CS 3110
Data Structures and Functional Programming
Lecture 1 - Course Overview

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Course Staff

- Instructor: Benjamin Ylvisaker
  - "Visiting" from GrammaTech, Inc
  - Into: software engineering, programming languages, concurrency and parallelism
  - Wrote a few thousand lines of O'Caml in grad school
- TAs and Consultants: Many
- We have a large and talented team. Make use of them!
- Office hours: on the website

Course Meetings

- Lectures: Tuesday & Thursday 10:10-11:00am

- Sections: Monday & Wednesday
  - Meeting at the end of lecture today to schedule TBD section

- New material in lecture and section

- Attendance is expected
  - Good attendance buys you priority when there is high demand for staff attention

Course Website

- http://www.cs.cornell.edu/Courses/cs3110/2013sp/
  - Course material
  - Problem sets
  - Announcements
- Course notes are fairly detailed, but course staff may say things in lecture and section that you will be expected to know
- Notes will be available before lecture/section
  - If you find the course challenging, try to at least skim them in advance
- Notes are not a replacement for attendance

Piazza and CMS

- Piazza
  - Online discussion forums
  - Monitored by TAs/consultants
  - Ask for help, but do not post solutions
- CMS
  - "Course Management System"
  - Built by Andrew Myers et al.
  - Assignments and grades posted there

Coursework

- 6 Problem sets
  - Due Thursdays at 11:59pm
    - Short, random grace period
  - PS 1 (out today) is due Thursday, Jan 31
    - Electronic submission via CMS
- 4 individual, 2 with teams of 2
  - 3 weeks for big assignments, with checkpoints
- 2 preliminary exams and a final

Grading

- Breakdown:
  - 50% Problem sets
  - 30% Preliminary exams
  - 20% Final exam

- Final grades determined by a combination of your scores relative to the class distribution and the success of the class overall

Late Policy

- You may submit up to when we start grading
  - 15 point penalty (out of 100) per day
  - As soon as we start grading, zero
- Submit early and often
  - CMS is your friend
  - Code that fails to compile will likely get a zero
- When emergencies come up, talk to Ben ASAP

Academic Integrity

- Strictly enforced
- We check your work for similarity
- If you do not do your own work, it will be unpleasant and painful for everyone involved
- To avoid temptation, start early
  - Learning new programming ideas often requires sleeping on it
  - Office hours almost every day of the week
  - Course staff is here to help

What this Course is About

- Programming isn't hard
- Programming well is very hard
  - 10x range in effectiveness
- We want you to write code that is
  - Reliable, efficient, readable, testable, provable, maintainable, ... beautiful
- Expand your problem solving skills
  - Recognize problems and map them onto known good solutions

Thinking Versus Typing

- "A year at the lab bench saves an hour at the library"
- Fact: There are infinitely many wrong programs
- Corollary: If your program isn't working and you don't know why, making random tweaks is unlikely to help
  - If you find yourself changing "<" to "<=" in hopes that your code will work, you're in trouble
- Lesson: Think before you type!

CS 3110 Challenges

- Some of you have gotten away with bad habits in previous programming classes
  - Just hack until it works
  - Solve everything by yourself
  - Write first, test later
- CS 3110 ≈ Tour de France
  - Professionals need good work habits and the right approach
- We need to think rigorously about programs and their models
  - Think for a few minutes, instead of typing for a few days!

Rule #1

- Good programmers are lazy
  - Never write the same code twice ("DRY")
  - Reusable libraries
  - Keep interfaces small and simple

- Pick a framework that makes it easy to write the code you need
  - Early focus on speed is a disaster

- Rapid prototyping

Main Goal of CS 3110

- Master key linguistic abstractions:
  - Procedural abstraction
  - Control: iteration, recursion, pattern matching, laziness, exceptions, events
  - Encapsulation: closures, ADTs
  - Parameterization: higher-order procedures, modules
- Mostly in service to rule #1
- Transcends individual programming languages

Other Goals

- Exposure to software engineering techniques:
  - Modular design
  - Integrated testing
  - Code reviews
- Exposure to abstract models:
  - Models for design & communication
  - Models & techniques for proving correctness
  - Models for analyzing space & time
- Rigorous thinking about programs!
  - Proofs, like in high school geometry

Choice of Language

- This matters less than you suspect
- Must be able to learn new languages
  - This is relatively easy if you understand programming models and paradigms
- We will be using OCaml, a dialect of ML
- Why use yet another language?
  - Not to mention an obscure one?
- Main answer: OCaml programs are easy to reason about

Why Caml caml.inria.fr/ ?

- Awesome OCaml feature: many common errors simply impossible
  - More precisely, they are caught at compile time
  - Early failure is very important (why?)
- Functional language
  - Programs have a clear semantics
  - Heavy use of recursion
  - Lots of higher-order functions
  - Few side effects
- Statically typed and type safe
  - Many bugs caught by compiler

Imperative (Procedural) Programming

- Program uses commands (a.k.a statements) that do things to the state of the system:
  - x = x + 1;

    a[i] = 42;

    p.next = p.next.next;
- Functions and methods can have side effects
  - int wheels(Vehicle v) { v.size++; return v.numw; }

Functional Style (1/2)

- Idea: program without side effects
  - Effect of a function is only to return a result value
- Program is an expression that can be evaluated to produce a value
  - For example, evaluating 2+2 yields 4
  - Just like mathematical expressions
- Enables equational reasoning about programs:
  - if x equals y, replacing y with x has no effect:
  - let x=f(0) in x+x equivalent to f(0)+f(0)

Functional Style (2/2)

- Bind variables to values, don't mutate existing variables
- No concept of x=x+1 or x++
- These do nothing remotely like x++
  - let x = x+1 in x
  - let rec x = x+1 in x
- The former assumes an existing binding for x and creates a new one (no modification of x)
- The latter is an invalid expression

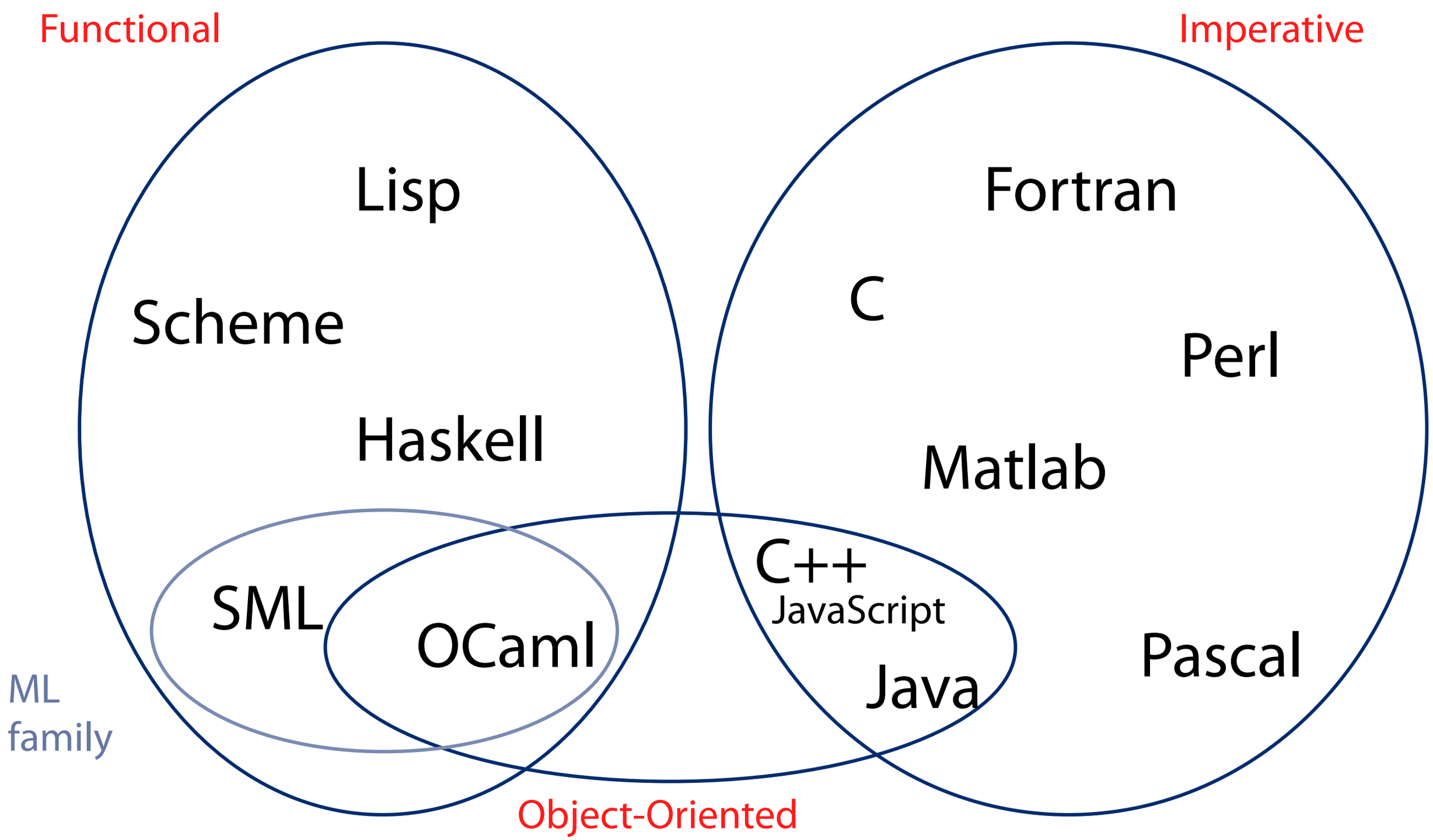
Trends in Industry Encouraging Functional Style

- Fantasy: program interacts with a single system state
  - Interactions are reads from and writes to variables or fields.
  - Reads and writes are very fast
  - Side effects are instantly seen by all parts of a program
- Reality: there is no single state
  - Multicores have own caches with inconsistent copies of state
  - Programs are spread across different cores and computers (PS5 & PS6)
  - Side effects in one thread may not be immediately visible in another
  - Imperative languages are a bad match to modern hardware

Imperative vs Functional

- Functional programming languages strongly encourage
  - Building code out of small functions
  - f(x) always gives the same result for the same x
  - Node side effects: easier to reason about programs
  - Better fit for modern hardware
- Functional style usable in Java, C, Python, ...
  - Example: "Lambda" support in C++
  - Often harder to stick with a purely functional style

Programming Language Map



OCaml Example 1

```
let rec sumsq n =
    if n=0 then 0
    else n*n + sumsq(n-1)
```

OCaml Example 2

- ```
  let rec sumop f n =
      if n=0 then 0
      else f n + sumop f (n-1)
  ```
- ```
  sumop cube 5
  ```
- ```
  sumop (function x -> x*x*x) 5
  ```
  ```

OCaml Example 3

```
let rec reverse lst =
    match lst with
      [] -> []
    | h::t -> reverse t @[h]
```

OCaml Example 4

```
let rec reverse lst =
    match lst with
      [] -> []
    | h::t -> reverse t @[h]
```

Why OCaml?

- Objective Caml is one of the most robust and general functional languages available
  - Used in financial industry
  - Lightweight and good for rapid prototyping
- Embodies important ideas better than Java, C++
  - Many of these ideas work in Java, C++, and you should use them...
- Learning a different language paradigms will make you a more flexible programmer down the road
  - Likely that Java and C++ will be replaced
  - Principles and concepts beat syntax
  - Ideas in ML will likely be in next-generation languages

Rough Schedule

- Introduction to functional programming (6)
- Functional data structures (5)
- Verification and Testing (5)
- Preliminary Exam #1
- Concurrency (1)
- Data structures and analysis of algorithms (5)
- Preliminary Exam #2
- Topics: streams, λ-calculus, garbage collection
- Final exam