Wired Communication

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Collective Embodied Intelligence Lab

Schedule & Other Details

- We noticed the struggle with Lab 2
  - Lab 2 is now due on October 5th
  - Milestone 2 is Due on October 12th
- Next week (Monday) there is an FPGA lecture
  - Will be given by Professor Bruce Land
  - You should definitely attend

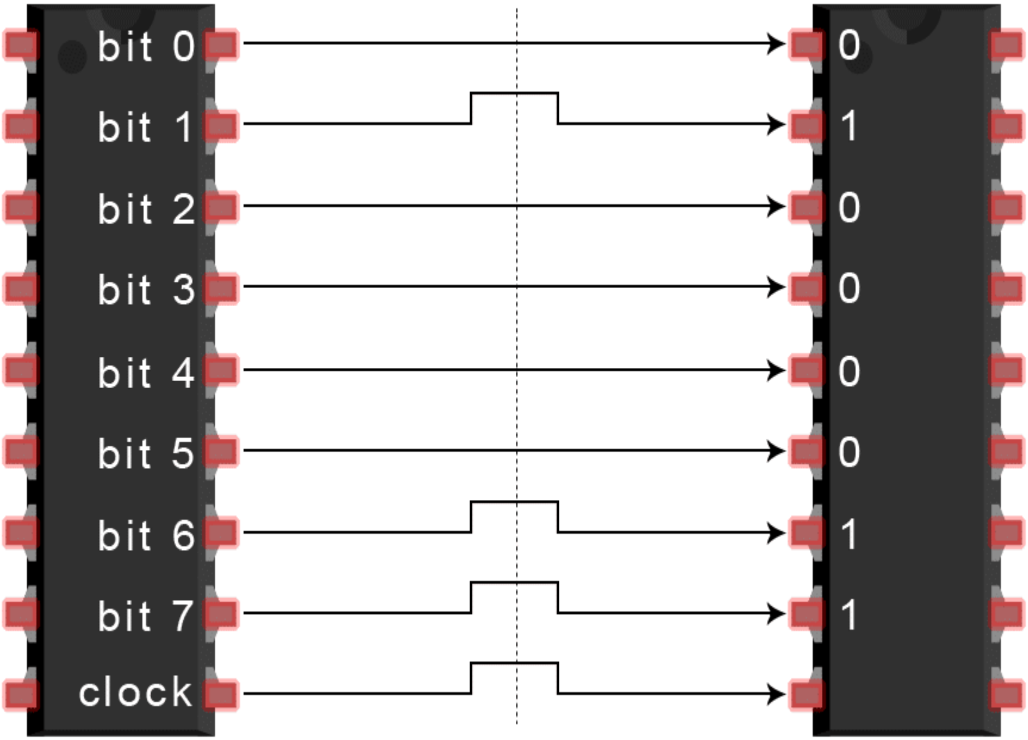
Wired Communication

Why Wired?

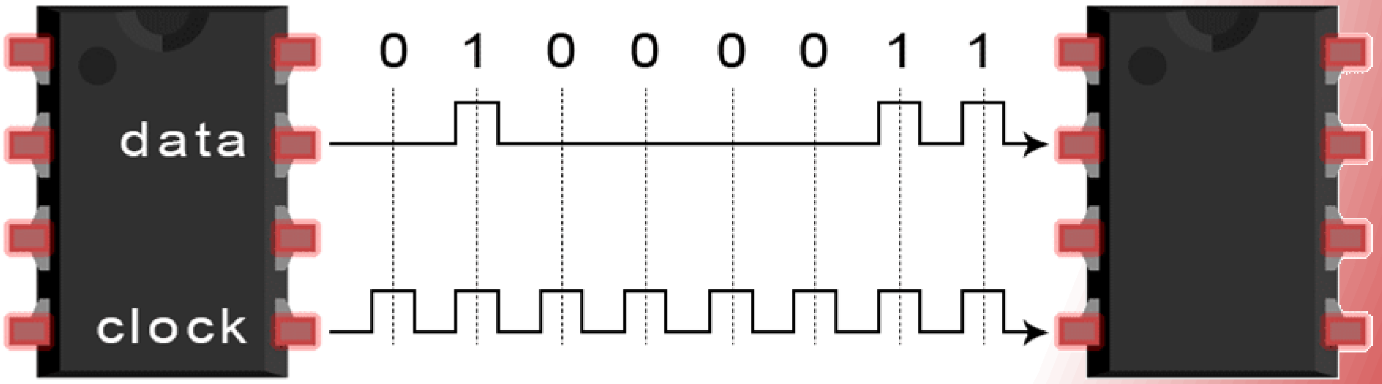
- Wired connectivity is by far the most prevalent type of interconnection on chip
- Important to understand how it functions if you intend on combining many chips together on a single board
- Allows for a wide variety of interfaces
- Reliable, fast, relatively straightforward to implement/understand

Parallel Vs. Serial

Sending Bit Pattern 01000011



Parallel



Serial

Parallel Vs. Serial

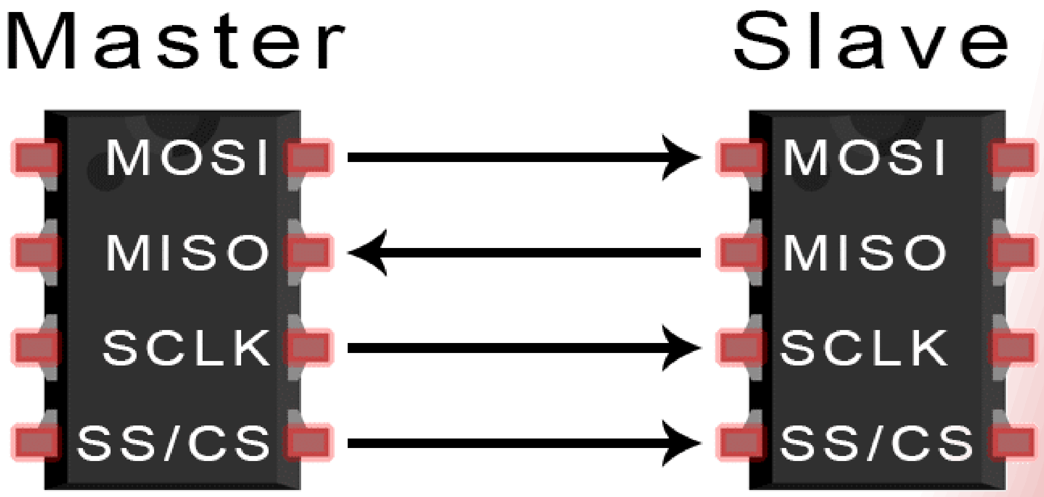
- Parallel
  - Pros
    - Transmit data over multiple channels simultaneously
  - Cons
    - Must always be clocked
    - Requires more wires and pins
    - Crosstalk
    - Intersymbol Interference (ISI)
- Serial
  - Pros
    - Simpler design (fewer wires and pins)
    - Can be clocked faster than parallel
    - Can be asynchronous
  - Cons
    - Sends a single stream of data
- PCI: Max Parallel Speed: 4.266 Gbits/s, Max Serial Speed: 256 Gbits/s

Serial Communication

	UART	SPI	I2C
Maximum Speed	115200b/s	10 Mbps	5 Mbps
Synchronous/ Asynchronous	Asynchronous	Synchronous	Synchronous
# Of Wires	2	4	2
Max # of Masters	1	1	Unlimited
Max # of Slaves	1	Unlimited*	1008

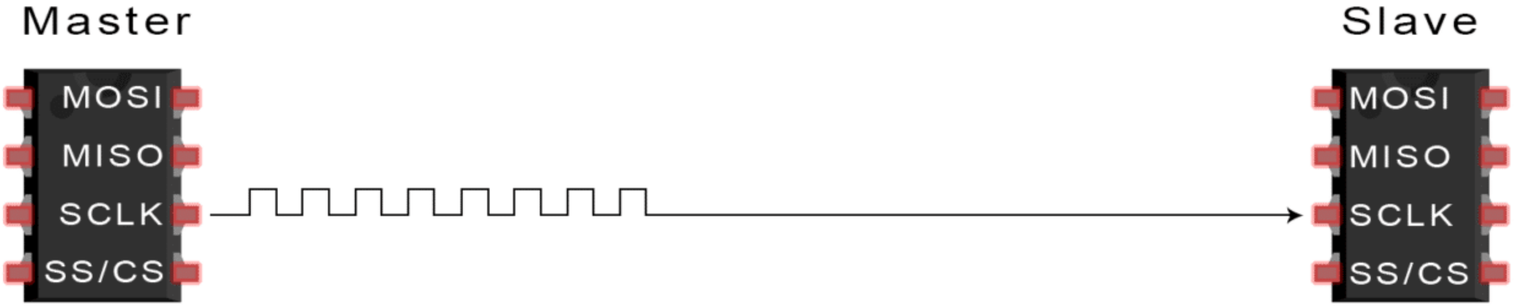
SPI (Serial Peripheral Interface)

- Master sends data on MOSI line
- Clocked by SCLK
- One bit per clock cycle
- Configurable clock
- Multiple slaves controlled by SS/CS (active low)
- Commonly used for: memory, memory cards, sensors, displays

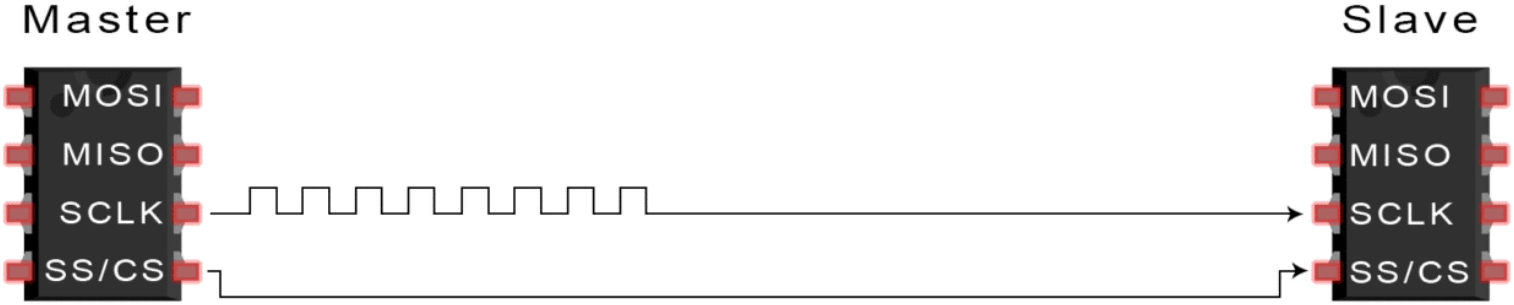


MOSI = Master Out/Slave In
MISO = Master In/Slave Out
SCLK = Serial Clock
SS/CS = Slave/Chip Select

Master Outputs Clock Signal

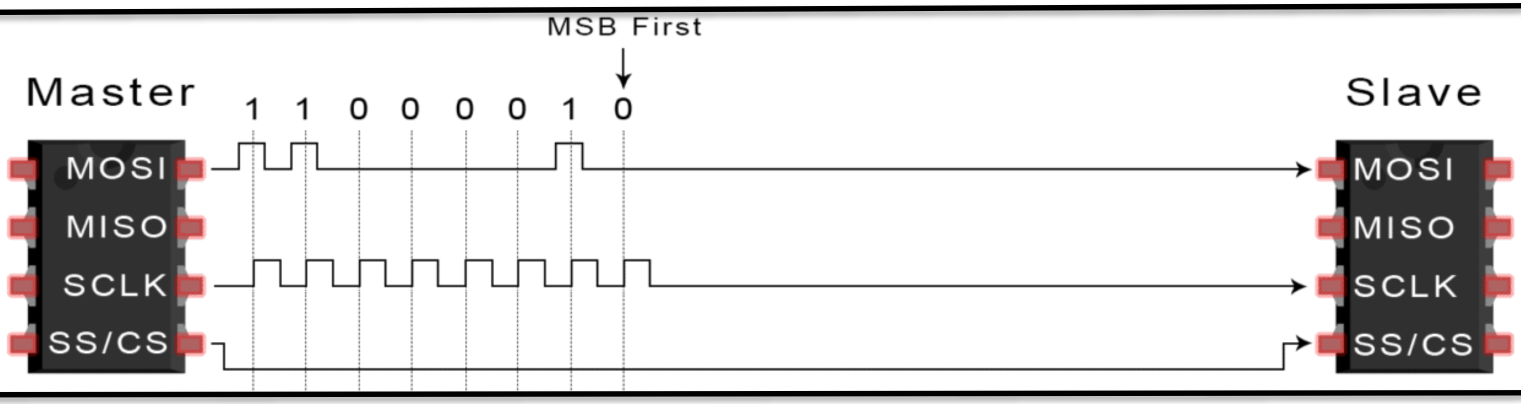


Master Switches SS/CS Low



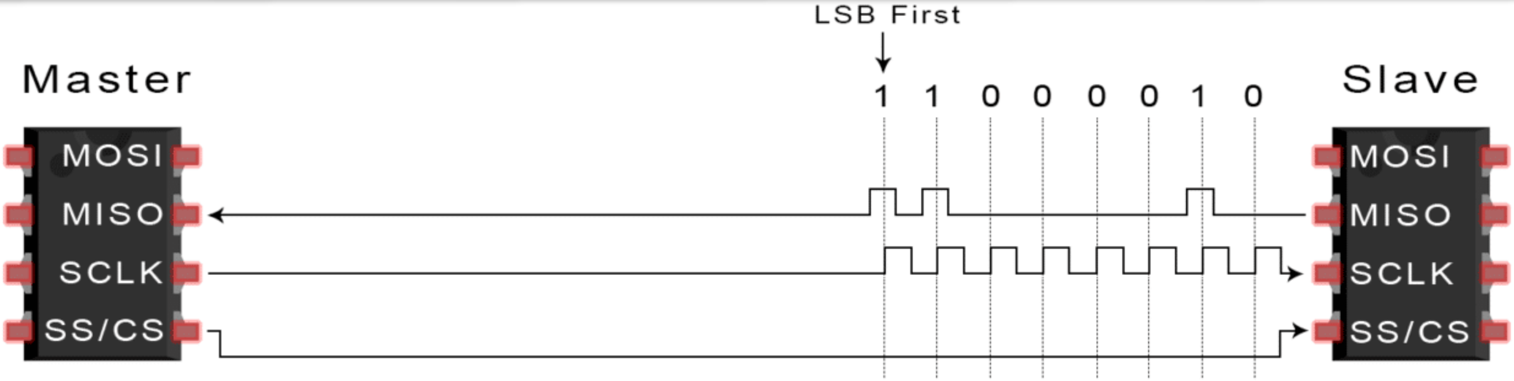
Slave Is Activated

Master Sends Data One Bit At A Time



Slave Reads Bits As They Are Received

Master Reads One Bit At a Time



Slave Responds Along MISO

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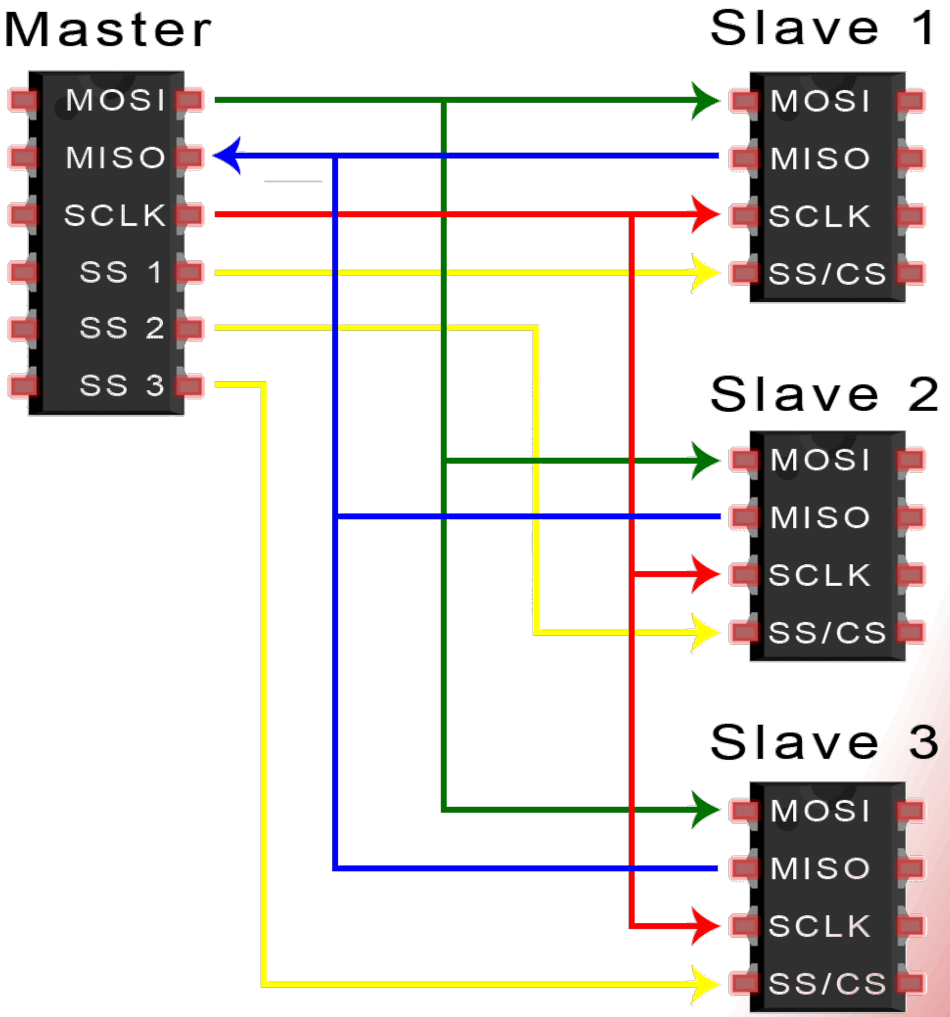
SPI

- Advantages
  - Stream bits (unlimited frame)
  - High speed
  - Send & receive lines
- Disadvantages
  - No error checking
  - No acknowledgement
  - Requires four wires
  - Single master



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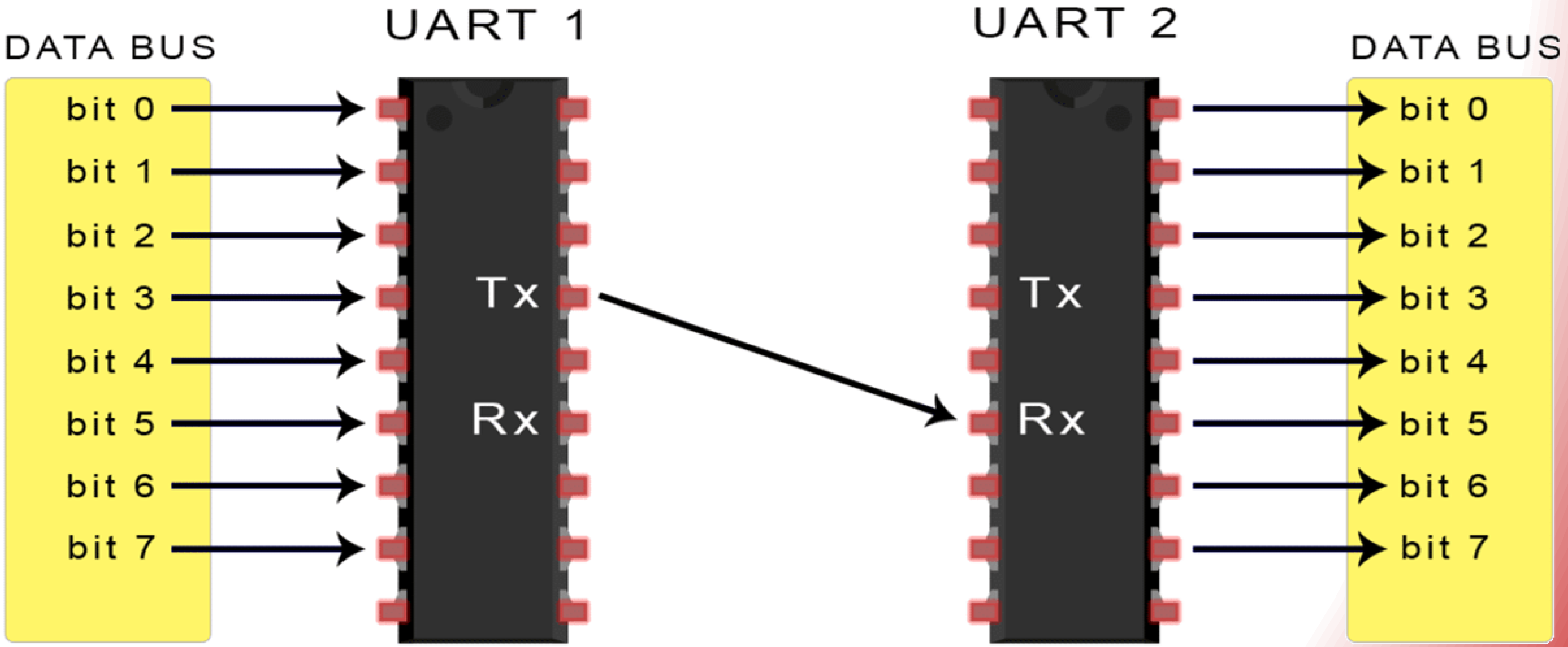
SPI

- Team Alpha implemented SPI communication to their FPGA
- Check out their website for Lab 4
- https://cei-lab.github.io/ECE3400-2017-teamAlpha/lab4.html

UART (Universal Asynchronous Receiver/Transmitter)



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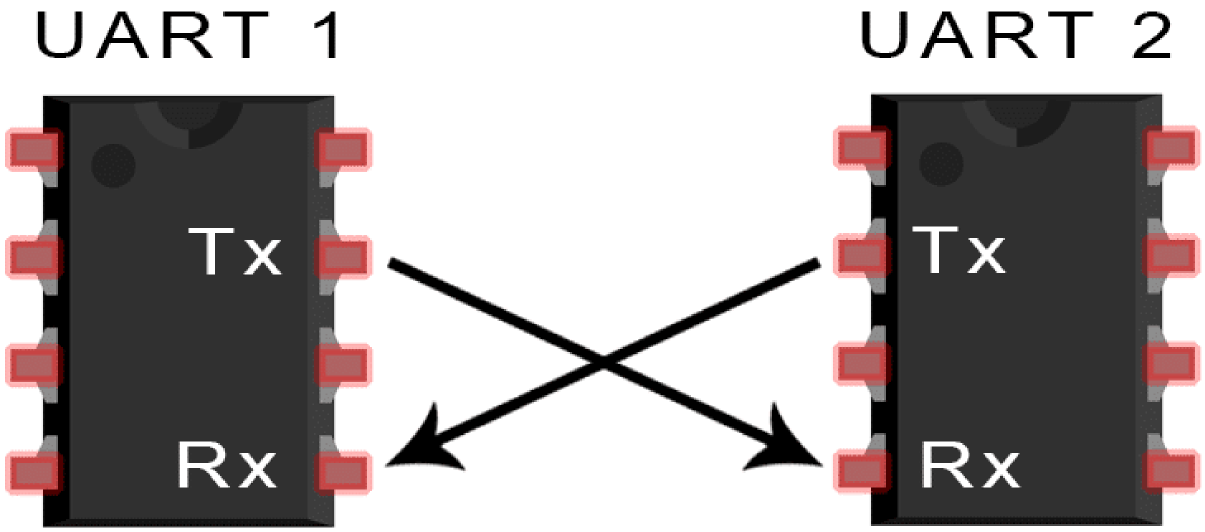
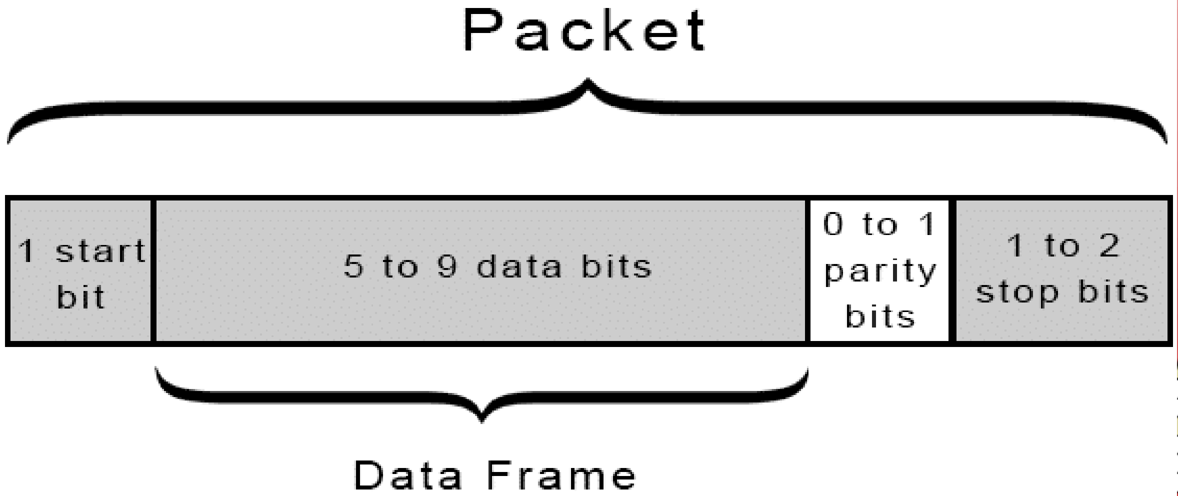
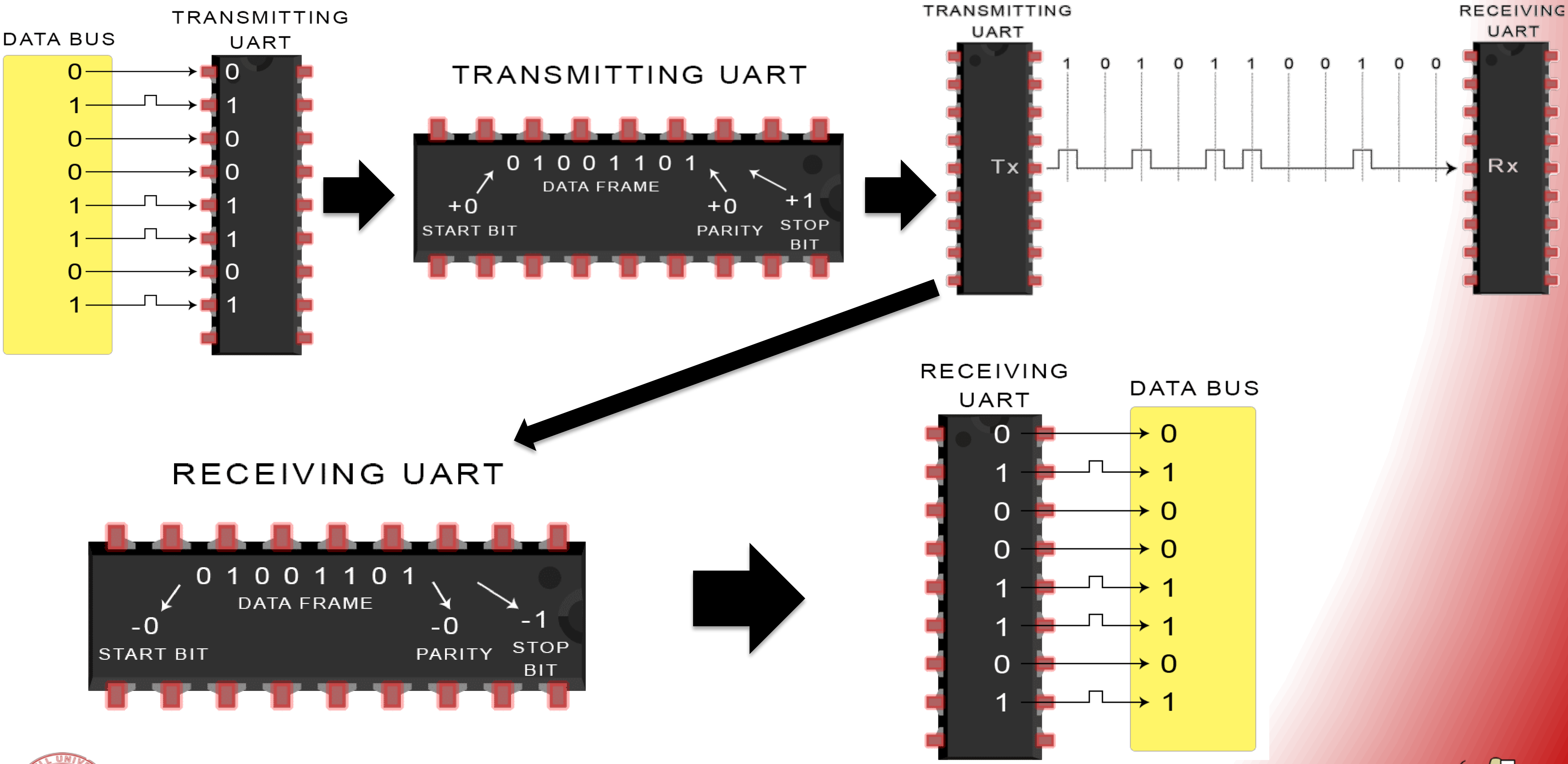
UART

- A UART is a physical IC (sometimes contained as part of an MCU)
- Two wire communication
- Converts incoming parallel data to serial, transmits, converts back
- Asynchronous
  - But there is an agreed upon baud rate
  - Start bit signals when reading begins
  - Use a particular "packet" format







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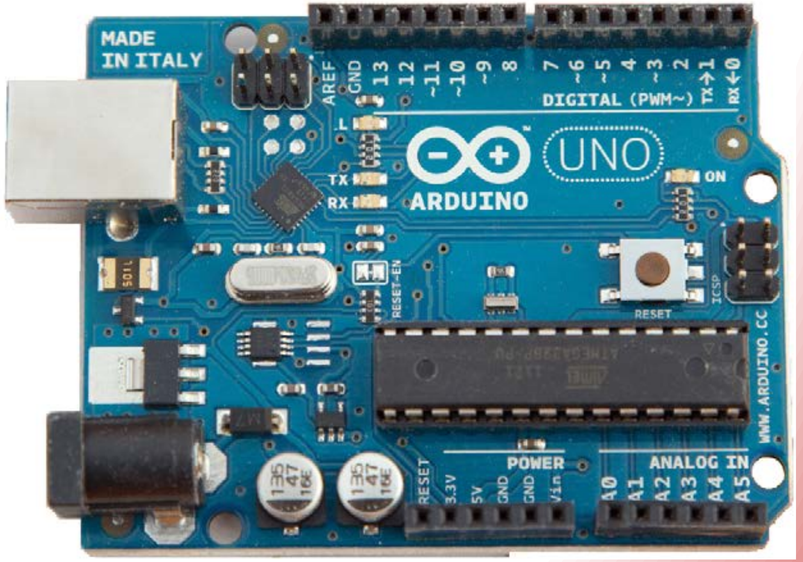
UART

- Advantages
  - Widely used
  - Requires only two wires
  - Asynchronous
  - Parity bit for error checking
- Disadvantages
  - Fixed packet size
  - Single Master/Slave
  - Baud rates must be within 10%

- Commonly Used For
  - GPS Modules
  - Bluetooth Modules
  - RFID Card Reader Modules



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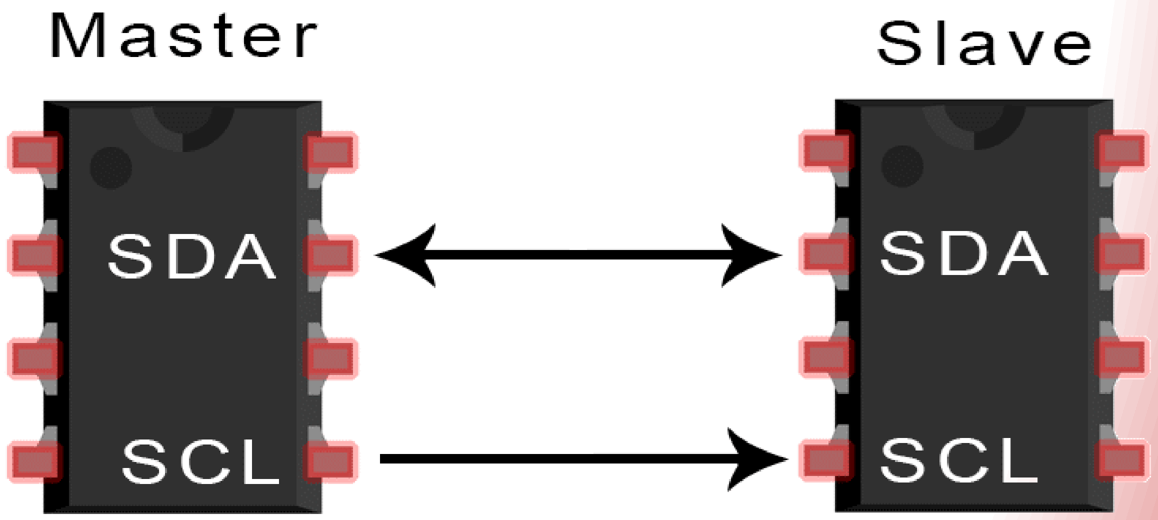
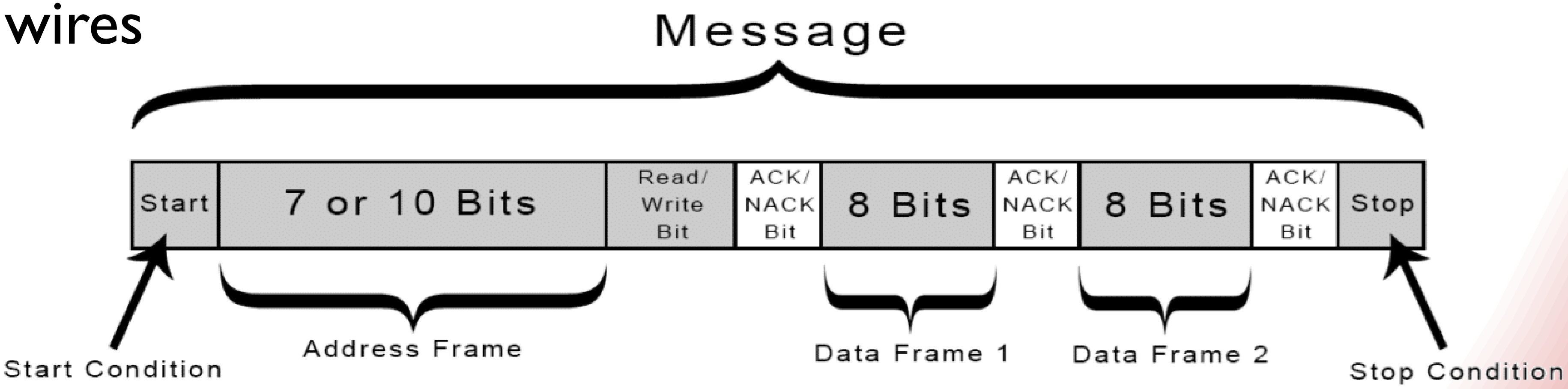
I2C (Inter Integrated Circuit)

- Inter Integrated Circuit combines SPI and UART benefits
  - Multiple masters and multiple slaves
  - 2 wires





Start Condition: SDA High to Low before SCL High to Low
Stop Condition: SDA Low to High after SCL High to Low

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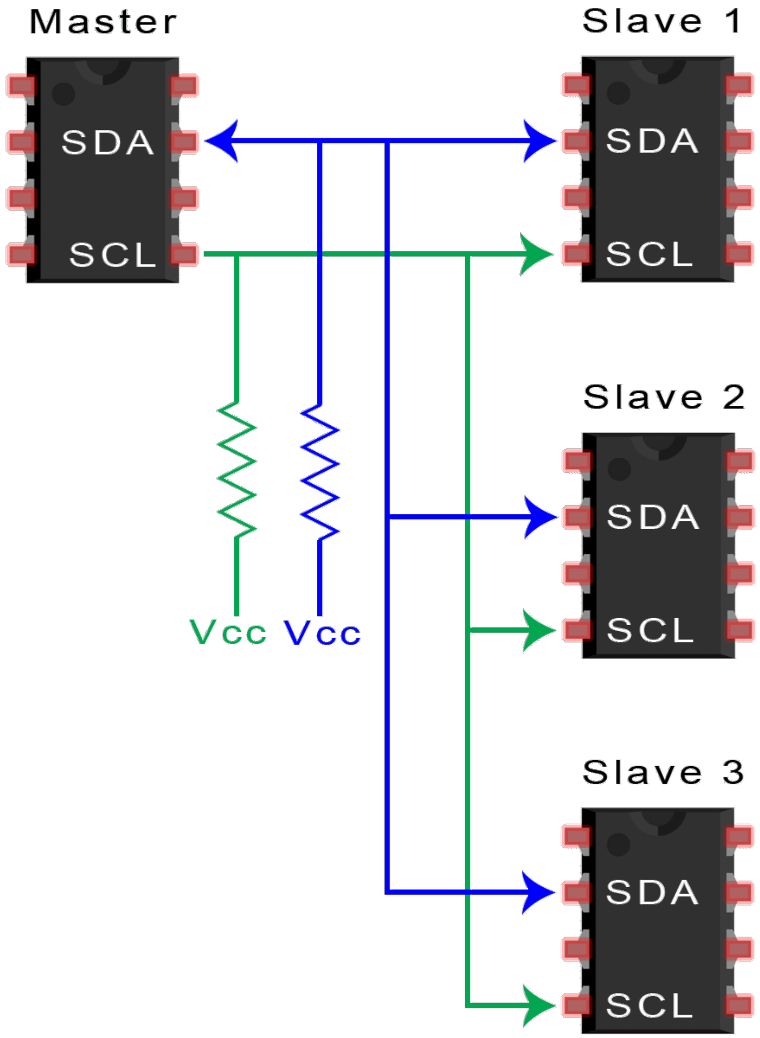
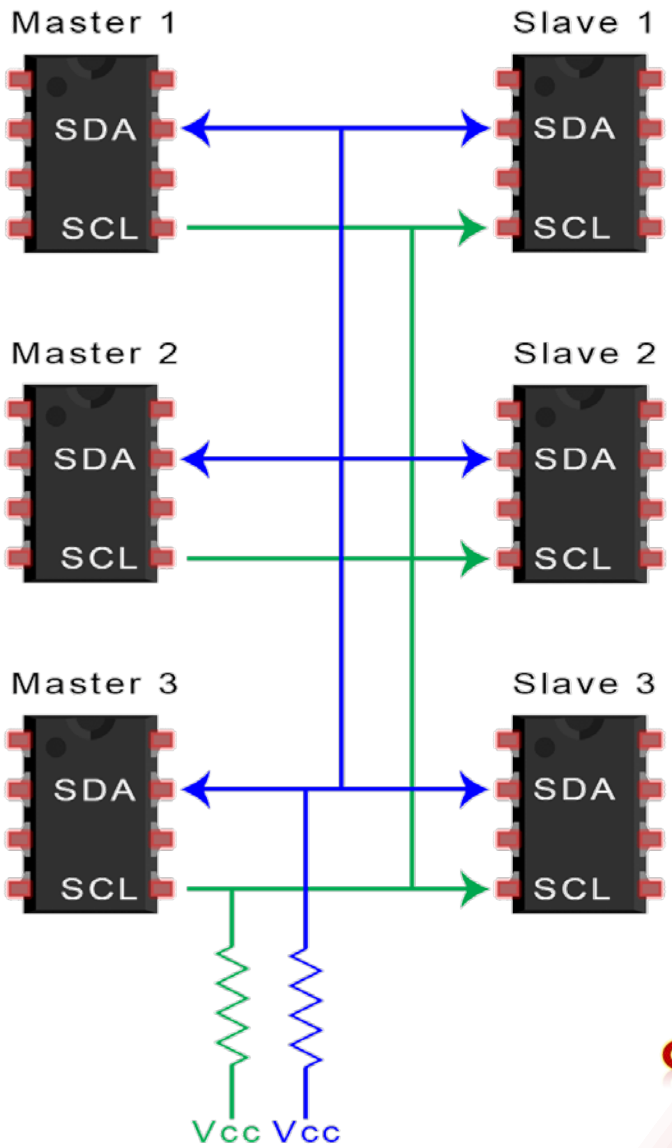
I2C Configurations





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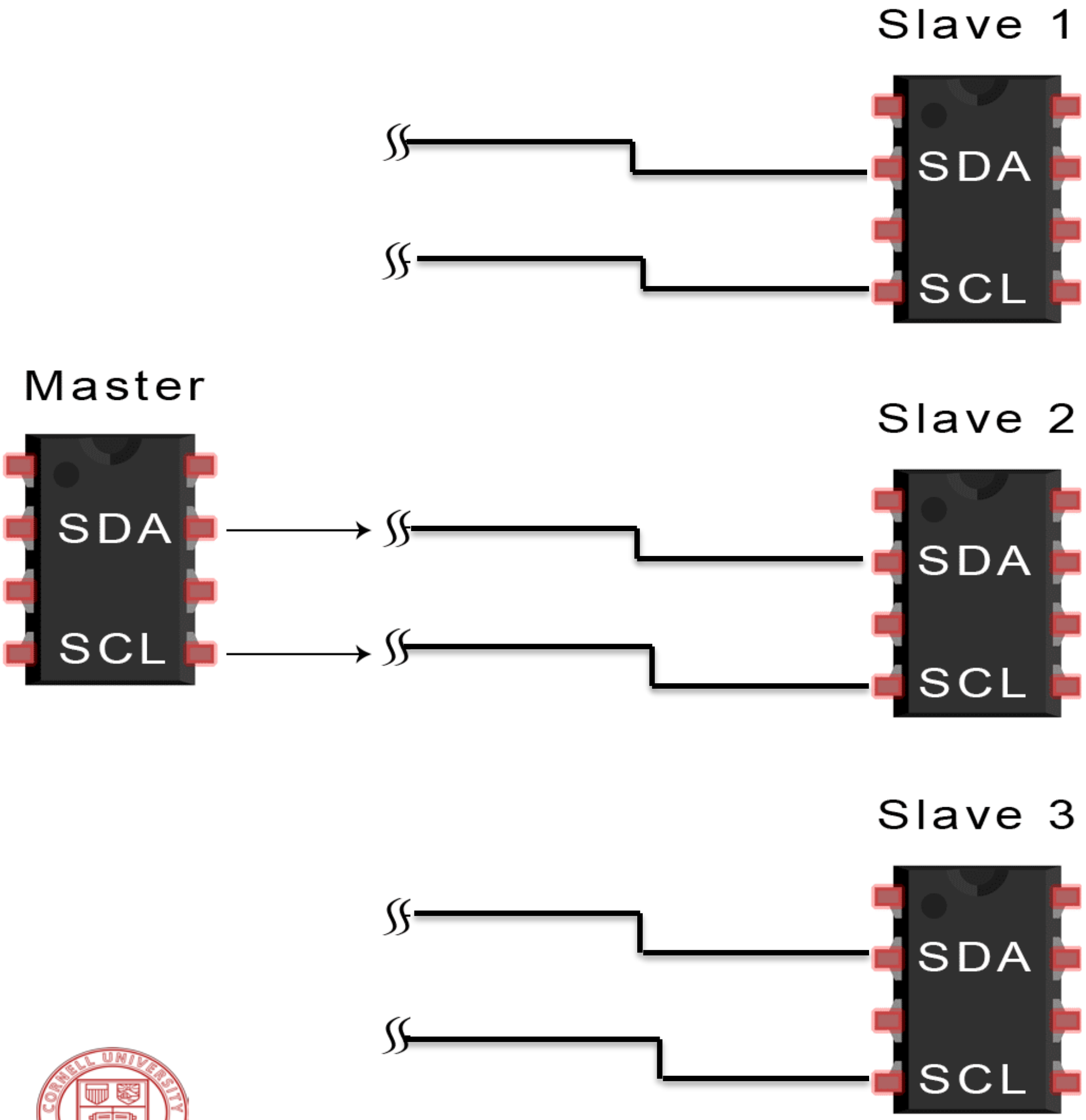
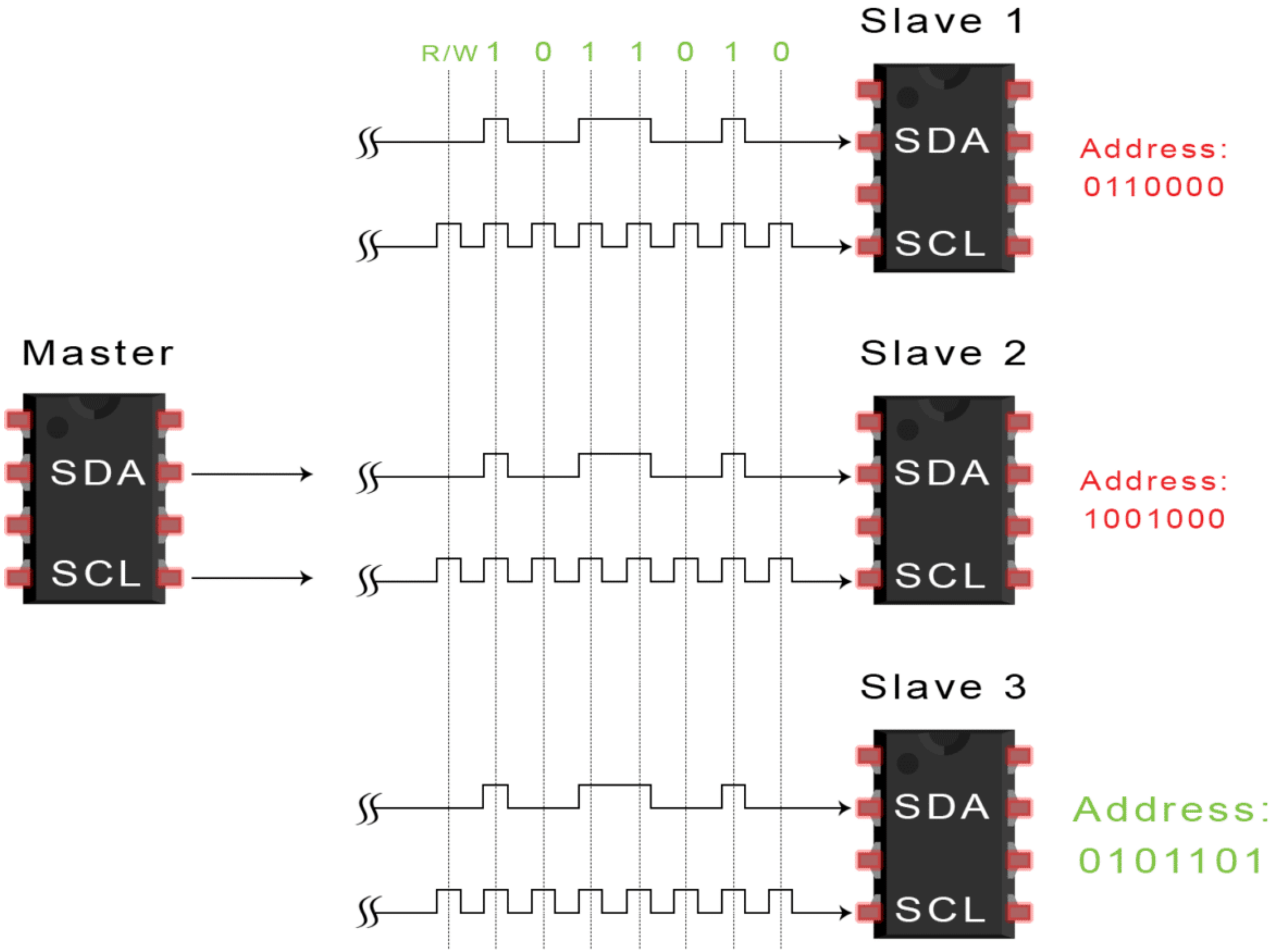
Start Condition Is Sent



Address is Sent



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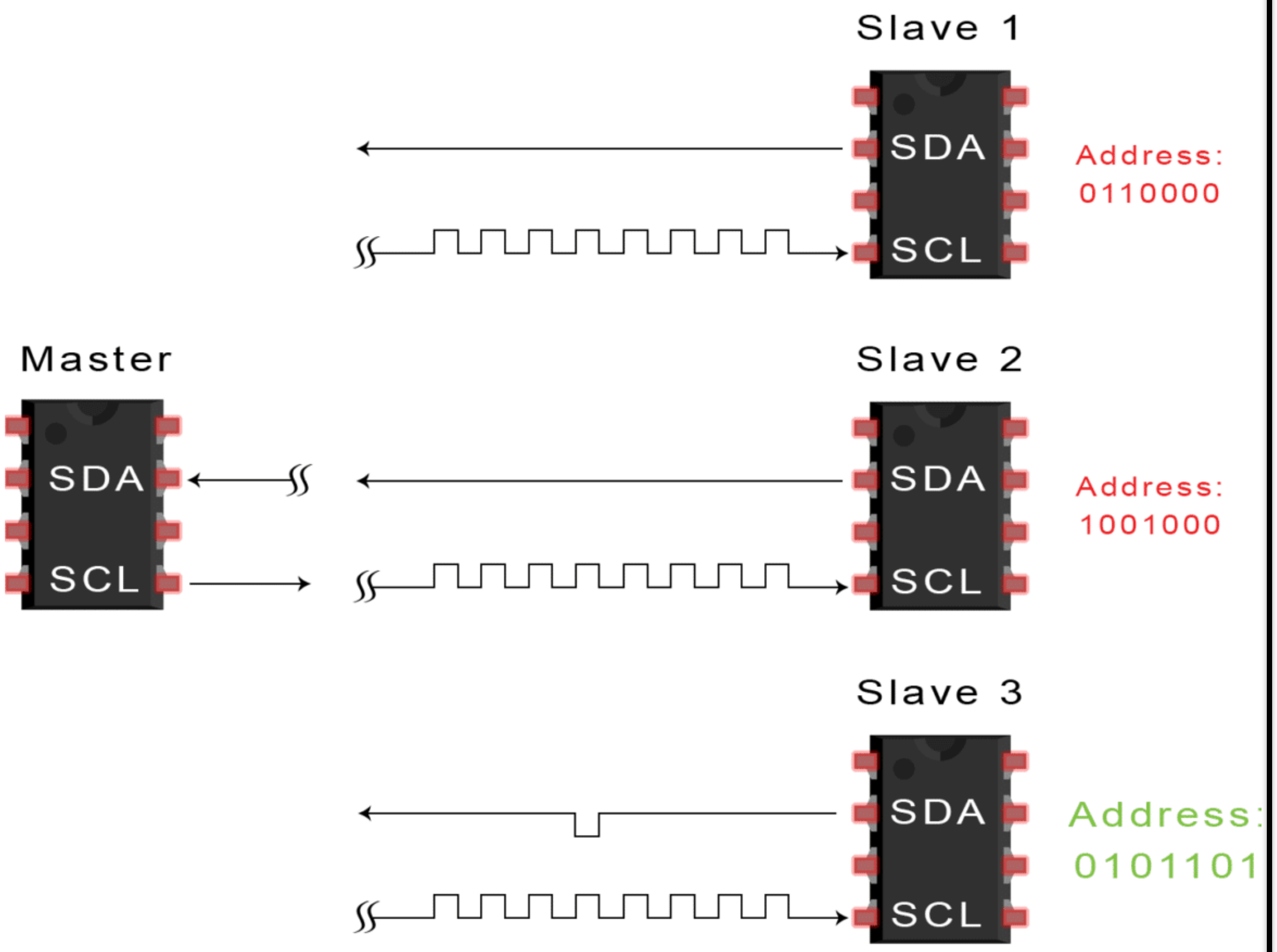
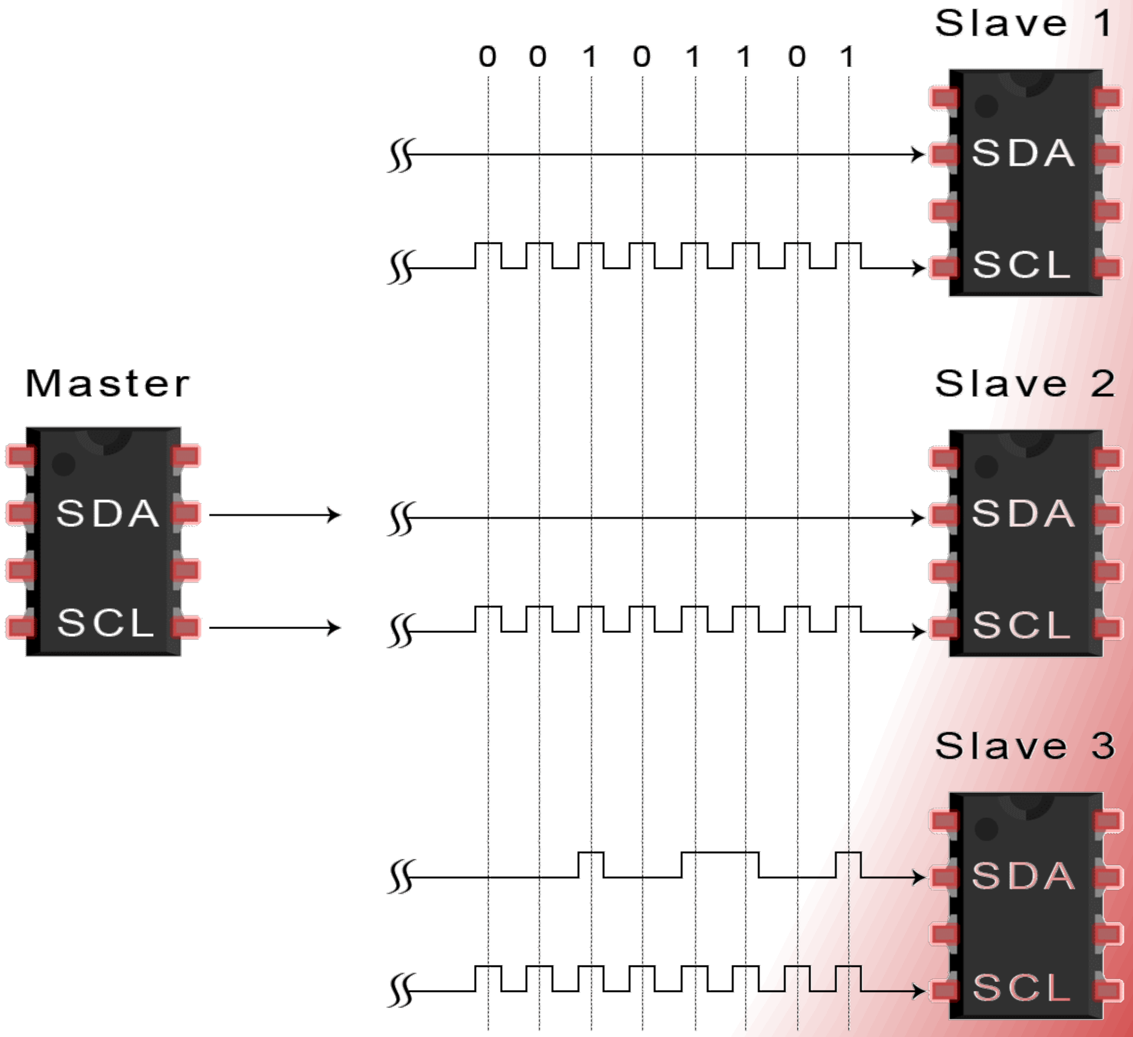
ACKnowledgement Sent (Pull SDA Line Low)



Master Sends or Receives Data



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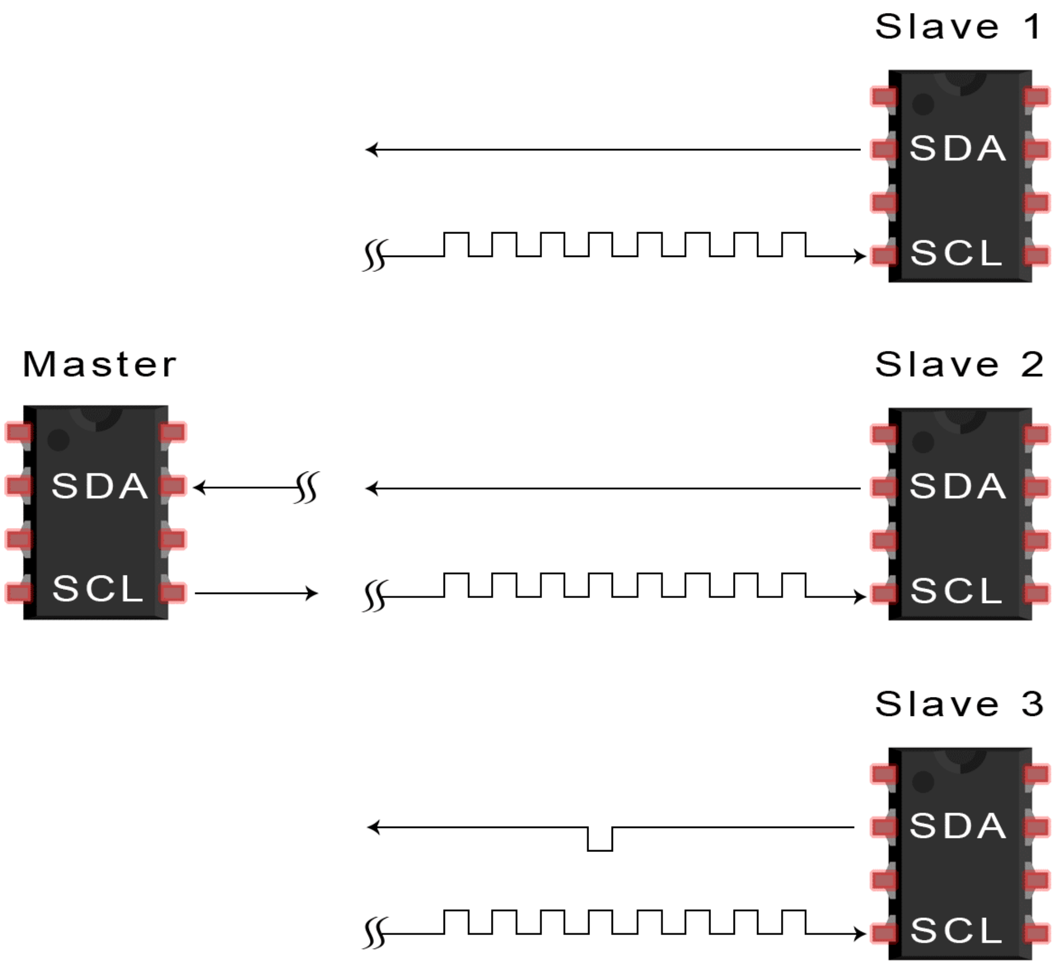
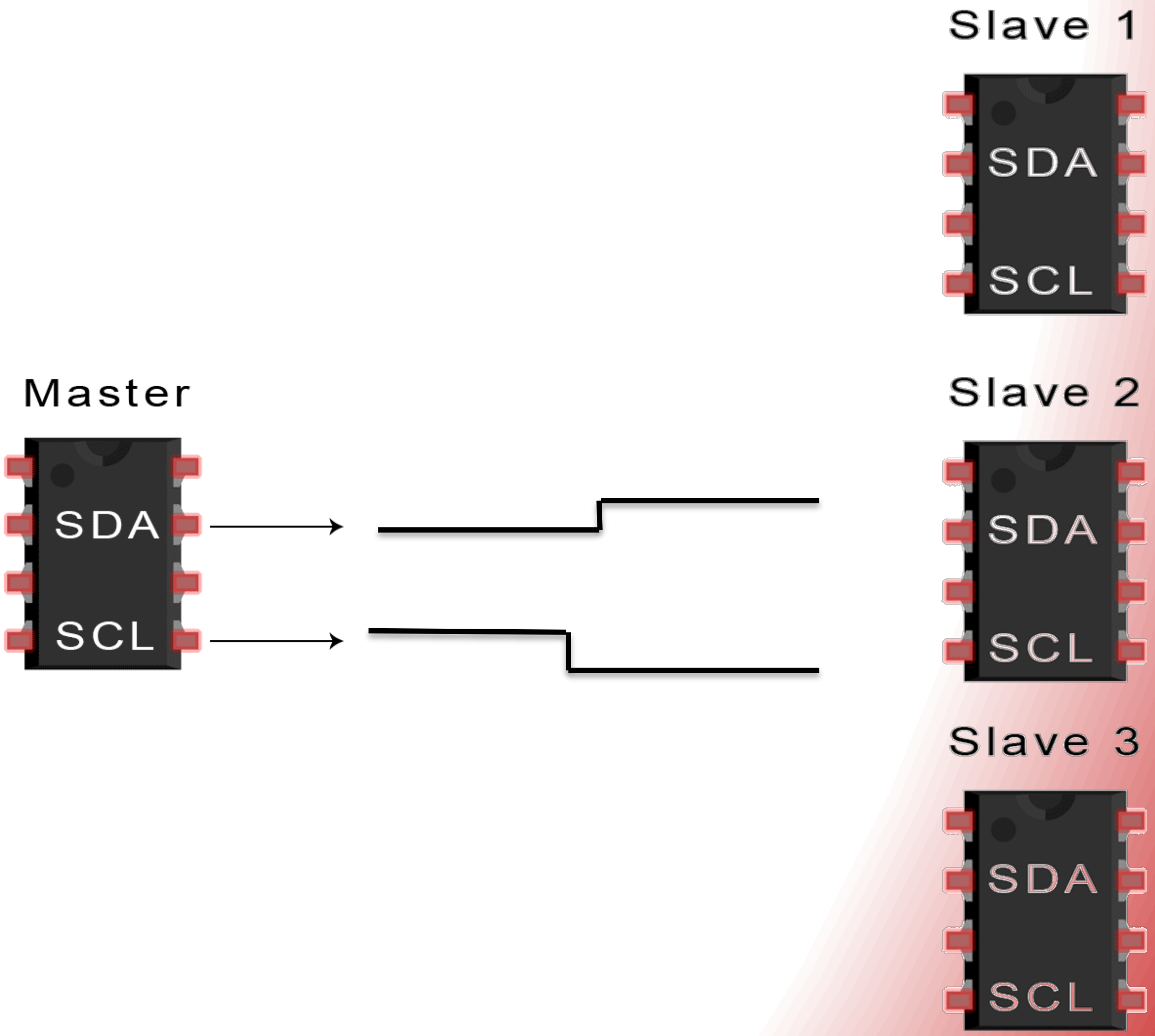
After Each Data Frame An ACK/NACK is Sent



Master Sends Stop Condition



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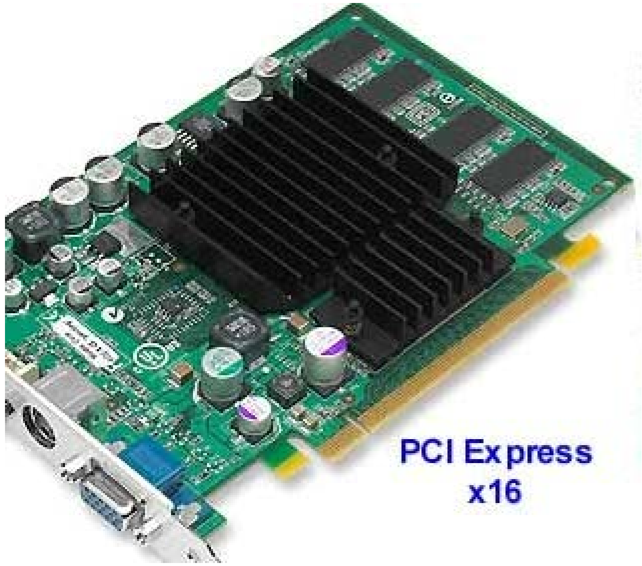
I2C

- Advantages
  - Widely used
  - Requires only two wires
  - Ack/Nack
  - Multiple master/multiple slave
- Disadvantages
  - Fixed frame size
  - Slower than SPI
  - More complicated than SPI
- Commonly Used For
  - Sensors
  - Control of multiple devices
  - OLEDs
  - Accelerometers

Other Serial Devices

- USB ,PCIe, SATA, CAN



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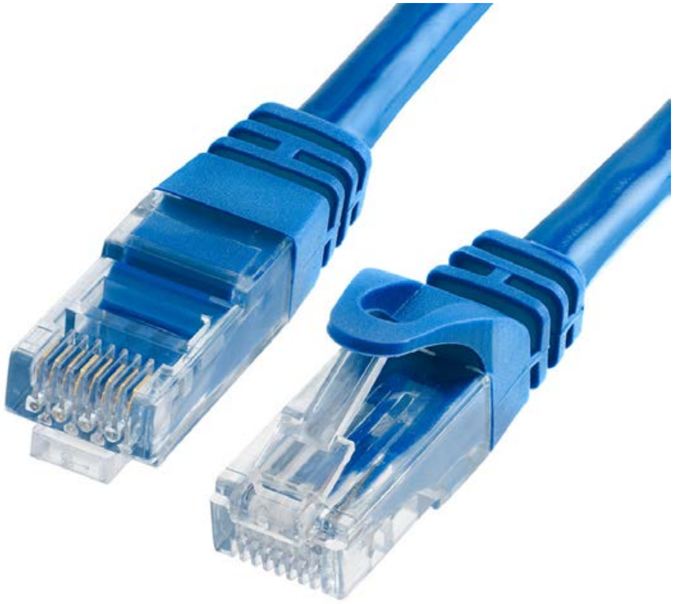
Even More Serial Devices

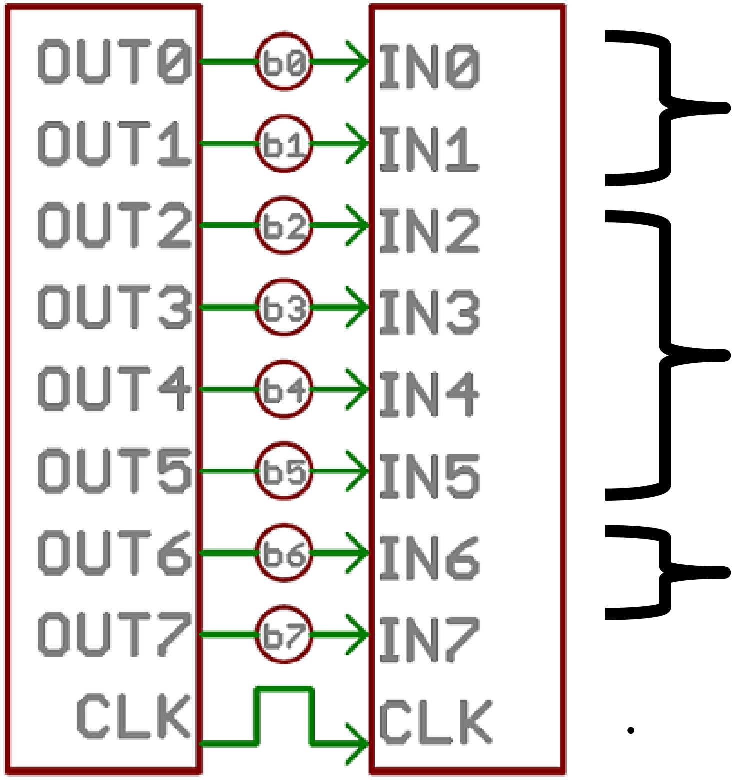
- Ethernet, HDMI, Coax (Digital Video), Display Port, Firewire



Parallel Communication

- Examples are PCI, PATA
  - No longer favorable because of limits in speed
  - Cable length
  - Hardware complexity
- However, is easy to implement on FPGA

Parallel Communication & FPGAs



<u>For example:</u>

2-bits for message type/header
(eg. moved to new location; found treasure at square, etc.)

3-bits for message body
(eg. moved to square 4,5; square 7,7 is type *wall*, etc.)

1-bit for started, stopped mapping…

and so on …

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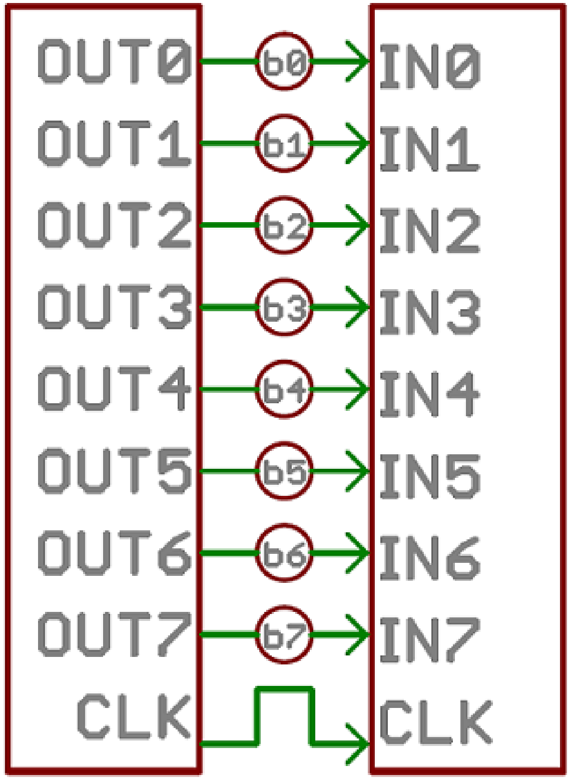
Parallel Communication & FPGAs



Drawback: Consumes a lot of pins

Plenty of ways to implement (pseudocode):

```
reg [2:0] grid_array [n-1:0][n-1:0];
wire [2:0] square_color;
assign square_color = GPIO_0_D[k:k-2];
…
always @ (*) begin
  if (square_color == 3'd0) begin
    grid_array[x][y] = square_color;
  end
…
```

Arduino sends color directly. Reserved GPIO pins specifically for color.

```
wire inputs [n:0];
assign inputs = GPIO_0_D[m:0];
…
always @ (*) begin
  if (inputs{1:0} == 2'd3) begin
    grid_array[x][y] = inputs{5:2};
  end
…
```

msg header
msg body

Arduino sends msg header {1:0} + body {5:2} indicating color change should take place at square x,y.

Choosing a Protocol

- Heavily dependent on what type of robot you want to build
- Considerations
  - Cost
  - Usable wire length
  - Device pin count
  - Speed
  - Etc.
- You can also make your own communication protocol!

References

- Much of this presentation material is based on material discussed in www.circuitbasics.com
  - SPI, UART, & I2C
- Sparkfun also has excellent discussions on these topics