Binary Representations, and the Teensy 3.5
Data Types

- short, int, long: size depends on the particular microprocessor
- In order to be clear about sizes, gcc (our compiler) provides a set of types, including:
  - int8_t 8-bit signed
  - uint16_t 16-bit unsigned
  - uint32_t 32-bit unsigned
- Use these for our projects – not short, int, long

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Teensy 3.5
Digital Input/Output

The Teensy encodes a digital value using 0V (low) and 3.5V (high)

• If a pin is an input:
  • We can ask the pin what its voltage state is
  • Possible answers: 0 or 1 (low or high)

• If a pin is an output:
  • We can drive the pin to be 0V or 3.3V
  • Again, these are encoded digitally as 0 or 1
Digital Input/Output

• Pins are organized into groups, called PORTS
• Each port can be composed of up to 32 pins
  • In practice, this number is generally much smaller
• The ports are named A … E
Teensy 3.5 Schematic

Key take-away: shows us the connection between the Teensy pin numbers and the Arm Cortex M4 I/O ports.
Teensy 3.5 Schematic

- Port C, bit 2
Teensy 3.5 Schematic

- Port C, bit 2
- Teensy pin 23
  - Also analog pin 9
Pins in the Arm Cortex M4

• Most pins have multiple possible functions
  • Can be a digital input or output
  • Can generate a continuous voltage (analog output)
  • Can read a continuous voltage (analog input)
Configuring a Pin for Digital Output

There is an on-board LED connected to PORT C, bit 5: let’s write code to blink the LED

• Initialization:

  // Initialize PORT C, bit 5 to be a digital I/O bit
  PORTC_PCR5 = PORT_PCR_MUX(0x1);

• PORTC_PCR5 is a special-purpose register (32 bits) that controls what this specific pin does

• PCR = Port Configuration Register

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Configuring a Pin for Digital Output

• Initialization, step 2:

```c
// Configure bit 5 to be an output (and all others to be inputs)
GPIOC_PDDR = 0x20;
```

• GPIO = General Purpose Input/Output

• PDDR = Port Data Direction Register

• On boot: all pins are configured as analog inputs
Setting to Pin into the High State

```c
// Turn on the bit (and all others off)
GPIOC_PDOR = 0x20;
```

- The pin is now in a high state
- PDOR = Port Data Output Register
Putting it Together in the Arduino Environment

This function is called when the processor first boots:

```c
void setup() {
  // Configure PORTC, bit 5 to be a digital I/O bit
  PORTC_PCR5 = PORT_PCR_MUX(0x1);

  // Configure bit 5 to be an output (and all others to be inputs)
  GPIOC_PDDR = 0x20;
}
```

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Putting it Together in the Arduino Environment

And this function is called repeatedly thereafter:

```c
void loop() {
    // Turn on the bit (and all others off)
    GPIOC_PDOR = 0x20;

    // Wait for 0.1 second
    delay(100);

    // Turn off the bit (and all others)
    GPIOC_PDOR = 0;

    // Wait for 0.1 second
    delay(100);
}
```

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An Alternative Implementation

```c
void loop() {
  // Turn on the bit (and all others off)
  GPIOC_PDOR ^= 0x20;

  // Wait for 0.1 second
  delay(100);
}
```

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Arduino Environment

The environment automatically includes the following function:

```c
void main() {
    setup();

    while(1) {
    
      loop();
    }
}
```
PORTS A .. E

- PORTx_PCRy = each bit has one register
- GPIOx_PDDR, GPIOx_PDOR: each port has one register

Note: the Arduino environment provides other ways to manipulate these pins. For digital I/O, we will use these registers. We get:
  - Efficiency
  - Simultaneous state change of multiple pins
Teensy 3.5 Schematic

• Let’s connect LEDs to PTD5 & 6
• Don’t forget the resistor!
Initialization

```cpp
void setup() {
    // Configure PORTD, pins 5 & 6 as digital I/O
    PORTD_PCR5 = PORT_PCR_MUX(0x1);
    PORTD_PCR6 = PORT_PCR_MUX(0x1);

    // Configure bit 5 & 6 to be outputs
    GPIOD_PDDR = 0x60;
}
```
What does this program do?

```c
void loop() {
  GPIOD_PDOR = 0x60;
  delay(250);
  GPIOD_PDOR = 0x20;
  delay(250);
  GPIOD_PDOR = 0x40;
  delay(250);
  GPIOD_PDOR = 0x0;
  delay(250);
}
```
What does this program do?

```c
void loop() {
  GPIOD_PDOR = 0x60;
  delay(250);
  GPIOD_PDOR = 0x20;
  delay(250);
  GPIOD_PDOR = 0x40;
  delay(250);
  GPIOD_PDOR = 0x0;
  delay(250);
}
```

Flashes LED on PD6 at 2 Hz on PD5: 1 Hz

Duty Cycle for each: 50%
… go to Bit Manipulation
Teensy 3.5 Schematic

• Let's connect a switch to PTC2
• Don't forget the pull-up resistor!

• If switch reads zero, turn PTD6 on and PTD5 off
• Otherwise, turn PTD6 off and PTD5 on

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void setup() {
    // Configure PORTD, pins 5 & 6 as digital I/O
    PORTD_PCR5 = PORT_PCR_MUX(0x1);
    PORTD_PCR6 = PORT_PCR_MUX(0x1);

    // Configure PORTC, pin 2 as digital I/O
    PORTC_PCR2 = PORT_PCR_MUX(0x1);

    // Configure bit 5 & 6 to be outputs
    GPIOD_PDDR = 0x60;
}
Loop Implementation

```c
void loop() {
    if(GPIOC_PDIR & 0x4) {
        // Switch open
        GPIOD_PDOR = (GPIOD_PDOR & ~0x60) | 0x40;
    } else {
        // Switch closed
        GPIOD_PDOR = (GPIOD_PDOR & ~0x60) | 0x20;
    }
}
```