CMSC 131

Object-Oriented Programming I

Algorithms, System Design

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This material is based on material provided by Ben Bederson, Bonnie Dorr, Fawzi Emad, David Mount, Jan Plane

Overview

- Algorithms
- System Design

What is an algorithm?

- The method used to solve a particular problem is called an **algorithm**.
- **Example**: Make a peanut butter and jelly sandwich:
  - Get a loaf of bread
  - Remove two slices
  - Get a jar of peanut butter
  - Get a knife
  - Open the jar
  - Using the knife, get some peanut butter and spread it on one slice
  - …blah, blah, blah
- There is essentially **one sequential process** being described.
- Pseudo-code is used to represent algorithms = step-by-step solutions to problems
- Algorithms are often coded as single methods

Concerns at the Algorithmic Level of Design

- Correctness

  Does my algorithm correctly solve the problem?

- Efficiency

  Is my algorithm fast enough for the job?

- Clarity

  Is my algorithm understandable? and is it implementable?

Putting all your eggs in one basket

- Problem: I have 16 baskets full of 12 eggs each; I want to "put all of my eggs in one basket". ☺
- Algorithm #1 ??
  - Combine #1 and #2
  - Combine result with #3
  - Combine result with #4; etc.
- Algorithm #2 ??
  - Combine #1, #2; combine #3, #4; combine #5, #6…
  - Combine <1,2> with <3,4>; Combine <5,6> with <7,8>…
  - Combine <1,2,3,4> with <5,6,7,8>
  - Combine last two …

Algorithmic Efficiency Analysis

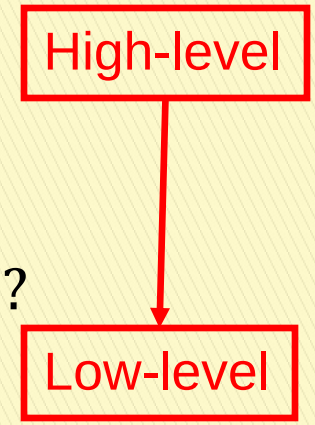
- Measuring which is better for time
- What if the time required for the merging machine is constant?
  - Both have 15 calls to the merging machine when there are 16 baskets to merge
  - What if the number of baskets is another value?
- What if the time required for the merging machine is dependent on the number of eggs being merged?
  - For example 1 second per egg (i.e. merging two baskets of 12 each takes 24 seconds)
  - This takes more math when you want to generalized on the number of baskets

Big-O Notation

- Categories of formulas
- What takes over as n approaches infinity
- **O(1)**
  - Constant time
  - **Example:** array indexing
- **O(log n)**
  - **Example:** binary search
- **O(n)**
  - **Example:** linear search
- **O(n log(n))**
  - **Example:** comparison-based sorting algorithm
- **$O(n^2)$**
  - **Example:** 2D Matrix addition

Coding vs. Software Design

- Coding: writing of (Java) code to implement classes, methods, etc.
  - Projects so far have been primarily coding
  - We have told you what to code
- Design: determination of what to code
  - What classes are needed?
  - How should classes interact?
  - What methods belong in each class?
  - How should method functionality be implemented?



Interfaces and Design

- Next level up the design hierarchy: what methods should go in classes?
- This information can be captured using interfaces
- These interfaces can also be used to identify opportunities for polymorphism (reusable code)
- Rules of Thumb
  - Keep interfaces small
  - Think carefully about operations needed "between classes"
  - Use interfaces to support polymorphism (and keep code size down)

Upper Levels of Software Design

- Where do ideas for classes, interactions between classes come from?
  - Software development part of larger system design process
  - System design requires identifying what system users expect system to do
  - These user requirements often suggest system components and how they fit together
- First part of software design: understand system design

System Design

- **Review:** We have already discussed software design techniques:
  - **Software lifecycle** (analysis, design, implementation, …)
  - **Incremental** (stepwise) **design** (from high-level to low-level)
  - **Pseudocode**
- **Wider view** of program development
- **Two principal aspects of system design**:

  A single computational entity: (for small tasks) What is the step-by-step process to produce a desired outcome.

  Coordinating a community of entities: (for large tasks) How to design a collection of entities that coordinate to solve a complex task.

Today we focus on this aspect of software design.

A Single Computational Entity

- Consider a **single computational entity** to solve a specific problem. The method used to solve the problem is called an **algorithm**.
- There is essentially **one sequential process** being described

System Design: What is it?

- **System Design**: Is concerned with coordinating a **community of computational entities** to achieve a complex process. Each entity has its own responsibilities to the others, to achieve an overall objective:

  Single entity ⟷ **Make a sandwich**

  System design ⟷ **Run a restaurant**

- Running a restaurant involves the **coordinated interaction** of many entities:
  - **Owner**
  - **Chefs**
  - **Waiters**
  - **Diners**

System Design: What is it?

- **System Design**: Identifying entities, assigning responsibilities, defining how these entities act and interact with each other.
- **Other Examples of Systems**:

Classroom environment: Lecturers, TAs, students, …

Library: Circulation (checkout and return), indexing services (online catalogue), library users, book buyers, …

Pharmacy: Patients (and medical records), pharmacists, doctors, drug retailers, the pharmacy (products in stock), …

Video game: Race cars, motorcycles, warriors, space ships, death squads, monsters, aliens, mutants, guns, swords, weapons of mass destruction, cute Japanese cartoon animals with huge eyes, …

Pikachu visits Doom3

Essential Questions

- **Challenges:** System design is very hard. Once the number of entities and interactions becomes large, it is very hard to foresee all the possible consequences of these interactions.
- **Essential Questions**:
  - What is the **desired behavior** of the program (as a whole)?
  - What are the **entities** that produce this behavior?
  - How does each one **work**?
  - How do these entities **interact**?

Behavior

- **Specifying Desired Behavior**: A **use case** is a description of the interaction of a user and the system. It includes:
  - **Prerequisites** (**pre-conditions**): What must hold for this use case to arise?
  - **Possible actions and interactions**: What happens?
  - **Effects** (**post-conditions**): What conditions hold, what changes have taken place, as a result of these actions
- **Example**: Customer in a restaurant
  - **Pre-conditions**:

    Customer: hungry and has money

    Restaurant: has food
  - **Actions**: get menu, order food, be served, eat, pay, leave
  - **Post-conditions**:

    Customer: less hungry and less money

    Restaurant: more money and less food

Principal Design Elements

- **Components**:
  - What are the **entities** that make up our system?
  - What are the **roles** they play?
  - How do we separate the system into **distinct units**?
- **Contract**: What are the **responsibilities** and services associated with each component? What **guarantees** does it make?
- **State**: What is the current status/state of the units that define our system?
- **Communication**: How do components request interactions with each other?
- **Example**: **Pharmacy Store System**

  Components: Pharmacist, customers, doctors, prescription, store stock.

  Fill-prescription Contract: A valid prescription is presented by the customer. Check patient records and inform of possible side-effects. Dispense the prescription. Update patient records. Deliver medication to patient.

  State: For a patient: Current prescriptions, number of times refilled, date of last refill, health insurance information.

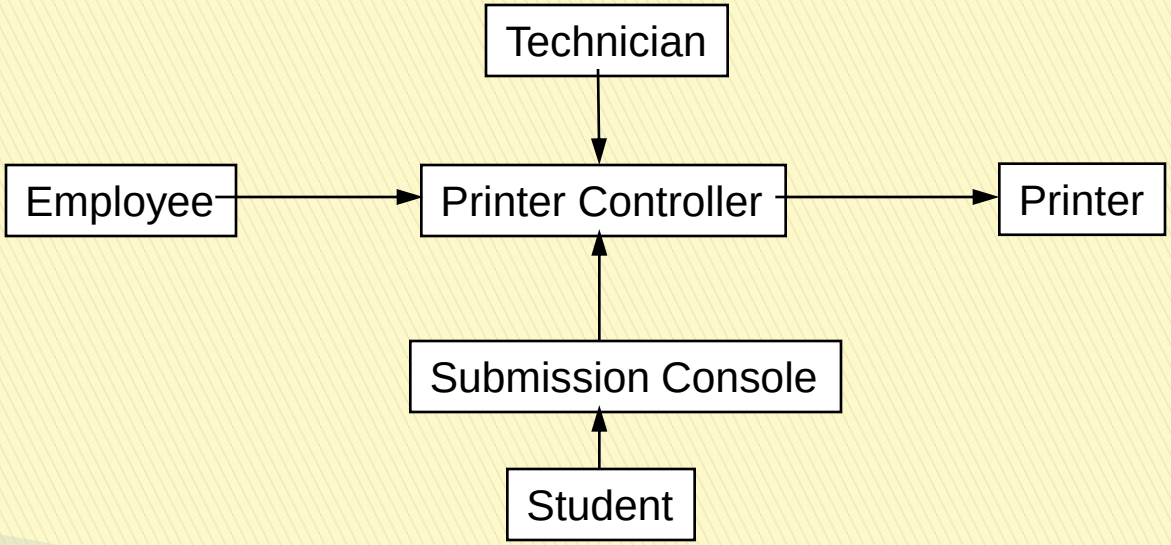
Relationship to Java

- **System**: A Java **program**
- **Components** (or **community members**): Java **class objects**
- **State**: Each object stores information about its current status. These are stored in class **instance variables**.
- **Contract** (or **specification**): This is called an **API** (Application Programmer Interface), or simply an **interface**. This is the **external** (class user) **view** of an object. It provides an abstraction of what the object does, without indicating how it is implemented. The interface provides the **signatures**, that is, details on how invoke, each action.

  The contract is implemented by the object's class **methods**.

Printer Controller Example

- **Printer System**: A printer system used by students to print projects, homeworks, etc.
  - Students enter a room where the printer resides. **Students** submit print requests from a **submission console**.
  - An **employee** operates a **printer controller**, and hands out a print job submitted by students.
  - A **technician** maintains the printer controller if anything breaks.



Printer Controller Example

- **Use Case Example 1**: A student prints a document

  Pre-conditions (prerequisites): A **document exist** and is ready to be printed.

  Actions:

  if (printer **operational** and there is **space available** in the printer queue)
  - specify **name of document** to print through the console
  - printer controller accesses document and **sends it to the printer**

  else
  - printing of the document **does not** occur
  - an appropriate **error message** is generated on the console

  Post-conditions (effects): A document has been **printed**, or an **error message** has been generated.

Printer Controller Example

- **Use Case Example 2**: A technician fixes a printer problem

  Pre-conditions (prerequisites): A **problem** has been identified in the printer controller

  Actions:

  - A technician enters his **password** in the printer controller (to gain access to the system)
  - The technician asks for a **status report** from the controller
  - The nature of the **problem is identified**
  - The technician proceeds to **repair** the problem area in the printer.

  Post-conditions (effects): The printer is **now operational** and the controller reflects the **new status**.

Printer Controller Example

- **Use Case Example 3**: An employee picks up a student print-out

  Pre-conditions (prerequisites): A document has been sent to the printer by a student through the console.

  Actions:

  - a student inquires about his/her particular document
  - the employee checks the stack of printed documents in the printer tray.
  - if document is found
    - the document is handed to the student
  - else
    - student is informed that the document is not printed

  Post-conditions (effects): A student has a **printed document** or has been informed that the document is **not been printed**.

Printer Controller Example: Components

- Examples of some components:

  Name: **Printer**
  Description: Provide paper printouts of documents.
  State: Paper quantity and other printer status information.

  Name: **Printer Controller**
  Description: Used by the Employee and Technician to interact with printer.
  State: Keeps track of documents to be processed, documents already finished, and the operational status of the printer, technician's access password.

  Name: **Printer Submission Console**
  Description: Used by students to submit a document to print.
  State: The set of user's allowed in the system, the set of students that are currently in the system.

Printer Controller Example: Interactions

- Examples of some interactions:

Interaction 1: **Controller and Printer**

The controller **sends documents** to process to the printer. It also gathers **status information** from the printer which is made available to the employee or technician.

Interaction 2: **Console and Controller**

The console **sends a query** to the controller which determines whether the document can be printed or not. It **schedules** the job to printed. Status information about the job is sent back to the console.