

SWE 621

FALL 2022

COURSE OVERVIEW, DESIGN AS CHOICE

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?

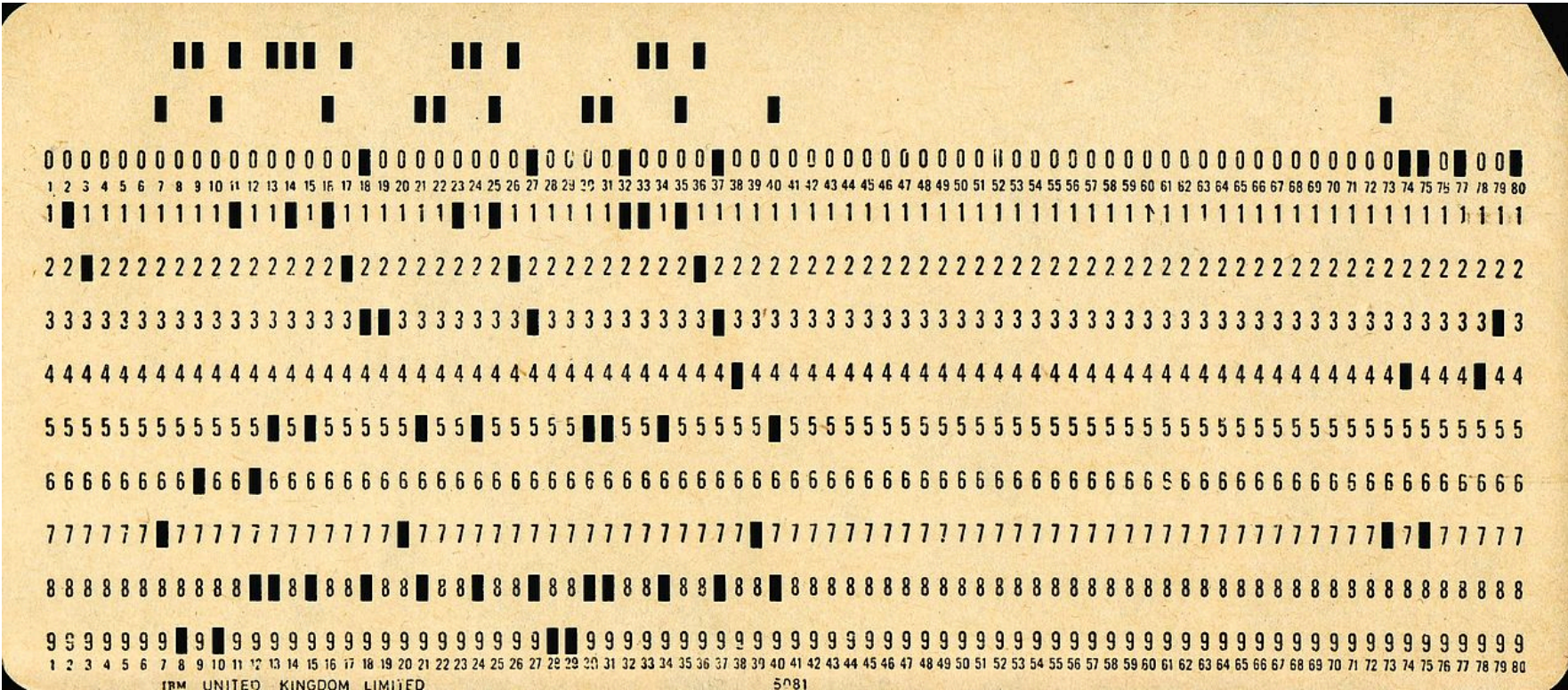
HOW DO YOU FOLLOW A DESIGN?

- ▶ 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

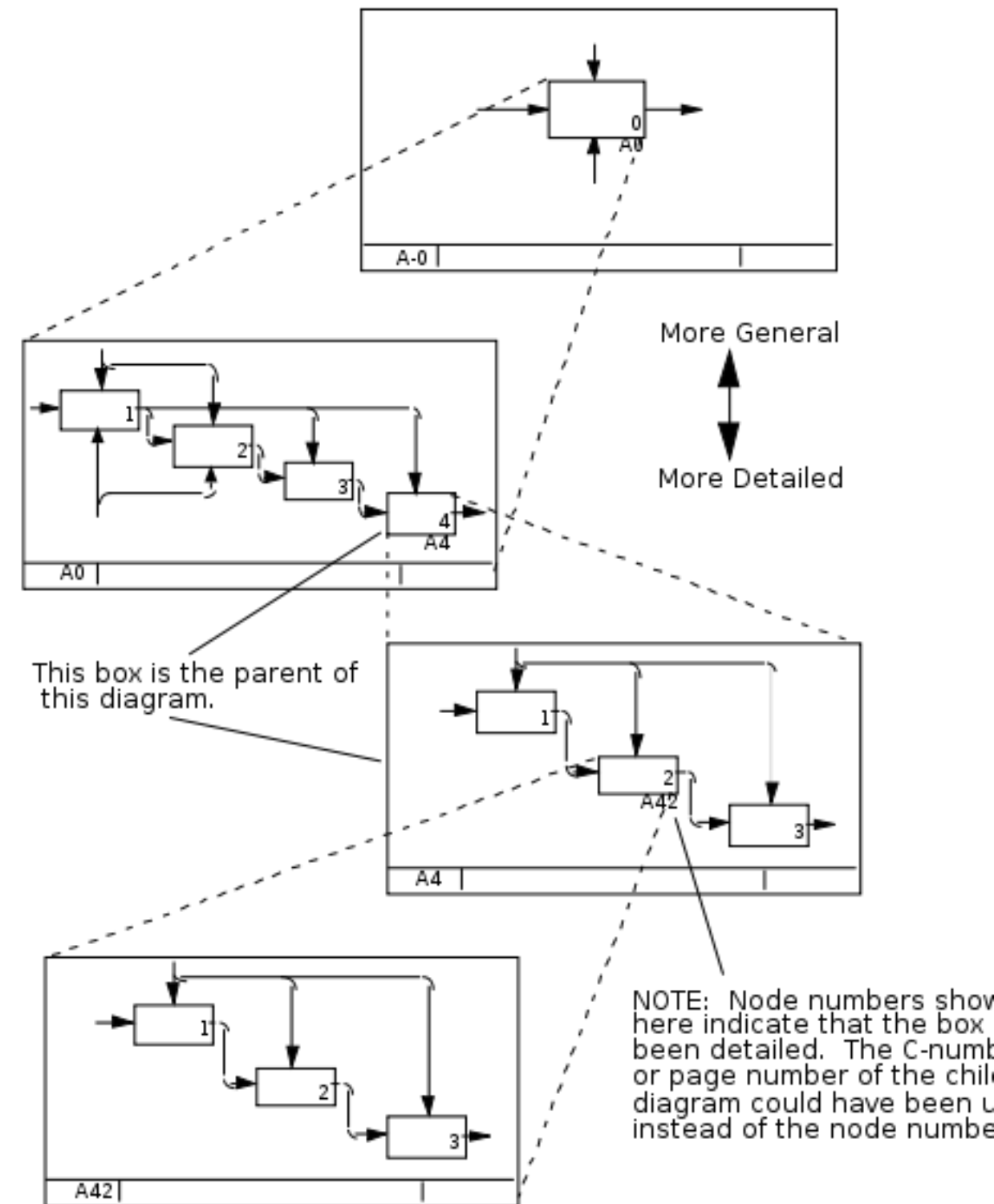


By Pete Birkinshaw from Manchester, UK - Used Punchcard, CC BY 2.0, <https://commons.wikimedia.org/w/index.php?curid=49758093>

- ▶ How do you make changes to this code?
- ▶ How do you organize this code?

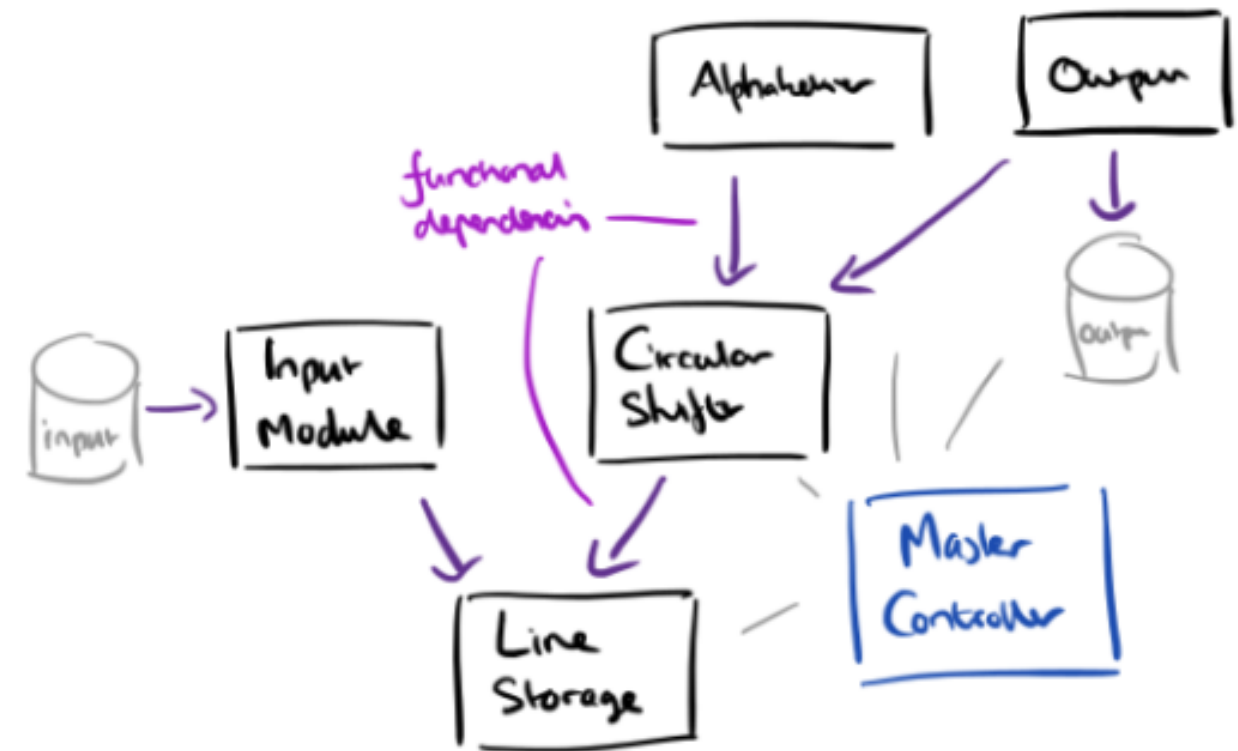
STRUCTURED DESIGN (1970S)

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



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

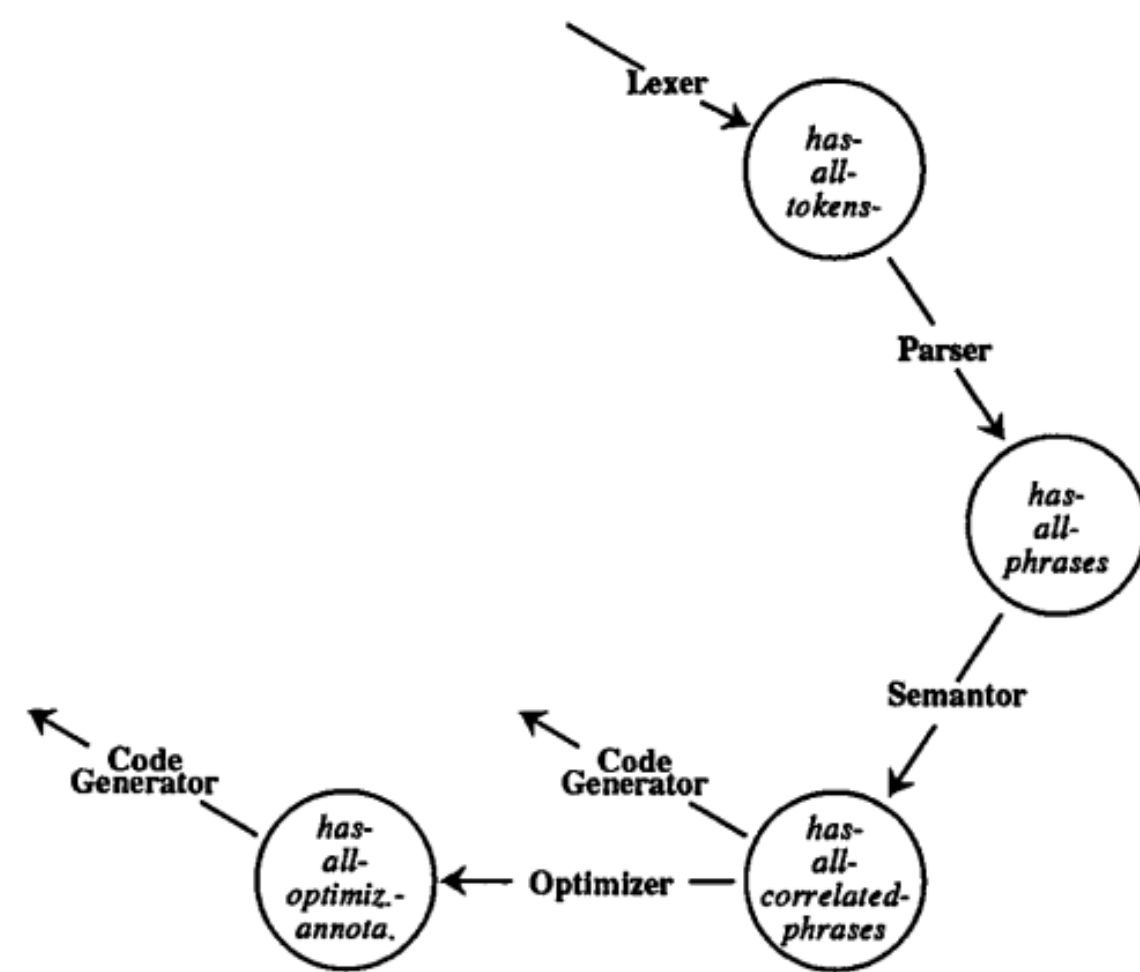
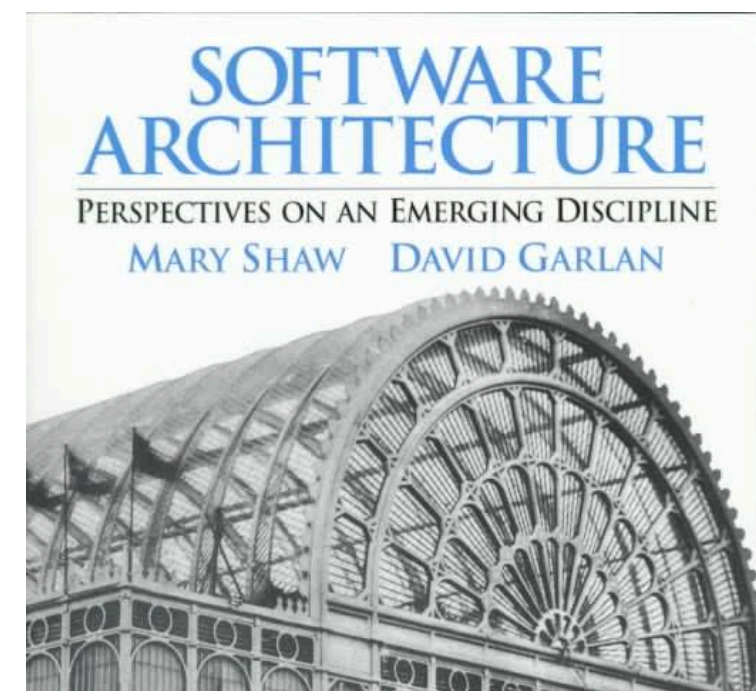


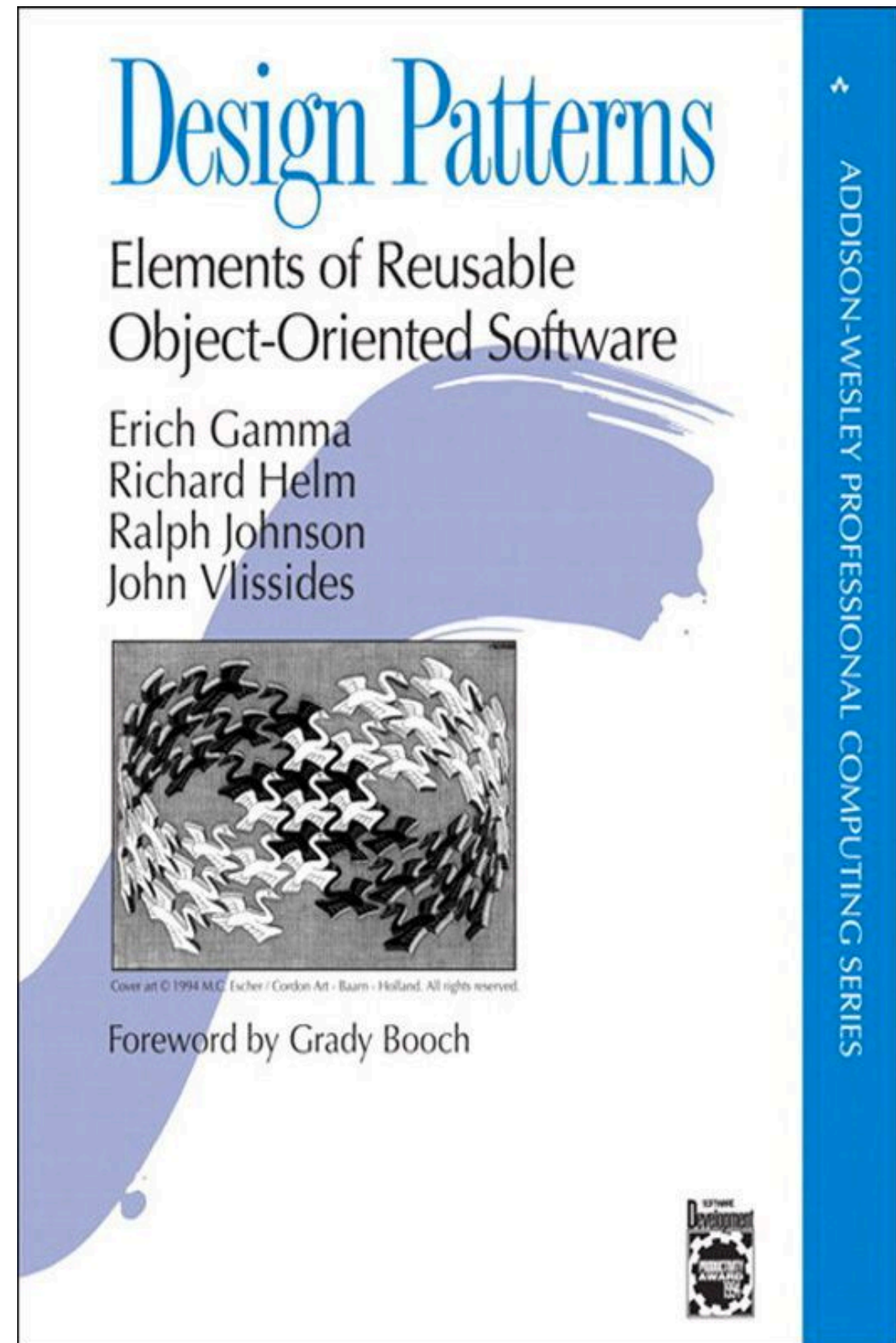
Figure 3: Data View of Sequential Compiler Architecture.

Perry and Wolf. (1992). Foundations for the study of software architecture. FSE.



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)

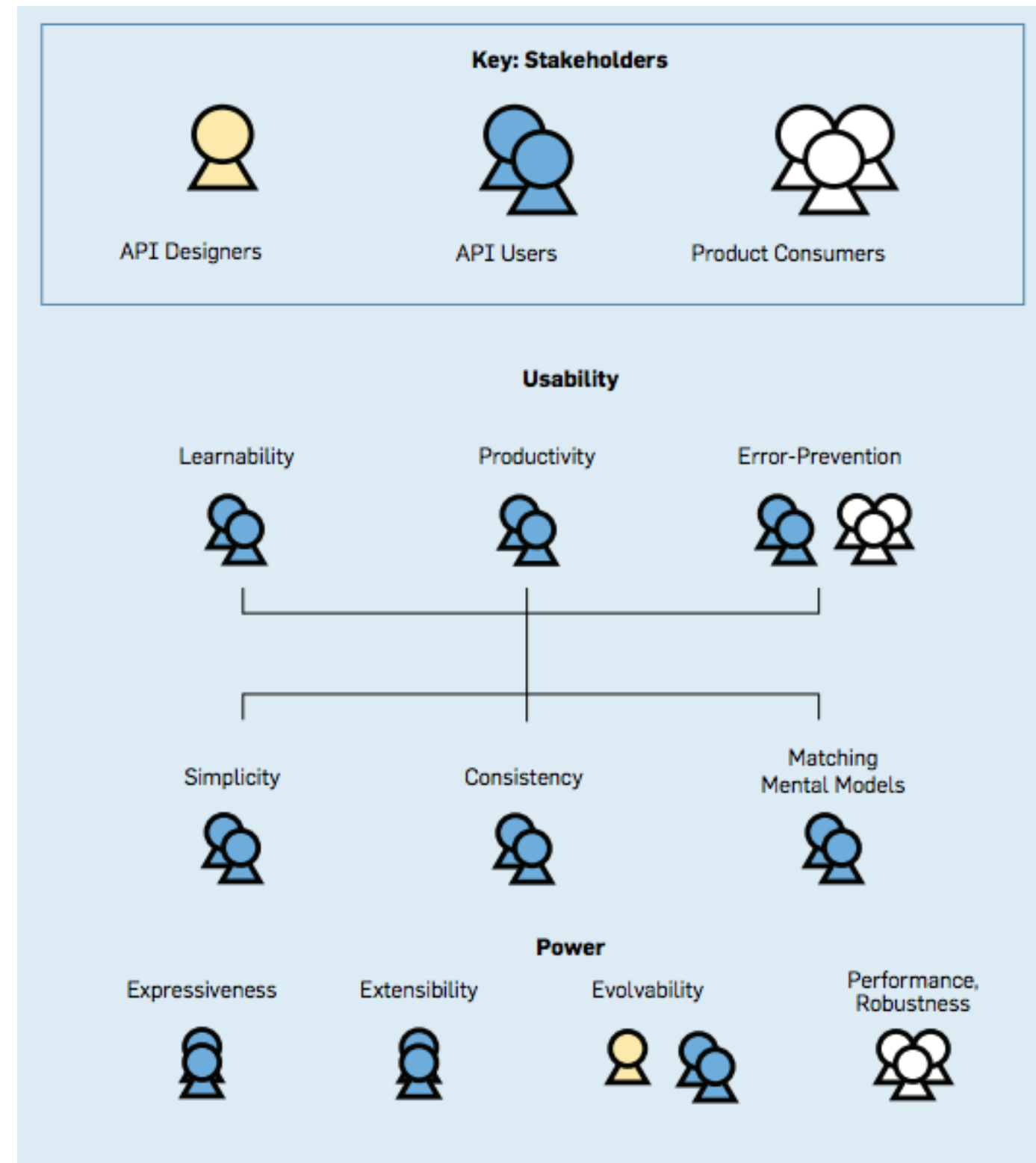
- ▶ Architecture built upfront can sometimes be mismatched to goals, particularly when new information is revealed later
- ▶ Update architecture and design to respond to change and better knowledge



<http://agilemanifesto.org/>

APIS (2000S)

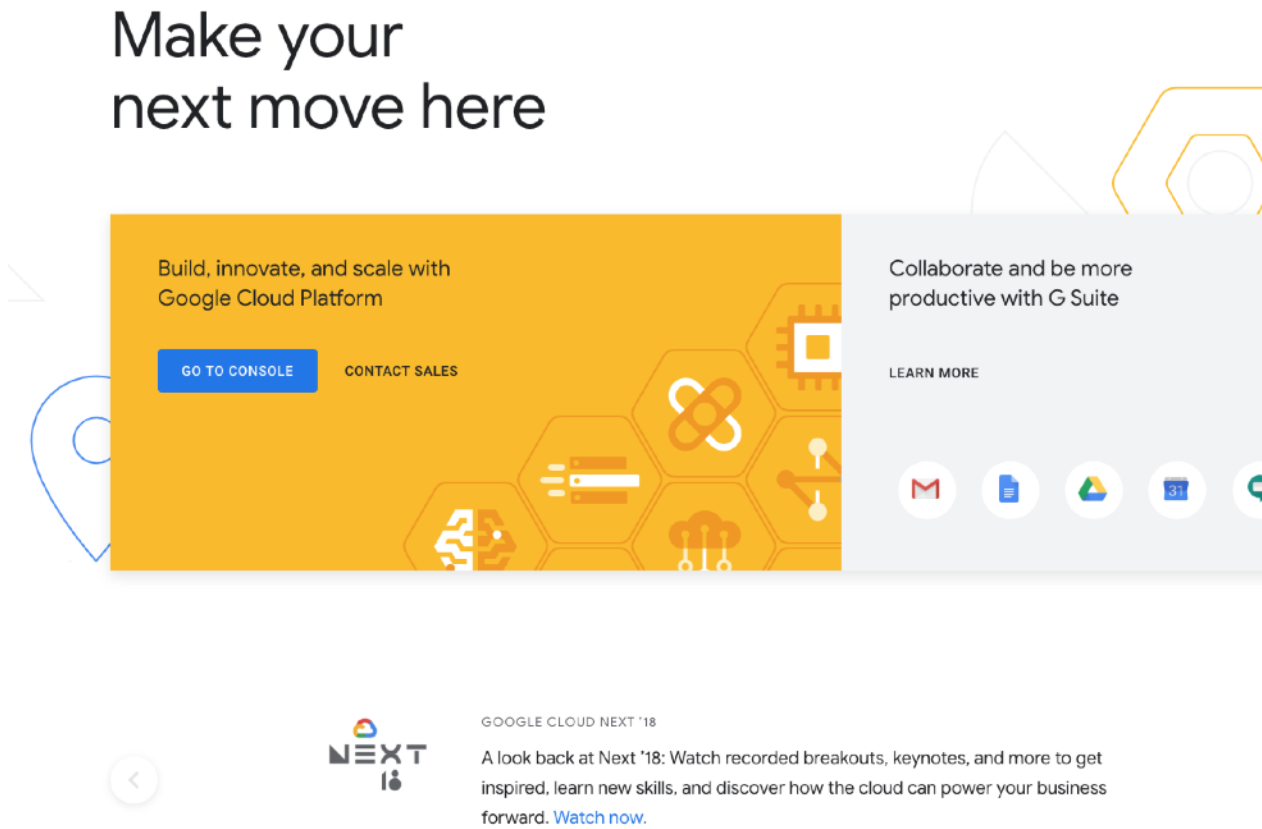
- ▶ Web increased availability and number of libraries and frameworks, often as free open source projects
- ▶ How do you learn how to use these?
- ▶ What can you do to make your API easier to learn and use?



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

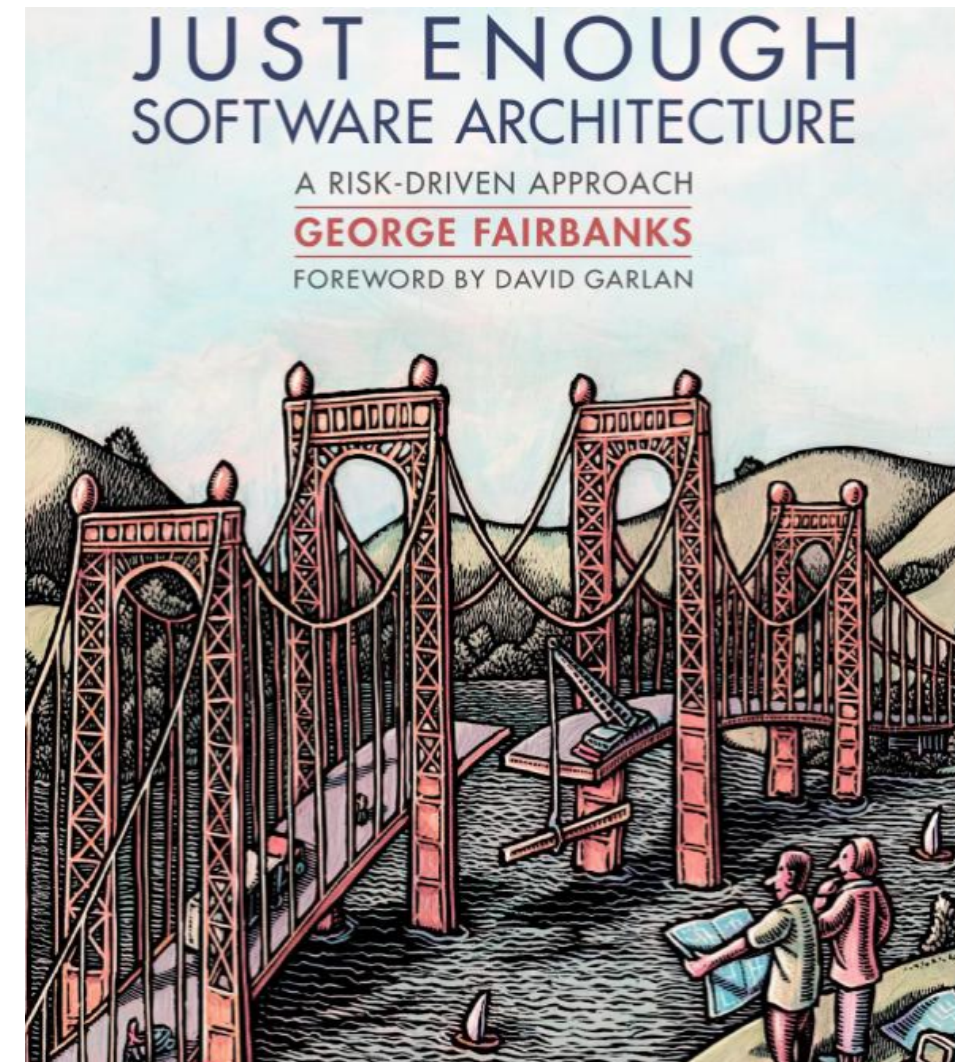
- ▶ Characterize a design space, including identifying risks and key architectural decisions
- ▶ Design abstractions that express a system or domain model
- ▶ Use notations to describe elements and relations in an architecture
- ▶ Reverse engineer design decisions, architectural styles, design patterns, 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**

HWO

- ▶ 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

GRADES

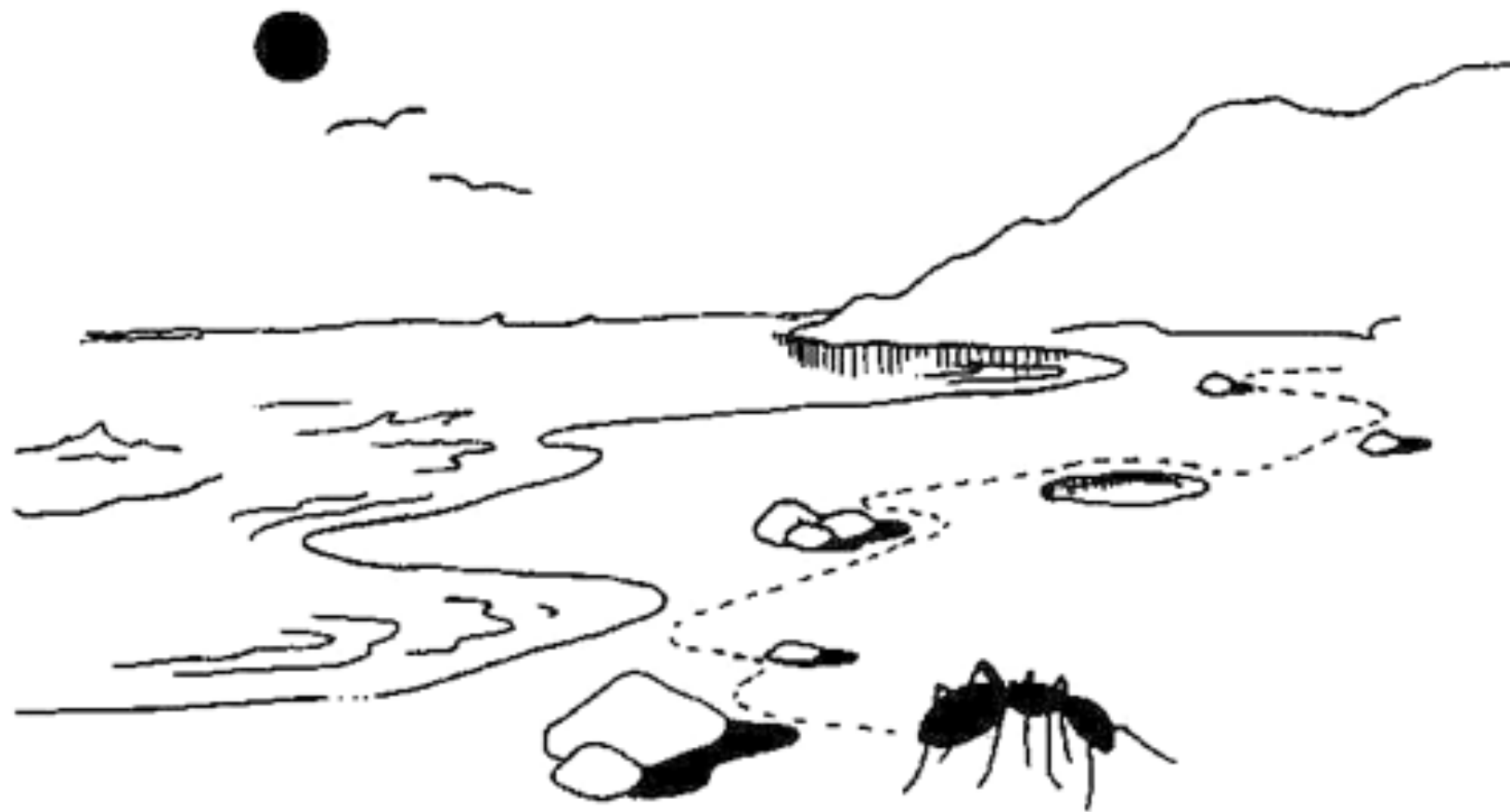
- ▶ In-Class Activities: 10%
- ▶ HWs and project presentation: 40%
- ▶ Mid-term exam: 20%
- ▶ Final exam: 30%

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

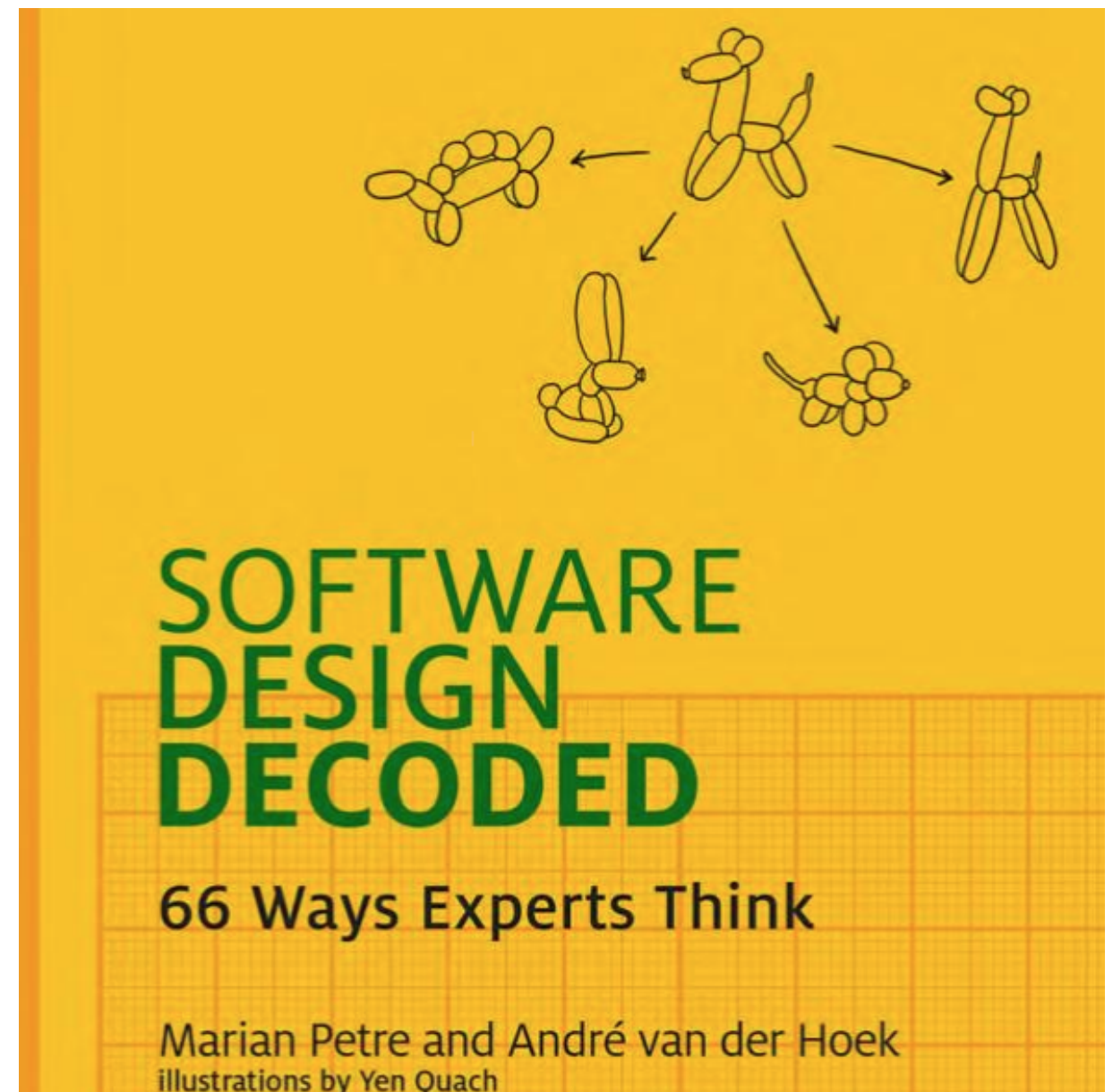
- ▶ Find a partner. Discuss with partner examples of projects where the system has been rebuilt.
- ▶ What motivated this?
- ▶ What changed? How much effort was it to change?

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 TEST

- ▶ 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 variety of scenarios steps 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?