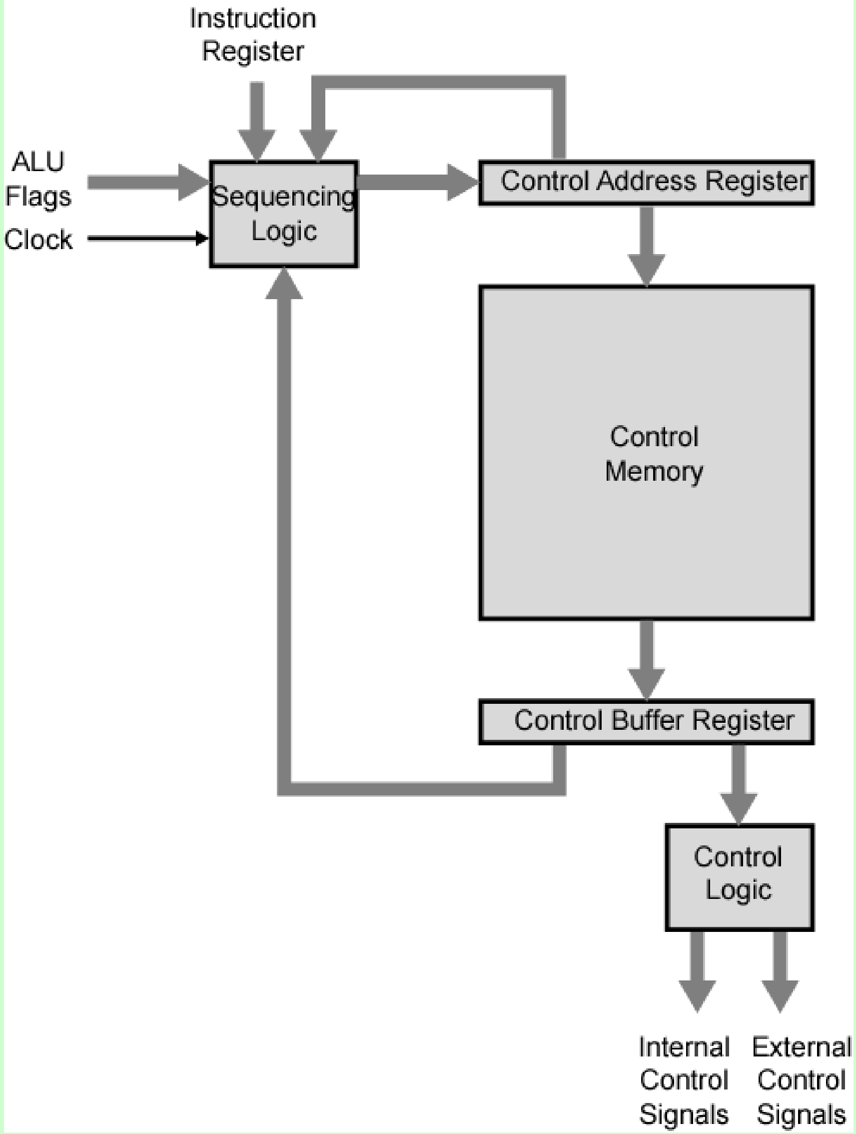
William Stallings
Computer Organization and Architecture
8^{th} Edition

Chapter 16

Micro-programmed Control

Control Unit Organization



Micro-programmed Control

- Use sequences of instructions (see earlier notes) to control complex operations
- Called micro-programming or firmware

Implementation (1)

- All the control unit does is generate a set of control signals
- Each control signal is on or off
- Represent each control signal by a bit
- Have a control word for each micro-operation
- Have a sequence of control words for each machine code instruction
- Add an address to specify the next micro-instruction, depending on conditions

Implementation (2)

- Today's large microprocessor
  - Many instructions and associated register-level hardware
  - Many control points to be manipulated
- This results in control memory that
  - Contains a large number of words
    - co-responding to the number of instructions to be executed
  - Has a wide word width
    - Due to the large number of control points to be manipulated

Micro-program Word Length

- Based on 3 factors
  - Maximum number of simultaneous micro-operations supported
  - The way control information is represented or encoded
  - The way in which the next micro-instruction address is specified

Micro-instruction Types

- Each micro-instruction specifies single (or few) micro-operations to be performed
  - (*vertical* micro-programming)
- Each micro-instruction specifies many different micro-operations to be performed in parallel
  - (*horizontal* micro-programming)

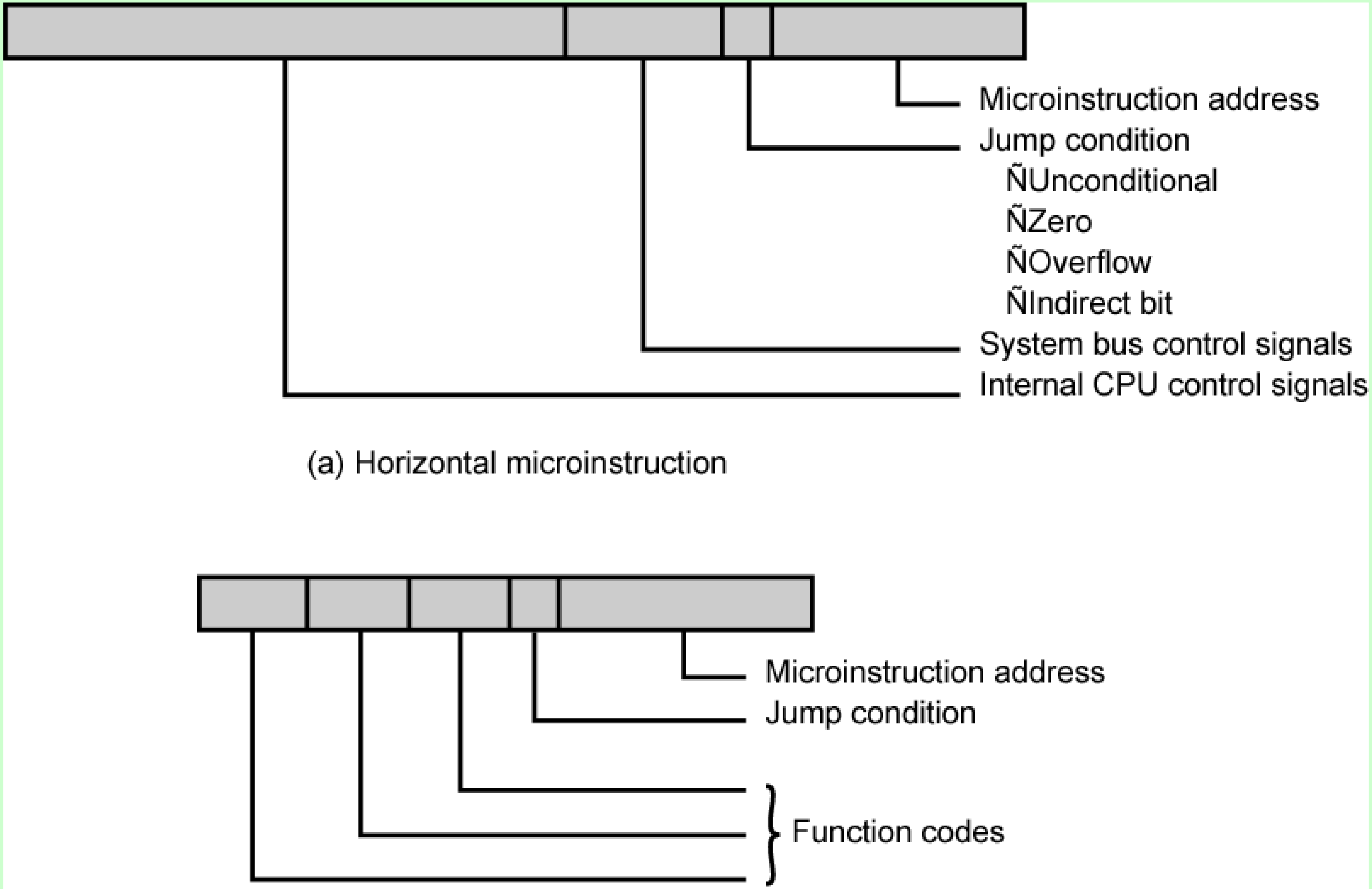
Vertical Micro-programming

- 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

Typical Microinstruction Formats



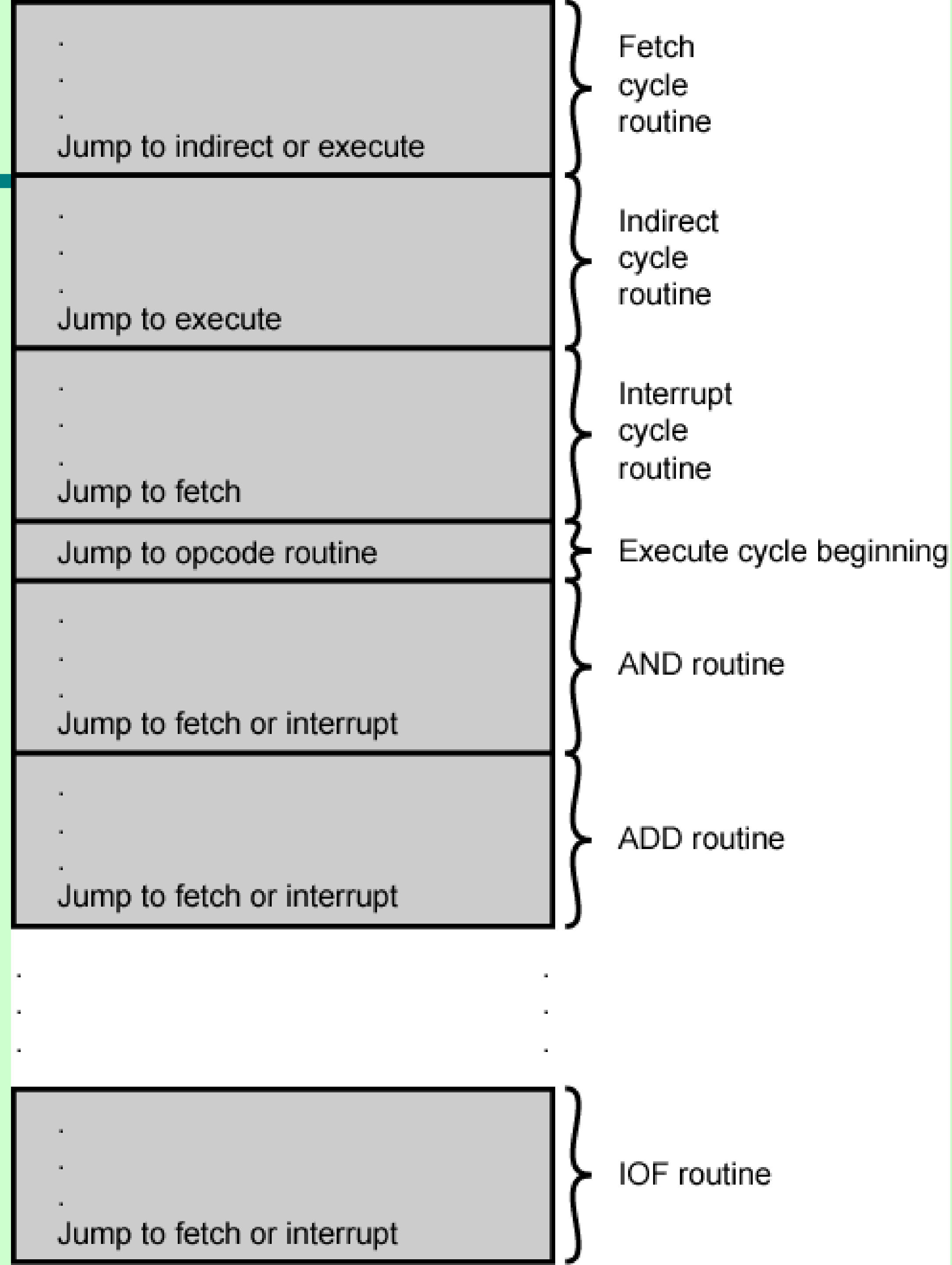
(a) Horizontal microinstruction

(b) Vertical microinstruction

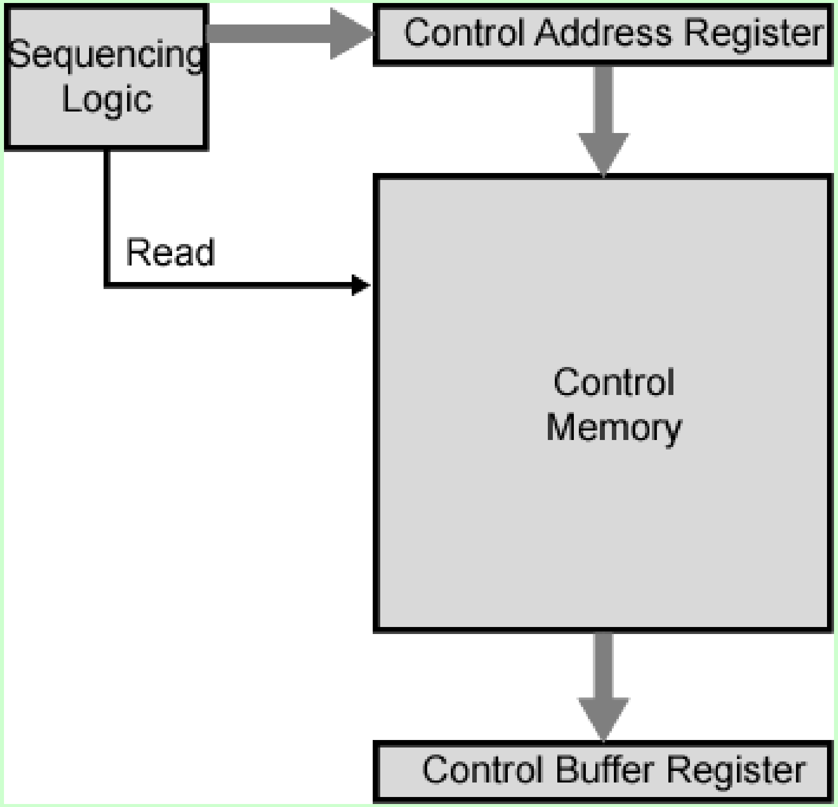
Compromise

- Divide control signals into disjoint groups
- Implement each group as separate field in memory word
- Supports reasonable levels of parallelism without too much complexity

Organization of Control Memory



Control Unit



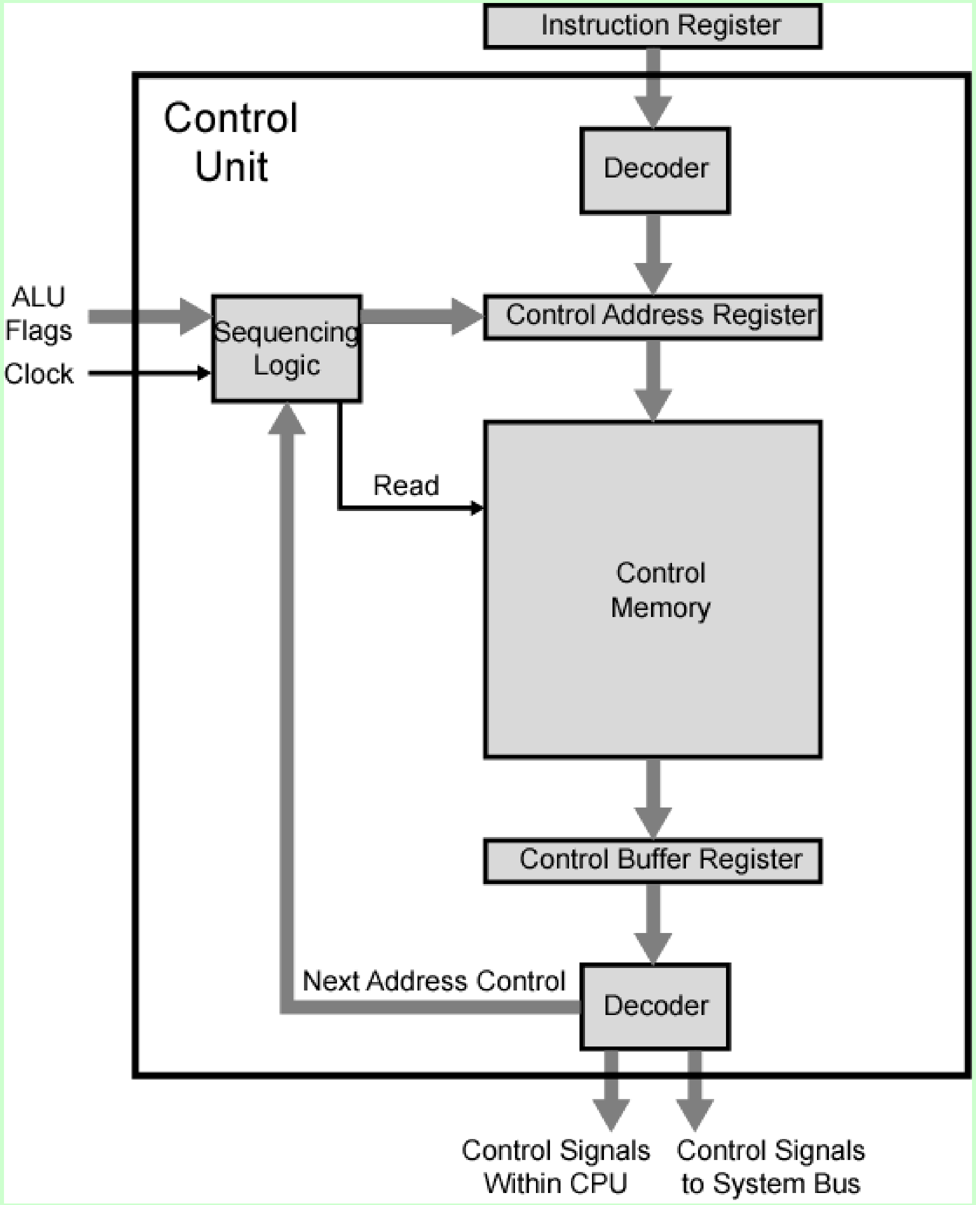
Control Unit Function

- Sequence login unit issues read command
- Word specified in control address register is read into control buffer register
- Control buffer register contents generates control signals and next address information
- Sequence login loads new address into control buffer register based on next address information from control buffer register and ALU flags

Next Address Decision

- Depending on ALU flags and control buffer register
  - Get next instruction
    - Add 1 to control address register
  - Jump to new routine based on jump microinstruction
    - Load address field of control buffer register into control address register
  - Jump to machine instruction routine
    - Load control address register based on opcode in IR

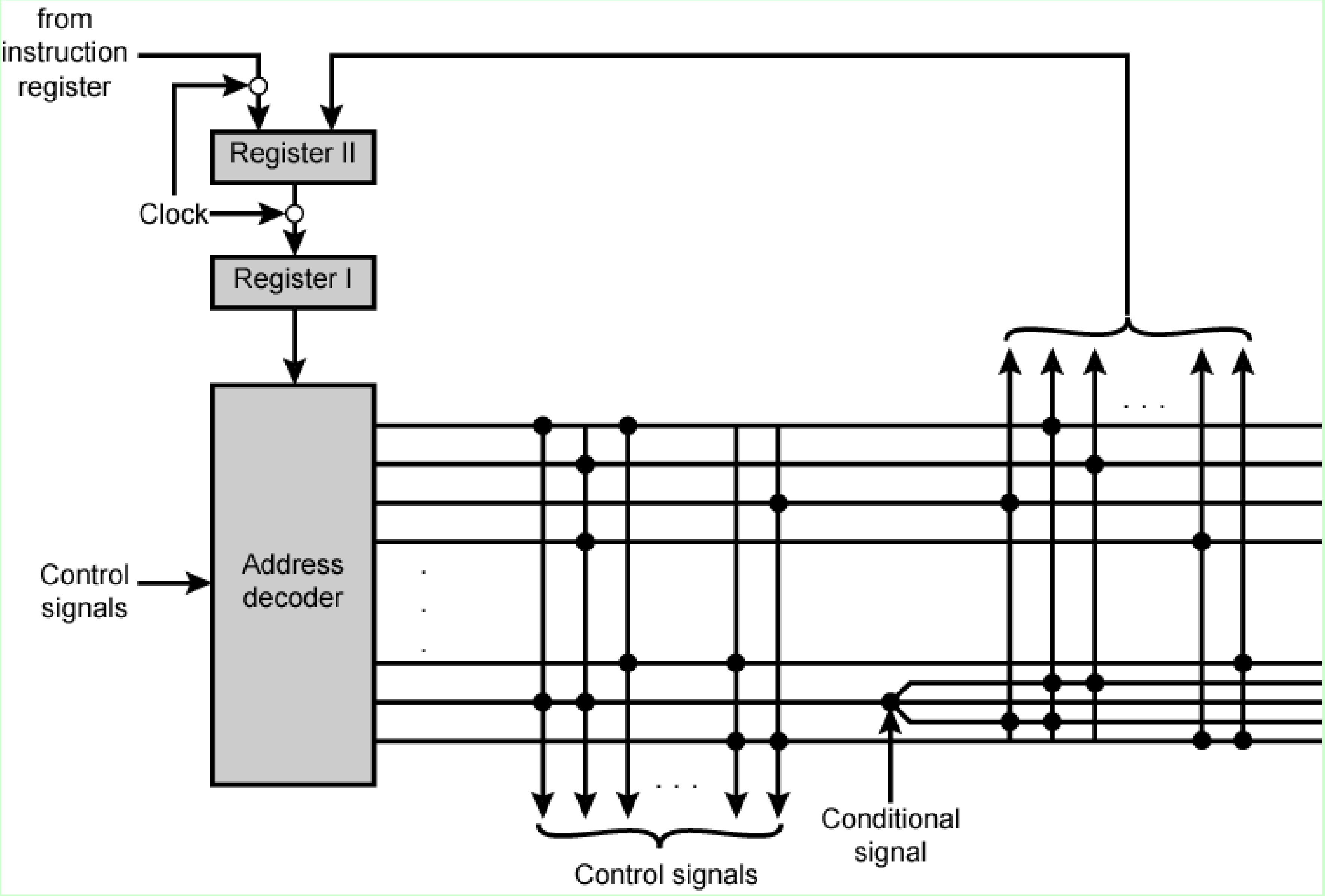
Functioning of Microprogrammed Control Unit



Wilkes Control

- 1951
- Matrix partially filled with diodes
- During cycle, one row activated
  - Generates signals where diode present
  - First part of row generates control
  - Second generates address for next cycle

Wilkes's Microprogrammed Control Unit



Advantages and Disadvantages of Microprogramming

- Simplifies design of control unit
  - Cheaper
  - Less error-prone
- Slower

Tasks Done By Microprogrammed Control Unit

- Microinstruction sequencing
- Microinstruction execution
- Must consider both together

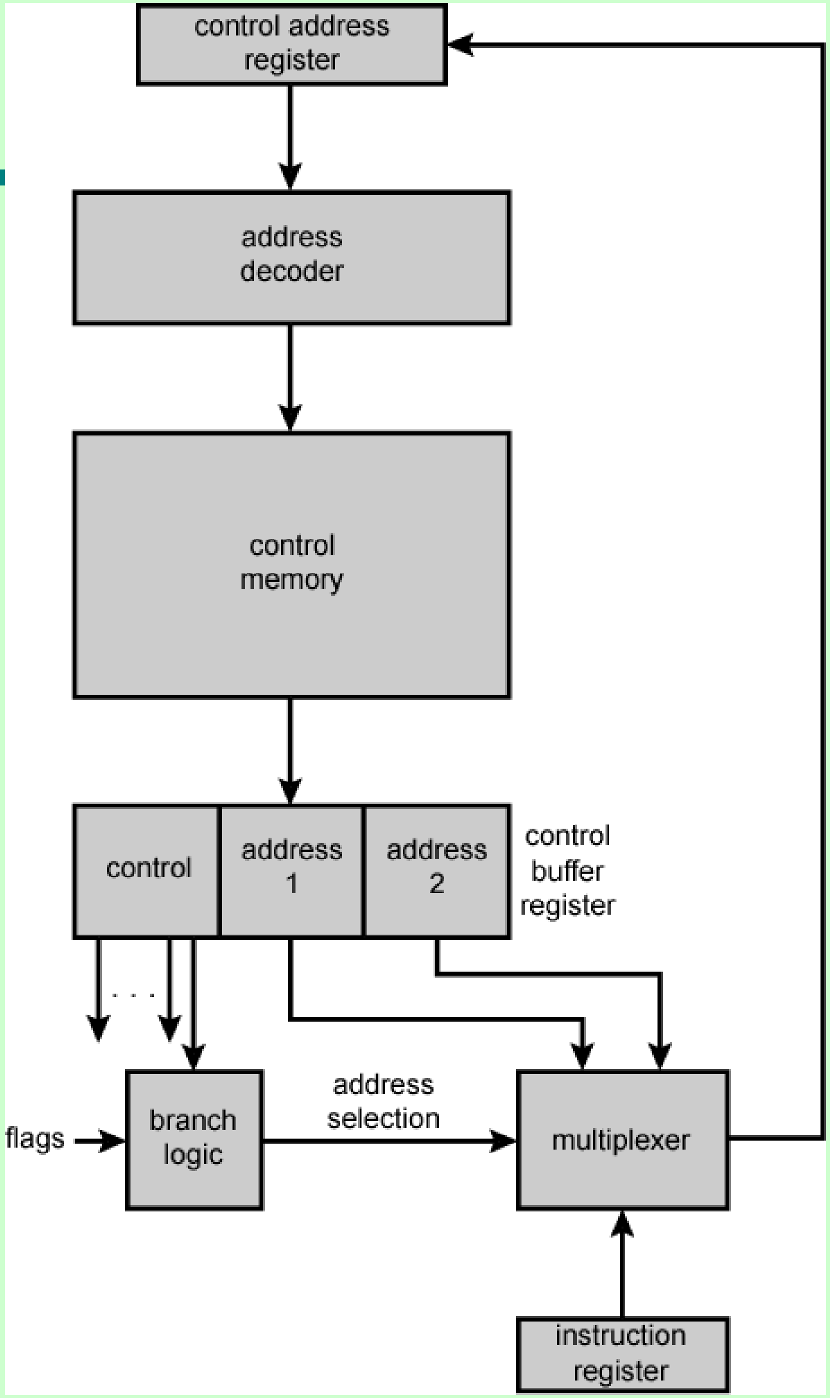
Design Considerations

- Size of microinstructions
- Address generation time
  - Determined by instruction register
    - Once per cycle, after instruction is fetched
  - Next sequential address
    - Common in most designed
  - Branches
    - Both conditional and unconditional

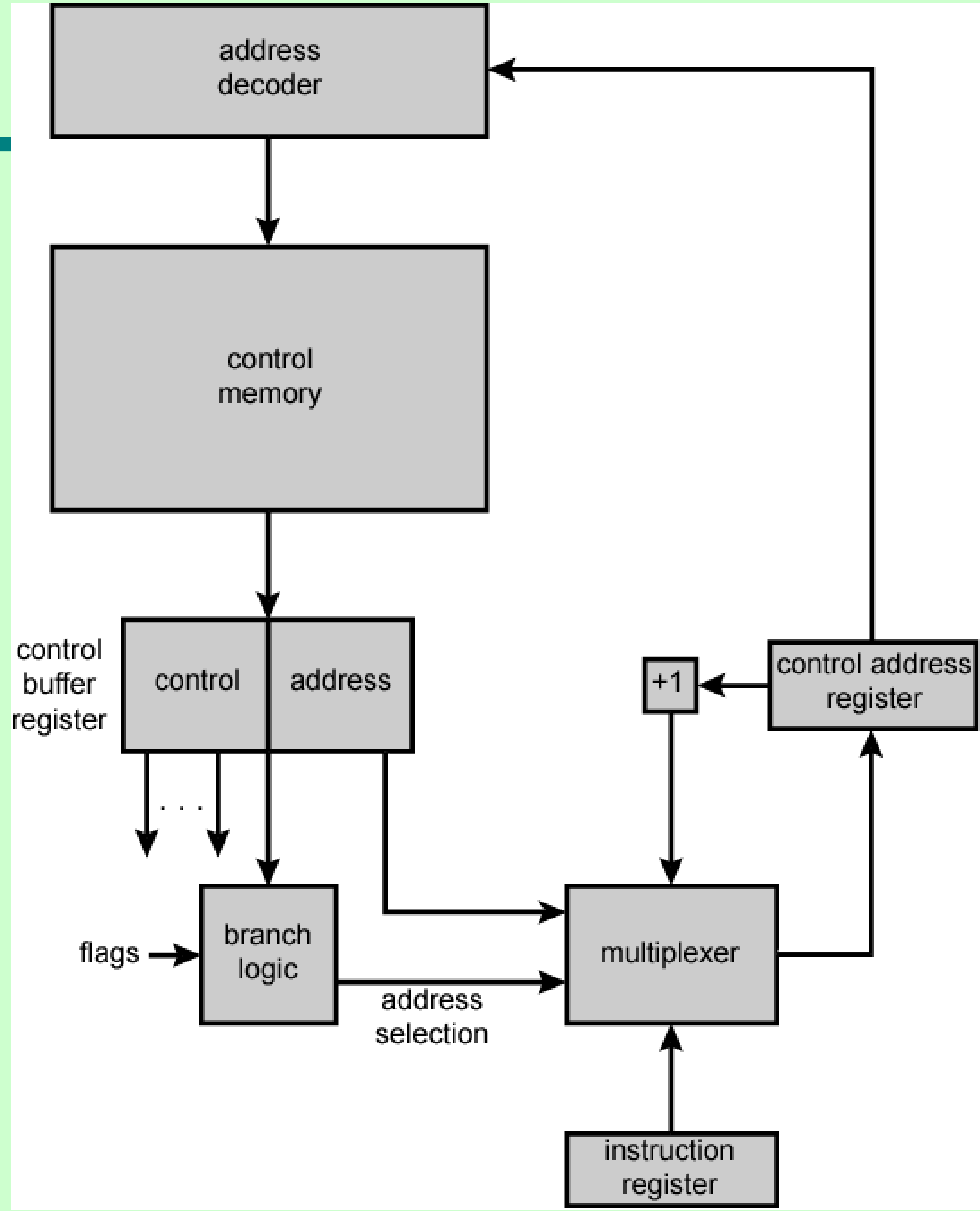
Sequencing Techniques

- Based on current microinstruction, condition flags, contents of IR, control memory address must be generated
- Based on format of address information
  - Two address fields
  - Single address field
  - Variable format

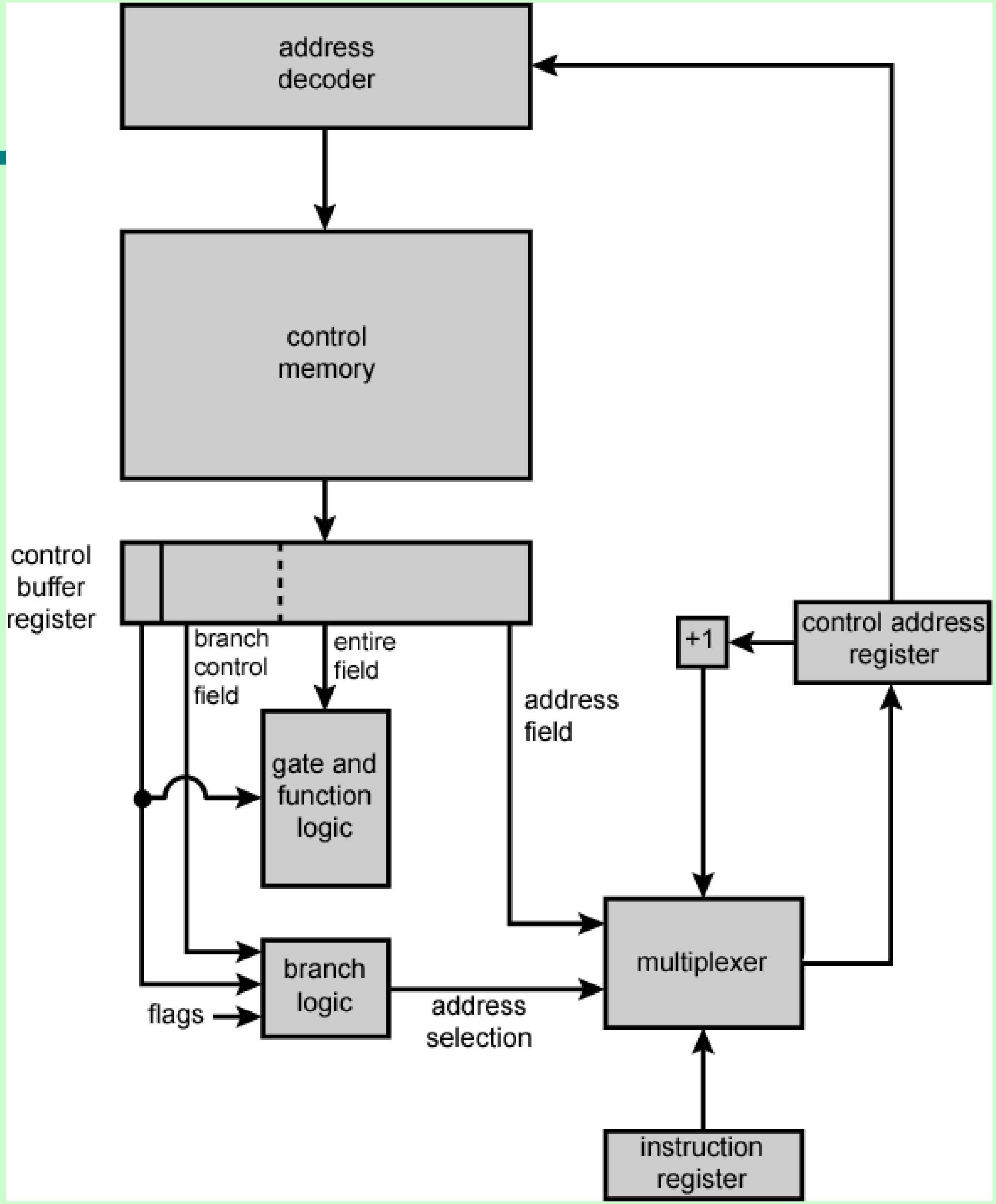
Branch Control Logic: Two Address Fields



Branch Control Logic: Single Address Field



Branch Control Logic: Variable Format



Address Generation

Explicit	Implicit
Two-field	Mapping
Unconditional Branch	Addition
Conditional branch	Residual control

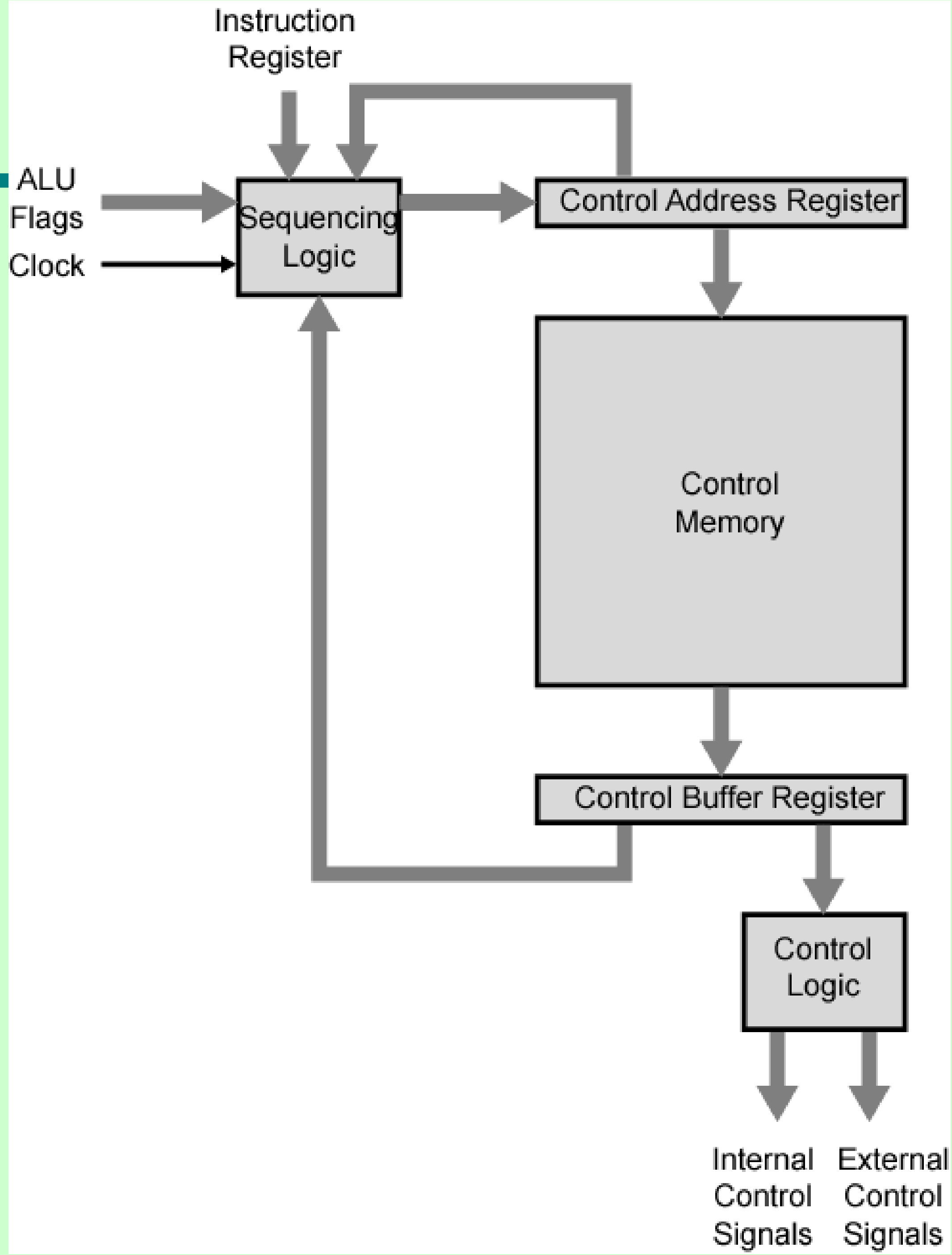
Execution

- The cycle is the basic event
- Each cycle is made up of two events
  - Fetch
    - Determined by generation of microinstruction address
  - Execute

Execute

- Effect is to generate control signals
- Some control points internal to processor
- Rest go to external control bus or other interface

Control Unit Organization



A Taxonomy of Microinstructions

- Vertical/horizontal
- Packed/unpacked
- Hard/soft microprogramming
- Direct/indirect encoding

Improvements over Wilkes

- Wilkes had each bit directly produced a control signal or directly produced one bit of next address
- More complex address sequencing schemes,
- using fewer microinstruction bits, are possible
- Require more complex sequencing logic module
- Control word bits can be saved by encoding and subsequently decoding control information

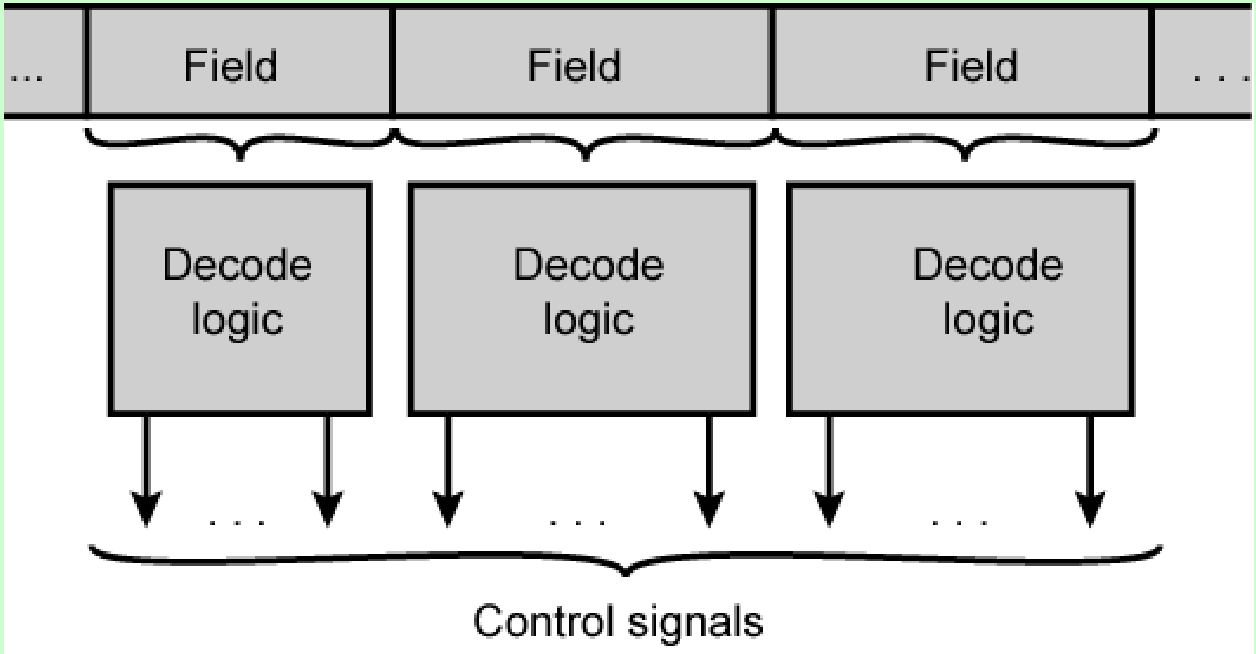
How to Encode

- K different internal and external control signals
- Wilkes's:
  - K bits dedicated
  - 2K control signals during any instruction cycle
- Not all used
  - Two sources cannot be gated to same destination
  - Register cannot be source and destination
  - Only one pattern presented to ALU at a time
  - Only one pattern presented to external control bus at a time
- Require Q < 2K which can be encoded with log2Q < K bits
- Not done
  - As difficult to program as pure decoded (Wilkes) scheme
  - Requires complex slow control logic module
- Compromises
  - More bits than necessary used
  - Some combinations that are physically allowable are not possible to encode

Specific Encoding Techniques

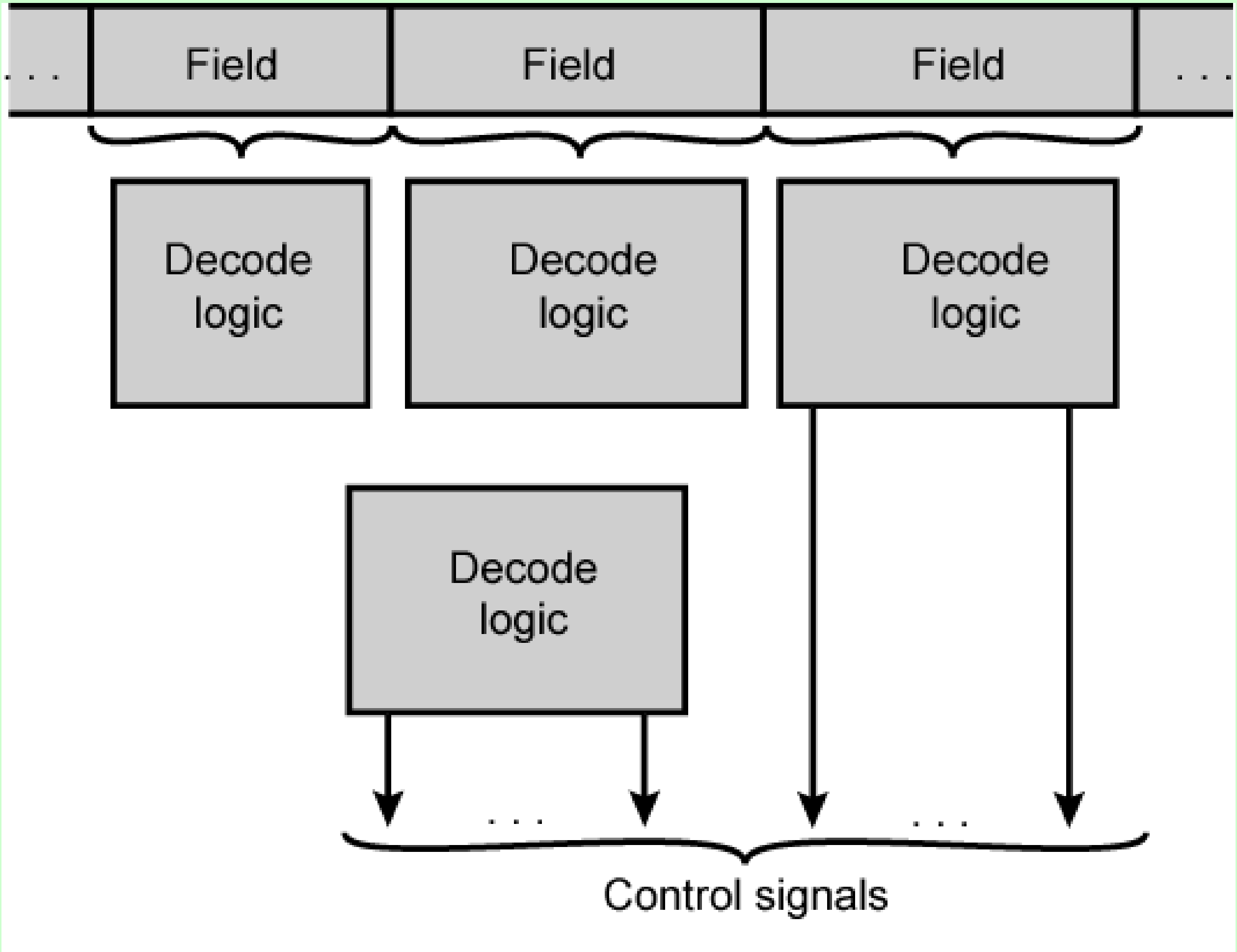
- Microinstruction organized as set of fields
- Each field contains code
- Activates one or more control signals
- Organize format into independent fields
  - Field depicts set of actions (pattern of control signals)
  - Actions from different fields can occur simultaneously
- Alternative actions that can be specified by a field are mutually exclusive
  - Only one action specified for field could occur at a time

Microinstruction Encoding
Direct Encoding



(a) Direct encoding

Microinstruction Encoding
Indirect Encoding



(b) Indirect encoding

Required Reading

- Stallings chapter 16