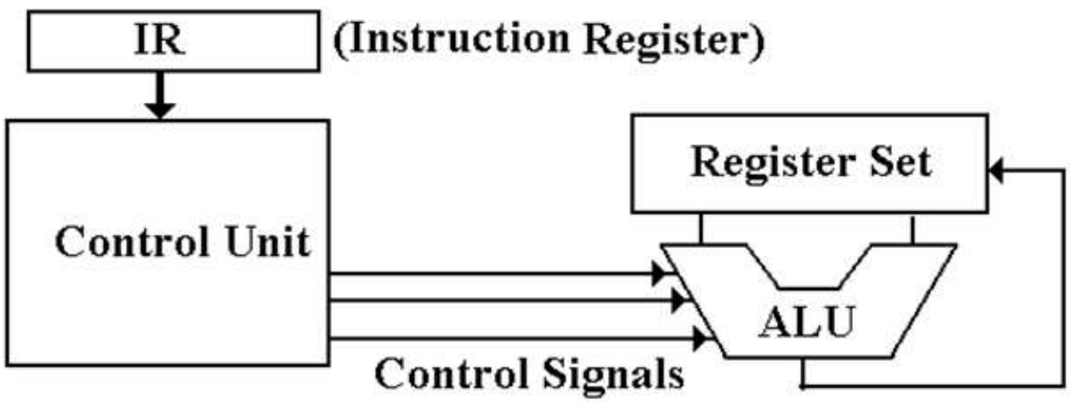
CONTROL UNIT

CPU is partitioned into Arithmetic Logic Unit (ALU) and Control Unit (CU).

The function of control unit is to generate relevant timing and control signals to all operations in the computer.

It controls the flow of data between the processor and memory and peripherals



Types:

There are two methods to implement the control unit:

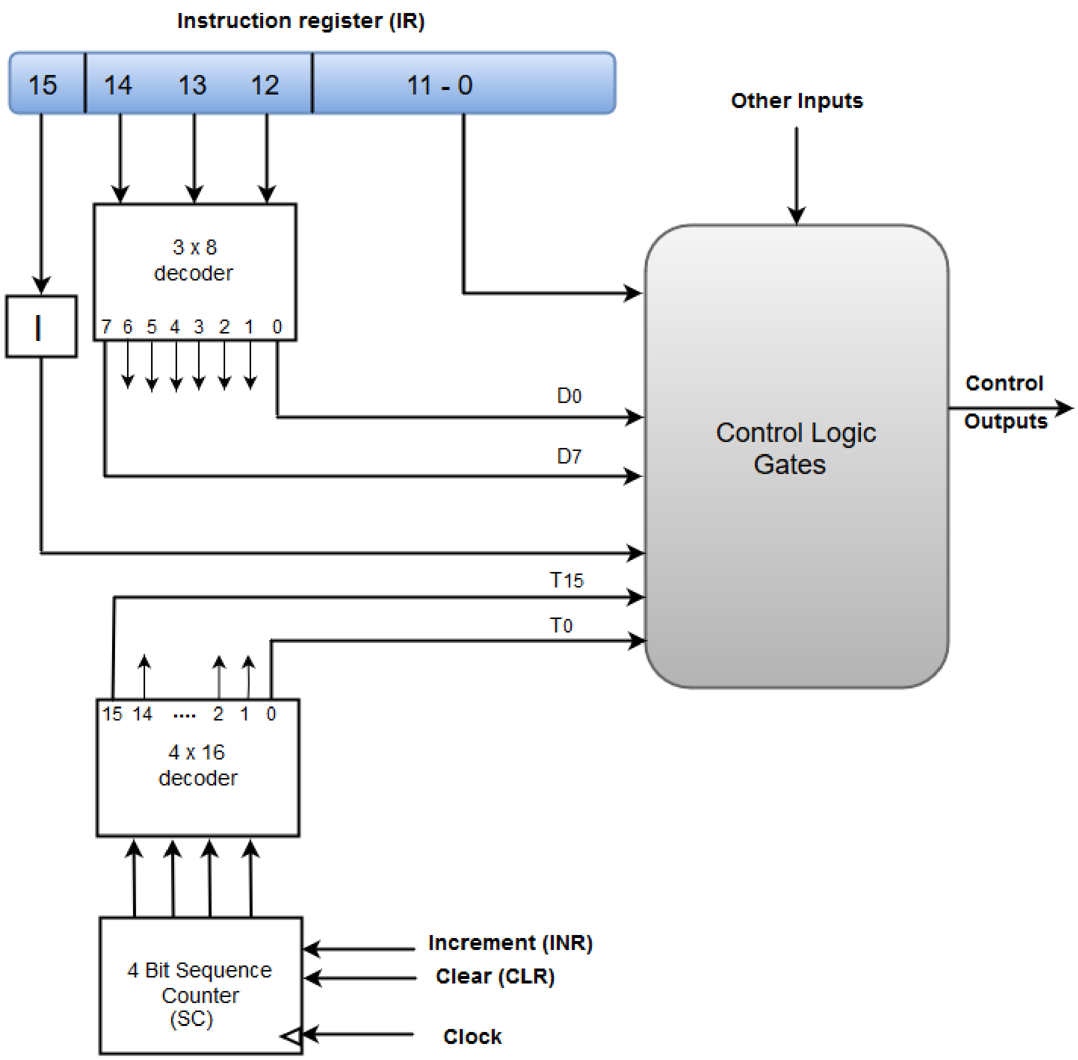
- **Hardwired:** The control signals are generated as an output of a set of basic logic gates, the input of which derives from the binary bits in the Instruction Register.
- **Microprogrammed:** The control signals are generated by a microprogram that is stored in Control Read Only Memory.

The Hardwired and Microprogrammed control unit generates the **control signals** to fetch and execute instructions. The fundamental difference between hardwired and microprogrammed control unit is that hardwired is a **circuitry** approach whereas, the microprogram control unit is implemented by **programming**.

HARDWIRED CONTROL UNIT

The hardwired control unit generates the control signals to execute the instructions in a proper sequence and at the correct time. The hardwired control unit is created with the hardware; it is a circuitry approach. It is designed for the RISC style instruction set.

Control Unit of a Basic Computer:



- A Hard-wired Control consists of two decoders, a sequence counter, and a number of logic gates.
- An instruction fetched from the memory unit is placed in the instruction register (IR).
- The component of an instruction register includes; I bit, the operation code, and bits 0 through 11.
- The operation code in bits 12 through 14 are coded with a 3 x 8 decoder.
- The outputs of the decoder are designated by the symbols D0 through D7.
- The operation code at bit 15 is transferred to a flip-flop designated by the symbol I.
- The operation codes from Bits 0 through 11 are applied to the control logic gates.
- The Sequence counter (SC) can count in binary from 0 through 15.

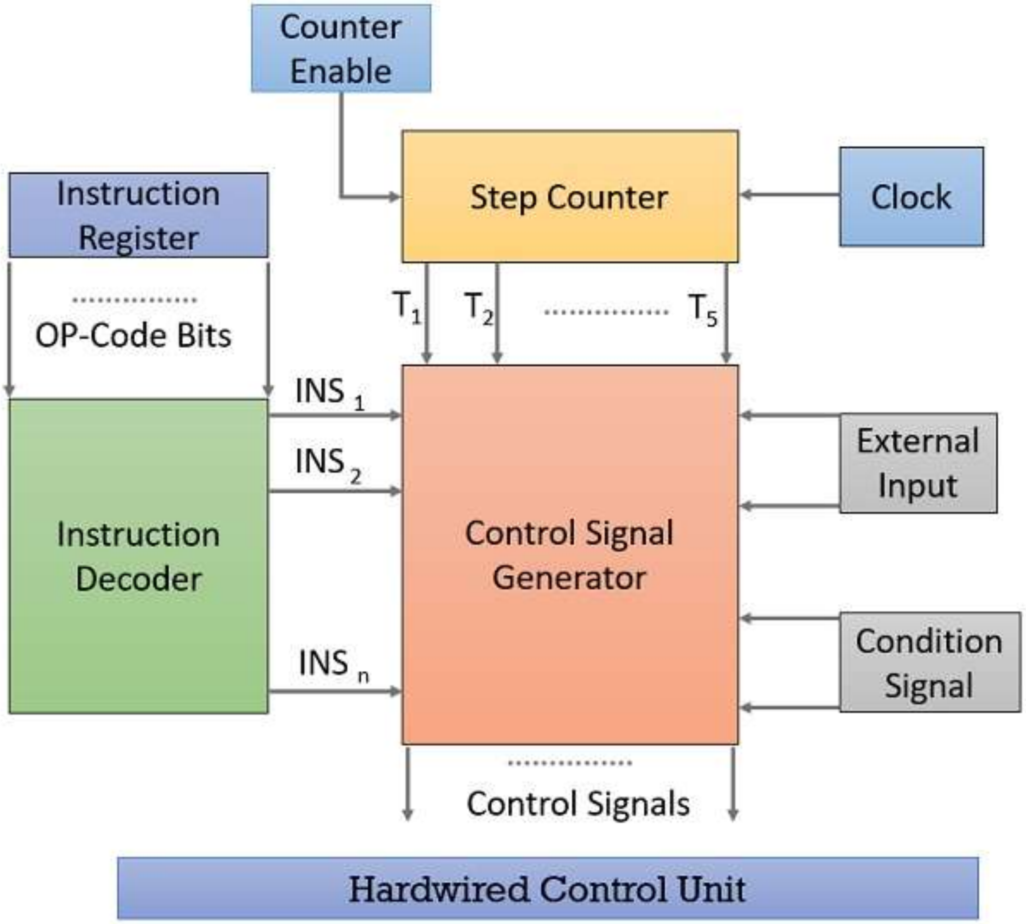
Hardwired Control Unit block diagram

- ***The decoder/encoder*** is a combinational circuit that generates a set of required control signals.
- ***A control step counter*** is used to keep track of the control steps. Each count of this counter corresponds to one control step.

The required control signals are determined by the following information:

1. Contents of the control step counter
2. Contents of IR register
3. Contents of the condition code flags
4. External input signals, like MFC and interrupt request

- ***The step decoder*** generate a separate clock signal for each step, or timeslot, in the control sequence.
- ***The instruction decoder*** decodes the instruction loaded in IR. The output of the instruction decoder consists of a separate line for each of the 'm' machine instruction



Hardwired Control Unit Design Methods

1. State-table Method
2. Delay-element Method: Uses clocked delay element (D-Flip Flop)
3. Sequence-counter Method: Uses counter for timing purposes
4. PLA Method: Uses programmable logic array

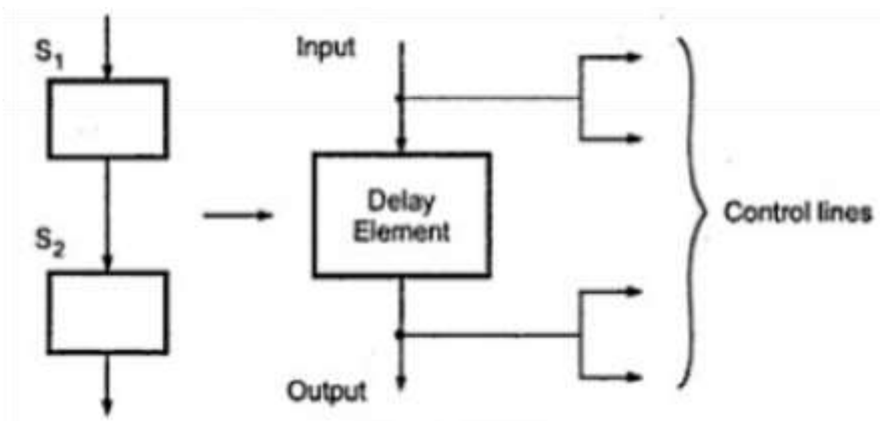
1. State-table Method

Classical method of sequential circuit design. Attempts to minimize the amount of hardware. It starts with the construction of state transition table. In every state the control unit generates a set of control signals.

2. Delay-element Method

Control signals or groups of control signals are activated in proper sequence. There is a specific time delay between activation of two consecutive control signals or groups of control signal.

For synchronous operation, delay elements are implemented using D flip-flops and controlled by common clock signal.



Rules for Delay-element Method

- Each sequence of two successive micro-operations requires a delay element.
- The signals that are intended to activate same control lines are logically ORed to get one common output signals

Advantages of Hardwired Control Unit

1. Fast because control signals are generated by combinational circuits.
2. The delay in generation of control signals depends upon the number of gates

Disadvantages

1. More the control signals required by CPU, more complex will be the design of control unit.

2. No Flexibility. Modification in control signal is very difficult i.e. it requires rearranging of wires in the hardware circuit.
3. Difficult to add new feature in existing design of control unit

Micro-Programmed Control Unit

A micro-programmed control unit is implemented using programming approach. A sequence of microoperations are carried out by executing a program consisting of micro-instructions.

Micro-program, consisting of micro-instructions is stored in the control memory of the control unit.

Execution of a micro-instruction is responsible for generation of a set of control signals.

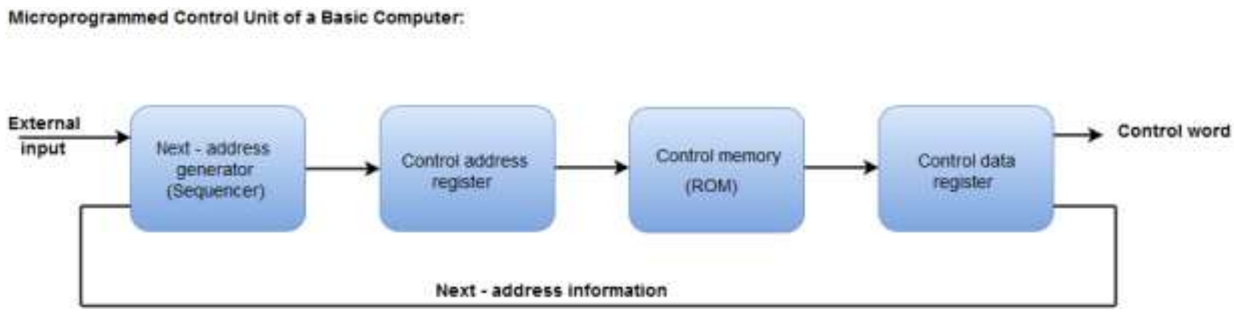
Important Terms

- ***Control Word:*** - The control variables at any time are represented by 1's and 0's, known as Control Word. Control words can be programmed to perform various operations.
- ***Micro-Operations:*** The operations performed on the data stored inside the registers are called micro-operations.
- ***Micro-Programs:*** Microprogramming is the concept for generating control signals using programs. These programs are called micro-programs.
- ***Micro-Instructions:*** The instructions that make micro-program are called micro-instructions.
- ***Micro-Code:*** Micro-program is a group of microinstructions. The micro-program can also be termed as micro-code.
- ***Control Memory:*** Micro-programs are stored in the read only memory (ROM). That memory is called control memory.

Micro-Programmed control Organization

1. Control Memory

2. Control Address Register
3. Sequencer (*Next Address Generator*)
4. Control Data Register (*Pipeline Register)*



Types of memory in MPC

1. Main Memory

The main memory is used for storing programs. The content of the main memory can be altered when data is manipulated and each time the program is changed. Program in main memory contains machine instructions and data.

2. Control Memory

Memory that is a part of the control unit is called Control memory. Control memory holds microprograms that cannot be altered by the user. The microprogram consists of microinstructions to execute register microoperations.

Machine instruction initiates a series of microinstructions in the control memory. The microinstruction generates microoperations to fetch instructions from main memory, to evaluate effective address, to execute the operations specified by instructions or to repeat the cycle for the next instruction.

Sequencer and Pipeline Register

Sequencer: The next address generator is called a sequencer, as it determines the address sequence that is read from the control memory.

Functions:

1. Incrementing the control register

2. Loading an address from control memory to CAR.

3. Loading an initial address

Pipeline Register: The control data register holds the present microinstruction while the next address is computed and read from the memory. This data register is called pipeline register.

Selection of address for Control Memory

Address Sequencing

Address Sequencing = Sequencer: Next Address Generator. Selection of address for control memory

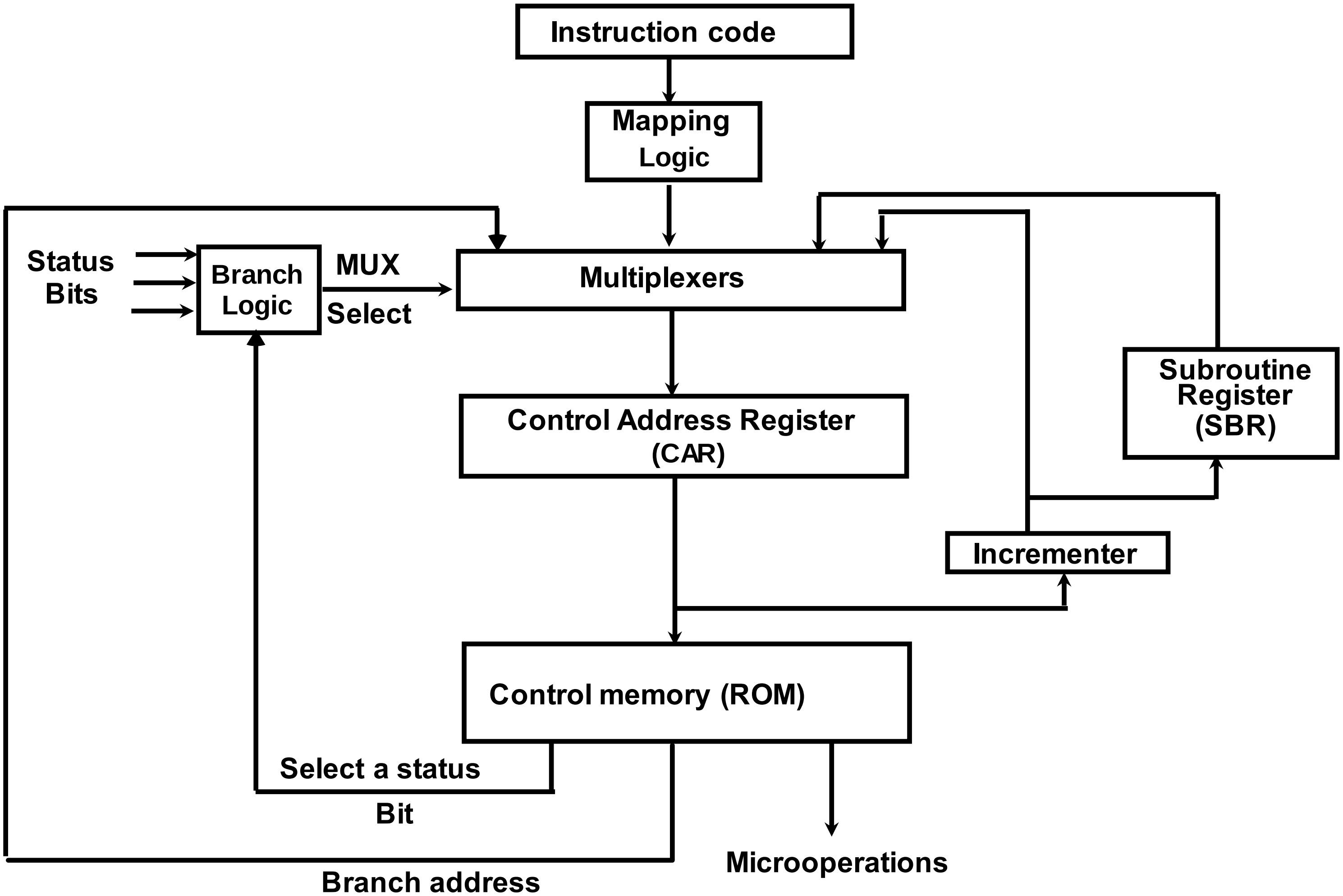
Routine: Microinstruction are stored in control memory *in groups*

Mapping

Instruction Code Address in control memory (*where routine is located*)

Address Sequencing Capabilities: ***control memory address***

1. Incrementing of the control address register
2. Unconditional branch or conditional branch, depending on status bit conditions
3. Mapping process (*bits of the instruction address for control memory*)
4. A facility for subroutine return



Multiplexer

1. CAR Increment
2. JMP/CALL
3. Mapping
4. Subroutine Return

***Control Address Register CAR*:** CAR receive the address from 4 different paths:

1. Incrementer
2. Branch address from control memory

3. Mapping Logic
4. SBR Subroutine Register

SBR Subroutine Register**:** Return Address cannot be stored in ROM. Return Address for a subroutine is stored in SBR

Conditional Branching

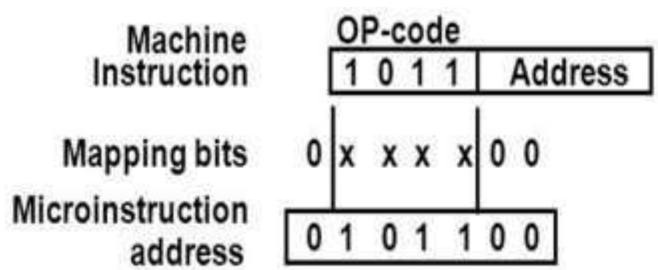
- Status Bits: Control the conditional branch decisions generated in the ***Branch Logic***
- Branch Logic: Test the specified condition and Branch to the indicated address if the condition is met; otherwise, the control address register is just incremented.

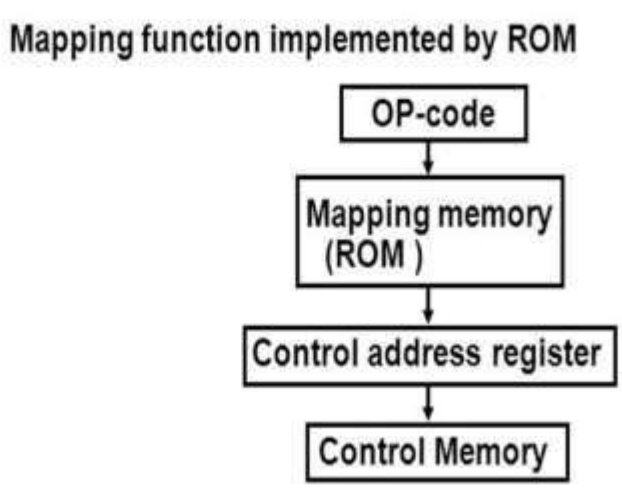
Mapping of Instruction

Mapping: transformation from instruction code bits to microinstruction address in control memory where routine is located.

Each computer instruction has its own microprogram

Routine stored in a given location of the control memory





4 bit Opcode = specify up to 16 distinct instruction

Mapping Process: Converts *the 4-bit Opcode* to *a 7-bit control memory address*

1. Place a “0” in the most significant bit of the address
2. Transfer 4-bit Operation code bits
3. Clear the two least significant bits of the CAR

Subroutine

Subroutines are programs that are used by other routines. Subroutine can be called from any point within the main body of the microprogram

Subroutine must have a provision for:

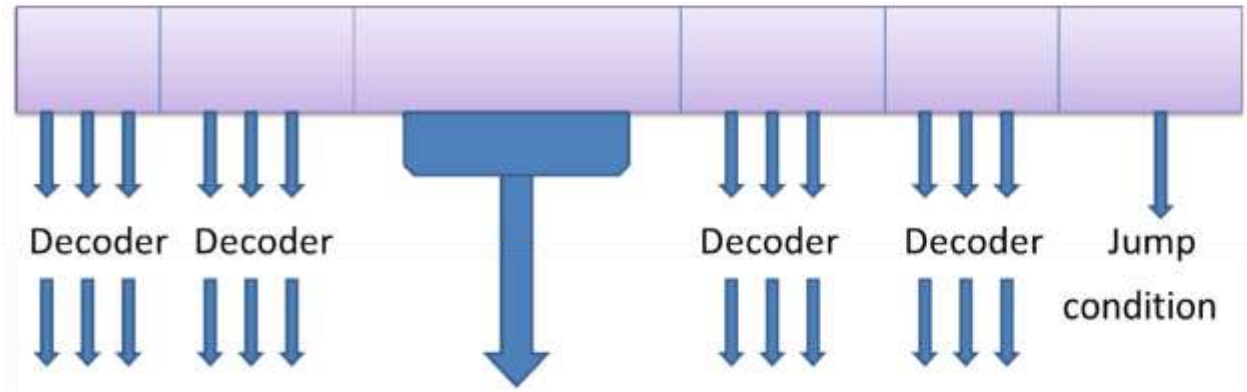
- Storing the return address during a subroutine call
- Restoring the address during a subroutine return (Last-In First Out(LIFO) Register Stack)

Micro-instruction Types

- Vertical Micro-Programming : Each micro-instruction specifies single (or few) micro-operations to be performed
- Horizontal Micro-Programming : Each micro-instruction specifies many different micro-operations to be performed in parallel

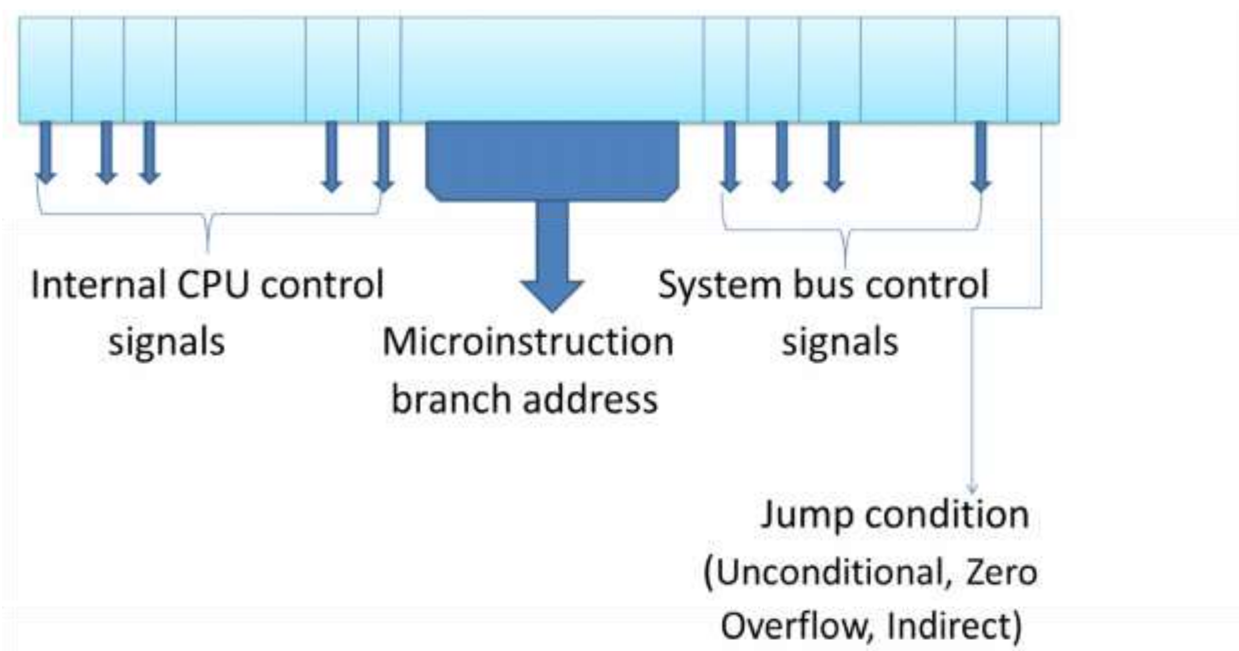
Vertical Micro-programming

- Width is narrow
- n control signals encoded into $\log_2 n$ bits
- Limited ability to express parallelism
- Considerable encoding of control information requires external memory word decoder to identify the exact control line being manipulated



Horizontal Micro-programming

- Wide memory word
- High degree of parallel operations possible
- Little encoding of control information



Advantages of Micoprogrammed Control Unit

1. The design of micro-program control unit is less complex because micro-programs are implemented using software routines.
2. The micro-programmed control unit is more flexible because design modifications, correction and enhancement is easily possible.
3. The new or modified instruction set of CPU can be easily implemented by simply rewriting or modifying the contents of control memory.
4. The fault can be easily diagnosed in the micro-program control unit using diagnostics tools by maintaining the contents of flags, registers and counters

Disadvantages:

1. The micro-program control unit is slower than hardwired control unit. That means to execute an instruction in micro-program control unit requires more time.
2. The micro-program control unit is expensive than hardwired control unit in case of limited hardware resources.
3. The design duration of micro-program control unit is more than hardwired control unit for smaller CPU.

Hardwired Control vs Microprogrammed Control

Difference between Hardwired Control and Microprogrammed Control

Hardwired Control	Microprogrammed Control
Technology is circuit based.	Technology is software based.
It is implemented through flip-flops, gates, decoders etc.	Microinstructions generate signals to control the execution of instructions.
Fixed instruction format.	Variable instruction format (16-64 bits per instruction).
Instructions are register based.	Instructions are not register based.
ROM is not used.	ROM is used.
It is used in RISC.	It is used in CISC.
Faster decoding.	Slower decoding.
Difficult to modify.	Easily modified.
Chip area is less.	Chip area is large.