CSE216
Programming Abstractions

Instructor: Zhoulai Fu

State University of New York, Korea

Course website:
https://github.com/zhoulaifu/23_cse216_fall

Some slides taken from SBU. Thanks!

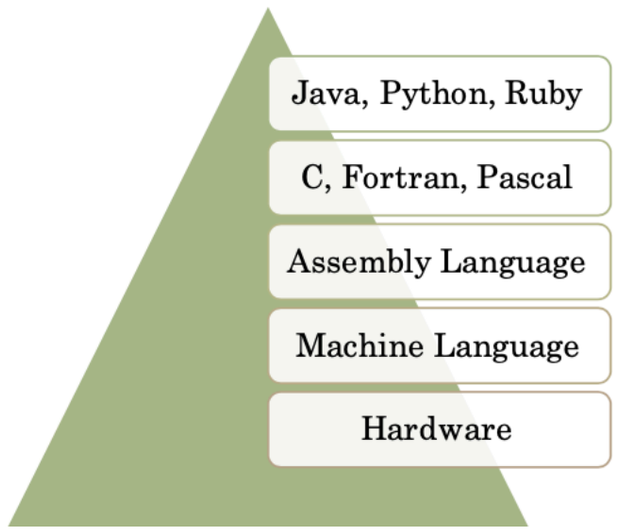
What is Programming Abstraction

- Programming abstraction is a technique used in computer programming **to simplify the complexity** of writing and understanding code. It involves creating higher-level abstractions that **hide low-level implementation details**, allowing programmers to focus on solving problems at a higher level of abstraction.

- Abstractions in programming can take many forms, including **data structures, functions, and classes**. For example, a programmer can use a class in object-oriented programming to group together related functions and data, creating a higher-level abstraction that makes it easier to work with the program.

Abstraction in Language Evolution

- Most programming languages are *high-level* languages, where the phrase "high-level" indicates a higher degree of abstraction.
- The second word of this course's name – **abstraction** – is among the most important ideas in programming.
- It refers to the degree to which the language's features are separated away from the details of a particular computer's architecture and/or implementation at *lower* levels.



Why abstraction?

We write code to solve problems. So, given a specific problem, writing good code involves

1. using the right **paradigm** for the problem,
2. using the proper amount of **abstraction, and**
3. having adequate modularity in your code.

- Programming abstraction is essential in software engineering because it allows programmers to manage the complexity of large software projects. By providing high-level abstractions, it makes it easier for developers to work collaboratively, and it allows for easier maintenance and testing of software code.

This course

- In this course, we work with three programming languages: **OCaml and C**. However, the course **does not solely focus on these individual programming languages**. If you approach the course with a narrow focus on the syntax of each language, you may find it more challenging than necessary.

- Instead, the course **emphasizes the underlying concepts that are common to all programming languages.** We examine the programming paradigms that have emerged. Each paradigm has its own strengths and weaknesses, and our goal is to **gain a deep understanding of the various ways of thinking about programming**. This will enable us to determine, based on a given scenario, which language and paradigm to use to write efficient and effective code.

Course outcomes

An understanding of programming paradigms and tradeoffs.

An understanding of functional techniques to identify, formulate, and solve problems.

An ability to apply techniques of object-oriented programming in the context of software development.

Logistic matters

- Team
- Textbook
- Schedule
- Homework
- Exams and grading
- Ask for help

Meet the Instructor

- Teaching CSE215 and CSE216
- Data & Intelligent Computing Lab (C404)
- Previous Work: France, US, Denmark and Korea
- Education: École Polytechnique, France
- Personal: Happily married; like dreaming and playing with my child; no special hobbies or talents.

TA

- Ha Yeonkyung <ha.yeonkyung@stonybrook.edu>

Team

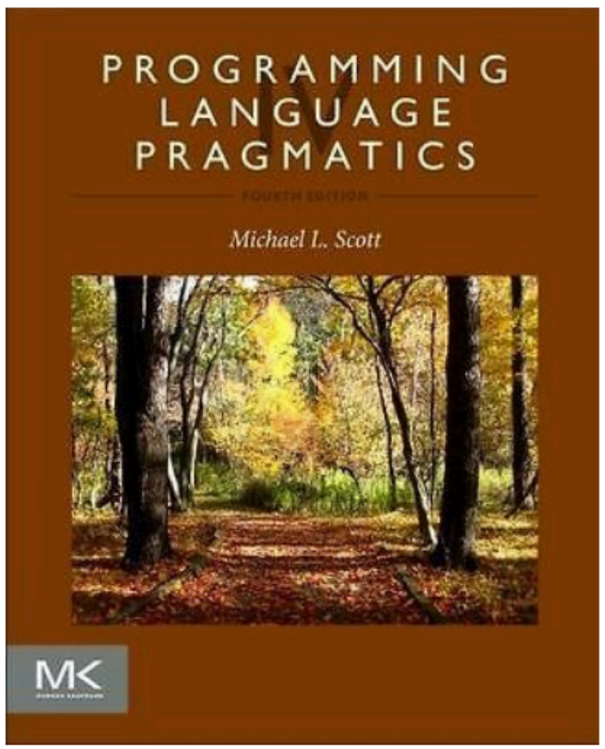
You	TA	Instructor	ChatGPT
Lectures		**Office hours**	**Not do homework**
Homework	**Office hours**	**Lectures**	**homework**
Ask questions	**Answer questions**	**Grading**	**Answer questions**
		Answer questions	

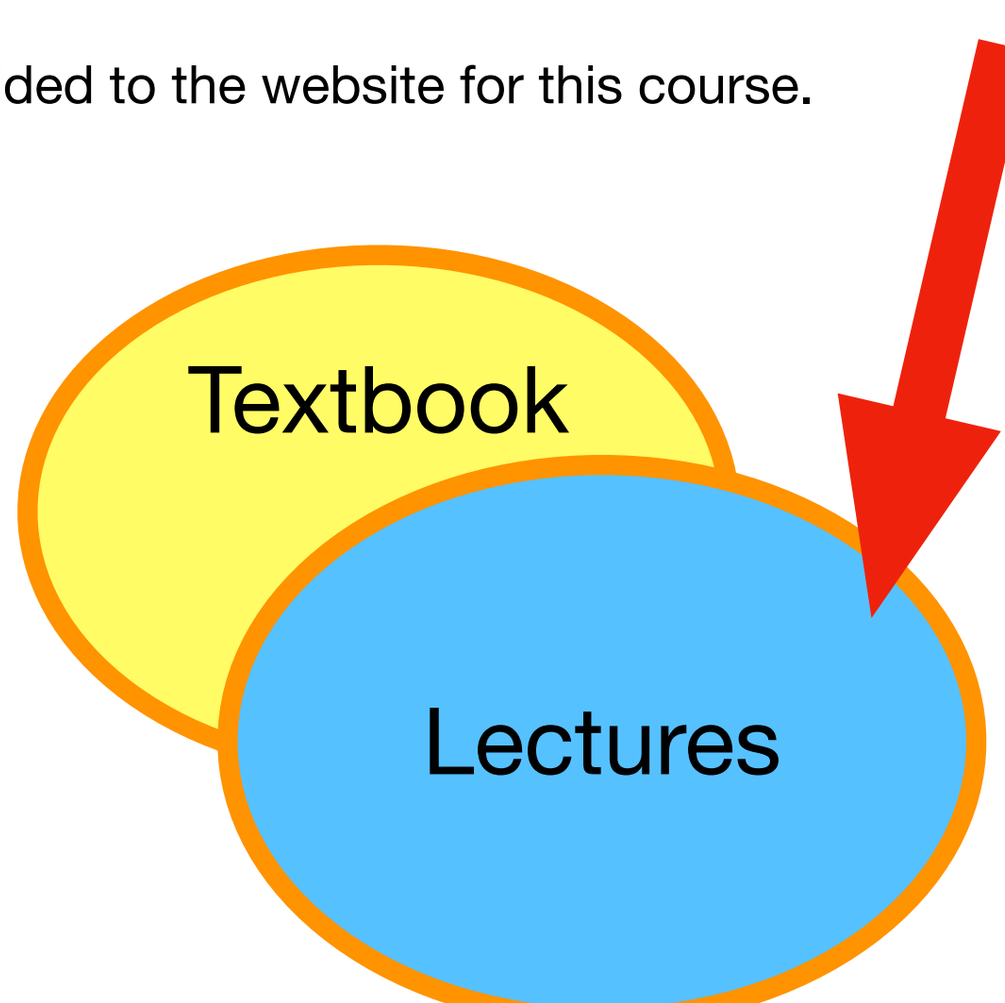
Reference books and reading material

- Michael L. Scott. Programming Language Pragmatics.

- For details pertaining to specific programming languages, the recommended material will mostly be from the following:
  Python tutorial: https://docs.python.org/3/tutorial/
  The official OCaml learning material from https://ocaml.org/learn/

- Other reading material (if used) will be added to the website for this course.





Schedule

- Lectures: TU, TH 9:00 - 10:20, at B203
- Recitation: TH 14:00 - 14:55, at B203
- For most recitations, we may have a quiz or homework announcement. Quiz is due by the end of the recitation. Homework is due by next Thursday 12h59 (included).
- Instructor's Office hours: TU and TH 16:40 - 17:40 at B424
- TA office hours: TBA
- Final: Dec. 11 (Monday) 9:00 - 11:30, at B203

Regarding the quiz

- It will involve reading new material
- No e-devices during quiz. But uploading PDF to Brightspace is needed in the end. (So prepare an app)
- Open notes. Unlimited paper-based notes are accepted.
- Individual work.

Numerical Grading

- Quiz (in-class): 15%
- Homework (take-home): 15%
- Midterm1: 20%
- Midterm2: 20%
- Final: 30%
- Students with regular participation and constructive feedback get 0.5% or 1% bonus

Letter Grade

- Absolute grading if median >= 90
- Relative grading otherwise

- Algorithm guarantees 50% A/A-

- Details: https://github.com/zhoulaifu/23_cse216_fall/blob/master/README.md#grading-letter-scores

```
def get_letter_grade(score, c):
    boundaries = {
        'A':  0.7*c + 30,
        'A-': c,
        'B+': c - 4,
        'B':  c - 7,
        'B-': c - 10,
        'C+': c - 14,
        'C':  c - 17,
        'C-': c - 20,
        'D+': c - 24,
        'D':  c - 27,
        'D-': c - 30,
    }

    for grade, boundary in boundaries.items():
        if score > boundary:
            return grade
    return 'F'
```

Recipe for Success in CSE216

- Attend lectures
- Ask questions
- **Do homework (VITAL)**

Quiz

- What is a super important thing to succeed in the class?
- Is ChatGPT allowed?
- How to ask for help?
- Where to find official course info?

Questions so far?

In the following

- Programming paradigms: imperative, procedural, reactive, declarative, object-oriented, functional

- Demo

Programming Paradigms

Programming Paradigms

- A programming paradigm is a style or approach to programming that provides **a framework for building a software system.** It is a **set of principles, concepts, and practices** that define the way of thinking and organizing the code to solve a specific problem.

There are several programming paradigms, and each has its unique way of approaching problem-solving, code organization, and design. Some of the popular programming paradigms include:

- **Imperative Programming:** This paradigm focuses on the sequence of **statements that modify the state of the program**, and how to control that sequence using conditional statements, loops, and other control flow constructs.

- **Object-Oriented Programming (OOP)**: This paradigm is based on the idea of **organizing software systems as a collection of objects** that interact with each other to solve a problem.

- **Functional Programming:** This paradigm emphasizes **the use of functions** to solve problems and avoid changing the state of the program.

- **Declarative Programming:** This paradigm focuses on **describing the problem** to be solved, rather than how to solve it.

PROGRAMMING PARADIGMS

Most programming languages support multiple paradigms, even though they may stress on one paradigm more than others.

- **Imperative**
  - **Procedural** — COBOL, FORTRAN, C
  - **Object-Oriented** — Smalltalk, Java, OCaML
- **Declarative**
  - **Functional** — Haskell, Scheme, ML
  - **Logic** — Prolog
  - **Constraint** — Mathematica, Prolog
  - **Dataflow**
    - **Reactive**

Choosing a programming paradigm for your work

- The choice of a programming paradigm depends on the problem domain, the team's expertise, and the software requirements. **Each paradigm has its strengths and weaknesses, and the choice of the paradigm can have a significant impact** on the design, maintainability, and performance of the software system.

Imperative programming

- Imperative programming is a programming paradigm that emphasizes the sequence of statements that **modify the state of the program.** In imperative programming, the program consists of a set of commands or statements that change the program's state.

- Imperative programming is **based on the Von Neumann architecture**, which describes a computer as a machine that stores data and instructions in memory, fetches instructions from memory, and executes them in a sequential manner.

- In imperative programming, the programmer specifies how the program should perform its tasks, by **giving a sequence of commands** to be executed by the computer. These commands can include assignments, loops, conditionals, and function calls.

- Examples of imperative programming languages include **C, Java, Python**, and many others. These languages offer a rich set of control flow constructs and operators that enable the programmer to manipulate the program's state in a variety of ways.

- One of the advantages of imperative programming is that it provides the programmer with **a great deal of control** over the program's behavior. However, it can be challenging to write, debug, and maintain large imperative programs, as they can quickly become complex and difficult to understand.

Imperative Programming

- A **statement** is a syntactic unit of an imperative programming language that expresses some action to be carried out.
- The program in such a language thus becomes a sequence of statements.

```
assert(x == 7);       /* assertion statement; programmer assumes the
                         value of x to be 7 after this line */
x = 2 + 3;            /* assignment statement */
2 + 3;                /* has no effect; smart compilers will discard
                         this line */
puts(“hello world”); /* a function call */
goto label;           /* a goto statement */
return 0;             /* a return statement */

x = sqrt(2); /* an assignment statement containing a function call */
```

Simple Statements

Imperative Programming

- An **assignment statement** performs an operation on information located in memory and stores the results in memory for later use.
  - Higher-level imperative languages permit evaluation of complex expressions that may consist of a combination of arithmetic operations and function evaluations.

```
assert(x == 7);          /* assertion statement; programmer assumes the
                            value of x to be 7 after this line */
x = 2 + 3;               /* assignment statement */
2 + 3;                   /* has no effect; smart compilers will discard
                            this line */
puts("hello world");     /* a function call */
goto label;              /* a goto statement */
return 0;                /* a return statement */

x = sqrt(2); /* an assignment statement containing a function call */
```

Simple Statements

Imperative Programming

- A conditional statement allows a sequence of statements (known as a *block* or a *code block*) to be executed only if some condition is met.
- Otherwise, the statements are skipped, and the execution sequence continues from the statement following them.

```
if (happy) {
    smile();
} else if (sad) {
    frown();
} else {
    stoic();
}
```

```
switch (i % 2) {
    case 0:
        type = EVEN;
        break;
    default:          /* equiv. to case 1 */
        type = ODD;
        break;
}
```

Compound Statements

Imperative Programming

- Looping statements allow a block to be executed multiple times.
- Loops can execute a block a predefined number of times, or they can execute them repeatedly until some condition changes.

```c
while ((c = getchar()) != EOF) {
    putchar(c);
}

do {
    computation(i);
    ++i;
} while (i < 10);

for (i = 1; i < n; i *= 2) {
    printf("%d\n", i);
}
```

Compound Statements

Procedural Programming

- Procedural programming is a programming paradigm that is based on the idea of **breaking down a program into smaller, reusable procedures**. In procedural programming, the program consists of a collection of procedures that operate on data, and the procedures are called in a specified sequence to perform a particular task.

- In procedural programming, the **focus is on the procedures** that are executed, rather than the data that is manipulated. The procedures are defined using a set of instructions that are executed in a sequence, with control structures such as loops and conditionals used to control the flow of the program.

- Procedural programming is particularly **useful for developing programs that perform a series of operations on data,** as the data can be passed between functions to perform various operations. It is widely used for developing programs that involve input/output operations, data processing, and mathematical calculations.

- Some popular languages that support procedural programming include C, Pascal, and Fortran. However, many modern programming languages, such as Python and Ruby, also support procedural programming in addition to other programming paradigms such as object-oriented programming and functional programming.

- One of the **advantages** of procedural programming is that it is relatively **easy to understand and debug,** as each function is responsible for a specific task. However, it can be challenging to write and maintain large procedural programs, as the functions can become complex and difficult to manage.

An example in C

```c
#include <stdio.h>

// Define a function that prints the Fibonacci sequence up to n
void fibonacci(int n) {
    int a = 0, b = 1, c, i;
    printf("%d %d ", a, b);
    for(i = 2; i < n; i++) {
        c = a + b;
        printf("%d ", c);
        a = b;
        b = c;
    }
}

// Call the function to print the Fibonacci sequence up to 10
fibonacci(10);
```

- In this example, we're using procedural programming to define a function that prints the Fibonacci sequence up to a specified number. We're specifying how the computation should be performed step-by-step, by using a for loop to calculate each number in the sequence and print it to the console.

- Note that we're specifying the details of how to perform the computation step-by-step, rather than just describing what we want to happen. This is the essence of procedural programming - we define a series of steps that the computer should follow to accomplish a task.

An example in Python

```python
# Function to calculate the area of a rectangle
def calculate_area(length, width):
    area = length * width
    return area

# Function to calculate the perimeter of a rectangle
def calculate_perimeter(length, width):
    perimeter = 2 * (length + width)
    return perimeter

# Main program
length = float(input("Enter the length of the rectangle: "))
width = float(input("Enter the width of the rectangle: "))

area = calculate_area(length, width)
perimeter = calculate_perimeter(length, width)

print("The area of the rectangle is:", area)
print("The perimeter of the rectangle is:", perimeter)
```

- In this example, we have two functions: calculate_area and calculate_perimeter. These functions take the length and width of a rectangle as inputs and return the area and perimeter, respectively.

- The main program prompts the user to enter the length and width of a rectangle, calls the calculate_area and calculate_perimeter functions, and then prints the results.

- This code demonstrates the basic principles of procedural programming, which involve **breaking down a program into smaller, reusable procedures, and calling these procedures in a specific sequence to perform a particular task**.

Object-oriented Programming

- Object-oriented programming (OOP) is a programming paradigm or a style of programming that is **based on the concept of "objects." An object is** a self-contained unit that consists of both **data and the methods** that operate on that data. In OOP, everything is treated as an object, and the code is organized around these objects.

- OOP is widely used in software development because it provides an **advantageous** way of **creating complex programs,** making it easier to write, test, and maintain code. Some of the most popular programming languages that use OOP include Java, C++, Python, and Ruby.

Core concepts in OOP

- **Encapsulation**: It means that the data and behavior of an object are **hidden** from the outside world, and only the methods that the object exposes can be used to interact with it.

- **Inheritance**: It allows for the creation of new classes by inheriting properties and methods **from existing ones**.

- **Polymorphism**: It means that objects can take on different forms and **exhibit different behaviors, depending on the context** in which they are used.

OOP concept 1: Encapsulation

- Encapsulation is one of the fundamental principles of object-oriented programming and refers to the practice of hiding the internal details of an object from the rest of the program. In Java, encapsulation is achieved through the use of access modifiers (public, private, protected) to restrict access to the variables and methods of a class.

- Encapsulation is important because it allows us to build more robust and maintainable code. By hiding the internal details of an object from the rest of the program, we can ensure that other parts of the program cannot interfere with the object's state in unintended ways. This makes our code more reliable and easier to understand and maintain.

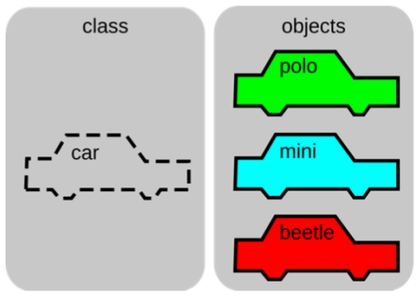
- In Java, we typically define instance variables as private and provide public getter and setter methods to access and modify the state of the object. This allows us to enforce any necessary validation or business logic before allowing changes to the object's state.

```java
public class BankAccount {
    private int balance;

    public BankAccount(int balance) {
        this.balance = balance;
    }

    public int getBalance() {
        return balance;
    }

    public void deposit(int amount) {
        balance += amount;
    }

    public void withdraw(int amount) {
        if (balance >= amount) {
            balance -= amount;
        } else {
            System.out.println("Insufficient funds");
        }
    }
}
```

OOP concept 2: Inheritance

- Inheritance is a fundamental concept in Object-Oriented Programming (OOP) that allows a new class to be based on an existing class. In other words, the new class (called a subclass or derived class) **inherits the properties and methods of the existing class** (called the superclass or base class).

- Inheritance **allows for code reuse and makes it easier to create and maintain complex programs**. The subclass can add new properties and methods or modify the existing ones of the superclass, while still inheriting the characteristics of the superclass. This allows for more efficient and modular code development.



Source: Pluke [CC0], from Wikimedia Commons

```java
class Vehicle {
    protected String make;
    protected String model;
    protected int year;

    public Vehicle(String make, String model, int year) {
        this.make = make;
        this.model = model;
        this.year = year;
    }
}

class Car extends Vehicle {
    private String country;

    public KoreanCar(String make, String model, int year, String country) {
        super(make, model, year);
        this.country = country;
    }

    public String getCountry() {
        return country;
    }
}

class Main {
    public static void main(String[] args) {
        Car car = new Car("Kia", "Seltos", 2022, "South Korea");
        System.out.println(car.make); // prints "Kia"
        System.out.println(car.model); // prints "Seltos"
        System.out.println(car.year); // prints 2022
        System.out.println(car.getCountry()); // prints "South Korea"
    }
}
```

- In this code, we created a new class Car that inherits from Vehicle and adds a new property country that represents the country of origin of the car. In the main method, we created a Car object with the make "Kia", model "Seltos", year 2022, and country "South Korea”.

- By using inheritance, we can avoid duplicating code that is common to all vehicles in the Car class. Instead, we can define these properties in the Vehicle class and let the Car class inherit them.

Polymorphism

- Polymorphism is the ability of objects of different classes to be treated as if they are objects of the same class. This means that **objects of a derived class can be used in place of objects of a base class**

- Polymorphism is an important concept in object-oriented programming because it allows for more flexible and modular code. By treating objects of different classes as if they are objects of the same class, we can write **more generic code that can work with a variety of different objects, making our code more reusable and easier to maintain.**

```java
// Base class
class Shape {
    public void draw() {
        System.out.println("Drawing a shape...");
    }
}

// Derived class 1
class Circle extends Shape {
    public void draw() {
        System.out.println("Drawing a circle...");
    }
}

// Derived class 2
class Square extends Shape {
    public void draw() {
        System.out.println("Drawing a square...");
    }
}

// Main class
class Main {
    public static void main(String[] args) {
        // Create an array of shapes
        Shape[] shapes = { new Circle(), new Square() };

        // Draw all the shapes in the array
        for (Shape shape : shapes) {
            shape.draw();
        }
    }
}
```

- n this example, we have a base class Shape and two derived classes Circle and Square. Each of these classes has its own implementation of the draw() method.

- In the Main class, we create an array of Shape objects that contains one Circle object and one Square object. We then use a for loop to iterate over the array and call the draw() method on each object.

- Thanks to polymorphism, we can treat each object in the array as if it were a Shape object, even though they are actually instances of different classes. This allows us to write code that is more flexible and reusable, as we can easily add new shapes to the array without having to change the for loop or any other code.

Reactive Programming

- Reactive programming is a programming paradigm that is **focused on reacting to changes in data or events**, rather than relying on a fixed flow of control. It involves using streams of data and functional programming concepts to react to changes in the data, rather than using imperative programming constructs.

- The fundamental idea behind reactive programming is to model data and events as streams that flow through the system, and then to use operators to transform and manipulate these streams in real-time.

- Reactive programming is **commonly used in web development**, where it's used to build reactive user interfaces that respond to user input and server-side events. It's also used in mobile and desktop development, gaming, and other areas where real-time data processing is necessary.

- As an overly simplistic idea, consider a statement such as **`x = y + z`**
  - In traditional imperative programming, the x is assigned the sum of the values of y and z. If the value(s) of y and/or z changes later, the value of x is not affected.
  - In reactive programming, the value of x is automatically updated whenever y and/or z change.

Declarative programming languages

- In declarative programming, the program **describes the desired result, rather than specifying how to achieve it.** This is in contrast to procedural programming, where the program specifies a series of steps to accomplish a task.

- One example of declarative programming is SQL (Structured Query Language), which is used to query relational databases. In SQL, a programmer specifies the criteria for selecting records from a database, and the database management system determines how to retrieve the data.

- Another example of declarative programming is HTML (Hypertext Markup Language), which is used to create web pages. In HTML, the programmer specifies the structure and content of the web page using tags, and the web browser determines how to render the page based on those tags.

Declarative programming example in SQL

```sql
-- Define a table of students
CREATE TABLE students (
  id INT,
  name VARCHAR(255),
  major VARCHAR(255),
  gpa FLOAT
);

-- Select all students with a GPA greater than 3.0
SELECT id, name, major
FROM students
WHERE gpa > 3.0;
```

- In this example, we're using SQL, which is a declarative programming language for working with databases. We're defining a table of students and then using a declarative SQL query to retrieve all students with a GPA greater than 3.0.

- Note that we're not specifying how to retrieve the data or iterating over it step-by-step, but rather describing the desired result in a declarative way. SQL takes care of the details of how to retrieve the data and return the desired result.

- So, this is an example of declarative programming - we declare what we want to happen, and the programming language takes care of the details.

Declarative programming example in HTML

```html
<!DOCTYPE html>
<html>
  <head>
    <title>My Web Page</title>
  </head>
  <body>
    <h1>Welcome to My Web Page</h1>
    <p>This is a paragraph of text.</p>
    <ul>
      <li>Item 1</li>
      <li>Item 2</li>
      <li>Item 3</li>
    </ul>
  </body>
</html>
```

- In this example, we're using HTML, which is a declarative markup language for creating web pages. We're declaring the structure and content of the web page using HTML tags, without specifying how to render the page or interact with it.
- Note that we're not specifying how the page should be rendered or manipulated step-by-step, but rather describing the structure and content of the page in a declarative way. The web browser takes care of the details of how to render the page and make it interactive based on the HTML markup. This is the essence of declarative programming - we declare what we want to happen, and the programming language or system does the rest.

Functional Programming

1

Based on recursive definitions.

- They are inspired by a computational model called **lambda calculus**, developed by Alonzo Church in the 1930s.

2

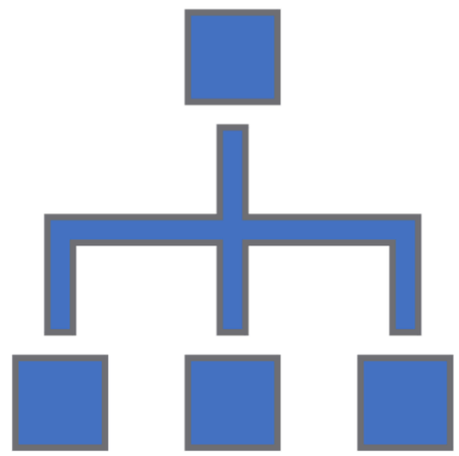
A program is viewed as a mathematical function that transforms an input to an output. It is often defined in terms of simpler functions.

- We will see many examples of functional programming in multiple languages (e.g., Java, Python, OCaML).

Break;

Demo

To finish by 3:20pm



- One Problem. Three paradigms.

- Implementing the greatest common divisor (GCD) solution in different paradigms and different languages.

The GCD problem: pseudocode

```
function gcd(a, b)
    while a ≠ b
        if a > b
            a := a − b;
        else
            b := b − a;
    return a;
```

Paradigm 1:
Imperative Programming in Python

```
1  def gcd (x, y):
2      while (x!=y):
3          if (x>y): x = x-y
4          else: y = y -x
5      return x
6
7  x = 15
8  y = 40
9  print (gcd(x,y))
```

Paradigm 2:
Object-Oriented Programming in Java

/MyClass.java

```java
public class MyClass {



    static int gcd (int x, int y){
        while (x!=y){
            if (x>y) x = x-y;
            else y = y -x;
        }
        return x;
    }



    public static void main(String args[]) {
      int x=10;
      int y=25;


      System.out.println("GCD of x+y = "+ gcd(x,y));
    }
}
```

Paradigm 3:
Functional Programming in Ocaml

```
1  let rec gcd (x, y) = if x> y then gcd (x-y, y) else if x < y then gcd (x, y -x) else x ;;
2
3  let r= gcd(15, 40);;
4
5  print_int r;;
6
```

Summary

- Imperative, functional, object-oriented paradigms

- Instead of learning languages by languages, it is much more efficient to learn programming language paradigms.