Simple Bus Timing

**Read Cycle**

- **R/W**
- **Enable**
- **Addr**
- **Data**

**Write Cycle**

- **R/W**
- **Enable**
- **Addr**
- **Data**
1982: The IBM PC
The ISA Bus: Memory Read

- CLK
- Addr
- BALE
- MEMR
- IOCHRDY
- Data

Time:
- C1
- C2
- Wait
- C3
- C4
The ISA Bus: Memory Write

- **CLK**
- **Addr**
- **BALE**
- **MEMW**
- **IOCHRDY**
- **Data**
Embedded System Legos. Stack ’em and go.
Memory-Mapped I/O

- To a processor, everything is memory.
- Peripherals appear as magical memory locations.
- Status registers: when read, report state of peripheral
- Control registers: when written, change state of peripheral
### Centronics Handshake

**nStrobe**

**Busy**

**nAck**

**Data**

### At Standard TTL Levels

<table>
<thead>
<tr>
<th>Signal Name</th>
<th>Signal Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>-Strobe</td>
<td>1</td>
</tr>
<tr>
<td>+Data Bit 0</td>
<td>2</td>
</tr>
<tr>
<td>+Data Bit 1</td>
<td>3</td>
</tr>
<tr>
<td>+Data Bit 2</td>
<td>4</td>
</tr>
<tr>
<td>+Data Bit 3</td>
<td>5</td>
</tr>
<tr>
<td>+Data Bit 4</td>
<td>6</td>
</tr>
<tr>
<td>+Data Bit 5</td>
<td>7</td>
</tr>
<tr>
<td>+Data Bit 6</td>
<td>8</td>
</tr>
<tr>
<td>+Data Bit 7</td>
<td>9</td>
</tr>
<tr>
<td>Acknowledge</td>
<td>10</td>
</tr>
<tr>
<td>+Busy</td>
<td>11</td>
</tr>
<tr>
<td>+Paper End</td>
<td>12</td>
</tr>
<tr>
<td>+Select</td>
<td>13</td>
</tr>
<tr>
<td>-Auto Feed</td>
<td>14</td>
</tr>
<tr>
<td>-Error</td>
<td>15</td>
</tr>
<tr>
<td>-Initialize</td>
<td>16</td>
</tr>
<tr>
<td>-Select Input</td>
<td>17</td>
</tr>
<tr>
<td>Ground</td>
<td>18-25</td>
</tr>
</tbody>
</table>
***Parallel Port Registers***

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>0x378</th>
</tr>
</thead>
<tbody>
<tr>
<td>Busy</td>
<td>Ack</td>
<td>Paper</td>
<td>Sel</td>
<td>Err</td>
<td>Sel</td>
<td>Init</td>
<td>Auto</td>
<td>Strobe</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Write Data
2. Assert Strobe
3. Wait for Busy to clear
4. Wait for Acknowledge

**Centronics Handshake**

- nStrobe
- Busy
- nAck
- Data
A Parallel Port Driver

```c
#define DATA 0x378
#define STATUS 0x379
#define CONTROL 0x37A

#define NBSY 0x80
#define NACK 0x40
#define OUT 0x20
#define SEL 0x10
#define NERR 0x08
#define STROBE 0x01

#define INVERT (NBSY | NACK | SEL | NERR)
#define MASK (NBSY | NACK | OUT | SEL | NERR)
#define NOT_READY(x) ((inb(x)^INVERT)&MASK)

void write_single_character(char c) {
    while (NOT_READY(STATUS)) ;
    outb(DATA, c);
    outb(CONTROL, control | STROBE); /* Assert STROBE */
    outb(CONTROL, control ); /* Clear STROBE */
}
```
Interrupts and Polling

Two ways to get data from a peripheral:

- Polling: “Are we there yet?”
- Interrupts: Ringing Telephone
Basic idea:

1. Peripheral asserts a processor’s interrupt input
2. Processor temporarily transfers control to interrupt service routine
3. ISR gathers data from peripheral and acknowledges interrupt
4. ISR returns control to previously-executing program
Many Different Interrupts

What’s a processor to do?
Interrupt Polling

Processor receives interrupt
ISR polls all potential interrupt sources
Prioritizes incoming requests & notifies processor
ISR reads 8-bit interrupt vector number of winner
IBM PC/AT: two 8259s; became standard