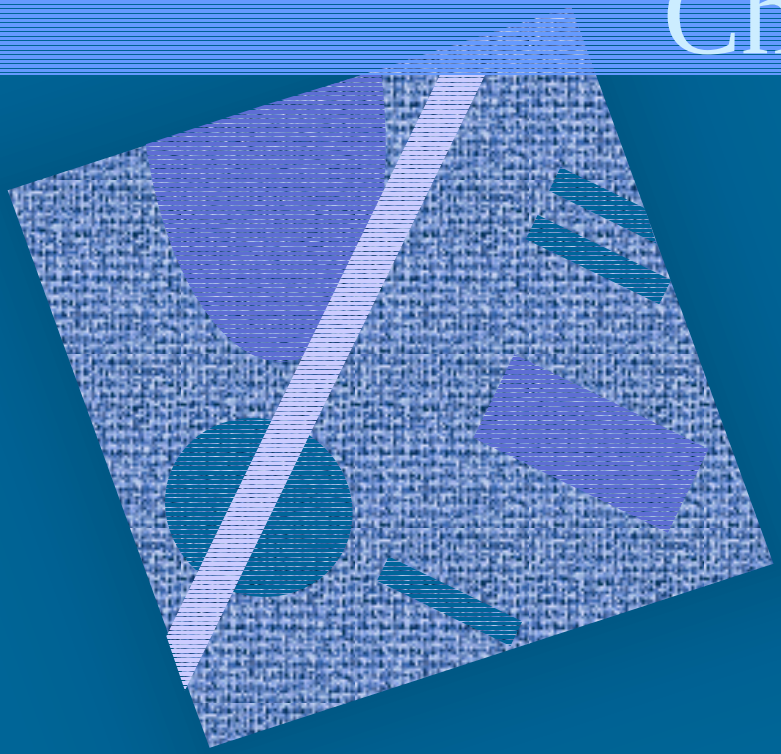
# Hardwired Control Unit
# Ch 14



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. 14.1

  - 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
  - cycle time determined by the longest micro-op!
- Micro-ops for (different) instructions can be executed simultaneously
  - non-conflicting, independent areas of circuitry

# Instruction Fetch Cycle (10)

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

Fig. 11.7

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 ← (PC)
READ

MBR ← (mem)
PC ← (PC) +1
IR ← (MBR)

# Instruction Fetch Micro-ops (3)

- 4 micro-ops
  - can not change order
  - s2 must be done after s1
  - s3 can be done simultaneously with s2
  - s4 can be done with s3, but must be done after s2

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

⇒ Need 3 ticks:

implicit

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

Assume: mem read in one cycle

# Micro-op Grouping

- Must have proper sequence
- 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

t1: MAR ← (PC)
t2: MBR ← (mem)

t2: MBR ← (mem)
t3: IR ← (MBR)

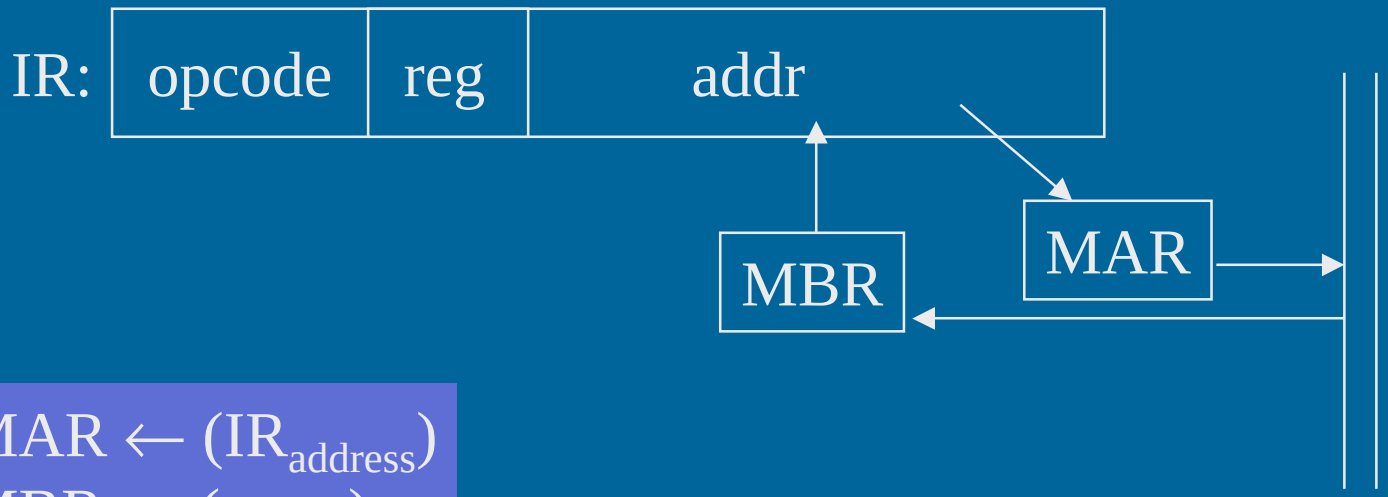
t2: PC ← (PC) +1
t3: R1 ← (R1) + (MBR)

# 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 indirect address of an operand, instead of direct operand address




$MAR \leftarrow (IR_{address})$
$MBR \leftarrow (mem)$
$IR_{address} \leftarrow (MBR)$

(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 ← (PC)
t2:   MAR ← save-address
      PC ← routine-address
t3:   mem ← (MBR)
```

implicit - just wait?

# Execute Cycle (3)

- Different for each op-code

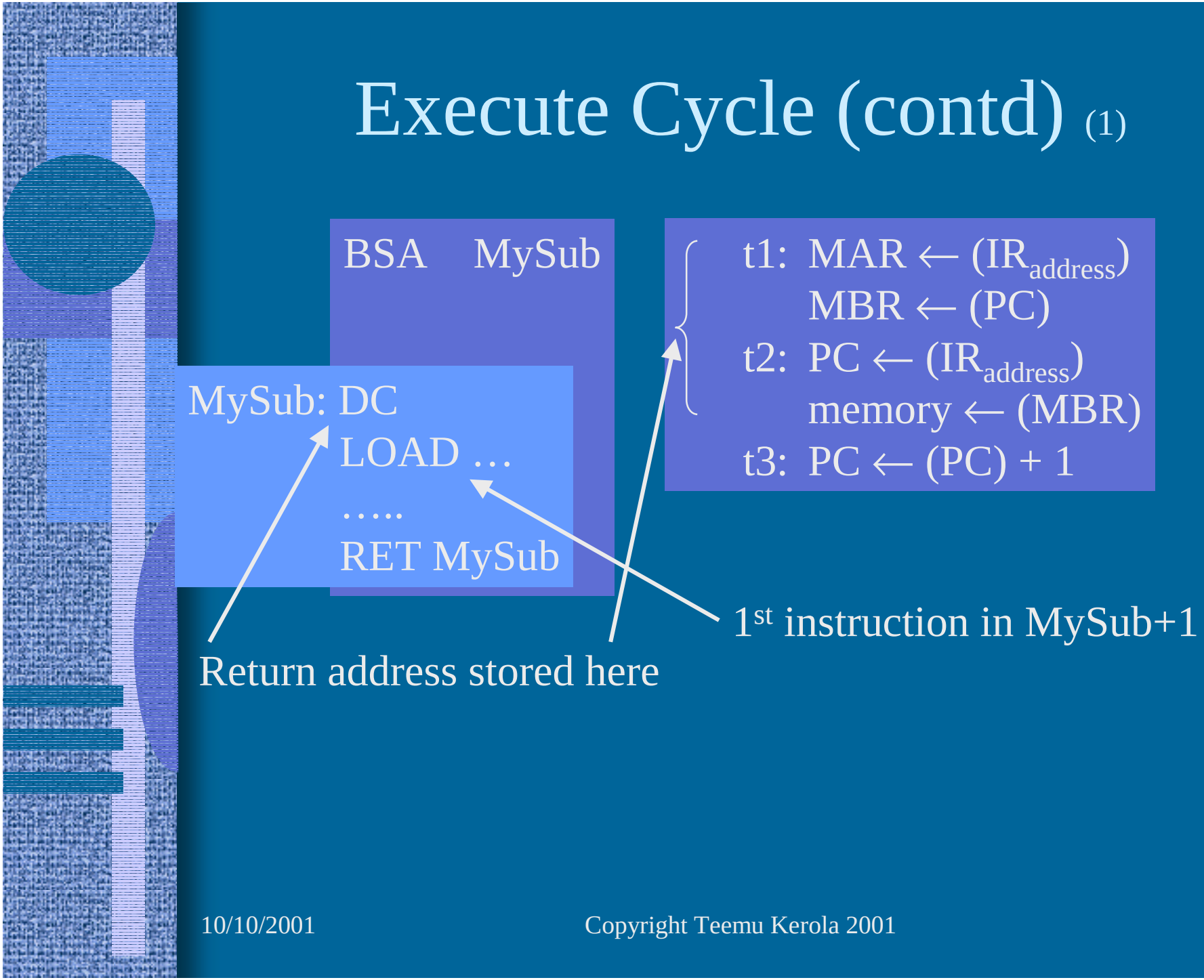
| | |
|---|---|
| ADD R1, X | t1: $MAR \leftarrow (IR_{address})$<br>t2: $MBR \leftarrow (memory)$<br>t3: $R1 \leftarrow (R1) + (MBR)$ |
| ADD R1, R2, R3 | t1: $R1 \leftarrow (R2) + (R3)$ |
| JMP LOOP | t1: $PC \leftarrow (IR_{address})$ |

Was this updated in indirect cycle?

| | |
|---|---|
| BZER R1, LOOP | t1: if ((R1)=0) then<br>$PC \leftarrow (IR_{address})$ |

Can this be done in one cycle?

# Execute Cycle (contd) (1)



# Instruction Cycle (3)

- Decomposed to micro-ops
- State machine for processor
  - state: execution phase
  - sub-state: current group of micro-ops

Fig. 14.3

- In each sub-state the control signals have specific values dependent
  - on that sub-state
  - on IR register fields and flags
    - including control signals from the bus
    - including values (flags) produced by previous sub-state

Fig. 14.4

# Control State Machine (2)

- Each state defines current control signal values

  Control execution

  – determines what happens in next clock cycle

- Current state and current register/flag values determine next state

  Control sequencing

# Control Signal Types (3)

- 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

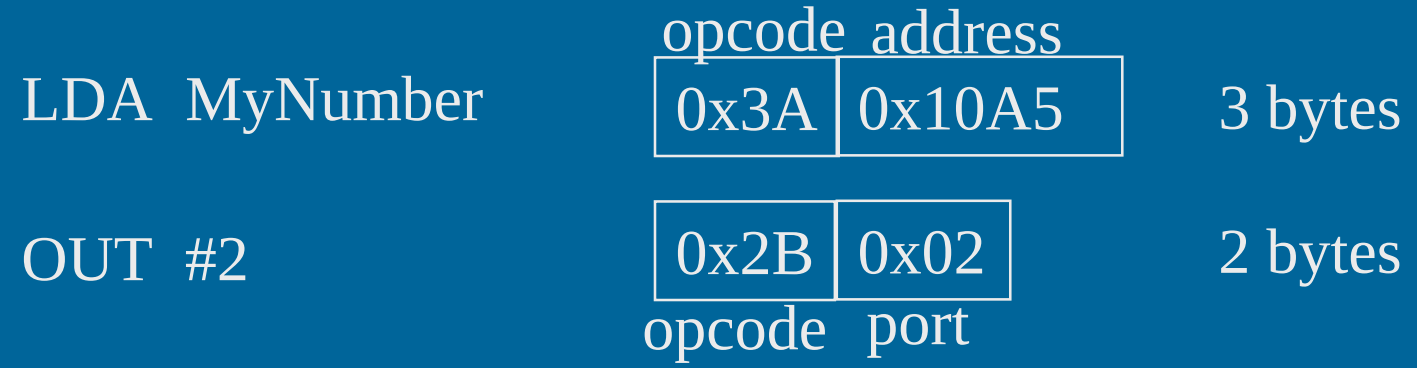
# Control Signal Example (4)

- Accumulator architecture Fig. 14.5
- Control signals for given micro-ops cause micro-ops to be executed Table 14.1
  - 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

# 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. 14.7



# Example: i8085 (6)

- Instead of complex data path all data transfers within CPU go via internal bus

  Fig. 14.7

  - may not be good approach for superscalar pipelined processor - bus should not be bottleneck
- External signals

  Table 14.2
- 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
- Example: OUT instruction

  Fig. 14.9

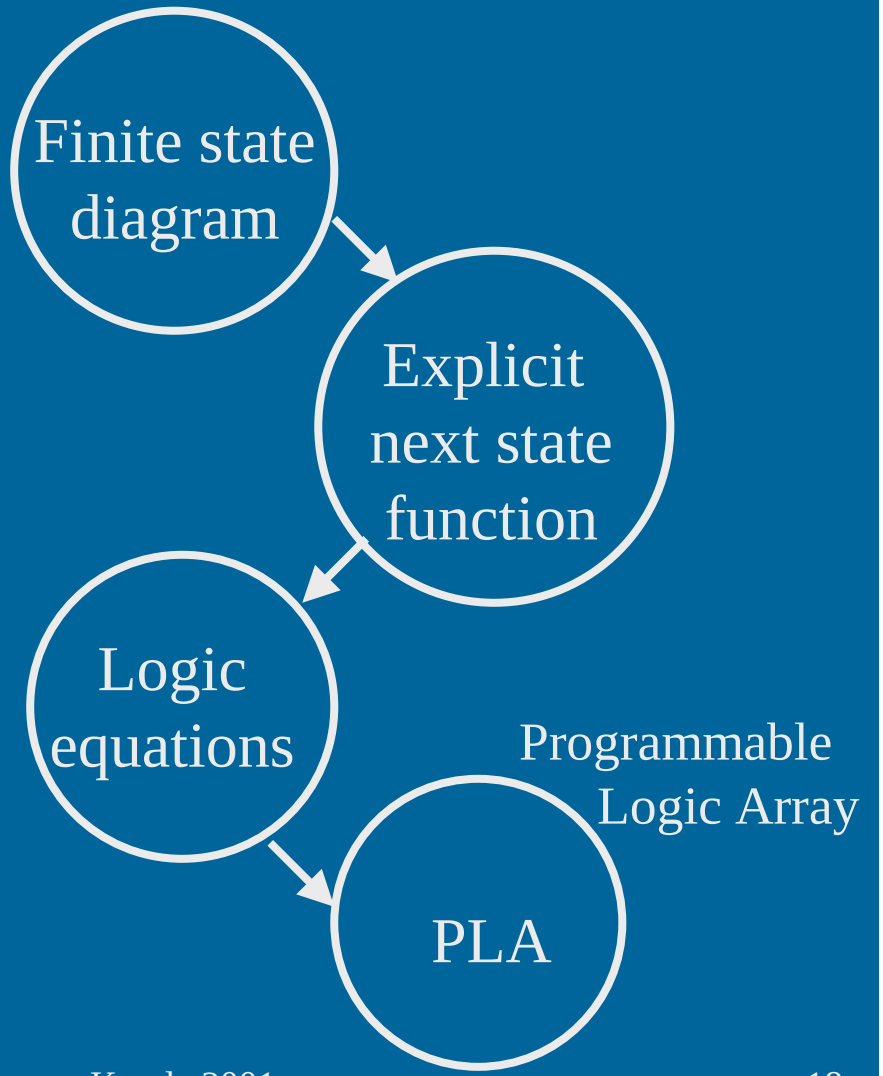
# Hardwired Control Logic Implementation (3)

Initial representation:

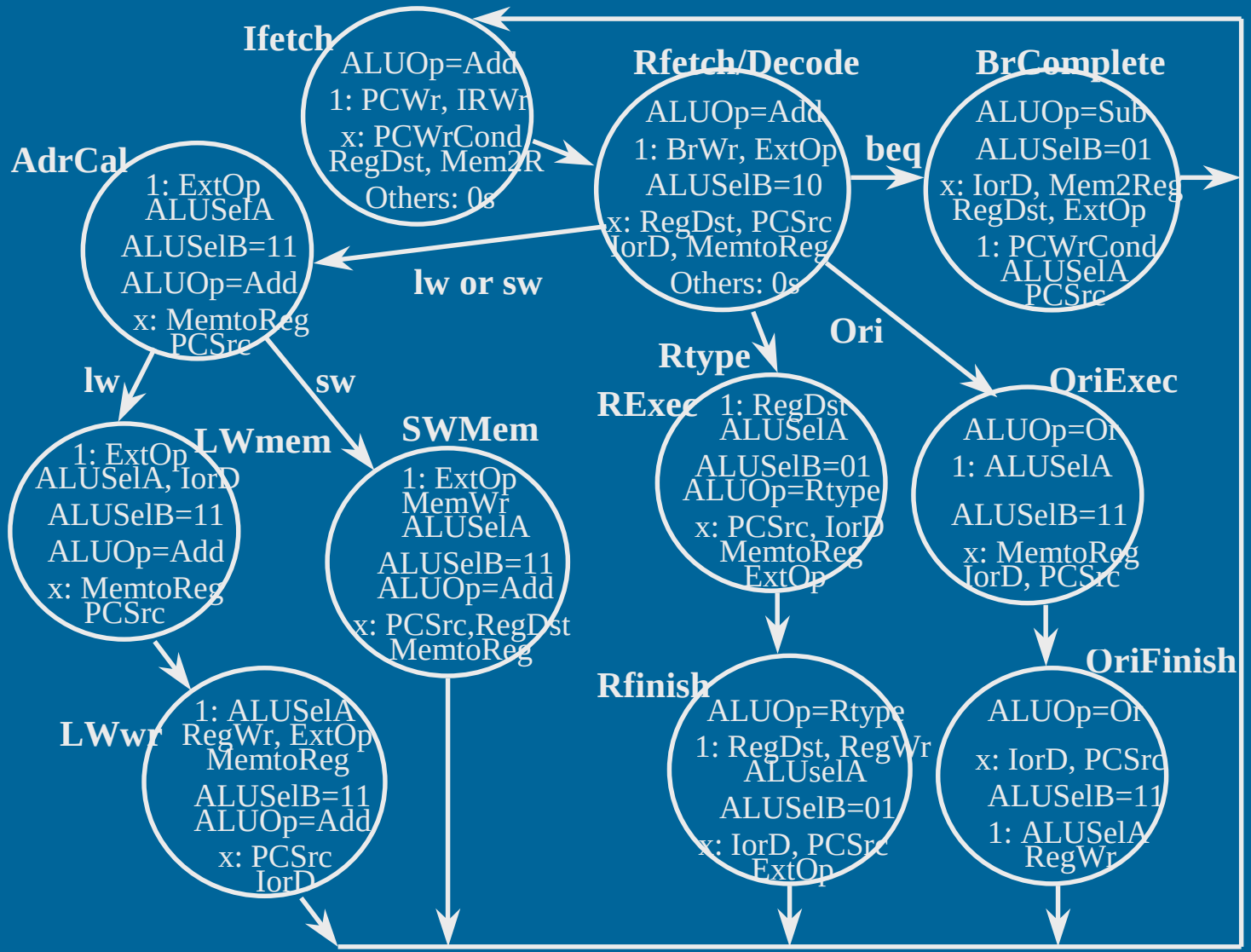
Sequencing control:

Logic representation:

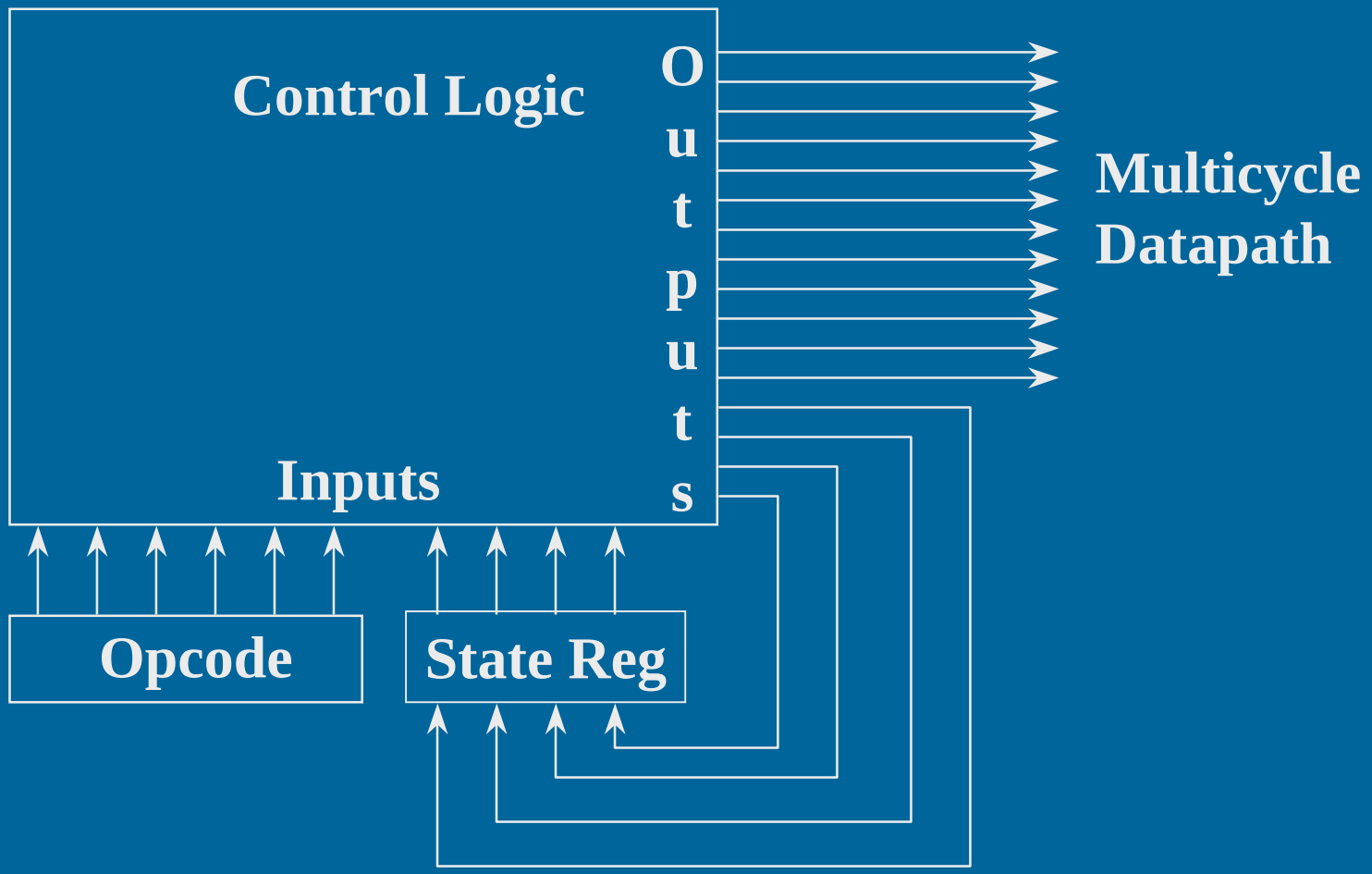
Implementation:



# Finite State Diagram



# Explicit Next State Function



# Logic Equations

Next state from current state

- State 0 -> State1
- State 1 -> S2, S6, S8, S10
- State 2 ->_____
- State 3 ->_____
- 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

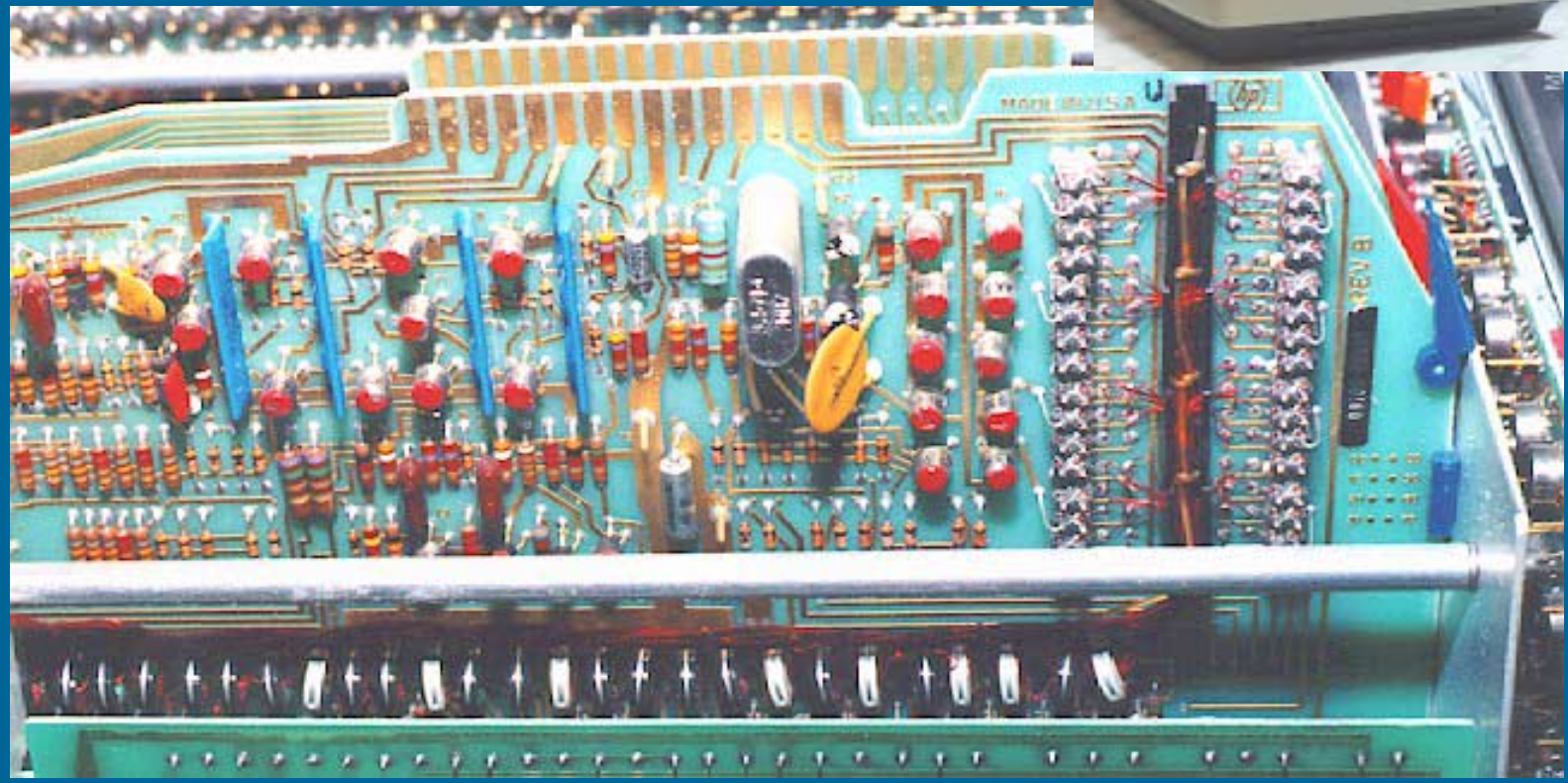
S4, S5, S7, S8, S9, S11 -> State0
_____ -> State1
_____ -> State 2
_____ -> State 3
_____ -> State 4
State2 & op = SW -> State 5
_____ -> State 6
State 6 -> State 7
_____ -> State 8
State3 & op = JMP -> State 9
_____ -> State 10
State 10 -> State 11

# 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

# -- End of Chapter 14: 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.jpg