**ECE 3401 Lecture 18**

**Microprogramming (I)**

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**Arithmetic Logic Unit (ALU)**

- Decompose the ALU into:
  - An arithmetic circuit & logic circuit
  - A selector to pick between the two circuits

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**Arithmetic Circuit Design**

- Arithmetic circuit design
  - Decompose the arithmetic circuit into:
    - An n-bit parallel adder
    - A block of logic that selects four choices for the B input to the adder

- There are only four functions of B to select as Y in \( G = A + Y + C_{in} \):
  - \( 0 \)
  - \( B \)
  - \( B \)
  - \( 1 \)

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**4-Bit Basic Left/Right Shifter**

- Serial Inputs:
  - \( b_0 \) for right shift
  - \( l_0 \) for left shift
- Shift Functions:
  - \((S_1, S_0) = 00\) Pass B unchanged
  - \(01\) Right shift
  - \(10\) Left shift
  - \(11\) Unused

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**Barrel Shifter**

- A rotate is a shift in which the bits shifted out are inserted into the positions vacated
- The circuit rotates its contents left from 0 to 3 positions depending on S:
  - S = 00 position unchanged
  - S = 10 rotate left by 2 positions
  - S = 11 rotate left by 3 positions

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**Combinational Shifter from MUXes**

- Example 8-bit:
  - Layer 1 shifts by 0, 4
  - Layer 2 shifts by 0, 2
  - Layer 3 shifts by 0, 1

- Large barrel shifters can be constructed using:
  - Layers of multiplexers
  - 2-dimensional array circuits designed at the electronic level
Datapath Representation

- In the register file:
  - Select inputs for multiplexers -> A address & B address
  - Decoder input -> D address
  - Load enable -> write
  - Input data to the registers -> D data
  - Multiplexer outputs -> A data & B data

- The register file now appears like a memory based on clocked flip-flops
- FS?

Definition of Function Unit Select (FS) Codes

<table>
<thead>
<tr>
<th>FS(3:0)</th>
<th>MF</th>
<th>G</th>
<th>H</th>
<th>Select(3:0)</th>
<th>Select(1:0)</th>
<th>Microoperation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>0</td>
<td>0</td>
<td>XX</td>
<td>0000</td>
<td>XX</td>
<td>F ← A</td>
</tr>
<tr>
<td>0001</td>
<td>0</td>
<td>0</td>
<td>XX</td>
<td>0001</td>
<td>XX</td>
<td>F ← A + 1</td>
</tr>
<tr>
<td>0010</td>
<td>0</td>
<td>0</td>
<td>XX</td>
<td>0010</td>
<td>XX</td>
<td>F ← A + B</td>
</tr>
<tr>
<td>0011</td>
<td>0</td>
<td>0</td>
<td>XX</td>
<td>0011</td>
<td>XX</td>
<td>F ← A + B + 1</td>
</tr>
<tr>
<td>0100</td>
<td>0</td>
<td>0</td>
<td>XX</td>
<td>0100</td>
<td>XX</td>
<td>F ← A</td>
</tr>
<tr>
<td>0101</td>
<td>0</td>
<td>0</td>
<td>XX</td>
<td>0101</td>
<td>XX</td>
<td>F ← A + B + 1</td>
</tr>
<tr>
<td>0110</td>
<td>0</td>
<td>0</td>
<td>XX</td>
<td>0110</td>
<td>XX</td>
<td>F ← A - 1</td>
</tr>
<tr>
<td>0111</td>
<td>0</td>
<td>0</td>
<td>XX</td>
<td>0111</td>
<td>XX</td>
<td>F ← A</td>
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<tr>
<td>1000</td>
<td>0</td>
<td>0</td>
<td>XX</td>
<td>1000</td>
<td>XX</td>
<td>F ← A + B</td>
</tr>
<tr>
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<td>0</td>
<td>1</td>
<td>XX</td>
<td>1001</td>
<td>XX</td>
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<td>1</td>
<td>XX</td>
<td>1010</td>
<td>XX</td>
<td>F ← A + B + 1</td>
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<tr>
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<td>XX</td>
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<td>XX</td>
<td>F ← A</td>
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<tr>
<td>1100</td>
<td>1</td>
<td>XXX</td>
<td>00</td>
<td>F ← B</td>
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<tr>
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<td>1</td>
<td>XXX</td>
<td>01</td>
<td>F ← s' B</td>
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<td></td>
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<tr>
<td>1110</td>
<td>1</td>
<td>XXX</td>
<td>10</td>
<td>F ← s B</td>
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</tr>
</tbody>
</table>

Boolean Equations:

\[ MF = F_3 F_2 \]
\[ GS = F_1 \]
\[ HS = F_1 \]

Control Word Encoding

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>FE (A)</td>
<td>0</td>
<td>FE (A - 1)</td>
<td>1</td>
<td>FE (A + B)</td>
<td>0</td>
<td>FE (A + B)</td>
<td>1</td>
</tr>
<tr>
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Microoperations for the Datapath – Symbolic & Binary Representation

Datapath Simulation