CS 3110

Software Design

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Fall 2016

Today's music: Top Down by Fifth Harmony

Review

Previously in 3110:

- architecture of large programs

Today:

- design of large programs

Review

- 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* proceeds, we get closer and closer to code
  - Design which modules will be part of system
  - Design the external specifications for those modules
  - Design the internal implementation of each modules
    - Which might involve iterating all the above for submodules

Review

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

HIGH-LEVEL DESIGN

High-level design

- aka *system design*
- Goal is to decide what modules are needed, their specifications, how they interact
- Artifacts produced:
  - interfaces
  - design document

Interfaces

- In OCaml, could be .mli files
- Name of modules
- Definitions of exposed types
- Names of functions
- Specifications of functions
  - precondition, postcondition, exceptions raised, etc.
  - [next lecture]

Design document

- Capture what decisions designers made and why
- Help another programmer understand the design
- Describe important features that might not jump out from .mli files
- Mention tempting designs that were rejected and why they're problematic so that others don't make the same mistakes later

Design strategies

- **Top down:** move from abstract to concrete
  - "I know I need a module for processing inputs"
  - "What are the pieces of processing an input?"
- **Bottom up:** move from concrete to abstract
  - "I know have a module for parsing strings with regular expressions"
  - "How could I use that to process my inputs?"
- Nearly always combined
  - Design new modules from top down
  - Build on existing libraries bottom up

Top down design

- 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
- Advantages of **top down design**:
  - get high-level design right
  - easier to design abstractions
- Disadvantages of **top down implementation**:
  - harder to test until program is complete

Bottom up design

- Start at bottom, most concrete level
- Proceed upwards, creating *layers of abstraction*
- Eventually reach powerful enough modules that they implement the desired system
- Advantages of **bottom up implementation**:
  - get low-level implementation right
  - always have testable code
- Disadvantages of **bottom up design**:
  - large-scale design flaws don't show up until too late

EVALUATING A DESIGN

1. What makes a design modular?

- **Partitioning:** modules are separated
- **Abstraction:** modules hide internal details
- Partitioning + abstraction yields...
  - *separation of concerns:* implement, maintain, reuse modules independently
  - changes to internals of one module don't require changes to other modules (even recompilation)

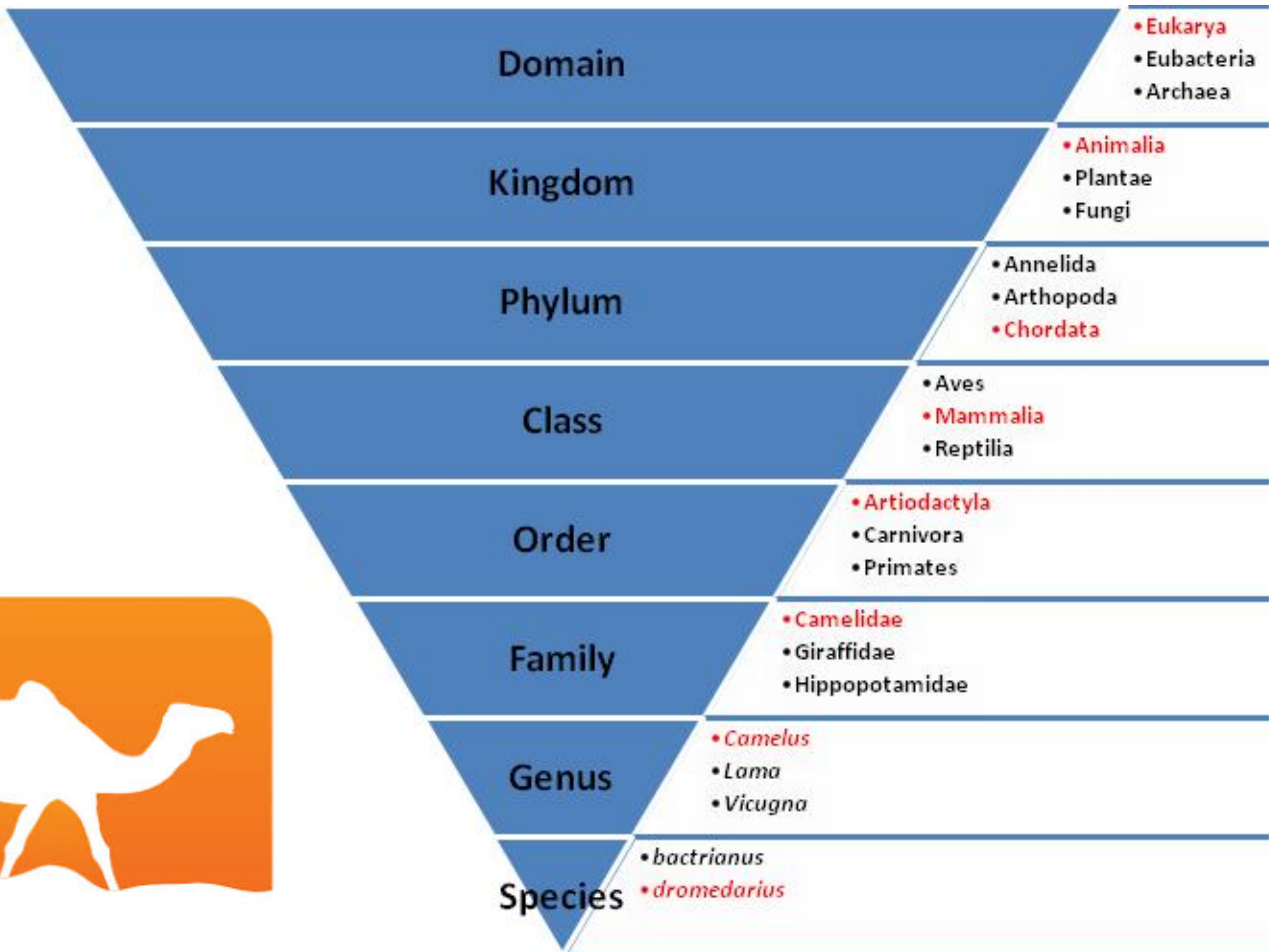
Partitioning

- Instance of **divide and conquer:** divide problem into smaller pieces, so that each piece can be solved separately
- Partitioning in software design is typically *hierarchical*: understanding can be deepened as necessary
  - at high level, code unit is library (at most a couple dozen modules)
  - at middle level, code unit is module (maybe a couple dozen functions)
  - at bottom level, code unit is function (maybe a couple dozen LoC)

Abstraction

- Interfaces describe the **external** behavior of a module, not the **internal** details that produce the behavior
- Design of one module can proceed with only abstractions of other modules
- Later, design proceeds from external behavior to internal details
- Abstraction enables:
  - Forgetting information
  - Treating different things as though they were the same
  - Example: animal kingdom...

Abstraction of the Camel



Computational Thinking

Jeanette Wing
Corporate VP,
Microsoft Research

- *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.*

https://www.cs.cmu.edu/~15110-s13/Wing06-ct.pdf
https://www.microsoft.com/en-us/research/video/computational-thinking/

2. What makes a design modular?

Coupling: strength of relationship between modules

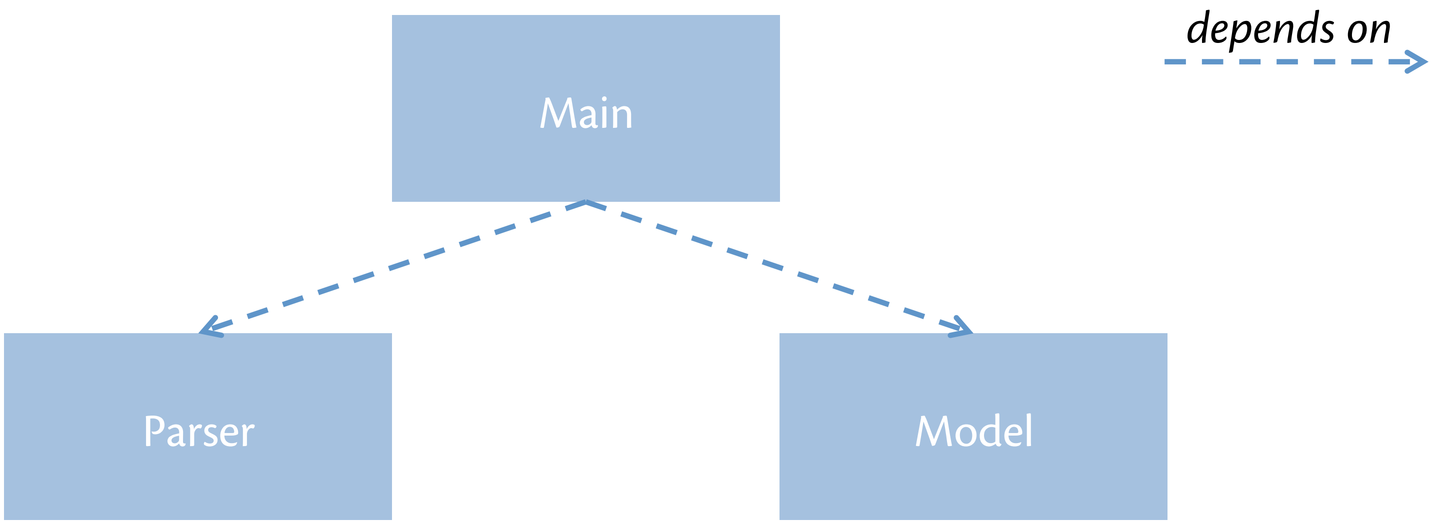
- *highly coupled* modules have strong relationships with other modules
  - maybe they aren't strongly partitioned
  - maybe they share details about one another's internals hence aren't strongly abstracted
- *loosely coupled* modules have weak relationships with other modules [good modularity]

To reduce coupling...

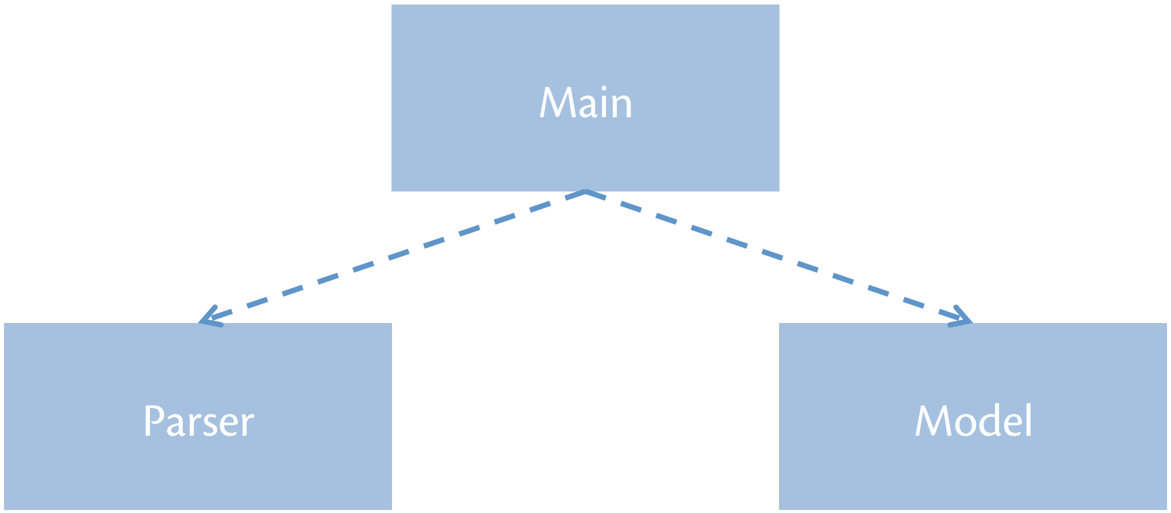
- Keep external interfaces *narrow:*
  - hide representation types
  - hide helper functions
  - keep the number of functions small
- Keep external interfaces *simple:*
  - keep functions arguments few and their types small
  - don't let return values contain too much or too little information
- Pass *data* through interfaces but not *control:*
  - Passing control means telling the module what to do or how it should behave in the future
  - Passing data means just providing inputs that will be transformed into outputs

Coupling results from dependence

- A module *depends on* another if it uses a value, function, or type from it
- Module dependency diagram (MDD) depicts that relationship



Dependence

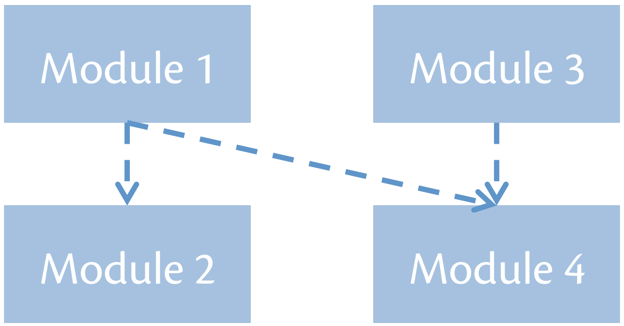


- **Fan out** of *M*: number of modules *M* depends on
- **Fan in** of *M*: number of modules that depend on *M*
- both increase coupling

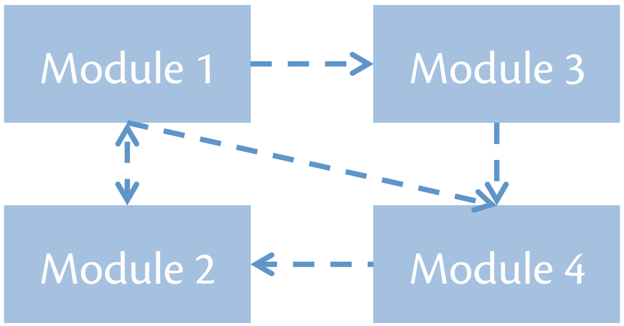
Question

Which of these MDDs exhibits weaker coupling?

A:



B:



Question

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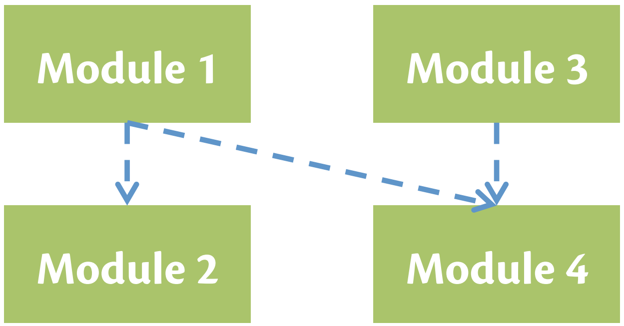
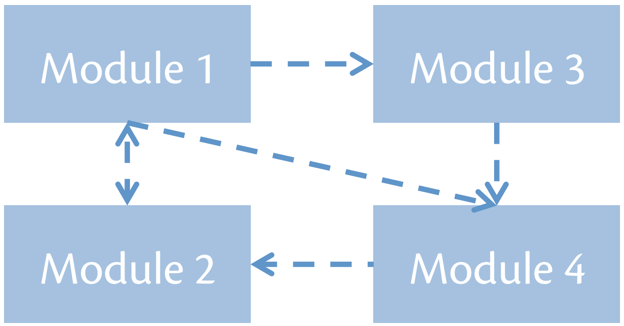


B:



3. What makes a design modular?

Cohesion: strength of relationship within module

- *loosely cohesive* modules have weak relationships within module
  – maybe it tries to implement two unrelated pieces of functionality
  – maybe it's just a collection of utility functions
- *highly cohesive* modules have strong relationships within module [good modularity]

To increase cohesion...

- Reduce coupling
  - Strong coupling can be a sign that code is in the wrong place
  - Redesign to move it into a more cohesive module
- Make sure all parts of interface are at least logically related
- Better yet, make sure all parts of module contribute toward performing a single purpose
- Try writing a single sentence that fully and accurately describes purpose of module
  - conjunctions, commas, and multiple verbs all suggest lower cohesion ("This module implements stacks and queues.")
  - a lack of a single specific object of a verb suggests lower cohesion ("This module performs all output.")

DESIGN REVIEW

How to assess finished design

- Design review: inspection of design by a team
  - designers
  - those who produced requirements for system
  - programmers who will implement
  - independent reviewers
- Meeting is non-judgmental: focus is on improving design not on blaming for errors
- Ideally all prepare in advance by studying design, making notes, preparing questions
- All try to come to consensus about aspects of design...

How to assess finished design

- Is the design complete?
  - System requirements met by the design?
  - Specifications provided for all modules?
  - Are external dependencies (third party libraries) identified?
- Is the design high quality?
  - Simple?
  - Modular? (partitioning, abstraction, loose coupling, high cohesion)
- Does the design support implementation and testing?
  - Will modules be implementable and testable independently?
  - Can the integration of modules be tested?

Upcoming events

- [next week] A3 released

This is designed.

THIS IS 3110

Acknowledgment

Parts of this lecture are based on this book:

Pankaj Jalote. *An Integrated Approach to Software Engineering*, third edition. Springer, 2005.