Programming Languages and Techniques (CIS120)

Lecture 37

April 23, 2012

Recap

Game Project

- Due Tuesday at Midnight
  - Submit as many times as you like, only the last one will be graded
  - Normal late policy (10 points per day, up to two days)

- Schedule a demo session with your TA
  - See assignment webpage for grading rubric. Be prepared to answer questions about your game according to this rubric.

Grade database

- Check your scores online for errors
  - Homework 1-9
  - Lab attendance
  - Midterms 1 & 2

- Send mail to tas120 if you are missing any grades.
- You are looking at the same database I will use to calculate final grades.
  - Homework 50%
  - Labs 8%
  - First midterm 12%
  - Second midterm 12%
  - Final exam 18%

FINAL EXAM

- **Tuesday May 8th, 9-11AM**
  - ***Skirkanich Auditorium***

- *Comprehensive* exam over course concepts:
  - OCaml material (though we won't worry much about syntax)
  - Java material
  - all course content

- Closed book
  - One letter-sized, personally handwritten sheet of notes allowed
- TA Review Session:
  - Sunday May 6th, 6-8PM, Wu & Chen
  - Review material posted on web page

CIS 120 Concepts

Design Recipe

1. Understand the problem
   What are the relevant concepts and how do they relate?
2. Formalize the interface
   How should the program interact with its environment?
3. Write test cases
   How does the program behave on typical inputs? On unusual ones? On erroneous ones?
4. Implement the required behavior
   Often by decomposing the problem into simpler ones and applying the same recipe to each

Unit Testing

- Concept: write tests *before* coding
  - *"test first"* methodology
- Examples:
  - Simple assertions for declarative programs (or subprograms)
  - Longer (and more) tests for stateful programs / subprograms
  - Informal tests for GUIs (can be automated through tools)

- Why?
  - Tests clarify the specification of the problem.
  - Thinking about tests informs the implementation.
  - Tests also helps with refactoring (let you know that you haven't broken anything)

Persistent data structures

- Concept: Store data in [illegible] ment computation as *transf*[illegible]
- Examples: immutable [illegible] 3), images in Java (HW7)

- Why?
  - Simple model of co[illegible]
  - Simple interface[illegible] it communicati[illegible]twee[illegible] faces are explicit)
  - *Recursion* amenable to mathematical analysis (CIS 121)
  - Have all intermediate values available

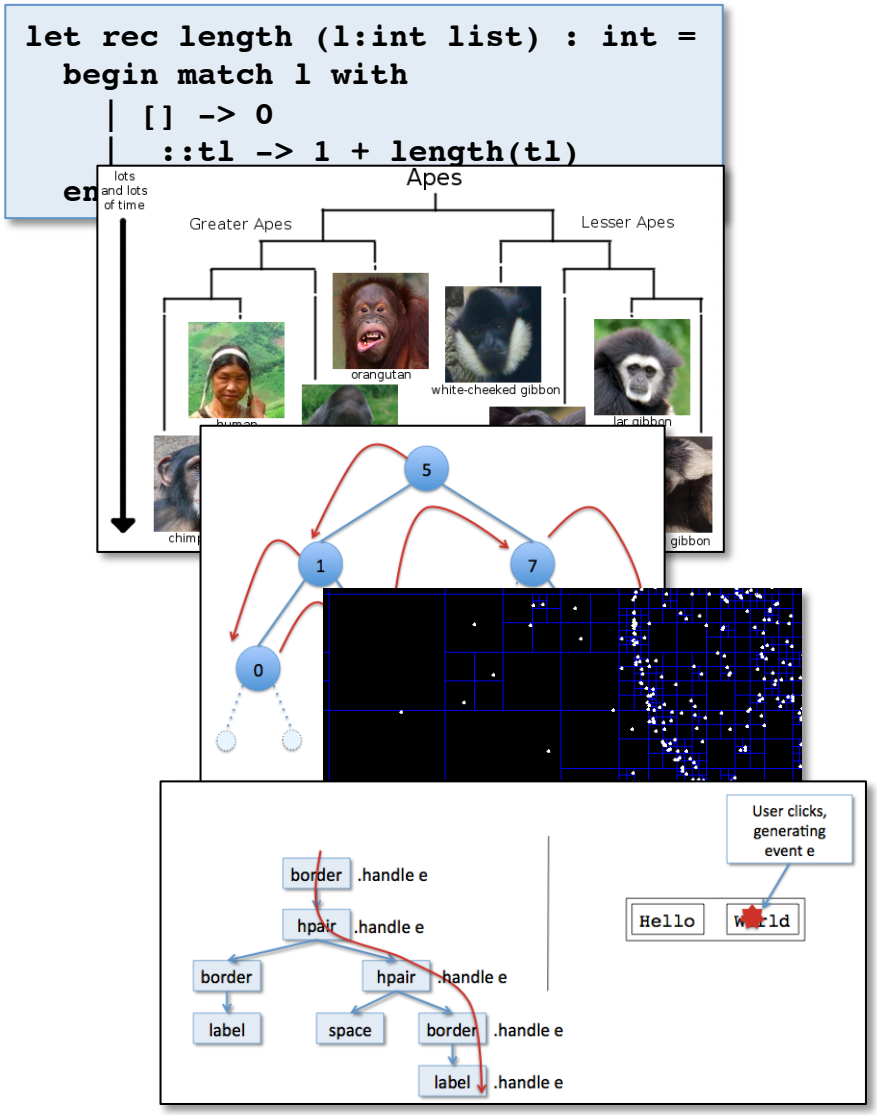
Recursion is the natural way of computing a function f(t) when t is an inductive data type:

1. Determine the value of f for the base case(s).
2. Show how to compute the value of f for larger cases by combining the results of recursively calling f on smaller cases.

Trees

- Lists (i.e. “unary” trees)
- Simple binary trees
- Trees with invariants: e.g. binary search trees
- Quad trees: spatial search
- Widget trees: spatial search + event routing
- Swing Components

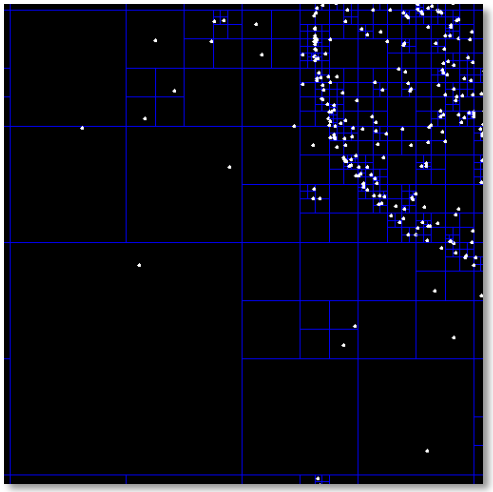
- Trees are ubiquitous in CS:
  - file system folders
  - URLs
  - hierarchy



Mutable Data in Persistant Structures

- Concept: Some data is ephemeral. Computation based on modifications of that data over time, even though the structure of that data doesn't change.
- Examples: Nbody simulation(HW4), arrays and images (HW 6), Characters (HW 8), many game logics (HW10)

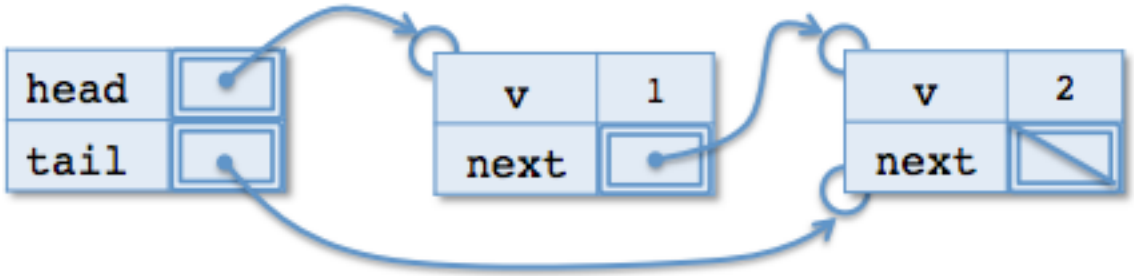
- Why?
  - Common in OO programming, which simulates the transformations that objects undergo when interacting with their environment
  - Necessary for event-based programming, where different parts of the application must communicate via shared state



Mutable data structures

- Concept: Some data *structures* are ephemeral. Computation based on modifications of those data structures over time.
- Examples: Queues, Deques (HW5), some GUI state (HW6/HW10), Dynamic Arrays, Dictionaries (HW9)

- Why?
  - Common in OO programming, which simulates the transformations that objects undergo when interacting with their environment
  - Necessary for event-based programming, where different parts of the application must communicate via shared state
  - Fundamental programming style for Java libraries (collections, etc.)



A queue with two elements

First-class computation

- Concept: code is a kind of data that can be defined in functions or methods, stored in data structures, and passed to other functions.
- Examples: map, fold (HW4), pixel transformer (HW7), Event listeners (HW6, HW10), dynamic dispatch

```
cell.addMouseListener(new MouseAdapter() {
    public void mouseClicked(MouseEvent e) {
        selectCell(cell);
    }
});
```

- Why?
  - Allows more flexibility in the structure of code, can factor out design patterns that differ only in certain computations
  - Necessary for reactive programming, where data structures store the "reactions" to various events

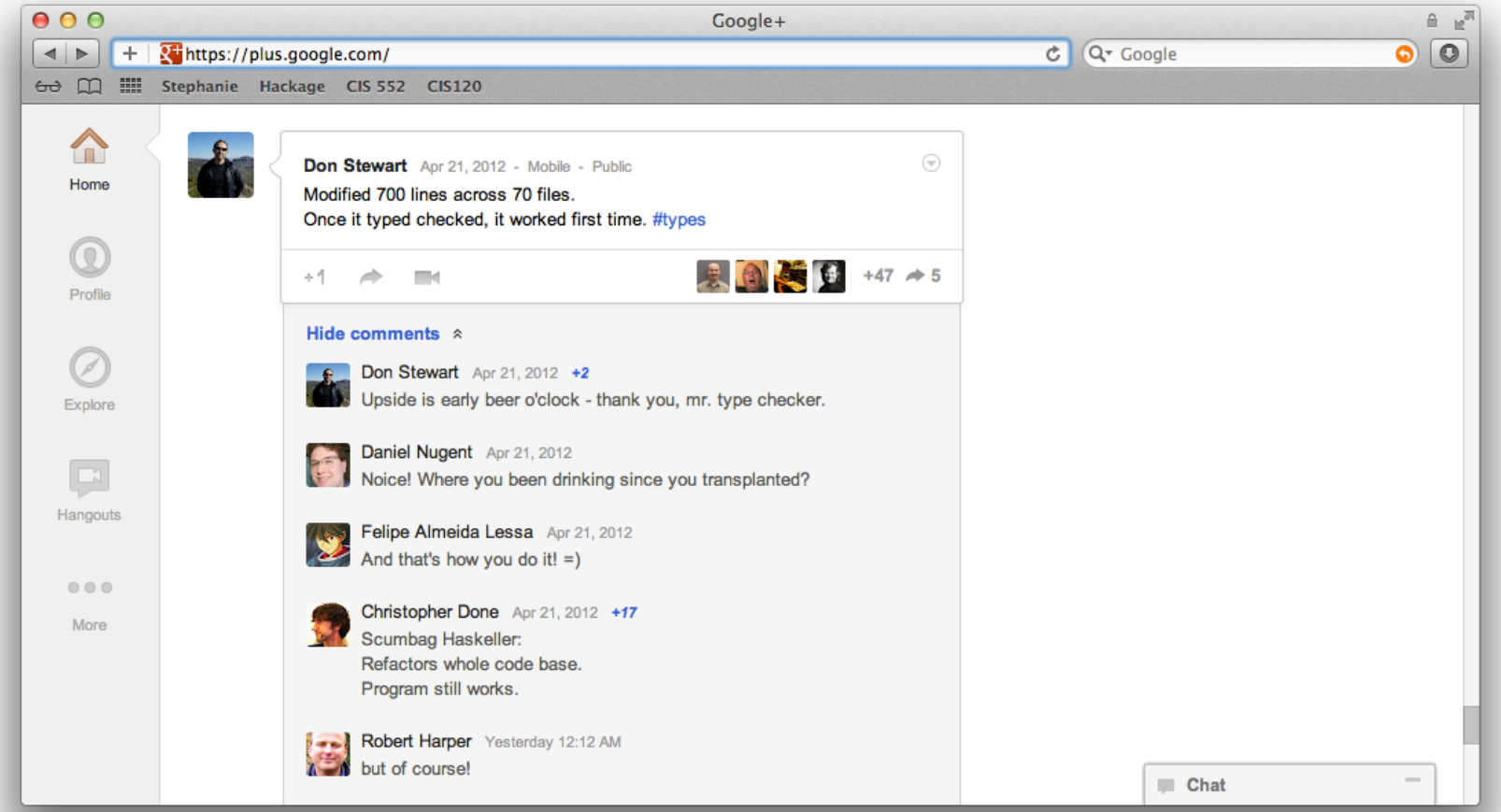
Types, Generics and Subtyping

- Concept: Static type systems define interfaces and prevent errors. Every expression has a static type, and OCaml/Java use the types to rule out buggy programs. Generics and subtyping make types more flexible and allow for code reuse.

```
let rec contains (x:'a) (l:'a list) : bool =
  begin match l with
    | [] -> false
    | h::tl -> x = a || (contains x tl)
  end
```

- Why?
  - Types make the interface explicit (and checked by the compiler)
  - Easier to fix problems indicated by a type error than to write a test case and then figure out why the test case fails
  - Promotes refactoring. Type checking ensures that basic invariants about the program are maintained as a program is modified.

Types and Refactoring



Abstract types and encapsulation

- Concept: Type abstraction hides the actual implementation of a datastructure, describes a datastructure by its interface (what it does vs. how it is represented)
- Examples: Set/Map interface (HW3), Queues in OCaml and Java, encapsulation and access control (HW8)

Invariants are a crucial way of structuring code and data:

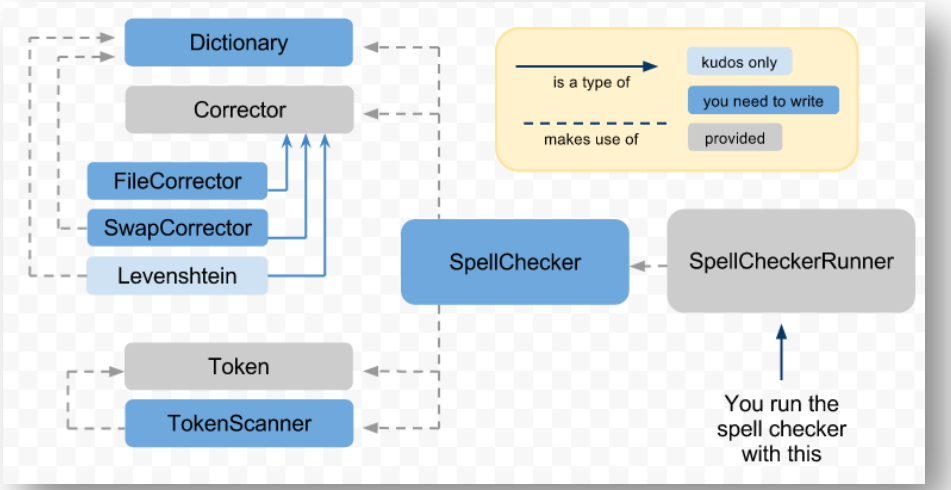
1. *Establish* the invariants when you create the structure.
2. *Preserve* the invariants when you modify the structure.

...ntation without modifying clients

...*variants* about the

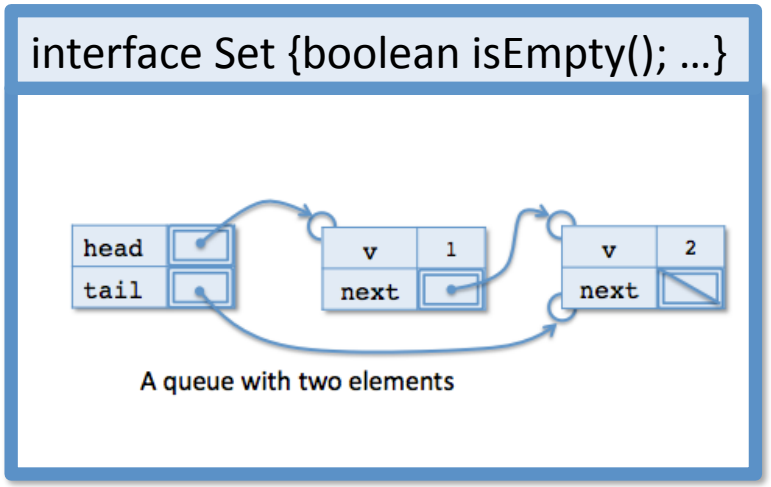
Sequences, Sets and Finite Maps

- Specific examples of abstract data types: sequences, sets and finite maps
- Examples: HW3, Java Collections, HW09
- Why?
  - These abstract data types come up *again and again* in computer science
  - Need aggregate data structures (collections) no matter what language you are programming in
  - Need to be able to choose the data structure with the right semantics



Lists, Trees, BSTs, and Queues

- Concept: specific implementations for abstract types
- Examples: HW2-5, Java Collections
- Why?
  - Need some concrete implementation of the abstract types
  - Different implementations have different trade-offs. Need to understand these trade-offs to use them well. (More in CIS 121!)
  - For example: BSTs use their invariants to speed up lookup operations compared to linked lists.



Lookup 'a'

Lookup 'a'

Lookup 'b'

Lookup 'b'

Do the Function call

Save Workspace; push l1, l2

Lookup l1

Lookup l1

Match Expression

Nil case Doesn't Match

Cons case *Does* Match

Simplify the Branch: push h, t

Lookup 'h'

Lookup 'h'

Lookup 'append'

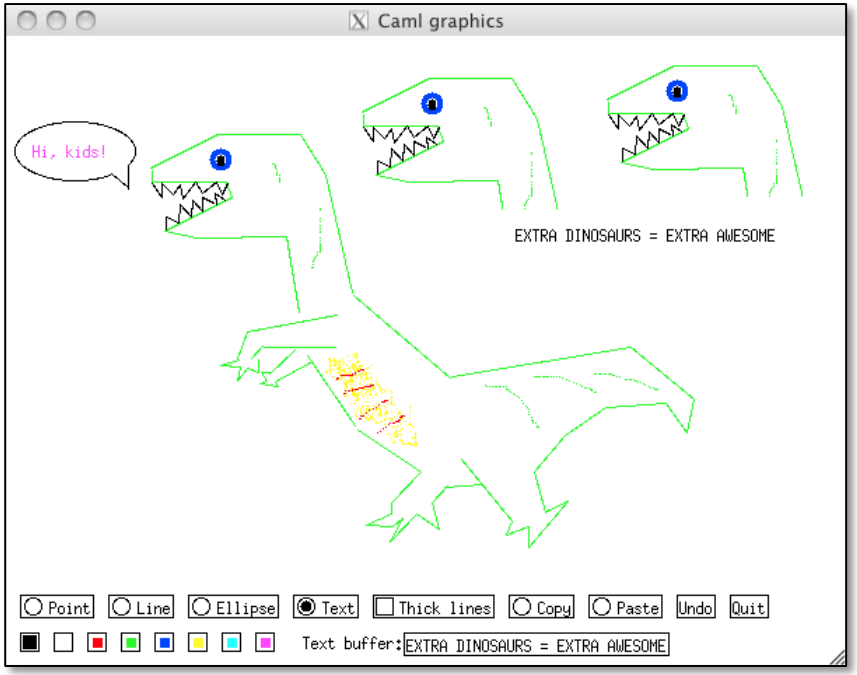
Lookup 'append'

Event-Driven programming

- Concept: Structure a program by associating "handlers" that run in reaction to program events. Handlers typically interact with the rest of the program by modifying shared state.

- Examples: GUI programming in OCaml and Java

- Why?
  - Practice with reasoning about shared state
  - Practice with first-class functions
  - Necessary for programming with Swing



Abstraction

- Concept: Don't Repeat Yourself. Find some way to generalize the code that you write to apply to more situations
- Examples: Functions/methods, generics, higher-order functions, interfaces, subtyping, abstract classes

- Why?
  - If you only write your code once, you only have to debug it once
  - Makes code easier to extend, can reuse the same code many times
  - Makes code easier to read, if parts of your program are meant to be similar, you can tell by reading the program

Why OCaml?

Why some other language?

- Experience with learning a new language
- Perspective about language-independent concepts
- Account for varying degrees of experience in the same class

…but, why OCaml?

Rich, orthogonal vocabulary

- In Java, primitive types, arrays, objects
- In OCaml, primitive types, arrays, objects, datatypes (including lists, trees, and options), records, refs and first-class functions and abstract types

- All of the above *can* be implemented in Java, but untangling various use cases of objects is subtle
- Concepts (like generics) can be studied in isolation, fewer intricate interactions with the rest of the language

Functional Programming

- In Java, every data structure is mutable by default
- In OCaml, persistent data structures are the default. Furthermore, the type system keeps track of what is and is not mutable

- Advantages of immutable/persistent data structures
  - Don't have to keep track of aliasing. Interface to the data structure is simpler
  - Often easier to think in terms of "transforming" data structures than "modifying" data structures
  - Simpler implementation (Compare lists and trees to queues and deques)
  - Powerful evaluation model (substitution + recursion).

The Billion Dollar Mistake

"***I call it my billion-dollar mistake. It was the invention of the null reference in 1965.*** *At that time, I was designing the first comprehensive type system for references in an object oriented language (ALGOL W). My goal was to ensure that all use of references should be absolutely safe, with checking performed automatically by the compiler. But I couldn't resist the temptation to put in a null reference, simply because it was so easy to implement.* ***This has led to innumerable errors, vulnerabilities, and system crashes, which have probably caused a billion dollars of pain and damage in the last forty years****. "*

Sir Tony Hoare, QCon, London 2009

Better interfaces: Optional values

- In Java, optional values are the default. *Any* reference type could be null.

- In OCaml, references are non-null by default and optional values must be specified by the programmer. Only values of type 'a option can be None.

- In Java, every method must specify what it does if its arguments are null. Many of them don't.
- In OCaml, the type of a method tells you whether an argument may be null. We didn't have to think about optional values until homework 5!

Fundamental abstract types

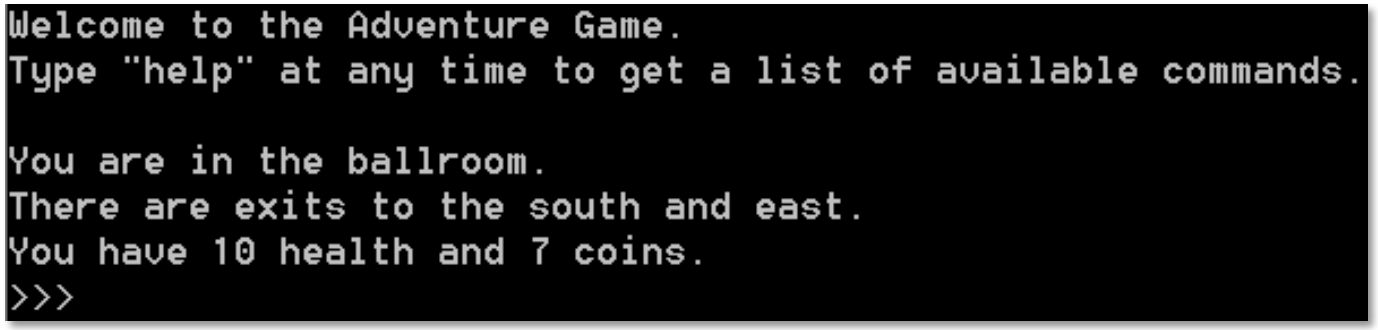
- An *abstract* type is defined by its *interface* not its *implementation*.
- Flexibility: interface can change without modification to clients
- Security: implementation invariants can be preserved

- In OCaml, direct expression of abstract data types through modules and signatures
- In Java, make types abstract via access modifiers (private), provide flexibility through interfaces

Why Java?

Object Oriented Programming

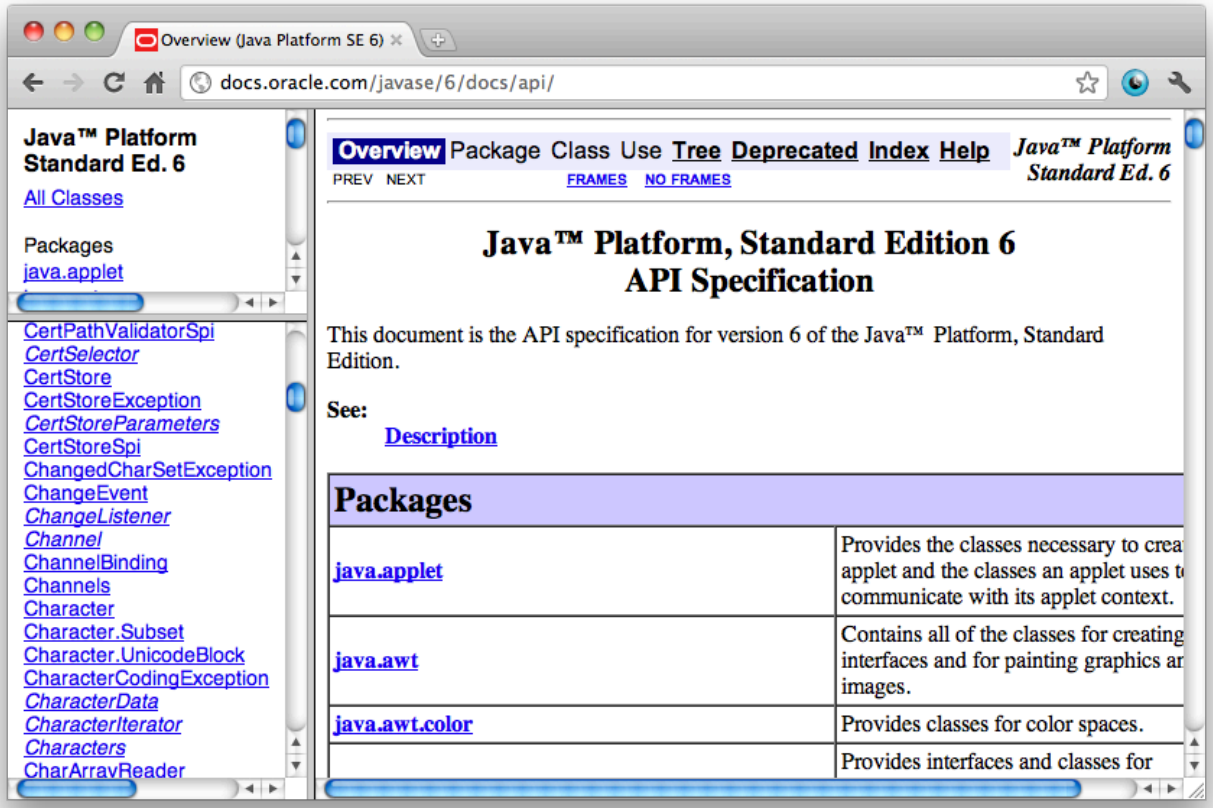
- Provides a different way of decomposing programs
- Basic principles:
  - Encapsulation of local, mutable state
  - Inheritance to share code
  - Dynamic dispatch to select which code gets run



- but why Java?

"Real" Programming Ecosystem

- Industrial strength tools:
  - Eclipse
  - JUnit testing framework
- Libraries:
  - Swing
  - Collections
  - I/O libraries
  - …

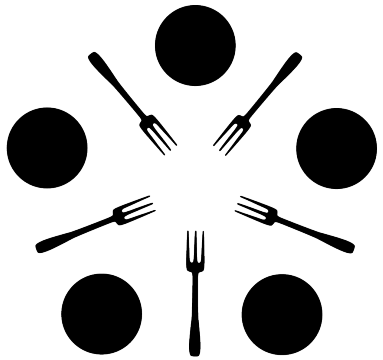


Onward…

What Next?

- Classes:
  - CIS 121, 262, 320 – data structures, performance, computational complexity
  - CIS 19x – programming languages
    - C++, C#, Python, Haskell, Ruby on Rails, iPhone programming
  - CIS 240 – lower-level: hardware, gates, assembly, C programming
  - CIS 341 – compilers (projects in OCaml)
  - CIS 371, 380 – hardware and OS's
  - And much more!
- Undergraduate research

WiCS
women in computer science



dining philosophers
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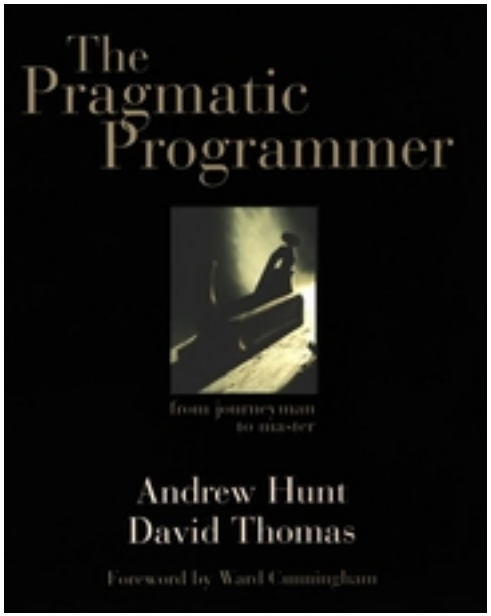
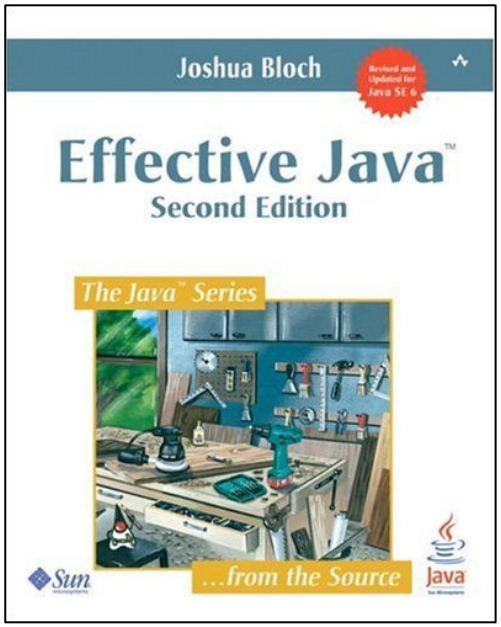
The Craft of Programming

- *The Pragmatic Programmer:*
  From Journeyman to Master

  by Andrew Hunt and David Thomas

  – Not about a particular programming language, it covers style, effective use of tools, and good practices for developing programs.





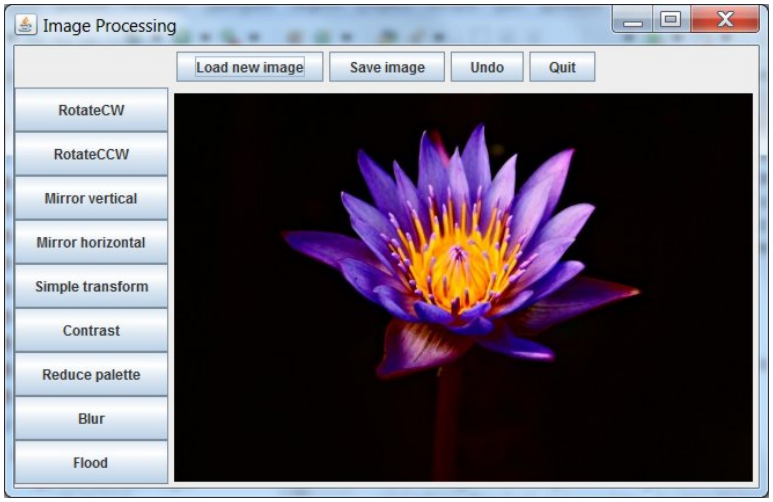
- *Effective Java*

  by Joshua Bloch

  – Technical advice and wisdom about using Java for building software. The views we have espoused in this course share much of the same design philosophy.

Parting Thoughts

- Improve CIS 120:
  - End-of-term survey link will be sent soon
  - Penn Course evaluations also provide useful feedback
  - We take them seriously, please complete them!



Finally: Thanks!

```
let rec length (l:int list) : int =
  begin match l with
    | [] -> 0
    | _::tl -> 1 + length(tl)
  end
```