 3B | ; | 91 | 01011011 | 133 | 5B | [ | 123 | 01111011 | 173 | 7B | { |
| 28 | 00011100 | 034 | 1C | FS | 60 | 00111100 | 074 | 3C | < | 92 | 01011100 | 134 | 5C | \ | 124 | 01111100 | 174 | 7C | \| |
| 29 | 00011101 | 035 | 1D | GS | 61 | 00111101 | 075 | 3D | = | 93 | 01011101 | 135 | 5D | ] | 125 | 01111101 | 175 | 7D | } |
| 30 | 00011110 | 036 | 1E | RS | 62 | 00111110 | 076 | 3E | > | 94 | 01011110 | 136 | 5E | ^ | 126 | 01111110 | 176 | 7E | ~ |
| 31 | 00011111 | 037 | 1F | US | 63 | 00111111 | 077 | 3F | ? | 95 | 01011111 | 137 | 5F | | 127 | 01111111 | 177 | 7F | DEL |

# Conceptual to Physical

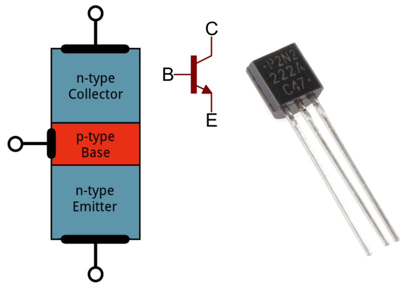


Claude Elwood Shannon, “father of information theory”

“A device with two stable positions, such as a [**transistor**], can store one bit of information. N such devices can store N bits.”

# Transistors

- **Semiconductors**, like silicon, are materials whose electrical properties can be altered.
- A **transistor** is a semiconductor device that can implement a **switch**:
  - When the base is charged current will flow from the collector to the emitter. **Switch is ON**.
  - When the base is not charged current will not flow from the collector to the emitter. **Switch is OFF**.





Black and White screen: 200 x 100 Resolution


256 Color screen: 200 x 100 Resolution

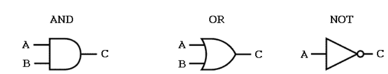
3

- The binary system can be used to represent and store information (e.g., encoding).
- The binary system can also be used to perform logical and mathematical computations (e.g., addition).


https://www.youtube.com/watch?time_continue=43&v=RgklPQ8rbkg

# Logic Gates

- **Logic gates** are combinations of transistors.
- Logic gates implement binary logic and binary math into physical components
- Logic gates can be combined into **electronic circuits** that perform operations.




| Inputs | | Output |
|---|---|---|
| A | B | C |
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

| Inputs | | Output |
|---|---|---|
| A | B | C |
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

| Input | Output |
|---|---|
| A | C |
| 0 | 1 |
| 1 | 0 |

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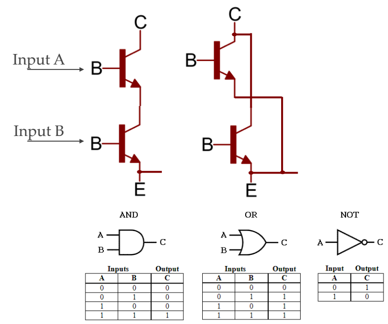
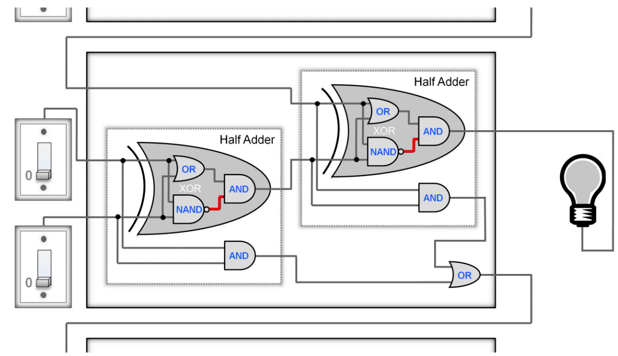
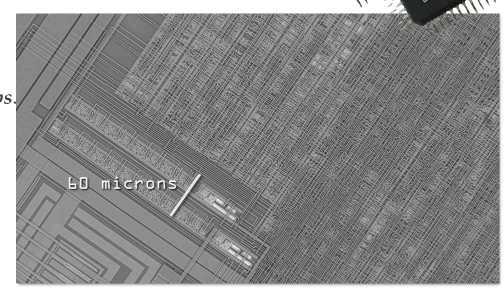



# An 8 bit Adder

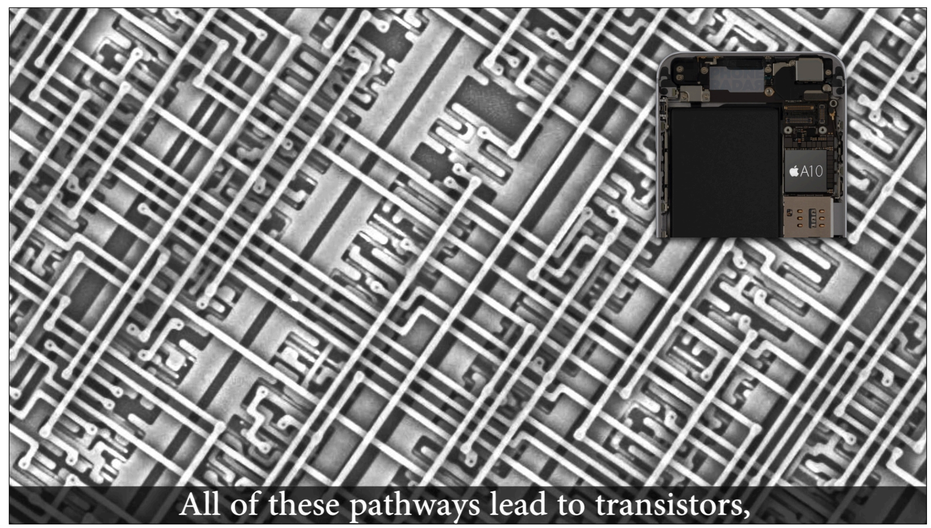



# Integrated Circuits

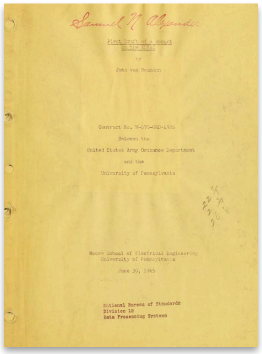

- **Integrated circuits** are combinations of electronic circuits etched onto a silicon chip.
- They are often called *chips* or *microchips*.
- Modern integrated circuits typically combine millions of logic gates (and billions of transistors).
  - iPhone 11 A14 chip: 11.8bn transistors

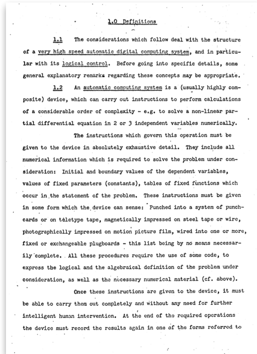






# The von Neumann Architecture





1.0 Definitions

1.1 The considerations which follow deal with the structure of a very high speed automatic digital computing system, and in particular with its logical control. Before going into specific details, some general explanatory remarks regarding these concepts may be appropriate.

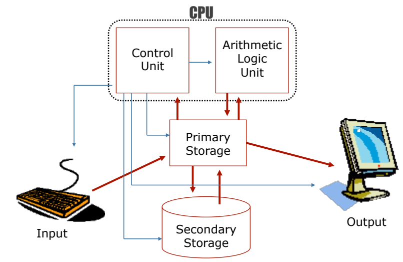
1.2 An automatic computing system is a (usually highly composite) device, which can carry out instructions to perform calculations of a considerable order of complexity - e.g. to solve a non-linear partial differential equation in 2 or 3 independent variables numerically.

The instructions which govern this operation must be given to the device in absolutely exhaustive detail. They include all numerical information which is required to solve the problem under consideration: Initial and boundary values of the dependent variables, values of fixed parameters (constants), tables of fixed functions which occur in the statement of the problem. These instructions must be given in some form which the device can sense: Punched into a system of punchcards or on teletype tape, magnetically impressed on steel tape or wire, photographically impressed on motion picture film, wired into one or more, fixed or exchangeable plugboards - this list being by no means necessarily complete. All these procedures require the use of some code, to express the logical and the algebraical definition of the problem under consideration, as well as the necessary numerical material (cf. above).

Once these instructions are given to the device, it must be able to carry them out completely and without any need for further intelligent human intervention. At the end of the required operations the device must record the results again in one of the forms referred to

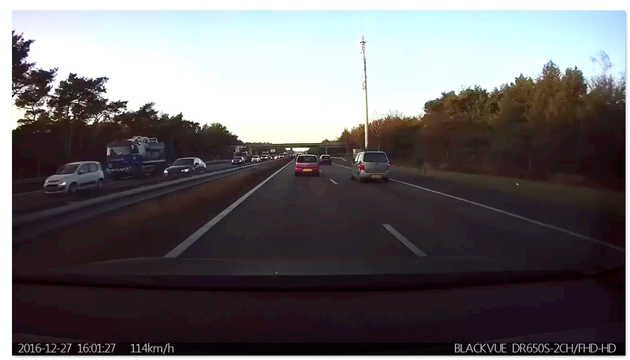
# The von Neumann Architecture in 1945

- First: Since the device is primarily a computer, […] a *central arithmetical* part […] will have to exist.
- Second: The logical control of the device, that is the proper sequencing of its operations, can be most efficiently carried out by a *central control* organ.
- Third: Any device that is to carry out long and complicated sequences of operations […] must have *memory*.
- […] instructions must be given in some form which the device can sense: Punched on a system of punch cards or on teletype […] That medium will be called the *outside recording medium* of the device.
- Fourth: The device must have organs to transfer information from [outside medium] into its specific parts. These organs form its *input*.
- Fifth: The device must have organs to transfer […] to [outside medium]. These organs form its *output*.




# Moore's Law at Work!


# Tesla Radar



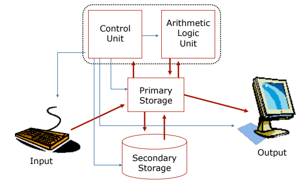
# The Stored Program Concept

John von Neumann, computer engineering pioneer

> “The instructions which govern this operation must be given to the device in absolutely exhaustive detail. [...] Once these instructions are given to the device, it must be able to carry them out completely without any need for further intelligent human intervention.”

# Logical and Physical Designs

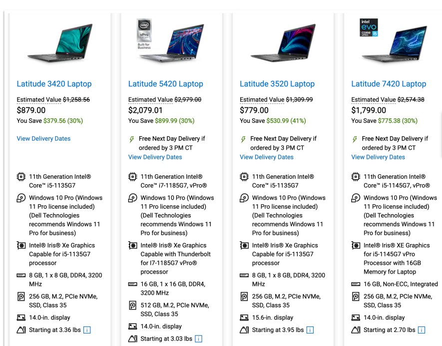
- Logical design: Abstract view of the components of a system and their relationships
- Physical design:
  - Form factor
  - Physical components




Bar Phone | Flip Phone | Slider Phone | Slate Phone

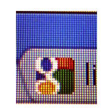
# The von Neumann Architecture in 2022

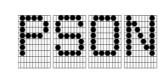
- Central Processing Unit (Processor)
  - Control Unit
  - Arithmetic Logic Unit
- Primary Storage (Memory)
- Secondary storage (Hard Drive)
- Input devices
- Output devices




# Digital Advantages

- Resilience: Less subject to decay.
- Reproduction fidelity: It is perfectly and infinitely replicable
- Versatility:
  - It can be stored on a wide variety of support media: Magnetic, Optical, Solid state
  - It can be processed by general purpose digital computers.

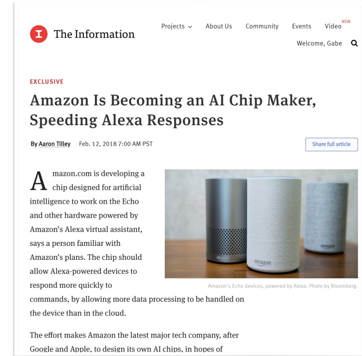




# Mac and Apple Watch


# Specialized Processors

- **Microprocessor**: The CPU of a general purpose digital computer with a general *instruction set*.
- Modern microprocessors are multicore.
  - A **core** is an independent processing unit (e.g., a CPU) within a microprocessor.
- Application Specific Integrated Circuits (ASIC):
  - **Coprocessors**: *Instruction set* optimized for specific tasks (e.g., Apple M9 motion sensing and analysis).
  - **Graphics Processing Unit** (GPU): *Instruction set* optimized for image processing
- Specialized Memory:
  - **Registers**: Small set of very fast data holding locations contained inside a CPU
  - **Cache**: Fast but expensive memory components



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EXCLUSIVE

**Amazon Is Becoming an AI Chip Maker, Speeding Alexa Responses**

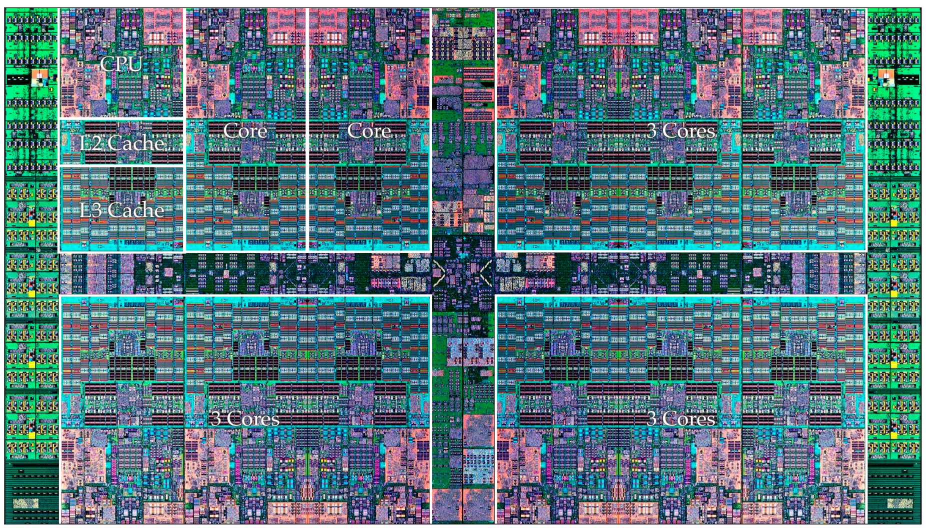
By Aaron Tilley Feb. 12, 2018 7:00 AM PST

Share full article

Amazon.com is developing a chip designed for artificial intelligence to work on the Echo and other hardware powered by Amazon's Alexa virtual assistant, says a person familiar with Amazon's plans. The chip should allow Alexa-powered devices to respond more quickly to commands, by allowing more data processing to be handled on the device than in the cloud.

Amazon's Echo devices, powered by Alexa. Photo by Bloomberg.

The effort makes Amazon the latest major tech company, after Google and Apple, to design its own AI chips, in hopes of




# What did we Learn

- Understand the basic representation model that computers use.
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- Understand and be able to describe the stored program concept.
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