Lecture 13: Lab 3 + UART communication

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Adapted from material by Blake Hannaford

November				
Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
04 14:30-15:50 Lecture MOR 220 *Lecture 12: Midterm Review* slides, slides (annotated) 16:00-17:00 OH (Vikram) ECE 345	05 12:00-14:00 OH (Yousef) ECE 345 14:00-15:00 OH (Vikram) ECE 345	06 14:30-15:50 Lecture MOR 220 *Lecture 13: I2C and SPI Communication* slides 16:00-17:00 OH (Vikram) ECE 345	07 12:00-14:00 OH (Kurt) ECE 345 14:00-16:00 OH (Kinner) ECE 345 16:00-17:00 OH (Yousef) ECE 345	08 11:00-13:00 OH (Kurt) ECE 345 15:00-16:00 OH (Yousef) ECE 345
11 Veteran's Day	12 12:00-14:00 OH (Yousef) ECE 345 14:00-16:00 OH (Kinner) ECE 345	13 14:30-16:00 Midterm MOR 220 (Lecture Room) 16:00-17:00 OH (Vikram) ECE 345	14 12:00-14:00 OH (Kurt) ECE 345 14:00-16:00 OH (Kinner) ECE 345 16:00-17:00 OH (Yousef) ECE 345	15 11:00-13:00 OH (Kurt) ECE 345 15:00-16:00 OH (Yousef) ECE 345
18 14:30-15:50 Lecture MOR 220 *Lecture 14: Lab 3 + UART Communication* 16:00-17:00 OH (Vikram) ECE 345	19 12:00-14:00 OH (Yousef) ECE 345 14:00-16:00 OH (Kinner) ECE 345	20 14:30-15:50 Lecture MOR 220 *Lecture 15: Intro to FreeRTOS* 16:00-17:00 OH (Vikram) ECE 345	21 12:00-14:00 OH (Kurt) ECE 345 14:00-16:00 OH (Kinner) ECE 345 16:00-17:00 OH (Yousef) ECE 345 23:59 Lab 3 due	22 11:00-13:00 OH (Kurt) ECE 345 15:00-16:00 OH (Yousef) ECE 345
25 14:30-15:50 Lecture MOR 220 *Lecture 16: Intro to Critical Sections and Semaphores* 16:00-17:00 OH (Vikram) ECE 345	26 12:00-14:00 OH (Yousef) ECE 345 14:00-16:00 OH (Kinner) ECE 345	27 14:30-15:50 Lecture Zoom (no in person class) *Lecture 17: FreeRTOS Examples* 16:00-17:00 OH (Vikram) ECE 345	28 Thanksgiving	29 Native American Heritage Day

Round Robin Scheduler

```
while(1) {
  taskA();
  taskB();
  taskC();
  time_delay();
}
```

Round Robin Scheduler

scheduler_min_directbit | Arduino IDE 2.2.1

```
// loop that runs forever
 void loop(){
  static int tmp = 0;
  taskA();  // assume these tasks take 0 time
  taskB();
  delay(1); // sync
 }

 // Flash the onboard LED 10x per second
 void taskA(){
  static int time;
  time++;
  if(time==50) {
    //digitalWrite(LED_INTERNAL, HIGH);
    LEDPORT |= L_I_BIT; // SET internal LED output bit
  }
  if(time==100) {
    //digitalWrite(LED_INTERNAL, HIGH);
    LEDPORT &= ~L_I_BIT; // CLEAR internal LED output bit
    time = 0;             // Reset our counter
  }
```

How fast does it run?

```
// loop that runs forever
 void loop(){
  static int flag = 0;
  taskA();  // assume these tasks take 0 time
  taskB();
  digitalWrite(LOOP_BIT, flag); // Toggle a bit every loop (~500 Hz)
  flag = flag ^ 0x01;
  delay(1); // sync
  /* NOTE: these tasks actually take some small amount of time
   * We actually get 488 Hz, but we can tune this a little bit
   * to get it closer to 500 Hz.
   */
  //delayMicroseconds(985);
 }

```

Using function pointers to start a task

We learned that the syntax:

```
type (*name)(type arg1, type arg2, ...)
```

indicates a function pointer called name which can point to any function having the same prototype. For example

```
int (*fp)(char x, int y, double z)
```

```
void start_function(void (*functionPTR)() ){
  functionPTR();
}
```

Keeping lists of functions

We can create an array of function pointers as follows:

```
#define NUMBER_OF_FUNCTIONS 10

void (*list_of_functions[NUMBER_OF_FUNCTIONS])(void *p)
```

Example:

```
#define NT_RUNNING 10
void (*runningTasks[NT_RUNNING])(void *p)
```

... a list of all the tasks which are currently running.

We can use a NULL pointer at the end of the list if there are less than NT RUNNING active tasks (similar to the zero byte at the end of a string).

```
//function prototypes for tasks
void taskA(void *p);
void taskB(void *p);
...

// function prototype for
scheduler void scheduler();


#define NTASKS 4

// lets make the task list global
// an array of function pointers,
// each one has a void*
// parameter.

void (*readytasks[NTASKS])
   (void *p);
```

```
//continued...
main() {
  // initialize array of pointers
  // to tasks

  readytasks[0] = taskA;
  readytasks[1] = taskB;
  ...

  // NULL signals the last task
  readytasks[2]= NULL;

  // now start scheduler
  while(1) {
    scheduler();
    time_delay(); // 1 ms timer
  }
} // end of main
```

Scheduler function (pseudocode)

```
scheduler() {
  if(readytasks[task_index] == NULL && task_index != 0) {
    task_index=0;
  }
  if(readytasks[task_index] == NULL && task_index == 0){
    // figure out something to do because
    // there are no tasks to run!
  } else {
    start_function(readytasks[task_index]);
    task_index++;
  }
  //   Round Robin/we're taking turns
  return;
}
```

Part III: Manipulating the Task Lists

```
halt_me() {
  // 1. Identify which task is currently running (i.e.
  //    look at task_index)

  // 2. Copy the function pointer from
  //    readytasks[task_index] to the
  //    haltedtasks array

  // 3. Move the remaining tasks up in readytasks[] to
  //    fill the empty hole and copy NULL into the
  //    last element.

  return;
}
```

Sleep function (pseudocode)

```
sleep(int d) {
  // 1. Copy function pointer from
  //    readytasks[task_index] to the
  //    waitingtasks[] array.
  // 2. Clean up readytasks[] as in halt_me();
  //    copy d into the delays array with the same
  //    index as the function pointer has in
  //    waitingtasks[]
}
```

Keeping track of sleep delays

```
  // continued...
  // 5. for each element of waitingtasks which is
  //    not NULL: decrement the delay value d.
  //    if (d==0) move the function pointer to the
  //    end of the readytasks[] array and remove
  //    it from waitingtasks.
  // end of scheduler
  return;
}
```

Sleep example

scheduler_sleep | Arduino IDE 2.2.1

scheduler_sleep.ino

```
int task_active = 0;

// Sleeptime is the number of ms to sleep for
void sleep(int sleeptime){
  delays[task_active] = sleeptime;
}

// setup routine that runs each time you power cycle or press reset
 void setup(){
  // initialize the LED pins as an output
  LEDDDR |= ( L_I_BIT | L_E_BIT );
  tasks[0] = taskA;
  tasks[1] = NULL;
  tasks[2] = taskB;
 }

// loop that runs forever
 void loop(){
```

Ln 1, Col 1 Arduino Mega or Mega 2560 on /dev/cu.usbmodem21301 [not connected]

Alternative Data Structure for Scheduling

Let's set up a struct **Task Control Block (TCB)** which contains everything we need to track about a Task:

```
typedef struct TCBstruct {
  void (*ftpr)(void *p);      // the function pointer
  void *arg_ptr;              // the argument pointer
  unsigned short int state; // the task state
  unsigned int delay;         // the task state
} ;
```

```
#define STATE_RUNNING  0
#define STATE_READY    1
#define STATE_WAITING  2
#define STATE_INACTIVE 3
TCBStruct TaskList[N_MAX_TASKS];

// Then we can set up the task // list as follows:
int j=0;
int task_B_Arg;

TaskList[j].ftpr = task_A();
TaskList[j].arg_ptr = NULL;
TaskList[j].state = STATE_INACTIVE;
TaskList[j].delay = 0;
j++;
```

```
// continued… start task B
TaskList[j].ftpr = task_B();

// (example: let's say we need an arg value of 56)
task_B_Arg = 56;
int *ip = &task_B_Arg;
TaskList[j].arg_ptr = (void*)ip;
TaskList[j].state = STATE_READY;
TaskList[j].delay = 0;
j++;

TaskList[j].fptr = NULL;        // marks end of list

... maybe other tasks   ...
```

Examples of halt_me(), start_task() and delay()

```
halt_me() {
  TaskList[t_curr].state = STATE_INACTIVE;
}

start_task(int task_id) {
  TaskList[task_id].state =  STATE_READY;
}

sleep(int d) {
  TaskList[t_curr].delay = d;
  TaskList[t_curr].state = STATE_WAITING;
}
```

Interrupt example (Pin change interrupt on pin 53)

interrupt_example | Arduino IDE 2.2.1

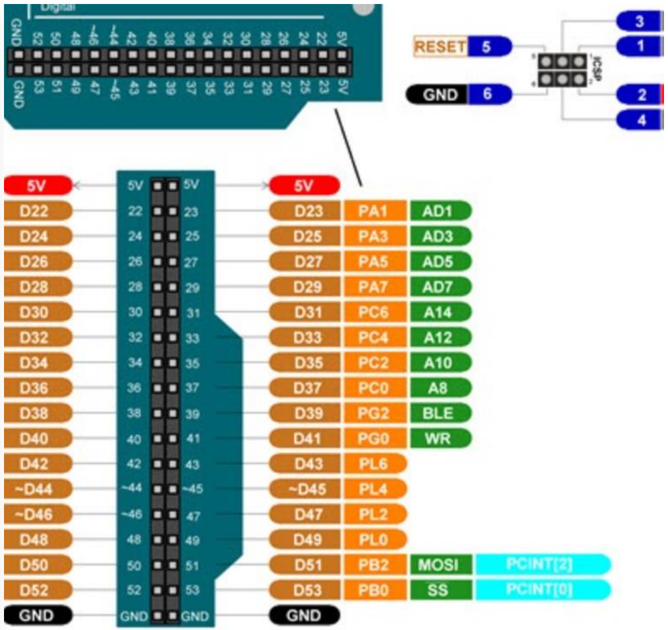
interrupt_example.ino

```
#define LED_INTERNAL 7    // Pin 13 = bit 7 MEGA, bit 5 Uno
#define LED_EXTERNAL 4    // Pin 10 = bit 4 MEGA, bit 2 Uno
#define LEDPORT       PORTB
#define LEDDDR        DDRB
#define L_I_BIT       1<<LED_INTERNAL
#define L_E_BIT       1<<LED_EXTERNAL

ISR (PCINT0_vect) {
  // handle pin change interrupt for D8 to D13 here
  LEDPORT ^= L_I_BIT; // SET internal LED output bit
} // end of PCINT0_vect

void setup () {
  // initialize the LED pins as an output
  LEDDDR |= ( L_I_BIT | L_E_BIT );

```

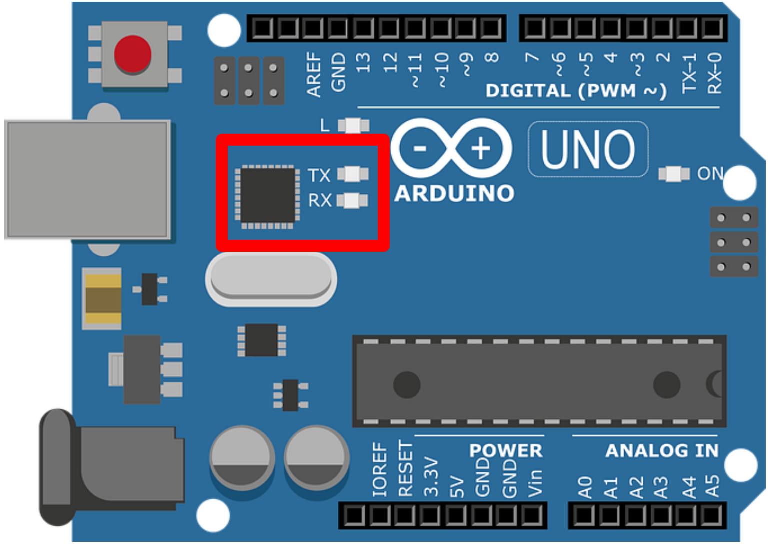


Serial Communication: RS232C

Goal: Send bits from point A to point B one at a time

RS232C: An international standard for serial communication (1960s). Very old but still influential in today's systems.

- This is how your Arduino communicates with the computer and why we do Serial.println
- FTDI chip converts between Serial and USB
- Some microcontrollers have native USB support
- Notation: RX = receive, TX = Transmit



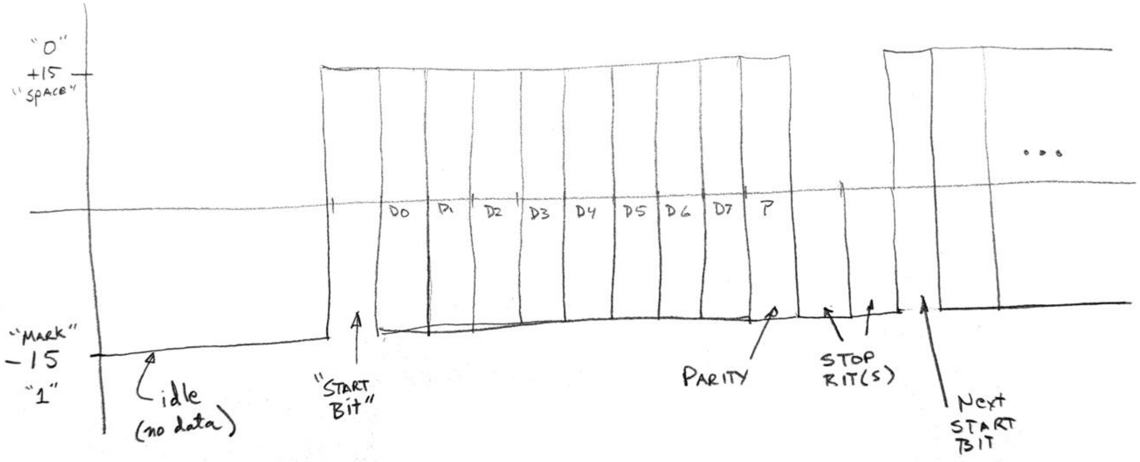
Electrical Signaling

+2.5V — +15V	logic 0	“space”
-2.5V — -15V	logic 1	“mark”

- When first designed the high voltage margin gave more immunity to noise
- These days it’s a hassle since many systems don’t otherwise need +15V, -15V supplies, modern processes can’t support high voltages
- Requires special driver chips for +- voltages.
- Arduino and many other systems use
  +5V → logic 0
  0V → logic 1
- Lower voltage saves power supply costs

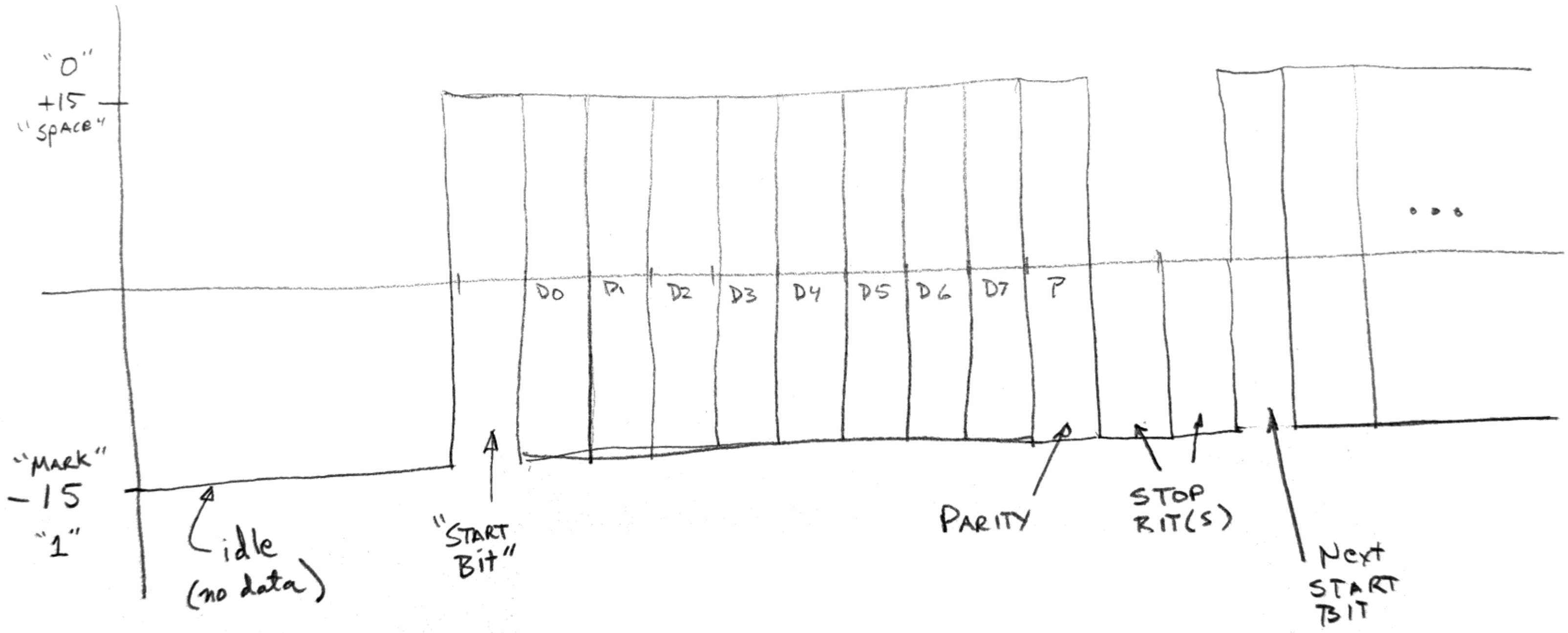
Serial Signaling

Pos.	Value	Function
0	space	Start Bit
1	X	Data 0 (lsb)
2	X	Data 1
…	X	…
8	X	Data 7 (msb)
9	X	Parity*
10	mark	Stop Bit 1
11	mark	Stop Bit 2*



Idle line in "mark" state (logic 1, -15V)
* Note: Parity and Stop Bit 2 are optional, can have 1.5 Stop Bits.

Serial Signaling



Parity

All communication systems can suffer from errors

Parity bit provides a simple error checking mechanism

Compute by taking the XOR of all data bits:
`P = D0 ^ D1 ^ D2 ... ^ D7`

Interpretation of XOR(bits) is
”1” if number of ones is ODD
”0” if number of ones is EVEN

Parity Eample

D0	D1	D2	XOR(D0,D1,D2)
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	1

Speed and Timing

Baud is short for Baudot, 19th century French telegrapher who invented first fixed length alphanumeric code.

Baud or **Baud rate** means number of signal changes on the line per second. Commonly equal to bits per second

Example: Arduino serial port default: 9600 Baud

```
Serial.begin(9600);      //Baud rate = 9600
Serial.begin(115200);    //Baud rate = 115200
```

Synchronization

There is no common clock between sender and receiver. How does receiver know when to test levels?

`A1:` Synchronus mode — Continuous stream of characters.

`A2:` Asynchronus mode — start bit is known to be logic 0. Falling (rising?) edge triggers a local clock in the receiver.

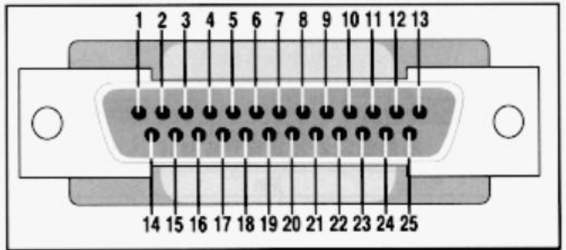
Multiplexing

Sending information in both directions. (Stringing 2 telegraph wires was very expensive!)
Terms:
Simplex One sender and one receiver.
Half Duplex One side can send at a time.
Full Duplex Both sides can send at same time.

Connections

Must have:
TX → RX
RX ← TX
Cables are easier to make if pins are “straight through”. i.e. pin n connects

23 pin (ancient, un-needed) 9 pin (IBM PC standard)
Two connector wiring types
DTE: pin 2 = RX, pin 3 = TX “Data Terminal Equipment”
DCE: pin 2 = TX, pin 3 = RX “Data Communications Equipment”
Thus, DCE can talk to DTE with a “straight through” cable.



Pin	Description	EIA CKT	From DCE	To DCE
1	Frame Ground	AA		
2	Transmitted Data	BA		D (Data)
3	Received Data	BB	D	
4	Request to Send	CA		C (Control)
5	Clear to Send	CB	C	
6	Data Set Ready	CC	C	
7	Signal Gnd/Common Return	AB		
8	Rcvd. Line Signal Detector	CF	C	
11	Undefined			
12	Secondary Rcvd. Line Sig. Detector	SCF	C	
13	Secondary Clear to Send	SCB	C	
14	Secondary Transmitted Data	SBA		D
15	Transmitter Sig. Element Timing	DB	T (Timing)	
16	Secondary Received Data	SBB	D	
17	Receiver Sig. Element Timing	DD	T	
18	Undefined			
19	Secondary Request to Send	SCA		C
20	Data Terminal Ready	CD		C
21	Sig. Quality Detector	CG		C
22	Ring Indicator	CE	C	
23	Data Sig. Rate Selector (DCE)	CI	C	
23	Data Sig. Rate Selector (DTE)	CH		C
24	Transmitter Sig. Element Timing	DA		T
25	Undefined			

Fig.6. RS232 DB25 connector

Flow Control

Sometimes a slow device cannot handle data as fast as sender (even at same baud rate).
Receiver needs a way to stop and start sender.

Hardware solution: Additional wires
RTS “Request to Send”. DTE sets this to mark to allow data to be sent to it by DCE.
CTS “Clear to Send”. DCE sets this to mark to allow data to be sent to it by DTE.

Hardware flow control can be enabled/disabled.

Software solution: Special Control Characters
XON (ctl Q) Start Transmitting
XOFF(ctl S) Stop Transmitting

Error Control

Unfortunately, serial communication is subject to errors. Sources:

- Electrical interference
- Long wire lengths
- Ground potential differences between communicating systems.
- Timing errors between sender and receiver clocks (should be within 1%).

Solutions

Character Parity 9th data bit. Very weak and bandwidth hog.

Checksum Add up a group of bytes. Send sum at end of packet.

Compare.
Parity Send parity of some group of bits (rows or colums) in the packet.
CRC Use theory of binary polynomials. Send a code so that combined message is divisible by some known polynomial.

Packets

Grouping bytes into packets gives structure to the serial communication. Packet structure must be same between software both sides.

Example Packet:

`Start`	`Type`	`Length`	`...`	`Checksum`

Start A character which the software can recognize as the start of a packet. Ideally should not appear anywhere else in packet.

Type Kind of packet.

Length value which tells how long the packet will be.
... some number of data bytes (the payload).

Checksum Checksum computed on previous packet.

Packet Error control

What if a packet is received and the Checksum is wrong?

Normal:
Sender sends the packet and saves the packet.
Receiver checks Checksum and acknowledges receipt of packet.
Sender discards packet and sends next packet.

Error:
Sender sends and saves the packet.
Receiver detects error and sends negative acknowledge.
goto step 1.

ACK/NAK Special short packets
ACK Acknowledge NAK Negative Acknowledge

Start	ACK/NAK	Checksum

Protocol Issues

What Happens If:
Transmission is so unreliable that Checksum fails every time?

ACK/NAK packets are subject to errors?

Do we have to send ACK/NAK on receipt of an ACK/NAK?

Answers to all these questions must be worked out in a protocol spec.