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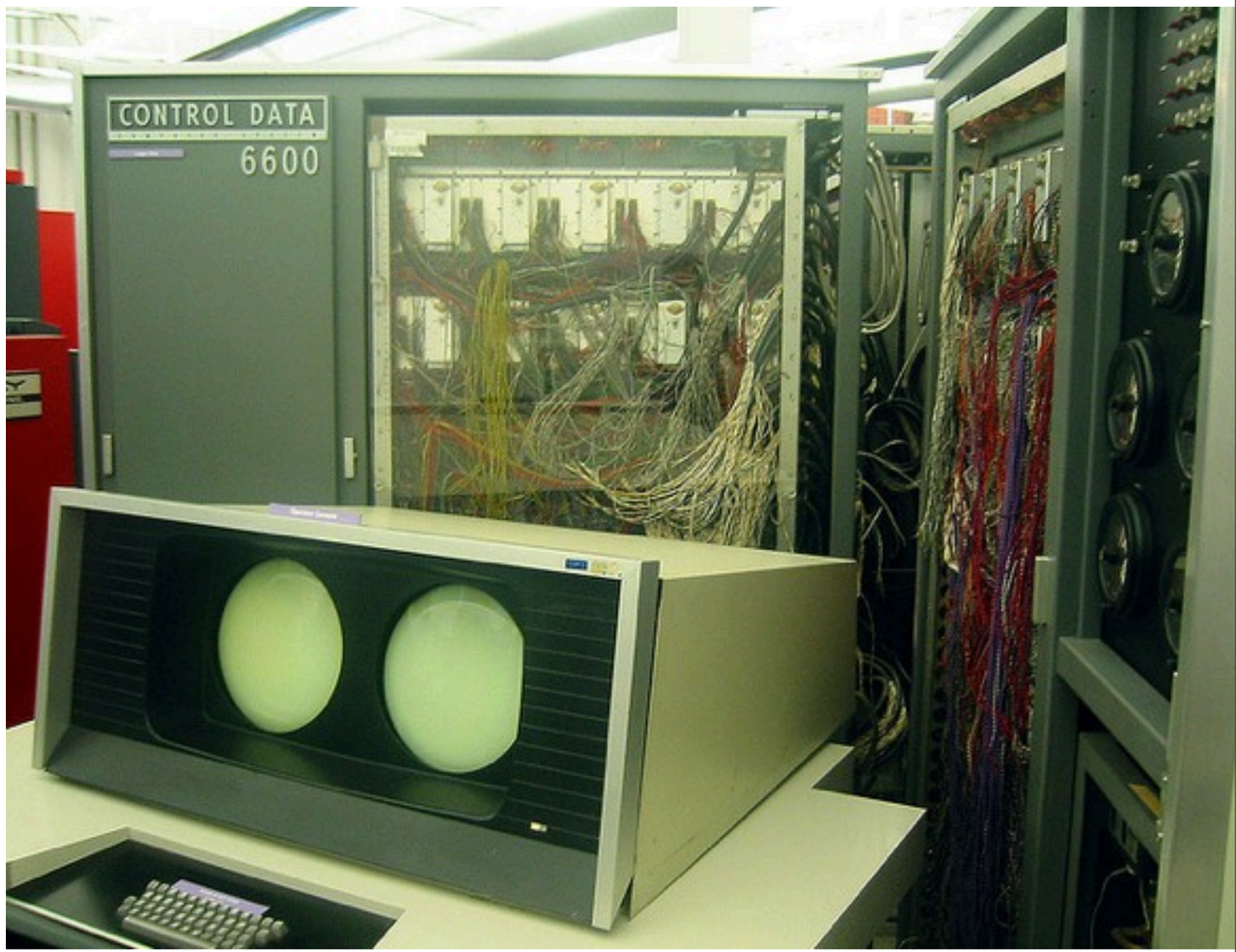
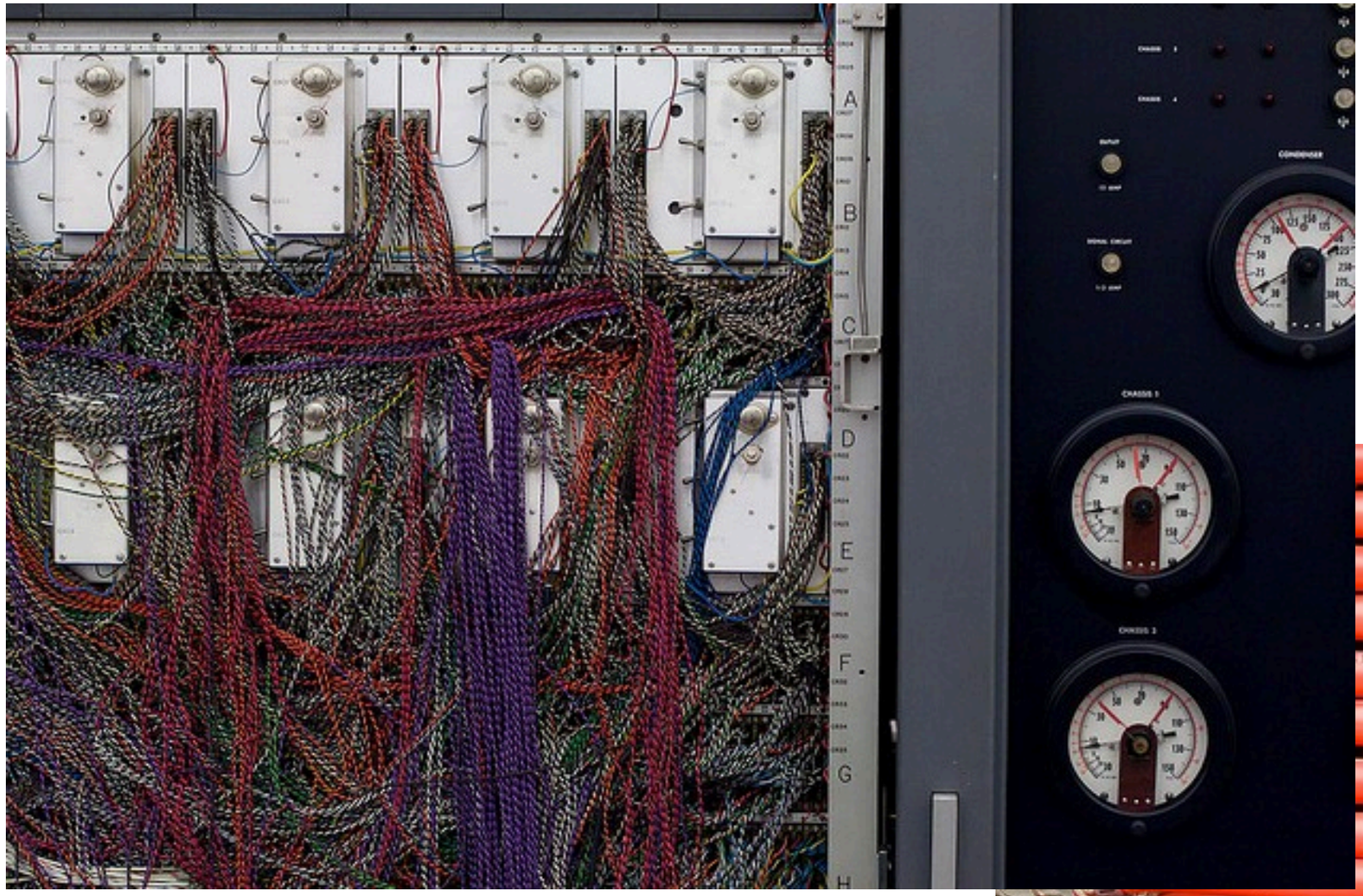
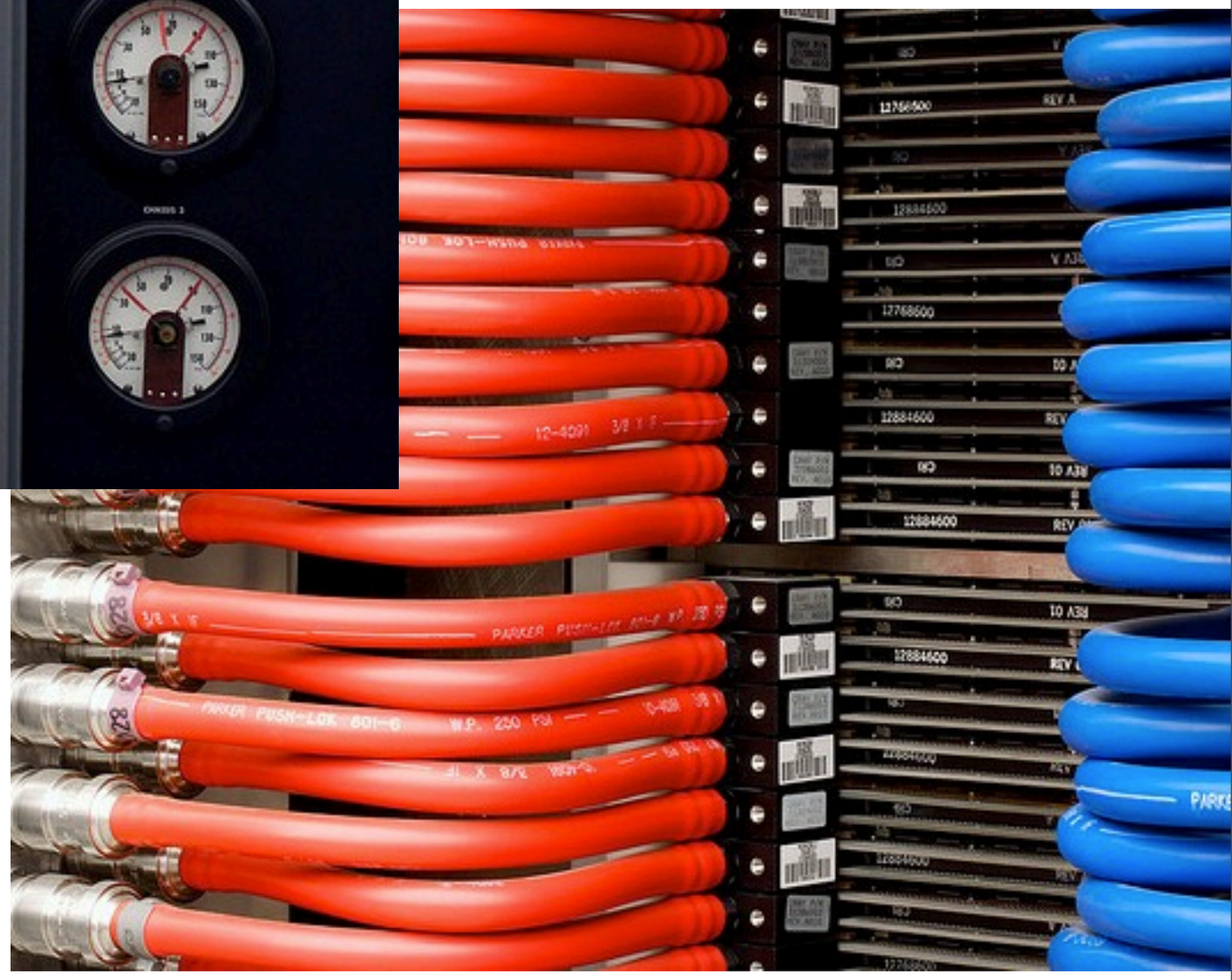
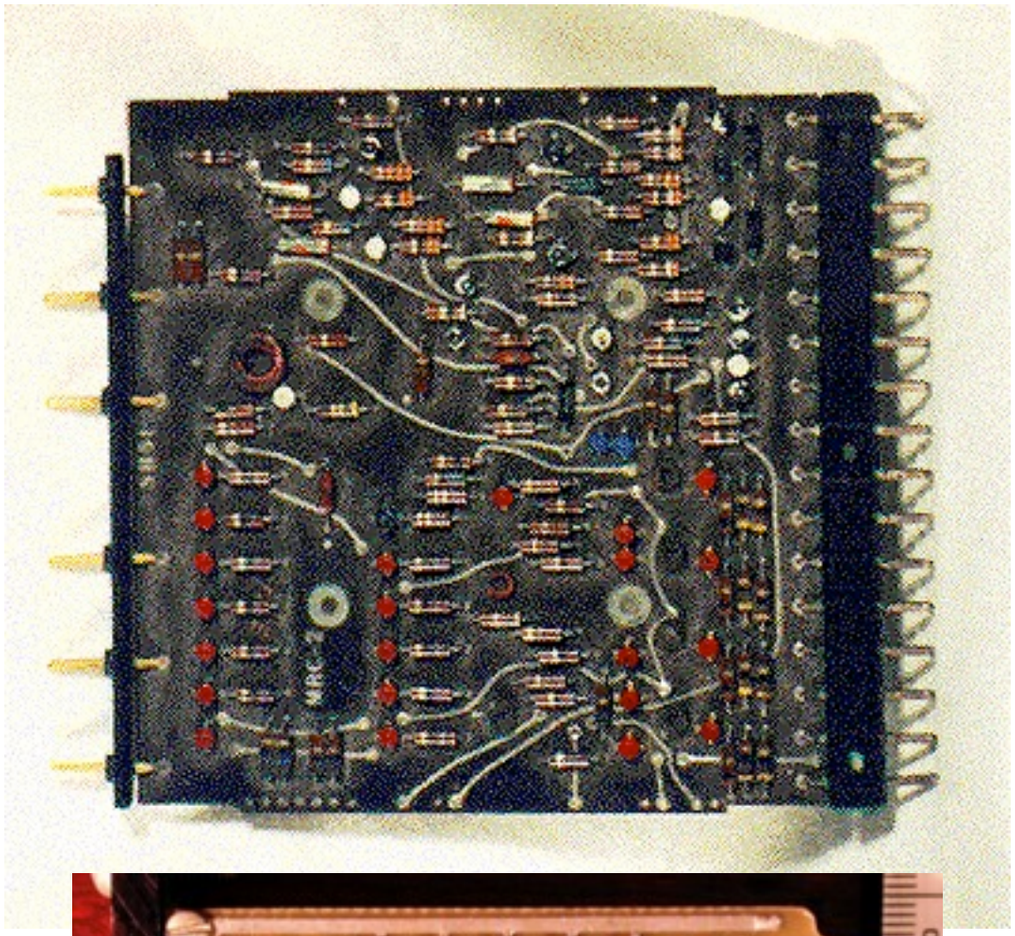
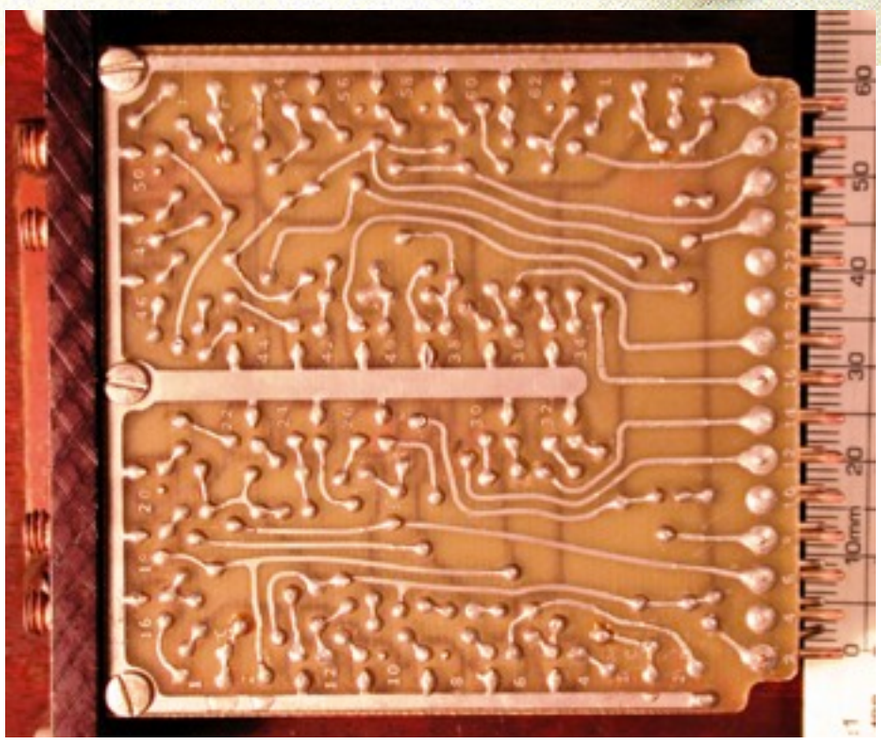
# Lecture 4 - CDC 6600


CONTROL DATA
6600




PARKER PUSH-LOK 601-6 W.P. 250 PSI





# Why bother with executing out of order?

- Faster (hopefully)
- Execute operations sooner than when they came in program sequence
- An instruction fetched later may not be dependent
- Compiler order != critical path order
- Dynamic loop unrolling
- Bypassing long-latency operations, maximize parallelism
- Compilers not up to snuff

# Mem->Issue

- Have:
  - Instruction & its bits
- WaitFor:
  - Spot in the scoreboard
- Do
  - Do it!  Move instruction to scoreboard

# Issue->Dispatch

- WaitFor
  - A functional unit that is free
    - Wait for result register to be free
- Do
  - Assign instruction to functional unit

# Dispatch->Execute

- WaitFor
  - Operands to be ready
    - For the execute path to be free
- Do
  - Execute!

# Execute -> Complete

- WaitFor
  - Execution to complete
  - Result bus
  - Wait for write-after-read conflicts to resolve
- Do
  - Broadcast result + metadata

# Complete

- WaitFor
  - Register write to complete

- Do
  - Erase it
  - Free the functional unit resources

# When is scoreboarding successful?

- When computing independent results written to different locations from a variety functional units

# Scoreboard Example

# Scoreboard Example

Instruction status

| Instruction | | j | k | Issue | Read operanc | Executi complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | | | | |
| LD | F2 | 45+ | R3 | | | | |
| MULTI | F0 | F2 | F4 | | | | |
| SUBD | F8 | F6 | F2 | | | | |
| DIVD | F10 | F0 | F6 | | | | |
| ADDD | F6 | F8 | F2 | | | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| | Mult1 | No | | | | | | | | |
| | Mult2 | No | | | | | | | | |
| | Add | No | | | | | | | | |
| | Divide | No | | | | | | | | |

Register result status

| Clock | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|
| FU | | | | | | | | | |

# Scoreboard Example Cycle 1

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | | | |
| LD | F2 | 45+ | R3 | | | | |
| MULTI | F0 | F2 | F4 | | | | |
| SUBD | F8 | F6 | F2 | | | | |
| DIVD | F10 | F0 | F6 | | | | |
| ADDD | F6 | F8 | F2 | | | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | Yes | Load | F6 | | R2 | | | | Yes |
| | Mult1 | No | | | | | | | | |
| | Mult2 | No | | | | | | | | |
| | Add | No | | | | | | | | |
| | Divide | No | | | | | | | | |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | FU | | | | Integer | | | | | |

# Scoreboard Example Cycle 2

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | | |
| LD | F2 | 45+ | R3 | | | | |
| MULTI | F0 | F2 | F4 | | | | |
| SUBD | F8 | F6 | F2 | | | | |
| DIVD | F10 | F0 | F6 | | | | |
| ADDD | F6 | F8 | F2 | | | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | Yes | Load | F6 | | R2 | | | | Yes |
| | Mult1 | No | | | | | | | | |
| | Mult2 | No | | | | | | | | |
| | Add | No | | | | | | | | |
| | Divide | No | | | | | | | | |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | FU | | | | Integer | | | | | |

# Scoreboard Example Cycle 3

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | |
| LD | F2 | 45+ | R3 | | | | |
| MULTI | F0 | F2 | F4 | | | | |
| SUBD | F8 | F6 | F2 | | | | |
| DIVD | F10 | F0 | F6 | | | | |
| ADDD | F6 | F8 | F2 | | | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | Yes | Load | F6 | | R2 | | | | Yes |
| | Mult1 | No | | | | | | | | |
| | Mult2 | No | | | | | | | | |
| | Add | No | | | | | | | | |
| | Divide | No | | | | | | | | |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | FU | | | | Integer | | | | | |

# Scoreboard Example Cycle 4

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | | | | |
| MULTI | F0 | F2 | F4 | | | | |
| SUBD | F8 | F6 | F2 | | | | |
| DIVD | F10 | F0 | F6 | | | | |
| ADDD | F6 | F8 | F2 | | | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | Yes | Load | F6 | | R2 | | | | Yes |
| | Mult1 | No | | | | | | | | |
| | Mult2 | No | | | | | | | | |
| | Add | No | | | | | | | | |
| | Divide | No | | | | | | | | |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | FU | | | | Integer | | | | | |

# Scoreboard Example Cycle 5

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | | | |
| MULTI | F0 | F2 | F4 | | | | |
| SUBD | F8 | F6 | F2 | | | | |
| DIVD | F10 | F0 | F6 | | | | |
| ADDD | F6 | F8 | F2 | | | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | Yes | Load | F2 | | R3 | | | | Yes |
| | Mult1 | No | | | | | | | | |
| | Mult2 | No | | | | | | | | |
| | Add | No | | | | | | | | |
| | Divide | No | | | | | | | | |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | FU | | Integer | | | | | | | |

# Scoreboard Example Cycle 6

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | | |
| MULTI | F0 | F2 | F4 | 6 | | | |
| SUBD | F8 | F6 | F2 | | | | |
| DIVD | F10 | F0 | F6 | | | | |
| ADDD | F6 | F8 | F2 | | | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | Yes | Load | F2 | | R3 | | | | Yes |
| | Mult1 | Yes | Mult | F0 | F2 | F4 | Integer | | No | Yes |
| | Mult2 | No | | | | | | | | |
| | Add | No | | | | | | | | |
| | Divide | No | | | | | | | | |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | FU | Mult1 | Integer | | | | | | | |

# Scoreboard Example Cycle 7

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | |
| MULTI | F0 | F2 | F4 | 6 | | | |
| SUBD | F8 | F6 | F2 | 7 | | | |
| DIVD | F10 | F0 | F6 | | | | |
| ADDD | F6 | F8 | F2 | | | | |

Functional unit status

| Time | Name | Busy | Op | Fi | Fj | Fk | Qj | Qk | Rj | Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | Yes | Load | F2 | | R3 | | | | Yes |
| | Mult1 | Yes | Mult | F0 | F2 | F4 | Integer | | No | Yes |
| | Mult2 | No | | | | | | | | |
| | Add | Yes | Sub | F8 | F6 | F2 | | Integer | Yes | No |
| | Divide | No | | | | | | | | |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | FU | Mult1 | Integer | | | Add | | | | |

# Scoreboard Example Cycle 8a

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | |
| MULTI | F0 | F2 | F4 | 6 | | | |
| SUBD | F8 | F6 | F2 | 7 | | | |
| DIVD | F10 | F0 | F6 | 8 | | | |
| ADDD | F6 | F8 | F2 | | | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | Yes | Load | F2 | | R3 | | | | Yes |
| | Mult1 | Yes | Mult | F0 | F2 | F4 | Integer | | No | Yes |
| | Mult2 | No | | | | | | | | |
| | Add | Yes | Sub | F8 | F6 | F2 | | Integer | Yes | No |
| | Divide | Yes | Div | F10 | F0 | F6 | Mult1 | | No | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | FU | Mult1 | Integer | | | Add | Divide | | | |

# Scoreboard Example Cycle 8b

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | | | |
| SUBD | F8 | F6 | F2 | 7 | | | |
| DIVD | F10 | F0 | F6 | 8 | | | |
| ADDD | F6 | F8 | F2 | | | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| | Mult1 | Yes | Mult | F0 | F2 | F4 | | | Yes | Yes |
| | Mult2 | No | | | | | | | | |
| | Add | Yes | Sub | F8 | F6 | F2 | | | Yes | Yes |
| | Divide | Yes | Div | F10 | F0 | F6 | Mult1 | | No | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | FU | Mult1 | | | | Add | Divide | | | |

# Scoreboard Example Cycle 9

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | | |
| SUBD | F8 | F6 | F2 | 7 | 9 | | |
| DIVD | F10 | F0 | F6 | 8 | | | |
| ADDD | F6 | F8 | F2 | | | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| 10 | Mult1 | Yes | Mult | F0 | F2 | F4 | | | Yes | Yes |
| | Mult2 | No | | | | | | | | |
| 2 | Add | Yes | Sub | F8 | F6 | F2 | | | Yes | Yes |
| | Divide | Yes | Div | F10 | F0 | F6 | Mult1 | | No | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 9 | FU | Mult1 | | | | Add | Divide | | | |

# Scoreboard Example Cycle 11

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | | |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | |
| DIVD | F10 | F0 | F6 | 8 | | | |
| ADDD | F6 | F8 | F2 | | | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| 8 | Mult1 | Yes | Mult | F0 | F2 | F4 | | | Yes | Yes |
| | Mult2 | No | | | | | | | | |
| 0 | Add | Yes | Sub | F8 | F6 | F2 | | | Yes | Yes |
| | Divide | Yes | Div | F10 | F0 | F6 | Mult1 | | No | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 | FU | Mult1 | | | | Add | Divide | | | |

# Scoreboard Example Cycle 12

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | | |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | 12 |
| DIVD | F10 | F0 | F6 | 8 | | | |
| ADDD | F6 | F8 | F2 | | | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| 7 | Mult1 | Yes | Mult | F0 | F2 | F4 | | | Yes | Yes |
| | Mult2 | No | | | | | | | | |
| | Add | No | | | | | | | | |
| | Divide | Yes | Div | F10 | F0 | F6 | Mult1 | | No | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 12 | FU | Mult1 | | | | | Divide | | | |

# Scoreboard Example Cycle 13

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | | |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | 12 |
| DIVD | F10 | F0 | F6 | 8 | | | |
| ADDD | F6 | F8 | F2 | 13 | | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| 6 | Mult1 | Yes | Mult | F0 | F2 | F4 | | | Yes | Yes |
| | Mult2 | No | | | | | | | | |
| | Add | Yes | Add | F6 | F8 | F2 | | | Yes | Yes |
| | Divide | Yes | Div | F10 | F0 | F6 | Mult1 | | No | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 13 | FU | Mult1 | | | Add | | Divide | | | |

# Scoreboard Example Cycle 14

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | | |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | 12 |
| DIVD | F10 | F0 | F6 | 8 | | | |
| ADDD | F6 | F8 | F2 | 13 | 14 | | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| 5 | Mult1 | Yes | Mult | F0 | F2 | F4 | | | Yes | Yes |
| | Mult2 | No | | | | | | | | |
| 2 | Add | Yes | Add | F6 | F8 | F2 | | | Yes | Yes |
| | Divide | Yes | Div | F10 | F0 | F6 | Mult1 | | No | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 14 | FU | Mult1 | | | Add | | Divide | | | |

# Scoreboard Example Cycle 15

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | | |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | 12 |
| DIVD | F10 | F0 | F6 | 8 | | | |
| ADDD | F6 | F8 | F2 | 13 | 14 | | |

Functional unit status

| Time | Name | Busy | Op | Fi (dest) | Fj (S1) | Fk (S2) | Qj (FU for j) | Qk (FU for k) | Rj (Fj?) | Rk (Fk?) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| 4 | Mult1 | Yes | Mult | F0 | F2 | F4 | | | Yes | Yes |
| | Mult2 | No | | | | | | | | |
| 1 | Add | Yes | Add | F6 | F8 | F2 | | | Yes | Yes |
| | Divide | Yes | Div | F10 | F0 | F6 | Mult1 | | No | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 15 | FU | Mult1 | | | Add | | Divide | | | |

# Scoreboard Example Cycle 16

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | | |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | 12 |
| DIVD | F10 | F0 | F6 | 8 | | | |
| ADDD | F6 | F8 | F2 | 13 | 14 | 16 | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| 3 | Mult1 | Yes | Mult | F0 | F2 | F4 | | | Yes | Yes |
| | Mult2 | No | | | | | | | | |
| 0 | Add | Yes | Add | F6 | F8 | F2 | | | Yes | Yes |
| | Divide | Yes | Div | F10 | F0 | F6 | Mult1 | | No | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 16 | FU | Mult1 | | | Add | | Divide | | | |

# Scoreboard Example Cycle 17

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | | |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | 12 |
| DIVD | F10 | F0 | F6 | 8 | | | |
| ADDD | F6 | F8 | F2 | 13 | 14 | 16 | |

Functional unit status

| Time | Name | Busy | Op | Fi (dest) | Fj (S1) | Fk (S2) | FU for j | FU for k | Fj? | Fk? |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| 2 | Mult1 | Yes | Mult | F0 | F2 | F4 | | | Yes | Yes |
| | Mult2 | No | | | | | | | | |
| | Add | Yes | Add | F6 | F8 | F2 | | | Yes | Yes |
| | Divide | Yes | Div | F10 | F0 | F6 | Mult1 | | No | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 17 | FU | Mult1 | | | Add | | Divide | | | |

# Scoreboard Example Cycle 18

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | | |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | 12 |
| DIVD | F10 | F0 | F6 | 8 | | | |
| ADDD | F6 | F8 | F2 | 13 | 14 | 16 | |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| 1 | Mult1 | Yes | Mult | F0 | F2 | F4 | | | Yes | Yes |
| | Mult2 | No | | | | | | | | |
| | Add | Yes | Add | F6 | F8 | F2 | | | Yes | Yes |
| | Divide | Yes | Div | F10 | F0 | F6 | Mult1 | | No | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 18 | FU | Mult1 | | | Add | | Divide | | | |

# Scoreboard Example Cycle 19

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | 19 | |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | 12 |
| DIVD | F10 | F0 | F6 | 8 | | | |
| ADDD | F6 | F8 | F2 | 13 | 14 | 16 | |

Functional unit status

| Time | Name | Busy | Op | Fi | Fj | Fk | Qj | Qk | Rj | Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| 0 | Mult1 | Yes | Mult | F0 | F2 | F4 | | | Yes | Yes |
| | Mult2 | No | | | | | | | | |
| | Add | Yes | Add | F6 | F8 | F2 | | | Yes | Yes |
| | Divide | Yes | Div | F10 | F0 | F6 | Mult1 | | No | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 19 | FU | Mult1 | | | Add | | Divide | | | |

# Scoreboard Example Cycle 20

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | 19 | 20 |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | 12 |
| DIVD | F10 | F0 | F6 | 8 | | | |
| ADDD | F6 | F8 | F2 | 13 | 14 | 16 | |

Functional unit status

| Time | Name | Busy | Op | Fi | Fj | Fk | Qj | Qk | Rj | Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| | Mult1 | No | | | | | | | | |
| | Mult2 | No | | | | | | | | |
| | Add | Yes | Add | F6 | F8 | F2 | | | Yes | Yes |
| | Divide | Yes | Div | F10 | F0 | F6 | | | Yes | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | FU | | | | Add | | Divide | | | |

# Scoreboard Example Cycle 21

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | 19 | 20 |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | 12 |
| DIVD | F10 | F0 | F6 | 8 | 21 | | |
| ADDD | F6 | F8 | F2 | 13 | 14 | 16 | |

Functional unit status

| Time | Name | Busy | Op | Fi | Fj | Fk | Qj | Qk | Rj | Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| | Mult1 | No | | | | | | | | |
| | Mult2 | No | | | | | | | | |
| | Add | Yes | Add | F6 | F8 | F2 | | | Yes | Yes |
| | Divide | Yes | Div | F10 | F0 | F6 | | | Yes | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 21 | FU | | | | Add | | Divide | | | |

# Scoreboard Example Cycle 22

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | 19 | 20 |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | 12 |
| DIVD | F10 | F0 | F6 | 8 | 21 | | |
| ADDD | F6 | F8 | F2 | 13 | 14 | 16 | 22 |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| | Mult1 | No | | | | | | | | |
| | Mult2 | No | | | | | | | | |
| | Add | No | | | | | | | | |
| 40 | Divide | Yes | Div | F10 | F0 | F6 | | | Yes | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 22 | FU | | | | | | Divide | | | |

# Scoreboard Example Cycle 61

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | 19 | 20 |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | 12 |
| DIVD | F10 | F0 | F6 | 8 | 21 | 61 | |
| ADDD | F6 | F8 | F2 | 13 | 14 | 16 | 22 |

Functional unit status

| Time | Name | Busy | Op | Fi (dest) | Fj (S1) | Fk (S2) | Qj (FU for j) | Qk (FU for k) | Rj (Fj?) | Rk (Fk?) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| | Mult1 | No | | | | | | | | |
| | Mult2 | No | | | | | | | | |
| | Add | No | | | | | | | | |
| 0 | Divide | Yes | Div | F10 | F0 | F6 | | | Yes | Yes |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 61 | FU | | | | | | Divide | | | |

# Scoreboard Example Cycle 62

Instruction status

| Instruction | | j | k | Issue | Read operand | Executic complet | Write Result |
|---|---|---|---|---|---|---|---|
| LD | F6 | 34+ | R2 | 1 | 2 | 3 | 4 |
| LD | F2 | 45+ | R3 | 5 | 6 | 7 | 8 |
| MULTI | F0 | F2 | F4 | 6 | 9 | 19 | 20 |
| SUBD | F8 | F6 | F2 | 7 | 9 | 11 | 12 |
| DIVD | F10 | F0 | F6 | 8 | 21 | 61 | 62 |
| ADDD | F6 | F8 | F2 | 13 | 14 | 16 | 22 |

Functional unit status

| Time | Name | Busy | Op | dest Fi | S1 Fj | S2 Fk | FU for j Qj | FU for k Qk | Fj? Rj | Fk? Rk |
|---|---|---|---|---|---|---|---|---|---|---|
| | Integer | No | | | | | | | | |
| | Mult1 | No | | | | | | | | |
| | Mult2 | No | | | | | | | | |
| | Add | No | | | | | | | | |
| 0 | Divide | No | | | | | | | | |

Register result status

| Clock | | F0 | F2 | F4 | F6 | F8 | F10 | F12 | ... | F30 |
|---|---|---|---|---|---|---|---|---|---|---|
| 62 | FU | | | | | | | | | |

# What are the "I/O" "processors"?

- FGMT processors on the 6600
- Uniform instruction set for I/O devices
- Why context switch main memory?
  - This is pre-virtual memory

# What is the FIFO instruction stack?

- A very primitive instruction cache
- 8, 60-bit words, up to 32 instructions
- optimized for back-edges

# Your questions

- Precise exceptions?
- How much ILP/dataflow study before this?
- How much influence?
- When did memory get slower than computation?
- Major cycle?
- Why 10 control processors?
- What sort of performance improvement was had?
- Why is WAW not immediately resolvable?
- How much overhead is scoreboarding?
- Interrupts?
- Anyone still use this?
- Is 2% contention to be believed?
- Why only communicate via memory?
- Is this truly OoO?
- What about memory dependencies?
- Cost of the broadcast result busses?
- Relationship to Stetch?  How to pipeline?
- Relationship between control processors and DMA?
- How much software actually ran on the CPs?
- How does scoreboarding work with timeslicing?
- Is there a place for physical registers in a scoreboarding machine?