Introduction to Embedded Systems

Unit 2.2: Raspberry Pi

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INCS 3610
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Single board computers

- Small boards with lots of I/O, often for use in embedded systems
- Often put out by companies trying to encourage use of their chips
- Examples:
  - TS-7600
  - Pandaboard / Beagleboard / Beaglebone
  - Gumstix
  - Raspberry Pi
  - Pi clones (Orange, Banana, etc)
  - Arduino Uno Q (brand new!)
  - Odroid

Raspberry Pi

- Note there are two separate (but related) organizations:
  - Raspberry Pi Foundation – charitable group to encourage computer science education
  - Raspberry Pi, Ltd – company that makes and sells Raspberry Pi Boards
  - Their goals don’t always line up
  - During parts shortage extremely limited board availability, Ltd was prioritizing businesses over education institutions

What is a Raspberry Pi?

- Raspberry Pi Foundation wanted small board to encourage CS in schools
- Easy to use and cheap enough that students can experiment without worrying too much about bricking it
- Back in the day small micro-computers encouraged hacking, modern Windows systems not so much

Why use a Raspberry Pi?

- There are other small embedded boards (Beaglebone, etc.) but Pi has many nice features
  - high performance (especially pi4/pi5)
  - low cost (relatively, with less RAM)
  - small footprint (about 9x6cm)
  - using Linux so no software-lock-in (STM hal?)
  - relatively well documented (but still not great)
  - available software/support (this is big!)
- Other ARM boards give kernel blob with no support and quickly gets out of date / no commits upstream

Raspberry Pi models

- Model names originally from BBC Micro
- Up through pi4 all have more or less same SoC.
  - VideoCore IV GPU runs show (VI pi4, VII pi5)
- First released in 2012
- They like to release new models just after I’ve bought the older models for my cluster

BCM2835/BCM2708 – ARM1176 (ARMv6)

- Single core, slow ethernet
- Model 1B – 700MHz, 512MB RAM, SD, USB hub+USB Ethernet
- Model 1B+ – like B but micro-SD, composite video-out inside of audio jack, 4 USB ports, longer GPIO header, re-arranged outputs, more mounting holes, fewer LEDs, lower power
- Model 1A / Model 1A+ – less RAM (256MB/512MB), no Ethernet, no USB hub, cheaper, less power
- Zero – 1GHz, 512MB, smaller, cheaper, $5
- Zero W – 1GHz, has wireless, $10
- Compute Node – like B but on SO-DIMM backplane, eMMC

BCM2836/BCM2709 – ARM Cortex A7 (ARMv7)

- Model 2B (original) – like 1B+ but with 1GB RAM, 900MHz Quad-core Cortex A7

BCM2837/BCM2710 – ARM Cortex A53 (ARMv8)

- Model 3B – 4-core 64-bit, 1.2GHz, wireless Ethernet, bluetooth (crash on OpenBLAS Linpack)
- Model 2B (v1.2) – update with Cortex A53
- Model 3B+ – better thermal, faster Ethernet (1GB but maxes at 300MB), power over Ethernet header. Still only 1GB RAM
- Model3 A+, Compute 3

BCM2711 – ARM Cortex A72 (ARMv8)

- Model 4B
  - 1.5GHz, Videocore VI at 500MHz
  - USB-C power connector
  - 1, 2, 4 or 8GB RAM
  - USB3, microHDMI*2
  - PCIe if you de-solder USB chip
  - Real gigabit Ethernet
  - GPIO header has more i2c/spi etc options
- pi400: built into keyboard (4GB 1.8GHz)

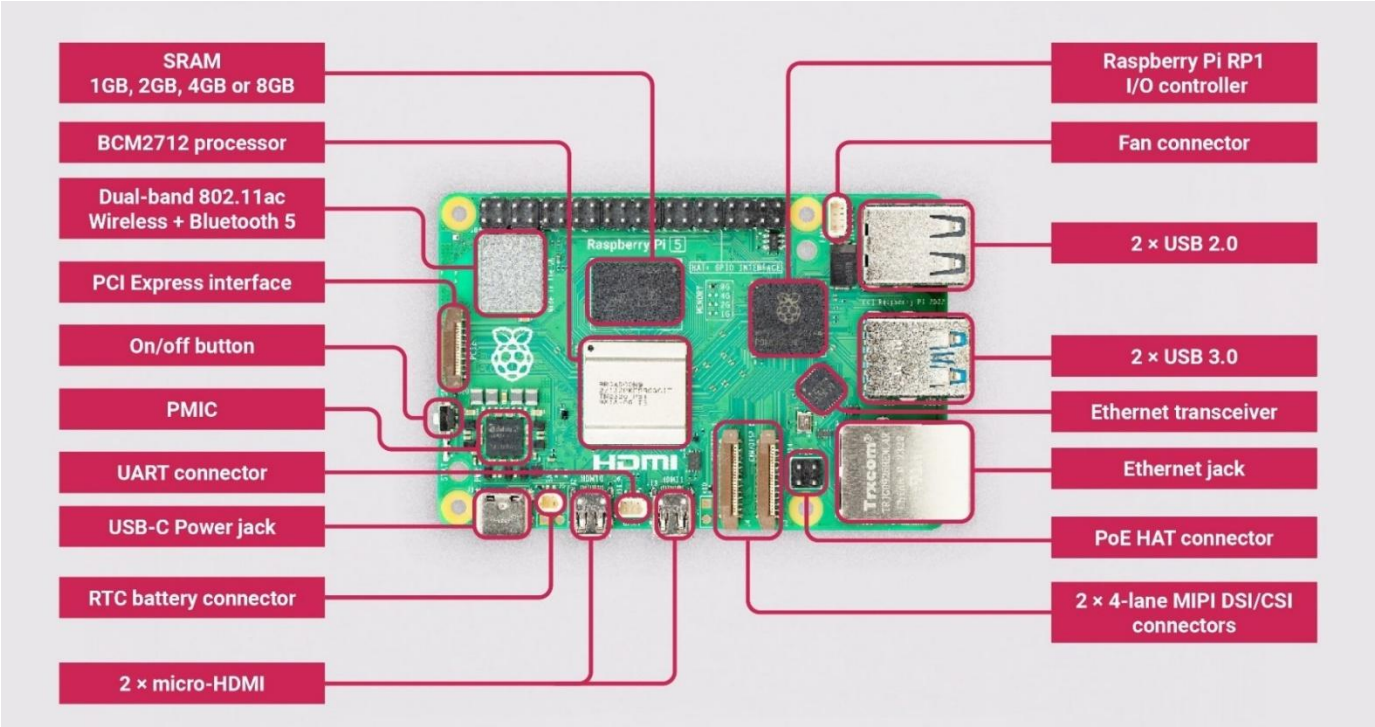
BCM2712 – ARM Cortex A76 (ARMv8.2)

- Model 5:
  - 2GB / 4GB / 8GB / 16GB(?) RAM
  - Power button!
  - Videocore VII
  - USB-C power (wants 5V at 5A if possible)
  - Official PCIe support
  - Drop headphone jack (composite video via header)
  - Move peripherals to separate chip built with older process
  - Real time clock (no battery by default)
  - PIO (programmable I/O), on-board Cortex M3?
- pi500: built into keyboard, 8GB

Pi Pico - RP2040

- Pi Pico
  - Can’t run Linux
  - Completely new design, custom SoC
  - 133MHz Dual core ARM-cortex M0+
  - 264k SRAM / 2MB Flash / $4
- Pi Pico2
  - ARM Cortex M33 and RISC-V processors
  - 520k RAM, optional wifi/bluetooth

Detailed view of Raspberry Pi Model 5 board



Raspberry Pi vs. Arduino

- Raspberry Pi (RP) is a Microcomputer
- It has an ordinary Operating System (OS)
- You can connect USB devices, Keyboard, Mouse, Monitors, etc.
- It has a “hard-drive“ in form of a microSD card
- RP has Bluetooth, Wi-Fi, and Ethernet connection
- RP has basically all the features an ordinary computer has but in a much smaller package
- 2, 4 or 8 Gb RAM
- RP runs Linux applications

- Arduino is a Microcontroller
- Arduino has a Bootloader and not an ordinary operating system
- Arduino is NOT a computer, only a small controller, whose purpose is to control things
- No Bluetooth, Wi-Fi (some models have), and Ethernet (but can be provided as so-called Shields)
- Has analog input pins
- Very little RAM (a few Kb)
- Inexpensive

- Both have digital pins
- Both have SPI and I2C

Raspberry Pi OS

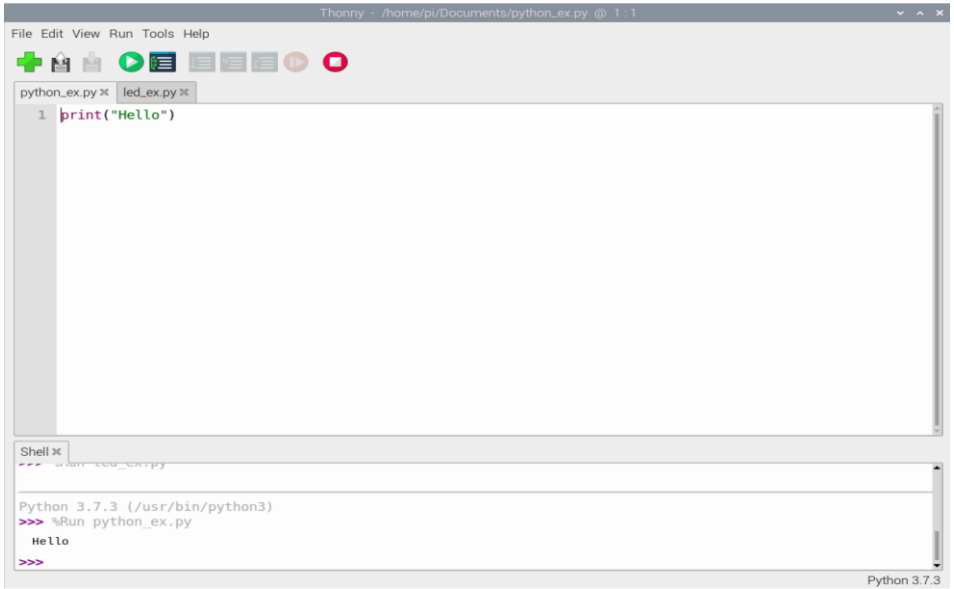
- A free operating system based on Linux kernel
- Optimized for the Raspberry Pi hardware
- 35,000+ packages
  - communication package
  - sound package
  - graphics package
  - Complete list: http://www.raspberryconnect.com/raspbian-packages-list
- Pre-installed software
  - Python, GCC, Mathematica, …
  - Other utilities

Other operating systems

- Risc OS
  - Unix-like OS
  - Incompatible with Linux software
- OpenELEC/RaspBMC
  - Entertainment system
  - Design for media play center
- Arch Linux/Ubuntu Mate
  - Linux experience required
  - Not for beginner
- Windows 10 IoT

Software/Programming the Pi

- Many, many options
- You'll likely use C or Python
- Raspberry Pi OS comes with a basic Python editor called "Thonny":

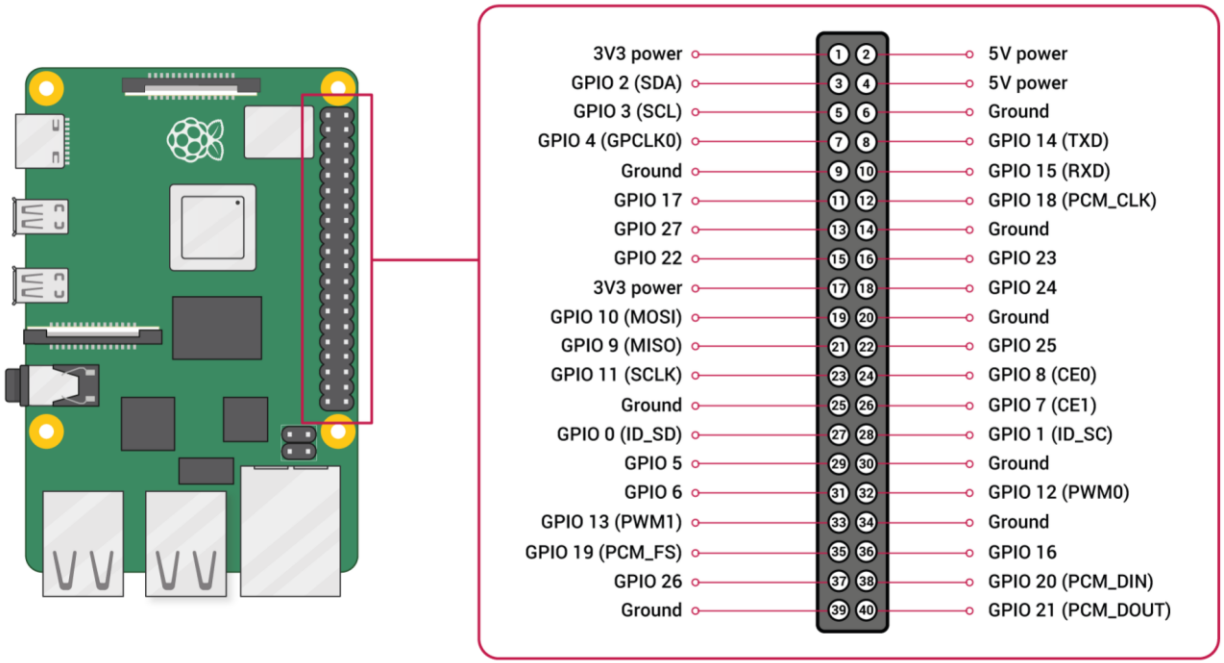


GPIO

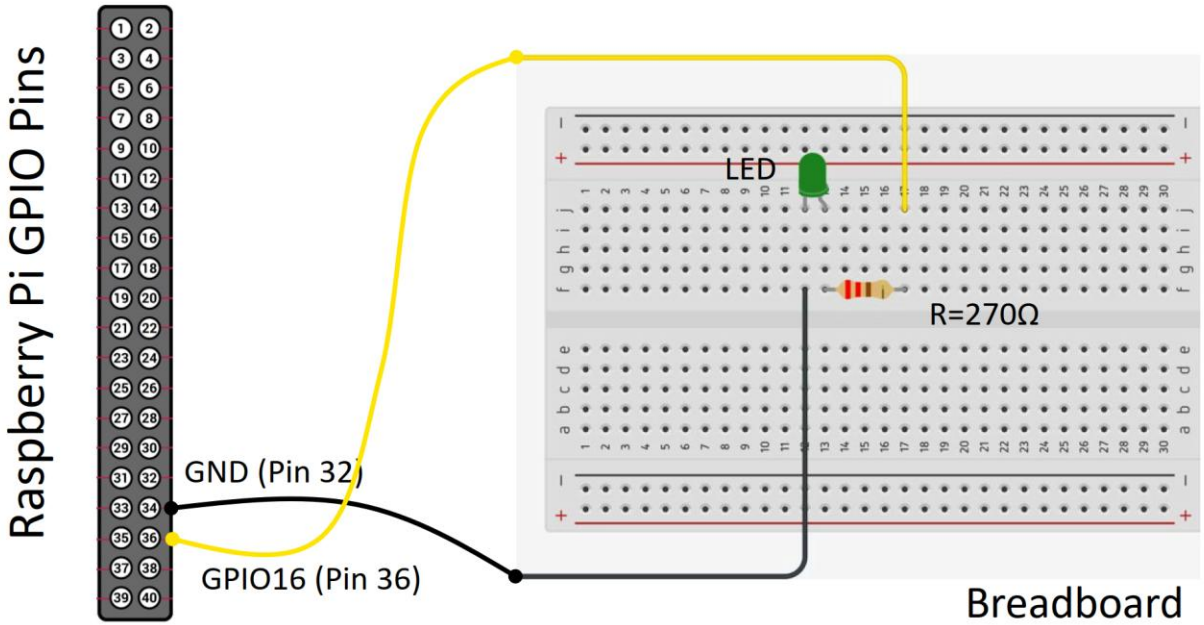
- Raspberry Pi is well-suited for prototyping, datalogging and different electronics projects using the GPIO pins
  - Either high (+3.3V) or low (0V)
  - Supports SPI, I2C, and PWM

- Can use Python in order communicate with GPIO pins via the GPIO Zero library
  - Comes pre-installed with Raspberry Pi OS

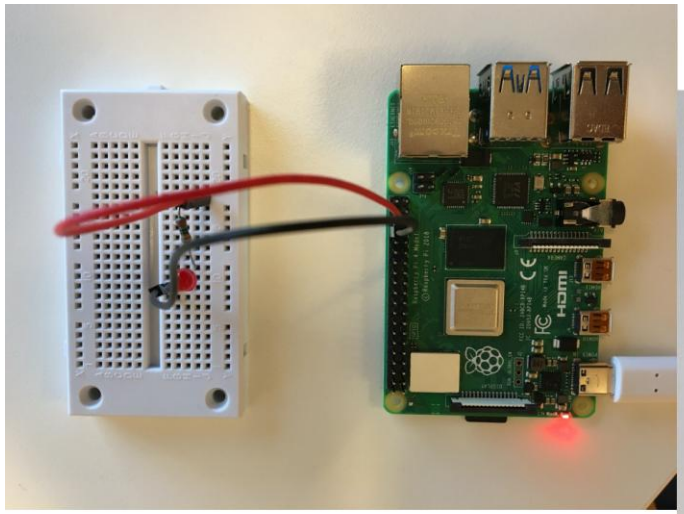
GPIO layout

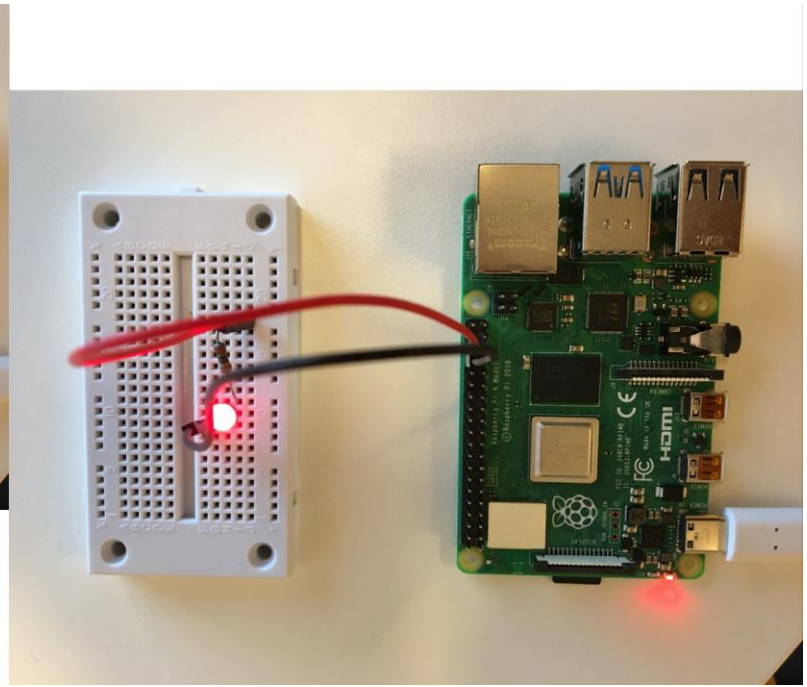

3V3 power
GPIO 2 (SDA)
GPIO 3 (SCL)
GPIO 4 (GPCLK0)
Ground
GPIO 17
GPIO 27
GPIO 22
3V3 power
GPIO 10 (MOSI)
GPIO 9 (MISO)
GPIO 11 (SCLK)
Ground
GPIO 0 (ID_SD)
GPIO 5
GPIO 6
GPIO 13 (PWM1)
GPIO 19 (PCM_FS)
GPIO 26
Ground
1 2
3 4
5 6
7 8
9 10
11 12
13 14
15 16
17 18
19 20
21 22
23 24
25 26
27 28
29 30
31 32
33 34
35 36
37 38
39 40
5V power
5V power
Ground
GPIO 14 (TXD)
GPIO 15 (RXD)
GPIO 18 (PCM_CLK)
Ground
GPIO 23
GPIO 24
Ground
GPIO 25
GPIO 8 (CE0)
GPIO 7 (CE1)
GPIO 1 (ID_SC)
Ground
GPIO 12 (PWM0)
Ground
GPIO 16
GPIO 20 (PCM_DIN)
GPIO 21 (PCM_DOUT)

Blinking LED GPIO example

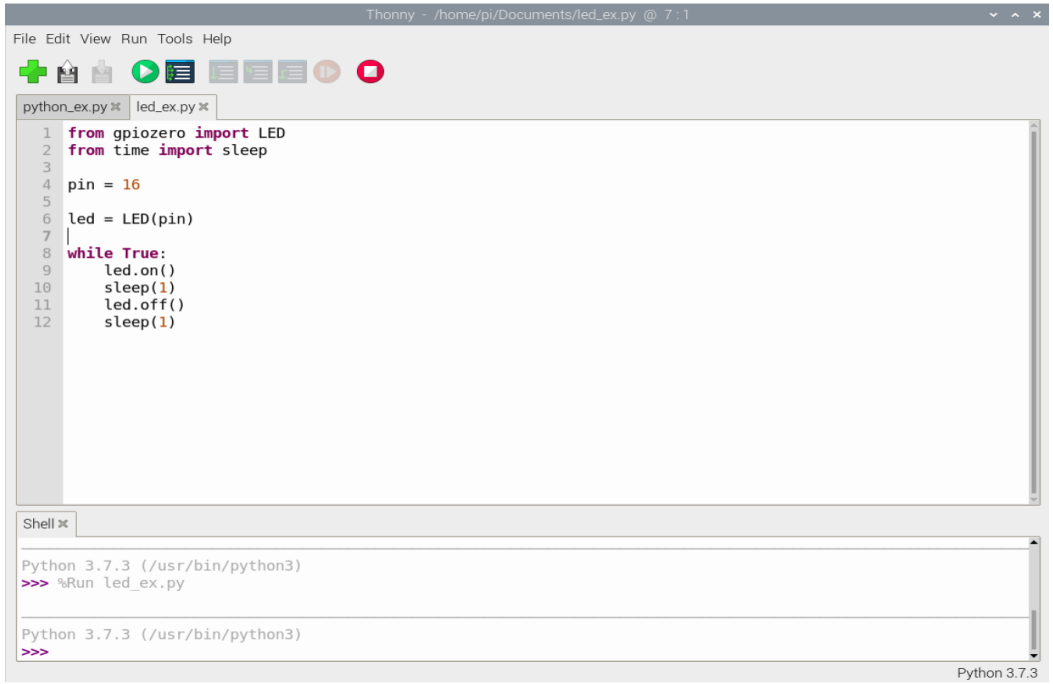


Blinking LED GPIO example





Blinking LED GPIO example



ThingSpeak with Raspberry Pi

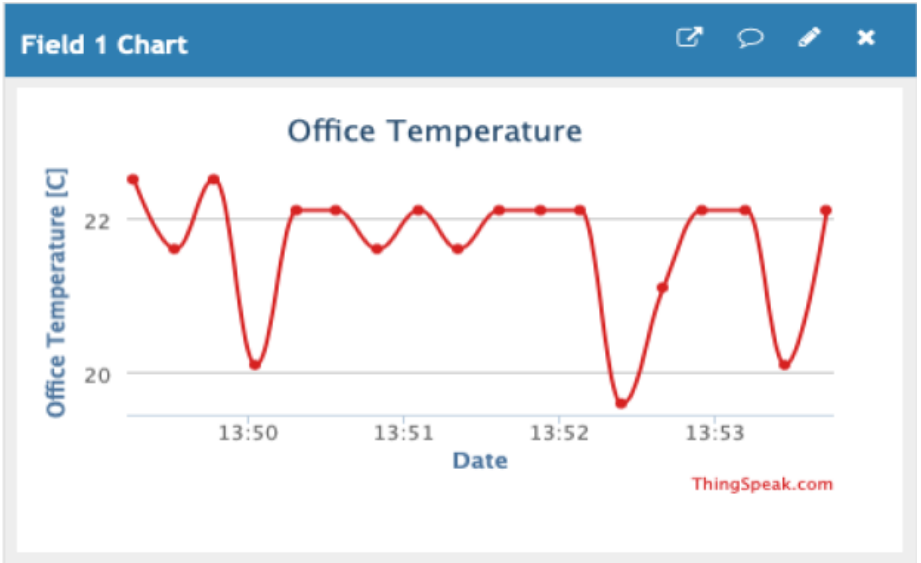
- ThingSpeak is a IoT cloud service that lets you collect and store sensor data in the cloud and develop IoT applications.
  - ThingSpeak homepage: https://thingspeak.com
- It works with Arduino, Raspberry Pi, etc.
- Can use Python to communicate with ThingSpeak channel
  - Python library: https://pypi.org/project/thingspeak/

Writing TMP36 temperature data example

```
import thingspeak
import time
from gpiozero import MCP3002

adc = MCP3002(channel=0, differential=False)

channel_id = xxxxxxx
write_key  = "xxxxxxxxxxxxxxxxx"

channel = thingspeak.Channel(id=channel_id, api_key=write_key)

N = 10
for x in range(N):
    #Get Sensor Data
    adcdata = adc.value #Scaled Value between 0 and 1
    voltvalue = adcdata * 5 # Value between 0V and 5V
    tempC = 100*voltvalue-50 # Temperature in Celsius
    tempC = round(tempC,1)
    print(tempC)

    #Write to ThingSpeak
    response = channel.update({'field1': tempC})
    time.sleep(15)
```

Writing TMP36 temperature data example

- Here we see the sensor data in ThingSpeak:



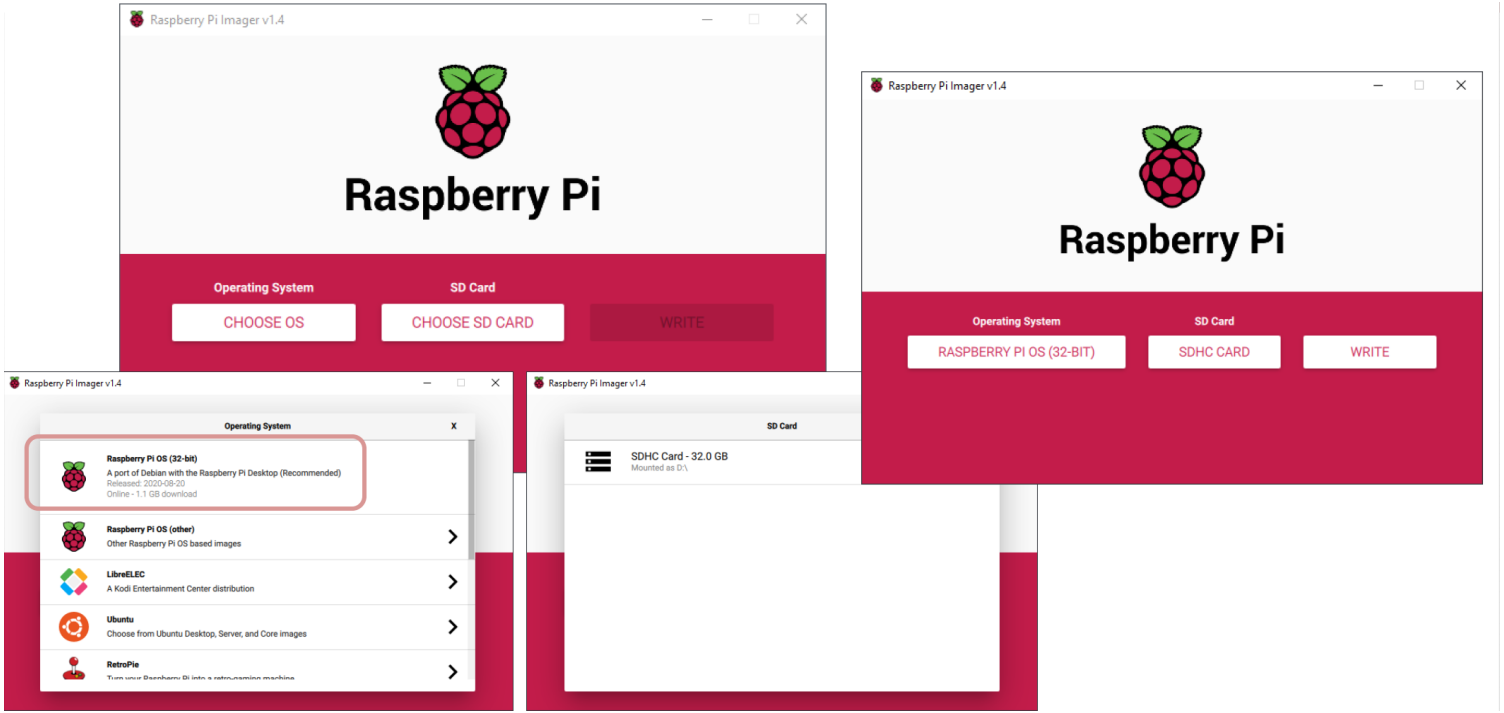
Getting started: what do you need

- Raspberry Pi
- Micro SD Card (+ Adapter)
- Power Supply
- microHDMI to HDMI Cable
- Monitor
- Mouse
- Keyboard

Installing Raspberry Pi OS

- Easiest way is to buy SD card with NOOBS pre-installed
- If starting with a blank SD card:
  - https://www.raspberrypi.com/software/ has images and even a tool you can use that will help you install things.
  - If Pi3 or later you can install the 64-bit version. Either 32-bit or 64-bit both fine for this class.
  - This includes the ability to pre-configure things like password, ssh, keyboard, locale, wifi
  - Warning: it's a large download (900MB?) and takes a while to write to SD (which is slow)
- If you end up instead manually writing an image to SD using command-line linux (the dd tool or similar) be sure to get right partition as the destination. It's easy to accidentally overwrite your laptop/desktop's hard drive

Raspberry Pi imager



Installing Raspberry Pi OS

- Put SD card in
- Hook up input/output
- Plug in the USB power adapter
  - *NOTE* can also draw power over serial or usb or sometimes HDMI
- Lights should come on and blink and should boot
- If you have a display hooked up you will get a rainbow gradient on screen which is GPU starting up.
- If installed GUI edition it will have a splash screen, if barebones text then instead a number of raspberries should appear and some Linux boot messages
- Things can also go wrong in ways hard to troubleshoot

Installing Raspberry Pi OS

- It will boot, generate SSH keys, re-size disk, and reboot
- Next a menu comes up. This varies depending on what OS you are on, I'm assuming Raspbian v12 (Bookworm) here
    - Will prompt for keyboard type. It will try to default to UK English (Pis are from England). Navigate to other / English (US), English.
- It will ask for username / password
- At this point it might continue until you get to a login prompt

More Configuration

- The system will prompt you to configure things. If for some reason it doesn’t you can always run “raspi-config” to configure more
- System Settings
  - Enable Wifi
  - Pick a Hostname
  - various other things
- Display Options
  - Only matter if you are using a TV as a display

More Configuration

- Interfaces
  - Can enable ssh for remote network logins
  - Can also enable SPI, i2c, and 1-wire
- Advanced
  - You might be able to expand the disk image to fill the whole sd-card, not sure if that’s automatic
  - Performance: can overclock, select how much RAM used by GPU
- Localization
  - Can pick language.
  - Pick timezone: Americas/Vancouver

Raspberry Pi OS desktop

Connecting to the Pi

- Monitor and keyboard (easiest)
  - HDMI monitor, USB keyboard, USB mouse (optional unless using gui)
  - Need HDMI cable (micro-HDMI on pi4/pi5)

Connecting to the Pi

- Wired Ethernet connection
  - Can run “headless” (though if something goes wrong on boot can be hard to troubleshoot)
  - Ethernet cable
  - Either an Ethernet port, or connect direct to PC
    - To direct connect to PC’s network, configure pi with a local address like 192.168.1.2 and set your wired Ethernet on PC side to something like 192.168.1.1 and then use ssh to connect
- WiFi
  - Recent Pis have built-in WiFi
  - Setting up eduroam tricky

Connecting to the Pi

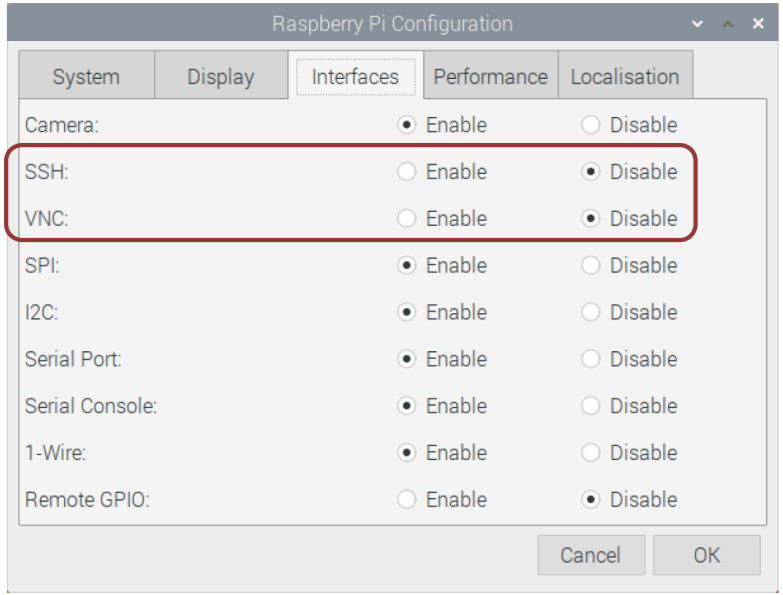
- Serial connection
  - Just mentioning this as it's possible, but it's unlikely you want to do this
  - Need USB/serial adapter
  - Need another machine to hook to, with a comm program like minicom, putty
  - Might need to set some obscure COM port settings (BAUD, stop bits, parity) and console TERM settings (ANSI, VT102).

Remote access to the Raspberry Pi

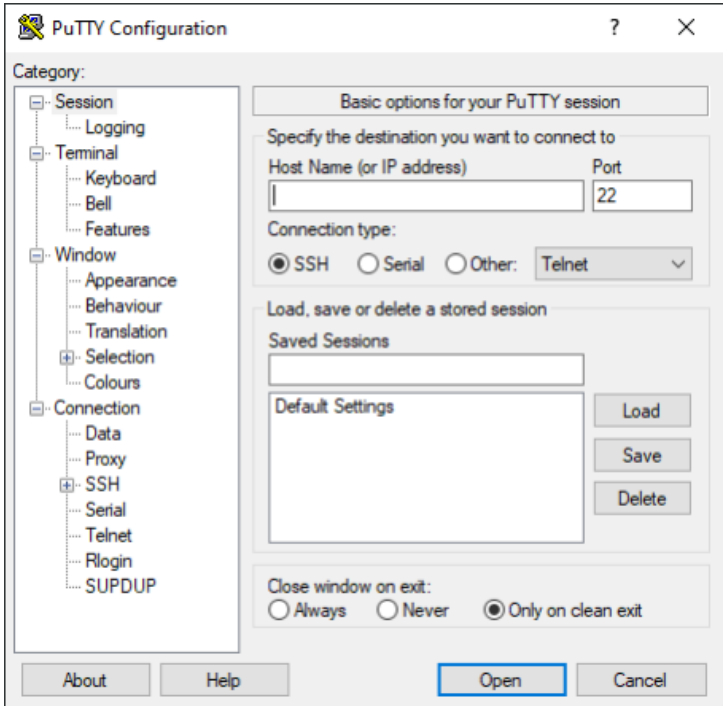
- You can use your Raspberry Pi in the same way as a desktop computer, but very often you want to connect to it remotely where your Raspberry Pi acts like a server and performing some tasks without the need of monitor, keyboard and mouse.
- Different options:
  - SSH
  - VNC
  - RDP
  - TeamViewer
  - Rpi-connect. Says you can connect via web-browser from around world

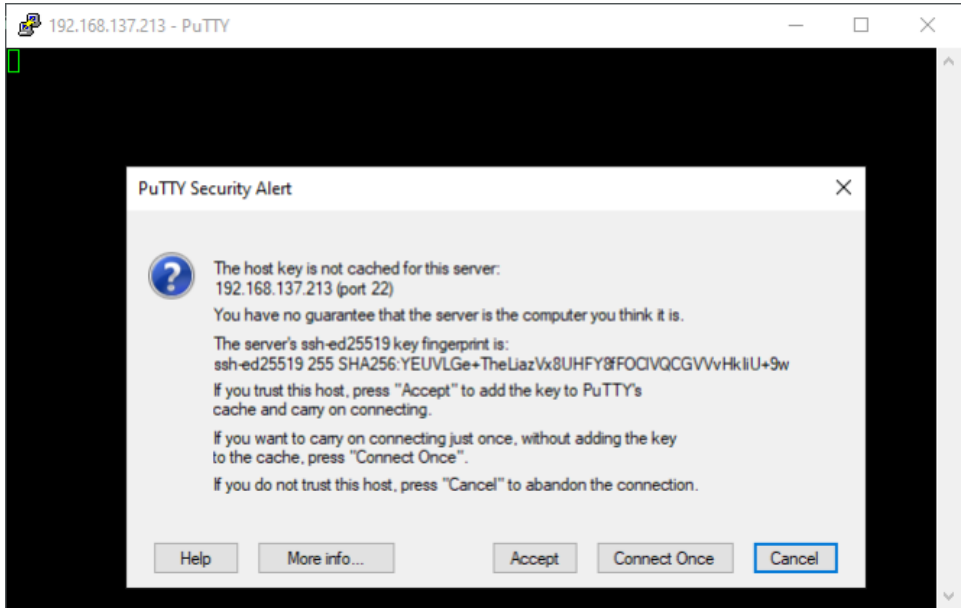
Remote access to the Raspberry Pi

- Make sure to enable the Feature you want to use:



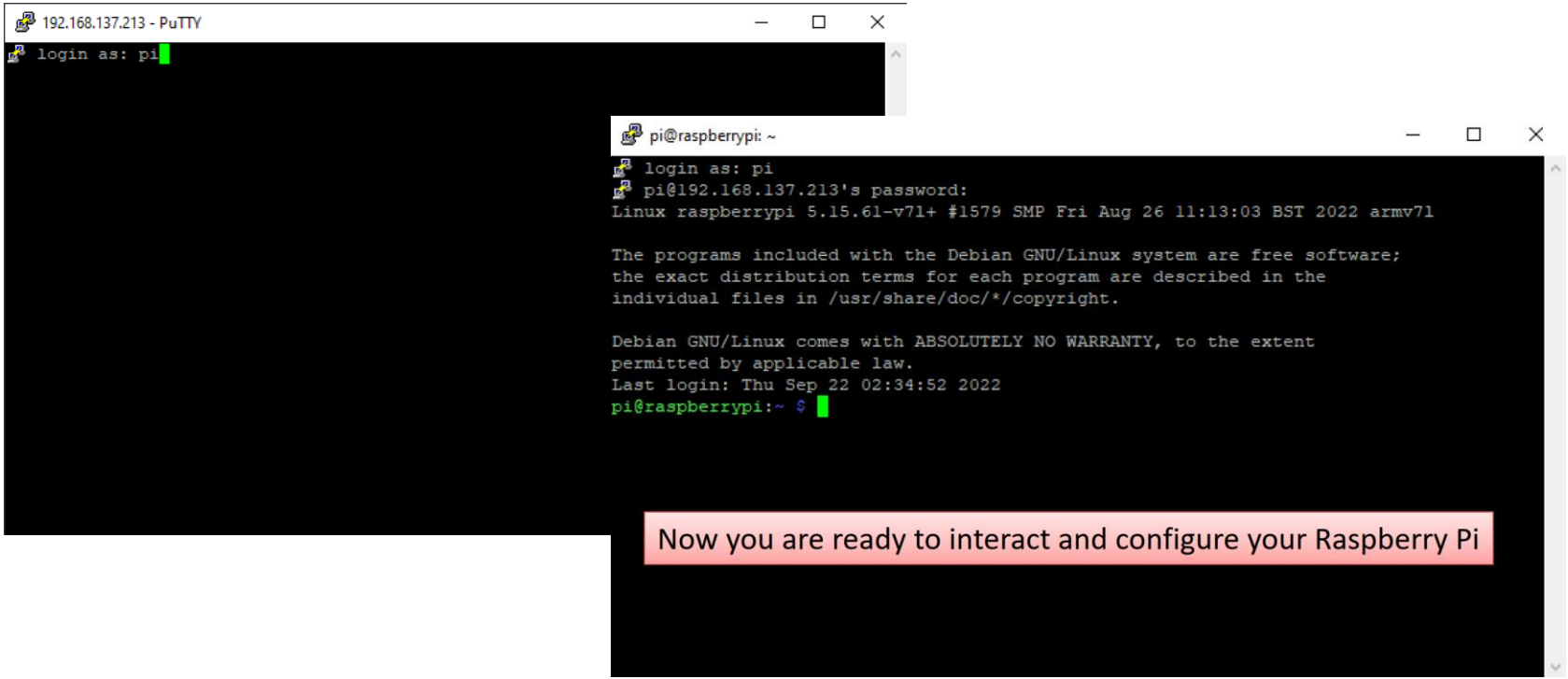
SSH + Putty





This appears only the first time. Click Accept

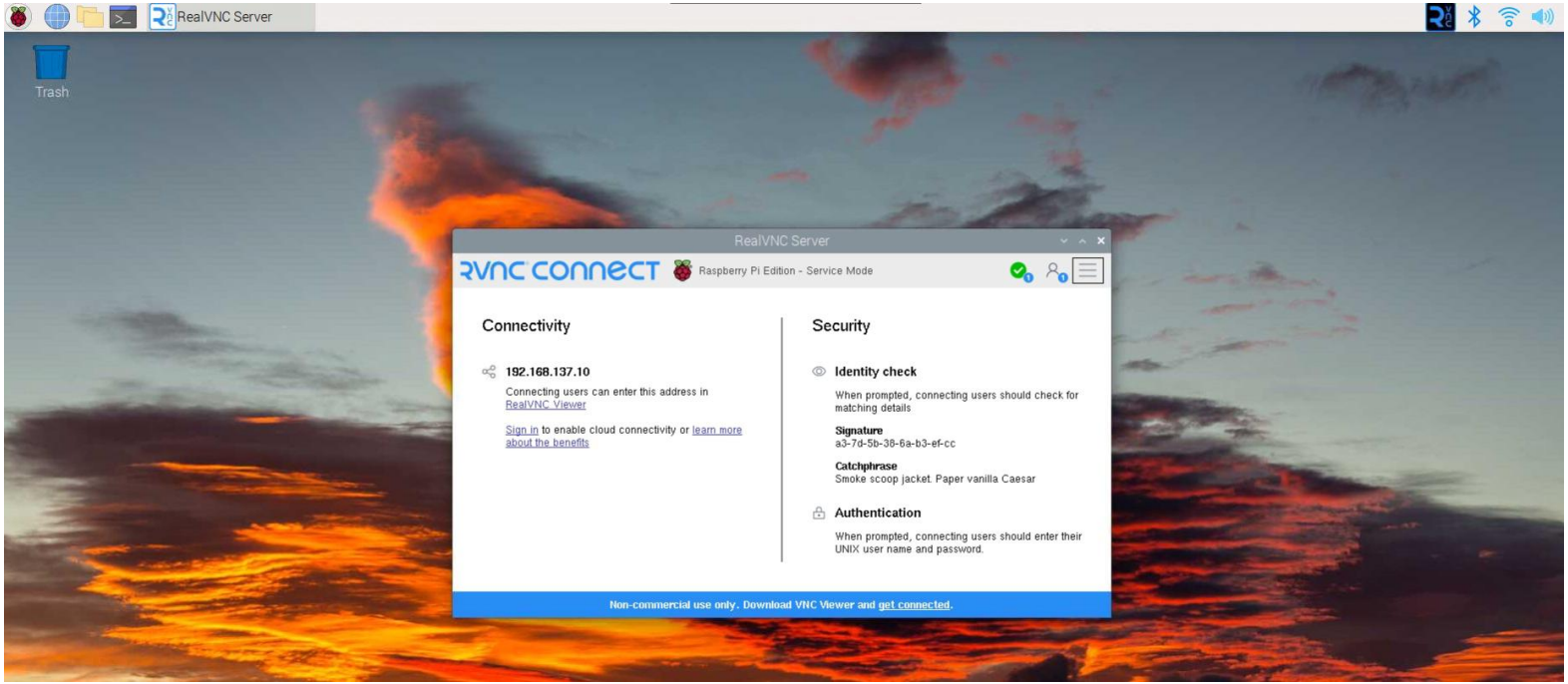
SSH + Putty


192.168.137.213 - PuTTY
login as: pi
pi@raspberrypi: ~
login as: pi
pi@192.168.137.213's password:
Linux raspberrypi 5.15.61-v7l+ #1579 SMP Fri Aug 26 11:13:03 BST 2022 armv7l
The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.
Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Thu Sep 22 02:34:52 2022
pi@raspberrypi:~ $
Now you are ready to interact and configure your Raspberry Pi

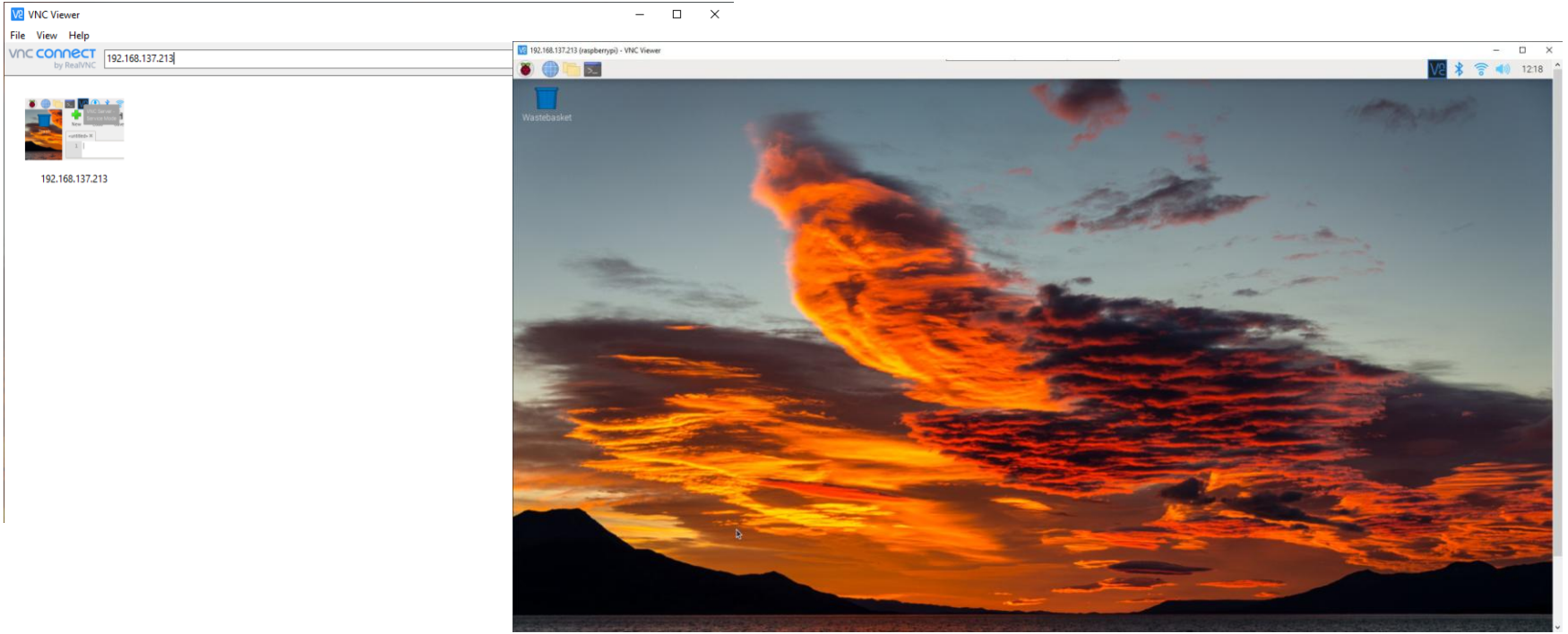
VNC

- Virtual Network Computing (VNC) is a graphical desktop-sharing system
- RealVNC Server is included with Raspberry Pi OS. It's completely free for non-commercial use; it just needs to be enabled.
- Then you need to install a VNC client on your PC.
- RealVNC is a free VNC Client
    - https://www.realvnc.com/en/connect/download/viewer/

VNC Server on the Raspberry Pi



VNC Viewer on your PC



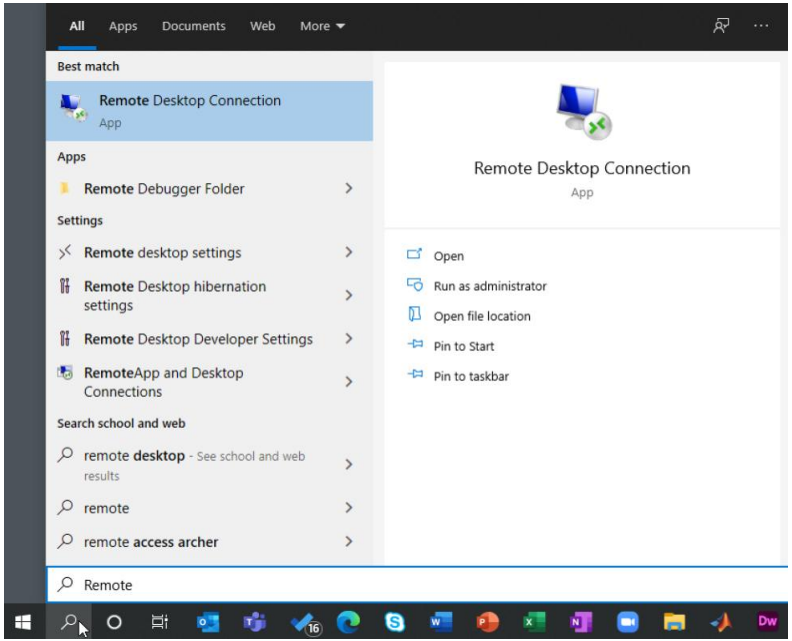
RDP

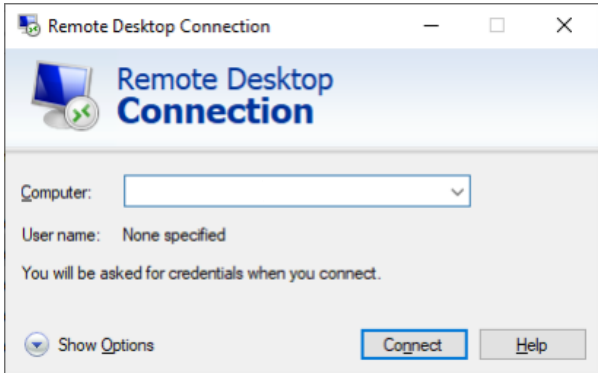
- Remote Desktop Protocol (RDP) is a network protocol developed by Microsoft that allows users to remotely access and interact with the graphical user interface of a remote Windows server
- You need to have an RDP server is installed on the remote server and an RDP client is installed on a local machine. Those are preinstalled on Windows Server and Windows clients (Windows 10/11).
- XRDP is a free and open-source implementation of Microsoft RDP (Remote Desktop Protocol) server. This software can be installed on the Raspberry Pi (which is our “server”)

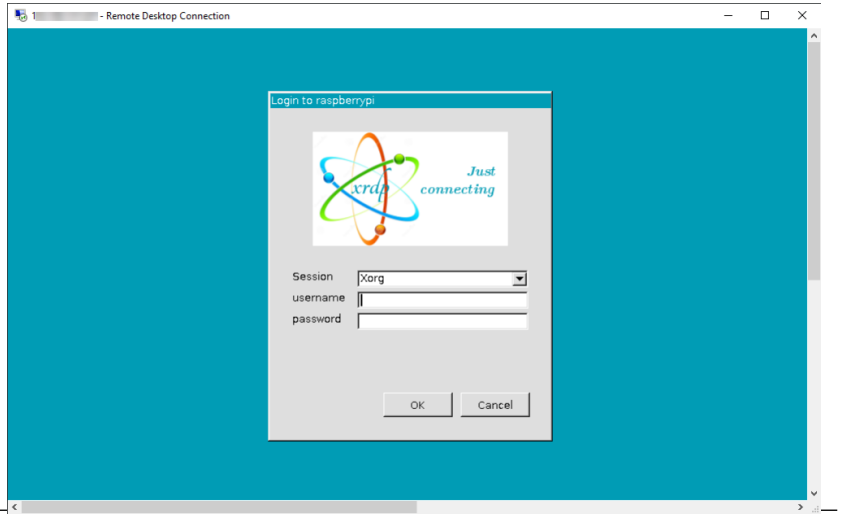
RDP

1. Install XRDP
   - XRDP is a free and open-source implementation of Microsoft RDP server.
   - Run in a terminal: `sudo apt-get install xrdp`
2. Open Remote Desktop Connection (RDC) on your Windows computer. RDS is also available for macOS
   - Enter Computer Name or IP Address
   - Default username is “pi” and default password is “raspberry” (unless you have changed it)

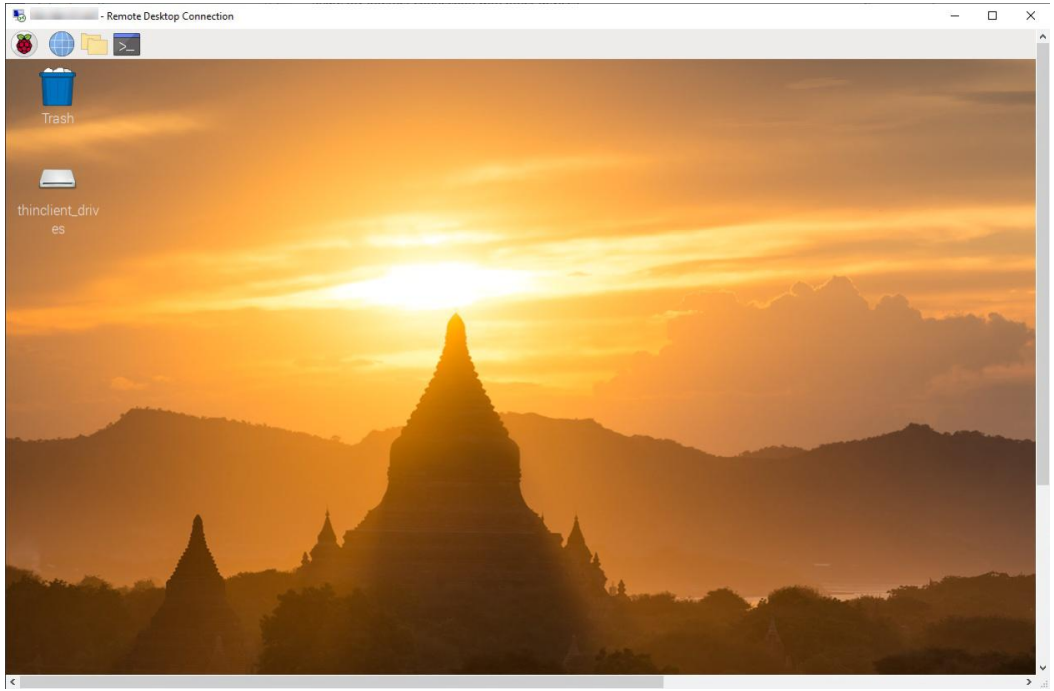
RDP


All
Apps
Documents
Web
More
Best match
Remote Desktop Connection
App
Apps
Remote Debugger Folder
Settings
Remote desktop settings
Remote Desktop hibernation settings
Remote Desktop Developer Settings
RemoteApp and Desktop Connections
Search school and web
remote desktop - See school and web results
remote
remote access archer
Remote
Remote Desktop Connection
App
Open
Run as administrator
Open file location
Pin to Start
Pin to taskbar


Remote Desktop Connection
Remote Desktop Connection
Computer:
User name: None specified
You will be asked for credentials when you connect.
Show Options
Connect
Help


- Remote Desktop Connection
Login to raspberrypi
xrdp
Just connecting
Session
Xorg
username
password
OK
Cancel

RDP



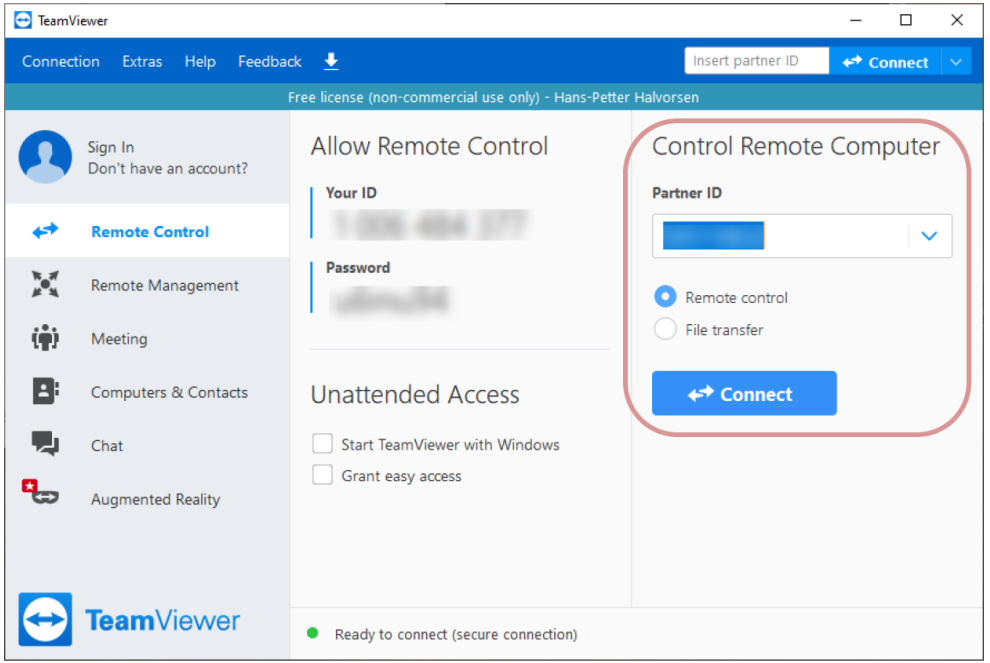
You are ready to start using Raspberry Pi remotely from your PC

RDP

- You may need to create another user on your Raspberry Pi if the Pi root user cannot RDP for whatever reason
- In a terminal: `sudo adduser <username>`
  - Give all kind of access to the new user: `sudo usermod <username> -a -G pi,adm,dialout,cdrom,sudo,audio,video,plugdev,games,users,input,netdev,spi,i2c,gpio`
  - "`pi`" is the name of the original/default user created, may be something else than "`pi`"
- Choose password
- Confirm password
- Hit enter for defaults
- Try RDC/RDP again with that login

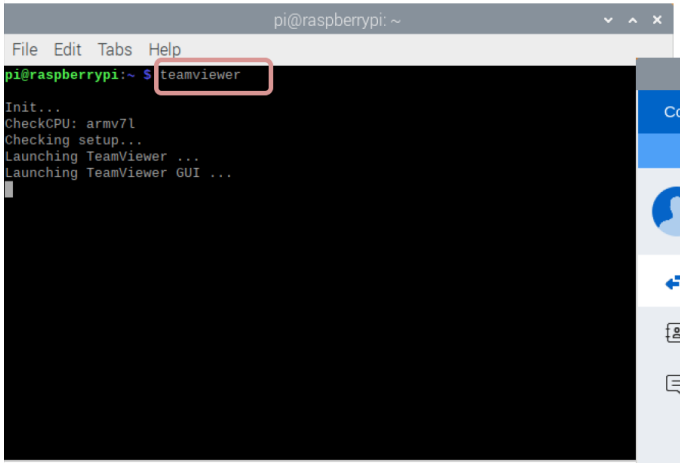
TeamViewer

- TeamViewer is propriety software (not open source). You can use it for free for non-commercial use
- You need to install TeamViewer software on both the Raspberry Pi and on your PC
- Here you see TeamViewer on your PC and the field to enter your Raspberry Pi's TeamViewer partner ID:



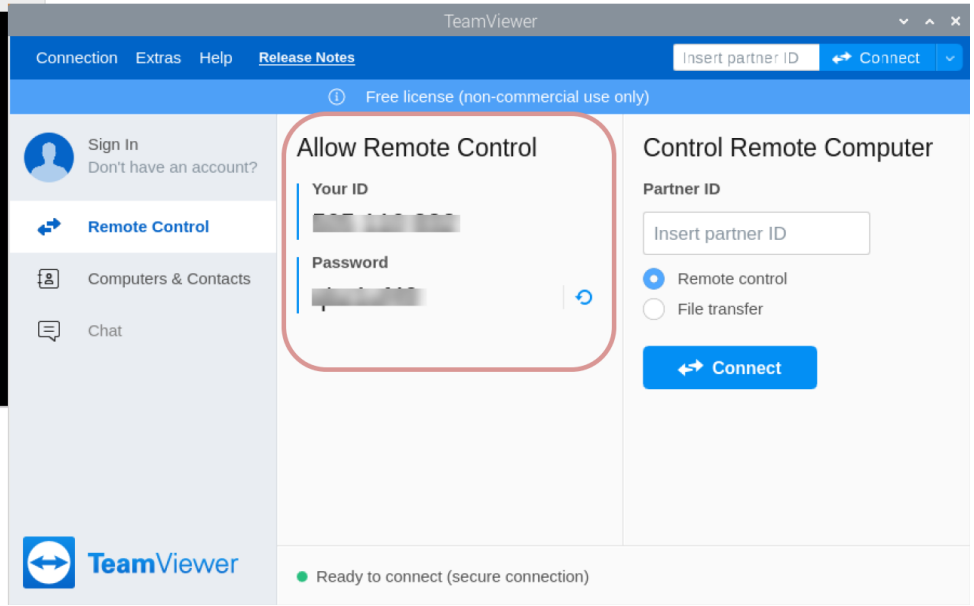
TeamViewer

Start TeamViewer on your Raspberry Pi:



Open TeamViewer by enter “teamviewer” in the Terminal

Here you see TeamViewer on your Raspberry Pi:



Transferring files

- Easiest: if using like a desktop just use web-browser
- USB-KEY: transfer data using a regular USB-key
  - In theory the Pi should auto-mount the drive for you
  - May need to mount / umount by hand or be root
- Network: just use ssh/scp (or putty/winscp)
- Serial: sz/rz ZMODEM
- Putting sd-card (after unpowering!) in another machine.
  - Challenge: Filesystem is in Linux format (ext4) so Windows and Macs can’t read it by default.

SD card digression

- BACK UP YOUR WORK. ALL THE TIME. SD cards corrupt easily.
- SHUTDOWN CLEANLY
  - via menu or `shutdown -h now`

Using the Pi

- Often you'll be doing things at the command line by starting a terminal emulator (like lxterm) in the GUI interface
- Get familiar with some basic commands of Linux.
- Resources:
  - https://www.hippocampus.si/ISBN/978-961-293-378-4.pdf
  - https://sites.calvin.edu/derek/docs/cs-with-rpi.pdf
- Sensor projects:
  - https://learning.oreilly.com/library/view/sensor-projects-with/9798868804649/