Lab 2

- Lab 2 will be announced today
  - Regarding I/O access and practices on I/O interfaces
  - The TA will give the lab lecture for lab 2 today

Recap from last class

data=1 data=2

- I/O programming
  - Memory-mapped I/O vs. special-purpose I/O instructions
  - Busy-wait is simplest but very inefficient
    - Devices are usually slower than CPU
- Interrupts
  - Using buffer to allow input/output at different rates
  - Priorities and vectors allow to handle multiple interrupts

mutual exclusion.

P1 P2

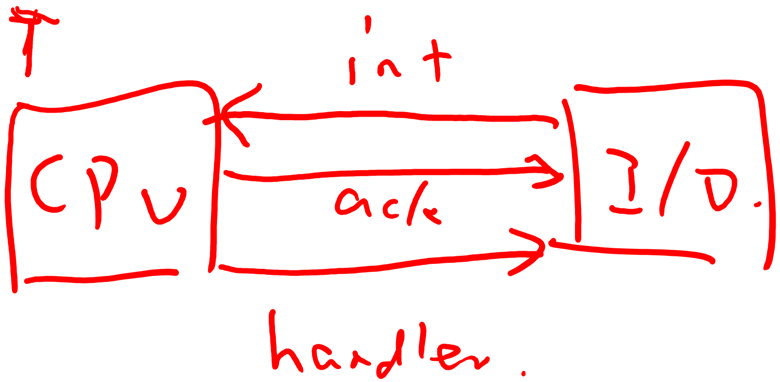
race.

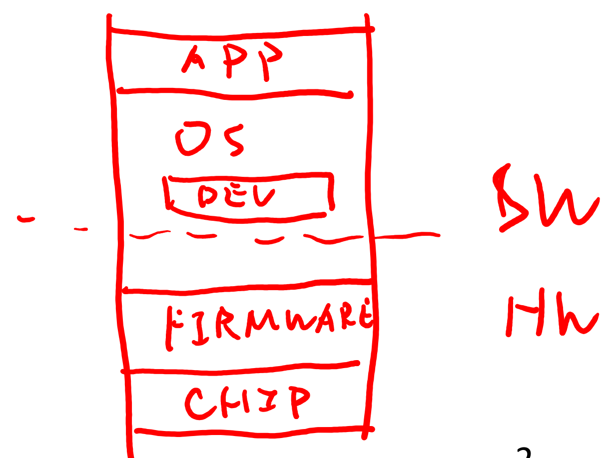
func

write data → I/O.

Test&Set

DD_WRT





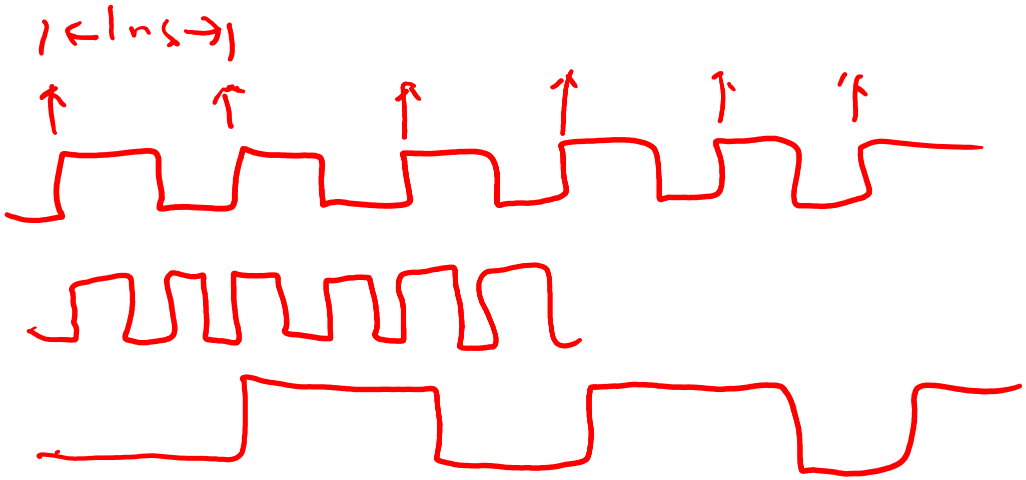
ECE 1175
Embedded Systems Design

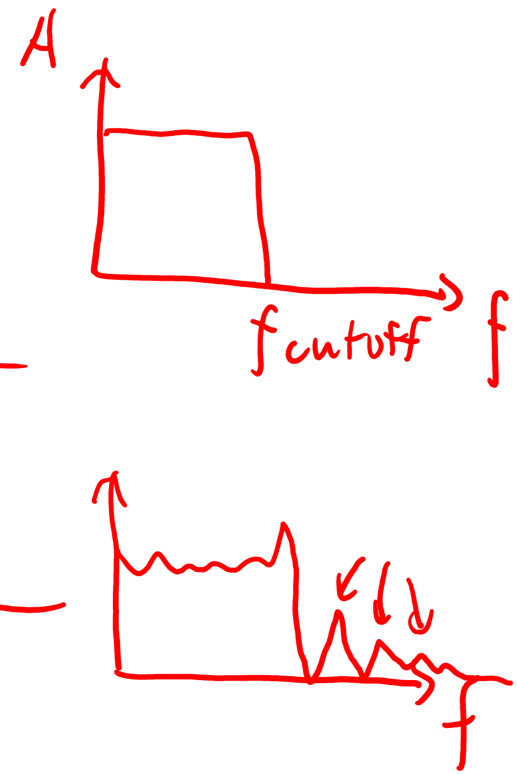
Practical I/O Interfaces

Wei Gao

Timers and Counters

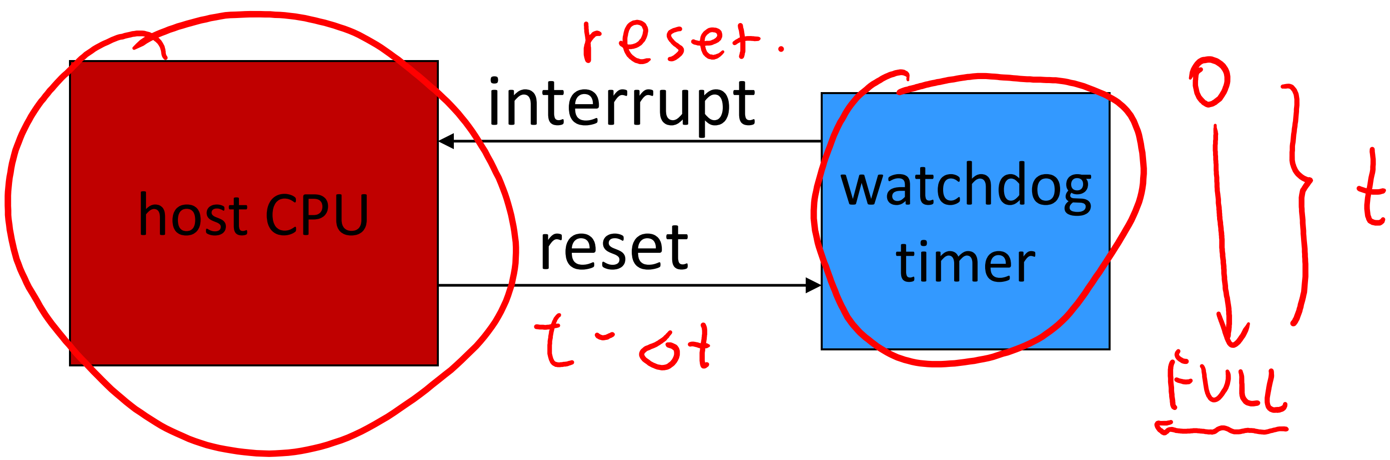
- Very similar:
  - a timer is incremented by a periodic signal;
  - a counter is incremented by an asynchronous, occasional signal.
- Timeout or rollover causes interrupt.



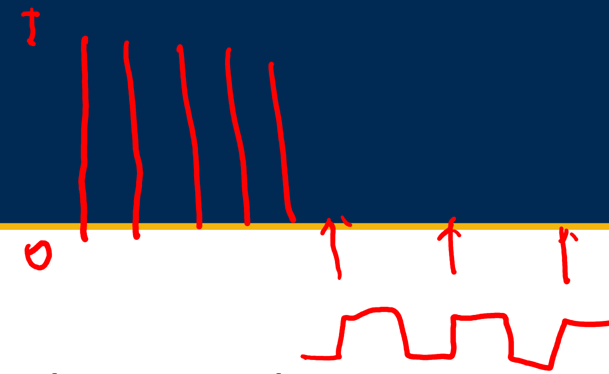


Watchdog Timer

- An I/O device for internal operation
- Watchdog timer is periodically reset by the system timer.
- If watchdog is not reset, its timeout generates an interrupt to reset the host.
  - Presumption: CPU is misbehaving so that watchdog is not reset



I/O Interfaces



- Parallel I/O and Serial I/O
  - Parallel I/O: multiple input/output simultaneously
    - Data Bus, Address Bus, Intel 8255, printer
  - Serial I/O: transferring data between CPU and peripherals one bit at a time, sequentially
    - Ethernet, USB, Inter-integrated Circuit, Serial Peripheral Interface

I/O Interfaces

- Parallel v.s. Serial
  - Parallel
    - Wider bandwidth
    - More wires indicate more overhead
    - Simple I/O operation
  - Serial
    - 1-bit transfer per time unit
    - Less wires indicate less overhead
    - Complex I/O protocol

interference.

I2C.

CLK DATA

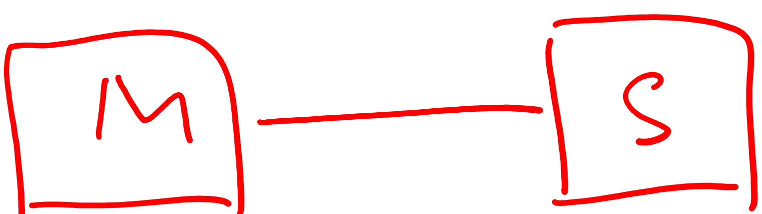
I/O Interfaces

- Serial over Parallel
  - Parallel interfaces have less reliability
    - Interference and noise corrupt data
    - Capacitance and mutual inductance affects bandwidth
  - Serial
    - Less mutual interference between wires
    - Higher clock frequency increases transmission rate

Inter-integrated Circuit (I2C)

SPI

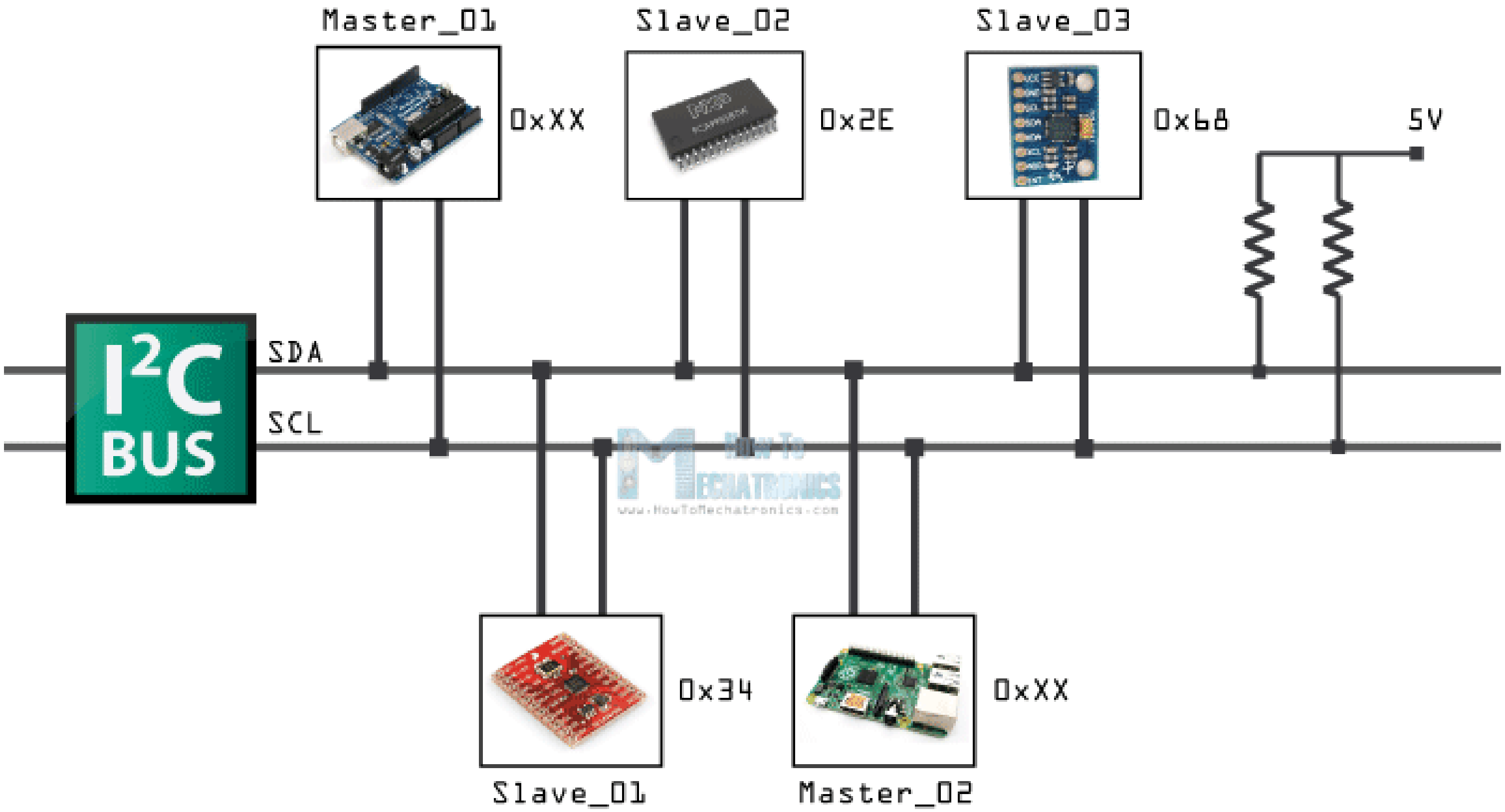
- Inter-integrated Circuit (I^2C or I2C)
  - Two-wire interface
  - Simple master/slave relationships
  - No strict baud requirement and a master generates a bus clock
  - Each device is software-addressable by a unique address
  - Philips semiconductors (now NXP)



invented I^2C in 1982

Inter-integrated Circuit (I2C)

- I^2C connection example

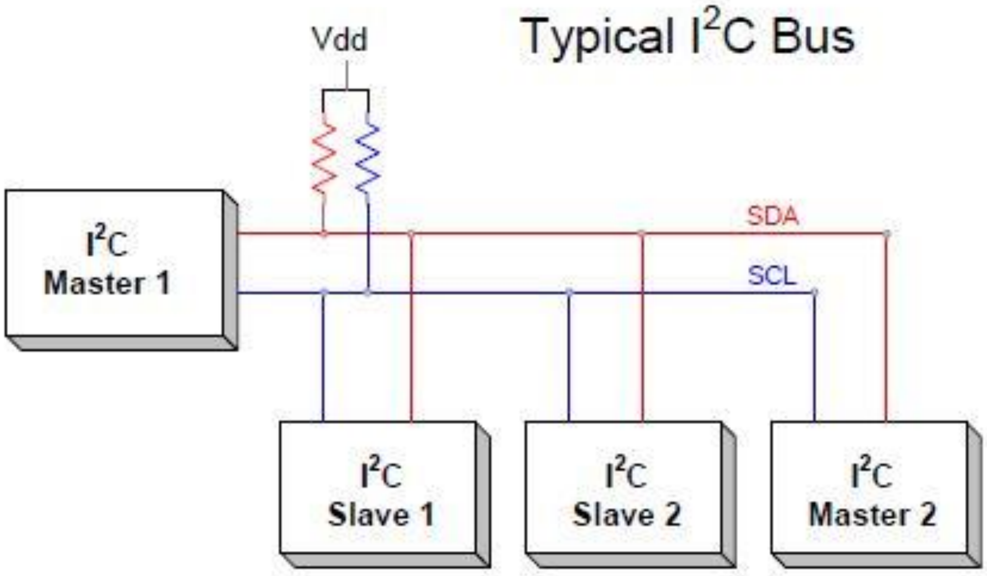


Inter-integrated Circuit (I2C)

- I^2C Terminology
  - Master: sends out signals (clock signal and communication signal) to slaves
  - Slave: listens to the bus and waits to be addressed by master
  - Multi-master: I2C allows connections of multiple masters
    Arbitration: decides which master to use wire

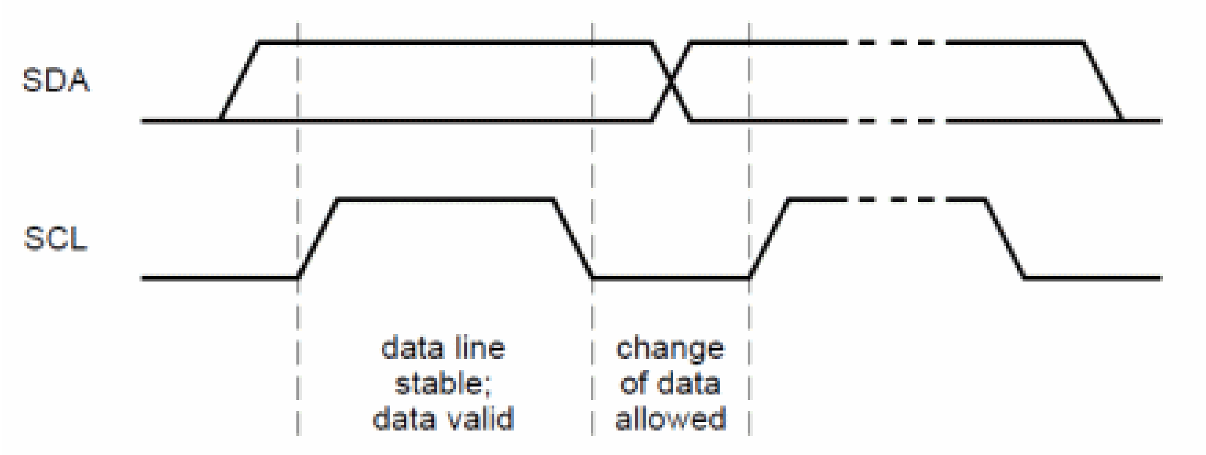
Inter-integrated Circuit (I2C)

- I^2C Bus Signal
  - Serial Clock Line (SCL): synchronize all data transfer over I2C bus
  - Serial Data Line (SDL): convey data among masters and slaves



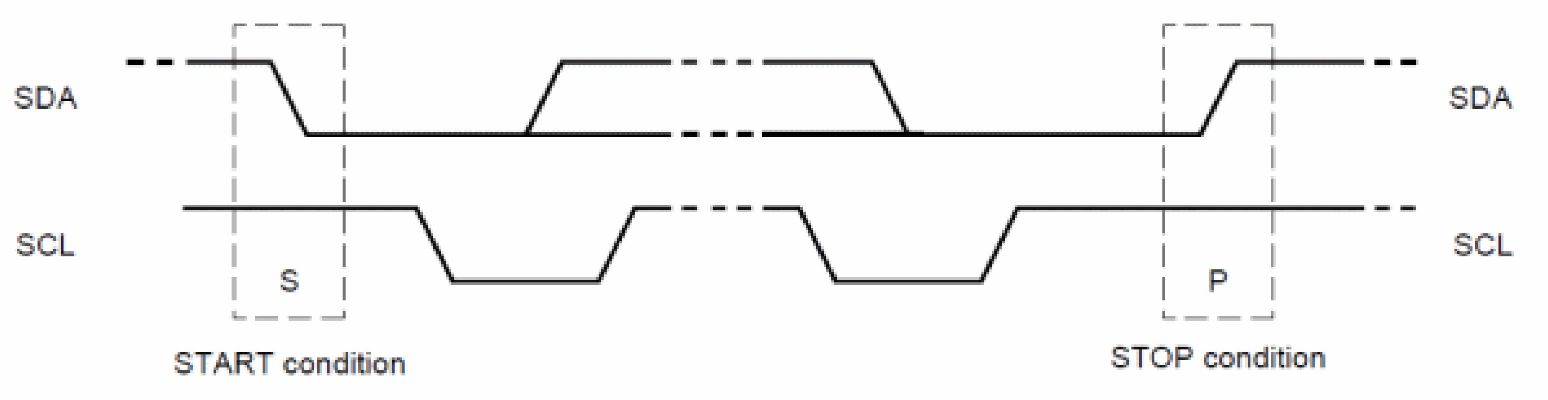
Inter-integrated Circuit (I2C)

- Serial Data Transfer
  - One bit data transferred per each clock pulse
  - SDA signal can only change when the SCL signal is low
  - Data should be stable when clock is high



Inter-integrated Circuit (I2C)

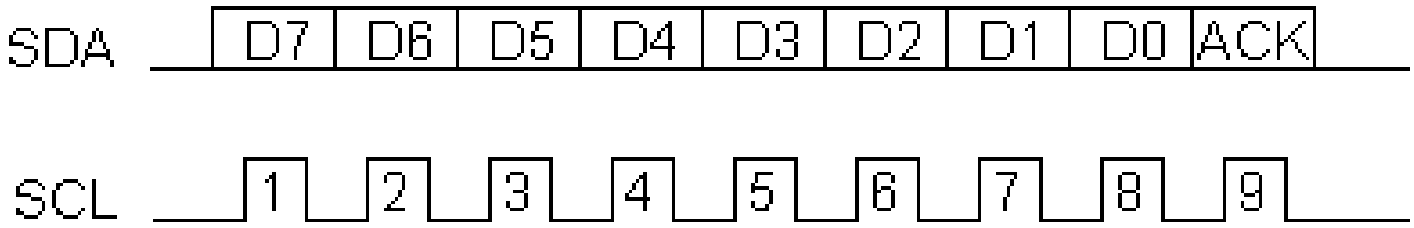
- Start and Stop condition
  - Both initiated by master
  - SCL has to be high in both case



  - SDA
    - High to low: START
    - Low to high: STOP

Inter-integrated Circuit (I2C)

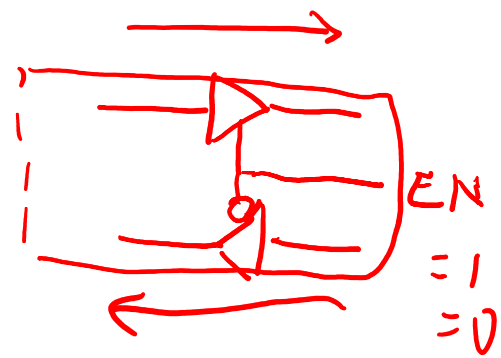
- Data Transfer
  - Data is transferred in sequence of 8 bits
  - Acknowledgement (ACK) bit follows 8-bit data transfer
  - 9 clock pulses are for each 8-bit data

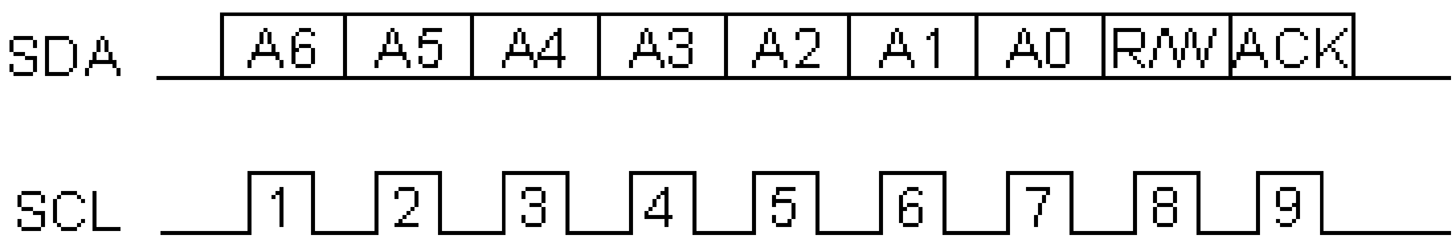


Inter-integrated Circuit (I2C)

- Device Addressing
  - 7-bit addresses

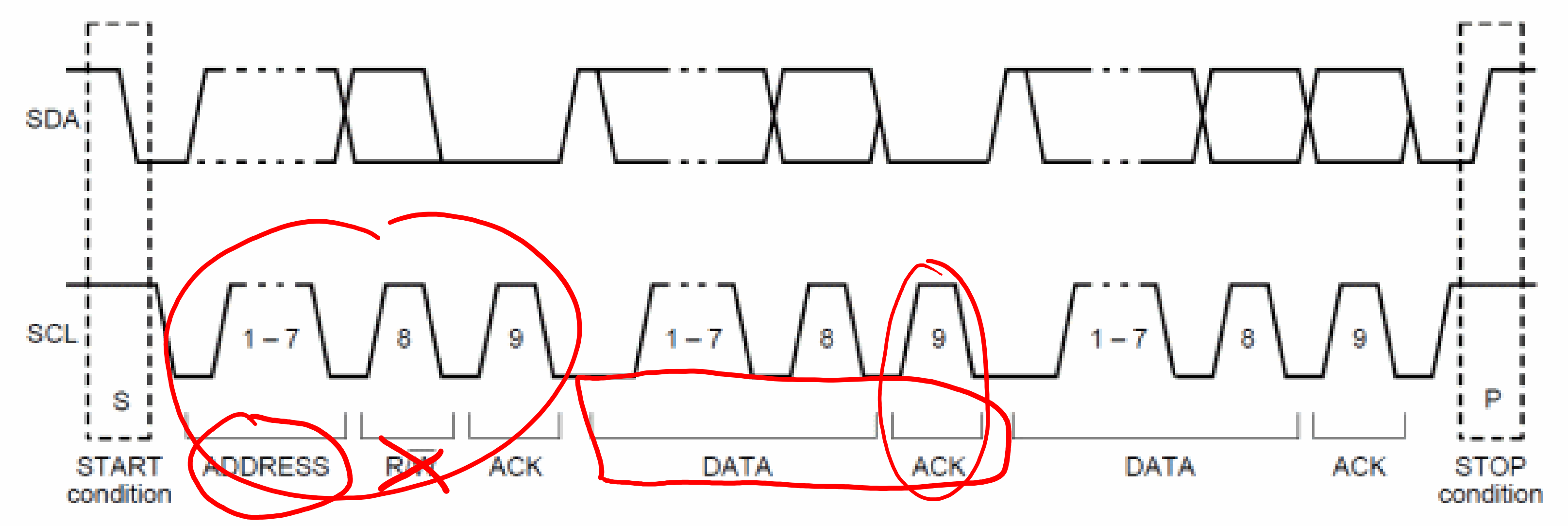
    R/W
  - Remaining 1 bit is for Read/Write command
    - 1 is for Read
    - 0 is for Write
    - Located at LSB
  - Each slave device has an unique address





Inter-integrated Circuit (I2C)

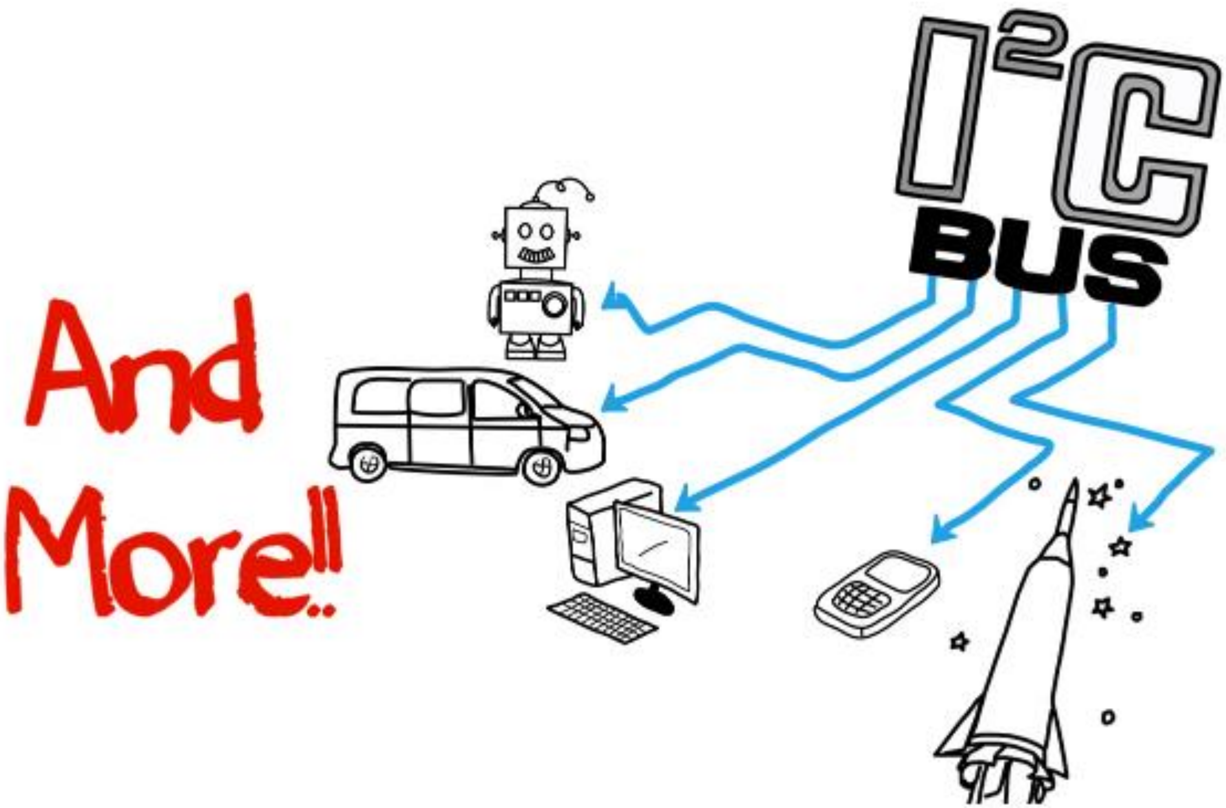
- Communication with 7-bit I2C Address



  - Initiating communication
  - Addressing slave device
  - Transferring data
  - Ending communication

Inter-integrated Circuit (I2C)

- Smart phone
- Automotive
- Instrument
- Robotics
- Aerospace
- …

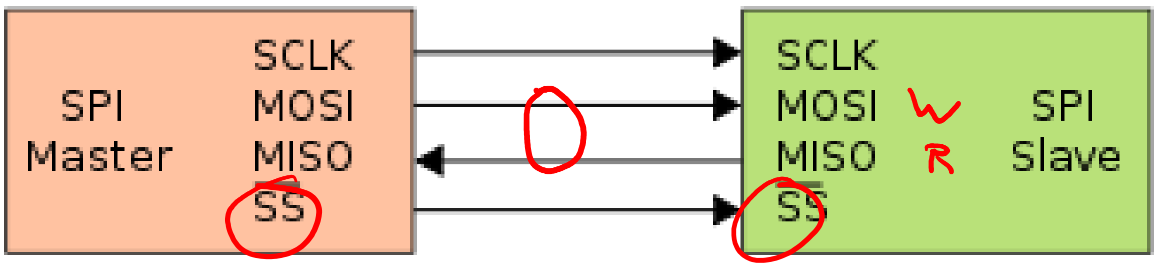


Serial Peripheral Interface (SPI)

- Serial Peripheral Interface (SPI)
  - Serial protocol
  - Peripheral connections in embedded system
    - Microcontroller
    - EEPROMs
    - …
  - Quick communication over short distance
  - Motorola

Serial Peripheral Interface (SPI)

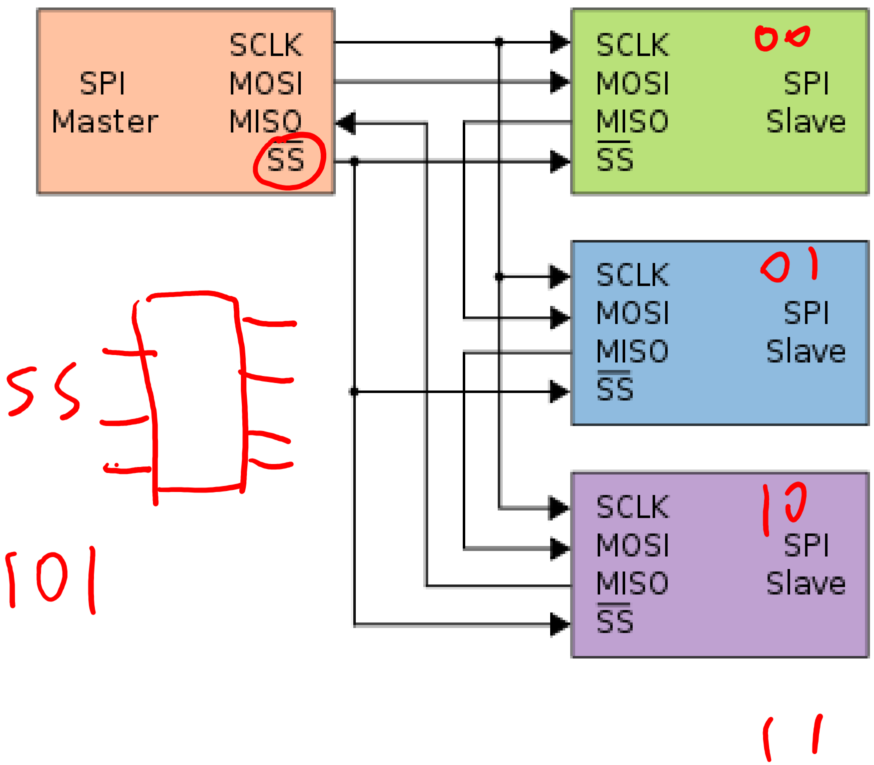
- Basic Model

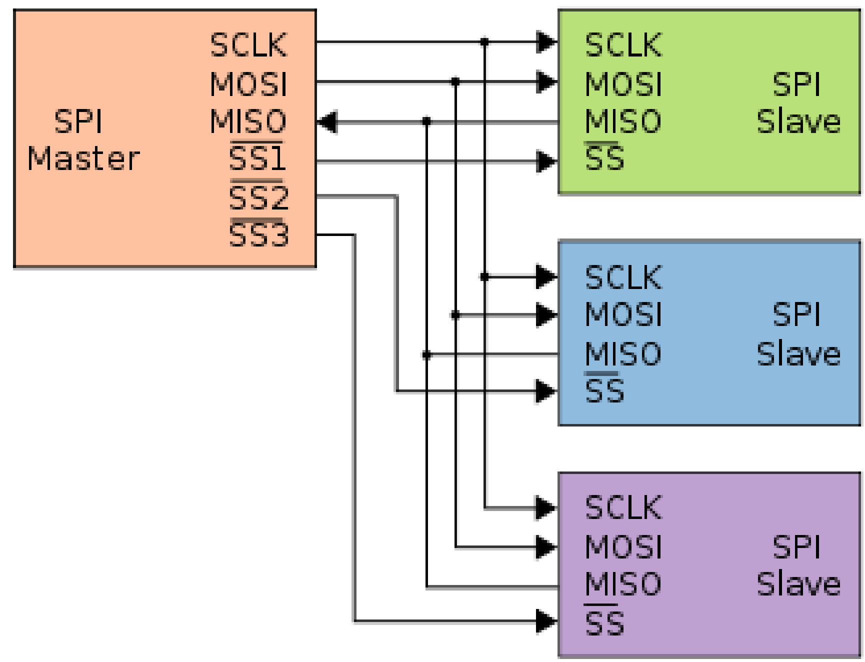


  - Serial Click (SCLK or SCK): clock pulse that synchronizes data transmission generated by master
  - Master In Slave Out (MISO): slave line for sending data to master
  - Master Out Slave In (MOSI): master line for sending data to peripherals.
  - Slave Select(SS): pin on which device the master could use to enable/disable specific devices

Serial Peripheral Interface (SPI)

- Multiple Slaves Model
  - One master
  - Full duplex communication





Serial Peripheral Interface (SPI)

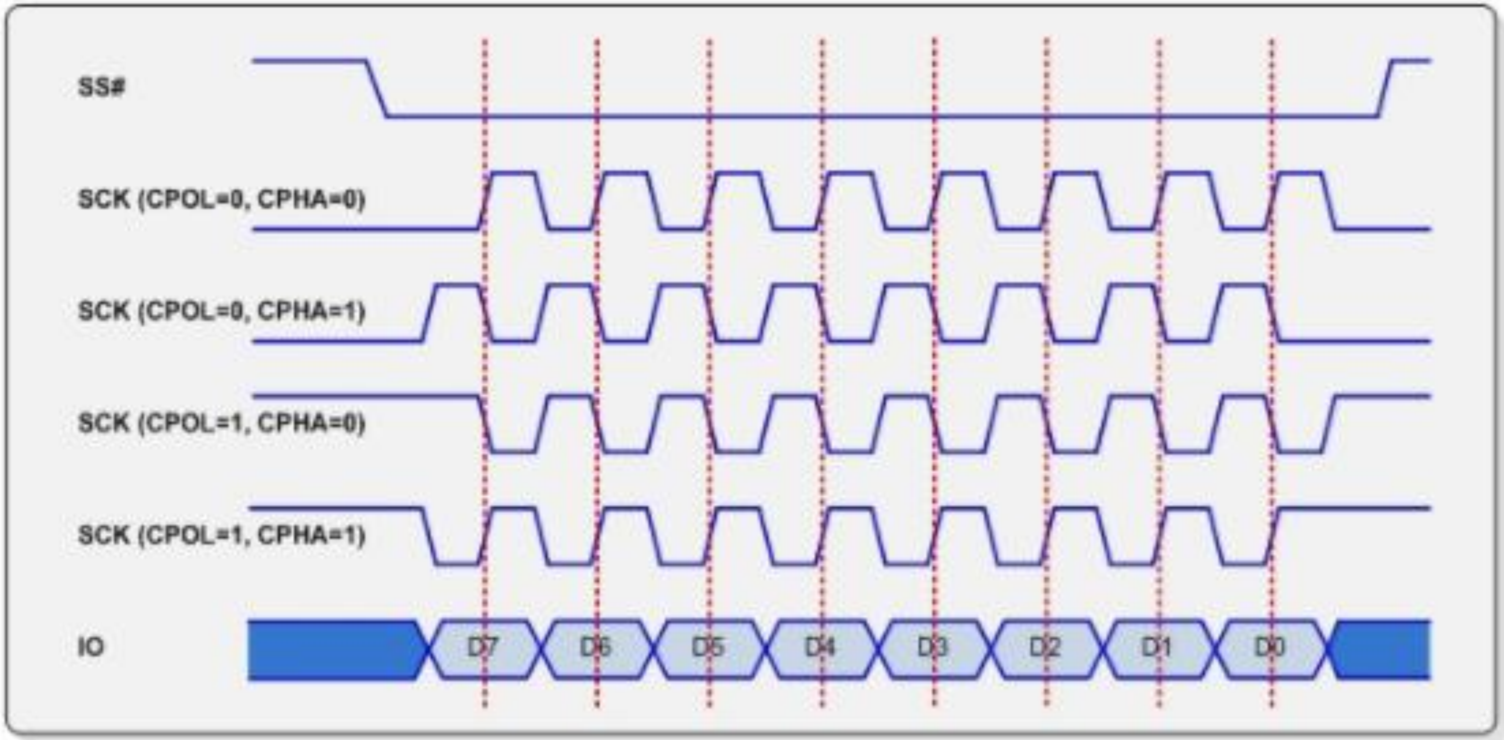
- Bus Standard
  - Clock Priority (CPOL): designate default value (high/low) of SCK signal
  - Clock Phase (CPHA): determine which edge of clock data is sampled(rising/falling)

Mode	CPOL	CPHA
0	0	0
1	0	1
2	1	0
3	1	1

CPOP = 0 and CPHA = 0 indicates that the data is sampled at rising edge.

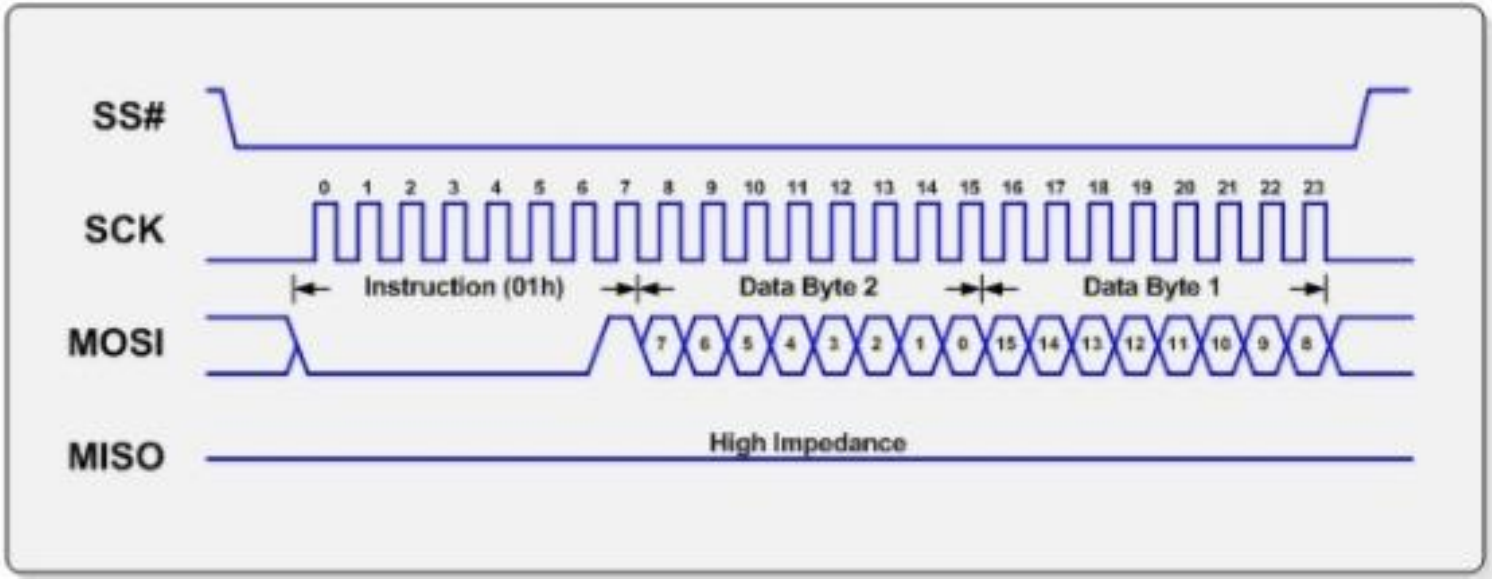
Serial Peripheral Interface (SPI)

- Bus timing



Serial Peripheral Interface

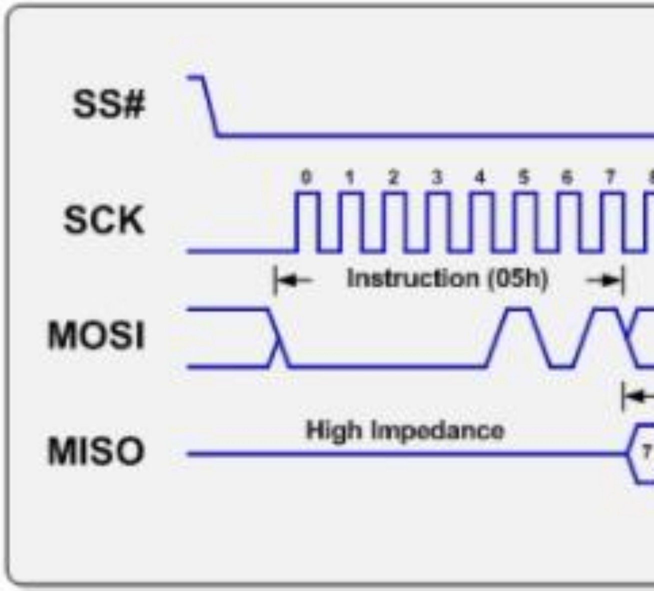
- Write/Read Transaction
  - Write Transaction



    - lower SS# to select slave device
    - sending instruction bytes and data bytes via MOSI

Serial Peripheral Interface

- Write/Read Transaction
  - Read Transaction



- lower SS# to select slave device
- sending instruction byte via MOSI and receiving data byte by MISO

SPI v.s. I2C

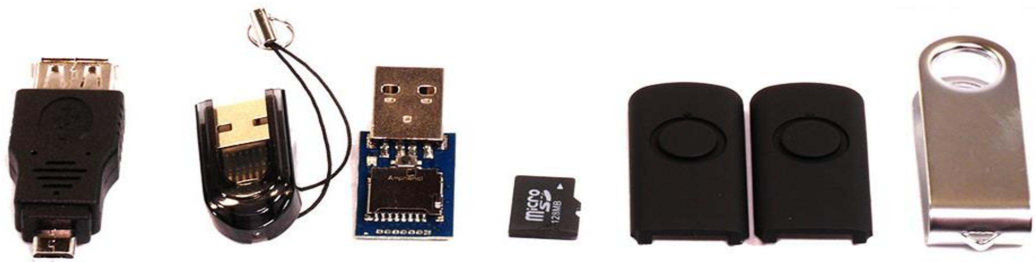
- Which one?
  - I2C require two wires while SPI may need more
  - SPI support full-duplex communication while I2C is slower
  - I2C is more power-consuming than SPI
  - I2C has ACK to verify data transfer while SPI is not
  - I2C may have multiple master but SPI only has one master

SPI v.s. I2C

- SPI
  - high speed and low consumption application
  - faster
- I2C
  - large number of peripheral requirement and multiple masters
  - flexible
- But both are robust protocols for embedded applications

Universal Serial Bus (USB)

- Universal Serial Bus (USB)
  - USB: cable, connector and communication protocols for connection, communication and power supply between computer and devices.



COMPAQ NORTEL Microsoft

digital

NEC IBM intel

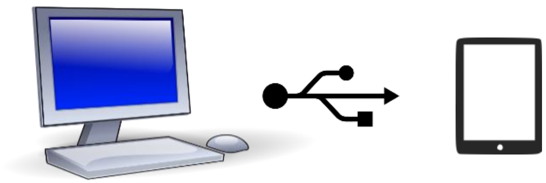
Universal Serial Bus (USB)

- USB Evolvement

Universal Serial Bus (USB)

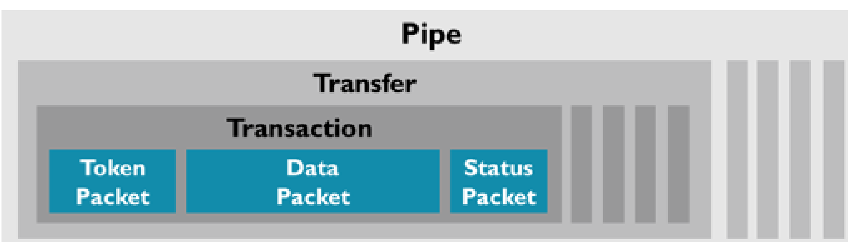
USB OTG cable.

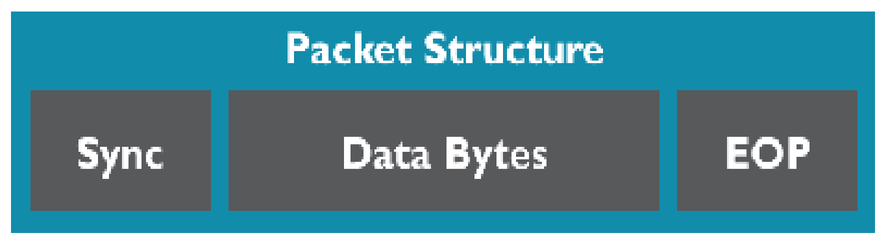
- Master-Slave connection
  - Master: deciding what happen
    - Hardware
      - Detecting USB connection
      - Providing electrical power
      - Controlling data transfer
    - Software
      - Handling connectivity
      - Configuring USB devices
      - Running device driver
      - Managing power and bandwidth
  - Slave: listening

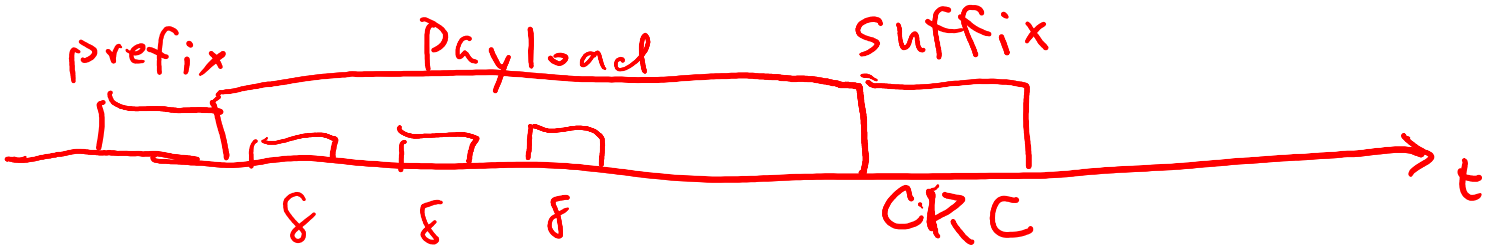


Universal Serial Bus (USB)

- Complex Protocol
  - Data Transmission consists of three packets
    - Token packet: header that defines transaction type, direction, device address and endpoint
    - Data packet: transmission of data
    - Handshake packet: acknowledgement of final status for transaction





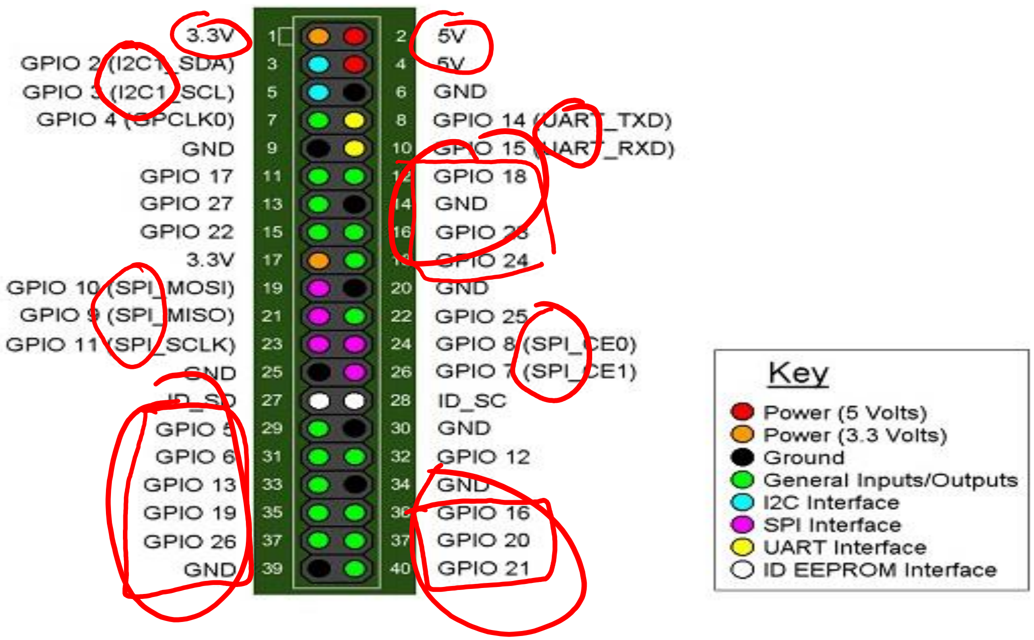


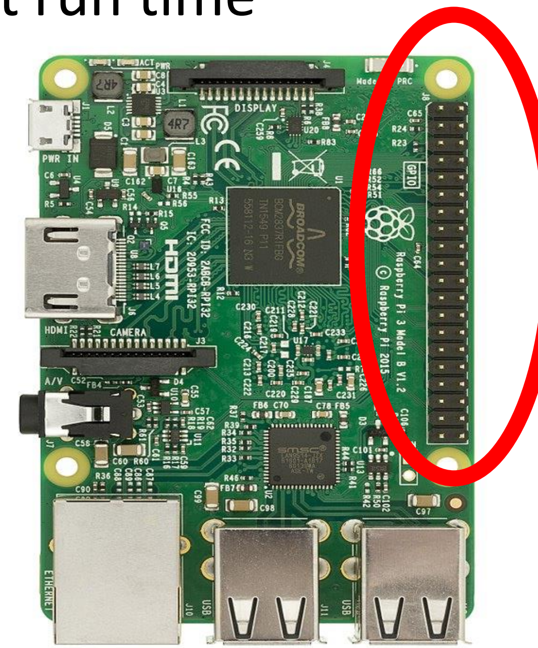
Universal Serial Bus (USB)

- 4 Data Transfer Type
  - Control transfer: exchange configuration, command information between device and host
  - Isochronous transfer: used by time-sensitive application such as speaker, video camera
  - Bulk transfer: used by scanners and printers that receive data in one big packet and time is not crucial
  - Interrupt transfer: used by peripherals which need immediate attention from host

General Purpose Input/Output

- General Purpose Input/Output (GPIO)
  - physical pins on board, not a bus
  - input/output behavior controlled by user at run time
  - no predefined purpose on pins

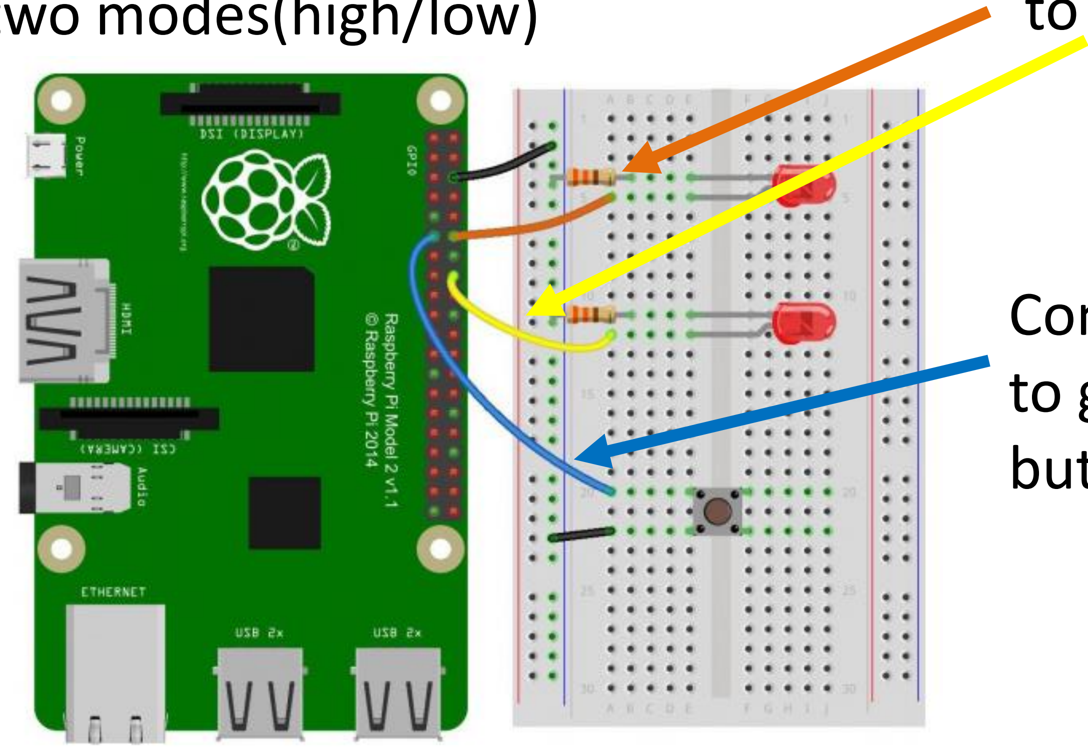




General Purpose Input/Output

- Pin Operation
  - pin could be configured input/output
  - pin could be disabled/enabled
  - two modes(high/low)

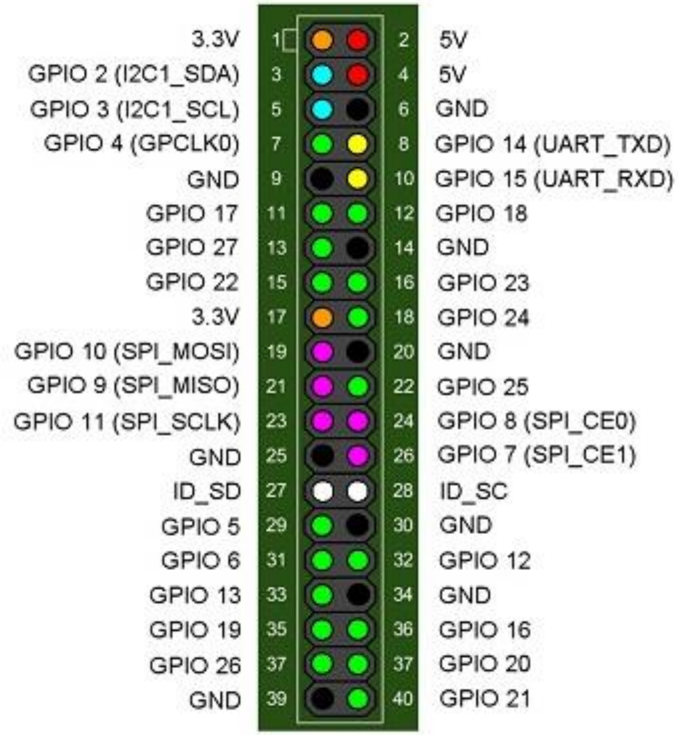
Configured as output to light LED



Configured as input to get motion of push button

General Purpose Input/Output

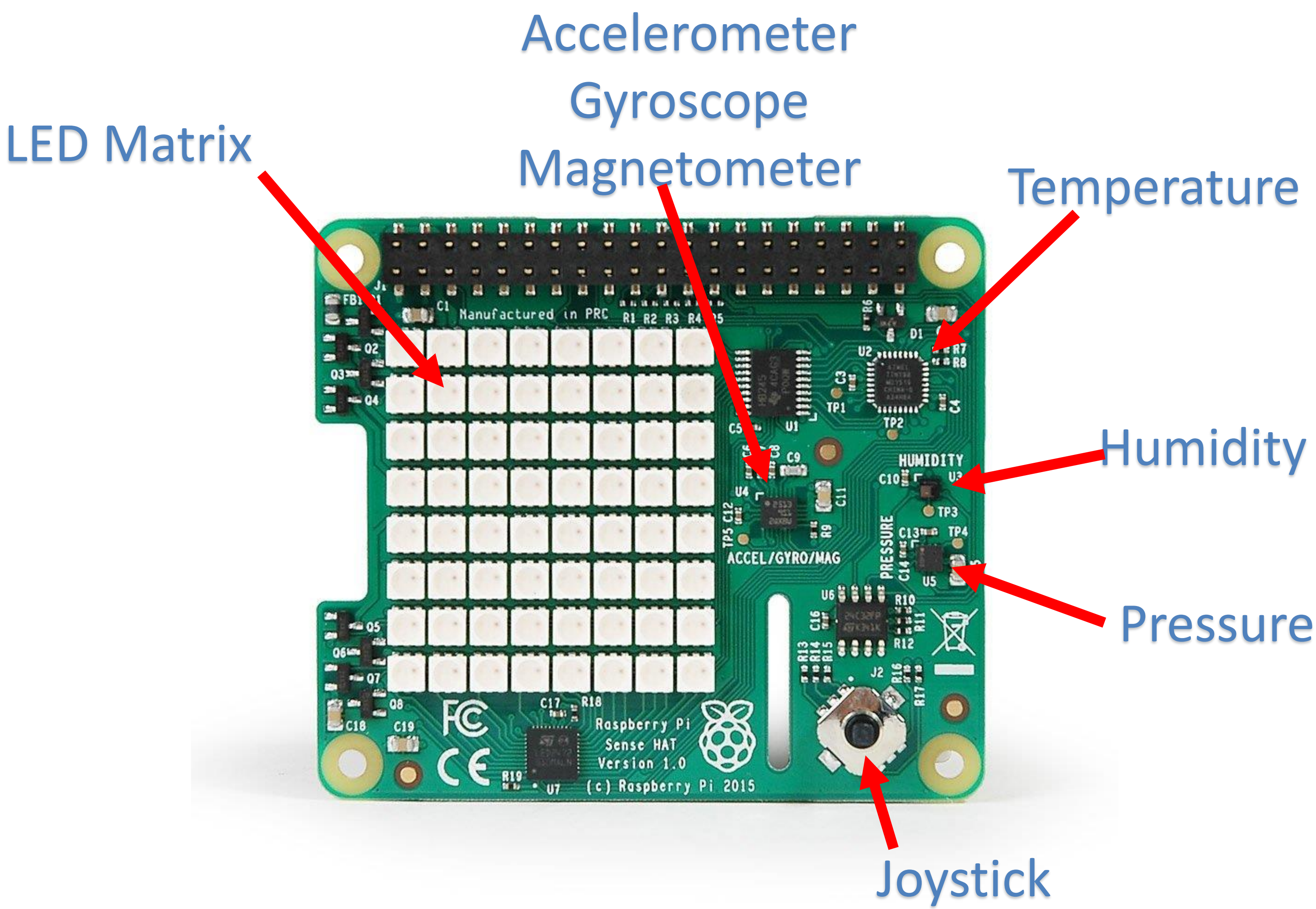
- Protocols on Pi’s GPIO
  - I2C
    - GPIO 2 & 3: SDA and SCL
  - SPI
    - GPIO 7 & 8: SS
    - GPIO 9, 10 & 11: MISO, MOSI, SCK
  - UART
    - GPIO 14 & 15: TXD and RXD
  - Other GPIO pin
    - power, ground and normal pin with Input/output configuration



Lab 2

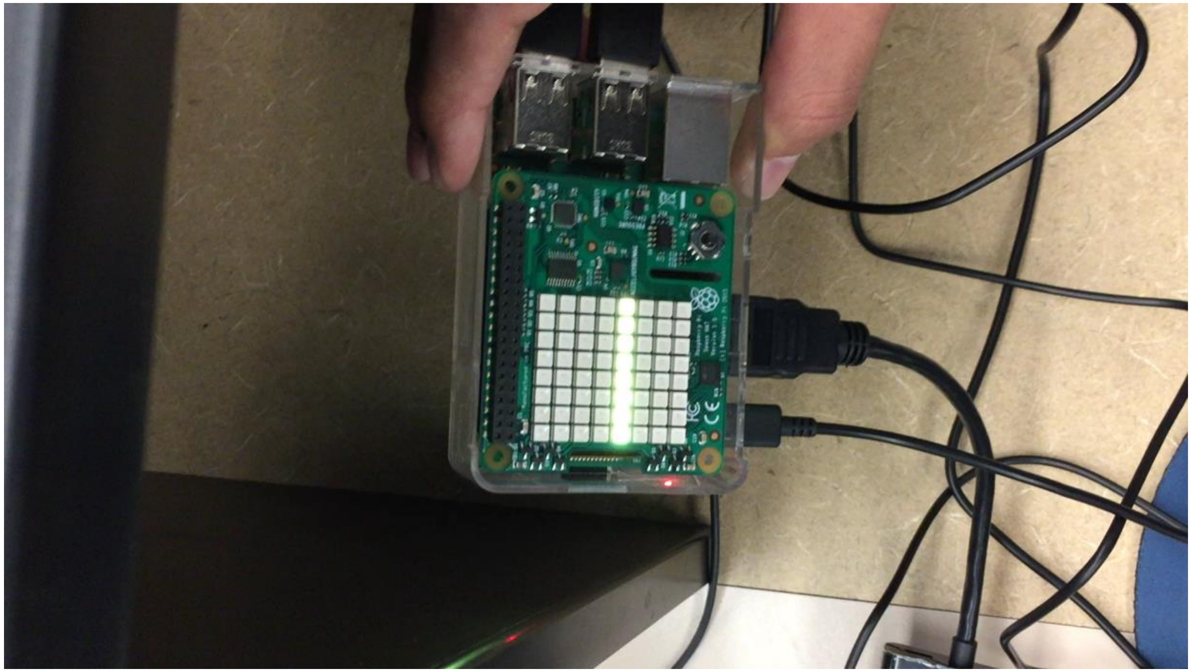
- Lab 2 is due on 2/14
  - 6% in final grade
  - You will work on it on your own
    - No collaboration is allowed!
  - Need to let the TA check you off
- Practicing with I/O over Raspberry Pi
  - Using the pre-installed Python libraries to operate SenseHAT
  - Interrupts over Linux OS

Sense HAT


Accelerometer
Gyroscope
Magnetometer
LED Matrix
Temperature
Humidity
Pressure
Joystick

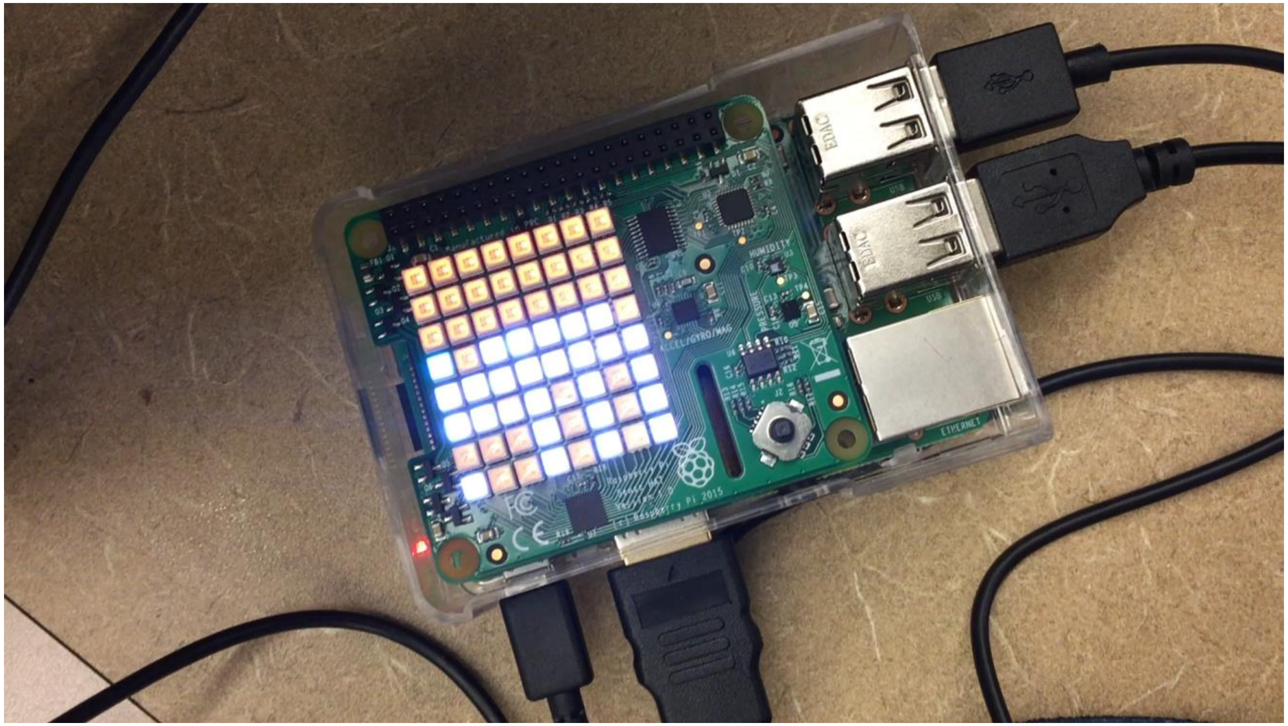
Sense HAT

- Python Library
  - Raspbian offers Python Library for easy access to everything on board.
  - Sensing accelerometer and showing direction



Sense HAT

- Python Library
  - Reading temperature, pressure and humidity data from sensors and displaying on LED matrix



Sense HAT

- Python Library
  - Displaying images