Your Microprocessor in Action...
Our Microprocessor (for today)

Components:

• Memory: 16 bytes (address: 0 ... 15)
• Arithmetic logical unit
• Status register
• General purpose registers: R0, R1, R2, R3
• Display
• Program counter
• Instruction decoder
• Compiler (not really part of the processor)
Memory

Operations:
- Store a register value into a memory location
- Read a memory location and give it to a register

Simplifications:
- We will allow names for memory locations
General Purpose Registers

Purpose: temporary storage of values for immediate computation

Operations:
• Receive a byte
• Send a byte
Status Register
(a special purpose register)

Individual bits:
• Zero: was the result of the last mathematical operation zero?
• Negative: was the result negative?
• Carry: was there a carry?
Arithmetic Logical Unit (ALU)

Operations:

- **A:**
  - **COMPUTE**
    - R1 + R3
  - **STORE**
    - R1
    - Add
Arithmetic Logical Unit (ALU)

Operations:

<table>
<thead>
<tr>
<th>COMPUTE</th>
<th>STORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1 + R3</td>
<td>-&gt; R1</td>
</tr>
<tr>
<td>R3 + R0</td>
<td>-&gt; R3</td>
</tr>
</tbody>
</table>

Andrew H. Fagg: Embedded Real-Time Systems: CPU Components
## Arithmetic Logical Unit (ALU)

### Operations:

<table>
<thead>
<tr>
<th>COMPUTE</th>
<th>STORE</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A: R1 + R3 )</td>
<td>( \rightarrow R1 )</td>
<td>Add</td>
</tr>
<tr>
<td>( A': R3 + R0 )</td>
<td>( \rightarrow R3 )</td>
<td>Add</td>
</tr>
<tr>
<td>( B: R0 + R2 + \text{carry} )</td>
<td>( \rightarrow R0 )</td>
<td>Add with carry</td>
</tr>
<tr>
<td>( B': R1 + R3 + \text{carry} )</td>
<td>( \rightarrow R1 )</td>
<td>Add with carry</td>
</tr>
</tbody>
</table>

Each operation can also update the status register:

- SR[zero]: is the result zero?
- SR[negative]: is the result negative?
- SR[carry]: was there a carry?

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# Arithmetic Logical Unit (ALU)

## Operations:

<table>
<thead>
<tr>
<th>COMPUTE</th>
<th>STORE</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>A: $R1 + R3$</td>
<td>-&gt; $R1$</td>
<td>Add</td>
</tr>
<tr>
<td>A': $R3 + R0$</td>
<td>-&gt; $R3$</td>
<td>Add</td>
</tr>
<tr>
<td>B: $R0 + R2 + carry$</td>
<td>-&gt; $R0$</td>
<td>Add with carry</td>
</tr>
<tr>
<td>B': $R1 + R3 + carry$</td>
<td>-&gt; $R1$</td>
<td>Add with carry</td>
</tr>
<tr>
<td>C: $R1 \times R3$</td>
<td>-&gt; $[R0, R1]$</td>
<td>Multiply</td>
</tr>
<tr>
<td>D: $R1 &amp; R3$</td>
<td>-&gt; $R1$</td>
<td>Bit-wise AND</td>
</tr>
<tr>
<td>E: $R1 \mid R3$</td>
<td>-&gt; $R1$</td>
<td>Bit-wise OR</td>
</tr>
<tr>
<td>F: $\sim R1$</td>
<td>-&gt; $R1$</td>
<td>Bit-wise NOT</td>
</tr>
<tr>
<td>G: $-R1$</td>
<td>-&gt; $R1$</td>
<td>2’s Comp Neg</td>
</tr>
<tr>
<td>H(x, y): $y$</td>
<td>-&gt; $R_x$</td>
<td>Copy value $y$ to $Rx$</td>
</tr>
<tr>
<td>J(x, y): $R_y$</td>
<td>-&gt; $R_x$</td>
<td>Copy $Ry$ to $Rx$</td>
</tr>
<tr>
<td>T: $R1 - R3$</td>
<td>XXXXXXXXXX</td>
<td>Compare</td>
</tr>
<tr>
<td>U: $R3 - R2$</td>
<td>XXXXXXXXXX</td>
<td>Compare</td>
</tr>
</tbody>
</table>

Each operation can also update the status register:

- **SR[zero]:** is the result zero? 
- **SR[negative]:** is the result negative? 
- **SR[carry]:** was there a carry?
Program Memory

• Stores our program

• We will start with C

• For each line of C, our compiler will translate into a sequence of “atomic” instructions
Program Counter
(special purpose register)

Keeps track of which part of the program that we are currently executing

Operations:
• Jump to the next line
• Jump up or down multiple lines
• Conditional (on status bit): jump up or down multiple lines
Display

One operation:
• Receive a byte

In response to this operation:
• Convert to written representation
• Write it
Instruction Decoder

Tells everyone what to do....

Sequence:

• Fetch the instruction that is currently indicated by the program counter
• For each operation in order: tell the relevant components what to do
• Repeat
Instruction Decoder

Must determine what is done by each component:

• Memory
• Registers
• Display
• ALU
• Program counter
Program #1

```c
uint8_t a;
a = 5;
display(a);
```
Program #2

```c
uint8_t a;
a = 5;
a = a + 7;
display(a);
```
Program #3

```c
#3
uint8_t a;
uint8_t b;
a = 5;
b = 17;
if (a < b) {
    a = a + b;
}
display(a);
```
Program #4

```c
uint8_t a;
uint8_t i;
a = 0;
for(i = 0; i < 4; ++i) {
    a = a + i;
}
display(a);
```
Program #5

```c
int8_t a;
int8_t b;
a = 5;
b = a * 100;
display(b);
```
Program #6

```c
int8_t a;
int16_t b;
a = 5;
b = a * 100;
display(b);
```
Program #7

```c
uint8_t a;
uint8_t i;
a = 0;
for(i = 1; i > 0; i*=2) {
    a = a | i;
    display(a);
}
```
Take-Home Messages

• Many different components
• The components must be coordinated to execute the program properly
• Instructions are translated into a set of control signals for your microprocessor
• Be aware of variable sizes:
  – Small is good for efficiency
  – But the computations that you are performing must fit within these small spaces
Caveats

• Variable names are handled by the compiler (and disappear before execution)
• Many more registers
  – Variables are stored longer in registers if they are used in consecutive lines (efficiency, but with challenges)
• Many more instructions