LECTURE V

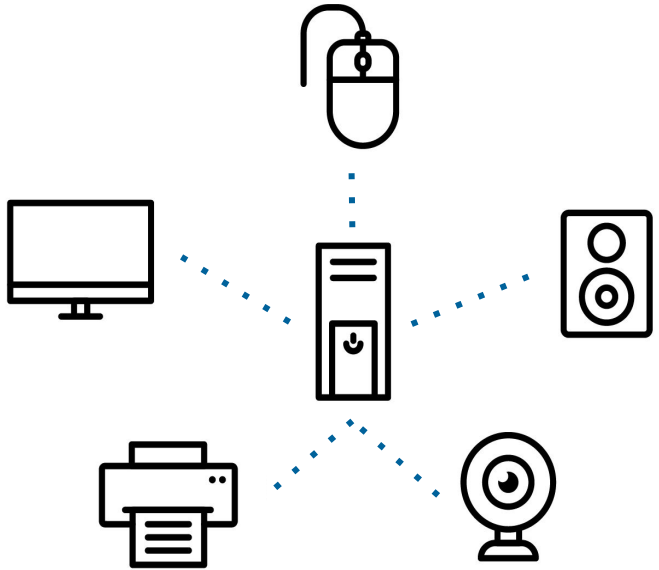
Communication Protocols I

SECTION I

What are Communication Protocols?

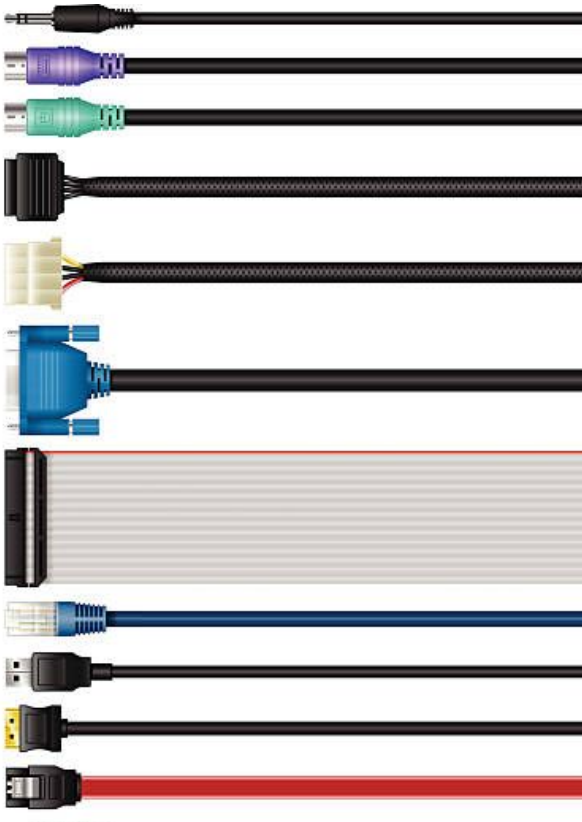
Communication

- Devices, like your home computer, **communicate** with other devices
  - i.e. mouse, monitor, printer, webcam, speakers
- Just like your computer, the Arduino board must communicate with devices too

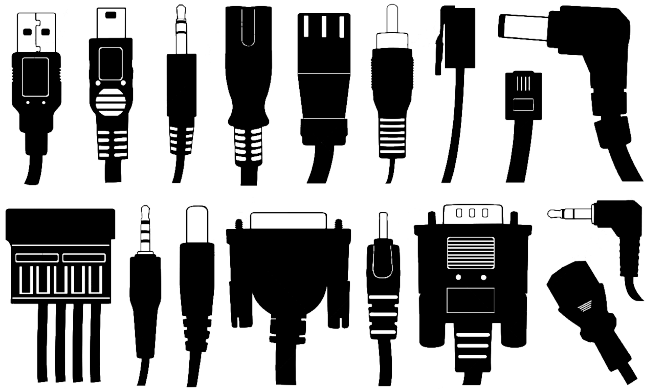


Communication Media

- Devices communicate over different **media**
  - i.e. copper wire, coaxial cable, radio, fiber optic wire, etc.
  - Some media are **wired** while others are **wireless**
- Devices communicate by **transmitting** and **receiving** electrical signals over a shared medium
  - Signals may be **digital** (1s and 0s) or **analog** (i.e. AM/FM radio)



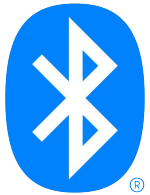
Communication Protocols

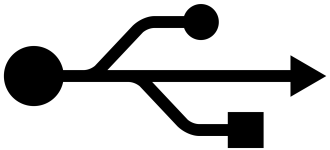


- Communicating devices **must share a common “language”** to understand messages transmitted between them
- The rules for how we send, receive, and interpret these signals are defined by **protocols**
- You already know of some protocols…

Communication Protocols (Cont'd)

- Your smartphone communicates with your wireless earbuds over a **Bluetooth** protocol
- All the laptops in the lecture hall connect to a wireless router using a **WiFi** protocol (a.k.a **IEEE 802.11x**)
- Your wired mouse connects to your computer using a **Universal Serial Bus** (**USB**) protocol

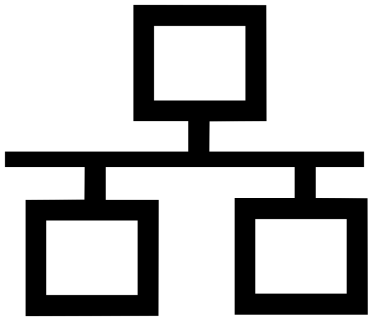


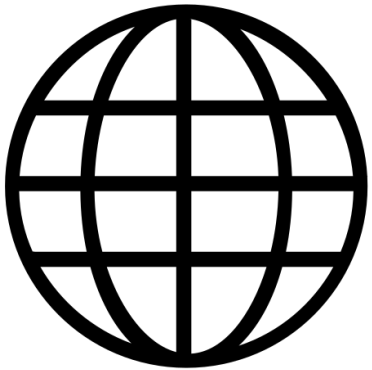


Communication Protocols (Cont'd)

I/A

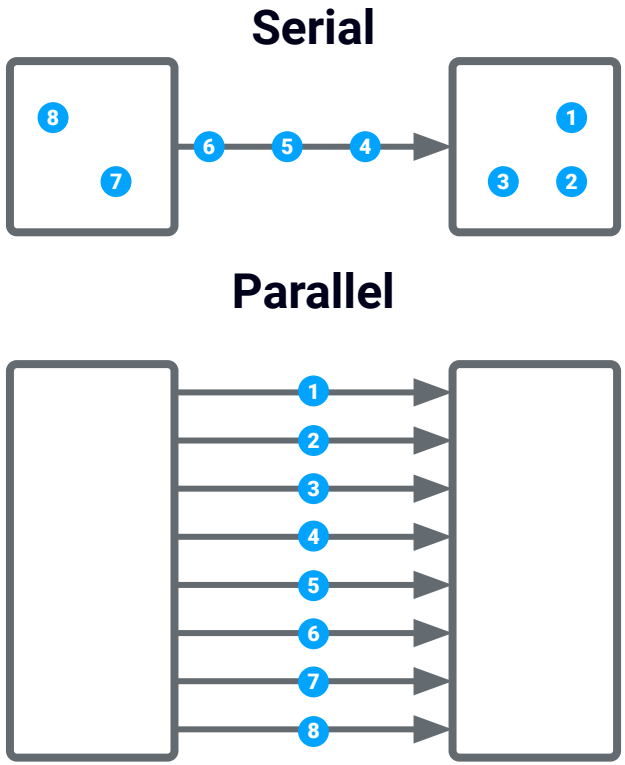
What are some more **examples** of communication protocols?





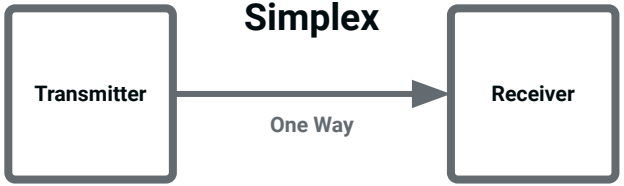
Serial vs Parallel Protocols

- **Serial** - bits are sent over a connection one by one to a device
  - Bits are sent in a specific order
  - The most common protocols are serial
- **Parallel** - multiple bits (often one byte) are sent simultaneously over a connection
  - This connection requires more wires, which takes up more space
  - Higher transmission rate

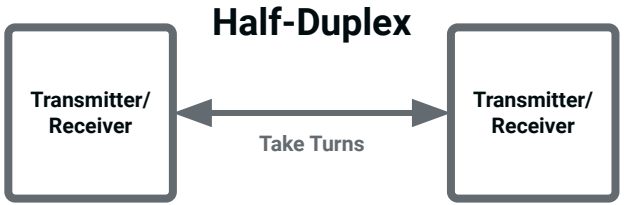


Transmission Modes

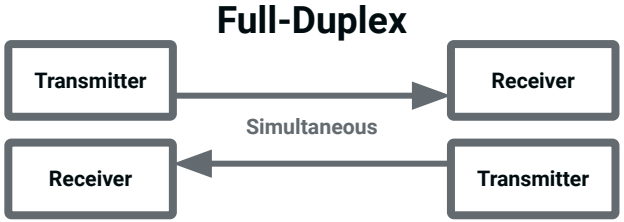
- **Simplex** protocols allow communication in only one direction



- **Half-Duplex** protocols allow communication in both directions but only in one direction at a time



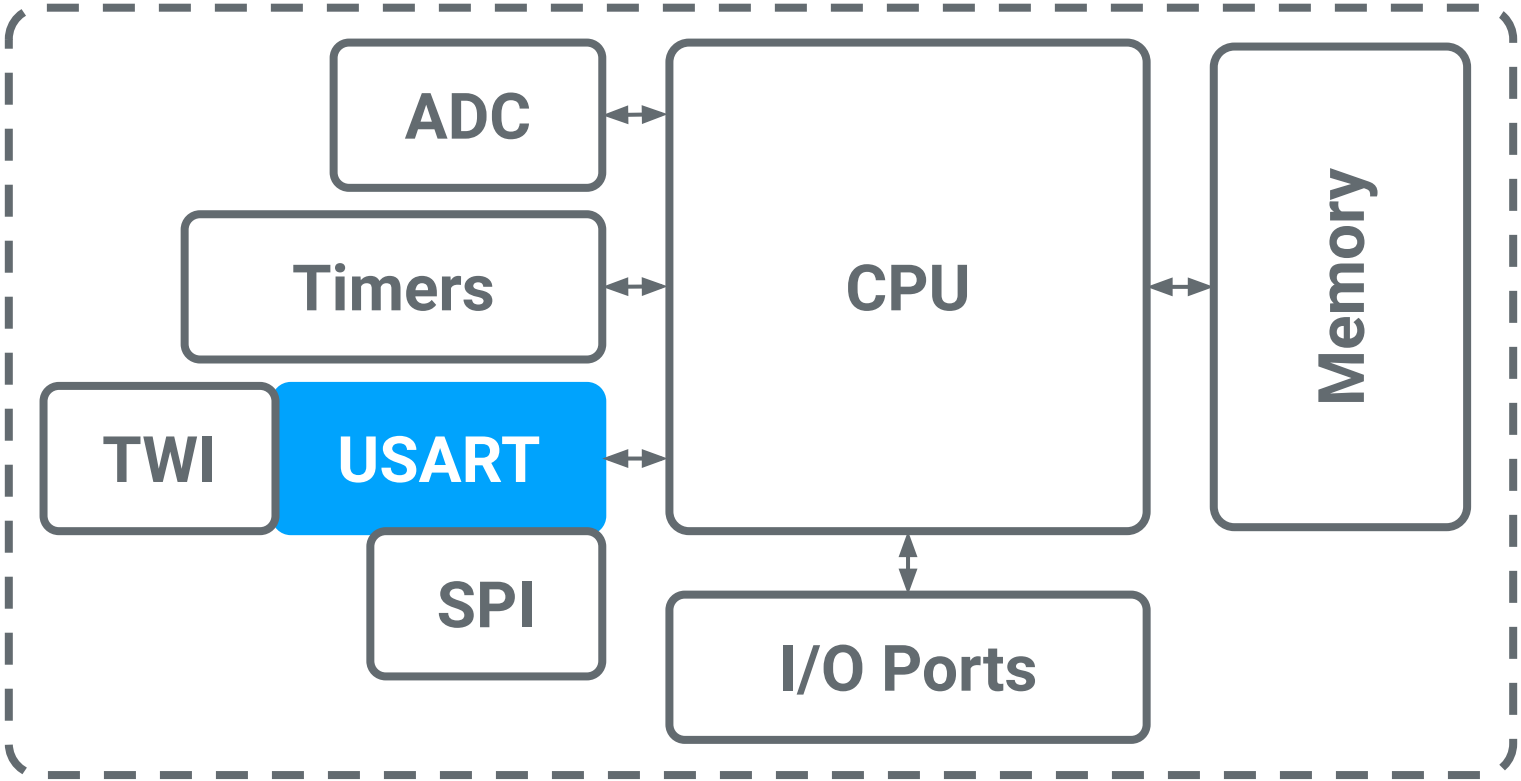
- **Full-Duplex** protocols allow communication in both directions simultaneously



SECTION II

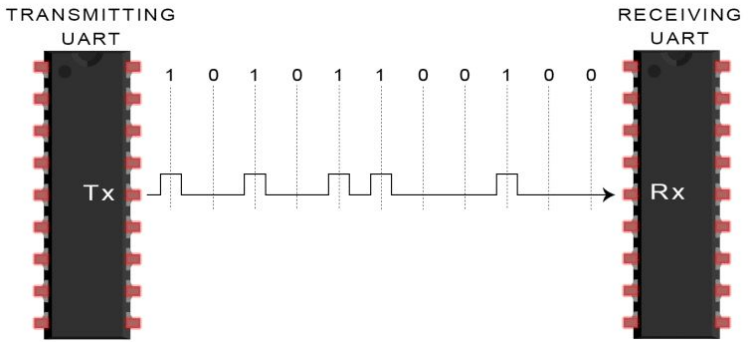
USART/UART

AVR Architecture



USART

- The **Universal Synchronous/Asynchronous Transmitter/Receiver** or **USART** is a hardware device that **serially communicates** with other USARTs
  - It is **integrated into microcontrollers** (as shown in the AVR Architecture slide)
  - In synchronous mode, the USARTs use a *shared* clock signal to time the transmission



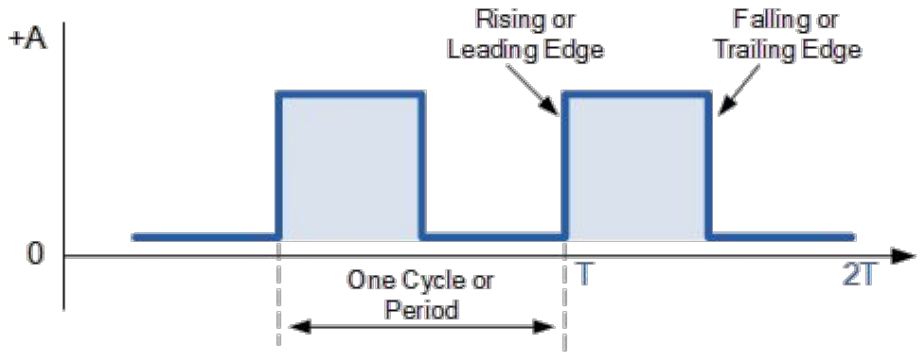
  - In **asynchronous mode**, there is **no shared clock signal**. This is functionally identical to a **UART** device (which is how we will use it)

UART Protocol

- The USART uses **UART protocol** when in asynchronous mode
  - Remember UART is a **communication protocol and a physical device**. It has rules for data transmission
- UART can be configured to **full-duplex, half-duplex,** and **simplex modes**
- There are only **two lines** (electrical connections)
  - There is **no clock signal**/line hence the “asynchronous” part of the title
- The data transmission speed is determined by a **baud rate**
  - It is quite **slow compared to other protocols**

Clock Signals

- **Digital signals** are timed to a **clock signal** - most often, a square wave with a 50% duty cycle
  - For example, in a serial signal, one bit of data is sent per clock cycle
    - The bit might be timed to the rising or falling edge of the clock signal
- **Clock speed** determines the rate at which data is transmitted
  - measured as **frequency (Hz)**
  - inversely proportional to cycle (or period)

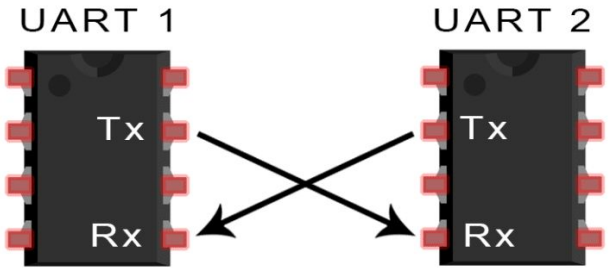


UART Baud Rate

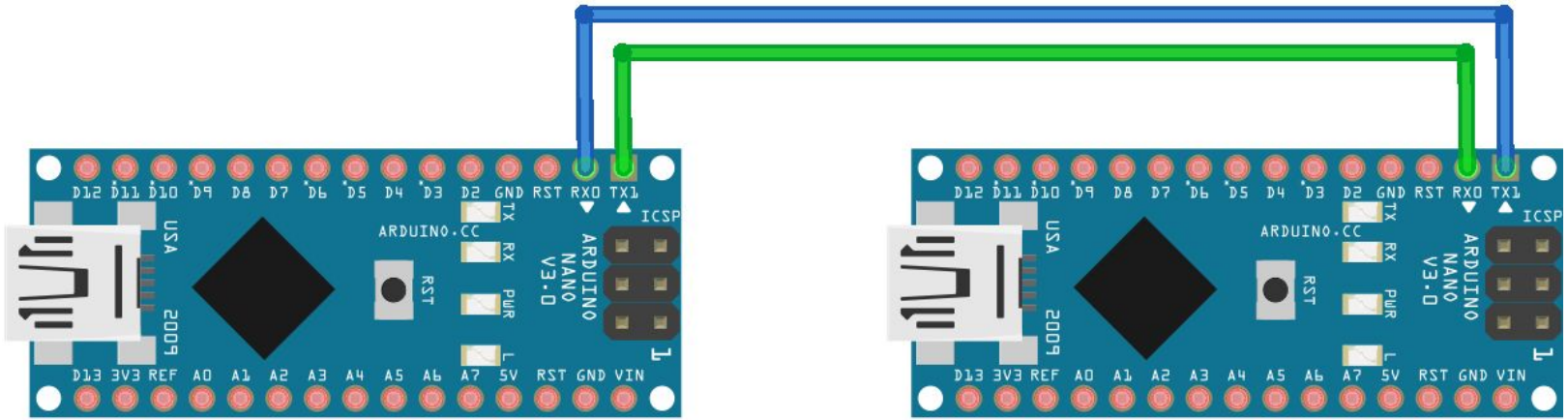
- A UART sends and receives transmissions at the speed of the **baud rate**
  - It is configured by the programmer on each UART
  - Measured in **bits per second**
- The baud rate **must be equal** on the two communicating UARTs to successfully send and receive the packets
  - Otherwise, messages are read at the wrong speed and become garbled

UART Layout

- Two UARTs may be connected as pictured
  - The **transmitter** (**TX**) pin of one UART is connected to the **receiver** (**RX**) pin of the other
  - The are two data lines, which **enables full-duplex communication**
- Data is sent from the transmitter of one UART to the receiver of the other UART



UART Layout (Cont'd)



Two Arduino Nanos connected via UART pins (TX/RX)

UART Frame Format

- Data is transmitted as segments of bits called **packets**
  - This data is sent one bit at a time (a.k.a **serially**) between UARTs
- Without modification, the UART packet follows this format:

UART Packet

UART Frame Format (Cont'd)

- A **start bit** indicates when the packet begins
  - The data transmission line is brought from a default HIGH voltage to a LOW voltage by the transmitting UART for one clock cycle
- The **data frame**, containing the data, follows the start bit
  - If the parity bit is used, it can be 5 to 8 bits. If the parity bit is not used, it can be 9 bits.

UART Packet

UART Frame Format (Cont'd)

- The **parity bit** is an **optional** bit comes after the data frame and is used by the receiving UART to check if the data is free of errors
  - If the parity bit is 0 (**even parity**), then the number of 1s in the data frame should be even
  - If the parity bit is 1 (**odd parity**), then the number of 1s in the data frame should be odd

UART Packet

UART Frame Format (Cont'd)

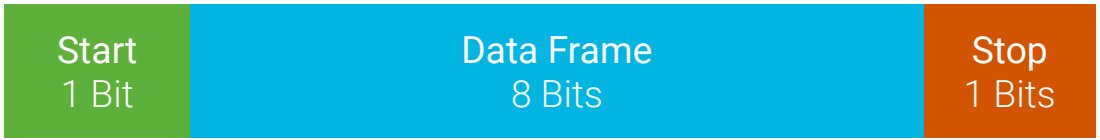
- Lastly, a **stop bit** indicates the end of a packet
  - The transmitting UART pulls the transmission line from a LOW to HIGH voltage for 1 or 2 clock cycles
- A USART frame looks identical to a UART frame
  - Remember that the only difference is that USART has a *shared* clock line

UART Packet

Arduino UART Frame Format

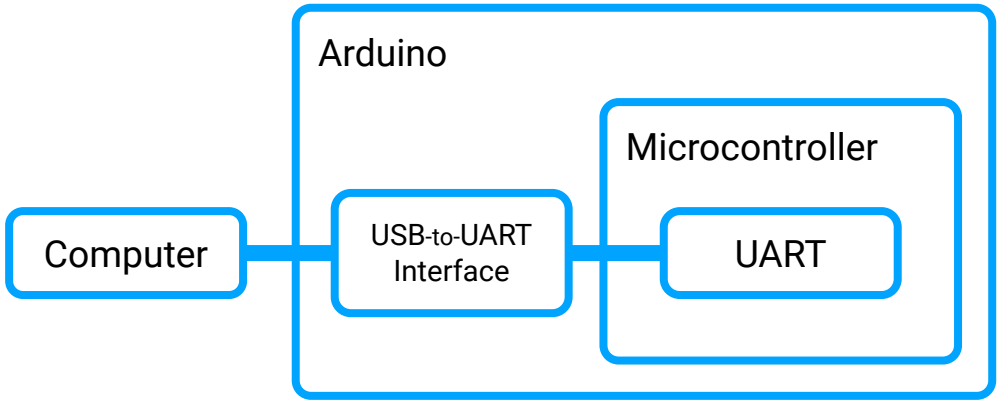
- Arduino's default UART frame is 10 bits in size by default
- The *optional* parity bit is removed
- The data frame is restricted to 8 bits (the most common size)
    - Consider that ASCII characters are 8 bits

UART Packet (Arduino)



USB on the Arduino

- Data is transmitted between the computer and Arduino Nano through a chip that converts USB signals to UART signals
    - Those converted signals are transmitted to and from the UART
- The Arduino's USB port is hardwired to the TX and RX pins of the board
- **Do not use the UART while simultaneously using USB**



SECTION III

Arduino Serial Library

Arduino Serial Library

- We can use the USART in our Arduino Nano to transmit data over UART protocol
  - To do so, we will enlist the help of the Serial library, which is already installed in the Arduino IDE
- The Arduino UNO and Nano have **only one USART**
  - One workaround is to use the SoftwareSerial library and emulate a second UART programmatically
  - Another workaround is to use a different protocol (to be discussed next lecture)

Serial.begin

- `Serial.begin(int baud_rate)`
  - `Serial` is an object that facilitates communication between the Arduino board and other devices over UART protocol
  - Pass `9600` bits per second as the argument for this member function
    - This is the default baud rate

```
void setup()
{
    pinMode(LED, OUTPUT);
    pinMode(RECEIVER, INPUT);
    Serial.begin(9600);
}
```

Serial.write

- `Serial.write` is used to transmit from the UART in the Arduino board

Common Variations

- `Serial.write(val)` - Sends `val`, a single byte of data
- `Serial.write(str)` - Sends `str`, a series of bytes represented by a string

```
Serial.write(62); // Sends 62
Serial.write("Hello"); // Sends “Hello” over multiple frames
```

Serial.available

- `Serial.available` returns true if the Arduino's UART has received any data
- The incoming data is stored in a sort of "mailbox" called a **receive buffer**. The buffer is ostensibly an array that stores the data
    - If the buffer is full, then the incoming data is dropped and lost forever

```
if (Serial.available())
{
    // If the buffer has data to be read, the program will enter this
    // block
}
```

Serial.read

- `Serial.read` returns the first byte of incoming serial data available (or -1 if no data is available
  - The data is returned as an `int`
  - Each time this function is called, the byte returned by it is dropped from the receive buffer

```
int incomingByte = Serial.read(); // Stores the incoming byte
```

SECTION III

Arduino UART Exercise

Arduino Echo Communication

I/A

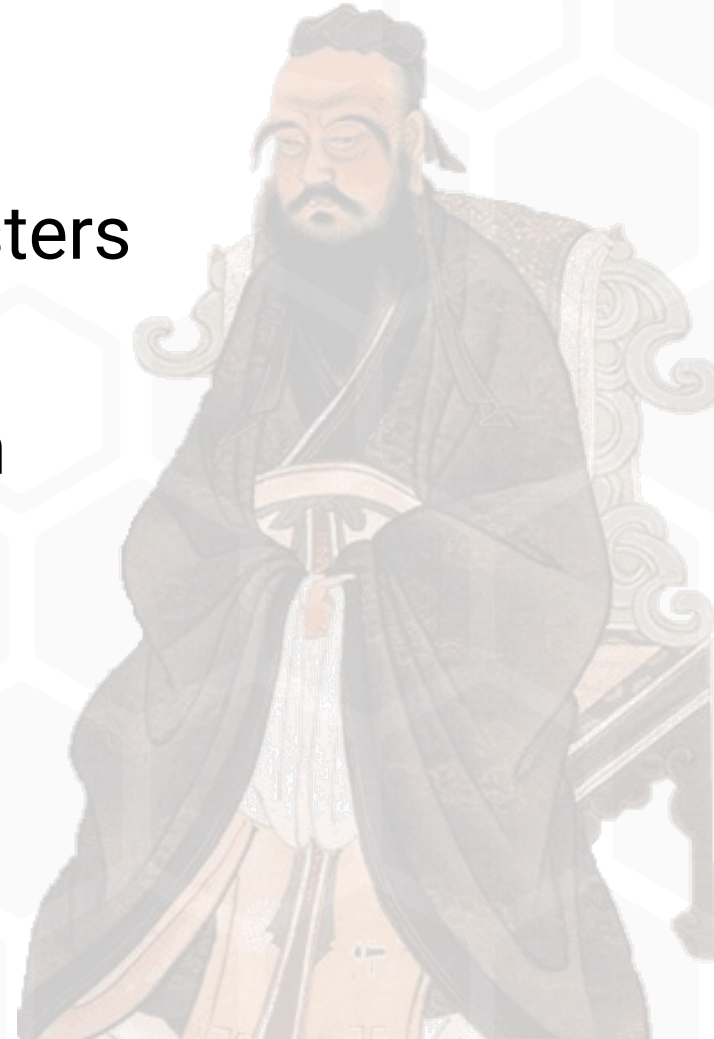
Write a program that satisfies the following requirements:

- You must write a program in which the **Arduino board “echoes” back any byte (0-255) sent to it over UART.**
- When the user enters a byte value (0-255) into the Arduino IDE Serial Monitor from their computer, the value is sent to the Arduino board. The board must send the same value back to the computer.
- The Arduino will **only “echo” back a value sent to it once**. It should not resend the value multiple times.
- The program must **run in an infinite loop**.

“The wise programmer who **masters** the **art of UART** shall establish a connection that **transcends** both distance and **baud rate**.”

Confucius (circa 551 BC)

Famous Misquotes



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