ECE 598 – Advanced Operating Systems Lecture 6

Vince Weaver

http://web.eece.maine.edu/~vweaver

vincent.weaver@maine.edu

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Announcements

- Homework #2 was due
- Homework #3 will be released shortly

BCM2835 UART on the Pi

- Section 13 of the Peripheral Manual
- Two UARTS. Mini (pc reg layout compat) and ARM PL011. We use the latter.
- No IrDA or DMA support, no 1.5 stop bits.
- Separate 16x8 transmit and 16x12 receive FIFO memory. Why 12? 4 bits of error info on receive. overrun (FIFO overflowed), break (data held low over full time), parity, frame (missing stop bit).

- Programmable baud rate generator.
- start, stop and parity. These are added prior to transmission and removed on reception.
- False start bit detection.
- Line break generation and detection.
- Support of the modem control functions CTS and RTS. However DCD, DSR, DTR, and RI are not supported.
- Programmable hardware flow control.

- Fully-programmable serial interface characteristics: data can be 5, 6, 7, or 8 bits
- even, odd, stick, or no-parity bit generation and detection
- 1 or 2 stop bit generation
- baud rate generation, dc up to UARTCLK/16
- 1/8, 1/4, 1/2, 3/4, and 7/8 FIFO interrupts

mini-UART Programming Differences

- Section 2.2 of BCM2835 document
- UART Clock scales with CPU frequency around this by now).
- Registers mixed in with SPI registers
- Roughly register compatible with popular 16550 UART
- Set up GPIOs first, if you don't it will see RX as zero and start receiving 0x0 bytes (it ignores stop bits) and FIFO will fill in 2.5usec
- 7 or 8 bit, parity not supported, RTS/CTS possible,

8-byte FIFO

BCM2835 UART

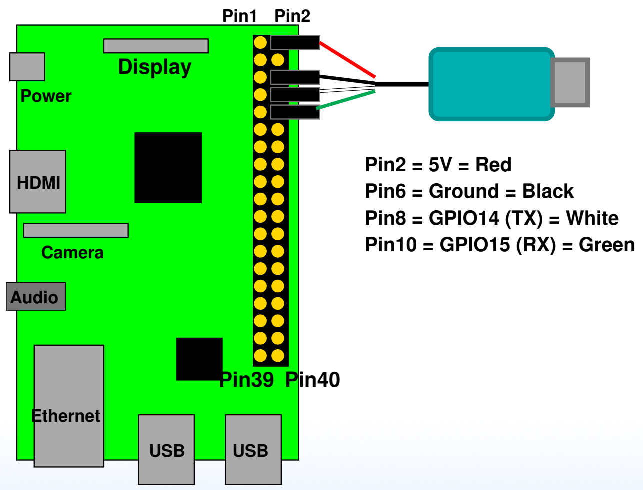
- Can map to GPIO14/15 (ALT0), GPIO36/37 (ALT2), GPIO32/33 (ALT3)
- Default mapping has RX/TX on GPIO14/15. It is possible to configure RTS/CTS pins for HW flow control, but our adapter doesn't support them anyway.
- Base address `0x3f201000`, 18 registers

Hooking up Cable to Pi

- Linux should come with a driver. May need to download PL2303 OSX or Windows driver.
- Some useful documentation:
  `http://www.adafruit.com/products/954`
  `https://learn.adafruit.com/adafruits-raspberry-pi-lesson-5-using-a-console-cable`
- Can provide 5V to your board with the red wire so you don't need USB-micro cable. This might be dangerous however as you are bypassing the power conditioning. If you are leaving USB micro hooked up, then don't

connect the red wire.

- Hookup:
  Red (5V) to pin 2,
  Black (GND) to pin 6
  White (TXD) to pin 8 (GPIO14)
  Green (RXD) to pin 10 (GPIO15)



Inline Assembly

- Can write assembly code from within C
- Alphabet soup
- gcc inline assembly is famously hard to understand/write
- volatile keyword tells compiler to not try to optimize the code within

Delay Inline Assembly Example

```
static inline void delay(int32_t count) {
        asm volatile("__delay_%=: subs %[count], %[count], #1; "
                        "bne __delay_%=\n"
                    : : [count]"r"(count) : "cc");
}
```

- : output operands
  = means write-only, + is read/write `r`=general reg
- : input operands
- : clobbers – list of registers that have been changed
  memory is possible, as is cc for status flags
- can use `%[X]` to refer to reg X that can then use `[X]"r"(x)` to map to C variable

MMIO

- Memory mapped I/O
- As opposed to separate I/O space (as found on x86 and some other processors)
- For HW#3 instead of using array for MMIO access, we will use inline assembly
- technically, to be correct, we need memory barriers (See BCM2835 Document 1.3). The AXI bus can return reads out of orders if talking to different devices. So when switching from one to another write barrier before

first write and read barrier after last read.

- `mmio_write()`, `mmio_read()`

-
  ```
  static inline void mmio_write(uint32_t address, uint32_t data) {
          uint32_t *ptr = (uint32_t *)address;
          asm volatile("str %[data], [%[address]]" :
                  : [address]"r"(ptr), [data]"r"(data));
  }
  ```

Writing a Device Driver

- Code to initialize the device
- Set of methods for interacting with device (read/write?)
- Code to run if device is removed?
- Interrupt handling

UART Init Code

```
/* Disable UART -- Command Register */
mmio_write(UART0_CR, 0x0);
```

Set up the GPIO Pins

```
/* Setup GPIO pins 14 and 15 */

/* Disable the pull up/down on pins 14 and 15 */
/* See the Peripheral Manual for more info */
/* Configure to disable pull up/down and delay for 150 cycles */
mmio_write(GPIO_GPPUD, GPIO_GPPUD_DISABLE);
delay(150);

/* Pass the disable clock to GPIO pins 14 and 15 and delay*/
mmio_write(GPIO_GPPUDCLK0, (1 << 14) | (1 << 15));
delay(150);

/* Write 0 to GPPUDCLK0 to make it take effect */
mmio_write(GPIO_GPPUDCLK0, 0x0);
```

Disable Interrupts

```
/* Mask all interrupts. */
mmio_write(UART0_IMSC, 0);

/* Clear pending interrupts. */
mmio_write(UART0_ICR, 0x7FF);
```

UART Interrupts

- Supports one interrupt (UARTRXINTR), which is signaled on the OR of the following interrupts:

1. UARTTXINTR – if FIFO less than threshold or (if FIFO disabled) no data present
2. UARTRTINTR – if receive FIFO crosses threshold or (if FIFO disabled) data is received
3. UARTMSINTR which can be caused by
   - UARTCTSINTR (change in nUARTCTS)
   - UARTDSRINTR (change in the nUARTDSR)

4. UARTEINTR (error in reception)
   - UARTOEINTR (overrun error)
   - UARTBEINTR (break in reception)
   - UARTPEINTR (parity error)
   - UARTFEINTR (framing error)

Set UART speed

- Calculate for 14.4kb/s
- Divider $= \frac{BaseFrequency}{16 \times Desired}$
- Divider $= \frac{3000000}{16 \times 14400} = 13.020$
- IBRD register = Integer part = 13.
  FBRD register $= (.020 \times 64) + 0.5 = 1.78$ so 1 or 2.
- `mmio_write(UART0_IBRD, 13);`
  `mmio_write(UART0_FBRD, 1);`

Set UART 8N1

```
/* Enable FIFO */
    /* And 8N1 (8 bits of data, no parity, 1 stop bit */
    mmio_write(UART0_LCRH, UART0_LCRH_FEN | UART0_LCRH_WLEN_8BIT);
```

Enable the UART

```
/* Enable UART0, receive, and transmit */
mmio_write(UART0_CR, UART0_CR_UARTEN |
                     UART0_CR_TXE |
                     UART0_CR_RXE);
```

UART Send byte

```
void uart_putc(unsigned char byte) {

        /* Check Flags Register */
        /* And wait until FIFO not full */
        while ( mmio_read(UART0_FR) & UART0_FR_TXFF ) {
        }

        /* Write our data byte out to the data register */
        mmio_write(UART0_DR, byte);
}
```

UART Receive byte

```c
unsigned char uart_getc(void) {

        /* Check Flags Register */
        /* Wait until Receive FIFO is not empty */
        while ( mmio_read(UART0_FR) & UART0_FR_RXFE ) {
        }

        /* Read and return the received data */
        /* Note we are ignoring the top 4 error bits */

        return mmio_read(UART0_DR);
}
```

Escape Codes

- VT102/Ansi
- Historical reasons, oldest terminals. Used to be hundreds of types supported (see termcap file)
- Color, cursor movement
- The escape character (ASCII 27) used to specify extra commands

Carriage Return vs Linefeed

- Typewriters
- Carriage return (\r), go to beginning of line
- Linefeed (\n), move down a row
- DOS uses both CRLF
- UNIX uses just LF
- Old MacOS used just CR
- Most com programs want both, so our code should output both

Do other OSes have to handle this CR/LF difference

From `linux/drivers/tty/serial/serial_core.c`

```
void uart_console_write(struct uart_port *port, const char *s,
                        unsigned int count,
                        void (*putchar)(struct uart_port *, int))
{
        unsigned int i;

        for (i = 0; i < count; i++, s++) {
                if (*s == '\n')
                        putchar(port, '\r');
                putchar(port, *s);
        }
}
```

Writing header files

- Including with “ ” versus <>

Writing printk

```
int printk(char *string,...) {

        va_list ap;
        va_start(ap, string);

        while(1) {
                if (*string==0) break;

                if (*string=='%') {
                        string++;
                        if (*string=='d') {
                                string++;
                                x=va_arg(ap, int);
```

Integer to String Conversion

This it the algorithm I use, there are other ways to do it that don't involve the backwards step (starting off by dividing by 1 billion and dividing the divisor by 10 each time).

- Repeatedly divide by 10.
- Digit is the remainder. Repeat until quotient 0.
- Make sure handle 0 case.
- Convert each digit to ASCII by adding 48 ('0')
- Why does the number end up backwards?

Division by 10

- ARM1176 in Pi has no divide routine, why isn't this a problem?
  We are on ARMv7/v8 which does, but for backwards compatibility we are compiling to ARMv6.
- Generic x=y/z division is not possible without fancy work (iterative subtraction? Newton approximation?)
- Dividing by a constant is easier
- C compiler cheats, for /10 it effectively multiplies by 1/10.

- Look at generated assembly, you'll see it multiply by `0x66666667`
- Why is it not a problem when dividing by 16?
- What does the C compiler do if you do divide by a non-constant? Makes a call to C-library or gcc-library divide routine, which we don't link in.