Bit Twiddling

Topics

1) What are the bitwise operators?
2) What is a bit flags and masks?
3) How to:
   a) Read / set single bits.
   b) Read / set multiple bits.
4) Can C access bits better than just bitwise?

Bitwise and Bitmasks

- **Bitwise operators**
  - | is OR - Set selected bits
  - & is AND -..  
  - ~ is NOT - Invert all bits
  - ^ is XOR - Invert selected bits.

- **Bit Flags**
  - Store multiple binary conditions in a multi-bit value.
  - Ex: encoding the state of 8 LEDs in one char.

- **Mask**
  - Used to..
  - Has all 1's for bits of that field; 0 elsewhere.

Running Example

- **STAT: GPIO Status Reg**

<table>
<thead>
<tr>
<th>Bit</th>
<th>15</th>
<th>14</th>
<th>13</th>
<th>12</th>
<th>11</th>
<th>10</th>
<th>9</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED3</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>LED2</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>LED1</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>LED0</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>BTN3</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>BTN2</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>BTN1</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>BTN0</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R/W</td>
</tr>
</tbody>
</table>

- **LEDx**: Set (1) when on
- **BUTTONx**: Read 0 when pressed; 1 otherwise.
- **SPD2-0**: Flash speed; between 0 (slow) and 7 (fast)
- **FLASH**: 1 means flashing; 0 means solid (on).
Running Example

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<tr>
<td>LED3</td>
<td>LED2</td>
<td>LED1</td>
<td>LED0</td>
<td>BTN3</td>
<td>BTN2</td>
<td>BTN1</td>
<td>BTN0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bit</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPD2</td>
<td>SPD1</td>
<td>SPD0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>FLASH</td>
<td></td>
</tr>
</tbody>
</table>

- What does this value mean? 0xC2A7

BIT Numbers and Masks

- Bit Numbers
  - #define LED3_BIT 15
  - #define LED2_BIT 14
  - #define LED0_BIT 8
  - #define BTN3_BIT 11
  - #define SPD2_BIT 7
  - #define SPD1_BIT 6
  - #define SPD0_BIT 5
  - #define FLASH_BIT 0

- Convert Bit Number to Mask
  - #define LED0_MASK (1 << LED0_BIT)

Reading a Bit

- Read an LED State
  - _Bool isLed0On = ..

- Read a Button State
  - _Bool isBtn0Pressed = ..

- As Macros
  - #define IS_LED_ON(pin) \n    (STAT & (1 << (pin)) != 0)
  - #define IS_BUTTON_PRESSED(pin) \n    (STAT & (1 << (pin)) == 0)

Reading Bits

- Read Multiple Bits
  - #define LED_MASK 0xF000;
  - _Bool isAnyLEDOn = ..
  - _Bool areAllLEDsOn = ..

- Read Multiple Active-Low Bits
  - #define BTN_MASK 0x0F00
  - _Bool isAnyButtonPressed = ..
  - _Bool areAllButtonsPressed = ..

  (STAT & BTN_MASK) == 0;
**Drive Bits**

- Turn on LED 2
  \[ \text{STAT} = \text{STAT} \quad (1 \ll \text{LED2_PIN}) \]
- Turn off LED 2
  \[ \text{STAT} = \text{STAT} \quad (1 \ll \text{LED1_PIN}) \]
- Turn off LEDs 1 and 2
  \[ \text{STAT} = \text{STAT} \quad (1 \ll \text{LED1_PIN}) \]
- Turn on / off all LEDs
  \[ \text{STAT} = \text{STAT} \quad (1 \ll \text{LED1_PIN}) \]
- Turn off all LEDs but LED2 (leave it)
  \[ \text{STAT} = \text{STAT} \quad (1 \ll \text{LED2_PIN}) \]

**Toggle Bits**

- // Toggle LED0
  \[ \text{STAT} = \text{STAT} \quad (1 \ll \text{LED2_PIN}) \]
- // Toggle all LEDs
  \[ \text{STAT} = \text{STAT} \quad (1 \ll \text{LED1_PIN}) \]

**Multi-Bit Fields**

- Read value
  ```
  #define SPD_MASK 0x00E0
  int speed =
  ```

- Set value
  ```
  void setFlashSpeed(int speed) {
    int newSpeed = (speed \ll SPD0_BIT) & SPD_MASK;
    \text{STAT} = (\text{STAT} \quad (1 \ll \text{LED1_PIN}) \quad (1 \ll \text{LED2_PIN}) \quad \text{SPD} \quad \text{MASK}) \quad \text{newSpeed};
  }
  ```

**Common Errors**

- ~ vs !, & vs &&, | vs ||
- &= vs &= ~(..)
- bit # vs mask: LED1_BIT vs (1 \ll LED1_BIT)
- use (1 \ll x) not pow(2, x)
- use (1 \ll x) \quad (1 \ll y), not 1 \ll (x \quad y)
- b &= ~(1 \ll x) is not b = ~(1 \ll x)
- (a & ~b) is not (~a & b)
Real World Example: ATMEL CAN128

8-bit Timer/Counter Register Description

Timer/Counter2 Control Register A – TCCR2A

<table>
<thead>
<tr>
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<th>6</th>
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<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read/Write</td>
<td>W</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
<td>R/W</td>
</tr>
<tr>
<td>Initial Value</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- **Bit 7 – FOC2A**: Force Output Compare A
  The FOC2A bit is only active when the WGM bits specify a non-PWM mode. However, for ensuring compatibility with future devices, this bit must be set to zero when TCCR2A is written when operating in PWM mode. When writing a logical one to the FOC2A bit, an immediate compare match is forced on the Waveform Generation unit. The OC2A output is changed according to its COM2A1:0 bits setting. Note that the FOC2A bit is implemented as a strobe. Therefore it is the value present in the COM2A1:0 bits that determines the effect of the forced compare.

A FOC2A strobe will not generate any interrupt, nor will it clear the timer in CTC mode using OCR2A as TOP.

The FOC2A bit is always read as zero.

- **Bit 6, 3 – WGM21:0**: Waveform Generation Mode
  These bits control the counting sequence of the counter, the source for the maximum (TOP) and Minimum ( BOTTOM) count, and whether the counter operates in CTC or PWM mode.

Harder Exercises

- Decrement the current speed (SPD) by 1. Don't decrement if already 0.
- Write a function to make it seem like an LED is bouncing back and forth.
- Write a function that does:
  If button N is pressed, turn on LEDs 0 - N.

C Bit-Fields

- Declare fields in a struct with sizes (# bits)
  - Compiler pushes fields together to conserve space.
- Ex:
  Represent a colour with 8 bits each for red, green, blue; and 1 bit for transparent:
  ```
  struct colour_s {
    unsigned int red : 8;
    unsigned int green : 8;
    unsigned int blue : 8;
    unsigned int transparent : 1;
  };
  ```
  - Entire struct needs only one unsigned int (32-bits)
Bit-field Details

- Access fields by name:
  - struct colour_s border = {0xff, 0xff, 0x00, 1}
    printf("Red %d\n", border.red);
  - Border.transparent = 1;
    When assigning a value, ensure you don't have more bits that expected
- WARNING:
The order the fields get packed..
  - Is the first field in the LSB, or is the last field in the LSB?

STAT Example

struct stat_s {
    unsigned int flash : 1;
    unsigned int : 4; // Unused bits ..
    unsigned int spd : 3;
    unsigned int btn : 4;
    unsigned int led : 4;
};

#define STAT_ADDR 0xC800153C
struct stat_s *pSTAT = (struct stat_s *) STAT_ADDR;

int main() {
    pSTAT->flash = 1;
    if (pSTAT->btn == 0x0F) {
        pSTAT->spd += 2;
    }
    pSTAT->led = pSTAT->btn;
    return 0;
}