IEMS 5780
Building and Deploying Scalable Machine Learning Services

Lecture 1 - Course Introduction

Albert Au Yeung

6th September, 2019

Agenda

Course Administration

- Course details
- Course schedule
- Assessment Schemes
- Policies and Rules

Course Content Overview

- Machine Learning
- Scalable Network Applications

Course Instructors

Lecturer: Albert Au Yeung

- Email: cmauyeung@ie.cuhk.edu.hk
- For lecture content, materials, details of assignments, reference materials, etc.

TA: TBC

- Email: TBC
- Contact the TA if you need specific help when working on your assignments

About Me

- BEng in IE, MPhil in CSE
- PhD in Computer Science (University of Southampton, UK)
- AI Technical Manager at Wisers AI Lab (https://www.wisers.ai)
- Was machine learning engineer & researcher at NTT, ASTRI and Huawei
- https://www.linkedin.com/in/albert-au-yeung/

Lectures

Venue & Time

- Lee Shau Kee Architecture Building (ARC) **G03**
- Thursday 7:00pm – 10:00pm
- **Lecture dates (13 lectures)**:
  - Sep 6, 13, 20, 27
  - Oct 4, 11, 18, 25
  - Nov 1, 8, 15, 22
  - Dec 13 (Final Examination)
- Refer to the course Website for the most up-to-date schedule of the course

Topics

- This course will be divided roughly into two parts
- **Part 1 - Machine Learning**:
  - Lecture 2: Machine learning basics
  - Lectures 3-4: Text classification
  - Lectures 5: Recommender Systems
  - Lecture 6: Computer Vision
- **Part 2 - Network Applications**:
  - Lecture 7: Network Programming
  - Lectures 8-9: Concurrent Programming
  - Lecture 10: Web Applications
  - Lecture 11: Asynchronous Tasks and Message Queues
  - Lecture 12: Deploying Machine Learning Applications

Assessment Scheme

IEMS 5780

- **10%** - Attendance (Lecture 2 to Lecture 12)
- **60%** - Programming Assignments
- **30%** - Final Examination (Written & Close books/notes)

Programming Assignments

- A total of **4** programming assignments
- All should be finished using the Python programming language
- Late submission will **NOT** be marked
- Topics of the assignments:
  - machine learning problems
  - network programming
  - Web application development
- We focus on building the **backend** applications, but we still need some **UI**, so we will use **bots** on Telegram

What should you expect?

Take this course if you:

- Have background in computer networks and related concepts
- Have basic understanding or willing to learn the Python Programming Language
- Would like to challenge yourself with interesting programming and system design problems

Approach of this Course

- Machine learning is a **huge** topic, to be good at machine learning, you will have to have good foundations in
  - Statistics
  - Linear algebra
  - Calculus
  - Probability theory
  - Signal processing
  - ...
- However, this is NOT a course that follow the usual path of introduction to machine learning

Approach of this Course

- In this course, we take a **hacker's** approach: to learn how to use machine learning in a practical way, and to focus on how to make machine learning available to other people/systems
- **Focus** of this course:
  - The workflow/pipeline of machine learning projects (from data collection to application deployment)
  - Building and deploying scalable network applications
- What you will **learn** after taking this course?
  - Working on common machine learning tasks
  - Network programming and concurrent programming in Python
  - How to build a distributed and scalable network application
  - How to serve machine learning models

Some Rules

What you should do in this course?

- Attend the lectures, and raise questions whenever you have any
- Seek help as **early** as possible (e.g. if you have difficulties in picking up Python programming, or if you cannot set up the development environment)
- Feel free to make **suggestions** to the course and/or lectures
- Do your own assignments, and do NOT make your work publicly available before the deadline
- **Actively learn** relevant skills and knowledge outside the classroom

Honesty in Academic Work

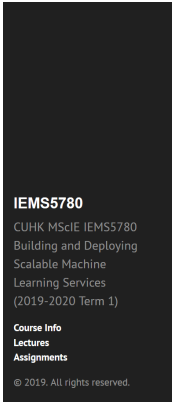
- **Zero tolerance** on cheating and plagiarism
- Read: http://www.cuhk.edu.hk/policy/academichonesty/
- Cite references whenever you use materials from any other sources
- It will be considered **plagiarism** no matter you copy other's work or allow others to copy your work

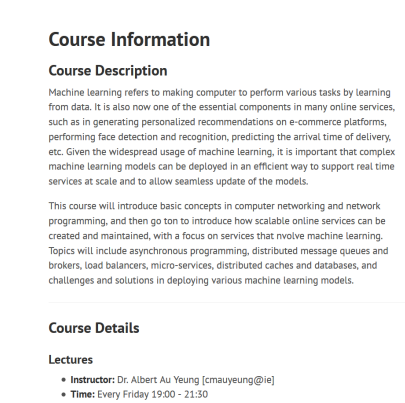
Online Resources

- Assignments will be released and collected on the CUHK E-Learning System: https://elearn.cuhk.edu.hk/
- You will submit your assignments there

Online Resources

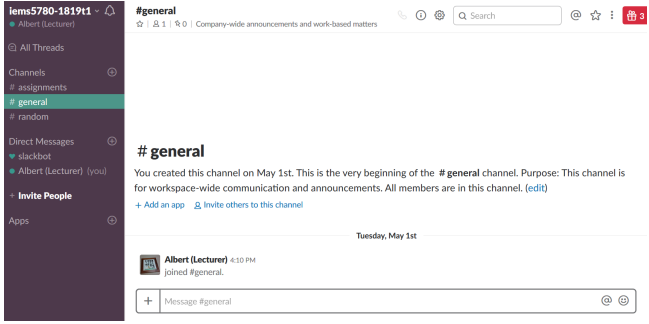
- Course Website: http://iems5780.albertauyeung.com/
- **Lecture slides**, **assignments**, **references** will be available there





Online Resources

- For more convenient communication among us and discussions among yourselves, we will use Slack in this course: https://iems5780-1819t1.slack.com/
- Sign up for an account on slack and join the above team
- NOTE: **DO NOT** post any solution of assignments on Slack or any other public channels



Using Cloud Services

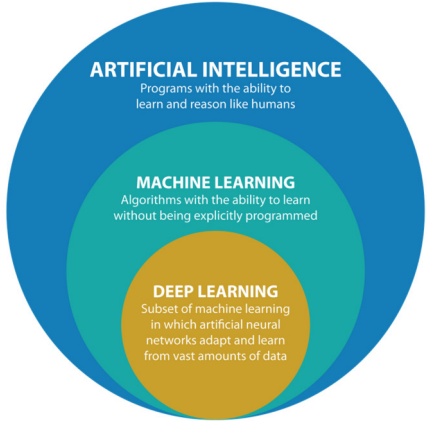
- In this course, we will use Python and its various packages for machine learning and networking
- In many cases, things will work on Windows / Mac OS / Linux
- However, you are advanced to prepare a **Linux environment** (preferrably **Ubuntu**)
- You can get a virtual machine running Ubuntu on:
  - Amazon AWS (https://aws.amazon.com/free/)
  - Google Cloud (https://cloud.google.com/free/)

Course Overview

Machine Learning

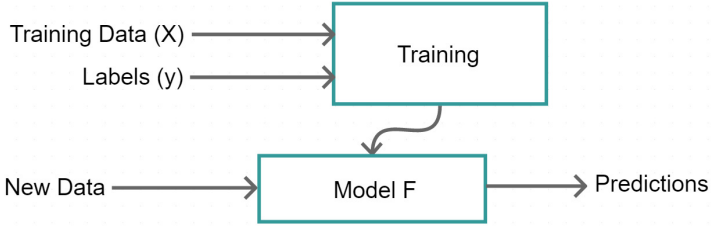
Machine Learning

- A computer program generates an input given and output, given some **pre-defined function(s)**
- ML aims at **learning** a function that maps the inputs to the outputs
- Instead of having a programmer writing down the **logic**, we let the computer **learn** from the data
- Given historical data, we train a **model** to generate predictions on **future or unseen** inputs



Machine Learning

- Given some input X and ouptut y, find a function $F(X)$ that maps X to y.
- Example: given (location, size) (X), predict the price of a house (y).
- Another example: give (previously watched movies) (X), predict the next movie(s) that will be watched (y).



Example: Hand-written Digit Recognition

- Recognize hand-written digits using a machine learning approach
  (one of the first widely used ML systems)

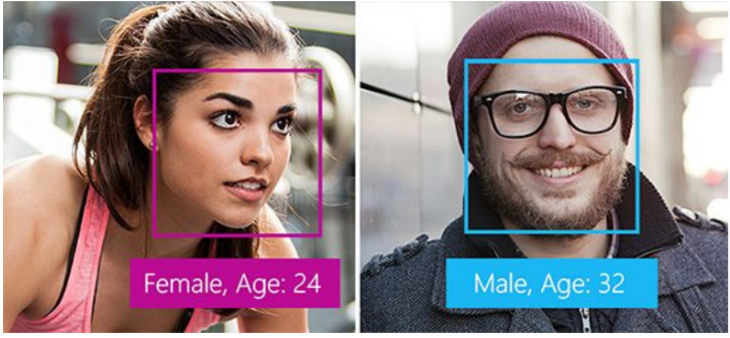
- References:
  - Reading handwritten digits: a ZIP code recognition system (PDF)
  - The MNIST Dataset

Example: Recommender Systems

- Learn to **recommend** movies or books to users based on their **past purchase and browsing behaviour**
- The Netflix Prize: a competition to build a movie recommender system for Netflix
- The winning algorithm: BellKor's Pragmatic Chaos

Example: Face Detection / Recognition

- Learn to detect **human faces** in an image or a video stream
- Recognize the persons with the faces
- Example: Microsoft's Face API

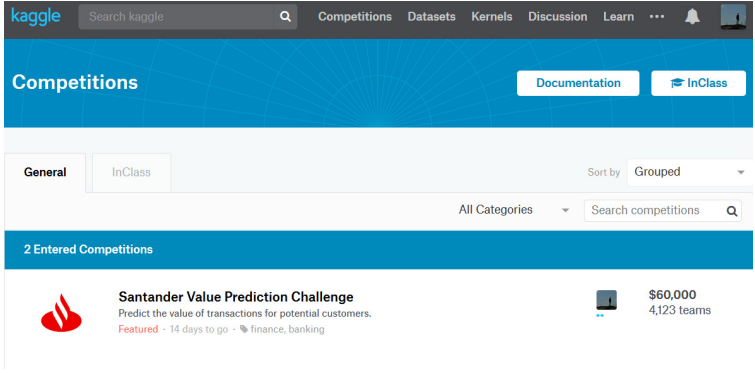


Example: Machine Translation

- Statistical machine translation (SMT) or Neural machine translation (NMT) learn to translate sentences from one language into another language by analysing parallel text corpora
- Google's Neural Machine Tranlsation: https://ai.google/research/pubs/pub45610

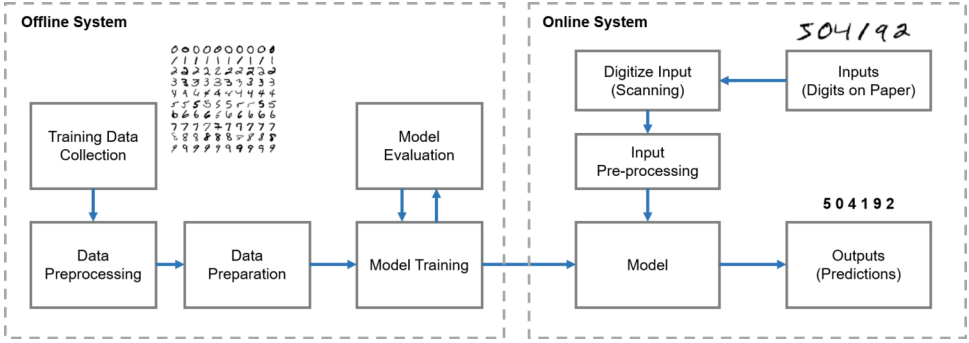
The "Kaggle" Way of Machine Learning

- Kaggle: a Website that host **machine learning competitions**
- You train a machine learning model, and generate predictions on the testing data
- The models that achieve the best performance on the leader board will win the prizes
- Everything is **offline**



Machine Learning Applications

- In practice, generating predictions is only a **small part** of a machine learning project
- Consider a system that uses machine learning to recognize hand-written letters



- Ref: Uber's Customer Obssession Ticket Assistant https://eng.uber.com/cota/

Common ML Systems Workflow

- There are several common **workflows** for machine learning systems
  1. Train offline ➤ Predict offline ➤ Store predictions in DB
  2. Train offline ➤ Embed model in a device ➤ Predict online
  3. Train offline ➤ Make model available as a service ➤ Predict online
- Notes:
  - **Offline**
    separate from a production system; does not have to be completed in real time
  - **Online**
    part of a production system; perform tasks in real time

Common ML Systems Workflow (1)

- Train offline ➤ Predict offline ➤ Store predictions in DB
- Example: **Recommender systems**
  - A model is trained **offline**
  - For each user, generate (pre-compute) a list of recommended items, store in **database**
  - When the user visits the Website, return the list of items

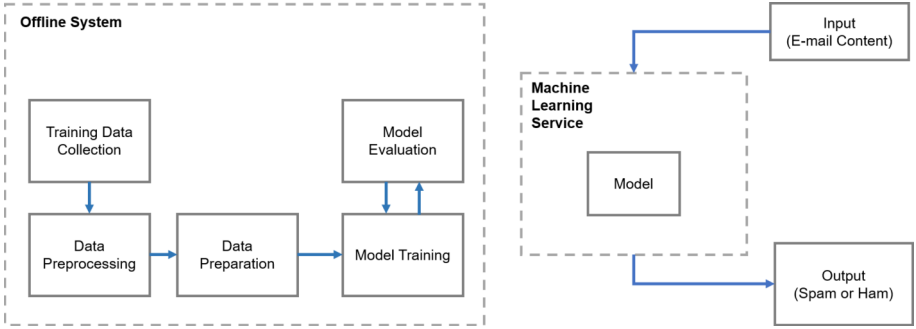
Recommendations for you in Books

Common ML Systems Workflow (2)

- Train offline ➤ Embed model in a device ➤ Predict online
- Example: **Object detection using a drone**
  - A model is trained offline
  - The model together with other processing logic are downloaded to the drone's computer
  - The drone detects objects while it is in operation

Common ML Systems Workflow (3)

- Train offline ➤ Make model available as a service ➤ Predict online
- Example: **Spam E-mail detection**
  - A classifier is trained offline with spam and non-span emails
  - Deployed as a service to serve users or other components in the system



Common ML Systems Workflow

- In (2) and (3), we need to think about how to **deploy** a machine learning model
- Definition of **deploy**:
  - To place some resources into a position so as to be ready to for action or use
- In this course, we will focus on **Use Case (3)**
  - How to make machine learning models **available** to other users/systems?
  - How to serve machine learning models over the **network**
  - How to deploy our models to serve **many** concurrent users?

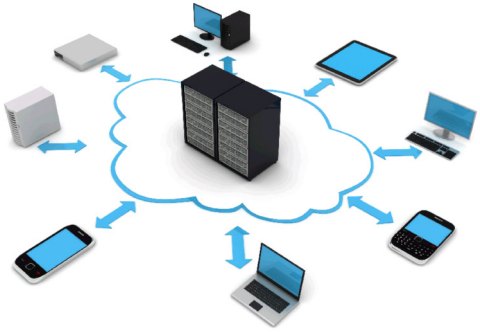
Challenges in Deploying Machine Learning Models

- Requirement of **computing resources** (RAM, CPU/GPU)
- **Time** required to generate a prediction
- How to **update** the model
- How to serve many **concurrent requests**
- How to **monitor** model performance
- ...

Computer Network

Computer Network

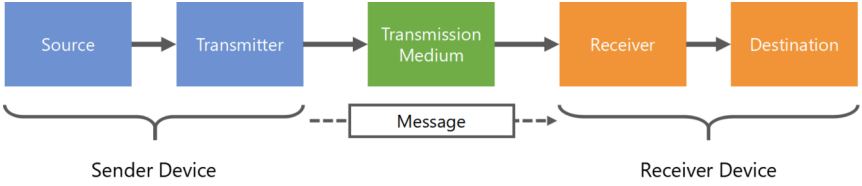
- A network that allows computers to perform data communication with one another



- The Internet is **a network of networks**. (Global Internet Traffic)

Data Communication

- Exchange of data between two devices using some form of transmission medium
- A simplified communication model:



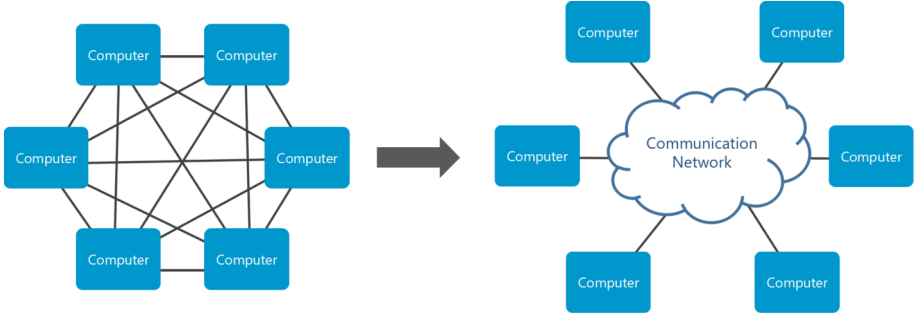
- When performing communication, we need **protocols**: rules that govern how data is transmitted in this system

Protocols

- **Network protocols** defines how computers talk to each other, including:
  - How to start a communication
  - The format of a message
  - What should be done when the data is corrupted during transmission
  - What should be done when the connection is broken during transmission
  - ...
- Examples: **TCP/IP**, **HTTP**, **FTP**
- Internet protocols are specified in documents called **Requests for Comment (RFC)**, such as:
  - RFC 793 - Transmission Control Protocol (TCP)
  - RFC 1180 - A TCP/IP Tutorial
  - RFC 6455 - The WebSocket Protocol

Computer Network

When we have many computers that want to talk to one another, point-to-point links become not practical, especially when the distance is too far



The History of Internet in 3 Minutes

Problems and Challenges in Computer Networking

Challenges in Networking:

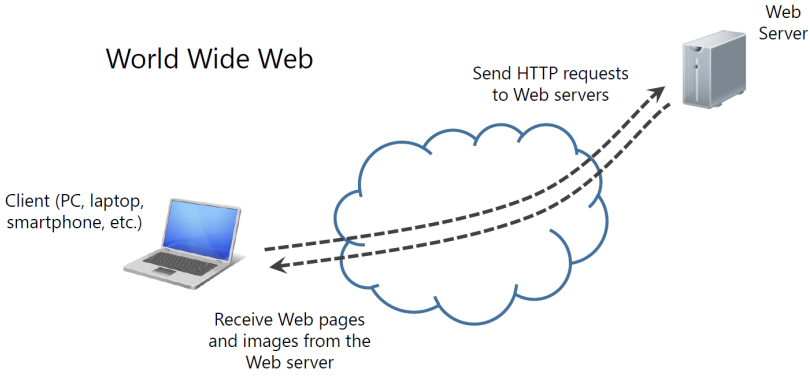
- How can data be transmitted from one node to another through the network?
  (e.g. routing/switching)
- How can we address the computers?
  (e.g. IP Address)
- How can we identify which applications on the computers the data should be delivered to?
  (port and socket)
- How to handle error or missing data?
  (e.g. the TCP protocol)
- What if a large amount of data is transmitted at the same time?
- How to **coordinate** a large number of applications over a network?

Applications

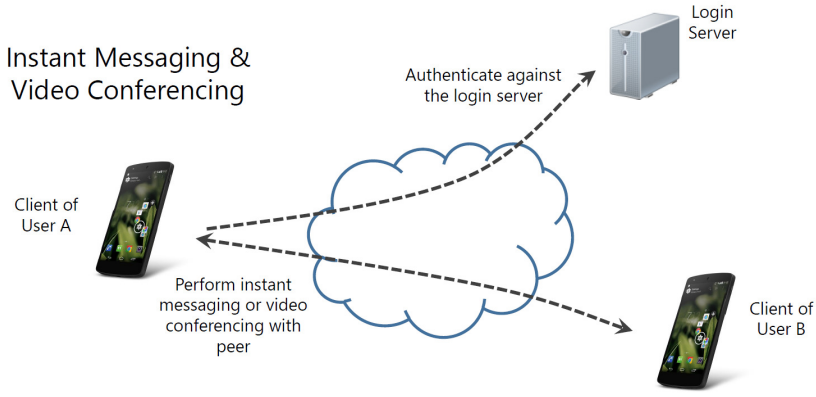
Common Applications on the Internet

- The World Wide Web (Web servers and browsers)
- File transfer (FTP servers and clients)
- Instant messaging & video conferencing (e.g. Skype, Whatsapp, Wechat)
- Peer-to-peer file sharing
- Video and audio streaming
- Cloud storage (Sync files across machines)
- ...

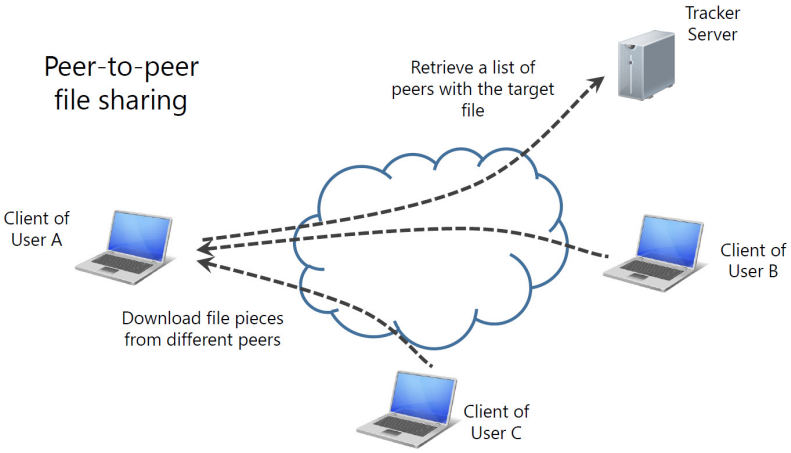
Example 1: The World Wide Web



Example 2: Instant Messaging & Video Conferencing



Example 3: P2P File Sharing



Major Topics

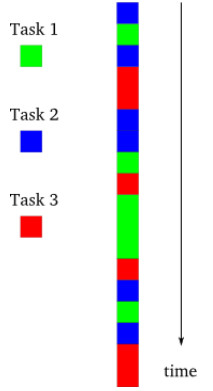
- **Network Programming**
  - How to make two or more computers talk to each other over a network?
  - How to use common protocols to send and receive data?
- **Concurrent Programming**
  - How to simultaneously carry out different task in a program
- **Scalable architecture**
  - How to make a system scalable when traffic increases and the system becomes more complex?
  - How to make a network application robust and efficient?

Network Programming

- Enable **communications** among computers using some protocols
- Our focus:
  - TCP/IP (TCP & UDP)
  - HTTP, Websockets
  - Develop your own servers and clients in Python
  - Data format for exchanging information (e.g. JSON, XML)
  - Serving **machine learning models** in network applications

Concurrent Programming

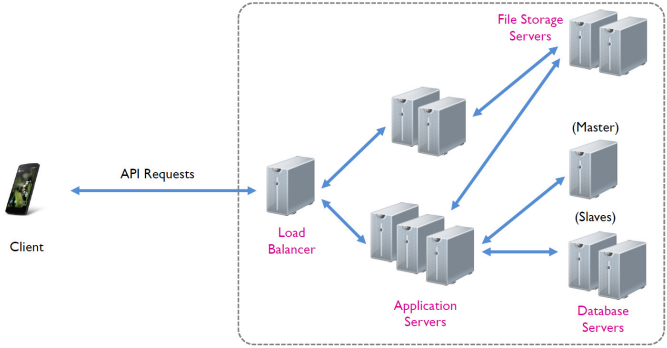
- How to perform tasks in parallel
- Our focus:
  - Threading and multiprocessing
  - Limitations of multithreading in Python
  - Aysnchronous model
  - Blocking and non-blocking calls



The Asynchronous model (Ref: Twisted Introduction - Part 1)

Scalable Architecture

- How to design the architecture of a network application?
- How to coordinate different components in system when complexity increases
- E.g. Using asynchronous tasks and message queues, caches, databases



Challenges in Network and Concurrent Programming

The Dining Philosophers Problem

- Details: Dining philosophers problem - Wikipedia
- Five philosophers sit at a round table with bowls of spaghetti. Forks are placed between each pair of adjacent philosophers.
- Each philosopher must alternately think and eat.
- A philosopher can only eat when he has both left and right forks.
- Each fork can be held by only one philosopher.
- A proper solution should never arrive in a **deadlock** situation.

Challenges in Network and Concurrent Programming

The CAP Theorem

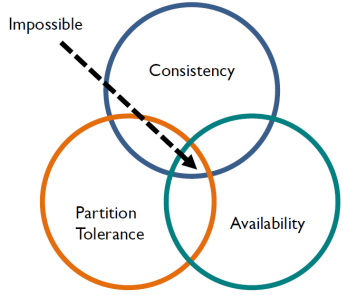
- Details: CAP theorem - Wikipedia
- In a distributed system, three properties are of particular interests:
  - C – Consistency
  - A – Availability
  - P – Partition Tolerance
- Recommended Reading: Kaushik Sathupadi. ‘A plain english introduction to CAP Theorem’ http://ksat.me/a-plain-english-introduction-to-cap-theorem/

The CAP Theorem

- **C: (Atomic) Consistency**
  - A ‘read’ to the system will always reflect the latest ‘write’ action
  - All node sees the same data at the same time
- **A: Availability**
  - Every request received by a non-failing node must result in a response (the system is continuously available to the clients)
  - It does not guarantee that the response is given in a specific period of time, however there should be a response for ever request
- **P: Partition Tolerance**
  - A distributed system has multiple nodes, partition tolerance requires that the system continues to operate even when the network fails

The CAP Theorem

- Also known as Brewer's Theorem
- It states that it is **impossible** for a distributed system to have **all 3 properties** at the same time.
- Reference: Seth Gilbert and Nancy Lynch, "Brewer's conjecture and the feasibility of consistent, available, partition-tolerant web services", ACM SIGACT News, Volume 33 Issue 2 (2002), pg. 51-59.



The CAP Theorem

Choosing between consistency and availability:

- **C + P**
  - When network is partitioned, partitioned nodes will not be able to return a response
  - Clients receive timeout or error
  - Preferred when **strict atom consistency is needed** (e.g. e-commerce site)
- **A + P**
  - A partitioned node will return the most recent version of the data it has, not guaranteed to be the same as the latest version
  - Opt for this if **availability** is important, and there is flexibility in returning the latest data to the clients

Python Programming

What is Python?

- An high-level interpreted programming language
- Created by Guido van Rossum in 1991
- Emphasizes code readability and flexibility (See Python's Design Philosophy)
- Current stable versions: Python 2.7 (Version 2), and Python 3.6 (Version 3)

Programming in Python

- Hello World in Python

- Type (or simply) to invoke the Python interpreter
- will output the arguments to standard output

Programming in Python

- Python programs (or scripts) are commonly named using the extension, and are called **modules**
- A "hello world" script :

```
```

- Executing the script:

```
```

What do people use Python for?

Python is a general purpose programming language and are widely used in different domains. (See Python Success Stories)

- Web and Internet applications backend (e.g. Youtube, Dropbox, Reddit)
- Scientific computing
- Data science and machine learning (e.g. Tensorflow, Keras)
- Data visualization
- Financial Analysis
- ...

Installing Python

- Available on Linux / Mac / Windows (https://www.python.org/downloads/)
- Note: Download **Python 3.6** for this course

- IDEs recommended for Python programming:

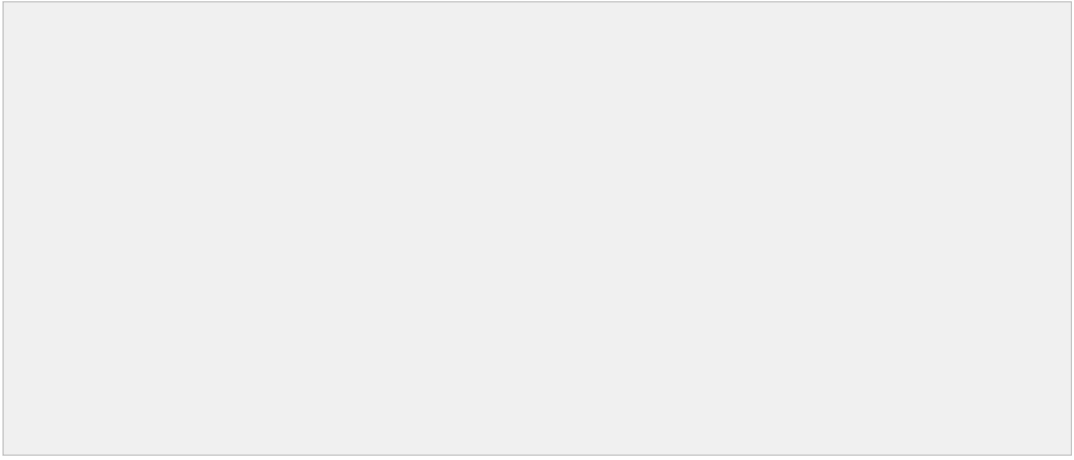
  1. JetBrains PyCharm (Community Edition is free)
  2. MS Visual Studio Code (Free and open source)

- Python comes with some standard modules, other modules can be installed using (https://pypi.python.org/pypi). For example:

Python Basics

- In Python, **indentation** is important: the statements in the same logical block should have the **same** indentation.
- Set your editor to use SPACES instead of TAB for indentation.
- You **do not** have to declare a variable before using it

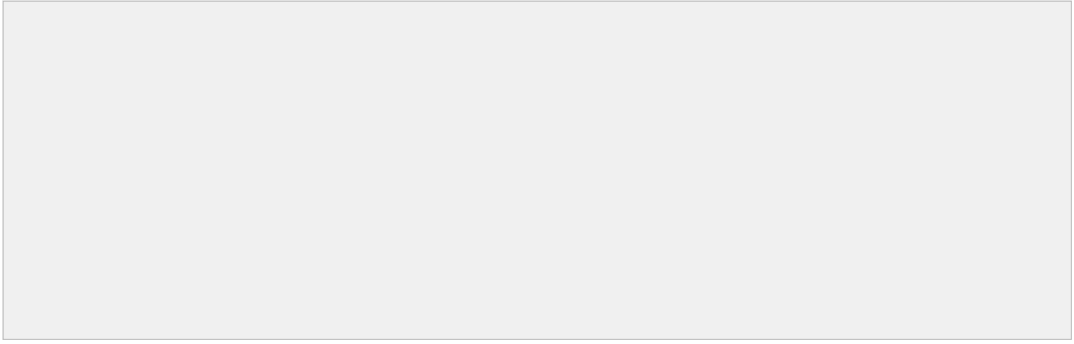
Python Basics



Python Data Structures

Lists

- Lists are like arrays in other languages, but are more flexible



Python Data Structures

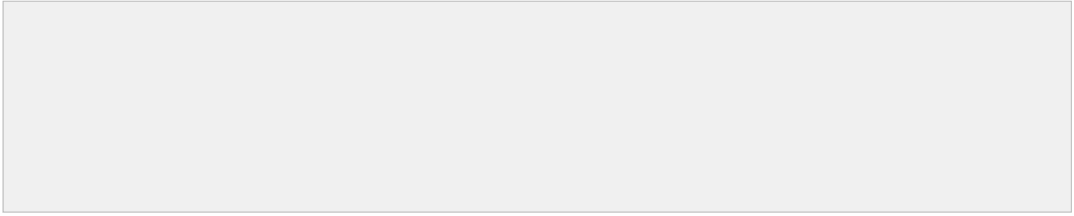
Using lists in for loops

- Lists are iterables, meaning that you can loop through each of its values as follows:

Python Data Structures

List methods

- List objects have a number of using methods:



- For a comprehensive list of methods, see https://docs.python.org/3/tutorial/datastructures.html

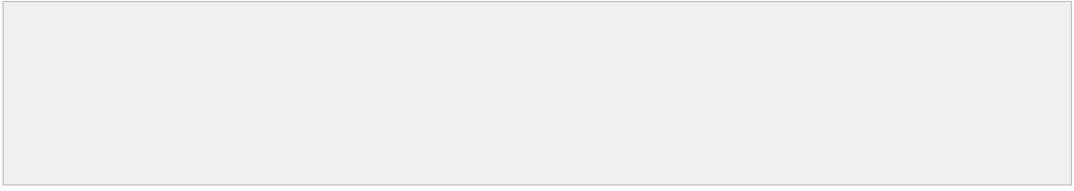
Python Data Structures

Dictionaries

- Another commonly used data structure in Python is the **dictionary**
- It can be used to store **key-value pairs** (Similar to the "associative arrays" in PHP)
- Keys must be immutable types (e.g. Lists cannot be used as keys)

Python Data Structures

- **Iterating over key-value pairs in a dictionary**
- Given that a dictionary is used to store key-value pairs, you can iterate over all key-value pairs using a loop as follows:



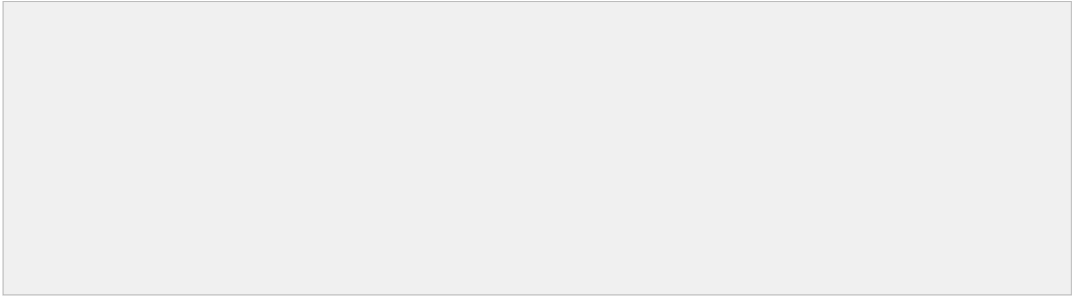
- In the above statement, is a string placeholder, is an integer placeholder.
- More can be found at https://docs.python.org/3/tutorial/datastructures.html

Files in Python

- In practice, it is better to specify the encoding of the file content

Python Modules

- A **module** in Python is a file containing Python definitions and statements
- Put your source codes in different modules to avoid having a huge single file
- You can **import** class, functions and variables from other modules



- Reference: https://docs.python.org/3/tutorial/modules.html

More about Python Programming

Documentations and Tutorials

- Read about the history of Python at https://en.wikipedia.org/wiki/Python_(programming_language)
- Read Python tutorials at https://docs.python.org/3/tutorial/
- Consult the documentation at https://docs.python.org/3/

More about Python Programming

Coding Convention and Styles

- Python's development is based on the Python Enhancement Proposals (PEP), which is a list of proposals of new features
- PEP 8 describes coding conventions or style guides for Python programming.

Others

- Explore Python packages and projects online: https://github.com/vinta/awesome-python

Using Virtualenv

Dependencies

- When working on a Python project, it is common that you will use modules outside of the standard library (e.g. requests, BeautifulSoup, numpy, pandas)
- Different projects may have different dependencies (on **different modules**, or even **different versions** of the modules)

Project isolation

- Virtualenv is a software that allows you to create an isolated environment for a project
- Install virtualenv by:

```
```

Using Virtualenv

- Once installed, you can create a virtual environment using the following command (is the name of the environment, which you can choose as you like):

- To activate the environemnt, use the following command:

- Once you see the prefix, it means that the virtual environment is successfully activated.
- From this point onwards, all command will only install packages **within this environment**
- To exit the environment, type

End of Lecture 1