IoT with python and Raspberry Pi

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Why would I do IoT?

- Its for everybody!
- Started just for fun
- Some serious experimentation
- Making scientific instruments
- Internet control gives multi-functionality to experiments

Outline of workshop

1. Introduction to IoT and Raspberry Pi (30 Minutes)
   - Intro to IoT
   - Various parts
   - Installing OS
2. Running python (30 minutes)
   - Writing simple programs
   - Installing packages
   - Running Numpy and Scipy
3. IoT with RPi (30 minutes)
   - Running RPi headless
   - Blinking LED
   - Some serious examples

Introduction to IoT

- IoT is a connecting **things** to internet
  - Example: Mobile phone
  - It was initially used only for two-way vice communication
  - Now it connects to internet too!
  - Its a **thing**, which is connected to **internet** $\Rightarrow$ IoT
- Two types:
  - Device computes locally and interacts on internet
    - This is simpler task which we will learn in present workshop
  - Device does not compute locally but interacts on internet
    - This is complex task outside the scope of present workshop

- Open Source hardwares
- Two examples:
  - Arduino
  - RPi
- We shall use RPi in this workshop
  - It has lot more features!
- Lets see how RPi is different than Arduino

Arduino vs RPi

Feature	**Ardunio**	**RPi**
Processor	16MHz	900 MHz
Resolution	8 bit	32 bit
Memory	32 K Flash, 2K SRAM	4GB flash, 512K/1GB SRAM
Voltage level	5V	3.3 V
Interface	No OS	Has OS

OS

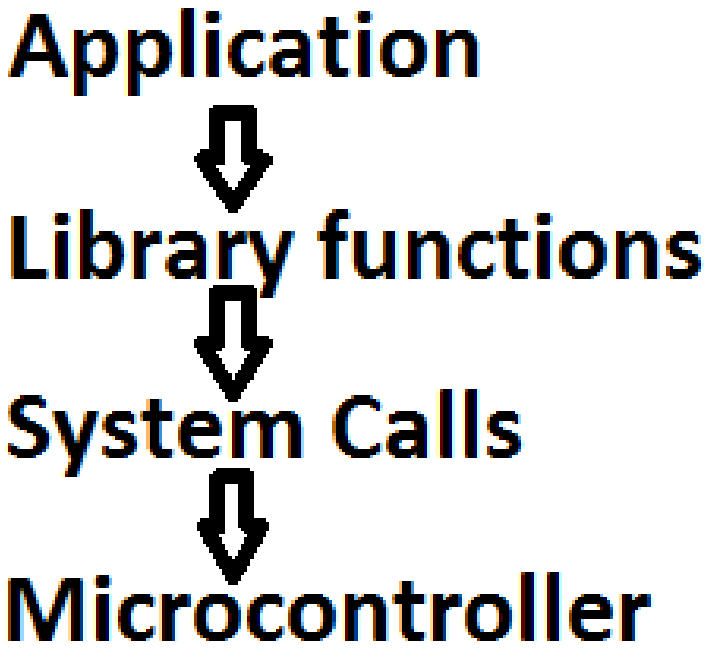


Figure: Working of OS

Arduino vs RPi

- Arduino has only an Application and a Micro-controller
  - Application directly controls the pins
- RPi has two extra layers i.e library functions and systems calls
  - Application does not directly control the pins
  - Application needs to call a library function, which in turn calls systems calls to control pins
  - **Not real time**
  - *Consumes a lot of memory for OS*

Advantages of having OS on board

User Interface

- Can use small programs provided by OS without writing code
  - Text based
    - Write commands to perform tasks
  - GUI-based
    - Point-click actions to perform tasks
- **Why use text based interface if you have GUI**
  - GUI provides only a small feature of control over OS
  - Command line provides full feature control
    - But one needs to memorize a **large** set of commands

Advantages of having OS on board

Multiple processes

- Can execute many processes concurrently
  - In Arduino, only one programs runs at a time
  - One needs to put all the features in a single program
  - In RPi, one can make a lot of small programs and call them from a master program at will
  - When one has a single core, multi-processing does not mean all processes running **at same time**
  - Time given to all processes is swapped so fast that we don't feel the difference
  - Advantage
    - Can run some processes in background while doing important tasks

Advantages of having OS on board

Easier changing hardware connected

- User Application ⇒ /dev/xxx ⇒ Device driver ⇒ Hardware device
- xxx is a file associated with a hardware device
- User simply interacts with all devices by accessing the file
- Every device is accessed in a uniform way
  - User simply interacts with file for device
  - File contains code to interact with device driver
  - The burden to working with device rests with the file
- Device driver is the code for accessing physical features of devices

Intro to RPi

- Microcomputer
  - Credit card sized (20×10 cm)
  - Weight $= 68$ g
- Very cost effective
  - Presently available for INR $2,875$ at amazon
- Low power consumption
  - We will use mobile phone charger
- Remote access over internet
  - We will use a LAN cable for connectivity
- Runs Linux
  - Raspbian is a version of Debian optimized for RPi

Versions of RPi boards

Name	**Release date**
RPi 1 Model A	February 2012
RPi 1 Model A+	November 2014
RPi 1 Model B	April-June 2012
RPi 1 Model B+	July 2014
RPi 2 Model B	February 2015
RPi zero	November 2015

Powerful IoT platform

- Broadcom 900 MHz BCM2836 ARMv7 Quad Core Processor SoC
- Broadcom VideoCore IV GPU
- 1 GB RAM
- Expanded 40-pin GPIO Header
- 4 x USB2.0 Ports with up to 1.2A output
- 4 pole Stereo output and Composite video port
- Full size HDMI
- CSI camera port for connecting the Raspberry Pi camera
- DSI display port for connecting the Raspberry Pi touch screen display
- Micro SD port for loading your operating system and storing data
- Micro USB power source

Ref: `https://www.raspberrypi.org/products/raspberry-pi-2-model-b/`

RPi

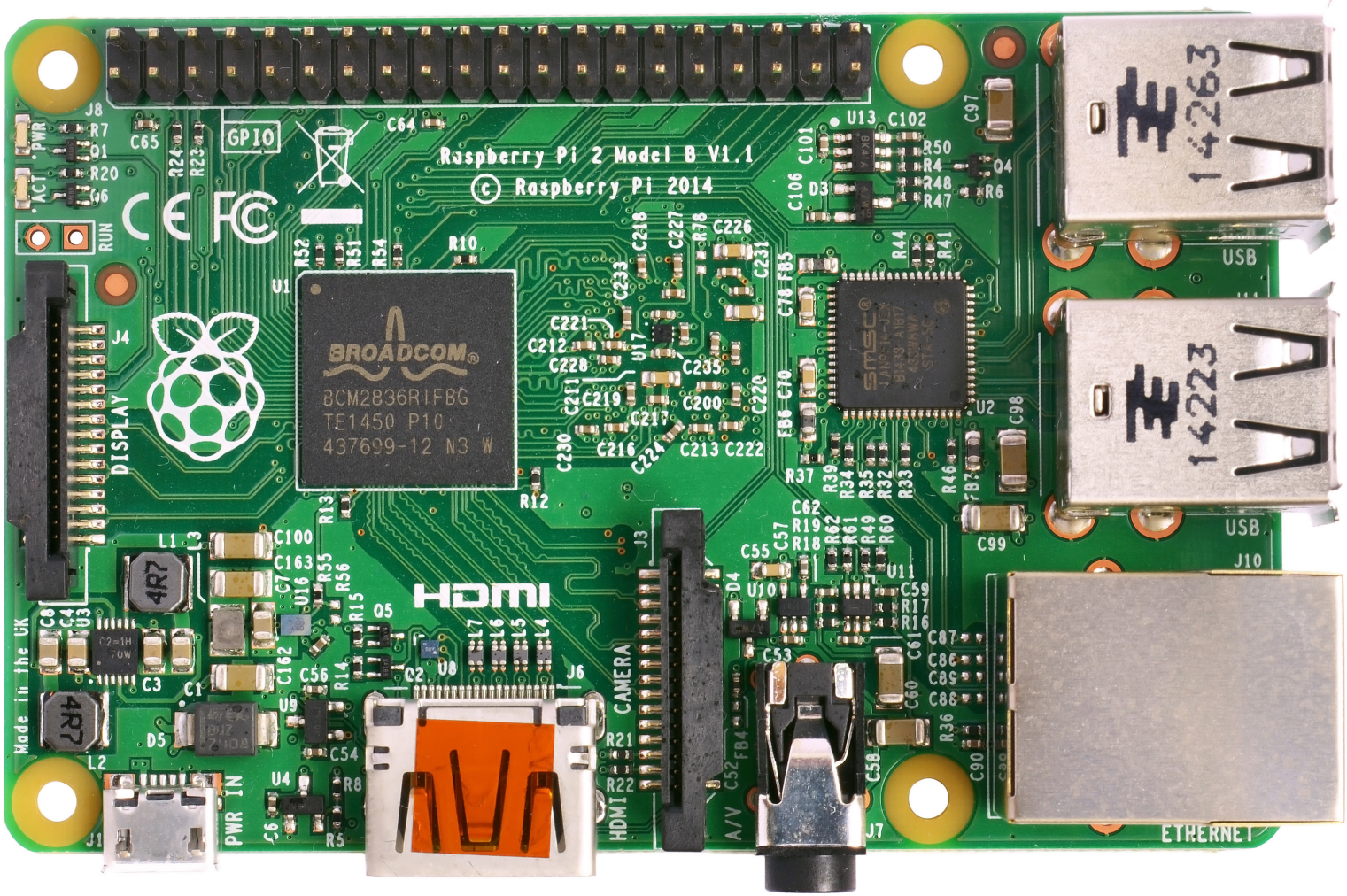


Figure: Top portion of Raspberry Pi 2 Model B

OS

- OS is installed on a micro SD card
- Raspbian is optimized OS for RPi
- Available at `https://www.raspbian.org/`
- Micro SD cards with pre-installed OS are also available
- Installation
  - Format the card
  - Install NOOBS
  - Choose Raspbian
  - Install

Hardware Connections

- Monitor
  - Using HDMI cable, connect a monitor/projector
  - If monitor has VGA port, use a VGA-HDMI adapter
- Keyboard and mouse
  - If you have wired keyboard and mouse, connect them individually to two USB ports
  - If you have set of wireless keyboard and mouse, use one USB port for adapter
- SD card
  - Use SD card slot on back side
  - Use 4GB + card for better performance and enough storage
- Power
  - Use a 5 V 2 A charger

Setup

1. Plug in monitor(HDMI), keyboard (USB), mouse (USB)
2. Get OS on a formatted microSD card
   - Format micro SD card using a SD reader
   - Use NOOBS (New Out-Of-Box Software)
   - Download from `https://www.raspbian.org/downloads`
   - Extract NOOBS download
   - Put it in micro SD card
3. Plug Micro SD card in RPi
4. Power ON the RPi
5. NOOBS GUI starts running on screen
6. NOOBS will install an OS on your micro SD card
   - Will offer a list of options
   - If you are connected to internet, it will offer a longer list
   - Click **Raspbian** and install

Configuring RPi

- First time RPi boots up, it runs a tool called **raspi-config**
  - Used to configure RPi
  - Defines username, password etc.
  - Can be invoked at any stage by writing raspi-config on terminal
  - Expand file system
    - Reformats micro SD card file system to access all the memory
  - Change User account
    - Default username is **pi** and password is **raspberry**
  - Enable boot to Console/Destop/Scratch
    - Console is default boot option
    - Choose Desktop
    - Scrach is a programming langauge for kids
  - Internationalization and Rastrack
    - Change Locale Change timezone Change keyboard Layout
  - Add to Rastrack
    - Service which allows RPi users to find one another based on IP location
    - Optional

Over Clocking

- Increasing clock frequency of device beyond recommendation
- There are a lot of clocks in RPi
- Example:
  - ARM frequency
  - SDRAM frequency
- Impact
  - Instructions are executed faster
  - About one instruction is executed per clock time period
- Risk
  - Signals might not reach destination on time
    - Whole machine fails
  - Heating
    - Lifetime of device gets shortens

Raspbian-Info

- Version of Debian(Linux) optimized for RPi
- Linux commands run
- Shell
  - Command line interface between OS and user
  - Many shells exist
  - We will use BASH (Bourne Again SHell)
  - BASH is default shell for Raspbian
- Console/Terminal
  - Text entry and display device
  - can be physical device
  - Now one mostly uses virtual terminal
    - A software emulator of terminal
  - LXTerminal is default terminal in Raspbian
  - Prompt is $

Raspbian-login

- User Accounts
  - Linux Machine can entertain multiple user accounts at same time
  - Each account is access using a **username** and a **password**
  - Process of accessing a machine using an account is called **login**
  - Default:
    - username = pi
    - password = raspberry

Raspbian-file system

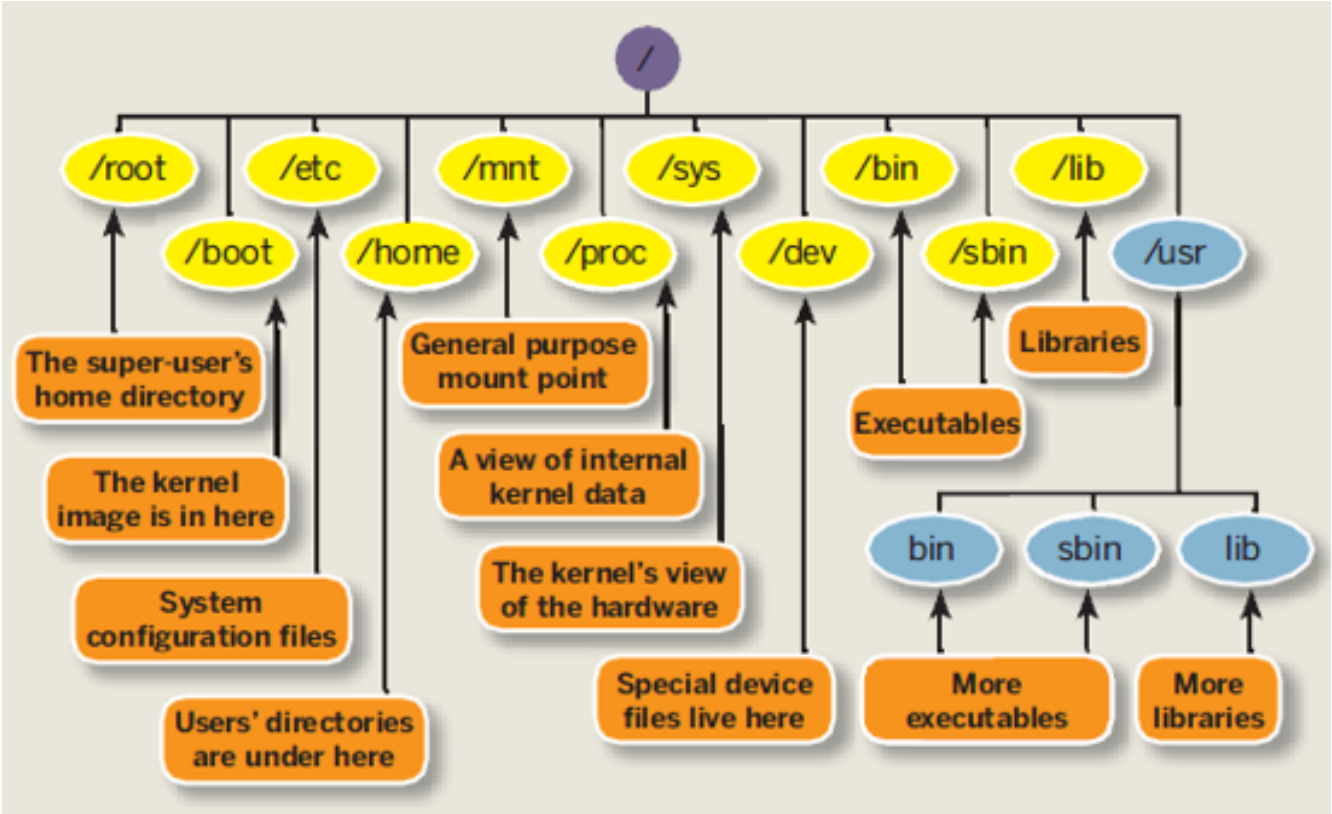


Figure: Linux file system

Ref: http://www.siongboon.com/projects/2013-07-08_raspberry_pi/images/linux_filesystem.png

Traversing raspbian file structure

- **pwd** = print working directory
- **mkdir** = make directory
- **rmdir** = remove directory
- **rmdir -r** = remove directory recursively
- **cd** = change directory
- **cd ..** = step back in directory by one step
- **/** = step back to home
- **ls** = lists the contents of directory
- **ls -l** = long list of contents with great details

Action

- Lets make a directory names "IoT"
- Lets make a subdirectory within "IOT" named "PyDelhi"
- Lets go back to directory "IoT"
- See the LIST of content of this directory
- Print the present working directory
- remove the subdirectory named "PyDelhi" and make it again

So we are ready to work on Raspbian!

Text Editors

- For creating and modifying a file
- A word processors but simpler
- Two types:
  - Command line based
    - emacs, vi, vim, nano
  - GUI based
    - gedit

Making and Viewing Files

- Write the name of text editor succeeded by file
- If a file does not exist, it is created and opened for editing
  - **nano test.py**
- **cat test** prints the file to the terminal
- **head test** prints the first 10 lines
- **last test** or **tail test** prints last 10 lines
- **cp test new-test** copes file **test** to a new file **new-test**
- **mv test a/test1** moves **test** file to a new destination (/a/) by *renaming* it **test1**
- create a file, view and edit the contents, make a copy and delete the copy and then rename it!

Making files and writing codes

- Make a file using **nano**
- Make a file named "hello.py"
- Make the following python program:
  - **print "hello world"**
- Save this file
- Check, where is this program saved!
- run this python code by writing the command
  - **python hello.py**
- Output can be checked in next line

Permission

- Files has owner (user) and defined permission
  - read (r)
  - write (w)
  - execute (x)
- Permission are assigned according to type:
  - user : file owner
  - group : a permission group
  - other : all users
- Type **ls -l** to see these permissions
- Do this at home directory
- For **Desktop** directory it shows following permission
  - **drwxr-xr-x**
  - **d** shows that its a directory
  - Next three symbols define *user* permissions **rwr**
  - Next three symbols define *group* permissions **r-x**
  - Next three symbols define *other* permissons **r-x**
- create a file and check out its permissions

Root

- Root account has highest permission level
- Key files and directory is accessible only to root
- Sometimes you would need to be root
  - To install a program
  - Change OS as per requirements
- **su** : super-user
  - asks for root password
  - If password is correct, one login as root
- **sudo**: super-user do
  - Just applies root permission for single command
  - Ex: **sudo ls** will simply apply root permission for listing the files
  - safer way!
- We would need **sudo** command to access Raspberry Pi pins

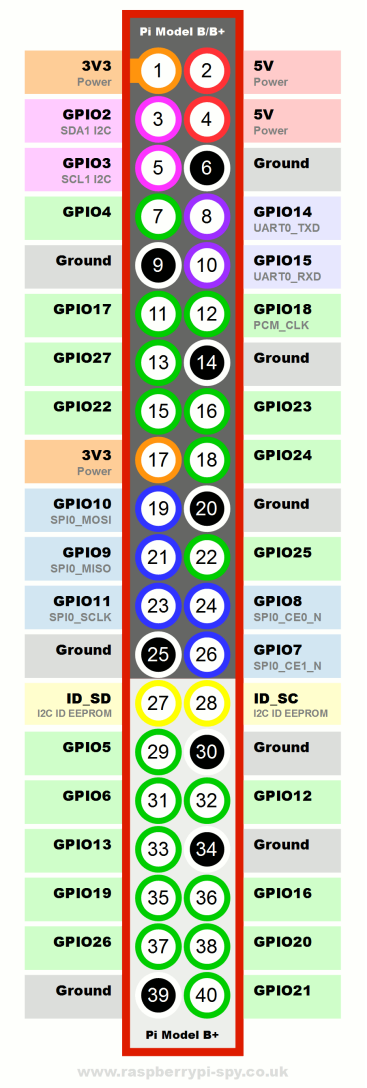
Python on RPi

- Used to program to access pins and process
- Can use any language!
- C and $C++$ requires a compiler called **gcc** which is pre-installed
- Python interpreter is also pre-installed
- We shall use Python 3 instead of Python 2 here because most packages for RPi usage are written in Python 3

Other ways to work with python on RPi

- Python programming Environments
  - IDE
    - Combines the facilities of interpreter and text editor
    - Default IDE is IDLE
    - Invoke: Menu $\rightarrow$ Programming $\rightarrow$ Python
    - Select Python 3
  - Text-editor and interpreter separately
    - Use **nano** to write code (ex: hello.py)
    - Execute the program by typing **python3 hello.py**

GPIO configuration



GPIO

- Dedicated power and ground pins
  - $3.3V (1, 17)$
  - $5V (2.4)$
  - GND $(6, 9, 14, 20, 30, 39)$
- GPIO = General Purpose Input Output
- Make pins *input* or *output* pins as per choice
- There are two numbering systems
  - pin number based on location
  - Pin number given as GPIO1, GPIO2 etc.

Protocol pins

- **I2C**
  - Pin no.3 (GPIO2) = SDA1 I2C
  - Pin No.5 (GPIO3) = SCL1 I2C
  - Serial communication protocol between two chips relatively closely placed and need to share a clock Two wire protocol (SDA = sends Data signal, SCL = sends Clock signal)
- If there are several I2C compatible devices, one can connect their SDA and SCL lines together for serial communication between them

Protocol Pins

- **SPI**
  - 19 (GPIO10) = MOSI (Master Out Slave In)
  - 21 (GPIO9) = MISO (Master In Slave Out)
  - 23 (GPIO11) = SCLK (S Clock)
  - 24 (GPIO8) = CE01 (Chip Enable)
  - 26 (GPIO7) = CE02 (Chip Enable)

Lets start!

Now lets start doing some stuff

Connecting RPi to internet

- Two ways:
  - Wired connection at built-in RJ45 connector
  - Use a USB wireless adapter compatible with Linux OS
    - Start **wifi config** program from the desktop
    - Click *Scan* to find networks
    - Select a network and give a password
    - DHCP (Dynamic Host Connection Protocol) is needed to get an IP address
    - Check connection using *ping*
    - RPi default browser is called *Epiphany*

Firewall

- Firewall block certain application
- Check the firewall of your network
- Get help from network administrator to unblock the application if you wish to use the same

Headless running Pi

- Remember that usually we use BASH (Bourne Again SHell) on RPi
- SSH (Secure SHell):
  - Used for *secured remote* connection
  - SSH runs on local machine (ssh client) to connect to a remote machine (ssh server)
  - Both machines must be connected to internet
  - For present workshop:
    - ssh client = Your laptop
    - ssh server = RPi
- *telnet* is another program which can connect to remote computer but it is not secured
- We shall use SSH in following lecture
- Commands typed at client are executed at server
- Text printed by server appears on client screen
- SSH has a command line tool!

Headless running Pi

- We will connect to RPi ssh server using virtual terminal in laptop (client)
- SSH client program is installed by default in Linux and MAC OSX
- Windows users can use putty (`http://www.putty.org/`)
- SSH server on RPi
  - SSH server must be **started**
  - Raspbian runs SSH server as demon by default so it need not be started
  - User must have an account on server machine
    - Must know username and password
  - Firewall must allow SSH application
- Open a terminal and type
  ssh < *username* > @ < *domainname* >
- If username is found on remote machine then *password* is needed to login

Headless running Pi

- You will get a message that address could not be authenticated
- Enter **yes** to continue
- It remembers the credentials for next time onwards
- Running RPi as SSH server removes the need for keyboard, mouse and monitor
- This is termed as **headless running**

Private host ID keys

- Should change private host ID keys
- Private host ID keys are provided during configuration
- They are same on all RPis so others can listen to your communication
- type the following command at the terminal as a single line
  sudo rm /etc/ssh/ssh_host_* && sudo dpkg-reconfigure openssh-server

Blinking an LED

```
# Python Program to blink an LED connected at pin 1

import Rpi.GPIO as GPIO
import time
GPIO.setmode(GPIO.BOARD)
GPIO.setup(13,GPIO.OUT)
while True:
    GPIO.output(13,True)
    time.sleep(1)
    GPIO.output(13,True)
    time.sleep(1)
```

Program: blink.py

Reading a pin connected to a sensor

```
# Python Program to read a sensor at pin 13

import Rpi.GPIO as GPIO
import time
GPIO.setmode(GPIO.BOARD)
GPIO.setup(13,GPIO.IN)
while True:
    value = GPIO.input(13)
    print value
```

Program: sensor.py

Generating Analog like signal using PWM

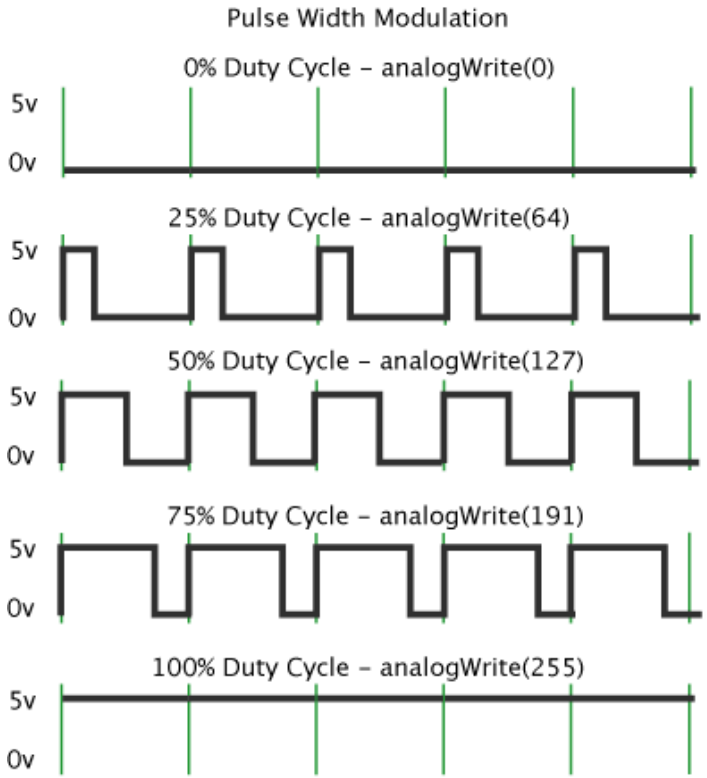


Figure: PWM signal showing different duty cycle

Ref: `https://upload.wikimedia.org/wikipedia/commons/4/49/Pwm_5steps.gif`

RPi Python commands for PWM

- **pwmObject = GPIO.PWM(18,500)**
  - A new objects named **pwmObject** is created at pin 18 which will be readied for generating signal at 400 Hz
  - Various methods can be assigned to this object
- **pwmObject.start(50)**
  - Starts generating a PWM signal at pin 18 with duty cycle of 50 %
- **pwmObject.changeDutyCycle(75)**
  - Changes duty cycle to 75 %

Because RPi has an OS which produces unpredictable time delays, the frequencies obtained by PWM may not be very accurate, especially at higher frequencies