

# The ALU Control Unit

## Lecture 33

### Section 4.3, Appendix D

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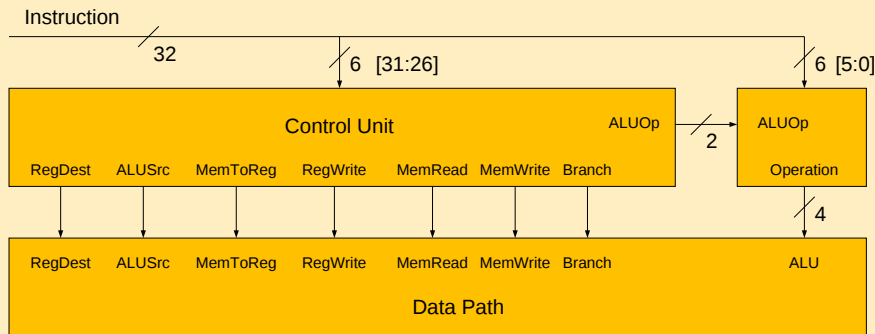
- 1 The Control Unit
- 2 The ALU Control Unit
- 3 Assignment

# Outline

- 1 The Control Unit
- 2 The ALU Control Unit
- 3 Assignment

# The Control Unit

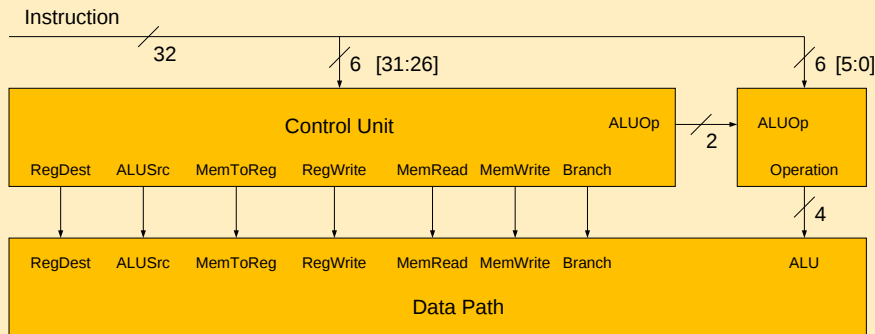
## The Control Unit



The ALU Control Unit receives input from the Control Unit (derived from the `opcode`) and from the `funct` field of the instruction.

# The Control Unit

## The Control Unit



The ALU Control Unit output is a 4-bit value that determines the arithmetic or logical operation performed by the ALU.

# The Op Codes

| Instruction | op Field | funct Field |
|-------------|----------|-------------|
| lw          | 100011   | XXXXXX      |
| sw          | 101011   | XXXXXX      |
| beq         | 000100   | XXXXXX      |
| addi        | 001000   | XXXXXX      |
| add         | 000000   | 100000      |
| sub         | 000000   | 100010      |
| and         | 000000   | 100100      |
| or          | 000000   | 100101      |
| nor         | 000000   | 100111      |
| slt         | 000000   | 101010      |

- The `funct` field matters only for R-type instructions.

# The ALUOp Codes

| Instruction     | op Field | ALUOp |
|-----------------|----------|-------|
| Load/store word | 100011   | 00    |
| Branch equal    | 000100   | 01    |
| Add immediate   | 001000   | 11    |
| R-type          | 000000   | 10    |

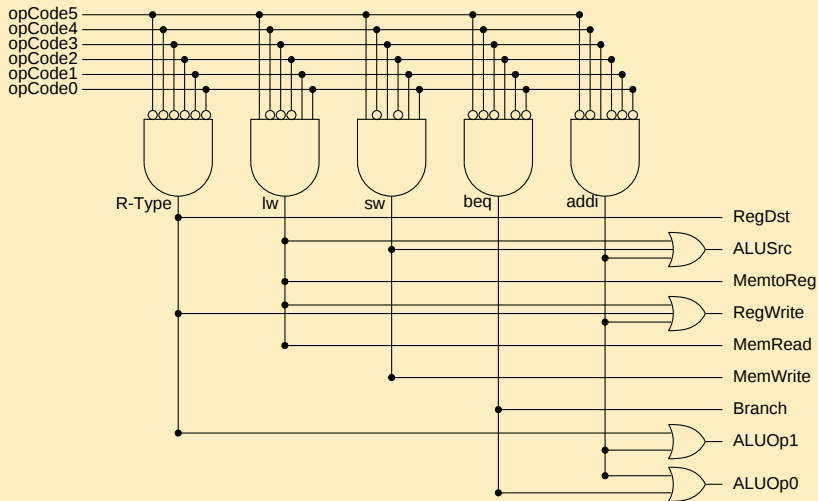
- The ALUOp is determined by the op code of the instruction.

# Summary of the Control Unit Output

## Control Unit Output

| Input |     |     |     |     |     |     | Output |        |          |          |         |          |        |        |        |
|-------|-----|-----|-----|-----|-----|-----|--------|--------|----------|----------|---------|----------|--------|--------|--------|
|       |     |     |     |     |     |     | RegDst | ALUSrc | MemtoReg | RegWrite | MemRead | MemWrite | Branch | ALUOp1 | ALUOp0 |
| OP    | Op5 | Op4 | Op3 | Op2 | Op1 | Op0 |        |        |          |          |         |          |        |        |        |
| RT    | 0   | 0   | 0   | 0   | 0   | 0   | 1      | 0      | 0        | 1        | 0       | 0        | 0      | 1      | 0      |
| lw    | 1   | 0   | 0   | 0   | 1   | 1   | 0      | 1      | 1        | 0        | 1       | 0        | 0      | 0      | 0      |
| sw    | 1   | 0   | 1   | 0   | 1   | 1   | X      | 1      | 0        | X        | 0       | 1        | 0      | 0      | 0      |
| beq   | 0   | 0   | 0   | 1   | 0   | 0   | X      | 0      | 0        | X        | 0       | 0        | 1      | 0      | 1      |
| addi  | 0   | 0   | 1   | 0   | 0   | 0   | 0      | 1      | 0        | 1        | 0       | 0        | 0      | 1      | 1      |

# The Control Unit



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# The ALU Control Unit Codes

| Instruction Operation | ALUOp | funct Field | ALU Action       | ALU Control Input |
|-----------------------|-------|-------------|------------------|-------------------|
| Load word             | 00    | XXXXXX      | Add              | 0010              |
| Store word            | 00    | XXXXXX      | Add              | 0010              |
| Branch equal          | 01    | XXXXXX      | Subtract         | 0110              |
| Add immediate         | 11    | XXXXXX      | Add              | 0010              |
| Add                   | 10    | XX0000      | Add              | 0010              |
| Subtract              | 10    | XX0010      | Subtract         | 0110              |
| And                   | 10    | XX0100      | And              | 0000              |
| Or                    | 10    | XX0101      | Or               | 0001              |
| Nor                   | 10    | XX0111      | Nor              | 1100              |
| Set on less than      | 10    | XX1010      | Set on less than | 0111              |

- The ALU Control Unit output is determined by the ALUOp and the `funct` field.

# The Truth Table

| Instr | Main Control |        | func Field |    |    |    |    |    | Operation |
|-------|--------------|--------|------------|----|----|----|----|----|-----------|
|       | ALUOp1       | ALUOp0 | F5         | F4 | F3 | F2 | F1 | F0 |           |
| lw    | 0            | 0      | X          | X  | X  | X  | X  | X  | 0010      |
| sw    | 0            | 0      | X          | X  | X  | X  | X  | X  | 0010      |
| beq   | 0            | 1      | X          | X  | X  | X  | X  | X  | 0110      |
| addi  | 1            | 1      | X          | X  | X  | X  | X  | X  | 0010      |
| add   | 1            | 0      | X          | X  | 0  | 0  | 0  | 0  | 0010      |
| sub   | 1            | 0      | X          | X  | 0  | 0  | 1  | 0  | 0110      |
| and   | 1            | 0      | X          | X  | 0  | 1  | 0  | 0  | 0000      |
| or    | 1            | 0      | X          | X  | 0  | 1  | 0  | 1  | 0001      |
| nor   | 1            | 0      | X          | X  | 0  | 1  | 1  | 1  | 1100      |
| slt   | 1            | 0      | X          | X  | 1  | 0  | 1  | 0  | 0111      |

- What are the Boolean functions that determine the ALU Control Unit's output?

# ALU Op<sub>0</sub>

| Instr | Instruction        |                    | funct Field    |                |                |                |                |                | Op <sub>0</sub> |
|-------|--------------------|--------------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|
|       | ALUOp <sub>1</sub> | ALUOp <sub>0</sub> | F <sub>5</sub> | F <sub>4</sub> | F <sub>3</sub> | F <sub>2</sub> | F <sub>1</sub> | F <sub>0</sub> |                 |
| lw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 0               |
| sw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 0               |
| beq   | 0                  | 1                  | X              | X              | X              | X              | X              | X              | 0               |
| addi  | 1                  | 1                  | X              | X              | X              | X              | X              | X              | 0               |
| add   | 1                  | 0                  | X              | X              | 0              | 0              | 0              | 0              | 0               |
| sub   | 1                  | 0                  | X              | X              | 0              | 0              | 1              | 0              | 0               |
| and   | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 0              | 0               |
| or    | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 0              | 0               |
| nor   | 1                  | 0                  | X              | X              | 0              | 1              | 1              | 1              | 0               |
| slt   | 1                  | 0                  | X              | X              | 1              | 0              | 1              | 0              | 1               |

# ALU Op<sub>0</sub>

| Instr | Instruction        |                    | funct Field    |                |                |                |                |                | Op <sub>0</sub> |
|-------|--------------------|--------------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|
|       | ALUOp <sub>1</sub> | ALUOp <sub>0</sub> | F <sub>5</sub> | F <sub>4</sub> | F <sub>3</sub> | F <sub>2</sub> | F <sub>1</sub> | F <sub>0</sub> |                 |
| lw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 0               |
| sw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 0               |
| beq   | 0                  | 1                  | X              | X              | X              | X              | X              | X              | 0               |
| addi  | 1                  | 1                  | X              | X              | X              | X              | X              | X              | 0               |
| add   | 1                  | 0                  | X              | X              | 0              | 0              | 0              | 0              | 0               |
| sub   | 1                  | 0                  | X              | X              | 0              | 0              | 1              | 0              | 0               |
| and   | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 0              | 0               |
| or    | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 0              | 0               |
| nor   | 1                  | 0                  | X              | X              | 0              | 1              | 1              | 1              | 0               |
| slt   | 1                  | 0                  | X              | X              | 1              | 0              | 1              | 0              | 1               |

$$\text{Op}_0 = \text{ALUOp}_1 \cdot \overline{\text{ALUOp}_0} \cdot (\text{F}_3 + \overline{\text{F}_1} \cdot \text{F}_0).$$

# ALU Op<sub>1</sub>

| Instr | Instruction        |                    | funct Field    |                |                |                |                |                | Op <sub>1</sub> |
|-------|--------------------|--------------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|
|       | ALUOp <sub>1</sub> | ALUOp <sub>0</sub> | F <sub>5</sub> | F <sub>4</sub> | F <sub>3</sub> | F <sub>2</sub> | F <sub>1</sub> | F <sub>0</sub> |                 |
| lw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 1               |
| sw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 1               |
| beq   | 0                  | 1                  | X              | X              | X              | X              | X              | X              | 1               |
| addi  | 1                  | 1                  | X              | X              | X              | X              | X              | X              | 1               |
| add   | 1                  | 0                  | X              | X              | 0              | 0              | 0              | 0              | 1               |
| sub   | 1                  | 0                  | X              | X              | 0              | 0              | 1              | 0              | 1               |
| and   | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 0              | 0               |
| or    | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 1              | 0               |
| nor   | 1                  | 0                  | X              | X              | 0              | 1              | 1              | 1              | 0               |
| slt   | 1                  | 0                  | X              | X              | 1              | 0              | 1              | 0              | 1               |

# ALU Op<sub>1</sub>

| Instr | Instruction        |                    | funct Field    |                |                |                |                |                | Op <sub>1</sub> |
|-------|--------------------|--------------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|
|       | ALUOp <sub>1</sub> | ALUOp <sub>0</sub> | F <sub>5</sub> | F <sub>4</sub> | F <sub>3</sub> | F <sub>2</sub> | F <sub>1</sub> | F <sub>0</sub> |                 |
| lw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 1               |
| sw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 1               |
| beq   | 0                  | 1                  | X              | X              | X              | X              | X              | X              | 1               |
| addi  | 1                  | 1                  | X              | X              | X              | X              | X              | X              | 1               |
| add   | 1                  | 0                  | X              | X              | 0              | 0              | 0              | 0              | 1               |
| sub   | 1                  | 0                  | X              | X              | 0              | 0              | 1              | 0              | 1               |
| and   | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 0              | 0               |
| or    | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 1              | 0               |
| nor   | 1                  | 0                  | X              | X              | 0              | 1              | 1              | 1              | 0               |
| slt   | 1                  | 0                  | X              | X              | 1              | 0              | 1              | 0              | 1               |

$$\text{Op}_1 = \overline{\text{ALUOp}_1} + \text{ALUOp}_0 + \overline{\text{F}_2}.$$

# ALU Op<sub>2</sub>

| Instr | Instruction        |                    | funct Field    |                |                |                |                |                | Op <sub>2</sub> |
|-------|--------------------|--------------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|
|       | ALUOp <sub>1</sub> | ALUOp <sub>0</sub> | F <sub>5</sub> | F <sub>4</sub> | F <sub>3</sub> | F <sub>2</sub> | F <sub>1</sub> | F <sub>0</sub> |                 |
| sw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 0               |
| lw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 0               |
| beq   | 0                  | 1                  | X              | X              | X              | X              | X              | X              | 1               |
| addi  | 1                  | 1                  | X              | X              | X              | X              | X              | X              | 0               |
| add   | 1                  | 0                  | X              | X              | 0              | 0              | 0              | 0              | 0               |
| sub   | 1                  | 0                  | X              | X              | 0              | 0              | 1              | 0              | 1               |
| and   | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 0              | 0               |
| or    | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 1              | 0               |
| nor   | 1                  | 0                  | X              | X              | 0              | 1              | 1              | 1              | 1               |
| slt   | 1                  | 0                  | X              | X              | 1              | 0              | 1              | 0              | 1               |

# ALU Op<sub>2</sub>

| Instr | Instruction        |                    | funct Field    |                |                |                |                |                | Op <sub>2</sub> |
|-------|--------------------|--------------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|
|       | ALUOp <sub>1</sub> | ALUOp <sub>0</sub> | F <sub>5</sub> | F <sub>4</sub> | F <sub>3</sub> | F <sub>2</sub> | F <sub>1</sub> | F <sub>0</sub> |                 |
| sw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 0               |
| lw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 0               |
| beq   | 0                  | 1                  | X              | X              | X              | X              | X              | X              | 1               |
| addi  | 1                  | 1                  | X              | X              | X              | X              | X              | X              | 0               |
| add   | 1                  | 0                  | X              | X              | 0              | 0              | 0              | 0              | 0               |
| sub   | 1                  | 0                  | X              | X              | 0              | 0              | 1              | 0              | 1               |
| and   | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 0              | 0               |
| or    | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 1              | 0               |
| nor   | 1                  | 0                  | X              | X              | 0              | 1              | 1              | 1              | 1               |
| slt   | 1                  | 0                  | X              | X              | 1              | 0              | 1              | 0              | 1               |

$$\text{Op}_2 = (\overline{\text{ALUOp}_1} \cdot \text{ALUOp}_0) + (\text{ALUOp}_1 \cdot \overline{\text{ALUOp}_0} \cdot F_1).$$

# ALU Op<sub>3</sub>

| Instr | Instruction        |                    | funct Field    |                |                |                |                |                | Op <sub>3</sub> |
|-------|--------------------|--------------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|
|       | ALUOp <sub>1</sub> | ALUOp <sub>0</sub> | F <sub>5</sub> | F <sub>4</sub> | F <sub>3</sub> | F <sub>2</sub> | F <sub>1</sub> | F <sub>0</sub> |                 |
| lw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 0               |
| sw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 0               |
| beq   | 0                  | 1                  | X              | X              | X              | X              | X              | X              | 0               |
| addi  | 1                  | 0                  | X              | X              | 0              | 0              | 0              | 0              | 0               |
| add   | 1                  | 0                  | X              | X              | 0              | 0              | 1              | 0              | 0               |
| sub   | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 0              | 0               |
| and   | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 0              | 0               |
| or    | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 1              | 0               |
| nor   | 1                  | 0                  | X              | X              | 0              | 1              | 1              | 1              | 1               |
| slt   | 1                  | 0                  | X              | X              | 1              | 0              | 1              | 0              | 0               |

# ALU Op<sub>3</sub>

| Instr | Instruction        |                    | funct Field    |                |                |                |                |                | Op <sub>3</sub> |
|-------|--------------------|--------------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|
|       | ALUOp <sub>1</sub> | ALUOp <sub>0</sub> | F <sub>5</sub> | F <sub>4</sub> | F <sub>3</sub> | F <sub>2</sub> | F <sub>1</sub> | F <sub>0</sub> |                 |
| lw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 0               |
| sw    | 0                  | 0                  | X              | X              | X              | X              | X              | X              | 0               |
| beq   | 0                  | 1                  | X              | X              | X              | X              | X              | X              | 0               |
| addi  | 1                  | 0                  | X              | X              | 0              | 0              | 0              | 0              | 0               |
| add   | 1                  | 0                  | X              | X              | 0              | 0              | 1              | 0              | 0               |
| sub   | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 0              | 0               |
| and   | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 0              | 0               |
| or    | 1                  | 0                  | X              | X              | 0              | 1              | 0              | 1              | 0               |
| nor   | 1                  | 0                  | X              | X              | 0              | 1              | 1              | 1              | 1               |
| slt   | 1                  | 0                  | X              | X              | 1              | 0              | 1              | 0              | 0               |

$$\text{Op}_3 = \text{ALUOp}_1 \cdot \overline{\text{ALUOp}_0} \cdot F_1 \cdot F_0.$$

# The ALU Control Unit

$$\text{Op}_0 = \text{ALUOp}_1 \cdot \overline{\text{ALUOp}_0} \cdot (F_3 + \overline{F_1} \cdot F_0),$$

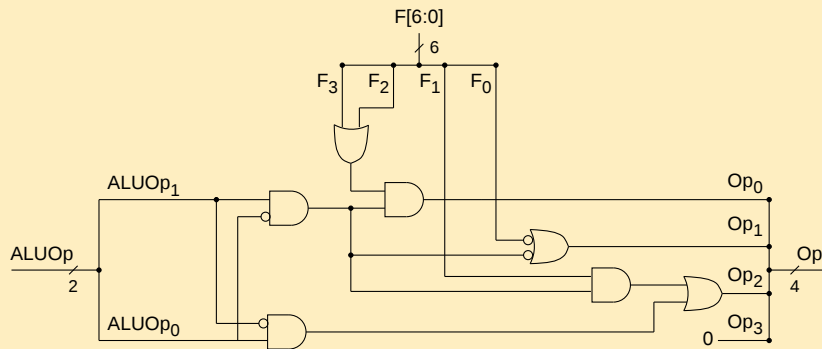
$$\text{Op}_1 = \overline{\text{ALUOp}_1} + \text{ALUOp}_0 + \overline{F_2},$$

$$\text{Op}_2 = (\overline{\text{ALUOp}_1} \cdot \text{ALUOp}_0) + (\text{ALUOp}_1 \cdot \overline{\text{ALUOp}_0} \cdot F_1),$$

$$\text{Op}_3 = \text{ALUOp}_1 \cdot \overline{\text{ALUOp}_0} \cdot F_1 \cdot F_0.$$

# The ALU Control Unit

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- Read Section 4.3, Appendix D.