Materials

W1 Wprowadzenie do przedmiotu.

Omawiane zagadnienia

- Introducing Computer Architecture -> [Subject basic information (lecture_00.md)]
- The evolution of automated computing devices
- Moore's law

The evolution of automated computing devices

You will see a few key historical computing devices and the leaps in technology associated with them.

Charles Babbage's Analytical Engine

Characteristic

- A working model of the Analytical Engine was never constructed but the detailed notes Charles Babbage developed from 1834 until his death in 1871 described a computing architecture that appeared to be both workable and complete.
- The Analytical Engine was intended to serve as a **general-purpose programmable computing device**.

Some notes of technical details

- Design was entirely mechanical.
- Dimension: 30 meters by 10 meters.
- It was designed to be driven by a steam engine.
- The Analytical Engine represented numbers in signed decimal form.
- All numbers consisted of 40 decimal digits + sign.
- No support for floating-point arithematics.
- Each number was stored on a vertical axis containing 40 wheels; a 41st number wheel contained the sign: any even number on this wheel represented a positive sign and any

odd number represented a negative sign. [1]
- Capable of holding 1,000 numbers of 50 decimal digits [2].
- Axis was somewhat analogous to the register used in modern processors except the readout of an axis was destructive.
- The memory was intended to **store data and the results of operations performed on them**.
- Operations in the Analytical Engine were sequenced by music box-like rotating barrels in a construct called the **mill**, which is analogous to the processing component of a modern CPU (like modern CPU, the mill would rely upon its own internal procedures).
- Able to perform all four arithmetic operations, plus comparisons and optionally square roots.
- Programmed using punched cards.
- Supports branching operations and nested loops.
- Based on Babbage's hypothesized execution speed, the addition of two 40-digit numbers, including the propagation of carries, would take about three seconds.

Usage

The most complex program for the Analytical Engine was developed by Ada Lovelace to compute the Bernoulli numbers.Babbage constructed a trial model of a portion of the Analytical Engine mill, which is currently on display at the Science Museum in London.

ENIAC

ENIAC, the Electronic Numerical Integrator and Computer, was completed in 1945 and was the first programmable general-purpose electronic computer.

Some notes of technical details

- Consumed 150 kilowatts of electricity.
- Occupied 1,800 square feet of floor space (167m2).
- Weighed 27 tons.
- The design was based on vacuum tubes, diodes, and relays. ENIAC contained over 17,000 vacuum tubes that functioned as switching elements.
- Similar to the Analytical Engine, it used base-10 representation of ten-digit decimal numbers.
- Input and output thanks to a punch-cards.
- The ENIAC architecture was capable of complex sequences of processing steps including **loops**, **branches**, and **subroutines**.
- The system had 20 ten-digit **accumulators** that were similar to registers in modern computers. However, it did not initially have any memory storage beyond the accumulators.
- Could perform about 385 multiplications per second.

Usage

ENIAC programs consisted of plugboard wiring and switch-based function tables.

Early applications of ENIAC included the computation of firing tables for long-range artillery.

In 1948, ENIAC was improved by adding the ability to program the system via punch cards rather than plugboards.

Emerge the idea (John von Neumann (?)) of a processing architecture based on a single memory region containing program instructions and data, a processing component with an arithmetic logic unit and registers, and a control unit with an instruction register and a program counter. Many modern processors continue to implement this general structure, now known as the **von Neumann architecture**.

Other technological breakthroughs

- The invention of the transistor in **1947** by John Bardeen, Walter Brattain, and William Shockley delivered a vast improvement over the vacuum tube technology prevalent at the time. Transistors were faster, smaller, consumed less power, and, once production processes had been sufficiently optimized, were much more reliable than the failure-prone tubes.
- The commercialization of integrated circuits in **1958**, led by Jack Kilby of Texas Instruments, began the process of combining large numbers of formerly discrete components onto a single chip of silicon.
- In **1971**, Intel began production of the first commercially available microprocessor, the Intel 4004. **The 4004 was intended for use in electronic calculators** and was specialized to operate on 4-bit binary coded decimal digits.

  Eeach 4-bit BCD number (digit) maps directly to one decimal number (digit):

```
0000 0      0101 5
0001 1      0110 6
0010 2      0111 7
0011 3      1000 8
0100 4      1001 9

63 in Binary:  0011 1111
63 in BCD:     0110 0011

597 in Binary: 0010 0101 0101
597 in BCD:    0101 1001 0111
```

- Maximum clock frequency – 740 kHz.
- Separate memory for program and data (so-called "Harvard architecture").
- 46 instructions.
- 16 four-bit registers.
- 3-tier stack.
- 2300 transistors (10*μ*m production technology).

Note: width of human hair

This measurement is not precise because human hair varies in diameter, ranging anywhere from 17µm to 181µm. One nominal value often chosen is 75µm.

```
1µm = 0.001mm
1000µm = 1mm

1µm = 1000nm
0.001µm = 1nm

75µm = 0.075mm
75µm = 75000nm

decy  = 10-1
centy = 10-2
mili  = 10-3
mikro = 10-6
nano  = 10-9

Apple A17 Pro (September 12, 2023):
3 nm (3333 smaller than 10µm and 25000 smaller than width of hu
19 billion transistors
3.78 GHz CPU clock
```

Note: F14 CADC

The F14 CADC (F-14A Central Air Data Computer) is a microprocessor designed by Steve Geller and Ray Holt for the US Navy for the F-14 Tomcat fighter.

The first copies of this system were created in June 1970, more than 12 months earlier than the first Intel 4004 microprocessor, which is widely considered to be the world's first microprocessor, but due to military secrecy, the existence of the F-14 CADC was revealed only in 1998.

Compared to the Intel chip, which was a simple 4-bit processor, the F-14 CADC was an extremely advanced 20-bit pipelined chip.

The 8088 microprocessor

Intel 8088 microprocessor:

- Running at a clock frequency of 4.77 MHz.
- Featured 16 KB of RAM, expandable to 256 KB.
- Contained fourteen 16-bit registers.
    - Four were general purpose registers (AX, BX, CX, and DX.)
    - Four were memory segment registers (CS, DS, SS, and ES) that extended the address space to 20 bits.

      The segment registers in the 8088 architecture provided a clever way to expand the range of addressable memory without increasing the length of most instructions referencing memory locations. Each segment register allowed access to a 64-kilobyte block of memory beginning at a physical memory address defined at a multiple of 16 bytes.

      With segment registers it was possible to obtain a physical memory address within a one megabyte range.

      ```
      2^8  =                  256
      2^10 =                 1024
      2^16 =                65536
      2^20 =              1048576
      2^32 =           4294967296
      2^64 = 18446744073709551616
      ```
    - The remaining 8088 registers were:
        - the Stack Pointer (SP),
        - the Base Pointer (BP),
        - the Source Index (SI),
        - the Destination Index (DI),
        - the Instruction Pointer (IP),
        - and the Status Flags (FLAGS).
- External data bus width of 8 bits, which meant it took two bus cycles to read or write a 16-bit value.

  This was a performance downgrade compared to the earlier 8086 processor, which employed a 16-bit external bus. However, the use of the 8-bit bus made the PC more economical to produce and provided compatibility with lower-cost 8-bit peripheral devices.

- Implemented the von Neumann architecture: program memory and data memory shared the same address space, and the 8088 accessed memory over a single bus.
- Instruction set included instructions for:
    - data movement,
    - arithmetic,
    - logical operations,
    - string manipulation,
    - control transfer (conditional and unconditional jumps and subroutine call and return),
    - input/output,
    - and additional miscellaneous functions.
- The processor required about 15 clock cycles per instruction on average, resulting in an execution speed of 0.3 million instructions per second (MIPS).

The IBM PC

The IBM PC was released in 1981 by the IBM company.

- Use Intel 8088 processor.
- The motherboard contained a socket for an optional Intel 8087 floating-point coprocessor.

  The designers of the 8087 invented data formats and processing rules for 32-bit and 64-bit floating point numbers that became in 1985 the IEEE 754 floating-point standard, which remains in near-universal use today.

  The 8087 could perform about 50,000 floating-point operations per second.

The 80286 and 80386 microprocessors

The second generation of the IBM PC was released in 1984. It was named the **PC AT** where AT stood for Advanced Technology.

The *advanced technology* referred to several significant enhancements over the original PC that mostly resulted from the use of the new **Intel 80286** processor.

- The 80286 (like the 8088) was a 16-bit processor, and it maintained **backward compatibility with the 8088**: **8088 code could run unmodified on the 80286**.
- 16-bit data bus and 24 address lines supporting a 16-megabyte address space.

- The instruction execution rate (instructions per clock cycle) was about double the 8088 in many applications.
- The original PC AT clocked the processor at 6 MHz and a later version operated at 8 MHz.
- The 6 MHz variant of the 80286 achieved an instruction execution rate of about 0.9 MIPS.
- Implemented a protected virtual address mode intended to support multiuser operating systems and multitasking.

The next generation of the x86 processor line was the 80386, introduced in 1985.

- The 80386 was a 32-bit processor with support for a flat 32-bit memory model in protected mode.
- The flat memory model allowed programmers to address up to 4 GB directly, without the need to manipulate segment registers.
- The initial version of the 80386 was clocked at 33 MHz and achieved about 11.4 MIPS.

The 80386 maintained a large degree of backward compatibility with the 80286 and 8088 processors. **The design implemented in the 80386 remains the current standard x86 architecture.**

The iPhone

In 2007, Steve Jobs introduced the iPhone to a world that had no idea it had any use for such a device. The iPhone built upon previous revolutionary advances from Apple Computer, combined the functions of the iPod, a mobile telephone, and an Internet-connected computer.

- 3.5" screen with a resolution of 320x480 pixels.
- 0.46 inches (11.7) thick (thinner than other smartphones).
- Weighed 4.8oz (136g).
- 2-megapixel camera built in.
- 128 MB of RAM and 4 GB, 8 GB, or 16 GB of flash memory.
- Supported Wi-Fi (802.11b/g), and Bluetooth.
- Touchscreen.
- Accelerometer detected whether the screen was being held in portrait or landscape orientation.
- 32-bit ARM11 processor (manufactured by Samsung) running at 412 MHz.
- It was powered by a 3.7V lithium-ion polymer battery. The battery was not intended to be replaceable, and Apple estimated it would lose about 20 percent of its original capacity afer 400 charge and discharge cycles. Apple quoted up to 250 hours of standby time and 8 hours of talk time on a single charge.
- Six months afer the iPhone was introduced, Time magazine named the iPhone the

"Invention of the Year" for 2007. In 2016, Time ranked the 50 Most Influential Gadgets of All Time . The iPhone topped the list.

Note: First Touchscreen Phone

Motorola DynaTAC 8000X (1983), the first commercial portable cellular phone.

The IBM Simon (1992) was the first touchscreen phone with smartphone capabilities (pager, calculator, games, etc.).

Moore's law

For those working in the rapidly advancing field of computer technology no one can ever be completely sure what the next leap in technology will be, what effects from it will ripple across the industry and its users, or when it will happen.

One technique that has proven useful in this difficult environment is to develop a rule of thumb, or empirical law, based on experience.

Gordon Moore co-founded Fairchild Semiconductor in 1957 and was later the chairman and CEO of Intel.

In 1965, Moore published an article in Electronics magazine in which he shared an observation that the number of formerly discrete components such as transistors, diodes, and capacitors that could be integrated onto a single chip **had been doubling approximately yearly** and the trend was likely to continue over the subsequent ten years.

This doubling formula came to be known as Moore's law.

This was not a scientific law in the sense of the law of gravity. Rather, it was based on observation of historical trends, and he believed this formulation had some ability to predict the future.

Moore's law turned out to be impressively accurate over those ten years.

In 1975, he revised the predicted growth rate for the following ten years to doubling the number of components per integrated circuit every two years rather than yearly.

This pace continued for decades, up until about 2010. In more recent years, the growth rate has appeared to decline slightly. In 2015, Brian Krzanich, Intel CEO, stated that the company's growth rate had **slowed to doubling about every two and a half years**.

Apple A17 Pro (September 12, 2023) is made in 3nm process. A typical human hair is about

75000nm thick in average (which is 25000 times more) and a water molecule (one of the smallest molecules) is 0.28nm across. There is a point beyond which it is simply not possible for circuit elements to become smaller as the sizes approach atomic scale.

Even as the rate of growth in transistor density slows, semiconductor manufacturers are pursuing several alternative methods to continue growing the power of computing devices. One approach is **specialization**, in which circuits are designed to perform a specific category of tasks extremely well rather than performing a wide variety of tasks merely adequately.

Graphical Processing Units (GPUs) are an excellent example of specialization. Original GPUs focused exclusively on improving the speed at which three-dimensional graphics scenes could be rendered, mostly for use in video gaming.

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