IN CLASS EXERCISE

- As you come in and take a seat

- What is software architecture?

- What is software design?

- Write down a description of what these terms mean to you
WHAT IS SOFTWARE ARCHITECTURE?
WHAT IS SOFTWARE DESIGN?
WHY STUDY SOFTWARE ARCHITECTURE AND DESIGN?
WHY DOES SOFTWARE HAVE TO BE REWRITTEN?

- Team spent 1 year building v1, decided to throw it away and build v2.
  - What happened?

- What **risks** cause software to need to be rewritten to meet its requirements?

- What activities can help **reduce** these risks?

- How much, or how little, design should you do **before** building your system?
HOW CAN YOU UNDERSTAND YOUR SOFTWARE?

- Your codebase is 900,000 lines of code.
  - You haven't read every one of the 900,000 lines (and your teammate might have changed them anyway).
  - You need to add a new feature. How can you build on top of what's already there? How do you understand how to do this?

- How can you find abstractions that let you focus on the right level of detail and reduce the amount of work?

- How can you use knowledge from the problem domain to help understand your system?
HOW CAN YOU DESCRIBE HOW YOUR SYSTEM SHOULD WORK?

- I'm implementing a new feature. That will add a dependence on this other part of the system.
  - Is that ok? What are the consequences of introducing this dependency here?
- How can we describe the system elements, relationships, and constraints on these relationships?
- What are the consequences of following these constraints, or violating these constraints?
WHAT CAN I BORROW?

- I'm trying to make my backend system scale better.
  - Others have solved similar design problems before.

- How can design solutions be described, generalized, and shared?
HOW DO YOU FOLLOW A DESIGN?

- What happens when developers make a decision that violates the existing design?
  - Might be intentional choice. Or accidental because of unawareness.

- What techniques and approaches can be used to reduce design violations?
How can I make it easier for others to reuse my code?

- Code often packaged into libraries and frameworks, which have application programming interfaces (APIs)
- How can I design the API so it's easy to learn and less likely to be used incorrectly?
- What happens when I need to change an interface that others depend on?
HISTORY OF SOFTWARE DESIGN AND ARCHITECTURE

- How do you make changes to this code?
- How do you organize this code?
STRUCTURED DESIGN (1970S)

- Can use representations beyond software to describe structure of design
- Make choices about structure in order to make software easier to modify and maintain

NOTE: Node numbers shown here indicate that the box has been detailed. The C-number or page number of the child diagram could have been used instead of the node numbers.
INFORMATION HIDING (1970s)

- Software contains **design decisions** which may change

- Code made more maintainable by **hiding** design decisions in module, enabling change to decision without change **rippling** outward and causing changes to dependencies
SOFTWARE ARCHITECTURE (1990s)

- Structural constraints on elements and element relationships can be codified as architectural styles
- Any system following an architectural has specific properties inherent to the architectural style

DESIGN PATTERNS (1990s)

- Reusable solution to a problem in a context
- Rather than solving problems from scratch, experts borrow existing solutions to common design problems.
- Giving them names allows them to be recognized and taught
AGILE SOFTWARE DEVELOPMENT (2000S)

- Architecture built upfront can sometimes be mismatched to goals, particularly when new information is revealed later.
- Update architecture and design to respond to change and better knowledge.

Manifesto for Agile Software Development

We are uncovering better ways of developing software by doing it and helping others do it. Through this work we have come to value:

- Individuals and interactions over processes and tools
- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

That is, while there is value in the items on the right, we value the items on the left more.

http://agilemanifesto.org/
APIS (2000s)

- Web increased availability and number of libraries and frameworks, often as free open source projects
- How do you learn how to use these?
- What can you do to make your API easier to learn and use?

Myers & Stylos, *Improving API Usability*, CACM 59 (6), 2016
SOFTWARE ECOSYSTEMS (2010s)

- Businesses expose web services
  - Market for software and services
- APIs create value for organizations
- Systems of systems, where no single owner controls the design of the system from end to end
- Work more distributed, through crowdsourcing, hackathons, bug bounties
- How do you change an interface, when widely used?
WHAT ARE SOME WAYS YOU'VE USED THESE IDEAS?
THIS COURSE

- Comprehensive introduction to software architecture and design, including methods, processes, and notations
- Will draw on
  - Guidelines and examples from experienced developers
  - Principles from software engineering research
  - Empirical results and theories from studies of software developers
EXPECTED LEARNING OUTCOMES

▸ Characterize a design space, including identifying risks and key architectural decisions

▸ Design abstractions that express a system or domain model

▸ Use notations to describe elements and relations in an architecture

▸ Reverse engineer design decisions, architectural styles, design patterns, design rules, and programming styles from existing systems

▸ Create and evaluate designs for modifiability and reuse
RESOURCES

- Course website - Syllabus, Schedule
- Piazza - Announcements, Assignments, Discussion, Questions
- Blackboard - grades
READINGS

- Weekly readings from the course textbook and from classic software engineering papers
- Should read the assigned readings before each class. Class may involve discussion of readings
- Papers available online
  - Access the link either through which you can get through Mason VPN if off campus
IN-CLASS ACTIVITIES

- Each class will include an extended in-class activity, often in groups
- Practice architecture and design on small problems
- Will generate a small deliverable, often in form of diagram, sketch, or list
- Graded
  - Satisfactory: put forth a good effort in accomplishing the activity's goals (10/10)
  - Needs improvement: substantially misunderstood the activity or did not make meaningful progress (5/10)
  - Not present: did not submit deliverable from activity (0/10)
- To accommodate planned or unplanned absences, three lowest scores (including absences) dropped
- Must be in-class to submit. Need to submit by end of class (7:10pm).
HWS (A.K.A. “PROJECT”)

- Most HW assignments will be related to a project
- Practice reverse engineering the architecture and design of real systems
- Gain experience with working with architecture and design in context of real world problems
- Reverse engineer the design and architecture of three competing open source applications that each offer alternative solutions to the same underlying problem
HWS: GROUPS

- Strongly encouraged (but not required) to form a project group of two or three.

- Many assignments require substantial work and have been designed with group in mind.

- Encourage you to work together and discuss your assignments over Zoom, Google Hangouts, IM, Slack, etc.

- May choose to work in a group of one, but responsible for the same work.
LATE HW ASSIGNMENTS

- Can submit up to 24 hours late, lose 10%
- HW submissions more than 24 hours late will receive a 0
HW0

- Due next Mon before class
- Form a group of 1, 2, or 3
- Select 3 systems to reverse engineer
EXAMS

- Midterm exam and comprehensive final
- Closed book.
- Includes both in class lectures and material from assigned readings
- Midterm in-class, final exam during scheduled final exam slot
GRADERS

- In-Class Activities: 10%
- HWs and project presentation: 40%
- Mid-term exam: 20%
- Final exam: 30%
WHAT CHOICES DO YOU MAKE WHEN DESIGNING?
DESIGN AS CHOICE

▸ Should you prioritize initial loading time or responsiveness?

▸ Should you choose a layered architecture, a pipes and filter architecture, or something else?

▸ Should you implement this feature in the server, the client, or both?

▸ Should you implement this feature in class A or class B?
ANT ON A BEACH

Herb Simon. The sciences of the Artificial.
SYSTEMS ADAPT TO TASK ENVIRONMENT

- Can describe the literal path the ant took.
- Or could describe the underlying environment that lead to the ant's behavior.
  - Task environment: What is the ant being asked to do. What can it do.
  - Goals / objectives: How is the performance of the ant assessed?
  - Solutions: What is the final realized behavior, given these objectives?
- Describing system in this way leads to deeper understanding of how system works.
EXAMPLE: RACKSPACE ARCHITECTURE V1

- Rackspace email server
  - Has log files which record what happened, helping respond to customer queries about problems

- V1
  - Each service on each email server writes to a separate log file.
  - To answer customer inquiry, execute grep query.

Challenges
- As system gained users, overhead of running searches on email servers became noticeable.
- Required engineer, rather than support tech, to perform search
EXAMPLE: RACKSPACE ARCHITECTURE V2

- Every few minutes, log data sent to central server and indexed in relational database
  - Support techs could query log data through web-based interface
- Challenges
  - Hundreds of servers constantly generating log data --> took long to run queries, load data
  - Searches became slow; could only keep 3 days of logs
  - Wildcard searches prohibited because of extra load on server
  - Server experienced random failures, was not redundant
EXAMPLE: RACKSPACE ARCHITECTURE V3

- Save log data into distributed file system (Hadoop)
  - Indexing and storage distributed across servers
  - All data redundantly stored
  - Indexed 140 GB of log data / day
  - Web-based search engine for support techs to get query results in seconds
  - Engineers could write new types of queries, exposed to support techs through API
COMPARISON

- All offer the same functionality
- But differ in their **quality attributes**
- Ease of modifiability
  - V1 and V2 supported ad hoc queries in seconds by writing a new grep expression or changing SQL query
  - V3 required a new program to be written to build a new query type
- Scalability --> V3 more scalable
- Liveness of results --> V1 always got latest results, V3 short delay
SYSTEMS DESIGNED WITH GOALS IN MIND

- Lists of requirements and features systems should include
- List of quality attributes by which to compare alternative designs, both of which offer the same features
EXAMPLES OF QUALITY ATTRIBUTES ("ILLITIES")

- Performance: how fast is the system
- Reliability: how likely is the system to be available
- Scalability: how well does adding more computing resources translate to better performance
- Maintainability: how hard is system to change
- Extensibility: in what ways can new components be added without changing existing components
- Configurability: how easily can the system behavior be changed by end-users
- Portability: in what environments can the system be used
- Testability: how easy is it to write tests of the system's behavior
IN CLASS ACTIVITY

- Find a partner. Discuss with partner examples of projects where the system has been rebuilt.
- What motivated this?
- What changed? How much effort was it to change?
DESIGN SPACE

- What are the **dimensions** along which a design could vary?
  - What are mutually exclusive design decisions?
- Goal: justify selection of design choices with regards to goals
- Sometimes just built something, and not clear what other ways might have been possible.
  - Requires brainstorming **alternatives**.
- Sometimes not clear if choice was correct
  - Requires considering which alternative best satisfies goals
TECHNIQUES FOR MAKING BETTER DECISIONS

- Researchers have observed expert designers and described how they work to build **guidelines** for making better design decisions.
EXPERTS WORK WITH UNCERTAINTY

- Experts keep options open
  - Know that decisions may be revised and defer decisions that do not need to be made yet

- Experts see error as opportunity
  - Understanding what happened reveals insights about the problem, such as assumptions, misconceptions, misalignments

- Experts make tradeoffs
  - Experts collect as much information as possible and consider how decision trades off with goals

- Experts adjust to the degree of uncertainty present
  - Routine problems have less uncertainty and decisions made earlier; original problems require more exploration, invention, and backtracking
EXPERTS ARE NOT AFRAID

- Experts focus on the essence
  - Identify a **core** set of considerations first, nailing the core before focusing effort on peripheral decisions
- Experts address knowledge deficiencies
  - Look for **gaps** in understanding of problem, try to address these deficiencies. Explicitly identify assumptions and try to test when possible.
- Experts try the opposite
  - When they are stuck, they might try the **opposite**, generating new ideas for alternatives.
Experts are skeptical

- When others are content, experts remain **skeptical** that the current leading solution is good or even good enough.

Experts simulate continually

- Experts imagine how a design will work, **simulating** aspects of the envisioned system and how it will support a variety of scenarios step by step.

Experts alert to evidence that challenges theory

- Open to **unexpected** information that does not conform with current understanding and which suggests problems lurking beneath the surface.
IN CLASS ACTIVITY
DESIGN ACTIVITY: VIRGINIA SQUARE MIXED USE DEVELOPMENT
DESIGN ACTIVITY

- Will explore **design space** for mixed-used development for Mason's new FUSE building in Mason Square in Arlington

- Problem: Design a site plan for how individual spaces within site will be arranged
  - Which spaces will be adjacent on same street, hallway, floor, building, etc.
    - e.g., Where will classrooms go?
    - e.g., Will fast food options be located on first floor or upper floor? Will restaurants be adjacent or located elsewhere?
  - Includes spaces of several types: office space for researchers, classrooms, office space for companies, restaurants, fast food, atriums and common spaces
  - Can assume for each type, will be several instances (e.g., at least 3 fast food restaurants)

- Example design goals: minimize pedestrian travel time, encourage spontaneous collaboration, make it easy for students to get to class
DESIGN ACTIVITY: LOGISTICS

- Form groups of 3 or 4
- Will occur in several steps. Each step will have a deliverable in the form of a separate piece of paper.
- Each deliverable should have names of group members, step number
- Submit deliverable at end of class (7:10pm) on paper
- Graded based on following design activity steps, not the quality of the final site design
- Have fun!
DESIGN ACTIVITY: STEP 1

- Deliverable: design a solution
  - Should list at least 4 key decisions and a short explanation (e.g., a sentence) justifying each one
  - Might (optionally) include a sketch of what site plan would look like
DESIGN ACTIVITY: STEP 2

- Switch groups: half of group go to new groups
- Use a **new** file
- At the top, put your names and the names of the design you are critiquing
- Write a critique of the design decisions made
- Deliverable: for each decision
  - What assumptions does it make?
  - Do you think these assumptions are reasonable? If not, why not? What additional analysis or evidence might help test these assumptions?
DESIGN ACTIVITY: STEP 3

▸ Return to your original group, with a link to the critiques

▸ Using the critique you just received, iterate on your design
  ▸ May change or keep original decision
  ▸ May add new decisions or delete decisions you want to leave open

▸ Deliverable
  ▸ New list of decisions
  ▸ Update rationale and assumptions for decisions based on critique
DESIGN ACTIVITY: STEP 4

- Join together with another group (not one you have exchanged materials)

- Deliverable: build a design space
  - List dimensions that you considered that characterize design solutions
  - List alternatives for each dimension
  - Briefly summarize tradeoffs between alternatives
DESIGN ACTIVITY: DISCUSSION

- What did you learn about the practice of design from this activity?