

Physics 124: Lecture 10

Under the Arduino Hood

Arduino Makes it Look Easy

- High-level functions remove user/programmer from processor details
 - on the plus side, this means you can actually get things done without a steep learning curve
 - on the down side, you don't understand fundamentally what your actions are doing...
 - ...or how to take advantage of processor capabilities that are not wrapped into high-level functions
- So today, we'll look a bit into what Arduino is *actually* doing—to a limited extent!

Where Do the Monsters Lurk?

- What I will call the **root** directory is at:
 - On a Mac:
 - `/Applications/Arduino.app/Contents/Resources/Java/hardware/arduino/`
 - On Windows:
 - `Arduino-Install-Directory/Hardware/Arduino/`
 - On Linux:
 - (likely) `/usr/share/arduino/`
 - also may check `/usr/local/`
- I'll describe contents as found on the Mac
 - it's what I have
 - hopefully is reasonably universal

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Contents of root directory

- On my Mac, the aforementioned directory has:


```
boards.txt      cores/          programmers.txt
bootloaders/   firmwares/     variants/
```

 - `boards.txt` has specific info for the various Arduino boards
 - `cores/` has only a directory called `arduino/`, which we will investigate later
 - `bootloaders/` has


```
atmega/   atmega8/   bt/           caterina/   lilypad/   optiboot/   stk500v2/
```
 - `variants/` has


```
eightanaloginputs/   leonardo/           mega/               standard/
```

 - each of which contains a single file: `pins_arduino.h`
 - maps pinouts of specific devices

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File Types in “Standard” C Programming

- Source Code
 - the stuff you type in: has `.c` extension, or `.cpp` for C++
- Compiled “Executable”
 - the ready-to-run product: usually no extension in Unix/Mac, `.exe` in DOS
- Header Files
 - contain definitions of useful functions, constants: `.h` extension
- Object Files
 - a pre-linked compiled tidbit: `.o` in Unix, `.obj` in DOS
 - only if you’re building in pieces and linking later

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In `root/cores/arduino/`

- Here’s what I show, broken out by extension
 - I have 36 files total in this directory, all `.c`, `.cpp`, or `.h`
- First, 6 C files:

```
mojo:arduino$ wc *.c
 298   1116   8198 WInterrupts.c
 324   1468   9394 wiring.c
 282   1133   7374 wiring_analog.c
 178    668   4931 wiring_digital.c
  69    416   2643 wiring_pulse.c
  55    236   1601 wiring_shift.c
```

- note: numbers apply to vers. 1.0.1: minor changes w/ time
- The `wc` function means word count
 - returns number of lines, # of words, # of characters for each file

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Directory, continued

- Now, 12 C++ files:

```
mojo:arduino$ wc *.cpp
 233    896    6718 CDC.cpp
 519   1677   13772 HID.cpp
 428   1442   11400 HardwareSerial.cpp
  56    115    1152 IPAddress.cpp
 263    798    5216 Print.cpp
 270   1137    7277 Stream.cpp
 601   1783   14311 Tone.cpp
 672   1734   13134 USBCore.cpp
  59    265    1649 WMath.cpp
 645   1923   14212 WString.cpp
  20     22     202 main.cpp
  18     41     325 new.cpp
```

- Note in particular main.cpp: 20 lines of fun
 - we'll look at in a bit

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Header files

- Finally, the 18 header files

```
mojo:arduino$ wc *.h
 215    677    5690 Arduino.h
  26     97     697 Client.h
  81    289    2363 HardwareSerial.h
  76    419    2978 IPAddress.h
  23     42     401 Platform.h
  78    328    2462 Print.h
  40    207    1332 Printable.h
   9     17     111 Server.h
  96    584    4005 Stream.h
 194    478    5224 USBAPI.h
 302    846    7855 USBCore.h
  63    236    1872 USBDesc.h
  88    691    4180 Udp.h
 167    699    4576 WCharacter.h
 205   1151    8470 WString.h
 515   1535   10379 binary.h
  22     62     562 new.h
  69    230    1752 wiring_private.h
```

- We'll look at Arduino.h next

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Arduino.h

- Contains function prototypes, definition of constants, some useful algorithms

- Excerpts follow

```
#include <stdlib.h>
#include <string.h>
#include <math.h>

#include <avr/pgmspace.h>
#include <avr/io.h>
#include <avr/interrupt.h>

#include "binary.h"
```

- These are standard C libraries that are being pulled in
 - note in particular that the math library is automatically used

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Arduino.h, continued

- Now we have some constants defined
 - recall, `#define` acts as text replacement

```
#define HIGH 0x1
#define LOW 0x0

#define INPUT 0x0
#define OUTPUT 0x1
#define INPUT_PULLUP 0x2

#define true 0x1
#define false 0x0

#define PI 3.1415926535897932384626433832795
#define HALF_PI 1.5707963267948966192313216916398
#define TWO_PI 6.283185307179586476925286766559
#define DEG_TO_RAD 0.017453292519943295769236907684886
#define RAD_TO_DEG 57.295779513082320876798154814105
```

- In some cases, to absurd precision!

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Arduino.h, continued

- The `#define` construct can also create useful functions

```
#define min(a,b) ((a)<(b)?(a):(b))
#define max(a,b) ((a)>(b)?(a):(b))
#define abs(x) ((x)>0?(x):- (x))
#define constrain(amt,lo,hi) ((amt)<(lo)?(lo):((amt)>(hi)?(hi):(amt)))
#define round(x) ((x)>=0?(long)((x)+0.5):(long)((x)-0.5))
#define radians(deg) ((deg)*DEG_TO_RAD)
#define degrees(rad) ((rad)*RAD_TO_DEG)
#define sq(x) ((x)*(x))

#define lowByte(w) ((uint8_t) ((w) & 0xff))
#define highByte(w) ((uint8_t) ((w) >> 8))

#define bitRead(value, bit) (((value) >> (bit)) & 0x01)
#define bitSet(value, bit) ((value) |= (1UL << (bit)))
#define bitClear(value, bit) ((value) &= ~(1UL << (bit)))
#define bitWrite(val, bit, bval) (bval ? bitSet(val, bit) : bitClear(val, bit))
```

- Some labels shortened to fit on this slide (hi, lo, etc.)

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Arduino.h, continued

- Also included are function prototypes
 - so that we know what types are expected in function calls

```
typedef uint8_t byte;           // 8-bit integer, same as char

void pinMode(uint8_t, uint8_t);
void digitalWrite(uint8_t, uint8_t);
int digitalRead(uint8_t);
int analogRead(uint8_t);
void analogReference(uint8_t mode);
void analogWrite(uint8_t, int);

unsigned long millis(void);
unsigned long micros(void);
void delay(unsigned long);

void setup(void);
void loop(void);
long map(long, long, long, long, long);
```

- This is just an excerpt, for familiar functions

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root/variants/standard/pins_arduino.h

- maps pins to functions—excerpts:

```
#define NUM_DIGITAL_PINS           20
#define NUM_ANALOG_INPUTS         6
#define analogInputToDigitalPin(p) ((p < 6) ? (p) + 14 : -1)

// ATMEL ATMEGA8 & 168 / ARDUINO
//
//
//          +-\/-+
//          PC6  1 |      | 28  PC5  (AI 5)
// (D 0) PD0  2 |      | 27  PC4  (AI 4)
// (D 1) PD1  3 |      | 26  PC3  (AI 3)
// (D 2) PD2  4 |      | 25  PC2  (AI 2)
// PWM+ (D 3) PD3  5 |      | 24  PC1  (AI 1)
// (D 4) PD4  6 |      | 23  PC0  (AI 0)
//          VCC  7 |      | 22  GND
//          GND  8 |      | 21  AREF
//          PB6  9 |      | 20  AVCC
//          PB7 10 |      | 19  PB5  (D 13)
// PWM+ (D 5) PD5 11 |      | 18  PB4  (D 12)
// PWM+ (D 6) PD6 12 |      | 17  PB3  (D 11) PWM
// (D 7) PD7 13 |      | 16  PB2  (D 10) PWM
// (D 8) PB0 14 |      | 15  PB1  (D 9)  PWM
//          +-----+
```

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root/cores/arduino/main.cpp

- Simple: initialize, run your setup, start infinite loop and run your loop, keeping a lookout for serial comm

```
#include <Arduino.h>

int main(void)
{
    init();

    #if defined(USBCON)
        USBDevice.attach();
    #endif

    setup();

    for (;;) {
        loop();
        if (serialEventRun) serialEventRun();
    }

    return 0;
}
```

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Finally, root/boards.txt

- Examples for Uno and Nano

```

uno.name=Arduino Uno
uno.upload.protocol=arduino
uno.upload.maximum_size=32256
uno.upload.speed=115200
uno.bootloader.low_fuses=0xff
uno.bootloader.high_fuses=0xde
uno.bootloader.extended_fuses=0x05
uno.bootloader.path=optiboot
uno.bootloader.file=
    optiboot_atmega328.hex
uno.bootloader.unlock_bits=0x3F
uno.bootloader.lock_bits=0x0F
uno.build.mcu=atmega328p
uno.build.f_cpu=1600000L
uno.build.core=arduino
uno.build.variant=standard

nano328.name=Arduino Nano w/ ATmega328
nano328.upload.protocol=arduino
nano328.upload.maximum_size=30720
nano328.upload.speed=57600
nano328.bootloader.low_fuses=0xFF
nano328.bootloader.high_fuses=0xDA
nano328.bootloader.extended_fuses=0x05
nano328.bootloader.path=atmega
nano328.bootloader.file=
    ATmegaBOOT_168_atmega328.hex
nano328.bootloader.unlock_bits=0x3F
nano328.bootloader.lock_bits=0x0F

nano328.build.mcu=atmega328p
nano328.build.f_cpu=1600000L
nano328.build.core=arduino
nano328.build.variant=eightanaloginputs

```

- Note core, variant
 - and CPU speed 16 MHz

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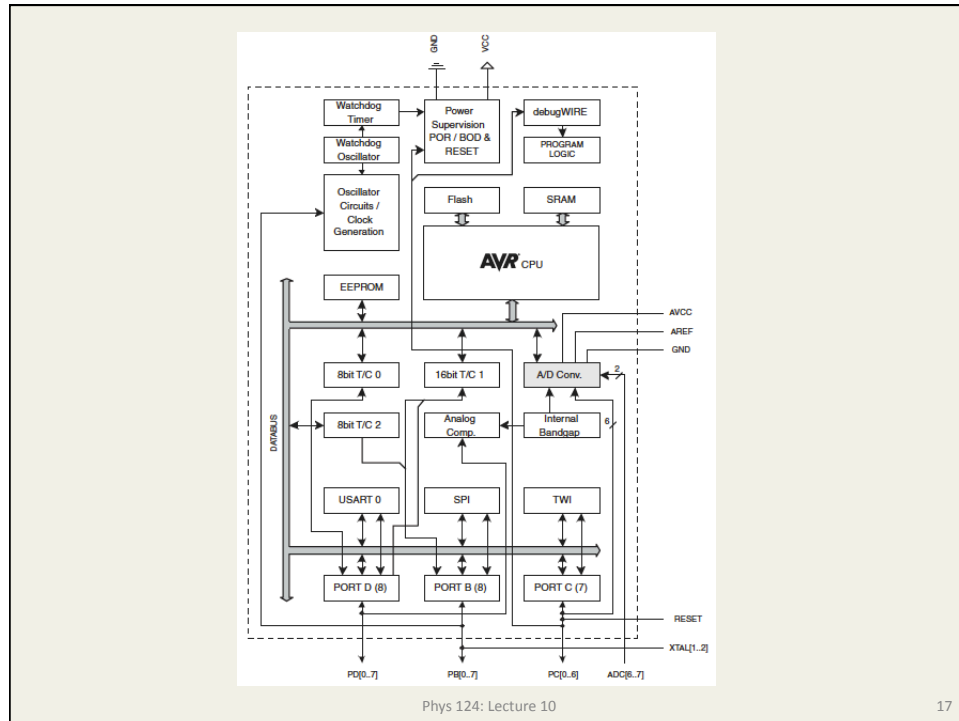
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But the Rabbit Hole Goes Much Farther

- Underneath it all is a microprocessor with staggering complexity
 - full datasheet (avail via course website) is 567 pages
 - summary datasheet (strongly encourage perusal) is 35 pp.
- Note in particular in the summary datasheet:
 - p. 2 the Uno uses the 28-pin PDIP (upper right)
 - read the port descriptions on pp. 3–4, even if foreign
 - block diagram p. 5
 - register map pp. 7–12
 - assembly instruction set pp. 13–15
 - can safely ignore pp. 16–35 ;-)

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Assignments/Announcements

- Absorb as much as possible from the summary datasheet
- Project proposals due end of week (2/5)
 - recommend pre-discuss with prof/TA, if haven't already
- Lab 4 due by 2PM on Feb 9/10 dep. on section
- Midterm next week (Wed, Feb 10)

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