IEMS 5780 / IERG 4080
Building and Deploying Scalable Machine Learning Services

Lecture 1 - Course Introduction

Albert Au Yeung
6th September, 2018

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)
- Machine learning engineer at Zwoop Ltd, a startup in Hong Kong
- Was researcher at NTT, ASTRI and Huawei
- https://www.linkedin.com/in/albert-au-yeung/

Lectures

Venue & Time

- Yasumoto International Academic Park (YIA) **LT7**
- Thursday 7:00pm – 10:00pm
- **Lecture dates (13 lectures)**:
  - Sep 6, 13, 20, 27
  - Oct 4, 11, 18, 25
  - Nov 1, 8, ~~15~~, 22, 29
  - Dec 4 (Make-up class, YIA LT4)
- Refer to the course Website for the most up-to-date schedule of the course
- **Final Examination**:
  - Dec 20 (YIA LT3)

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 5-6: Computer Vision
  - Lecture 7: Recommender Systems
- **Part 2 - Network Applications**:
  - Lecture 8: Network Programming
  - Lectures 9-10: Concurrent Programming
  - Lecture 11: Web Applications
  - Lecture 12: Asynchronous Tasks and Message Queues
  - Lecture 13: Deploying Machine Learning Applications

Assessment Scheme

IERG 4080

- **10%** - Attendance (Lecture 2 to Lecture 13)
- **60%** - Programming Assignments
- **30%** - Final Examination (Written & Close books/notes)

IEMS 5780

- **10%** - Attendance (Lecture 2 to Lecture 13)
- **45%** - Programming Assignments
- **15%** - Mini Project
- **30%** - Final Examination (Written & Close books/notes)

Programming Assignments

- A total of **4 / 5** 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 Slack or 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

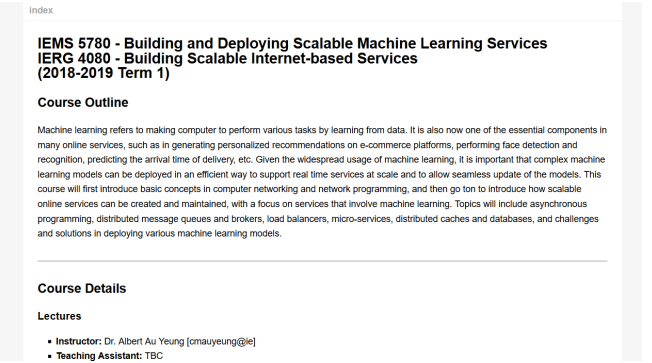
- **Zero tolerance** on cheating and plagiarism
- Read: http://www.cuhk.edu.hk/policy/academichonesty/
- Cite references whenever you use materials from any other sources
- It will be considered **plagiarism** no matter you copy other's work or allow others to copy your work

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: https://course.ie.cuhk.edu.hk/~iems5780/ or http://iems5780.albertauyeung.com
- **Lecture slides**, **assignments**, **references** will be available there



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IEMS 5780 - Building and Deploying Scalable Machine Learning Services
IERG 4080 - Building Scalable Internet-based Services
(2018-2019 Term 1)

Course Outline

Machine learning refers to making computer to perform various tasks by learning from data. It is also now one of the essential components in many online services, such as in generating personalized recommendations on e-commerce platforms, performing face detection and recognition, predicting the arrival time of delivery, etc. Given the widespread usage of machine learning, it is important that complex machine learning models can be deployed in an efficient way to support real time services at scale and to allow seamless update of the models. This course will first introduce basic concepts in computer networking and network programming, and then go ton to introduce how scalable online services can be created and maintained, with a focus on services that involve machine learning. Topics will include asynchronous programming, distributed message queues and brokers, load balancers, micro-services, distributed caches and databases, and challenges and solutions in deploying various machine learning models.

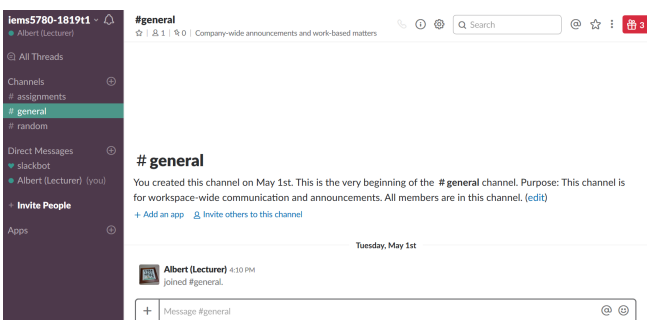
Course Details

Lectures

- **Instructor:** Dr. Albert Au Yeung [cmauyeung@ie]
- **Teaching Assistant:** TBC

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

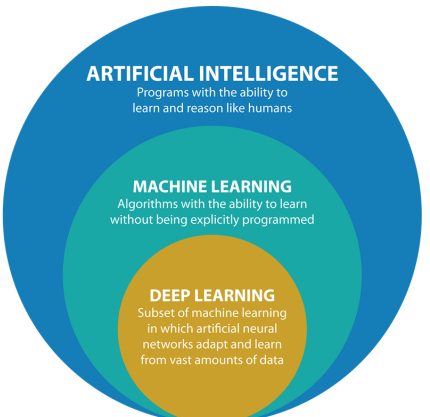
- In this course, we will use Python and its various packages for machine learning and networking
- In many cases, things will work on Windows / Mac OS / Linux
- However, you are advanced to prepare a **Linux environment** (preferrably **Ubuntu**)
- You can get a virtual machine running Ubuntu on:
 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

Course Overview

Machine Learning

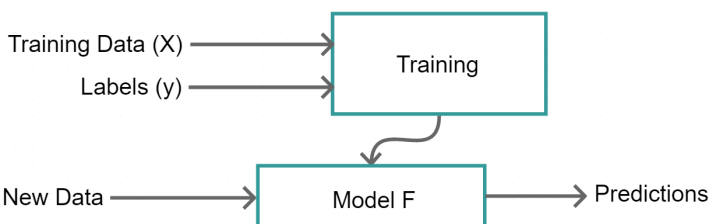
Machine Learning

- 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)

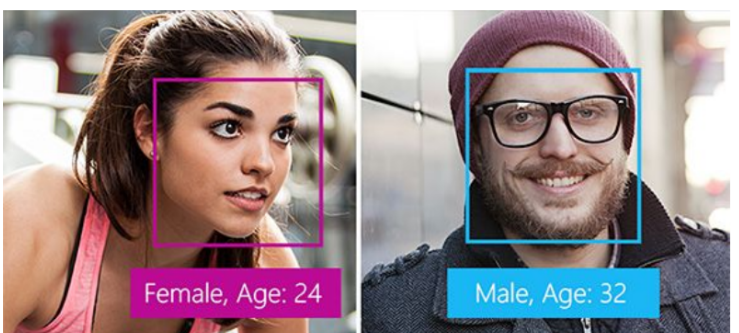
- References:
  - Reading handwritten digits: a ZIP code recognition system (PDF)
  - The MNIST Dataset

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

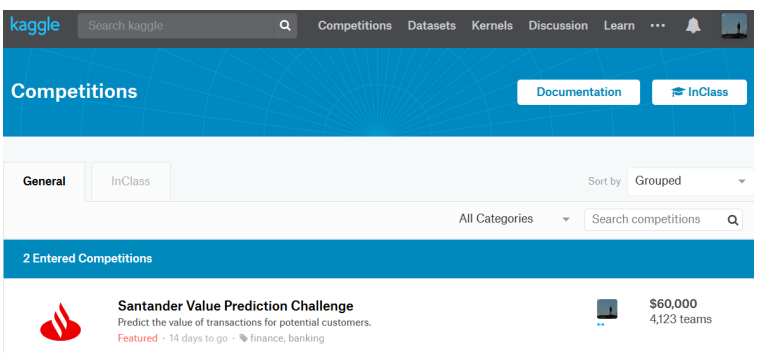


Example: Machine Translation

- 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

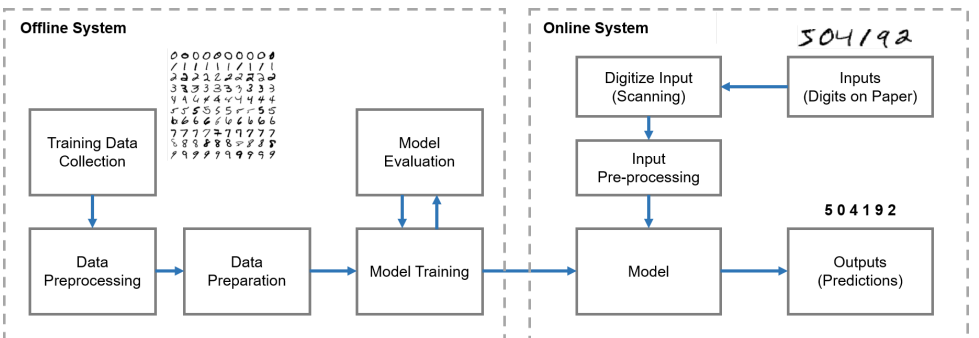
The "Kaggle" Way of Machine Learning

- 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/

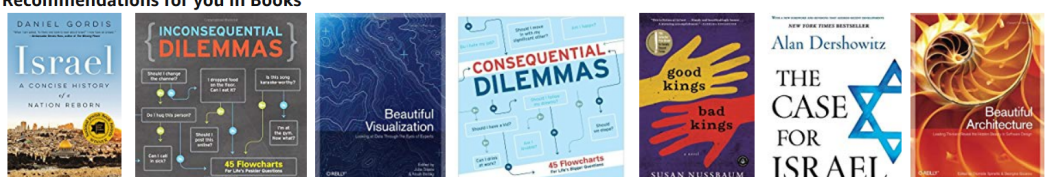
Common ML Systems Workflow

- 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

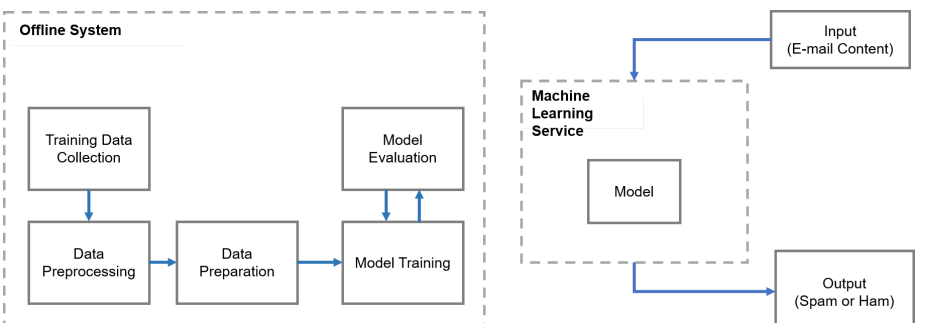


Common ML Systems Workflow (2)

- 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?

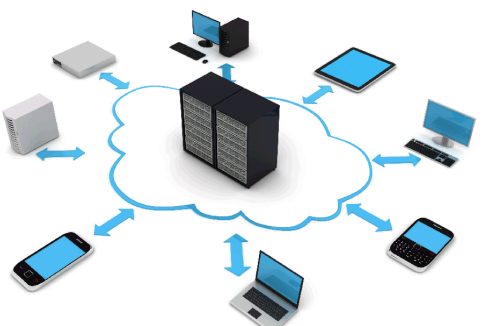
Challenges in Deploying Machine Learning Models

- 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

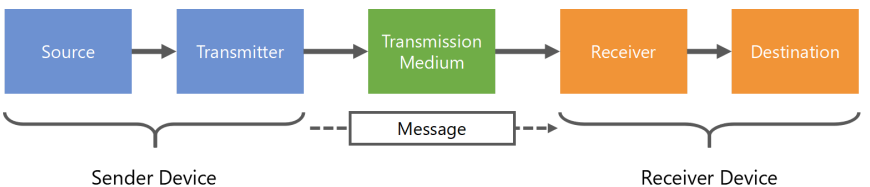
- A network that allows computers to perform data communication with one another



- 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:



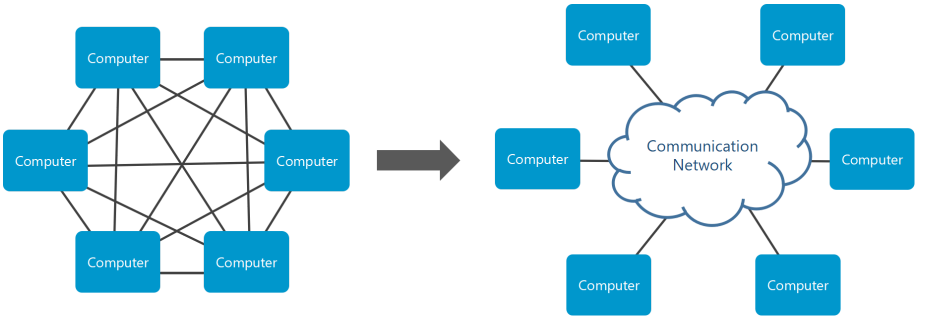
- When performing communication, we need **protocols**: rules that govern how data is transmitted in this system

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?

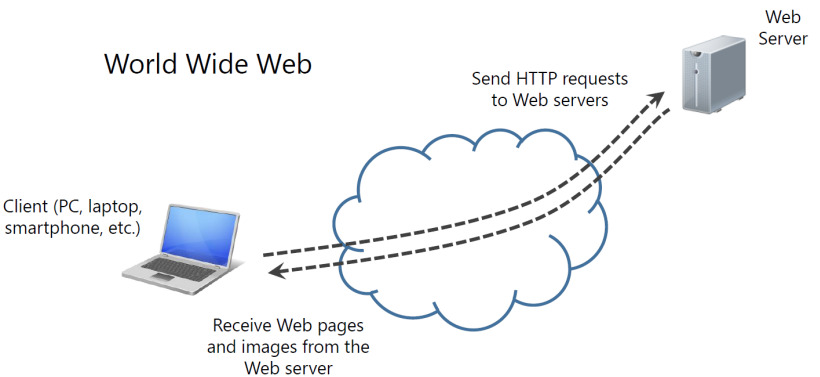
  (e.g. the TCP protocol)
- What if a large amount of data is transmitted at the same time?
- How to **coordinate** a large number of applications over a network?

Applications

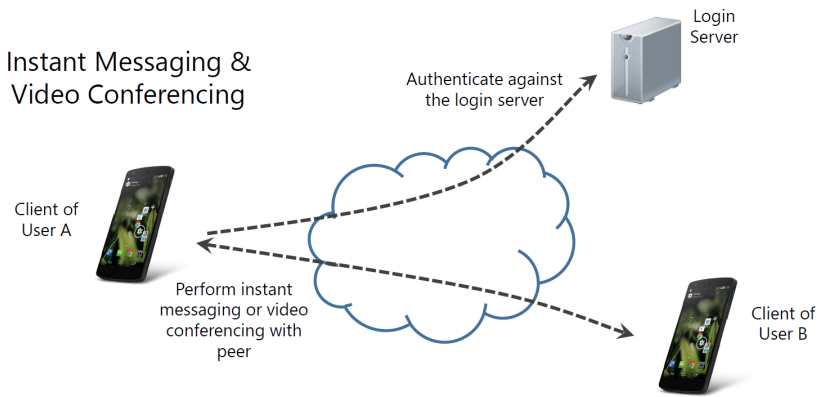
Common Applications on the Internet

- 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)
- ...

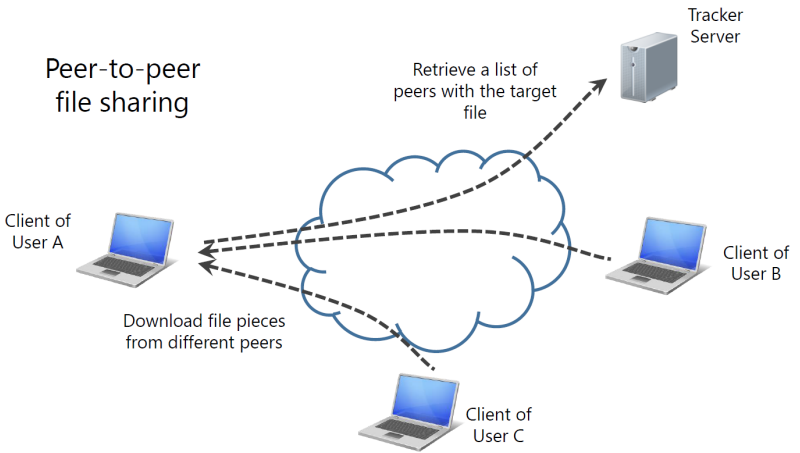
Example 1: The World Wide Web



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

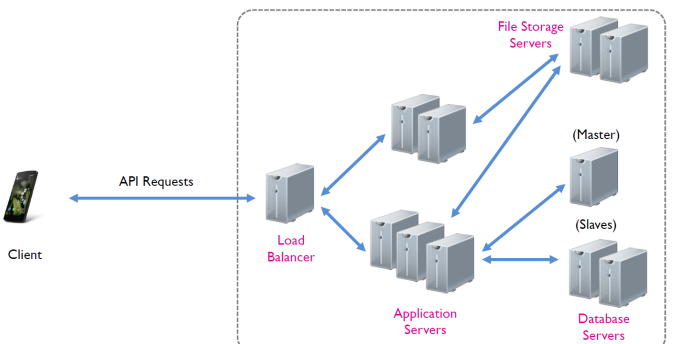
Concurrent Programming

- 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

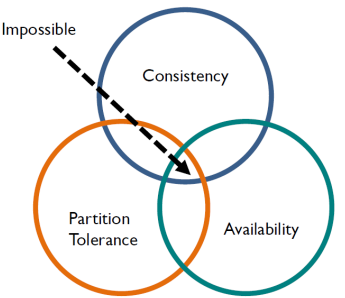
- Details: CAP theorem - Wikipedia
- In a distributed system, three properties are of particular interests:
  - C – Consistency
  - A – Availability
  - P – Partition Tolerance
- Recommended Reading: Kaushik Sathupadi. ‘A plain english introduction to CAP Theorem’ http://ksat.me/a-plain-english-introduction-to-cap-theorem/

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

```
$ python3
Python 3.5.2 (default, Nov 23 2017, 16:37:01)
[GCC 5.4.0 20160609] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>> print("Hello World!")
Hello World!
>>>
```

- Type **`python3`** (or simply **`python`**) to invoke the Python interpreter
- **`print()`** will output the arguments to standard output

Programming in Python

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

```
print("Hellow World!")
```

- Executing the script:

```
$ python3 hello.py
Hello World!
$
```

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 `pip` (https://pypi.python.org/pypi). For example:

```
$ python3 -m pip install requests
```

Python Basics

```
# Everything after a `#` is comment
# import modules using the import keyword
import math

# define functions using def
def power_three(x):
    return math.pow(x, 3)

if __name__ == "__main__":
    print(power_three(10))

# Executing this script prints 1000.0
```

- 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

```
# if-then-else statements
if x == 0:
    print("Zero!")
elif x > 0:
    print("Larger than Zero!")
else:
    print("Less than Zero")

# while loop
x = 0
while x < 10:
    x += 1

# for loop
for x in range(10):
    print(x)
```

Python Data Structures

Lists

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

```
cities = ["Hong Kong", "Macau", "Taipei", "Beijing"]
print(cities[0])     # prints "Hong Kong"
print(cities[2])     # prints "Taipei"

print(cities[-1])    # prints "Beijing"

print(len(cities))   # prints 4

print(cities[1:3])   # prints ["Macau", "Taipei"]
print(cities[:3])    # prints ["Hong Kong", "Macau", "Taipei"]
print(cities[2:])    # prints ["Taipei", "Beijing"]
print(cities[::-1])  # prints ["Beijing", "Taipei", "Macau", "Hong Kong"]
```

Python Data Structures

Using lists in for loops

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

```
numbers = [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]
sum = 0
for n in numbers:
    sum += n

print(sum)  # prints 55
```

Python Data Structures

List methods

- List objects have a number of using methods:

```
x = [1, 2, 3]

x.append(4)           # x becomes [1, 2, 3, 4]
x.insert(0, 0)        # x becomes [0, 1, 2, 3]
x.extend([4, 5])      # x becomes [1, 2, 3, 4, 5]
x.sort(reverse=True)  # x becomes [3, 2, 1]
x.index(2)            # this returns 1, the index of the element 2
```

- 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)

```
exam_scores = {"John": 70, "Mary": 80}

print(exam_scores["John"])   # prints 70
print(exam_scores["Mary"])   # prints 80

print(list(exam_scores.keys()))    # prints ["John", "Mary"]
print(list(exam_scores.values()))  # prints [70, 80]
```

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:

```
exam_scores = {"John": 70, "Mary": 80}

# exam_scores.items() actually returns [("John", 70), ("Mary", 80)]
# which is a list of 2-tuples
for name, score in exam_scores.items():
    print("{:s} scores {:d} in the exam.".format(name, score))
```

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

Files in Python

```
f = open("file.txt", "r")   # open a file in read mode
for line in f:
    print(line)

f.close()  # Always close the file after use
```

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

```
f = open("file.txt", "r", encoding="utf-8")
for line in f:
    print(line)

f.close()
```

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 `.py` file
- You can **import** class, functions and variables from other modules

```
# This is in my_functions.py
def factorial(n):
    f = 1
    for i in range(n):
        f *= i + 1
    return f

# In another file, e.g. main.py
from my_functions import factorial
print(factorial(5))  # prints 120
```

- 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:

```
$ python3 -m pip install virtualenv
```

Using Virtualenv

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

```
$ virtualenv venv
```

- To activate the environemnt, use the following command:

```
$ source venv/bin/activate
(venv) $
```

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

Assignment 0

Python Programming Exercises

- http://iems5703.albertauyeung.com/assignment-0.html
- Refer to the instructions on the course Web site
- Submit your files in the format described in the instruction
- Late submissions will **NOT** be marked
- Make sure that your program can be executed under **Python 3.5** or above
- Search for "Python exercises" if you think this is not enough

End of Lecture 1