Chapter 20 - Microprogrammed Control (9^{th} edition)

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Motivation

Remember what we talked about in the last class?

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- **μ-operations** - the most basic instruction executed by a processor:
- **Control signals** - to send data from the various locations;
- **Control unit operation** - how to control signals and micro-operations.

We saw that it was possible to operate the control unit through:

- An hardwired version:
  - Complete boolean circuit;
  - Difficult to implement for complex systems.
  - Impossible to add an instruction after implementing the circuit.

So what is the alternative? Any ideas?

Alternative: μ-programmed control unit

- The logic of the control unit is specified by a microprogram;
  - Also known as **firmware**.
- A microprogram consists of a sequence of μ-operations.

Microinstructions

> How can we use the concept of microprogramming to implement a control unit?

For each μ-operation:

- Control unit is allowed to generate a set of control signals;
- Each control line is either on / off;
- This state can be represented by a binary digit for each control line.

Idea: construct a control word (a.k.a. μ-instruction)

- Bit represents one control line
- Each μ-op would be represented by a different pattern of 1s and 0s.

Format of the μ-**instruction** or control word is as follows:

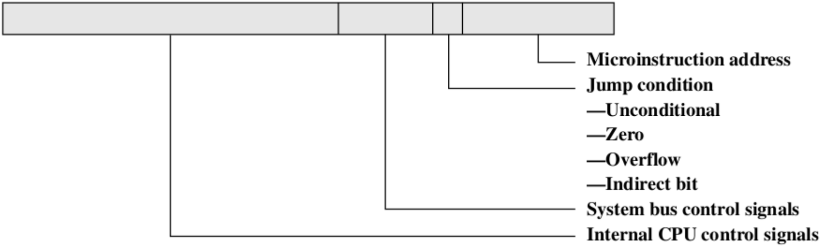


Figure: Microinstruction (Source: (Stallings, 2015))

- One bit for each internal processor control line;
- One bit for each system bus control line;
- Condition field indicating the condition under which there should be a branch (JMP);
- Field with the address of the μ-instruction to be executed next when a branch is taken.

Such a microinstruction is interpreted as follows:

- Activate control lines indicated by a 1 bit;
- Deactivate control lines indicated by a 0 bit;
- If condition indicated by the condition bits is
  - **False:** execute the next microinstruction in sequence;
  - **True:** execute the instruction indicated in the address field.

Microprogrammed Control Unit

How can we process these μ-instructions?

Processing a μ-program requires:

- Going through a sequence of μ-instructions;
- Jumping to other addresses of μ-instructions;
- *I.e.* normal procedure for processing instructions:
  - Only difference is that these instructions are comprised of μ-operations.

Lets take a look at one possible architecture:

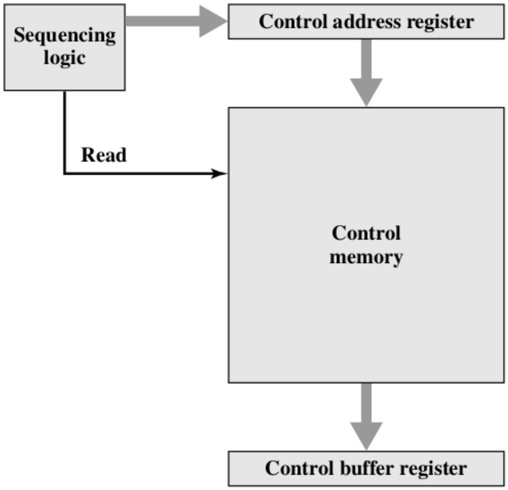


Figure: Control Unit Microarchitecture (Source: (Stallings, 2015))

- **Control memory:**
  - Containing the set of μ-instructions;
- **Control address register (CAR):**
  - Containing the address of the next μ-instruction to be read;
  - Remember MAR?
- **Control buffer register (CBR):**
  - Containing the μ-instruction read from the control memory;
  - After μ-instruction is read it can be executed;
  - Remember MBR?
- **Sequencing logic:**
  - Loads CAR and issues a read command.

In greater detail:

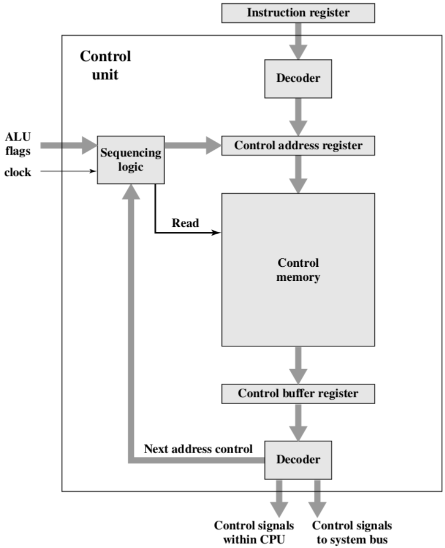


Figure: Function of microprogrammed control unit (Source: (Stallings, 2015))

The control unit functions as follows to execute an instruction:

1. Sequencing logic unit:
   - Loads an address to be read into CAR;
   - Issues a READ command to the control memory;
2. Word is read into CBR;
3. Content of the CBR generates:
   - Control signals for the CPU;
   - Next address for the sequencing logic unit;
4. Sequencing logic unit:
   - Loads a new address into the CAR;
   - Based on the next-address information from the CBR and the ALU flags.

All this happens during one clock pulse.

Does all of this sound strangely familiar? Sense of *deja vu*?

Does all of this sound strangely familiar? Sense of *deja vu?*

- Similar to how control unit processed different stages of an instruction.
- Remember?
  - **MAR**
  - **MBR**
  - **PC**
  - **Fetch cycle**
  - **Indirect cycle**
  - **Interrupt cycle**
- But now are doing it in a "smaller" scale within the control unit:
  - Instead of a system-wide: processor, bus, ram...

Advantages and Disadvantages

Main **advantage** of the use of μ-programming:

- Simplifies the design of the control unit;
  - Both cheaper and less error prone to implement.
- Hardwired control unit must contain complex logic:
  - Microprogrammed control unit components are simple pieces of logic.

Main **disadvantage** of a μ-programmed unit:

- Slower than a hardwired unit of comparable technology;

μ-Instruction sequencing

Tasks performed by a microprogrammed control unit are:

- **μ-instruction sequencing:**
    - Get next μ-instruction from the control memory.
- **μ-instruction execution:**
    - Generate control signals needed to execute the μ-instruction.

Lets focus on the first one.

Address of next μ-instruction to be executed is:

- Determined by instruction register or;
- Next sequential address or;
- Branch (JMP).

Decision is based on:

- Current μ-instruction;
- Condition flags;
- Contents of the instruction register;

Wide variety of techniques to generate the next μ-instruction address:

- Two address fields
- Single address field
- Variable format

Two address fields

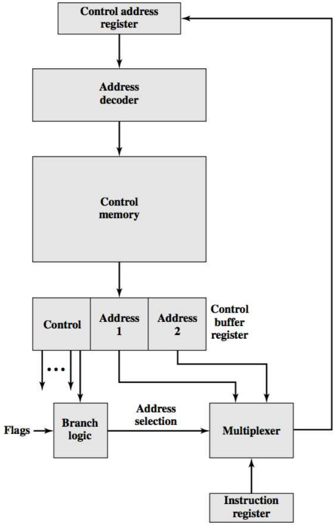
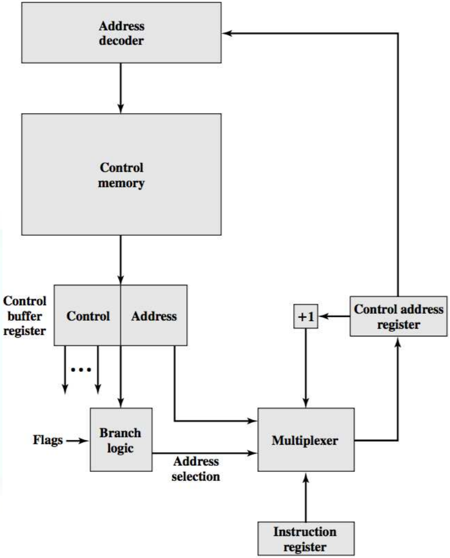


Figure: Branch Control Logic: Two Address Fields (Source: (Stallings, 2015))

Simplest approach: provide two address fields:

- Multiplex between both address fields and IR:
  - Updating CAR accordingly.
- CAR is decoded to produce the next μ-instruction address;
- Branch logic module selects the address-selection signals:
  - Based on control unit flags and
  - Bits from the control portion of the μ-instruction.

Single address field



Two-address approach is simple but:

- Requires more bits in the μ-instruction than other approaches.
- **Idea:** Use additional logic to have only one address field;

Options for next address are as follows:

- Address field;
- IR code;
- Next sequential address (+1).

However:

Often, the address field will not be used... Can we do better? Any ideas?

Variable Format

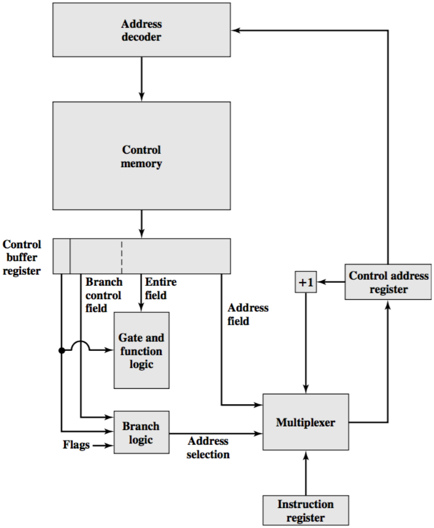


Figure: Branch Control Logic: Variable Format (Source: (Stallings, 2015))

Provide for two entirely different microinstruction formats:

- **Format 1:** bits are used to activate control signals:
  - Next address is either: {next sequential address, address derived from IR}.
- **Format 2:** some bits drive the branch logic, remaining provide address:
  - Either a conditional or unconditional branch is being specified.

μ-Instruction Execution

Tasks performed by a microprogrammed control unit are:

- **μ-instruction sequencing:**
  - Get next microinstruction from the control memory.
- **μ-instruction execution:**
  - Generate control signals needed to execute the μ-instruction.

Lets focus on the second one.

From the previous classes:

Do you remember what is the function of the control unit?

Remember this?

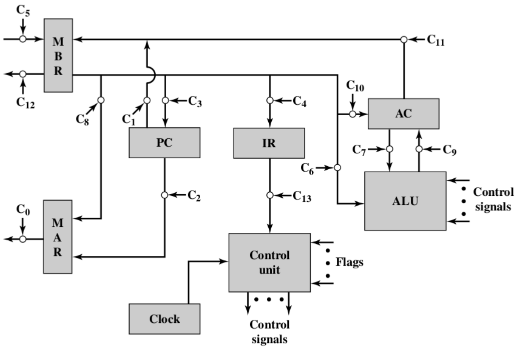


Figure: Data paths and control signals (Source: (Stallings, 2015))

Execution of a μ-instruction: generate control signals.

- Some signals control points internal to the processor;
- Other signals go to the system bus;

We can now update our previous Figure 3:

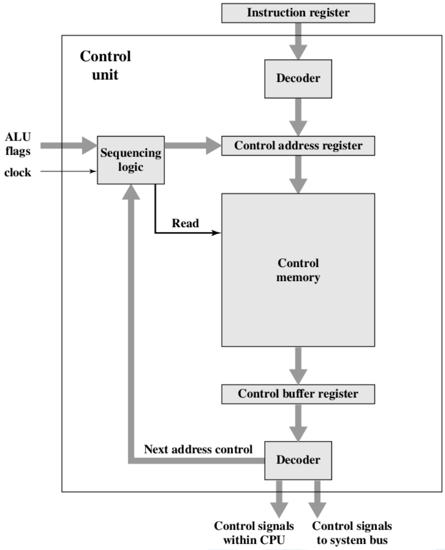


Figure: Function of microprogrammed control unit (Source: (Stallings, 2015))

With this one:

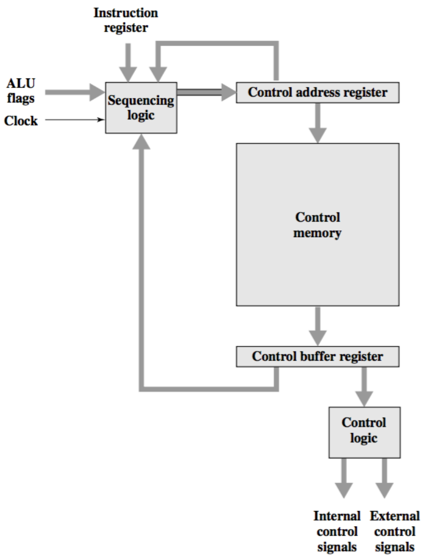


Figure: Control Unit Organization (Source: (Stallings, 2015))

What is the difference between pictures?

First picture focused on the sequencing logic module:

- Containing logic to generate address of next μ-instruction using:
    - as inputs the IR, ALU flags, CAR, CBR.
- Driven by a clock that determines the timing of the μ-instruction cycle.

Second picture introduces **control logic module:**

- Generates control signals as a function of the μ-instruction;

Control signals can be transmitted in various ways (1/2):

- K control signals:
  - Can be controlled using K lines, allowing for 2^k possibilities;
  - Not all of these possibilities are valid, *e.g.*:
    - Two sources cannot be gated to the same destination;
    - A register cannot be both source and destination;
    - Only one pattern of control signals can be presented to the ALU at a time.
    - Only one pattern of control signals can be presented to the external control bus at a time.
  - We can do better than this...

Control signals can be transmitted in various ways (2/2):

- Let Q represent all allowable combinations of control signals:
  - Possible combinations: Q with $Q < 2^K$ possibilities;
  - We can encode these Q combinations using $\log_2 Q$ bits;
  - Therefore $\log_2 Q < 2^K$

Advantages / Disadvantages:

- **Unencoded format:**
  - Advantage:
    - Little or no decode logic is needed;
    - Each bit generates a particular control signal.
  - Disadvantage:
    - Requires more bits than necessary.
- **Encoded format:**
  - Advantage:
    - Requires less bits.
  - Disadvantage:
    - Requires complex logic to encode / decode resulting in loss of performance.

Example (1/5)

Assume a processor with:

- Single accumulator register;
- Several internal registers:
  - Such as a program counter and a temporary register for ALU input.
- Instruction format where:
  - First 3 bits indicate the type of operation;
  - Next 3 encode the operation;
  - Final 2 select an internal register

Example (2/5)

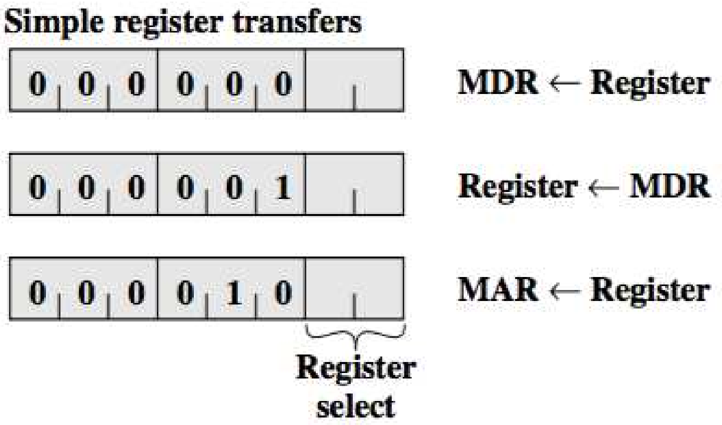


Figure: Simple register transfers (Source: (Stallings, 2015))

Example (3/5)

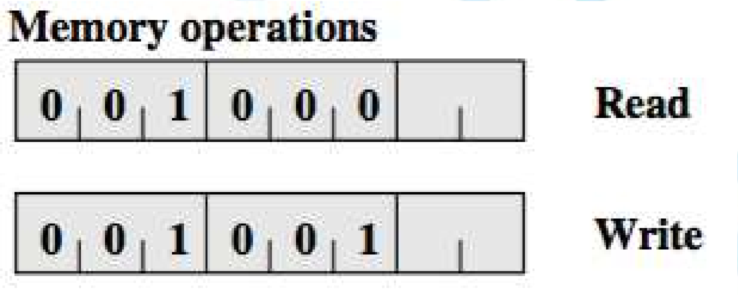


Figure: Memory Operations (Source: (Stallings, 2015))

Example (4/5)

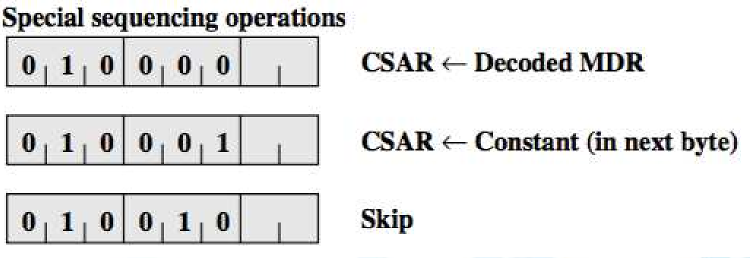


Figure: Special sequencing operations (Source: (Stallings, 2015))

* CSAR = channel system address register, special register for controlling bus lines that exists in some processors.

Example (5/5)

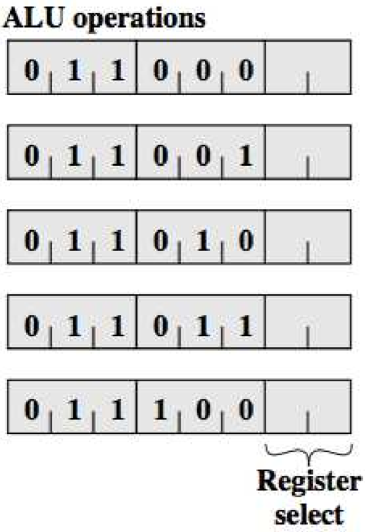


Figure: ALU operations (Source: (Stallings, 2015))

Where to focus your study (1/2)

After this class you should be able to understand that:

- Execution of an instruction involves the execution of substeps:
  - Each cycle is in turn made up of μ-operations;
- Control unit causes the processor to go through a series of μ-operations:
  - in the proper sequence;
  - and generating the appropriate control signals;

Where to focus your study (2/2)

After this class you should be able to understand that:

- Alternative to a hardwired control unit is a μ-programmed control unit:
  - logic is specified by a μ-program:
    - which consists of a sequence μ-operations.
- μ-programmed control unit is a simple logic circuit capable of:
  - sequencing through μ-instructions;
  - generating control signals to execute each μ-instruction.
- As in a hardwired control unit:
  - Control signals generated by a μ-instruction are used to cause register transfers and ALU operations.

Less important to know how these solutions were implemented:

- details of specific hardware solutions.

Your focus should always be on the building blocks for developing a solution =)

References I

Stallings, W. (2015).

Computer Organization and Architecture: Designing for Performance.

Pearson Education, 10th edition edition.