Introduction to Software System Design

17-423/723 Software System Design

Lecture 1
Jan12, 2026

Today’s Agenda

- Introduction and motivation for software design
- Course logistics

Learning Goals

After today's lecture, you will be able to:

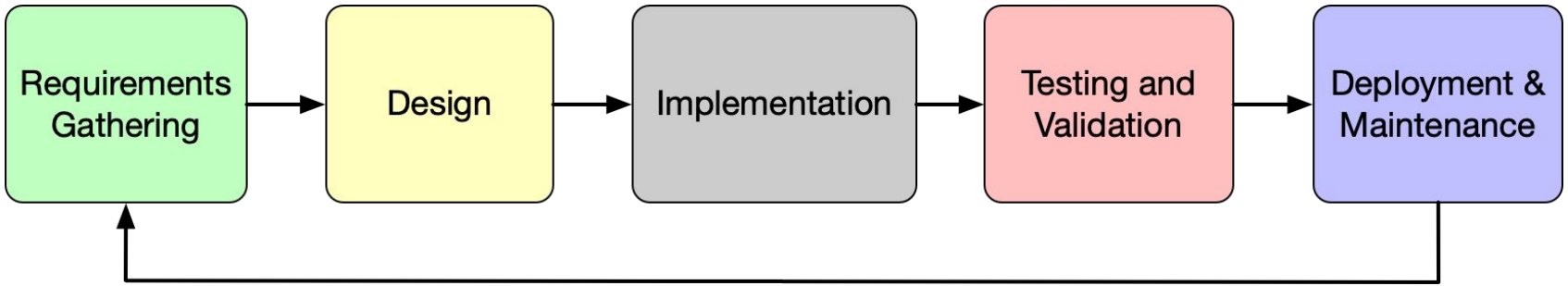
- Describe what software design is and why it is important
- Describe the risk-driven approach to software design
- Describe the generate-communicate-evaluate (GCE) paradigm to designing software
- Describe the role of software designer in AI-based development
- Describe the course logistics

Why design?

What is Design?

What is Design?

- **(Verb**.) To follow a process for planning how a product will work before it is implemented
- **(Noun.**) The result of a design activity, such as design documents, sketches, diagrams, which may serve as a plan for implementation

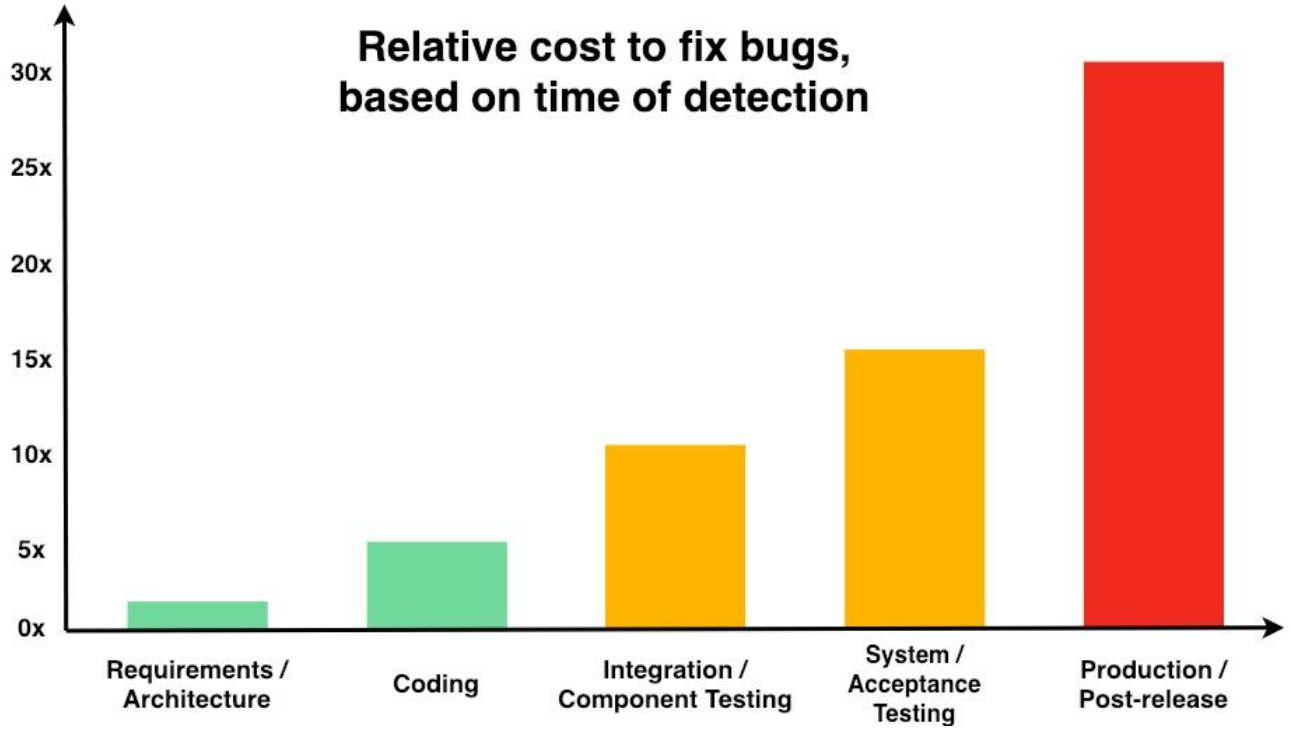


Design in Engineering Products

Software Design in Practice

- Systematic and deliberate design is less common in software industry
- Temptation is to start coding right away
  - “Why bother with design? It’s fine as long as it works!”
- Even if you skip deliberate design, you will end up with an implicit or “default” design anyway
  - But most likely, the default design is not going to have desirable qualities of a successful product
  - As a product/system grows more complex, the cost of improving the design will also become more expensive
  - No deliberate design => higher development costs in the long term!

Discovering Issues Early in Design



US National Institute of Standards and Technology (NIST)

Consequences of Poor or “Default” Design

- Poor or lack of design can cause loss of customers, product failures, injuries, deaths, property/environmental damage, or financial loss
- Throughout the class, we will use case studies of software failures (as well as successes) to extract lessons and design principles

Risk-Driven Approach to Design

Why makes software design hard?

Reason #1: Design is less well-understood by software engineers

- Design is often considered “art” or “talent” rather than teachable skills
- This course is intended to change this perspective! We will teach you design principles and methods that will make you a better designer

Why makes software design hard?

Reason #2: Requirements change frequently

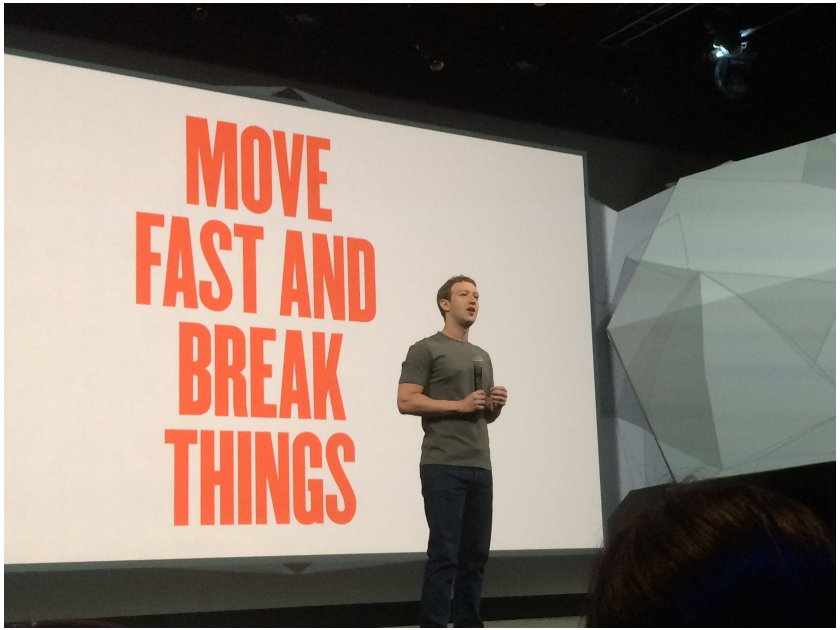
- Your design may become obsolete over time
- But you **can** design systems to be ready for such changes
- “Designing for change” will be a major theme throughout the class

"The client kept changing the requirements on a daily basis, so we decided to freeze them until the next release."

Why makes software design hard?

Reason #3: Tension between deliberate design vs. time-to-market

- Pressure to release your product as soon as possible
- Often used as an excuse to avoid any deliberate design



Why makes software design hard?

Reason #3: Tension between deliberate design vs. time-to-market

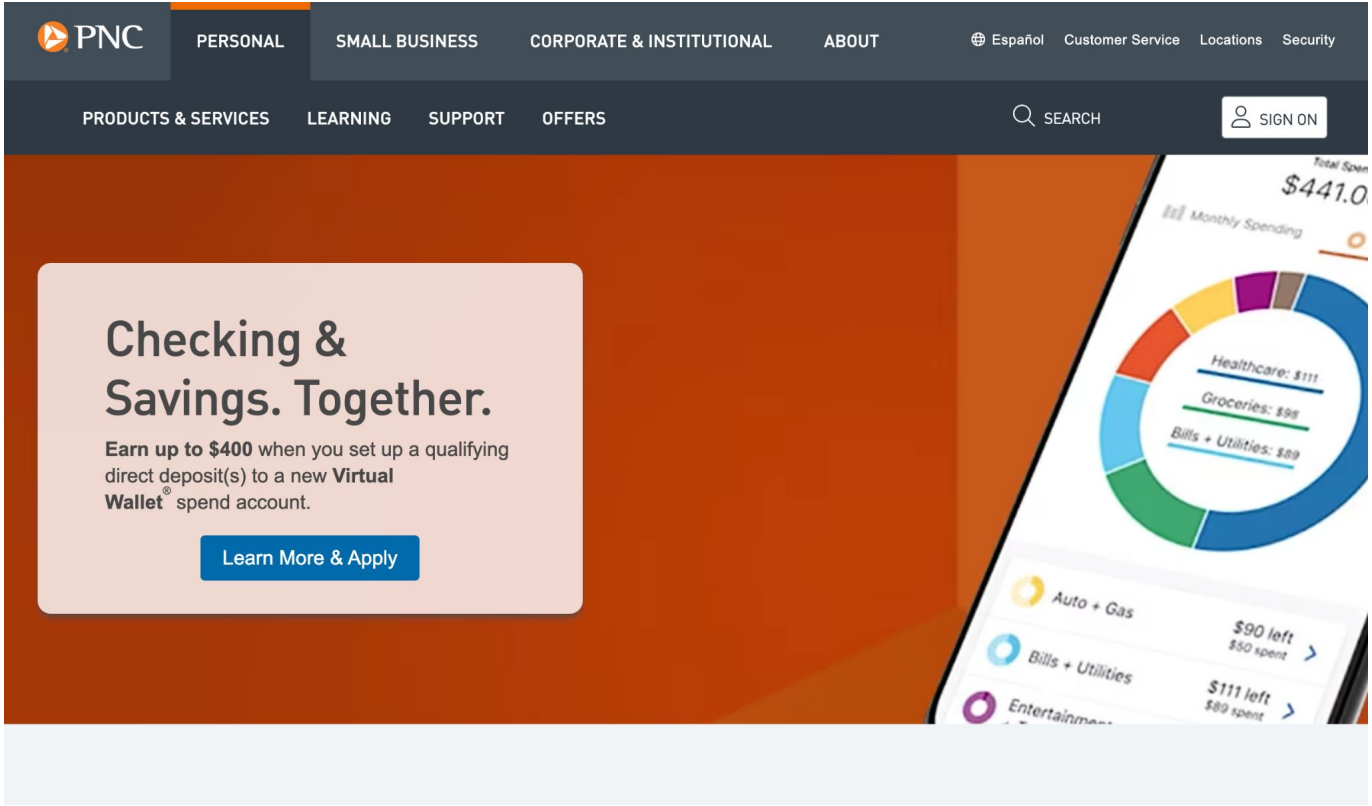
- Pressure to release your product as soon as possible
- Often used as an excuse to avoid any deliberate design
- But as the system scales, it must eventually deal with poor/lack of design!

Risk-Driven Approach to Design

- What is the “right” amount of design to do?
- Risk = (cost of failure)*(likelihood of failure)
- **Ask**: What are possible costs to my organization/stakeholders if my product/system fails?

Cost of a Possible Failure?

Cost of a Possible Failure?



Cost of a Possible Failure?

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Risk-Driven Approach to Design

- What is the “right” amount of design to do?
- Risk = (cost of failure)*(likelihood of failure)
- **Ask**: What are possible costs if my product/system fails?
  - **The amount of design should be proportional to the level of risks**
- Cost of failure: Examples
  - Loss of customers & revenue due to poor availability
  - Loss of customers & revenue due to poor usability
  - Extra development costs and project delays due to poor extensibility
  - Theft of sensitive information due to poor security
  - Injuries or loss of lives due to poor safety
- The goal is not to achieve a perfect product, but to **identify & eliminate “bad” designs that are likely to result in high-risk failures**

What does designing involve?

Types of Design

- Conceptual design
  - What are the key concepts in our system? What does the data model look like?
- Functional design
  - How are the key functionalities of the system implemented? What does the business logic look like?
- Architectural design
  - What are the key components in the system? What are the interfaces between components look like?
- Interaction design
  - How does the user interact with the system? How do we ensure that the system is easy and intuitive for them to use?
- Performance design
  - How do we scale the number of users? How do we ensure high service uptime?
- Security and reliability design
  - How do we protect the system against malicious actors? How do we make system resilient against possible failures in the network?

Quality Attributes

- Design is “easy” if the only goal is to build a functional system
- **Quality attributes (QAs)** are what makes design challenging
  - Often these are cross-cutting and in conflict with each other
  - Designing will frequently involve making **trade-offs** among these quality attributes
- QAs that we will study in this class include:
  - Extensibility
  - Reusability
  - Interoperability
  - Testability
  - Scalability
  - Robustness
  - Security
  - Usability
  - and others…

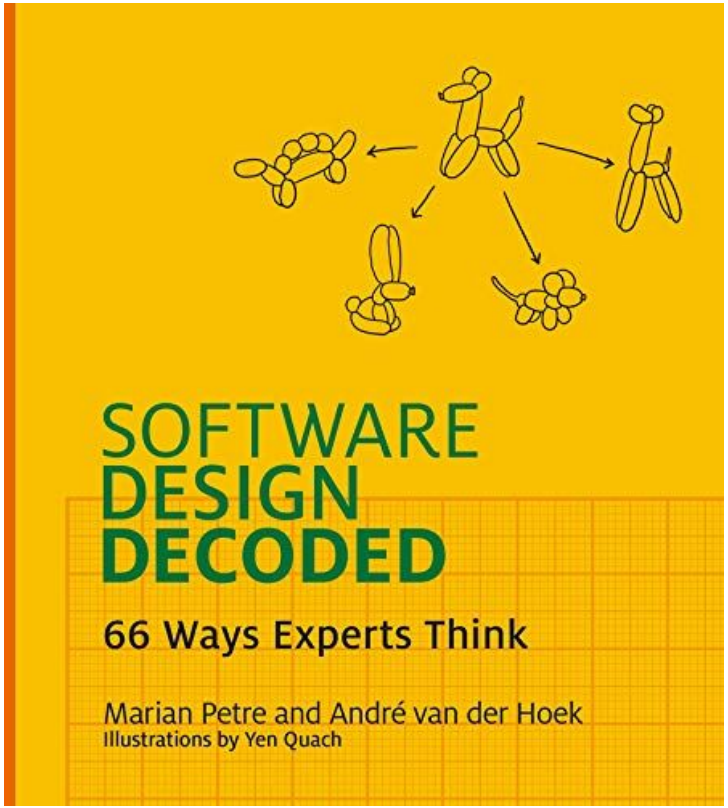
What do designers do?

Activity: Design Challenge

Problem: Develop a system to estimate the number of people using the Internet at the current time

1. Working individually, come up with a solution to the problem (**~3 min**)
2. Turn to the person next you; introduce yourself
3. Explain your solution to each other
4. Provide feedback on the other person's solution: Does it work well? Is it feasible? Is it fast enough? Is it too costly? Under what conditions can it fail?
5. Work together to develop a new and/or combined solution

What do designers do?



What do designers do?

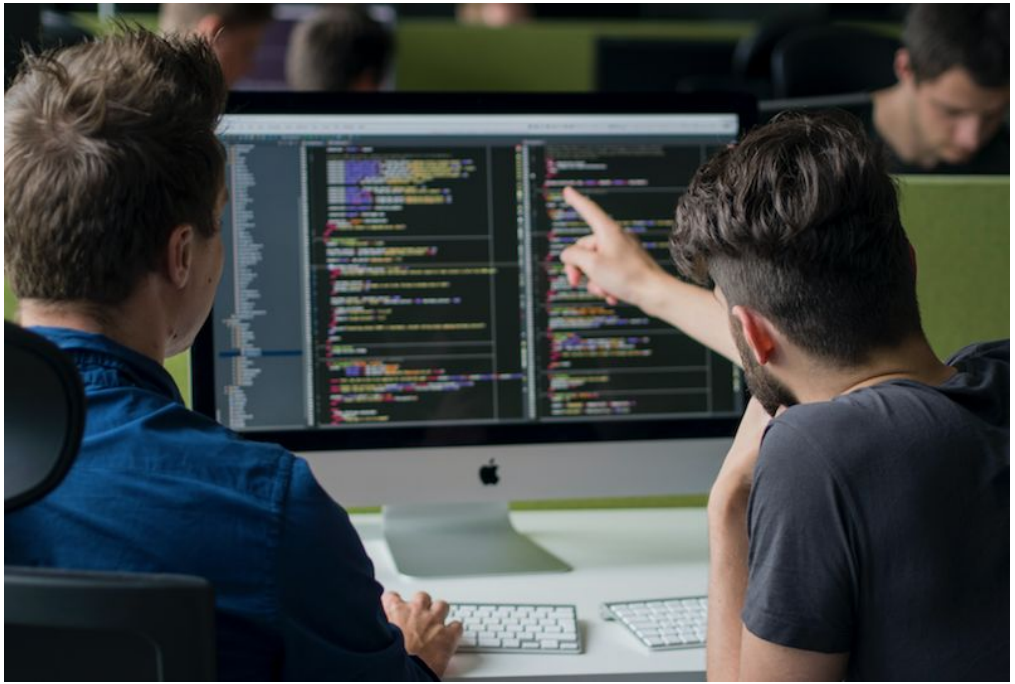
- **Generate**, brainstorm, and explore a space of candidate design solutions

What do designers do?

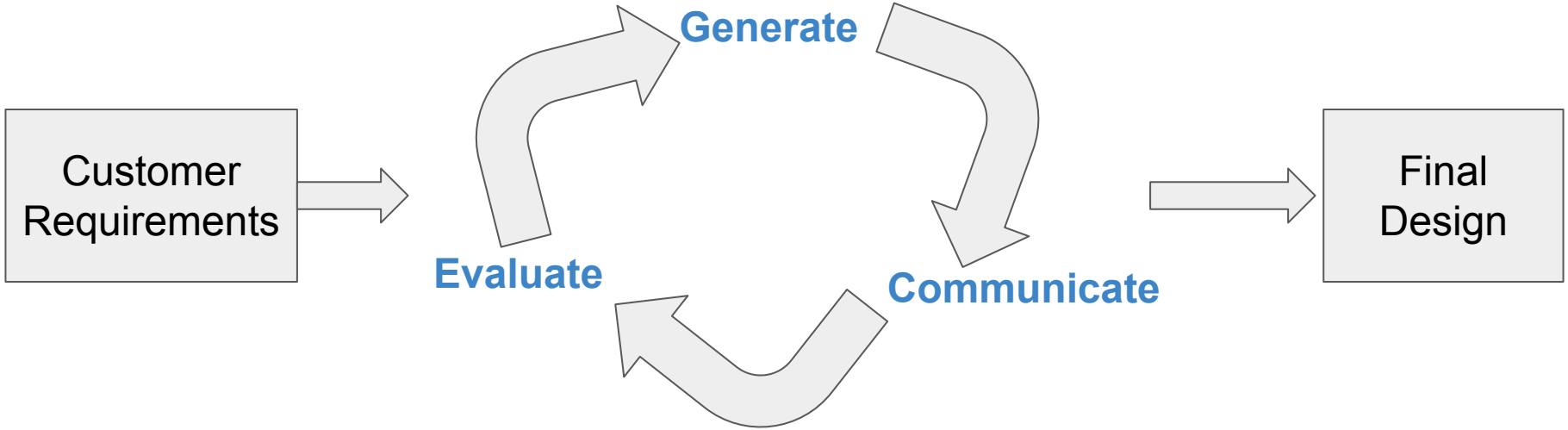
- **Generate**
- **Communicate** designs to team members & clients through design sketches, documentation & prototyping

What do designers do?

- **Generate**
- **Communicate**
- **Evaluate** designs for various quality attributes & identify possible flaws

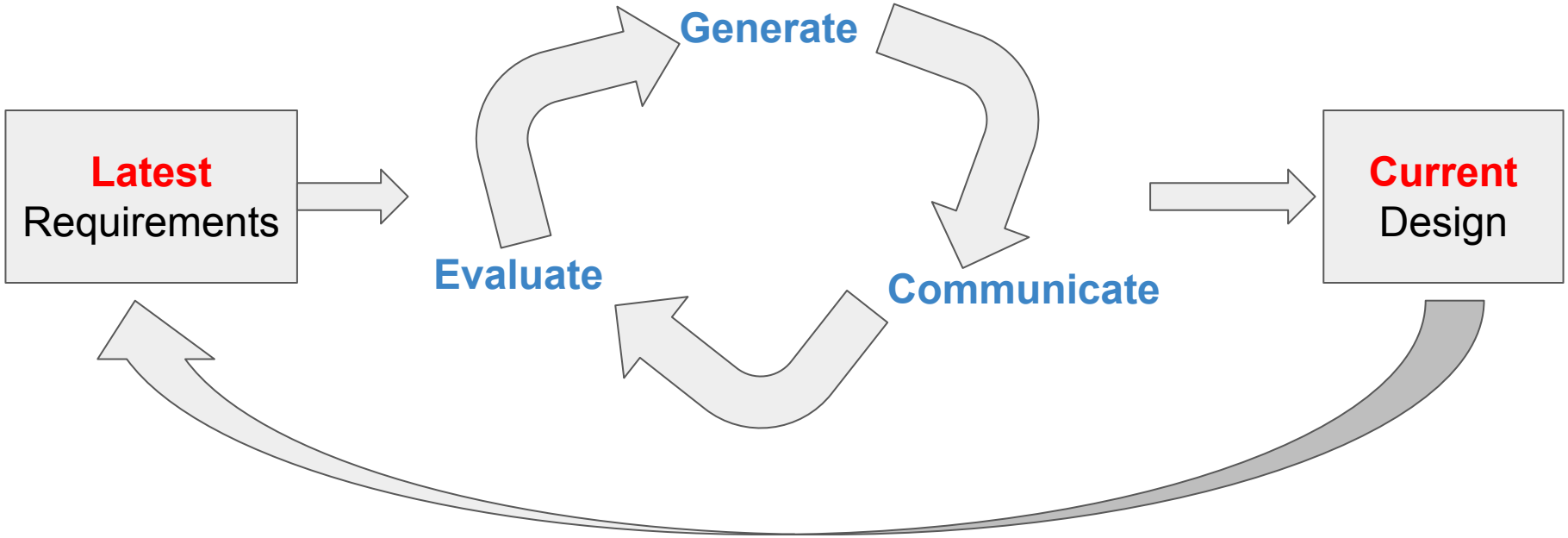


Generate-Communicate-Evaluate (GCE) Paradigm



We will cover a set of principles, techniques, and tools for generating, communicating, and evaluating designs w.r.t. various quality attributes

Generate-Communicate-Evaluate (GCE) Paradigm



Design is never “finished”; it’s a continuous, iterative process!

Software Design and AI

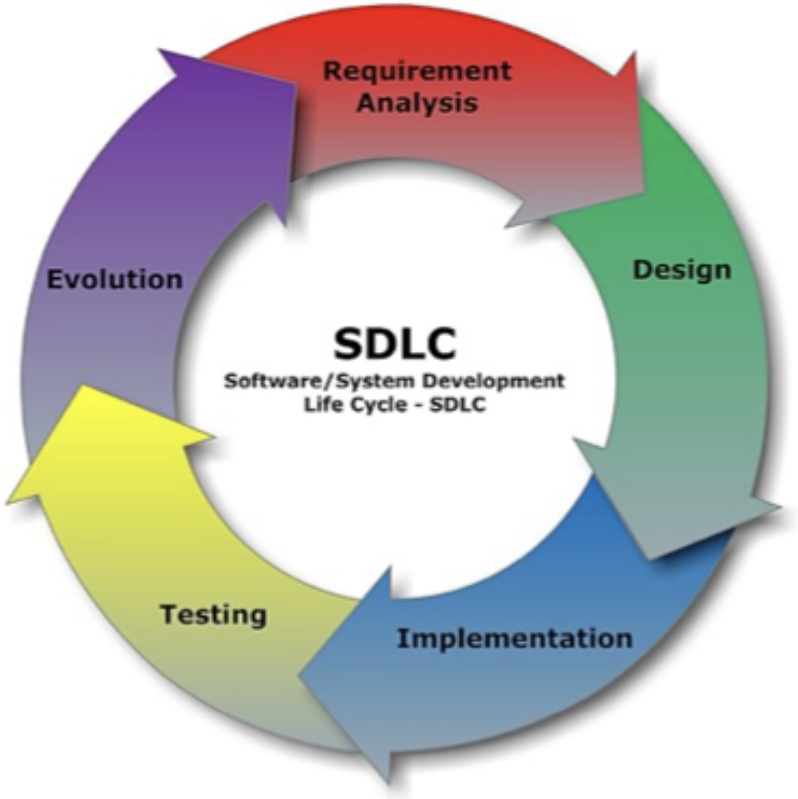
The End of Programming

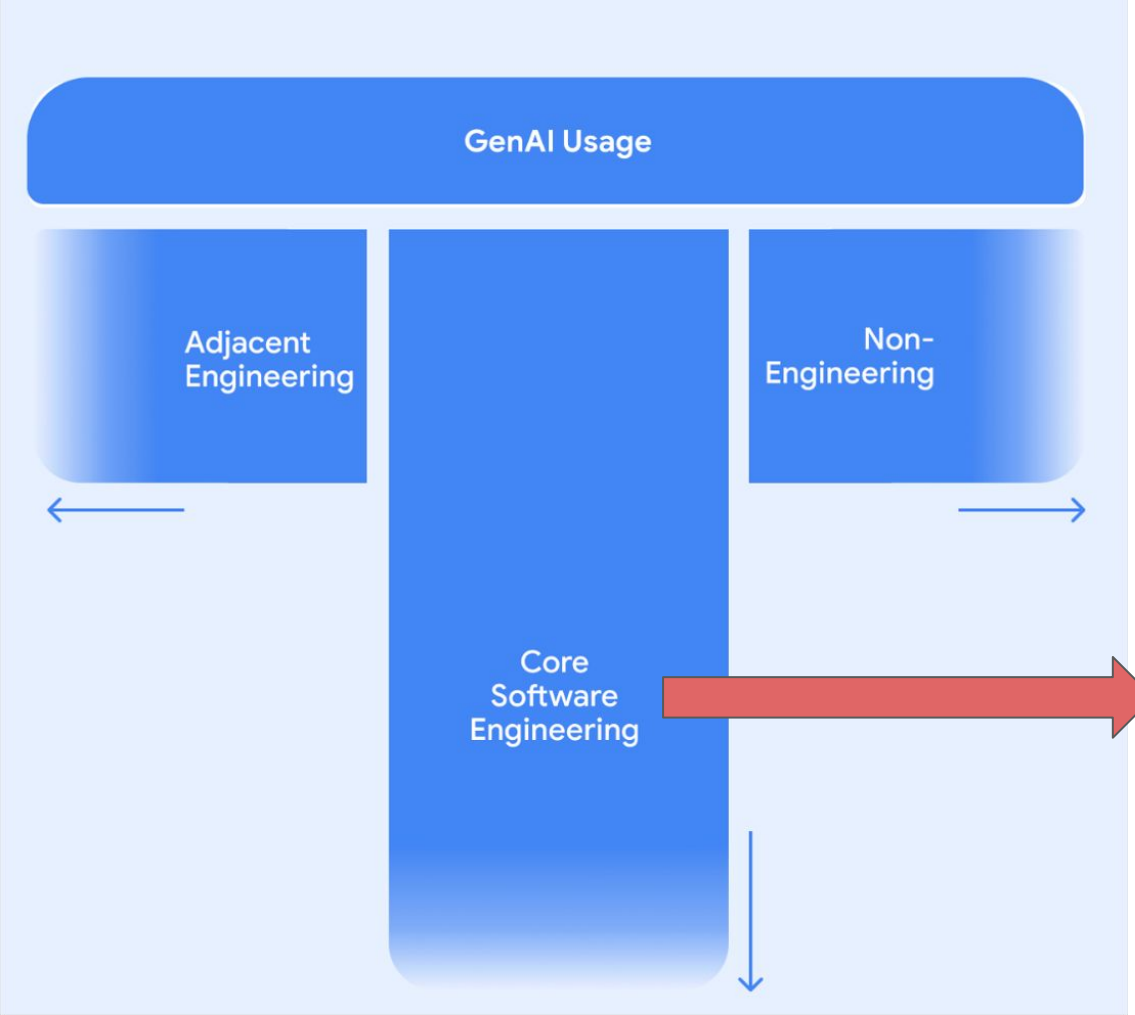
The end of classical computer science is coming, and most of us are dinosaurs waiting for the meteor to hit.

By Matt Welsh

Posted Jan 1 2023

Software Engineering != Programming





"...good system design (e.g., possessing a deep understanding of existing and alternative system architectures, design & system constraints, and carefully weighing the potential benefits and drawbacks of multiple design solutions to meet requirements)..."

***What do professional software developers need to know to succeed in an age of Artificial Intelligence?* (2025)**

Human vs. AI Engineer

- **AI engineer**: Extremely efficient, but occasionally makes mistakes (sometimes confidently); limited by context
- **Human engineer**: Slower, but good at high-level planning, critical thinking, and judgement; understanding of the problem context

Future of SE: More time designing, less time coding

- Most of the code will be written by AI in the future
- Human engineer's primary role will be: (1) identifying system requirements, (2) creating & modifying high-level design, (3) evaluating work done by AI and (4) planning for failures.
- **Requirements** and **design specifications**, not code, will become the primary artifacts in software development
- **Q. Why design? Why isn't vibe coding enough?**
- Throughout this class, we will explore strategies for working with AI coding agents as a software designer
    - You are encouraged to experiment with AI tools (e.g., Cursor, Amazon Kiro, Spec-kit)
    - Be flexible and open-minded: Things are changing very quickly in AI & software development

Why take this course?

- Develop skills for a career as a system architect/designer
  - “System design” questions are common in interviews for software engineering positions

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- Role of AI/LLMs in software development
  - Coding will be more and more automated
  - Role of software engineers will likely change & involve more high-level design
  - Design skills and knowledge will become increasingly more valuable

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- Role of AI/LLMs in software development
  - Coding will be more and more automated
  - Role of software engineers will likely change & involve more high-level design
  - Design skills and knowledge will become increasingly more valuable
- For PhD & research-oriented students:
  - Software design is still relatively less understood by researchers
  - This course will discuss some open questions and opportunities in software design research

Course Logistics

Course Staff

Instructor
Eunsuk Kang
eunsukk@andrew

TA
Yining She
yiningsh@andrew

Office hours TBD; Watch out for announcement after class!

Communication

- Email us or ping us on Slack (invite link on Canvas)
- Post questions on Slack
- All announcements through Slack #announcements and Canvas
- Submissions through Canvas & Gradescope
- Other non-public materials (readings) on Canvas
- Please use #questions or #assignments and post publicly if possible; your classmates will benefit from your Q&A!

Disclaimer: Relatively New Class (Year 3)

- Expect rough edges & moving parts over the semester
- Please be flexible & patient!
- We welcome your candid feedback! Let us know:
  - Topics that you'd like to us cover in more/less detail
  - Concepts that could be better explained
  - Tools/techniques that you'd like us to cover
  - An assignment that takes too much (little) time or is too hard (easy)
  - Readings that are too boring/obscure/hard to follow
  - And anything else, really!
- You have a chance to shape the future offerings of this course!

Course Learning Goals

After taking this course, you will be able to:

- Design software systems for various quality attributes, including reusability, extensibility, interoperability, robustness, scalability, testability, security, usability
- Explain how to adapt a software design process to fit different domains, such as robotics, web apps, mobile apps, and medical systems
- Identify, describe, and prioritize relevant requirements for a given design problem
- Generate viable design solutions
- Apply appropriate abstractions & modeling techniques to communicate and document design solutions
- Evaluate design solutions based on their satisfaction of common design principles and trade-offs between quality attributes

Course Philosophy

- Hands-on experience in a collaborative project
- Growth mindset & learning from failures
  - Learning from real-world case studies
  - Learning from your own mistakes in the project
- Active student participation
  - We encourage you to ask questions and participate in class discussions
  - Wrong answers support learning! (see growth mindset)

This is a Software Engineering Class!

- Focused on engineering judgment
- Arguments, trade-offs, and justification, rather than a single correct answer
- The answer will often be: "It depends..."
- Practical engagement, building systems, testing, automation
- Strong teamwork component

Recitations

- Additional exercises to supplement concepts from the lectures
- Cover hands-on topics, such as tools, frameworks, best practices,
- First recitation this Friday!
- Participation in recitations will also be considered as part of “Class Participation” grade (see later on Grading)

Grade Breakdown

- 20% Homeworks
- 50% Project
- 20% Midterm & final
- 10% Class participation
  - In-class discussions
  - Participation in recitation activities
  - Exit tickets

Participation: Exit Tickets

- Goal: Recall and summarize the key ideas from the lecture
  - Also to help us understand how well we conveyed those ideas
- In the last 5~10 min of each class, we will ask you to answer a couple of quick questions about that day's content (on Canvas)
- Not graded on correctness; any on-topic & "reasonable" answers will be accepted
- 3 free passes throughout the semester
  - Let us know if you have any exceptional circumstances (illness, travel, interviews, etc.,)

Team Project

- Goal: Gain experiences designing, implementing, and iteratively improving a complex software system
- Six milestones over the semester
  - M1: Initial design and specification
  - M2: Initial prototype implementation
  - M3: Iterative design for changeability & interoperability
  - M4: System integration
  - M5: Iterative design for robustness & scalability
  - M6: Final design report & presentation
- More details about the project next lecture

Individual Homeworks

- Goal: Practice applying design principles and techniques not covered by the project milestones
- We expect that these will take no more than 2~3 hours to complete

Participation: In-class Discussions

- Most lectures will involve case studies & discussions
- Please don’t hesitate to contribute your ideas and experiences!

  Remember, there’s no one “correct” answer to problems in this class

Use of Generative AI

- You are free & encouraged to use generative AI (e.g., ChatGPT) for homeworks/project
  - We are interested to explore the potential utility of LLMs for software design!
    - Generate design alternatives, generate documentation, synthesize code given a specification, etc.,
- But you are **NOT** allowed to use it for **exams** or **exit tickets**
- It's your responsible to check the quality of the output from an LLM
  - These models will sometimes hallucinate and generate superficial, bogus output
- In your submissions, clearly document how you've used these tools

Looking Ahead

Next 2~3 weeks: Foundational techniques and tools for design

Domain & design modeling, quality attributes & trade-offs, generating design ideas, design review, design processes

Second half of the course: Designing for quality attributes

Design for change, interoperability, reuse, scalability, robustness, security, AI,...

Slack Introductions

- Before Friday's recitation, introduce yourself on #social channel:
  - Your (preferred) name
  - In 1~2 sentences, your software engineering background and goals (e.g., coursework, internships, work experience)
  - Your favorite programming languages, tools, or frameworks
  - One topic you are particularly interested in learning during this course?
  - A hobby or a favorite activity outside school

Exit ticket!

- See Canvas

Summary

- Systematic design is common in many engineering disciplines.
- Decisions to invest in design should be driven by the amount of risks in the product or system.
- Designers generate, communicate, and evaluate design solutions.
- Designing is a continuous, iterative process.