Modular Design

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Today’s music: Top Down by Fifth Harmony
Review

Previously in 3110:
• language features: modules, structures, signatures, abstract types, includes, functors
• purposes: namespaces, encapsulation, code reuse

Today:
• how to design large programs
• (until after Prelim 1: no new features)
ARCHITECTURE
Architecture

• Highest-level design of software system

• Elements of architecture:
  – Code **components**
    • e.g. modules, libraries
    • *module*: logically separable part of program w.r.t. compiling and loading; in OCaml actually called a module or set thereof; in other languages might be called class or package or...
  – Externally visible **properties** of those components
    • e.g., types, signatures, documentation
  – **Relationships** among components
    • e.g., implemented-by, shares-data-with, independent-of
Why analyze architecture?

• **Understanding**
  – Communicate system design to implementers, testers, maintainers, clients, users
  – Reduce system to a few parts; abstract from details; simplify
    • Working memory: humans can pay attention to only a small number of things at a time (3 or 4? 7?)

• **Reuse**
  – Identify what components can be repurposed from other systems
  – Assembly line model: cheaply produce system out of stock components
    • e.g., web mashups, new 3110 website

• **Construction**
  – Division of (independent) labor
  – How to add new features
Architecture of survey system

Requirements:
• present multiple-choice questions to user
• collect and store answers
• present results-in-progress to user after they submit
Architecture of survey system

New requirement: only some users are authorized to take survey; must authenticate users before they can register response
Building blocks of architecture

Components:

• Computation elements or data stores
• Primarily from the view of **run time**: what happens while system is executing?
• Not necessarily from the view of **compile time**: how is code physically organized?
Building blocks of architecture

Connectors:

• Protocol: agreed upon means of communication
  – e.g., TCP, function call

• Topology could vary: binary, broadcast, ring, ...
Ex: Pipes and filter architecture

- **Filter**: component that transforms data
  - receives data on input pipes
  - sends output data over pipes to other filters
  - might have >1 inputs, >1 outputs
  - each filter is independent of others and operates concurrently

- **Pipe**: connector that relays data
  - unidirectional
  - does not change data
  - pipes handle storage, synchronization, rate of transfer, etc.
Ex: Pipes and filter architecture

MapReduce as a pipe and filter architecture:
**Ex: Shared data architecture**

- **Data repository**: component that stores data
  - provides reliability, persistence, access control
  - might be passive or might actively notify accessors about changes in data
- **Data accessor**: component that does computation with data
  - gets data from repository, computes, puts data back to repository
  - accessors do not directly communicate with one another
- **Interfaces**: connectors that gives read/write access to repository
Ex: Shared data architecture

File system as a shared data architecture:

- User applications
- File system
- Kernel

User API

Kernel API
**Ex: Client–server architecture**

- **Server**: component that provides service/resources
  - When server provides a storage service, might reduce to shared data arch.
- **Client**: component that accesses service/resources
  - clients do not directly communicate with one another
  - clients need not be co-located with server
- **Channels**: connectors that allow client to make request, then server to return response
  - asymmetric: client can contact server, not vice-versa
  - (a)synchronous: client waits for response?
- Generalizes to *n-tier architecture*, in which server acts as client to another server, etc.
Ex: Client–server architecture

CMS as client-server architecture:

- Browser
- CMS
- J2EE server
- Oracle DBMS

Connections:
- http
- jdbc
Ex: Client–server architecture

CMS as client-server architecture:

- **Browser**
- **CMS J2EE server**
- **Oracle DBMS**

Connections:
- **http** between browser and CMS J2EE server
- **jdbc** between CMS J2EE server and Oracle DBMS

Client–server architecture
Ex: Client–server architecture

CMS as client-server architecture:
CMS as 3-tier architecture:

- **Browser** (client tier) sends requests to **J2EE server** (business tier) using **http**.
- The **J2EE server** communicates with the **Oracle DBMS** (database tier) using **jdbc**.

**Client tier** | **Business tier** | **Database tier**
Question

Which architecture best describes the Enigma cipher?

A. Pipe and filter
B. Shared data
C. Client–server
D. None of the above
E. YNOXQ
Question

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D. None of the above  
E. YNOXQ
From architecture to design

• Architecture is a kind of design
  – focuses on highest level structure of system
  – based on principle of divide and conquer
• But architecture isn’t about code per se
• As the design process iteratively proceeds, we get closer and closer to code
• Design as a phase of software development has a more specific connotation:
  – **System design**: decide what modules are needed, their specification, how they interact
  – **Detailed design**: decide how the modules themselves can be created such that they satisfy their specifications and can be implemented
SYSTEM DESIGN
Design criteria

• **Simplicity:** easily understood
• **Efficiency:** uses minimal resources
• **Completeness:** solves the entire problem
• **Traceability:** every aspect of design is motivated by some requirement

...not independent

...simplicity by default trumps everything else
Design principles

• **Divide and conquer (partitioning):** divide problem into smaller pieces, so that each piece can be solved separately
  – but rarely can pieces be completely independent
  – they rather cooperate to achieve goal
  – so software design is typically *hierarchical:* understanding can be deepened as necessary
    • at the bottom level, code units are functions (maybe a couple dozen LoC)
    • at the middle level, code units are modules (maybe a couple dozen functions)
    • at higher levels, code unit is package (at most a couple dozen modules)
Design principles

- **Abstraction**: describe the external behavior of a module, not the internal details that produce the behavior
  - design proceeds from external behavior to internal details
  - great design leaves behind documentation of abstractions (more on that next class)
  - in absence of that, understanding a system involves reinventing the abstractions (be what they may)
Abstraction of the Camel

- Domain: Eukarya, Eubacteria, Archaea
- Kingdom: Animalia, Plantae, Fungi
- Phylum: Annelida, Arthropoda, Chordata
- Class: Aves, Mammalia, Reptilia
- Order: Artiodactyla, Carnivora, Primates
- Family: Camelidae, Giraffidae, Hippopotamidae
- Genus: Camelus, Loma, Vicugna
- Species: bactrianus, dromedarius
Abstraction

• Forgetting information
• Treating different things as though they were the same

  e.g., animal kingdom
  e.g., files vs. block devices, inodes
  e.g., high-level programming languages vs. machine instruction set
  e.g., floating point arithmetic vs. idealized math
Computational Thinking

- Computational thinking is using abstraction and decomposition when... designing a large, complex system.
- Thinking like a computer scientist means more than being able to program a computer. It requires thinking at multiple levels of abstraction.

Jeanette Wing
Corporate VP, MSR

https://www.cs.cmu.edu/~15110-s13/Wing06-ct.pdf
Design principles

• **Modularity**: modules are separate
  – design of one module should be able to proceed with only abstractions of other modules
  – changes to a module don't require changes to other modules (even recompilation)
  – *separation of concerns*: implement, maintain, reuse modules independently
  – roughly, *modularity* = *partitioning* + *abstraction*
Design strategies

• **Top down:**
  – start at top, most abstract level of hierarchy
  – proceed downwards, adding more detail to design as you deepen: *stepwise refinement*
  – eventually reach concrete enough design that it can be implemented

• **Bottom up:**
  – start at bottom, most concrete level
  – proceed upwards, creating *layers of abstraction*
  – eventually reach powerful enough modules that they implement the desired system

• In practice, these are nearly always **combined**
  – Design new modules from top down
  – But keeping in mind existing libraries that can be built on from the bottom up
Top down vs. bottom up

• Advantages of **top down**:  
  – get high-level design right  
  – easier to design abstractions

• Disadvantages of **top down**:  
  – harder to test until program is complete

• Advantages of **bottom up**:  
  – get low-level implementation right  
  – always have testable code

• Disadvantages of **bottom up**:  
  – large-scale design flaws don’t show up until too late
Upcoming events

• [today] A2 due (soft deadline)
• [Saturday] end of automatic 48 hour extension on A2 (hard deadline)

This is good design.

THIS IS 3110
Acknowledgment

Parts of this lecture are based on this book: