Introduction to Microprocessors

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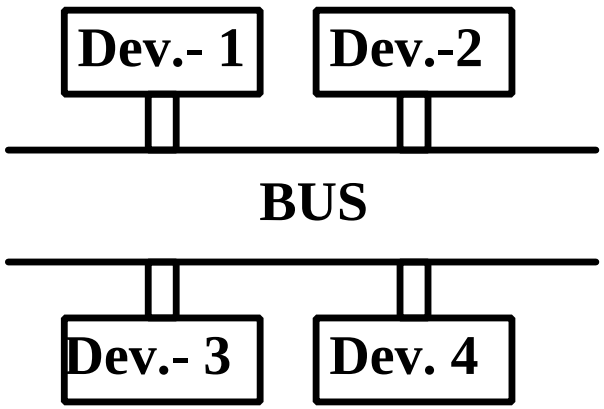
Connecting Digital Circuits using a “Bus”



When connecting multiple digital devices, it is convenient if we can use common wires for data communication among them. This is called a **bus**.

However, outputs of conventional digital circuits cannot be shorted together.

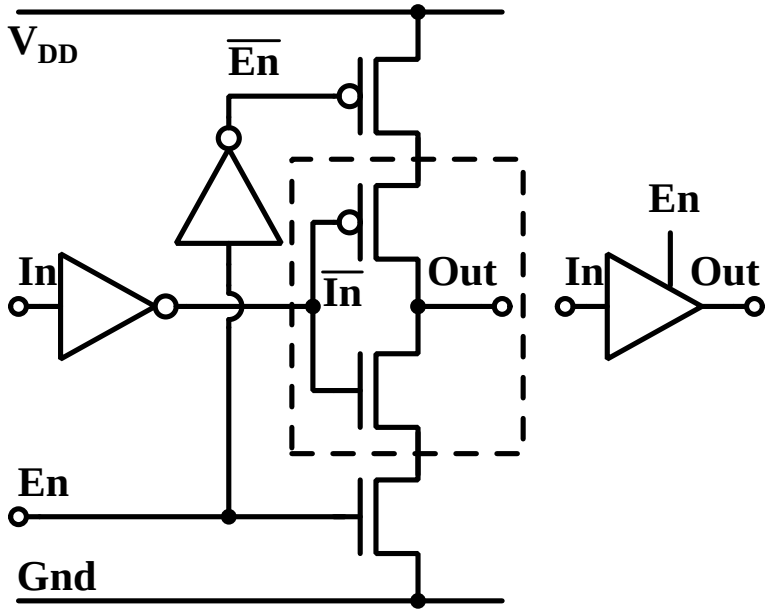
- Outputs of conventional digital circuits can only be ‘0’ or ‘1’. If we short the outputs of multiple devices, some will try to make the output ‘High’ while the others may try to pull it ‘Low’.
- This can lead to indeterminate outputs and heavy current being drawn from the supply.
- We can manage connecting outputs of all devices to the same wire by using **tri-stateable** outputs or **open-collector outputs**.

Tri-stateable Devices

- The output of tri-stateable digital circuits can have three states. It could be ‘0’ or ‘1’ like the conventional digital circuits, or it could be in a high impedance state called ‘Z’.
- In the high impedance state, the circuit is **disconnected** from the output and does not interfere with other outputs connected to the same wire.

The figure on the right shows the circuit diagram and the symbol for a tri-stateable buffer.

The circuit has an extra input to enable it (– labelled as ‘En’ in the circuit).
When En = 1, the circuit acts as a buffer, but when En = 0, the circuit is disconnected from the output.



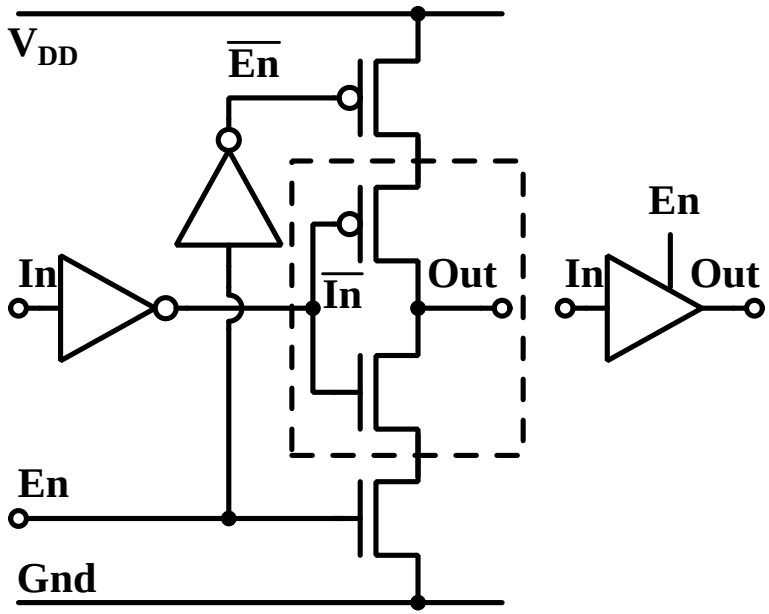
Tri-stateable devices

Circuits which can disconnect their output drivers from the output terminal are called **tri-stateable** devices.

The connection to supply and ground is through the top pMOS and bottom nMOS transistors.

Both of these are OFF when En = 0 (and $\overline{\text{En}} = 1$).

Both are ON when En = 1 and $\overline{\text{En}} = 0$, applying power to the circuit in the dashed box.



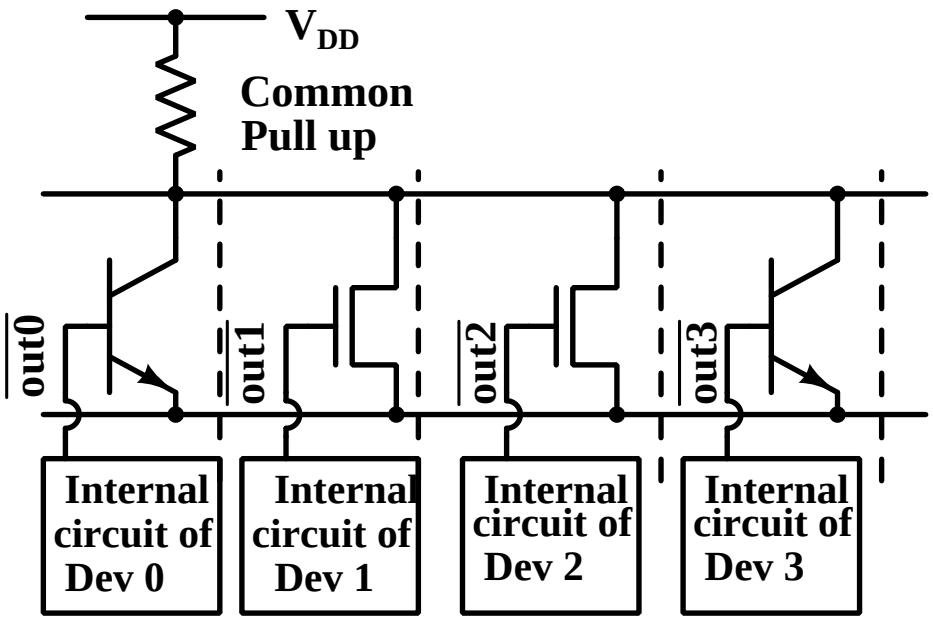
When En = 1, the middle two transistors in the dashed box form an inverter, which inverts the output of the first inverter, thus providing a buffer function.

Tri-stateable devices

- One of the devices on the bus acts as the **“bus master”**.
- It decides which of the devices on the bus will be **listeners** for the data on the bus and which will be the **talker**.
- While there can be multiple listeners on the bus, only one device can be a talker. The bus master manages this by setting the Enable line of the designated talker to TRUE and that of all others to FALSE.
- The bus itself contains many wires for carrying the data and a few driven by the bus master to enable devices on the bus (and for other bus administration functions such as designating roles as listeners or talkers).

Open Collector Outputs

Another way for direct connection of outputs to common wires is to use open-collector/open-drain drive.



Every circuit has an open collector (or open drain) device to pull the output to '0' when required. There is a common pull up resistor for all devices which are connected in parallel.

To write '1' to the output, the output device is turned OFF.
Then the output is pulled up by the common pull up resistor.

To write '0' to the output, the output device is turned ON. This will force the output to '0'. Thus a '0' is dominant over a '1' in this system.

To disable a device, it is enough to write a '1' to the output.

Need For a programmable device

- Design of complex integrated circuits has a high fixed cost component.
- If sold in large quantities, the cost of an integrated circuit can be made quite low.
- It makes sense to design a programmable device which can be configured to perform different functions for different products.
- Now this device can be used for a variety of products and will thus be required in large quantities.
- The specific function performed by the device needs to be selected by a digital input. This is called an **instruction**.
- The device is given a series of instructions to perform a task. This sequence of instructions is a **program**.

The Processor

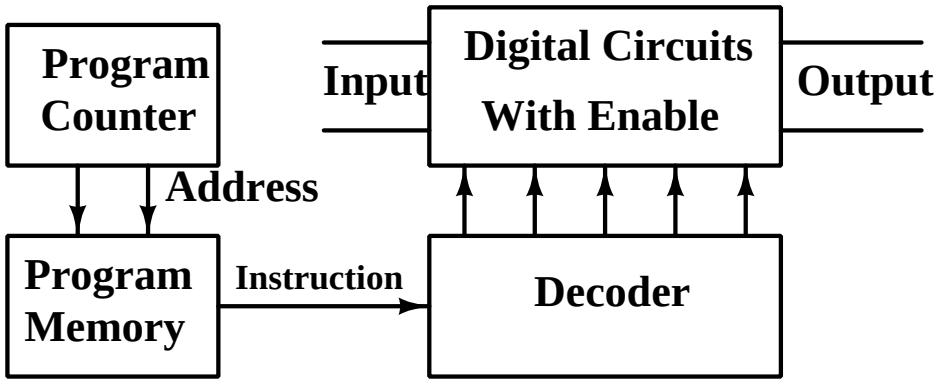
- The programmable digital device which can run a series of instructions (program) is called a **processor**.
- A processor which is implemented on a single chip using VLSI technology (Very Large Scale Integration) is called a **microprocessor**.
- Modern microprocessors can be quite complex – a Pentium processor used in PCs has upwards of 100 million transistors!
- The basic logic in a processor just performs the following loop endlessly:
  - Fetch next instruction
  - Decode it
  - Execute the instruction

Storing Instructions

- The actual task performed by a processor may require a series of operations to be carried out.
- For example, we may wish to multiply a variable by a coefficient and then add the product to an accumulating sum.
- This requires a series of instructions, to be executed in a sequence.
- This sequence of instructions is called a **program**.

We store the sequence of instructions in a memory called the *program memory*.

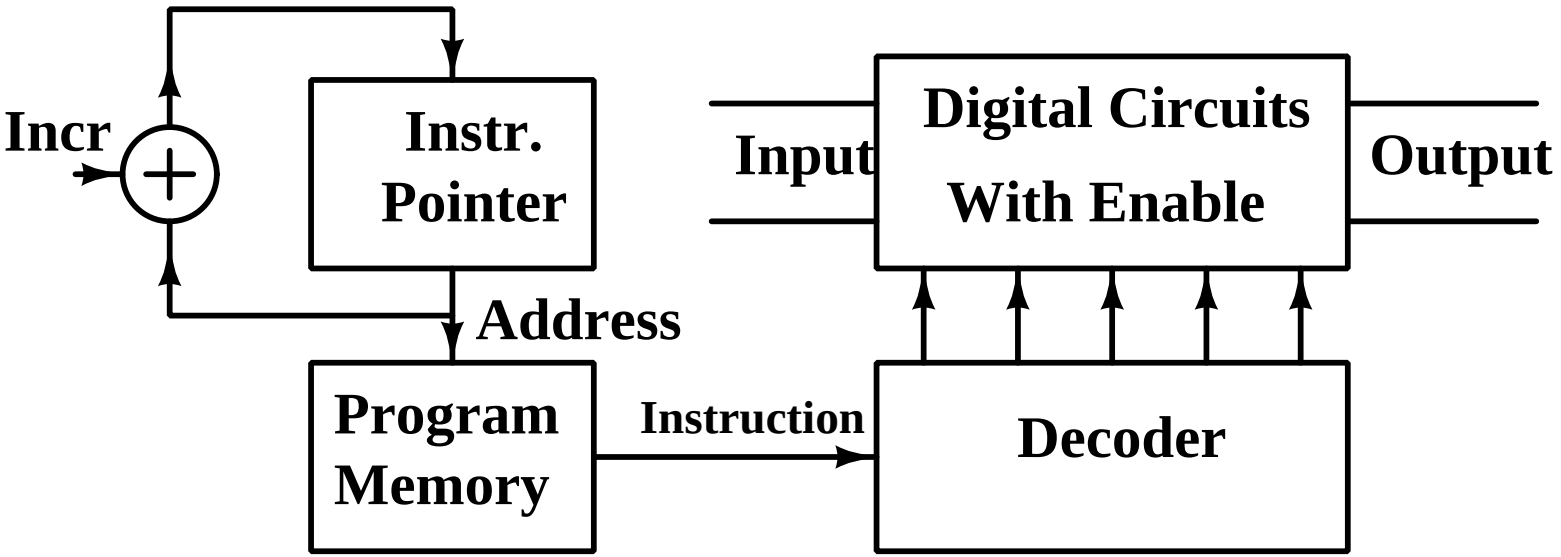
Fetching Instructions



- To fetch each instruction, we need to provide its address to the program memory.
- From where will this address come?

- We can include a counter to generate sequential addresses for the program memory.
- Every time an instruction is fetched from the memory, the counter will increment the address to point to the next instruction.
- The counter which provides addresses to the program memory is called a **program counter**.

Fetching Instructions

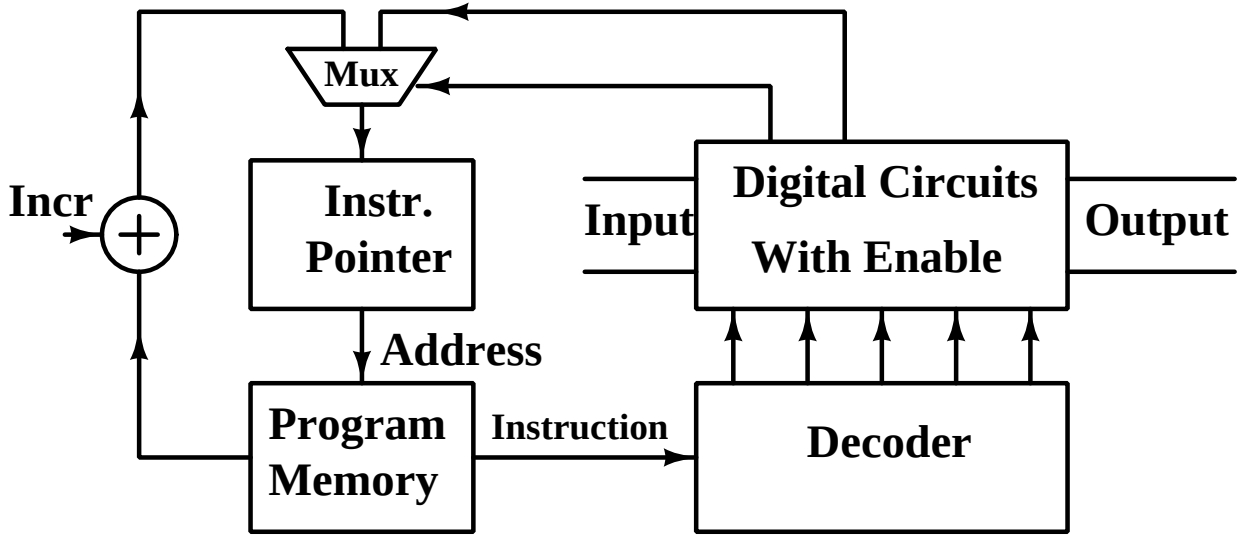


Fetch - Decode - Execute

- The program counter is just a register to store a value and an adder to increment the value stored in the register.
- This register is also referred to as the **instruction pointer**.

Fetching Instructions

- The instruction pointer needs to be initialized to some value when the whole operation starts.

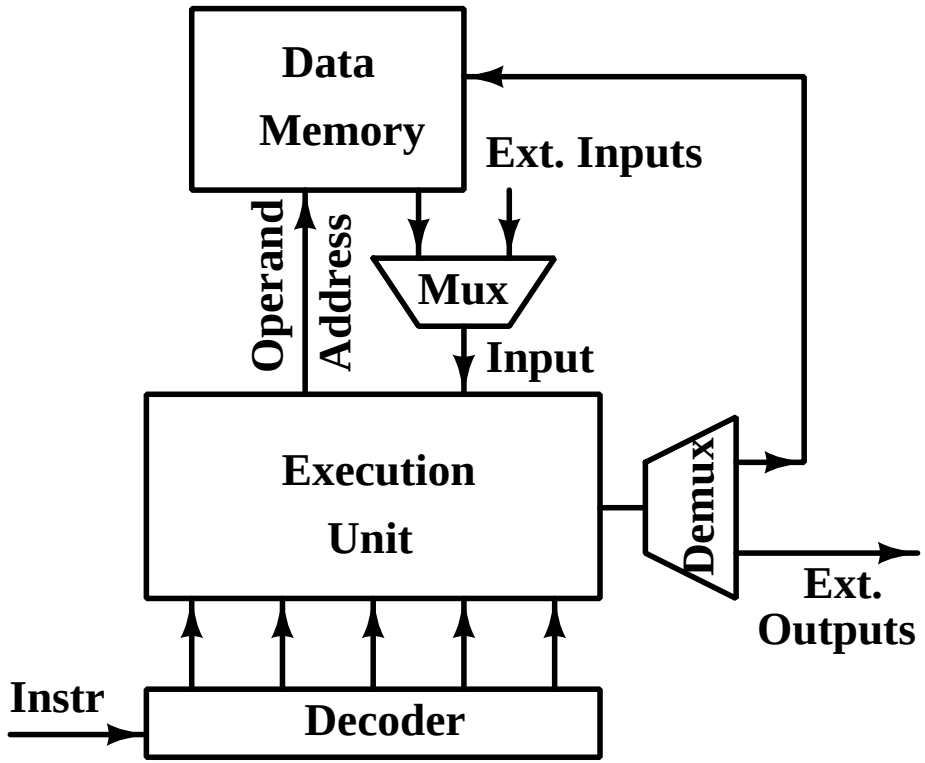


- Instructions need not be executed in a strict sequence. After finishing a block of instructions, we may wish to execute a different block of instructions, stored at some other address.
- Defining an instruction which loads data into the instruction pointer gives us the ability to alter the flow of instructions in the program during its run time.
- When a new value is loaded in the instruction pointer, the next instruction will be fetched from this new location.

Managing data

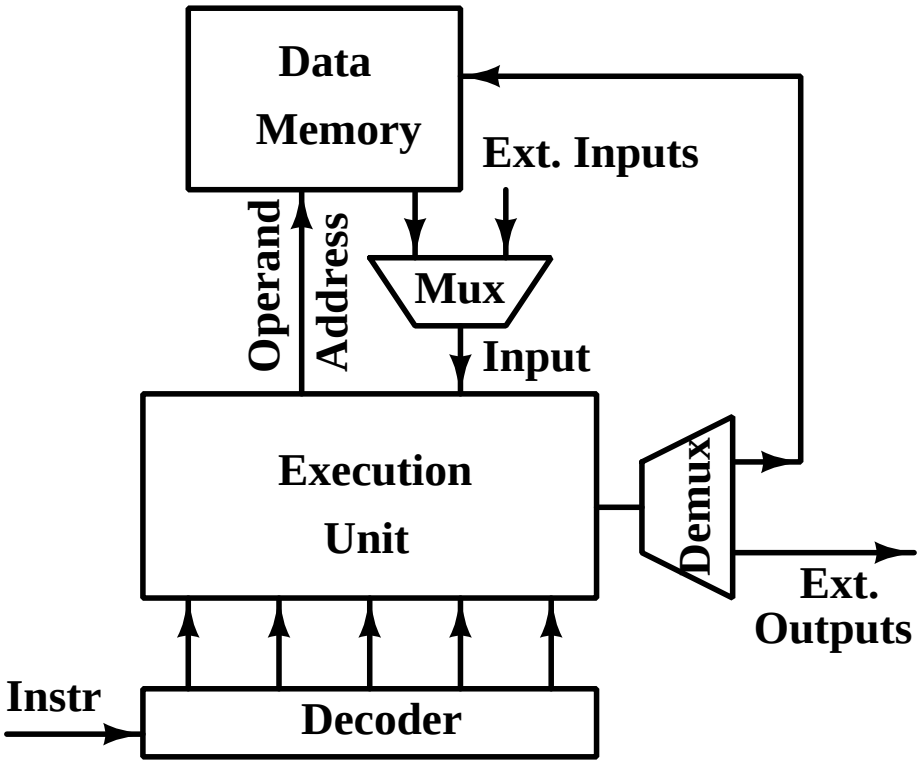
So far we have concentrated on the flow of instructions and control path. What about the data path?

- Different instructions will, in general, operate on different data. How do we propose to manage the flow of data?
- Data can also be stored in a memory. Successive data items can then be fetched from/written to this memory.



Data I/O with external world

The microprocessor should also be capable of fetching data from **external** sources and to output data to destinations other than the data memory.

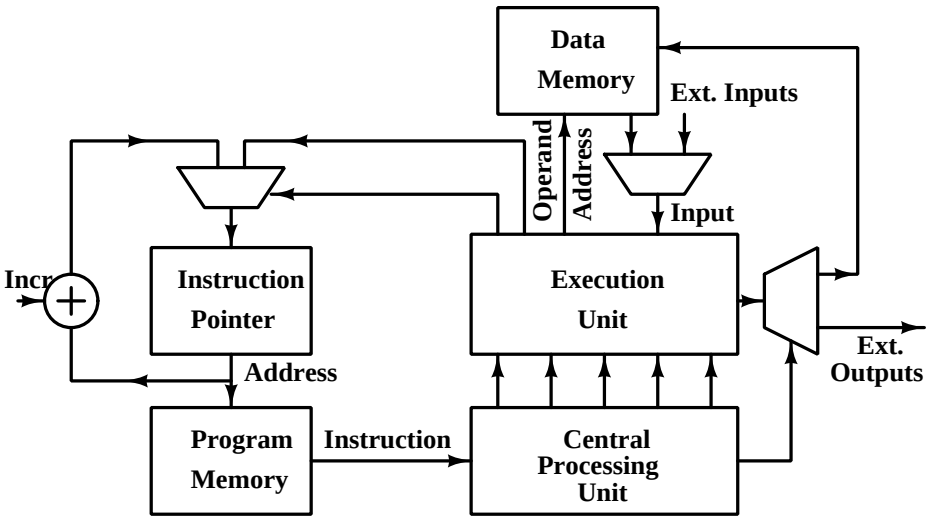


- We can place multiplexers in the input and demultiplexers in the output data path to choose between data memory and external IO.
- Control for these multiplexers should be included in the instruction.

The data and program memory need not be physically distinct and a common memory with different address blocks may be used for the two.

The Central Processing Unit

We have oversimplified the evolution of this circuit by assuming that just a combinational circuit like a decoder is needed to execute instructions.



Fetch - Decode - Execute

- In fact each instruction may need a sequence of actions to be executed properly.
- Therefore, we need a sequential circuit like a finite state machine to interpret and carry out an instruction.

- The circuit which generates the sequence of control inputs to the execution unit is called the Central Processing Unit or CPU.

The Central Processing Unit

- The central processing unit generates control inputs for the sequence of operations to be carried out.
- At the top level, it repetitively carries out the three steps:
  - Fetch the next instruction
  - Decode the instruction
  - Execute it
- Each of these operations may involve a series of transactions with the memory or with internal execution units.
- Instruction execution may involve data processing or controlling the flow of instruction through writing to the instruction pointer.

We have designed a microprocessor! How to use it?

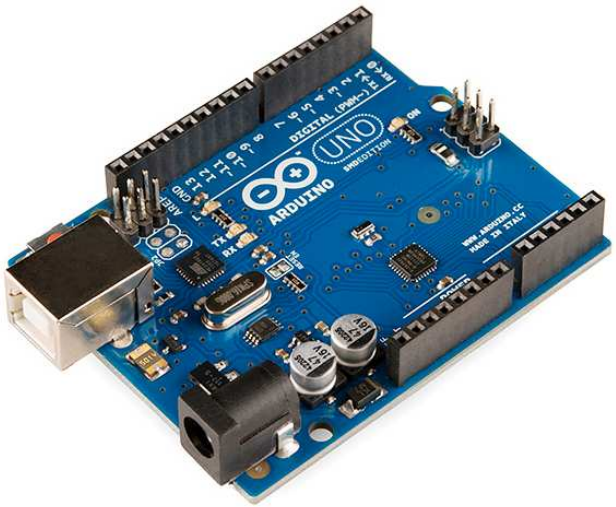
- The architecture which has evolved through this discussion describes the skeleton of a microprocessor.
- However, we need many devices external to the microprocessor to make a useful system – For example, program and data memories, display device drivers, keyboard readers etc.
- So with microprocessors, we invariably need multiple ICs on a circuit board to perform any useful function.

  For example, the old 8085 processor needed a program memory chip (say, type 2764, 8Kx8 EEPROM), data memory chip (type 6264, 8Kx8 RAM), 3 to 8 decoder (74LS138) to select I-O devices, data transceiver etc. in order to make an operational circuit.

Microcontroller based systems

- As technology has progressed, it has become possible to put many of the components required in the system along with the microprocessor on the same IC.
- Processors which have these components on the same IC are called **microcontrollers**.
- A system using microcontrollers can be quite compact and can be made operational in practical systems with very few external components.
- Ready-made cards with microcontrollers and the essential external components are available with varying capabilities.
- “Raspberry Pi” is an example for such cards and uses the popular ARM processor. This is a 32 bit or 64 bit system and is used in somewhat high end applications.

Microcontroller based systems



- “Arduino” is a family of cards whose design is open source. These are therefore made by several manufacturers and are quite economical.
- There are many models of Arduino cards. The most popular among these are UNO R3 and nano, which are based on the 8 bit AVR microcontroller (ATMega 328P).
- These cards are suitable for low-cost and simple applications. The UNO R3 card can be bought for under Rs. 500, while the nano card is even cheaper.

Microcontroller AtMega 328P

- Arduino R3 and nano boards use the microcontroller AtMega 328P.
- This microcontroller contains:
  - an 8 bit microprocessor with 32 registers,
  - 32KB of flash memory to store the program,
  - 1 KB Electrically Eraseable and Programmable memory,
  - 2 KB SRAM to store data,
  - 3 Counter/Timers,
  - 10 bit A to D converter with 6 input channels,
  - Serial communication using RS232C, I^2C as as well as SPI protocols.

The Arduino **board** adds a USB controller to the microcontroller resources to provide USB connectivity.

Application Development with Microcontroller boards

Having selected a microcontroller board with the necessary resources, we need to program it to perform the function we need. As discussed earlier, this can be done using instructions recognized by the microcontroller.

- Instruction to the microcontroller are groups of ‘1’s and ‘0’s – which do not make much sense to human beings. These instructions are said to be in **machine code**.
- Meaningful mnemonics are associated with each machine code instruction which indicate the purpose for that instruction.
  For example, we associate MOV R31, R0 with a pattern like: 0010 1101 1111 0000 for an instruction which copies the contents of register number 0 to Register no. 31.
- The collection of such mnemonics are then “assembled” into machine code by a program (typically run on an external computer).
- The program which does the assembly of mnemonics into machine code is called an **assembler**.

Application Development with Microcontroller boards

- While assembly language programs make sense to human beings, these are very detailed and it is laborious to write programs in assembly language.
- High level languages (such as C and C++) can express what needs to be done much more compactly.
- It is then possible to translate this high level language program to assembly language and eventually to machine language using a program called a **compiler**.
- Once the translation is complete, the bit pattern corresponding to the machine language must be downloaded to the microcontroller. This requires a communication program to run on the external computer and a receiver program to run on the microcontroller.
- The receiver program is a small program which is pre-loaded into the program memory of the microcontroller at the time of manufacture. This is called **boot code**.

Application Development with Microcontroller boards

so the application development cycle involves

1. Writing the application program in a high level language (C or C++).
2. Compiling it on the PC – usually using an Integrated Development Environment (IDE) supporting the board we shall be using. (The Integrated Development Environment includes an editor for writing the program, a compiler, a library with useful pre-written functions and the software required to download the machine code to the microcontroller board).
3. Downloading the compiled program to the board using IDE on the PC and the boot loader on the microcomputer.
4. Running the downloaded program on the board.
5. Testing and debugging the application program.

Still to come . . .

In the next lecture, we'll discuss the application development process with a few examples.