Computer Architecture
Lecture 3
Basic Units

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Basic Units

There are three to five (depending on how you count) basic units that make up a computer

- Arithmetic-Logic Unit (**ALU**)
- Control (**ROM**)

Central Processing Unit (**CPU**)

- Memory (**RAM**)

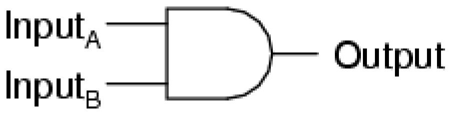
- Input
- Output

Input/Output (**I/O**)

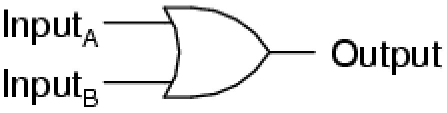
Arithmetic/Logic Unit

- So much of what goes on inside a computer is just holding of and/or movement of data, but the *actual computation* (the manipulation of data to generate "new" data) takes place in the **ALU**.
- Because data is represented in binary form (1's and 0's), the ALU is mainly comprised of **logic gates**, circuits made from transistors that take inputs (combinations of highs and lows) and produce outputs (different combinations of highs and lows).
- Logic in which the output depends solely on the input is called **combinatorial**.

2-input AND gate

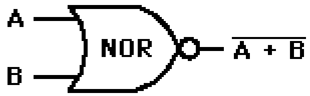


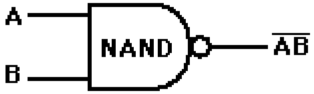
2-input OR gate



Logic Gates and Boolean operators

- There is a correspondence between logic gates and **Boolean operators**
  - **AND**: when two or more Boolean expressions are ANDed, both must be true for the combination to be true.
  - **OR**: when two or more Boolean expressions are ORed, if either one or the other or both are true, then the combination is true.
  - **NOT**: takes one Boolean expression and yields the opposite of it, true → false and vice versa.
  - **NAND**: equivalent to an AND followed by a NOT
  - **NOR**: equivalent to an OR followed by a NOT





Registers and Accumulators

- The ALU is not entirely *combinatorial*, it also has some **sequential** components, which can temporarily hold information.
- These little holding units are known as **registers**.
- The primary registers associated with the ALU go by the name **accumulators**.

Hierarchy of bit holders

- An electronic circuit that holds a single bit (a 1 or a 0) is called a **flip-flop**.
- A small collection of flip-flops (8 or 16 or 32, etc.) is called a **register**.
  - A ***counter*** is a kind of register that in addition to holding bit values can increment the number they represent.
  - A ***shift register*** can hold a number as well as "shift" it.
    - 00101101
    - 01011010
    - 10110100, etc.
- A collection of registers along with a way to address (select out) a particular register is called **memory**.

Control Unit

- Control is responsible for determining what action is to be performed on what data.
- If the action is a calculation, then control will deliver the necessary data to the ALU, inform the ALU what particular action is to be performed, and then directs the output to the appropriate location.

Control Unit (cont.)

- All of the other units of a computer have “control inputs” that determine **whether** or not they are **active** and **what particular action** they will perform (if they can do more than one thing).
- Control takes code down to this lowest level of making the appropriate control inputs high or low, active or inactive.
  - Not all devices are active when the control input is high, some devices are ***“active low.”***

Control is ROM

- At a high level, instructions may be arranged in new and different orders (this after all is what makes the computer programmable). But at the low level the ***control sequences for a given instruction do not change***.
- Control sequences are thus made of **Read Only Memory (ROM)** which are reprogrammed rarely if at all.

Memory

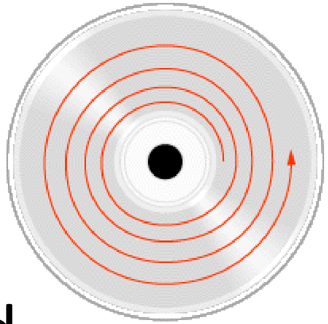
- Memory consists of circuits whose primary purpose is to **hold information**, but only temporarily.
- Memory holds the data that the processor has just acted on, is acting on or will soon act on.
- When we use the term memory, we usually mean **Random Access Memory (RAM)**.

Memory

Memory is collection of holding cells (like registers).
Each cell has an address.

Address	Value (An example)
0000	10010100
0001	01010010
0010	00101100
0011	01011100
0100	01100110
…	

Random Access



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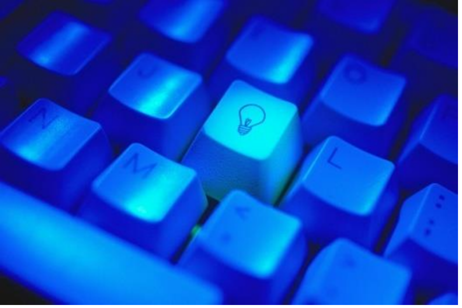
- The data in any holding cell can be accessed immediately for purposes of reading or writing by supplying its address.
  - Any **random** site can be “immediately” **accessed**.
  - As opposed to **<u>sequential access</u>** in which one must pass through all intermediate data between one’s current location and the next desired location.
    - VCR tapes are sequential;
    - DVDs are random access (they support scene selection and don’t have to be rewound).

Memory versus Storage

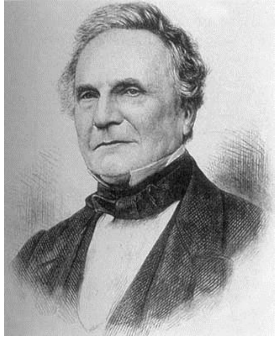
- Memory is a temporary holding place that interacts fairly directly with the processor.
  - Memory is ***volatile***, the holding of the information requires power. No power, no data held.
- Longer term holding of data not currently being processed is done in storage (hard disks, floppy disks, CDs). These are non-volatile, with permanent data held.
- In this “basic units” picture of the computer storage belongs to the Input/Output unit.



Input / Output

- The Input unit allows programs and data to be entered into the computer.
- The Output unit allows the results of processing to be exported to the outside world or other devices or saved to be used later.
- This other device may be in the same case as the processor, but it is output as far as the processor and memory are concerned. Thus the **hard drive** is both an **input and an output device** in this picture.

Charles Babbage



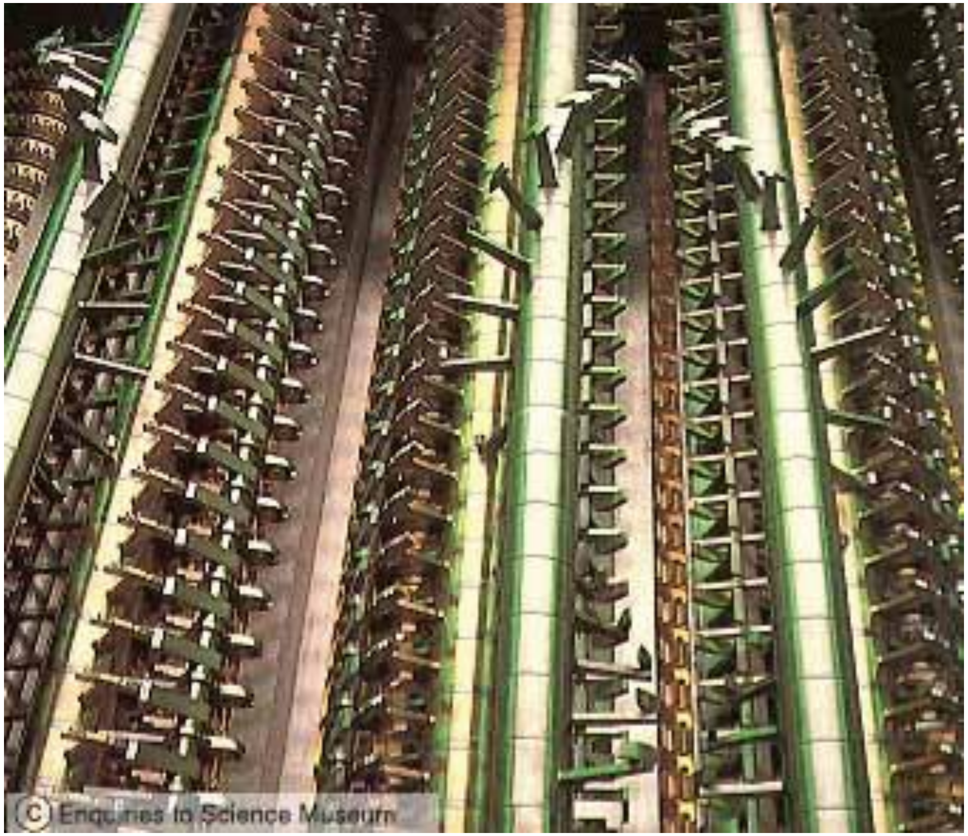
- In the early 1800’s **Charles Babbage** designed two machines: first the **Difference Engine** and then the **Analytical Engine** that were mechanical machines capable of performing calculations.
- The Difference Engine, most (but not all) of which was built in Babbage’s time, was a **special purpose** machine (i.e. it could only do particular calculations).
- The Analytical Engine, which was designed but not built in Babbage’s time, was more ambitious in that it was *programmable*.

Ada Lovelace

Babbage’s design

- Babbage’s design had the basic units we have been describing.
- He conceived of it as having four components:
  - the **store** (memory)
  - the **mill** (computational unit, control + ALU)
  - the **input section** (punched card reader)
  - the **output section** (punched and printed output).

Babbage’s “Mill”



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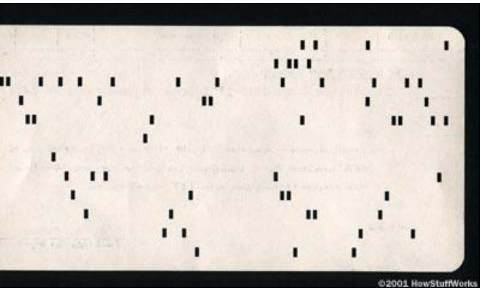
Built later based on Babbage’s specifications.

Babbage (Cont.)

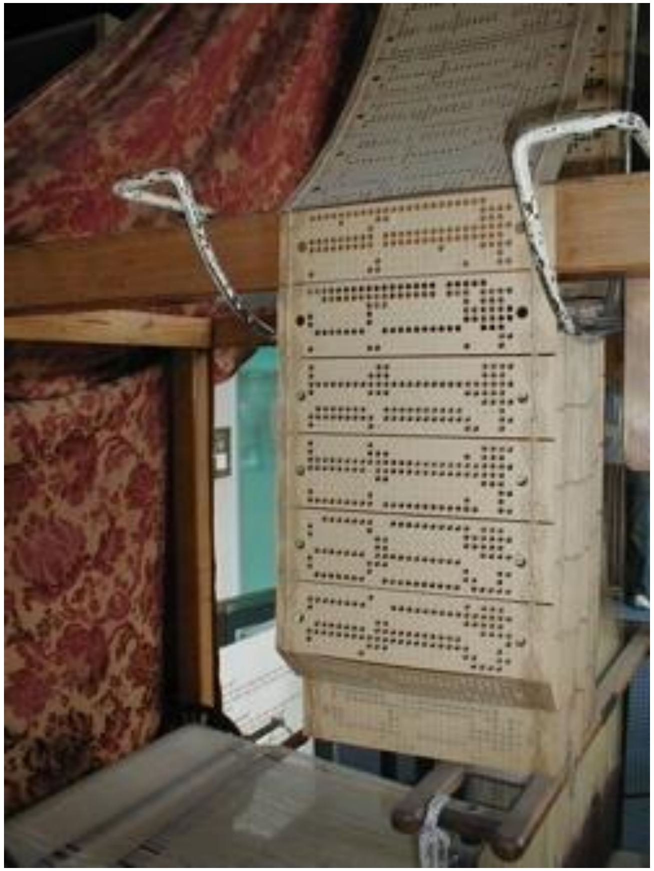
- Babbage’s engines were entirely mechanical and were comprised of gears and cogs and such.
- The **store** held 1000 words of 50 decimal digits used to hold variables and results.
- The **mill** (processor) could take data from the store, add, subtract, multiply or divide them, and return the answer to the store.



Babbage Input and Output

- The engine's input was from **punched cards.**
  - Punch cards started being used in industry (weaving) since the early 1800's. They disappeared in the 1980's.
- The data input was not simply data from the calculations but also data for instructions, making the engine programmable.
- Instructions included being able to test whether a number was positive or negative (an **if**).
- The engine's output could be punched into a copper engraver's plate producing a ***hardcopy***.

Jacquard Loom Punch Card



After a hundred years

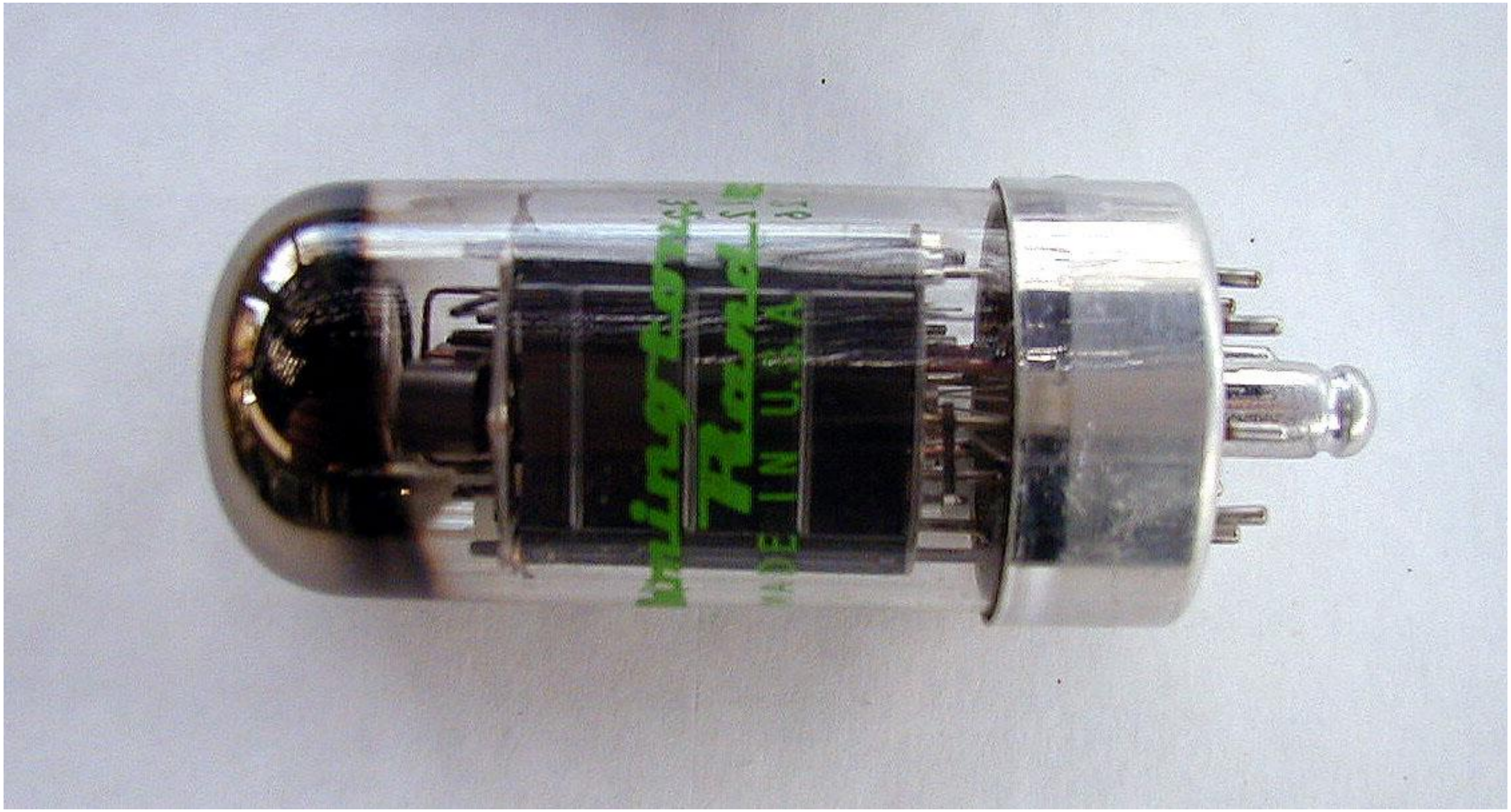
- In the 1940’s the ***Electronic Numerical Integrator And Computer*** (**ENIAC**) was built at the Moore School of the University of Pennsylvania.
- It was completed in 1946 at the Moore School of the University of Pennsylvania.
- The two driving forces behind it were **John W. Mauchly** and **J. Presper Eckert**.
- There were other computers built during WWII notably the one developed at Bletchley Park, UK to aid in their code breaking mission.

Alan Turing

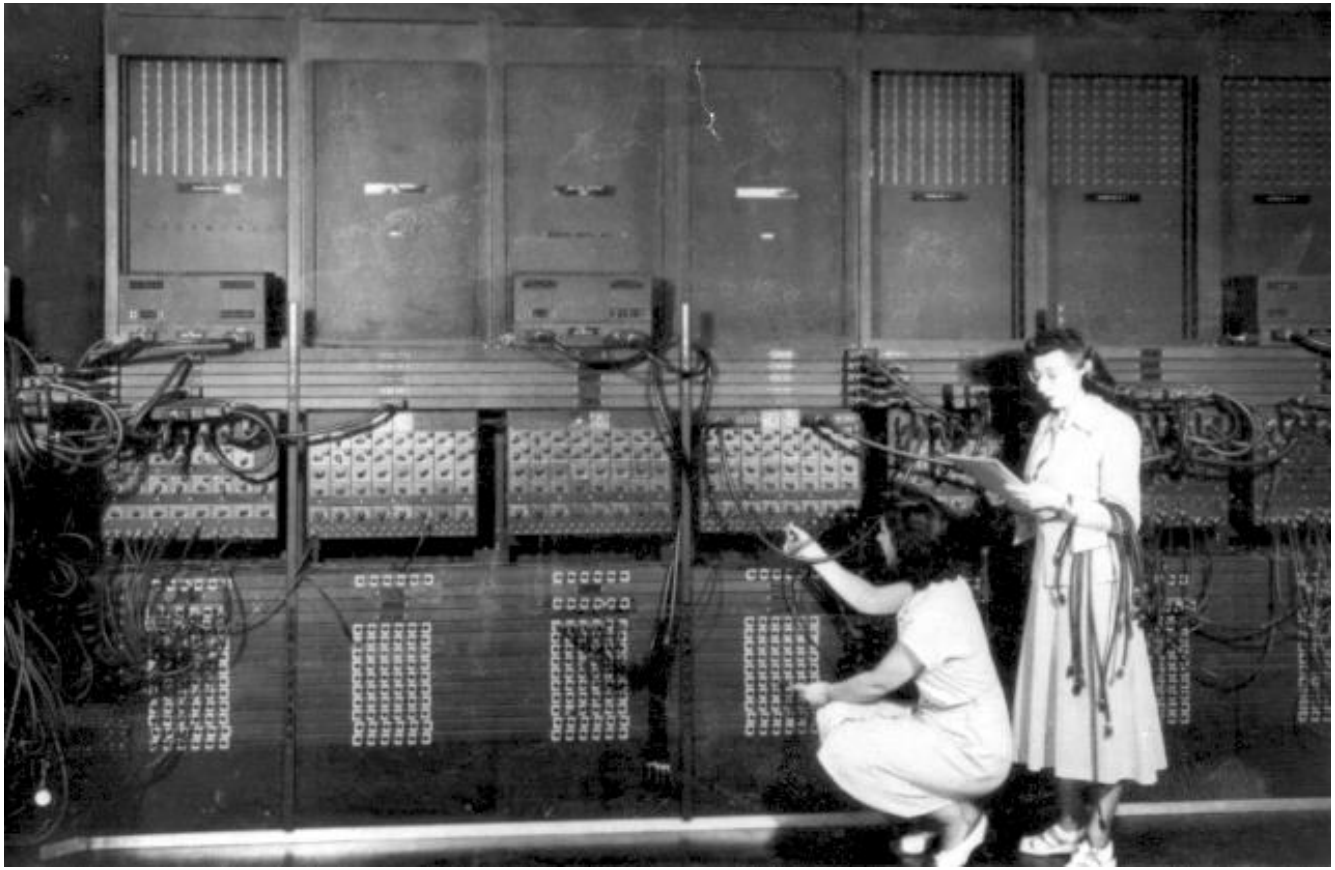
ENIAC

- The ENIAC consisted of 17,480 vacuum tubes operating at 100,000 pulses per second.
  - Think of a vacuum tube as a “souped up light bulb.”
- **Vacuum tubes** play the same role that **transistors** do in modern computers (one can use them to “realize” **logic gates**)
  - The switch from vacuum tubes to transistors marked a dramatic shift in computer size and speed. People talk about the computers as belonging to different “***generations***.” Moving to transistors is a generational shift.
  - The Pentium 4 processor introduced in 2000 had 42,000,000 transistors. The Itanium 2 in 2004 had 592,000,000 transistors. The size and power requirements of vacuum tubes would have prohibited these kind of numbers. The more recent Core i7 processor has a transistor count is 731 Million.

Vacuum tube

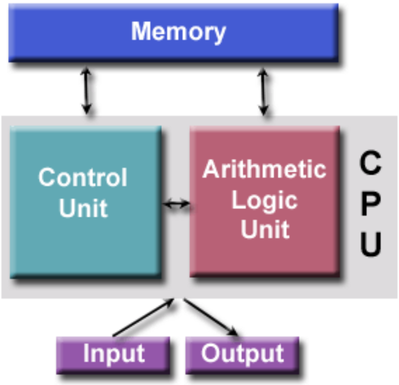


Early Programmers



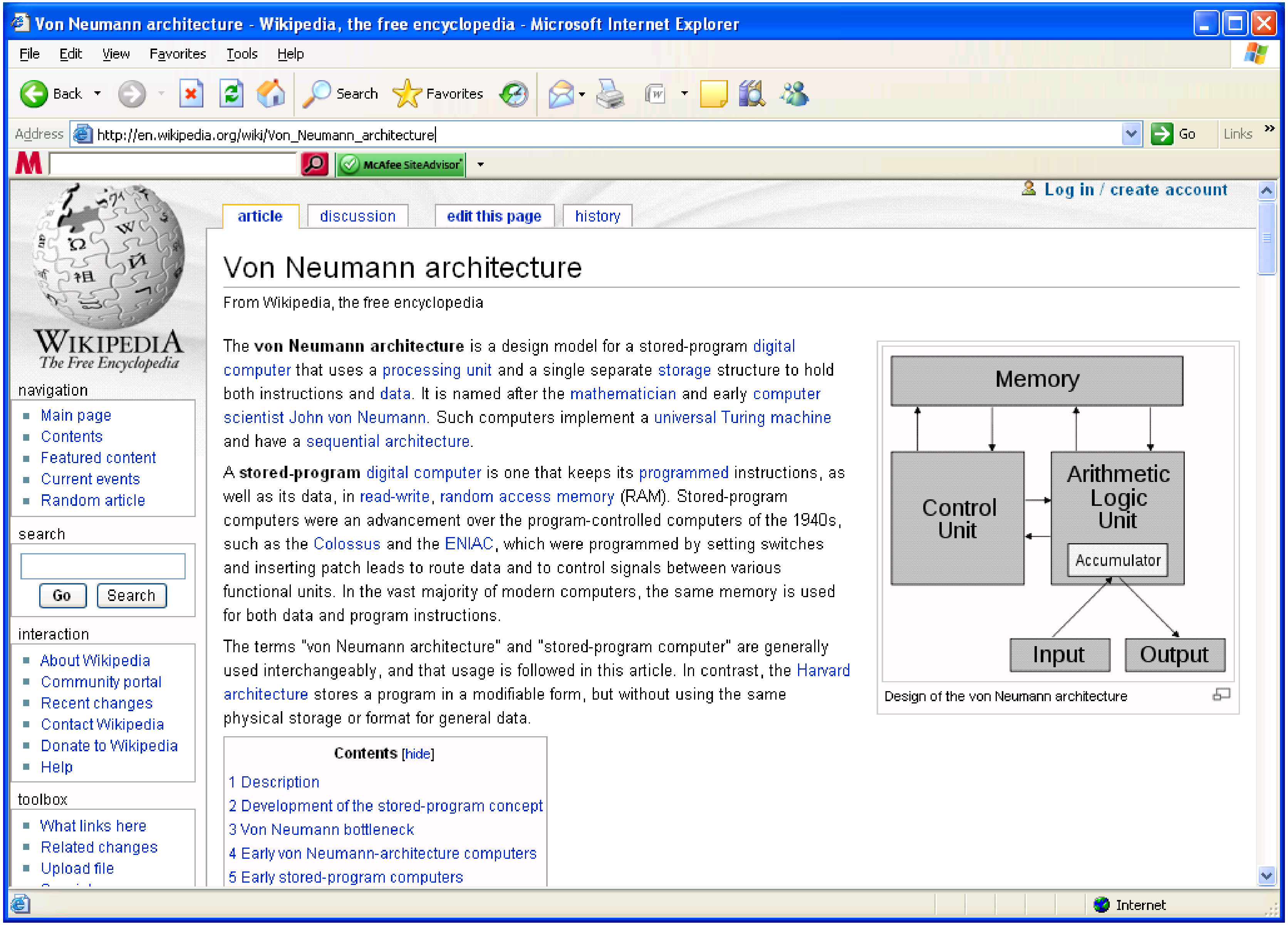
Programming

- One drawback to the ENIAC was the way it was programmed — with wires.
- A new program required rewiring.
- Mauchly, Eckert and **John von Neumann** discussed designs of future computers (like EDVAC) in which the programs (instructions) would be stored in the computer's memory.



Von Neumann Architecture

- John von Neumann was a consultant to the ENIAC project. The team discussed changing the way computers were programmed. Von Neumann publicized and popularized these ideas.
- The instructions could be converted into numbers and placed in memory along with the data. This is known as the **stored program concept**.
- The combination of the basic units (ALU, control, memory, input and output) and the stored program concept give one the *"**von Neumann architecture**."*



Von Neumann architecture

From Wikipedia, the free encyclopedia

The **von Neumann architecture** is a design model for a stored-program digital computer that uses a processing unit and a single separate storage structure to hold both instructions and data. It is named after the mathematician and early computer scientist John von Neumann. Such computers implement a universal Turing machine and have a sequential architecture.

A **stored-program** digital computer is one that keeps its programmed instructions, as well as its data, in read-write, random access memory (RAM). Stored-program computers were an advancement over the program-controlled computers of the 1940s, such as the Colossus and the ENIAC, which were programmed by setting switches and inserting patch leads to route data and to control signals between various functional units. In the vast majority of modern computers, the same memory is used for both data and program instructions.

The terms "von Neumann architecture" and "stored-program computer" are generally used interchangeably, and that usage is followed in this article. In contrast, the Harvard architecture stores a program in a modifiable form, but without using the same physical storage or format for general data.

Design of the von Neumann architecture

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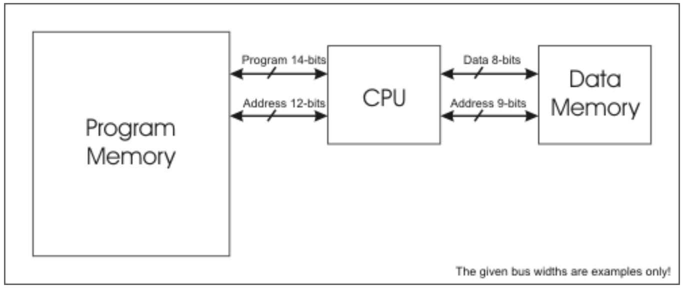
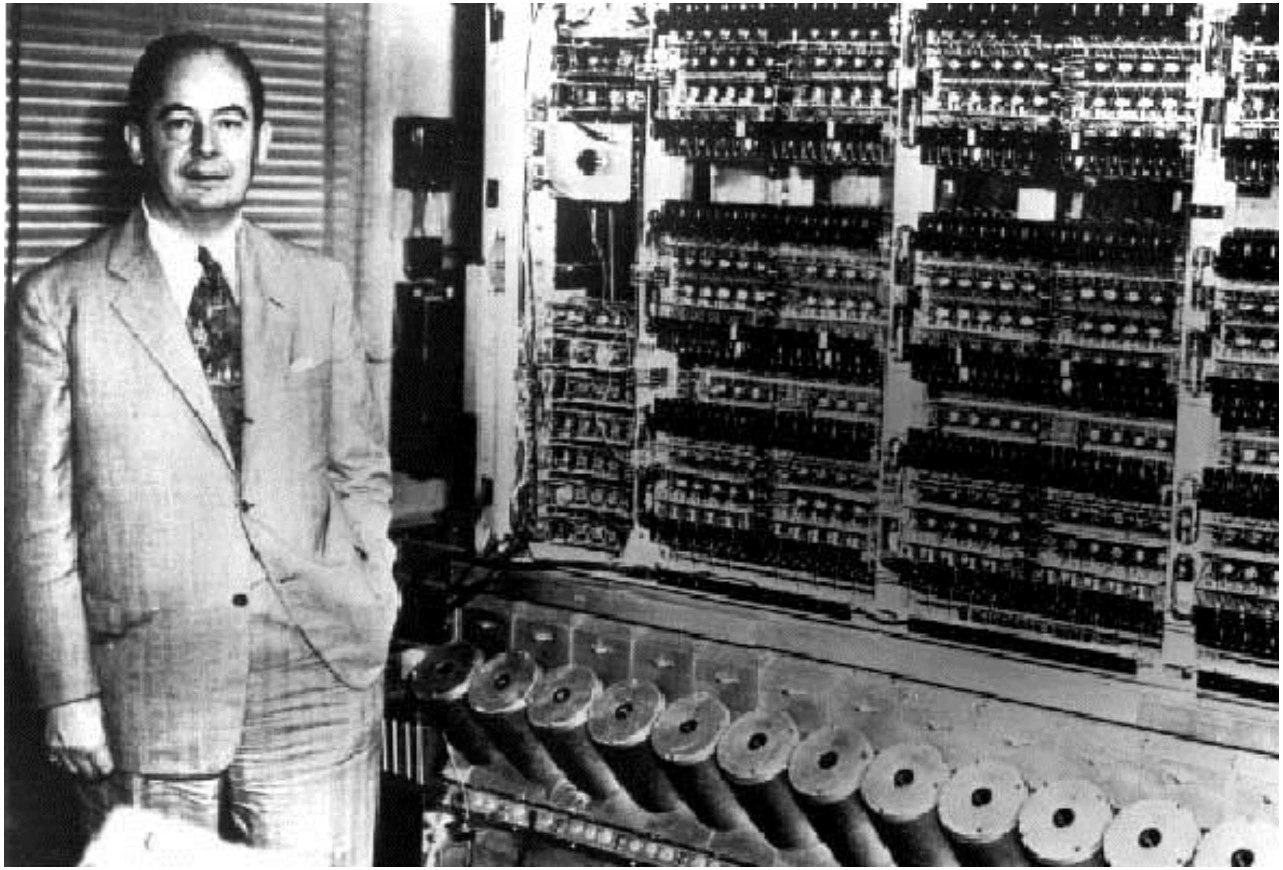


Harvard architecture

- In the von Neumann architecture, the instructions and data are held in the same memory.
- A variation on this, known as the **Harvard architecture**, has the instructions and data held in separate memories.
- A more modern variation on the Harvard architecture is to have the data and instructions in the same main memory but to place them in separate ***caches***.

John von Neumann



Micro-code

- What’s held in the memory is a low-level (**assembly** or **machine code**) instruction which may have resulted when some **high-level language** program was **compiled**.
- Below that is **micro-code**, the instructions at the lowest level, those control signals fed directly to the hardware.
- Any higher-level instructions (including assembly) must ultimately be converted to a lower level by control.
- A single machine-language instruction (like Load Accumulator A) typically consists of several micro-code instructions.
  - Similarly a single high level instruction (such as principle = principle*(1+interestRate)) often consists of several assembly level instructions.

Where is microcode stored?

- It used to literally be wired in (hence the term “hard wired”).
- Typically it is stored in ROM.
- If the code is stored in EEPROM, it can be changed; this is known as *microprogramming.*
  - **EEPROM**: Electrically Erasable Programmable ROM
- But this is something one does on a rare occasion
- Sometimes referred to as “**firmware**,” an intermediate between software and hardware.

Machine language

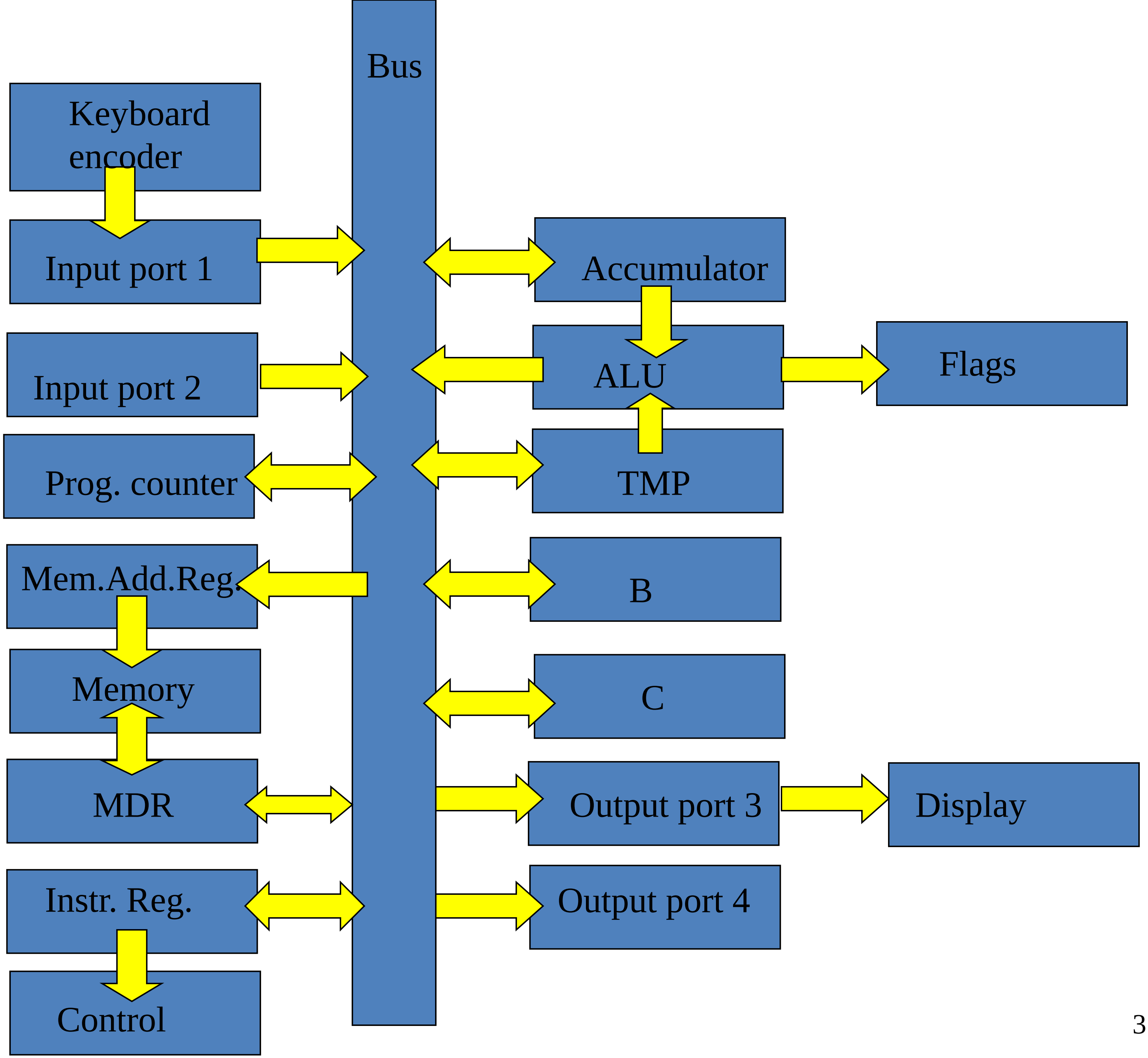
- **Machine language** is a level above micro-code
- The instructions are numbers, which really are the addresses of the micro-code instruction in ROM.
  - Machine language is typically machine dependent. The locations in ROM of the microcode vary from one make of a computer to the next.
- A mnemonic version of machine language is called **assembly language**.

Getting down to hardware’s level

- High-level programs are translated into assembly language or machine language by a **compiler**. Assembly language programs are translated into machine language by an **assembler**.
- Each processor has its own unique machine language. Thus code must be rewritten or at least recompiled to run on different processor (different hardware).

A simple design

- Next we will show a computer design.
- It uses a very basic “bus architecture.”
- A bus is a shared path used to transmit and receive information.


Bus
Keyboard encoder
Input port 1
Input port 2
Prog. counter
Mem.Add.Reg.
Memory
MDR
Instr. Reg.
Control
Accumulator
ALU
Flags
TMP
B
C
Output port 3
Display
Output port 4

One Bus, Two Bus

- In this very primitive architecture, there is only one bus.
- Recall that memory can be thought of as values located at addresses. Here the same bus is used for both data (values) and addresses.
- This will make accessing memory (reading or writing) a two-step process – deal with the address, then deal with the data.
  - Dealing with memory is always a two step process, but in this architecture the one and only bus is tied up for both step (no parallelism allowed).
- That is not the usual case. Most architectures have an address bus and a data bus.

Input ports

- Keyboard encoder: converts key pressed into corresponding string of bits (ASCII)
- Input port 1: where keyboard data is entered, usually contains some memory (a buffer) where data is held until the processor is ready for it.
- Input port 2: where non-keyboard data is entered.

Program counter

- The **program counter** points to the current line of the program (which is stored in memory)
- This design shows arrows connecting the “PC” to and from the bus.
  - Sometimes the next instruction to be executed is not the next line of code in memory, such as
    - If
    - Loops
    - Subroutines, functions, etc.

MAR, MDR and Memory

- **MAR** (***Memory Address Register***) holds the address of the memory location being read from or written to
  - Not necessarily same as program counter
- Memory (RAM): the place where data and instructions are stored
- **MDR** (***Memory Data Register***) holds the data that is being read from or written to memory
  - Bi-directional connection to bus for reading and writing

Instruction Register

- **Instruction register** holds the instruction that is currently being executed.
- A given line of assembly or machine language code involves several micro-code instructions, the instruction register holds onto the instruction until all of the micro-instruction steps are completed.
  - It plays a role somewhat like the MAR but for ROM instead of RAM

Controller/Sequencer

- Executes the program at the lowest level.
- Sends signals to the control pins of all the devices involved.
- These lowest-level instructions are in ROM
- ***Each assembly-level instruction has a numerical counterpart (machine language); the numerical counterpart is the address of the microcode for that instruction stored in ROM.***
- Not shown, controller connects to everything

Accumulator and ALU

- **Accumulator**: register used in conjunction with the ALU
- Data upon which arithmetic or logic operations will eventually be performed is stored here; also the results of these are stored here.
- **ALU** (Arithmetic Logic Unit) where operations that change the data (as opposed to just moving it around) are done.

Flags

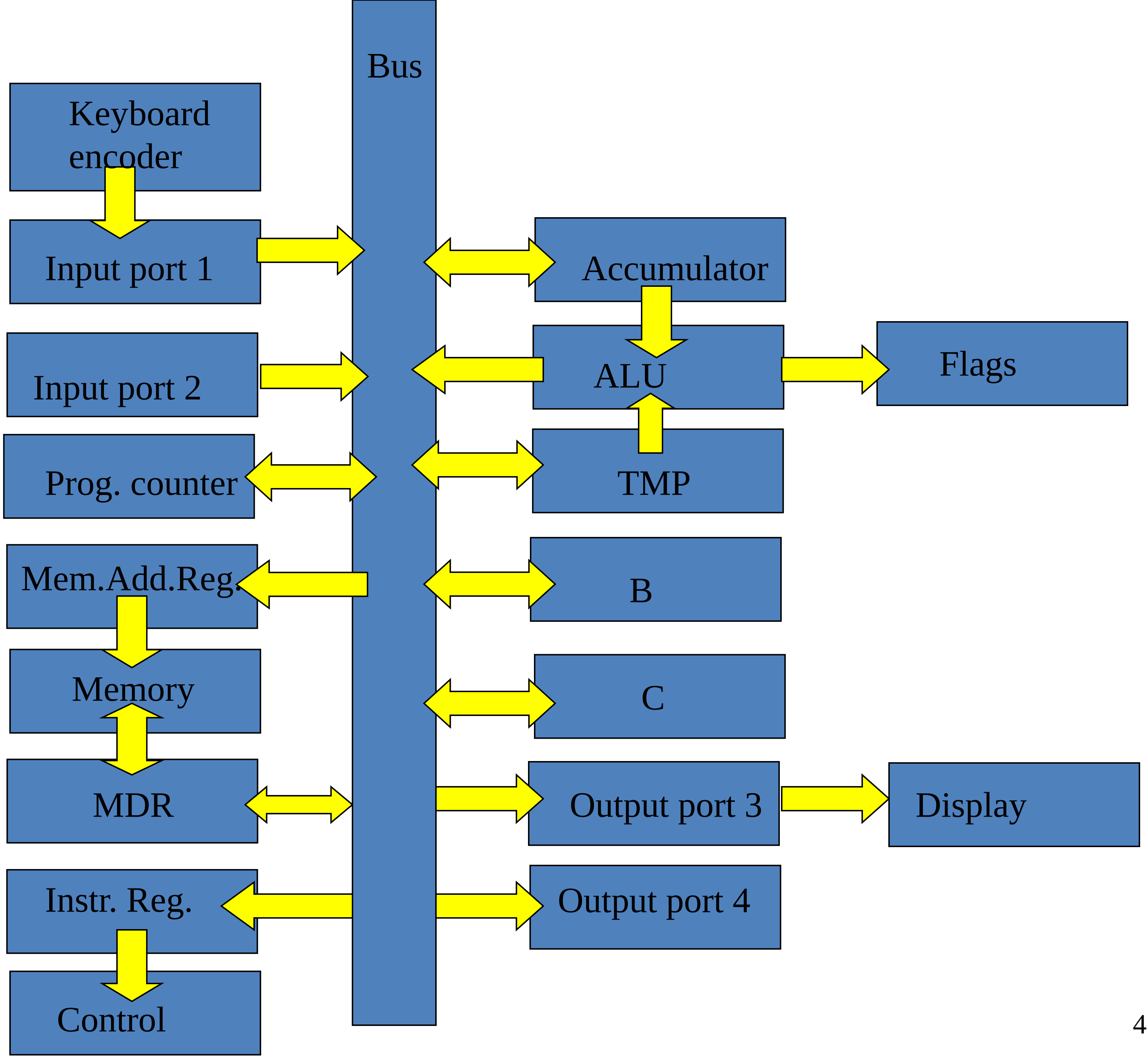
- **Flags** are output from the ALU that are distinct from data (data output goes to Acc. A)
- For example,
  - A carry from an addition
  - An indication of overflow
    - These are needed for program control or to indicate possible errors
  - The result of a logical comparison (<, >, =)
    - These are needed for control (ifs, loops, etc)

TMP, B and C

- **TMP** is the other register used in conjunction with the ALU; the distinction is that answers are generally sent to Accumulator A
- B and C are additional registers used for holding data temporarily
  - They allow additional flexibility and reduce the amount that must be written to memory.

Output ports

- **Output port** a connection to the “outside world”
  - Usually includes a buffer
  - This design has one for displayed output and a second for other output (e.g. storage)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B
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C
MDR
Output port 3
Display
Instr. Reg.
Output port 4
Control

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