Fundamentals of Programming Languages

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Meeting 1: Welcome

CSCI 5535, Spring 2009
http://www.cs.colorado.edu/~bec/courses/csci5535-s09/

Introductions

- Who am I?
- About you?
  - What do you want to get out of this class?

Administrivia

- Website
  http://www.cs.colorado.edu/~bec/courses/csci5535-s09/
  - readings, slides, assignments, etc.
- Office hours
  - MW 1:30pm-2:30pm?
  - and by appointment
  - ECOT 621

Today

- Some historical context
- Goals for this course
- Requirements and grading
- Course summary
- Convince you that PL is useful

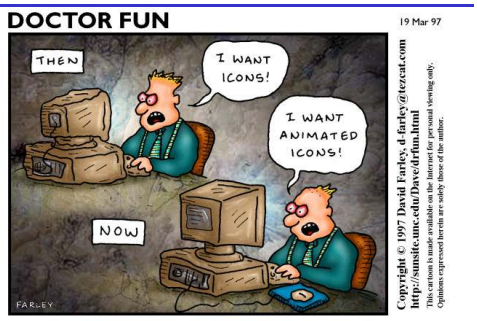
Meta-Level Information

- Please interrupt at any time!
- It's completely ok to say:
  - I don't understand. Please say it another way.
  - Slow down!
  - Wait, I want to read that!
- More discussion, less lecture

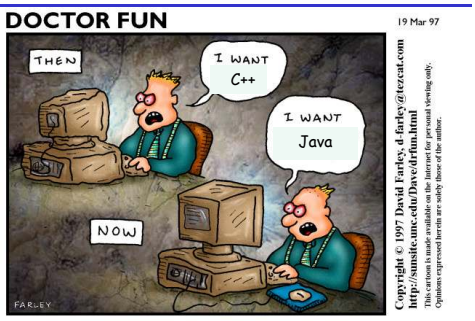
"Isn't PL a solved problem?"

- PL is an old field within Computer Science
- 1920's: "computer" = "person"
- 1936: Church's Lambda Calculus (= PL!)
- 1937: Shannon's digital circuit design
- 1940's: first digital computers
- 1950's: FORTRAN (= PL!)
- 1958: LISP (= PL!)
- 1960's: Unix
- 1972: C Programming Language
- 1981: TCP/IP
- 1985: Microsoft Windows

New and Better Compilers?



A Dismal View of PL Research



Programming Languages

- Touches most other areas of CS
  - Theory: DFAs, TMs, language theory (e.g., LALR)
  - Systems: system calls, memory management
  - Arch: compiler targets, optimizations, stack frames
  - Numerics: FORTRAN, IEEE FP, Matlab
  - AI: theorem proving, search
  - DB: SQL, transactions
  - Networking: packet filters, protocols
  - Graphics: OpenGL, LaTeX, PostScript
  - Security: buffer overruns, .NET, bytecode, PCC, …
  - Computational Biology: pathway models
  - Software Engineering: software quality, development tools
  - Human Computer Interaction: development tools
- Both theory (math) and practice (engineering)

Overarching Theme

- I assert (and shall convince you) that
- PL is one of the most vibrant and active areas of CS research today
  - It is both theoretical and practical
  - It intersects most other CS areas
- You will be able to use PL techniques in your own projects

Goals

Goal 1

Learn to use PL techniques

No Useless Memorization

- I will not waste your time with useless memorization
- This course will cover complex subjects
- I will teach their details to help you understand them the first time
- But you will never have to memorize anything low-level
- Rather, learn to apply broad concepts

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Goal 2

When (not if) you design a language, it will avoid the mistakes of the past, and you will be able to describe it formally

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Discussion: Language Design

- Languages are adopted to fill a void
  - Enable a previously difficult/impossible application
  - Orthogonal to language design quality (almost)
- Training is the dominant adoption cost
  - Languages with many users are replaced rarely
  - But easy to start in a new niche. Examples:

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Why so many languages?

- Each useful for diff things
- "I can build it better"
- Diff problem need diff language

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Why so many languages?

- Examples:
  - AI: symbolic computation (Lisp, Prolog)
  - Scientific Computing: high performance (Fortran)
  - Business: report generation (COBOL)
  - Systems Programming: low-level access (C)
  - Scripting (Perl, Python, TCL)
  - Distributed Systems: mobile computation (Java)
  - Web (PHP)
  - Special purpose languages: …

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Language Paradigms

- Imperative
  - Fortran, Algol, Cobol, C, Pascal
- Functional
  - Lisp, Scheme, ML, Haskell
- Object oriented
  - Smalltalk, Eiffel, Self, C++, Java, C#, Javascript
- Logic
  - Prolog
- Concurrent
  - CSP, dialects of the above languages
- Special purpose
  - TEX, Postscript, TrueType, sh, HTML, make

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What makes a good language?

- No universally accepted metrics for design
- "A good language is one people use"?
  - Make it easier to solve a problem
  - Library support

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What are good language features?

- Simplicity (syntax and semantics)
- Expressive
- Consistency – "not weird"
- Efficiency
- Safety
- Documentation – Supporting large systems
- Price / Open Source
- Portability / Compatibility

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Designing good languages is hard

- Goals almost always conflict.
- Examples:
  - Safety checks cost something in either compilation or execution time.
  - Type systems restrict programming style in exchange for strong guarantees.

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Story: The Clash of Two Features

- Real story about bad programming language design
- Cast includes famous scientists
- ML ('82) functional language with polymorphism and monomorphic references (i.e., pointers)
- Standard ML ('85) innovates by adding polymorphic references
- It took 10 years to fix the "innovation"

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Polymorphism (Informal)

- Code that works uniformly on various types of data
- Examples of function signatures:
  - length : α list $\rightarrow$ int (takes an argument of type "list of α", returns an integer, for any type α)
  - head : α list $\rightarrow \alpha$
- Type inference:
  - generalize all elements of the input type that are not used by the computation

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References in Standard ML

- Like "updatable pointers" in C
- Type constructor: τ ref
  - x : int ref "x is a pointer to an integer"
- Expressions:
  - ref : $\tau \rightarrow \tau$ ref
    (allocate a cell to store a τ, like malloc)
  - !e : τ when e : τ ref
    (read through a pointer, like *e)
  - e := e' with e : τ ref and e' : τ
    (write through a pointer, like *e = e')
- Works just as you might expect

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Polymorphic References: A Major Pain

Consider the following program fragment:

Code	Type inference
fun id(x) = x	id : $\alpha \to \alpha$ (for any α)
val c = ref id	c : $(\alpha \to \alpha)$ ref (for any α)
fun inc(x) = x + 1	inc : int $\to$ int
c := inc	Ok, since c : (int $\to$ int) ref
(!c) (true)	Ok, since c : (bool $\to$ bool) ref

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Reconciling Polymorphism and References

- Type system fails to prevent a type error!
- Commonly accepted solution today:
  - value restriction: generalize only the type of values!
    - easy to use, simple proof of soundness
  - many "failed fixes"
- To see what went wrong we needed to understand semantics, type systems, polymorphism and references

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Story: Java Bytecode Subroutines

- Java bytecode programs contain subroutines (jsr) that run in the caller's stack frame (why?)
- jsr complicates the formal semantics of bytecodes
  - Several verifier bugs were in code implementing jsr
  - 30% of typing rules, 50% of soundness proof due to jsr
- It is not worth it:
  - In 650K lines of Java code, 230 subroutines, saving 2427 bytes, or 0.02%
  - 13 times more space could be saved by renaming the language back to Oak

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Recall Goal 2

When (not if) you design a language, it will avoid the mistakes of the past, and you will be able to describe it formally

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Goal 3

Understand current PL research (POPL, PLDI, OOPSLA, TOPLAS, …)

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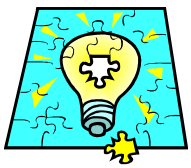
Most Important Goal

Have Lots of Fun!



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Requirements

Prerequisites

- "Programming experience"
  - exposure to various language constructs and their meaning (e.g., CSCI 3155)
  - ideal: undergraduate compilers (e.g., CSCI 4555)
- "Mathematical maturity"
  - we'll use formal notation to describe the meaning of programs
- If you are an undergraduate or from another department, please see me.

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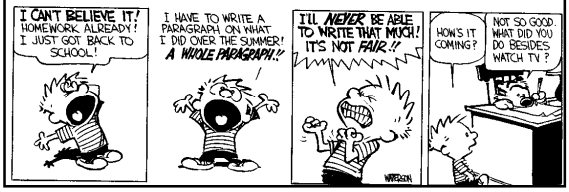
Assignments

- Reading and participation (each meeting)
- Weekly homework (for half semester)
- Take-home midterm exam
- Final project



Reading and Participation

- ~2 papers/book chapter, each meeting
  - Spark class discussion, post/bring questions
- Online discussion forum
  - Post $\geq$1 substantive comment, question, or answer for each lecture
  - On moodle.cs.colorado.edu
  - Due before the next meeting

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Homework and Exam

- Homework/Problem Sets
  - You have one week to do each one
  - First half of the semester only
  - Some material will be "mathy"
  - Collaborate with peers (but acknowledge!)
- Take-Home Midterm Exam
  - Like a longer homework

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Final Project

- Options:
  - Literature survey
  - Implementation project
  - Research project
- Write a 5-page paper (conference style)
- Give a ~10 minute presentation
- On a topic of your choice
  - Ideal: integrate PL with your research
- Pair projects possible if **large**

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Course Summary

Course At-A-Glance

- Part I: Language Specification
  - Semantics = Describing programs
  - Evaluation strategies, imperative languages
  - Textbook: Glynn Winskel. *The Formal Semantics of Programming Languages.*
- Part II: Language Design
  - Types = Classifying programs
  - Typed λ-calculus, functional languages
- Part III: Applications

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Core Topics

- Semantics
  - Operational semantics
    - rules for execution on an abstract machine
    - useful for implementing a compiler or interpreter
  - Axiomatic semantics
    - logical rules for reasoning about the behavior of a program
    - useful for proving program correctness
  - Abstract interpretation
    - application: program analysis
- Types
  - λ-calculus
    - tiny language to study core issues in isolation

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Possible Special Topics

- Software model checking
- Object-oriented languages
- Types for low-level languages
- Types for resource management
- Shape analysis

- What do you want to hear about?

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First Topic: Model Checking

- Verify properties or find bugs in software
- Take an important program
  - e.g., a device driver
- Merge it with a property
  - e.g., no deadlocks, asynchronous IRP handling, BSD sockets, database transactions, …
- Transform the result into a boolean program
- Use a model checker to exhaustively explore the resulting state space
  - Result 1: program provably satisfies property
  - Result 2: program violates property "right here on line 92,376"!

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For Next Time

- Join the course moodle and introduce yourself (forum discussion for today)
- Read the two articles on SLAM
  - see the website under "Schedule"

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