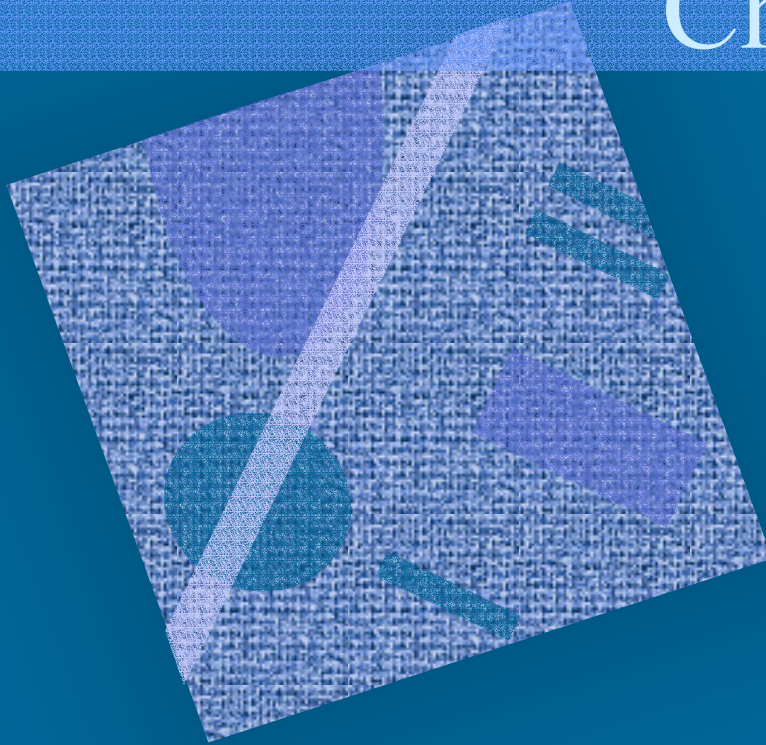


# Hardwired Control Unit

## Ch 16



Micro-operations  
Controlling Execution  
Hardwired Control

# What is Control (2)

- So far, we have shown what happens inside CPU
  - execution of instructions
    - opcodes, addressing modes, registers
    - I/O & memory interface, interrupts
- Now, we show how CPU controls these things that happen
  - how to control what gate or circuit should do at any given time
    - control wires transmit control signals
    - control unit decides values for those signals

# Micro-operations (2)

(mikro-operaatio)

- Basic operations on which more complex instructions are built Fig. 16.1 (Fig. 14.1 [Stal99])
  - each execution phase (e.g., fetch) consists of one or more sequential micro-ops
  - each micro-op executed in one clock cycle in some subsection of the processor circuitry
  - each micro-op specifies what happens in some area of cpu circuitry
  - system cycle time determined by longest micro-op!
- Many micro-ops (for successive instructions) can be executed simultaneously
  - if non-conflicting, independent areas of circuitry

# Instruction Fetch Cycle (10)

- 4 registers involved
  - MAR, MBR, PC, IR
- What happens?

Fig. 12.6

(Fig. 11.7 [Stal99])

Address of next instruction is in PC  
Address (MAR) is placed on address bus  
READ command given to memory  
Result (from memory) appears on data bus  
Data from data bus copied into MBR  
PC incremented by 1  
New instruction moved from MBR to IR  
MBR available for new work

micro-ops?

$MAR \leftarrow (PC)$   
READ

$MBR \leftarrow (mem)$   
 $PC \leftarrow (PC) + 1$   
 $IR \leftarrow (MBR)$

# Instruction Fetch Micro-ops (2)

- 4 micro-ops

- can not change order, can do some ops at the same time

- s2 must be done after s1

- s3 can be done simultaneously with s2 implicit READ

- s4 can be done with s3, but must be done after s2

⇒ Need 3 ticks:

```
s1: MAR ← (PC), READ
s2: MBR ← (mem)
s3: PC ← (PC) + 1
s4: IR ← (MBR)
```

```
t1:   MAR ← (PC)
t2:   MBR ← (mem)
      PC ← (PC) + 1
t3:   IR ← (MBR)
```

assume: mem read in one cycle

# Micro-op Grouping (4)

- Must maintain proper sequence (semantics)
- No conflicts
  - no write to/read from with same register (set?) at the same time
  - each circuitry can be used by only one micro-op at a time
    - E.g., ALU or some bus

t1: MAR  $\leftarrow$  (PC)  
t2: MBR  $\leftarrow$  (mem)

t2: MBR  $\leftarrow$  (mem)  
t3: IR  $\leftarrow$  (MBR)

t2: PC  $\leftarrow$  (PC) + 1  
t3: R1  $\leftarrow$  (R1) + (MBR)

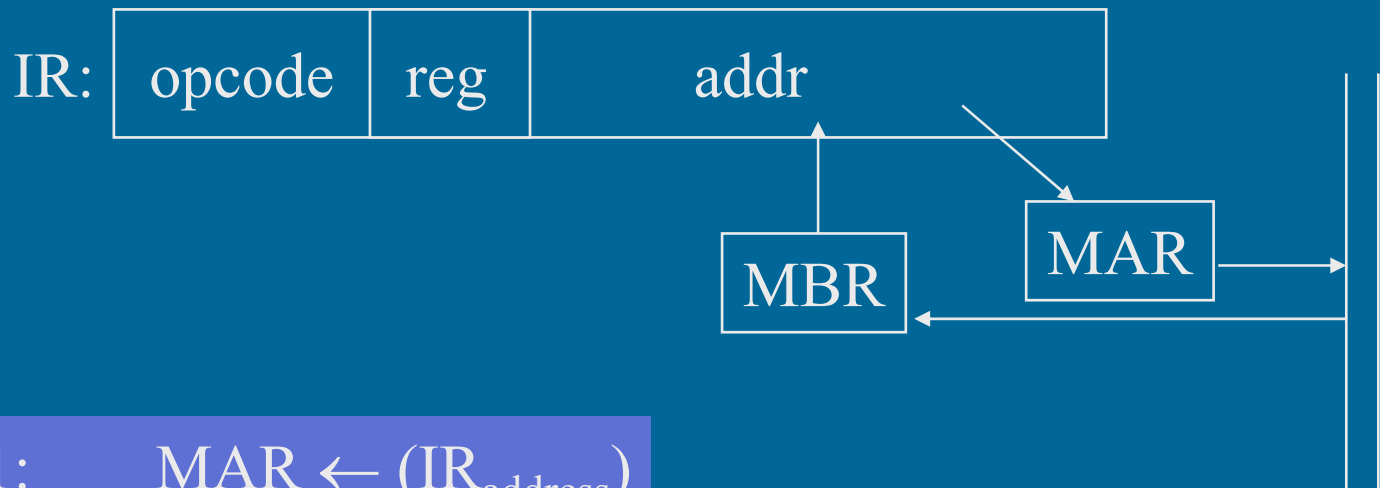


# Micro-op Types (4)

- Transfer data from one reg to another
- Transfer data from reg to external area
  - memory
  - I/O
- Transfer data from external to register
- ALU or logical operation between registers

# Indirect Cycle

- Instruction contains address of an operand, instead of direct operand address



t1:  $MAR \leftarrow (IR_{\text{address}})$   
t2:  $MBR \leftarrow (\text{mem})$   
t3:  $IR_{\text{address}} \leftarrow (MBR)$


(Replace indirect address  
by direct address)



# Interrupt Cycle

- After execution cycle, test for interrupts
- If interrupt bits on, then
  - save PC to memory
  - jump to interrupt handler
  - or, find out first correct handler for this type of interrupt and then jump to that (need more micro-ops)
  - context saved by interrupt handler

t1: MBR  $\leftarrow$  (PC)  
t2: MAR  $\leftarrow$  save-address  
PC  $\leftarrow$  routine-address  
t3: mem  $\leftarrow$  (MBR)

 implicit - just wait?

# Execute Cycle (4)

- Different for each op-code

t1: ALU1  $\leftarrow$  (R2)  
ALU2  $\leftarrow$  (R3)  
t2: ALUout  $\leftarrow$  “+”  
t3: R1  $\leftarrow$  ALUout

ADD R1, X

t1: MAR  $\leftarrow$  (IR<sub>address</sub>)  
t2: MBR  $\leftarrow$  (memory)  
t3: R1  $\leftarrow$  (R1) + (MBR)

ADD R1, R2, R3

t1: R1  $\leftarrow$  (R2) + (R3)

JMP LOOP

t1: PC  $\leftarrow$  (IR<sub>address</sub>)

Was this updated in indirect cycle?

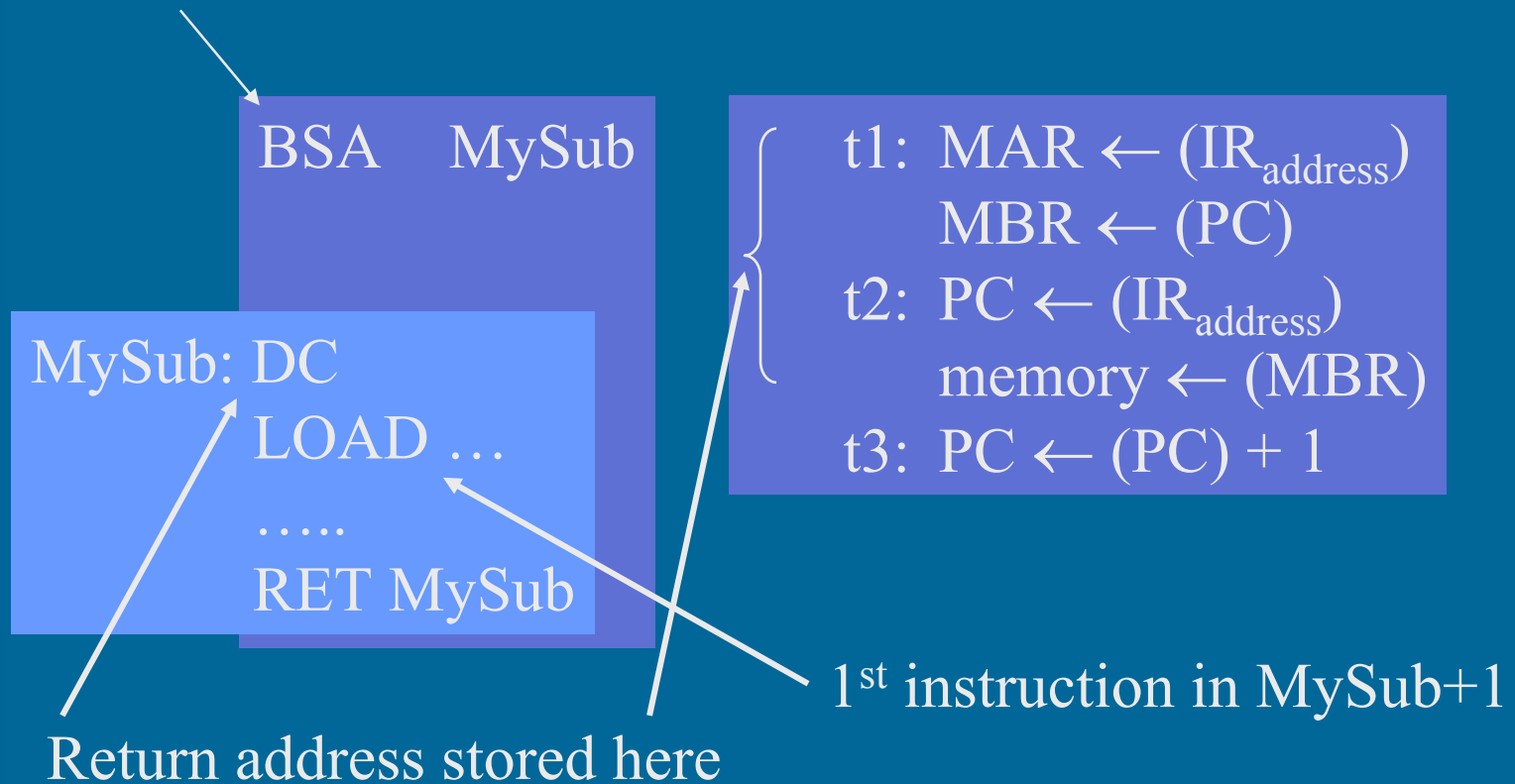
BZER R1, LOOP

t1: if ((R1)=0) then  
PC  $\leftarrow$  (IR<sub>address</sub>)

Can this be done in one cycle?

# Execute Cycle (contd) (1)

Branch and Save Address (subroutine call instruction)



# Instruction Cycle (3)

- Decomposed to micro-ops
- State machine for processor
  - state: execution phase
  - sub-state: current group of micro-ops executable in one clock cycle (tick)
- In each sub-state the control signals have specific values dependent
  - on that sub-state
  - on IR register fields and on flags
    - including control signals from the bus
    - including values (flags) produced by previous sub-state

(Fig. 14.3 [Stal99])

Fig. 16.3

(Fig. 14.4 [Stal99])

Fig. 16.4

# Control State Machine (2)

- Each state defines current control signal values
  - determines what happens in next clock cycle
- Current state and current register/flag values determine next state

Control execution

Control sequencing

# Control Signal Types

- Control data flow from one register to another
- Control signals to ALU
  - ALU does also all logical ops
- Control signals to memory or I/O devices
  - via control bus

# Control Signal Example (5)

- Accumulator architecture
- Control signals for given micro-ops cause micro-ops to be executed
  - setting  $C_2$  makes value stored in PC to be copied to MAR in next clock cycle
    - $C_2$  controls Input Data Strobe for MAR (see Fig. A.30 for register circuit)
  - setting  $C_R$  &  $C_5$  makes memory perform a READ and value in data bus copied to MBR in next clock cycle
  - micro-op = collection of control signals?

(Fig. 14.5 [Stal99])

Fig. 16.5

Table 16.1

(Tbl 14.1 [Stal99])

# Example: Intel 8085 (5)

- Introduced 1976
- 3, 5, or 6 MHz, no cache
- 8 bit data bus, 16 bit address bus
  - multiplexed
- One 8-bit accumulator

Fig. 16.7

(Fig. 14.7 [Stal99])

LDA MyNumber	<table border="1"><thead><tr><th>opcode</th><th>address</th></tr></thead><tbody><tr><td>0x3A</td><td>0x10A5</td></tr></tbody></table>	opcode	address	0x3A	0x10A5	3 bytes
opcode	address					
0x3A	0x10A5					
OUT #2	<table border="1"><tbody><tr><td>0x2B</td><td>0x02</td></tr></tbody></table> opcode port	0x2B	0x02	2 bytes		
0x2B	0x02					



# Example: i8085 (6)

- Instead of complex data path all data transfers within CPU go via internal bus (Fig. 14.7 [Stal99])
  - may not be good approach for superscalar pipelined processor - bus should not be bottleneck Fig. 16.7
- External signals Table 16.2 (Tbl 14.2 [Stal99])
- Each instruction is 1-5 machine cycles
  - one external bus access per machine cycle
- Each machine cycle is 3-5 states
- Each state is one clock cycle (Fig. 14.9 [Stal99])
- Example: OUT instruction Fig. 16.9

# Hardwired Control Logic Implementation (3)

Initial representation:

Finite state  
diagram

Sequencing control:

Explicit  
next state  
function

Logic representation:

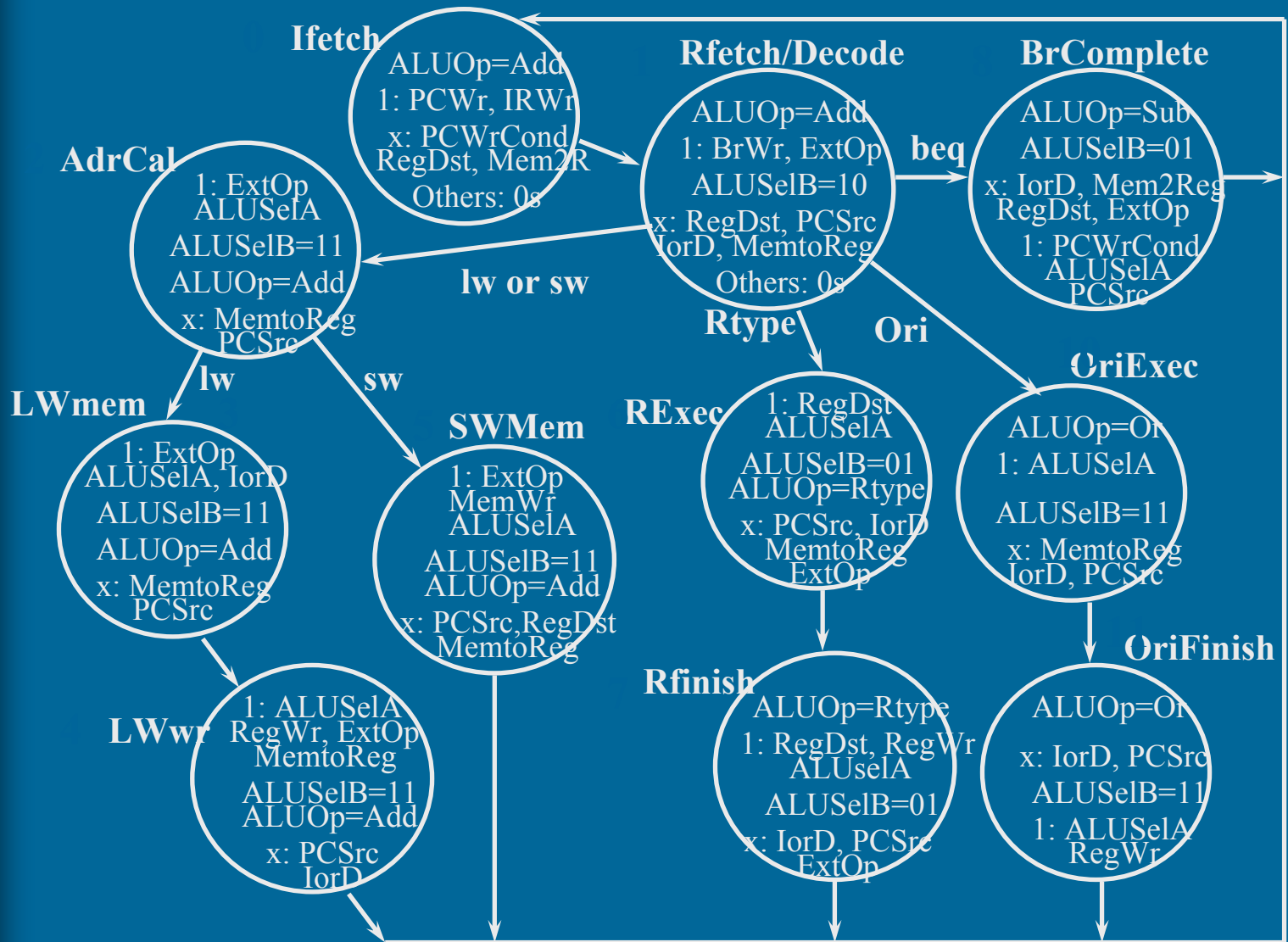
Logic  
equations

Programmable  
Logic  
Array

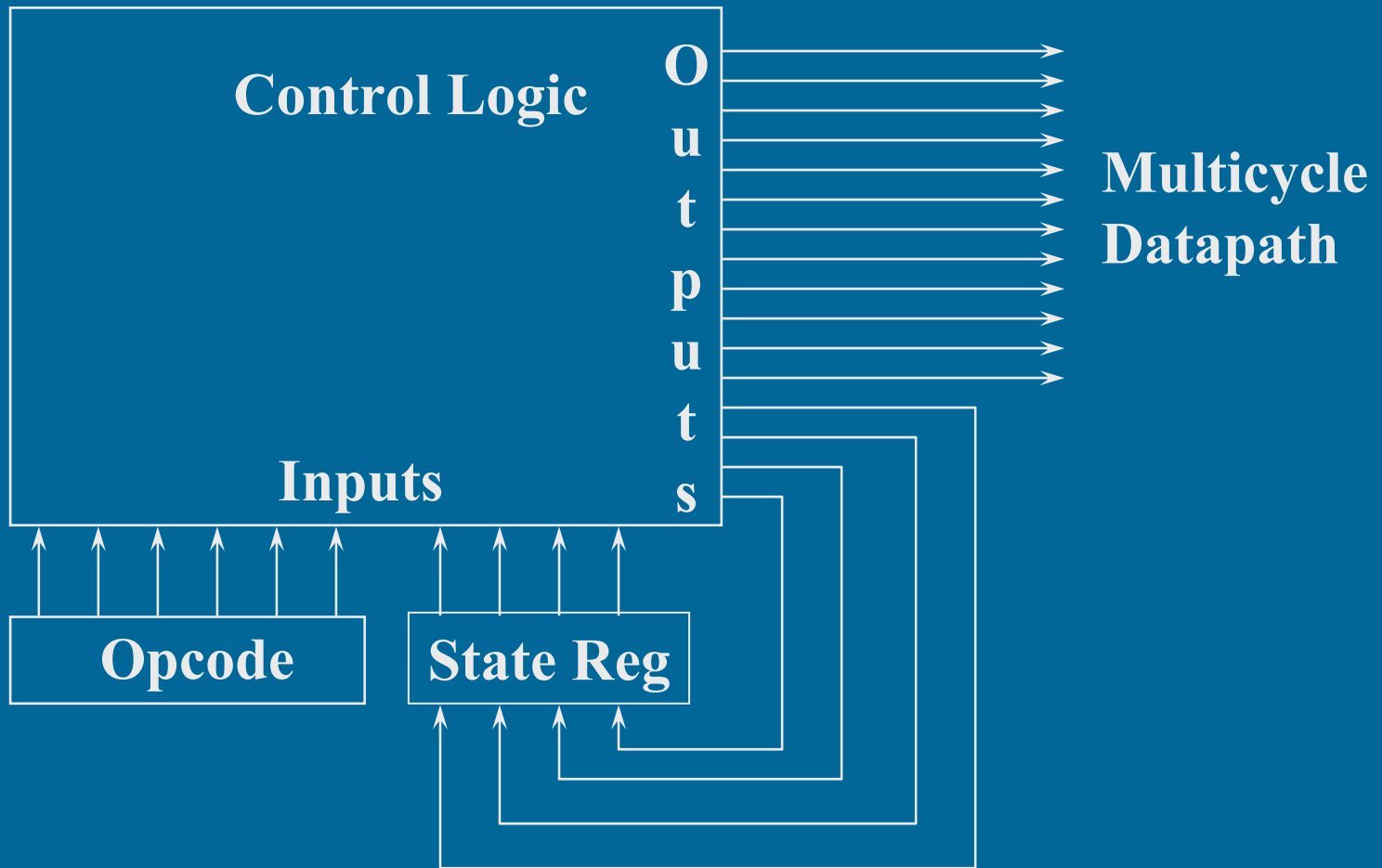
Implementation:

PLA

# Finite State Diagram



# Explicit Next State Function



# Logic Equations (2)

## Next state from current state

- State 0 -> State 1
- State 1 -> S2, S6, S8, S10
- State 2 -> S5 or ...
- State 3 -> S9 or ...
- State 4 -> State 0
- State 5 -> State 0
- State 6 -> State 7
- State 7 -> State 0
- State 8 -> State 0
- State 9 -> State 0
- State 10 -> State 11
- State 11 -> State 0

## Alternatively, prior state & condition

S4, S5, S7, S8, S9, S11 -> State0

\_\_\_\_\_ -> State1

\_\_\_\_\_ -> State 2

\_\_\_\_\_ -> State 3

\_\_\_\_\_ -> State 4

State2 & op = SW -> State 5

\_\_\_\_\_ -> State 6

State 6 -> State 7

\_\_\_\_\_ -> State 8

State3 & op = JMP -> State 9

\_\_\_\_\_ -> State 10

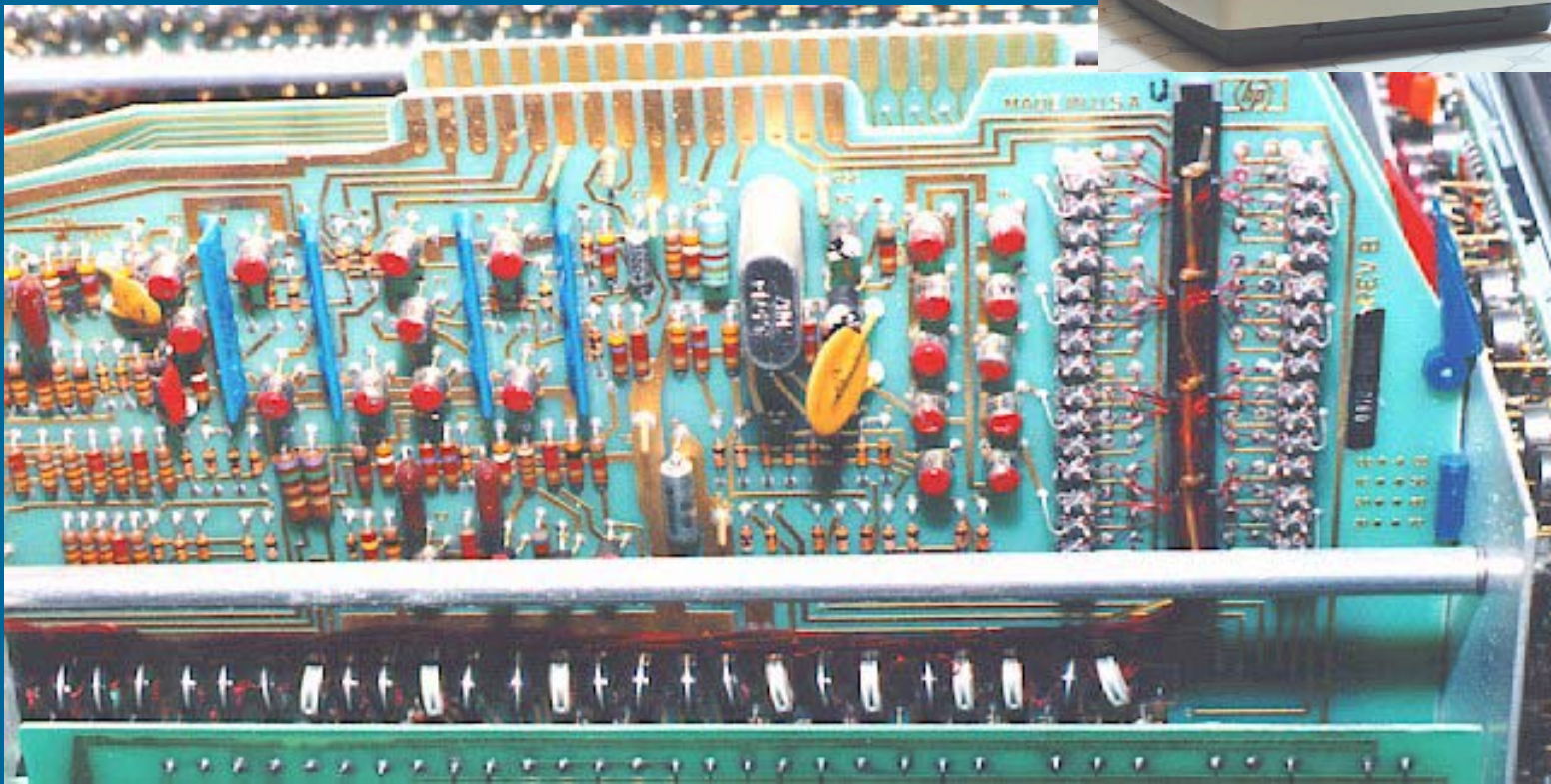
State 10 -> State 11

# Hardwired Control Logic (3)

- Circuitry becomes very big and complex very soon
  - may be unnecessarily slow
  - simpler is smaller, and thus faster
- Many lines (states) exactly or almost similar
- Have methods to find similar lines (states) and combine them
  - not simple
  - save space, may lose in speed
  - must be redone after any modification

# -- End of Chapter 16: Hardwired Control --

HP 9100 Calculator (1968), 20 kg,  
\$5000, 16 regs (data or 14 instructions/reg),  
32Kb ROM, 2208 bit RAM magnetic core memory



Hardwired Control Logic board <http://www.hpmuseum.org/9100cl.jp>