Language Design and Implementation

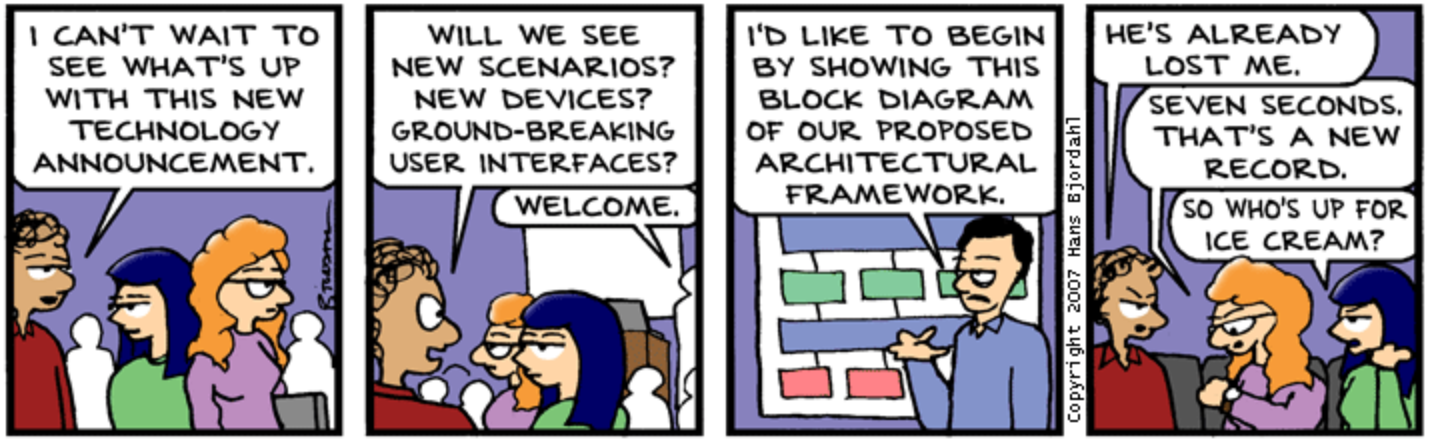
Wes Weimer

TR 3:30 - 4:45

Thornton E-303

Cunning Plan

- Administrivia
  - Webpage, Wes, Kevin Leach, undergrad TAs
- What Is This Class About?
- Easy or Hard? Work and Grading.
- Understanding a Program in Stages



Course Home Page

- Find via Weimer webpage or Lou's List
- **http://dijkstra.cs.virginia.edu/ldi/**
- Lectures slides are available before class
  - You should still take notes!
- Assignments are listed
  - also grading breakdown, regrade policies, etc.

- Use the class forum for all public questions

Language Design and Implementation Course Goals

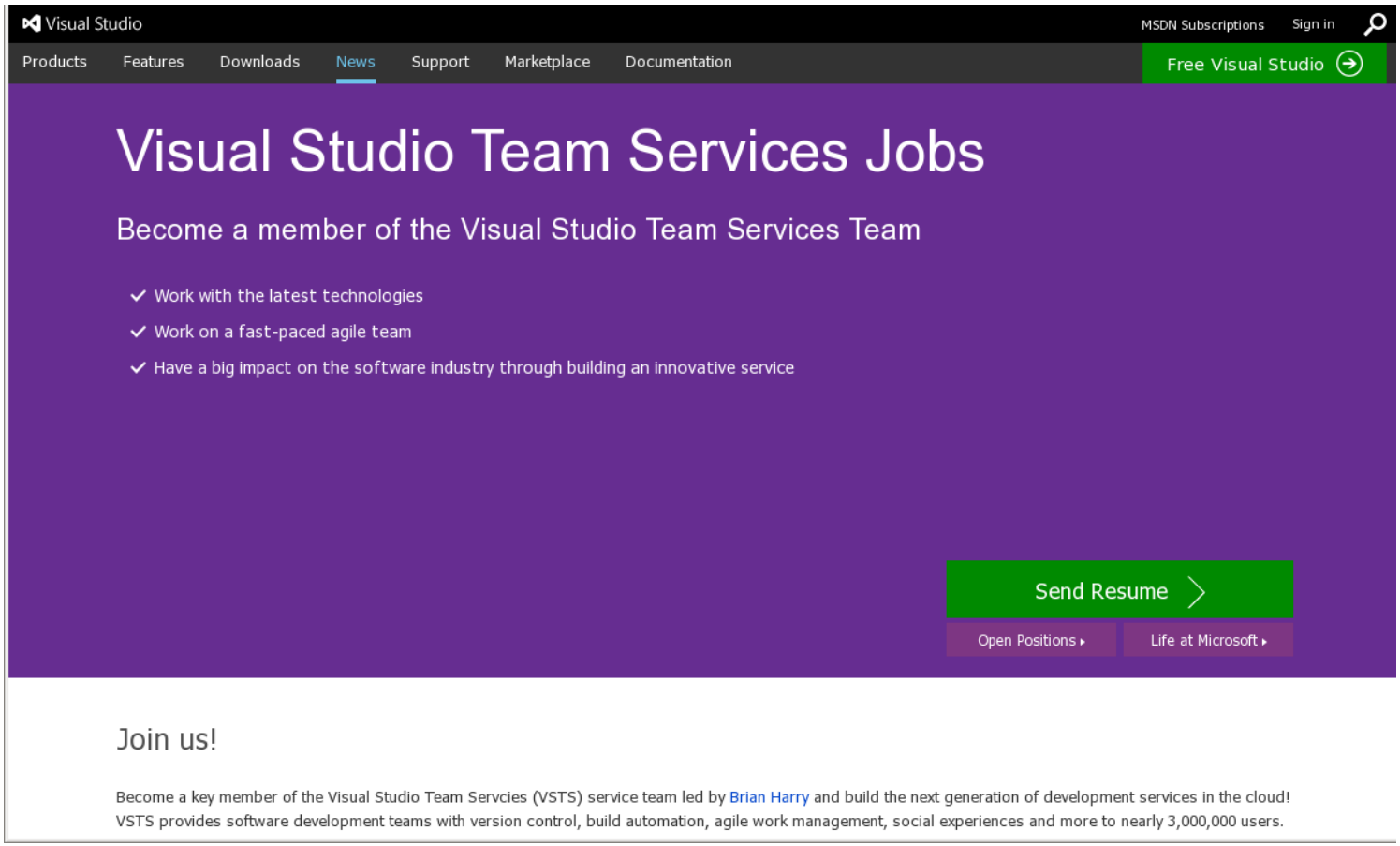
- At the end of this course, you will be acquainted with the fundamental concepts in the **design** and **implementation** of high-level programming **languages**. In particular, you will understand the **theory** and **practice** of **lexing**, **parsing**, **semantic** analysis, and **code** interpretation. You will also have gained practical experience programming in **different** languages.

Who Cares?

- In most cases, there is a clear mapping between 4000-level electives and jobs or internships:
- Take Databases (4750) -> work at Oracle
- Take E-Commerce (4753) -> work at Amazon
- Take Networks (4457) -> work at Cisco
- Take Graphics (4810) -> work at Nvidia
- Take LDI (4501) -> ???
- *Which companies develop compilers or interpreters?*

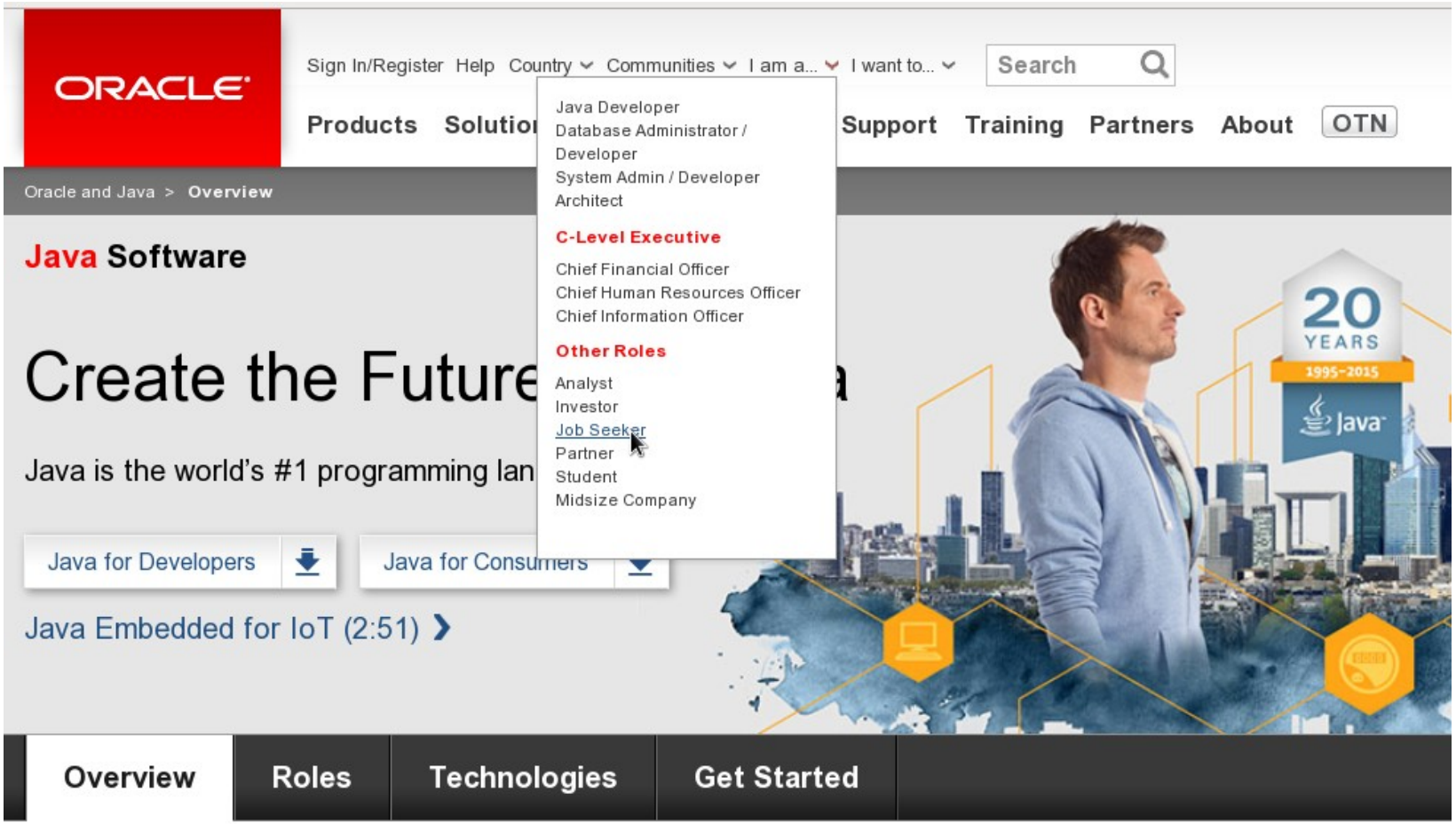
Microsoft

- Visual Studio, Excel, etc.



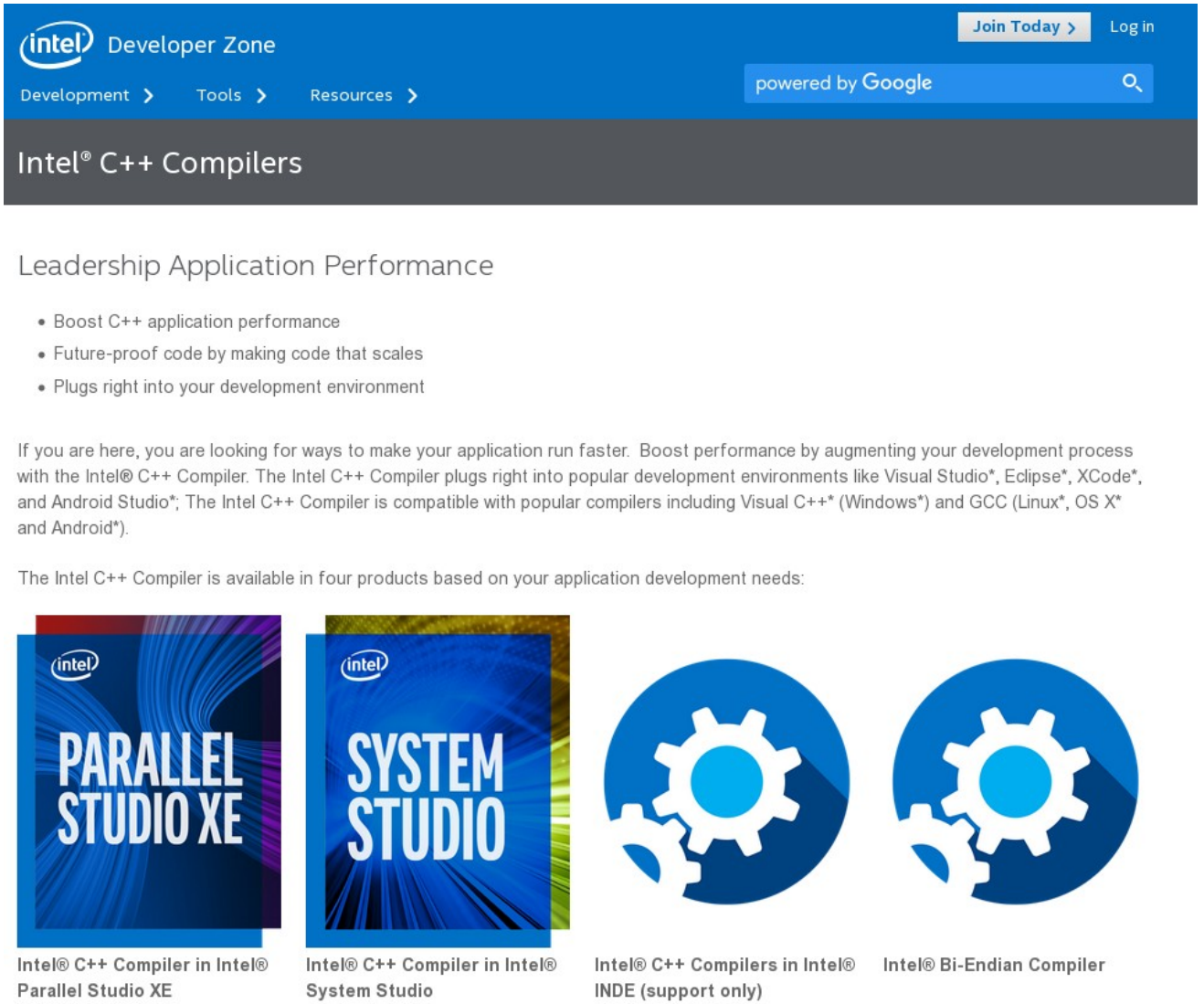
Oracle

- Java Compiler, Java Virtual Machine



Intel

- ICC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Intel® C++ Compilers
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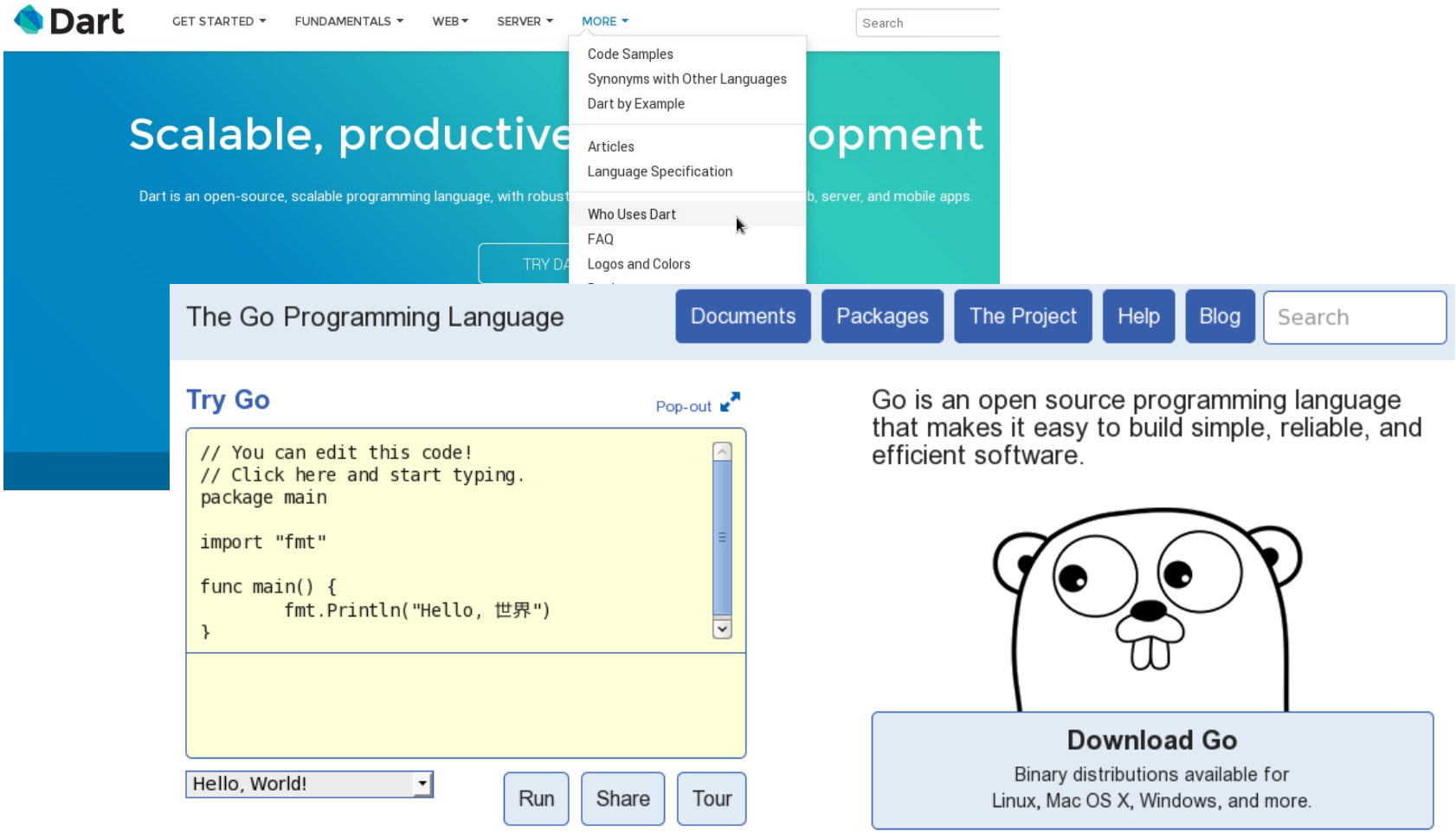
Future-proof code by making code that scales
Plugs right into your development environment
If you are here, you are looking for ways to make your application run faster. Boost performance by augmenting your development process with the Intel® C++ Compiler. The Intel C++ Compiler plugs right into popular development environments like Visual Studio*, Eclipse*, XCode*, and Android Studio*; The Intel C++ Compiler is compatible with popular compilers including Visual C++* (Windows*) and GCC (Linux*, OS X* and Android*).
The Intel C++ Compiler is available in four products based on your application development needs:
PARALLEL STUDIO XE
SYSTEM STUDIO
Intel® C++ Compiler in Intel® Parallel Studio XE
Intel® C++ Compiler in Intel® System Studio
Intel® C++ Compilers in Intel® INDE (support only)
Intel® Bi-Endian Compiler

Google

- Go, Dart, etc.

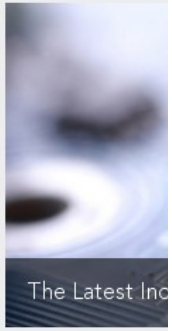


Wind River, Green Hills

- Embedded!

DIAB COMPILER

For over 25 years, Wind River Diab Compiler has been help
industrial, medical, and aerospace industries. Diab Compile
footprint, and produce high-quality, standards-compliant c



Diab Compiler's unique optimization technology generates extremely fast, high-quality object code in the smallest possible footprint.

Due to collabora
Diab Compiler is
microcontrollers
older processors
of time to allow
of the compiler f

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Green Hills Software is always looking for qualified Engineering, Sales, and Marketing staff. Please submit your resume to the Corporate Office where it will be processed and reviewed by the hiring manager.

Click on a job title below for a complete description of the position:

- Corporate Field Applications Engineer (Santa Barbara, CA)
- Embedded Software Consultant (Santa Barbara, CA)
- Embedded Solutions Test Engineer (Santa Barbara, CA)
- Field Engineer (Santa Barbara, CA)
- Field Services Engineer (Santa Barbara, CA)
- Functional Safety Software Engineer (Santa Barbara, CA)
- Product Engineer (Santa Barbara, CA)
- Sales Managers (location TBD)
- Software Development Engineer (Santa Barbara, CA)
- Technical Marketing Engineer (Santa Barbara, CA)

Click here for information on applying.
Green Hills Software is an Equal Opportunity / Affirmative Action Employer.

Software Development Engineer (Santa Barbara, CA)

Job description:

A software engineer has complete engineering responsibility for one or more major components of the Green Hills product line. For an experienced programmer this is a satisfying position in which you have personal responsibility for creating a tool used by thousands of programmers around the world. Our engineers are involved in Language Front Ends, Code Generators, Real Time Operating Systems, our MULTI Development Environment, our Secure Workstation, and Target Systems.

Here are the groups for which we are hiring:

- **Compiler:** Create, update, and maintain a language front end or a target architecture backend for the highly-optimizing family of Green Hills compilers. A compiler engineer might work on new language extensions, specific cutting-edge optimizations for the latest chips to hit the market, or on general optimizations that will benefit our entire product line. An ideal candidate understands low level microarchitecture designs and is comfortable working with assembly code, yet can also develop tools written in high level languages.

Wait, what? Embedded?

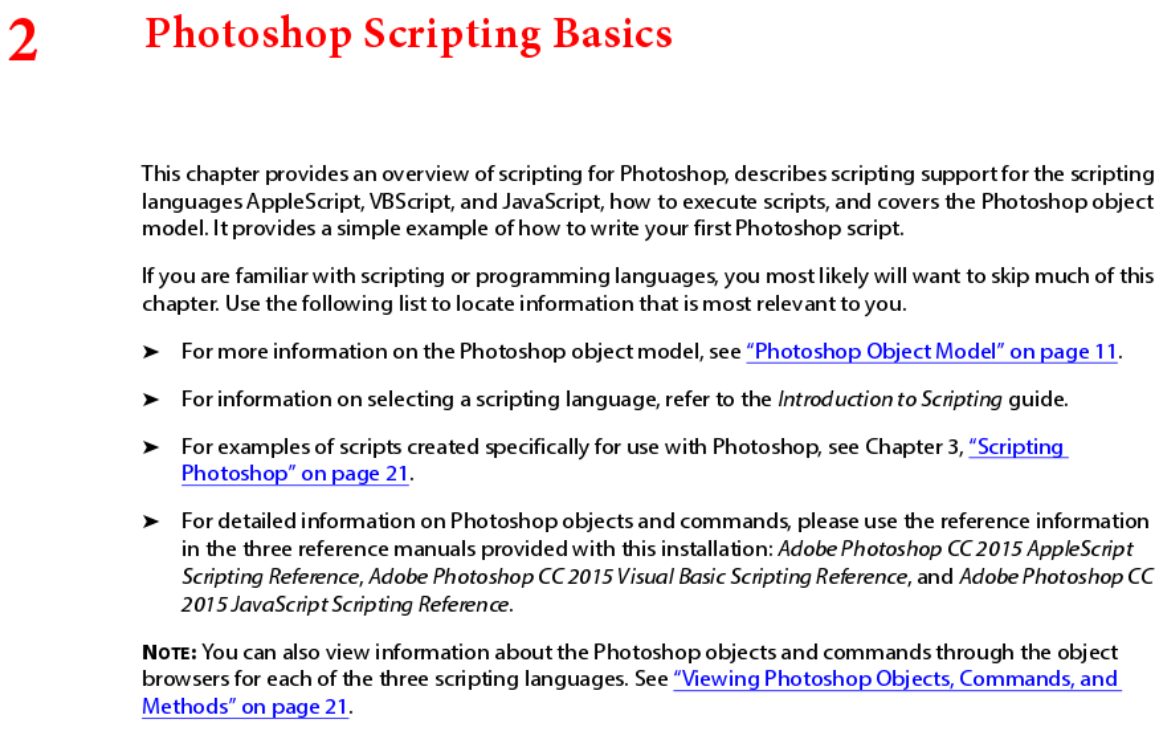
- Curiosity Mars Rover, Cell Phones, Satellites, Engine Control Modules, Computed Radiology, Fighter Jets, Digital Cameras, Turbines, Anti-Lock Brakes, Wii U Game Console, ...

Eight years ago, NASA Jet Propulsion Laboratory (JPL) first began its work on the Mars Science Laboratory rover, Curiosity. Because of its long record of success with Wind River® on more than 20 JPL missions, NASA chose VxWorks® for the most technologically advanced autonomous robotic spacecraft and geologist set ever to be deployed by any space venture. Wind River VxWorks powered the craft's controls from the second the rocket left Earth on November 26, 2011, to its successful landing in the Gale Crater on Mars on August 5, 2012, and will support Curiosity's exploratory capability throughout the life of the mission.

Stay tuned for future updates as Wind River VxWorks continues to play a strategic role in NASA's groundbreaking mission to determine whether Mars is or has ever been capable of supporting life and to assess the planet's habitability for future human missions.

Adobe

- Photoshop contains interpreters …



2 Photoshop Scripting Basics

This chapter provides an overview of scripting for Photoshop, describes scripting support for the scripting languages AppleScript, VBScript, and JavaScript, how to execute scripts, and covers the Photoshop object model. It provides a simple example of how to write your first Photoshop script.

If you are familiar with scripting or programming languages, you most likely will want to skip much of this chapter. Use the following list to locate information that is most relevant to you.

- For more information on the Photoshop object model, see "Photoshop Object Model" on page 11.
- For information on selecting a scripting language, refer to the *Introduction to Scripting* guide.
- For examples of scripts created specifically for use with Photoshop, see Chapter 3, "Scripting Photoshop" on page 21.
- For detailed information on Photoshop objects and commands, please use the reference information in the three reference manuals provided with this installation: *Adobe Photoshop CC 2015 AppleScript Scripting Reference*, *Adobe Photoshop CC 2015 Visual Basic Scripting Reference*, and *Adobe Photoshop CC 2015 JavaScript Scripting Reference*.

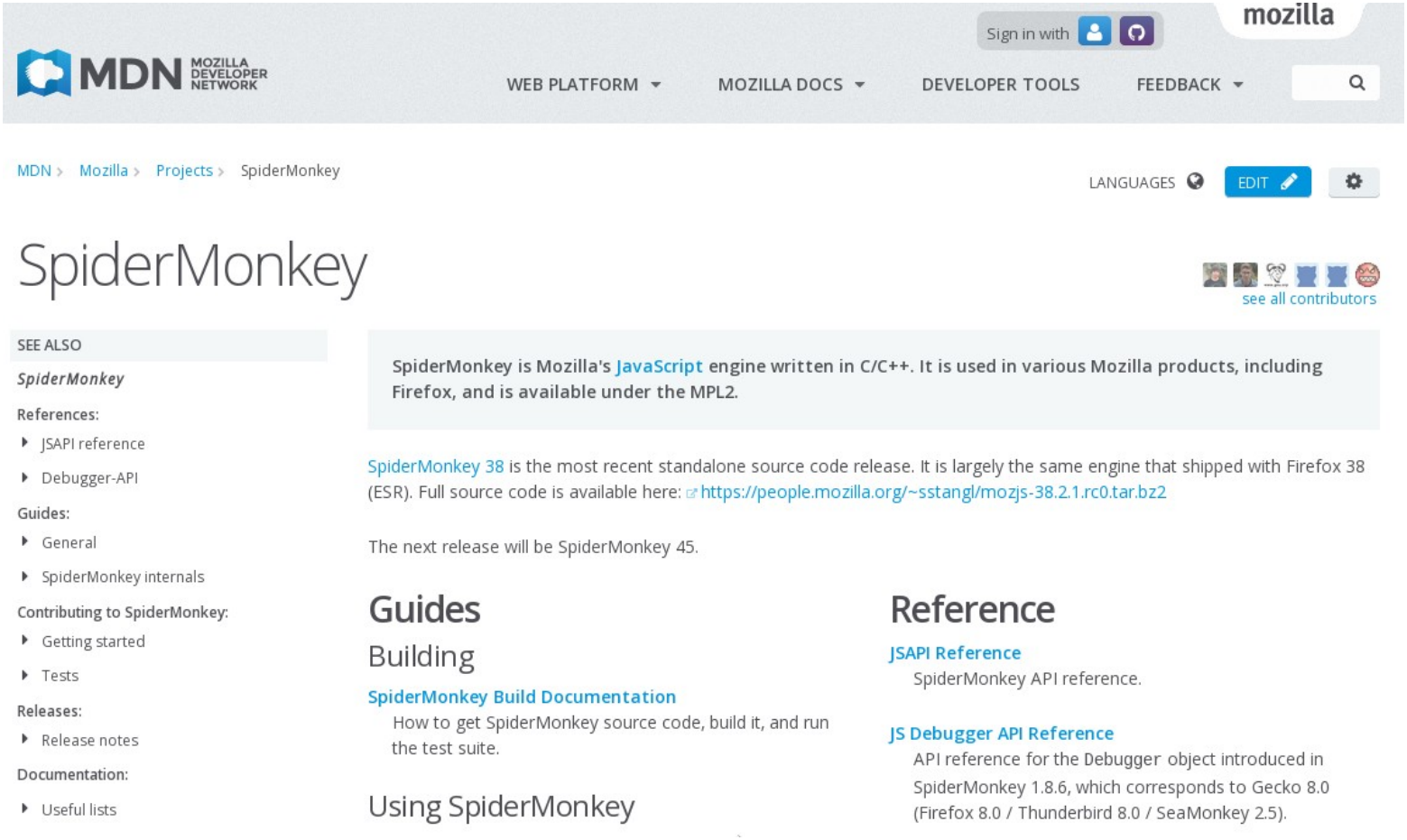
NOTE: You can also view information about the Photoshop objects and commands through the object browsers for each of the three scripting languages. See "Viewing Photoshop Objects, Commands, and Methods" on page 21.

Scripting Overview

A script is a series of commands that tells Photoshop to perform a set of specified actions, such as applying different filters to selections in an open document. These actions can be simple and affect only a single object, or they can be complex and affect many objects in a Photoshop document. The actions can call Photoshop alone or invoke other applications.

Mozilla

- SpiderMonkey JavaScript Engine



Epic Games

- Unreal Engine: Blueprints Scripting

Unreal Engine 4 Documentation

SHARE:

Blueprints Visual Scripting

Unreal Engine 4.9

The **Blueprints Visual Scripting** system in Unreal Engine is a complete gameplay scripting system based on the concept of using a node-based interface to create gameplay elements from within Unreal Editor. This system is extremely flexible and powerful as it provides the ability for designers to use virtually the full range of concepts and tools generally only available to programmers.

Through the use of Blueprints, designers can prototype, implement, or modify virtually any gameplay element, such as:

QuakeC

QuakeC is an interpreted language developed in 19
id Software to program parts of the video game *Qua*
programmer is able to customize *Quake* to great ext
weapons, changing game logic and physics, and pr
scenarios. It can be used to control many aspects of
parts of the AI, triggers, or changes in the level. The
only game engine to use QuakeC. Following engine
modules for customization written in C and C++ from id Tech 4 on.

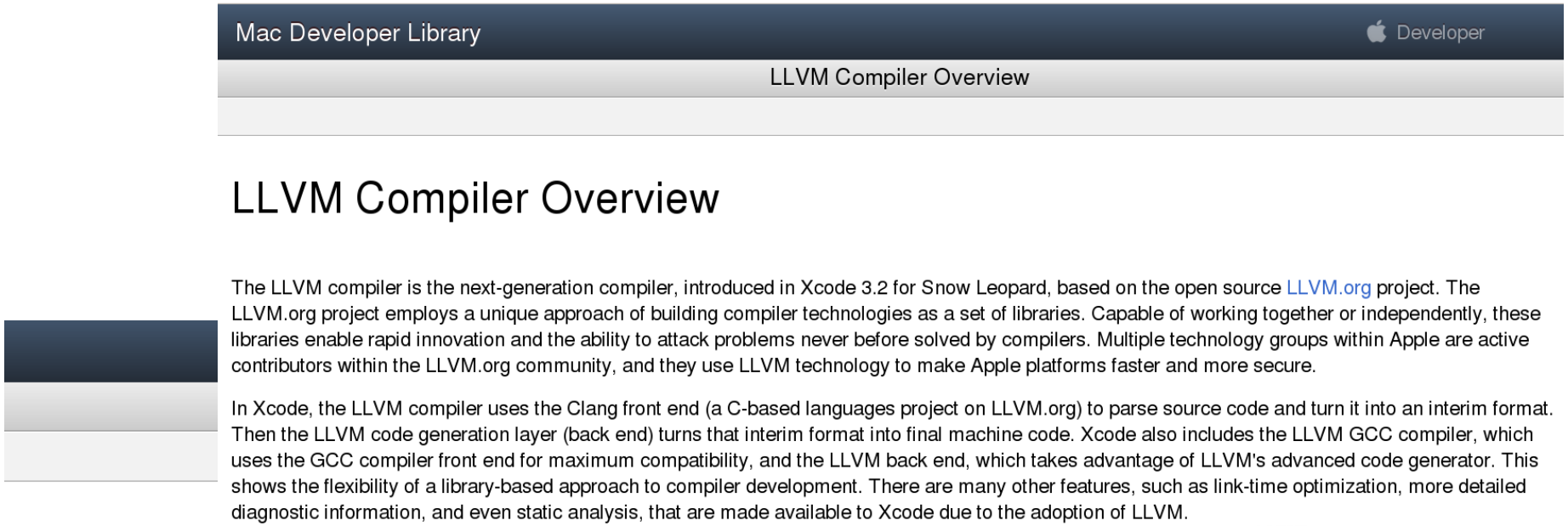
Typing discipline	static, strong
Major implementations	
Quake C Compiler, FastQCC, QCCx, GMQCC	
Influenced by	
C	

Contents

- Overview
- Limitations

Apple

- Objective-C. LLVM.



Compilers and Interpreters

- Back End Optimization, Chips, etc.
  - Intel, AMD, nVidia, Green Hills, etc.
- Platform Vendors
  - Apple, Oracle, etc.
- Tooling, IDEs
  - Microsoft, Google, etc.
- Domain-Specific Languages
  - Photoshop, Game Studies, MATLAB, SQL, Wolfram Alpha, etc.

Surprise: Flash, Postscript.

The language

PostScript is a Turing-complete programming language, belonging to the concatenative group. Typically, PostScript programs are not produced by humans, but by other programs. However, it is possible to write computer programs in PostScript just like any other programming language.[5]

PostScript is an interpreted, stack-based language similar to those found in Lisp, scoped memory and, since language le Polish notation, which makes the order of operations unamb one has to keep the layout of the stack in mind. Most *operat* the stack, and place their results onto the stack. *Literals* (for on the stack. Sophisticated data structures can be built on th system, which sees them all only as arrays and dictionaries, "types" is left to the code that implements them.

ActionScript

ActionScript is an object-oriented programming language originally developed by Macromedia Inc. (now dissolved into Adobe Systems). It is a derivation of HyperTalk, the scripting language for HyperCard.[2] It is now a dialect of ECMAScript (meaning it is a superset of the syntax and semantics of the language more widely known as JavaScript), though it originally arose as a sibling, both being influenced by HyperTalk.

ActionScript is used primarily for the development of websites and software targeting the Adobe Flash Player platform, used on Web pages in the form of embedded SWF files.

ActionScript 3 is also used with Adobe AIR system for the development of desktop and mobile applications. The language itself is open-source in that its specification is offered free of charge[3] and both an open source compiler (as part of Apache Flex) and open source virtual machine (Mozilla Tamarin) are available.

ActionScript is also used with Scaleform GFx for the development of 3D video game user interfaces and HUDs.

ActionScript

Paradigm	Multi-paradigm: object-oriented (prototype-based), functional, imperative, scripting
Designed by	Gary Grossman
Developer	Macromedia (now dissolved into Adobe Systems)
First appeared	1998
Stable release	3.0 / June 27, 2006
Typing discipline	strong, static
Website	adobe
Major implementations	
Adobe Flash Player, Adobe AIR, Apache Flex, Scaleform GFx	
Influenced by	
JavaScript, Java	

Surprise: Flash, Postscript.

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Adobe Flash Player, Adobe AIR, Apache Flex, Scaleform GFx	
Influenced by	
JavaScript, Java	

Flash Player, Your Printer,
Your Cell Phone, Acrobat Reader:
they are contain *Interpreters*.

Who Cares?

- The *computer* is unique among "machines" (e.g., lever, pulley, etc.) in that it magnifies our mental force rather than our physical force.
  - Computers can assist with decision making, model and predict outcomes, etc.
- Programming Languages are the mechanism for communicating with and commanding the only tool available that magnifies your mind.

Plus Work, Double-Plus Easy

- Unhappiness is related to unrealized desires or unmet expectations
- CS 4610 is arguably the department's most difficult elective: 5 credits of work in a 3-credit course with a tough curve
- Language Design and Implementation is an approachable, streamlined variant
  - 3.5 credits of work in a 3-credit course with a very very generous curve

In A Nutshell

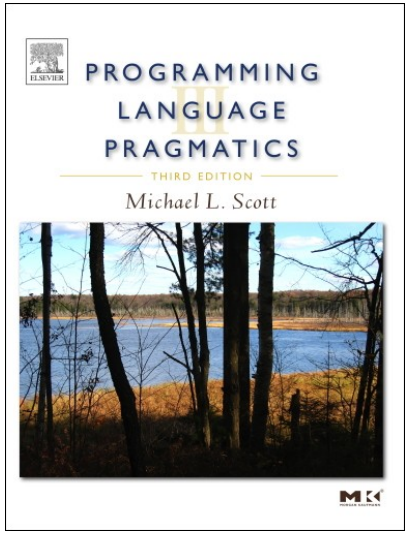
- Language Design and Implementation is
  - One notch more work than a standard elective
  - Two notches more generous than a standard elective
- Is that a good fit for your schedule?
- “Add this course!”

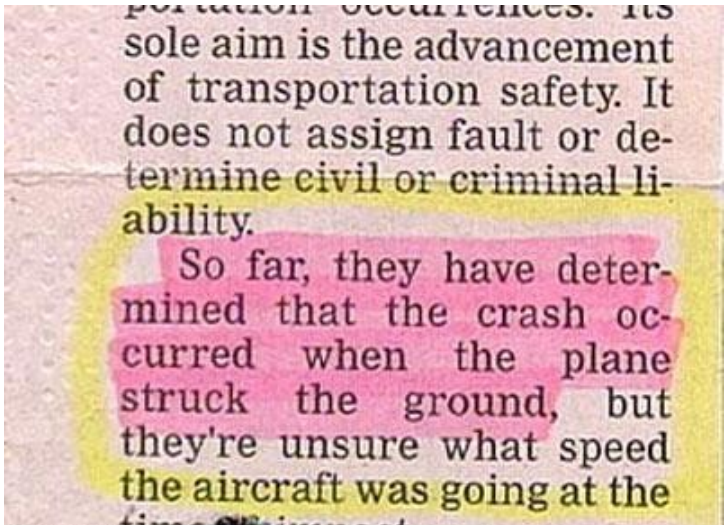
Course Structure

- Course has theoretical and practical aspects
  - Best of both worlds!
- Need both in programming languages!
- Reading = both
  - Many external and optional readings
- Review Sets = theory
  - Not graded, practice problems for exams
- Programming assignments = practice
  - Electronic hand-in
- Strict deadlines
  - Ask me why ...

Resources

- Textbook
  - Programming Language Pragmatics
  - Michael L. Scott, third edition
- Video Guides
- Free Online Materials
  - Udacity CS 262
- Optional Readings




sole aim is the advancement of transportation safety. It does not assign fault or determine civil or criminal liability.

So far, they have determined that the crash occurred when the plane struck the ground, but they're unsure what speed the aircraft was going at the

Academic Honesty

- Don't use work from uncited sources
  - Including old code
- We often use plagiarism detection software

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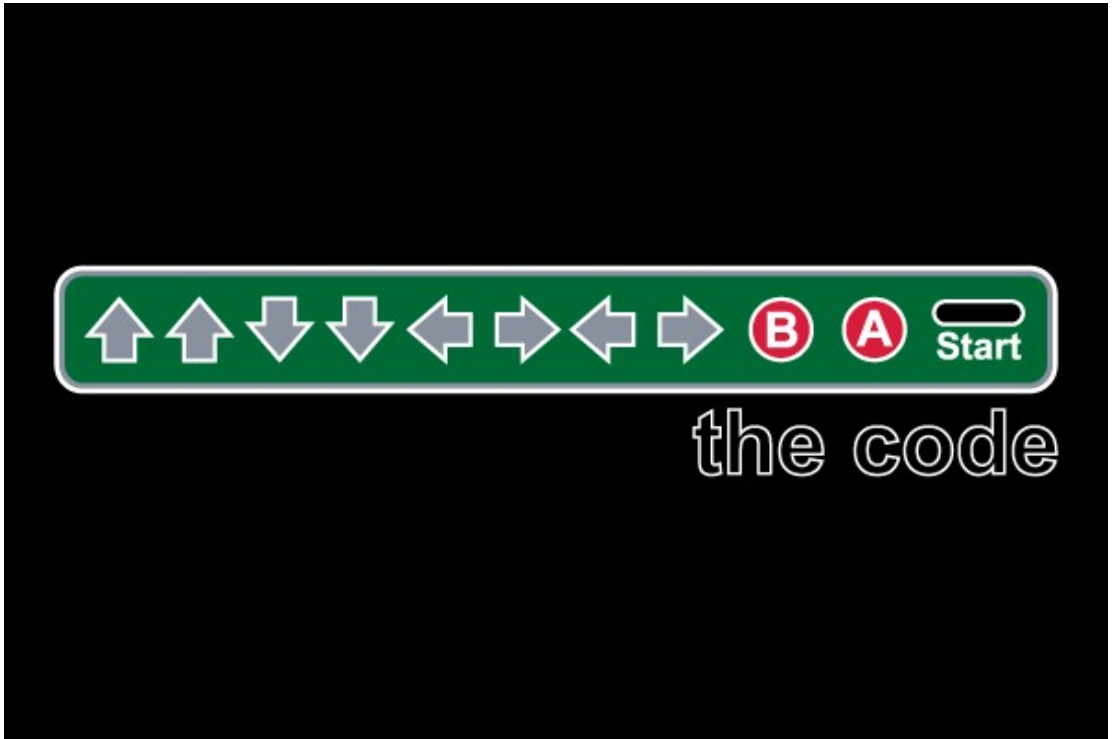
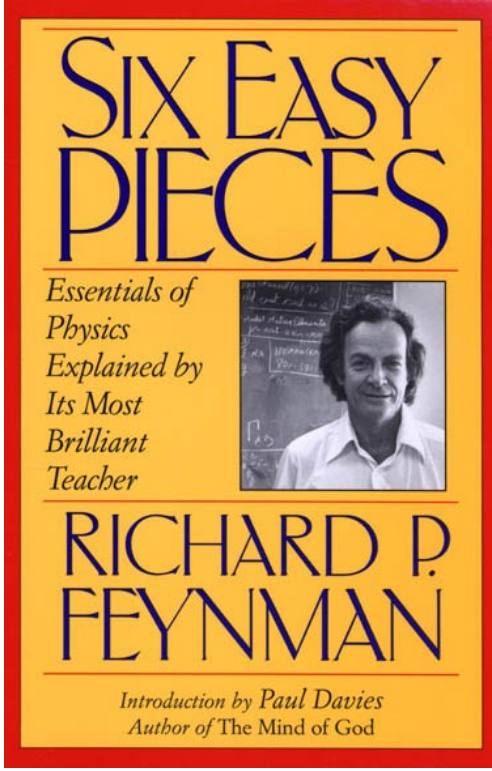
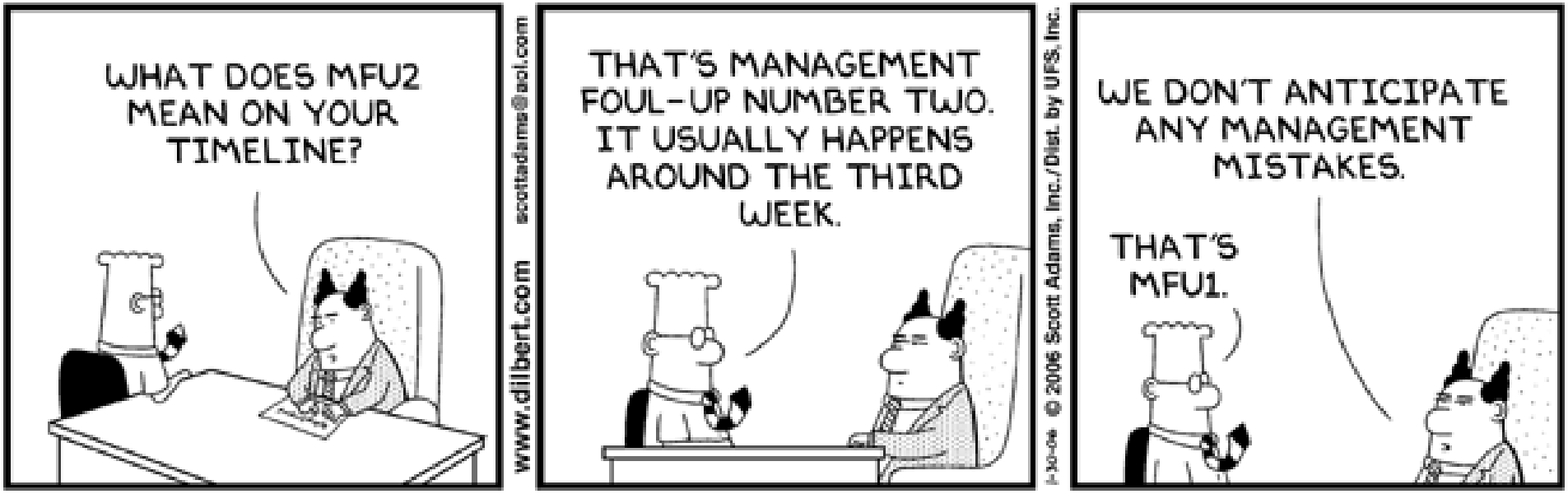


LDI Course Project

- A big project: an Interpreter!
- … in four easy parts
- You may optionally work in pairs.



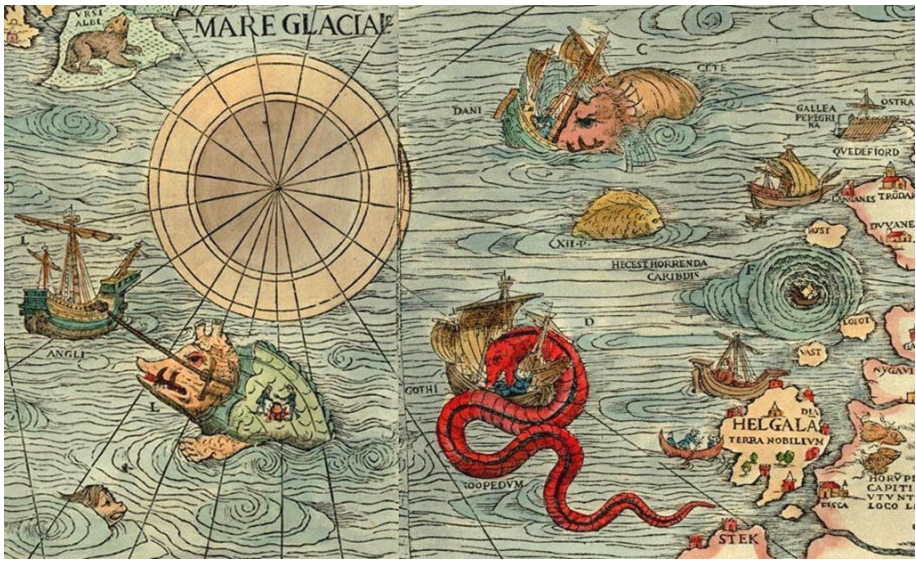


Compilers Practicum Section

- There will be one sixty-minute Compilers Section each week (about 10 sections)
  - Hosted by Kevin Leach
- When do those meet?
  - Vote for times that everyone can make
  - Notes posted on web.
- Course will only fire if 12+ stay signed up

“Explaining Unicorns”

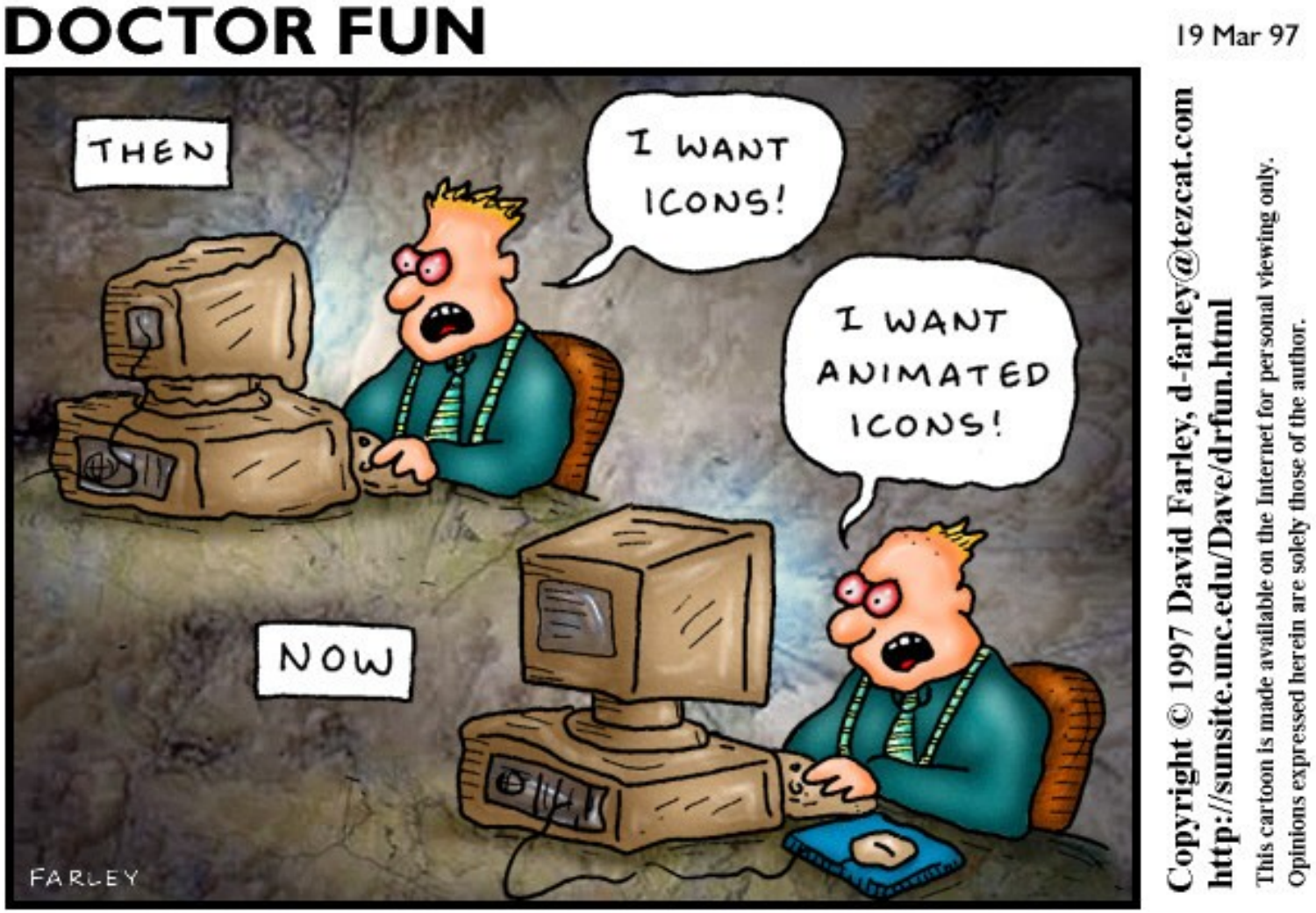
- Visual Studio, JVM, Exceptions, Memory, Debugging, Linking, Shared Libraries, ...



How are Languages Implemented?

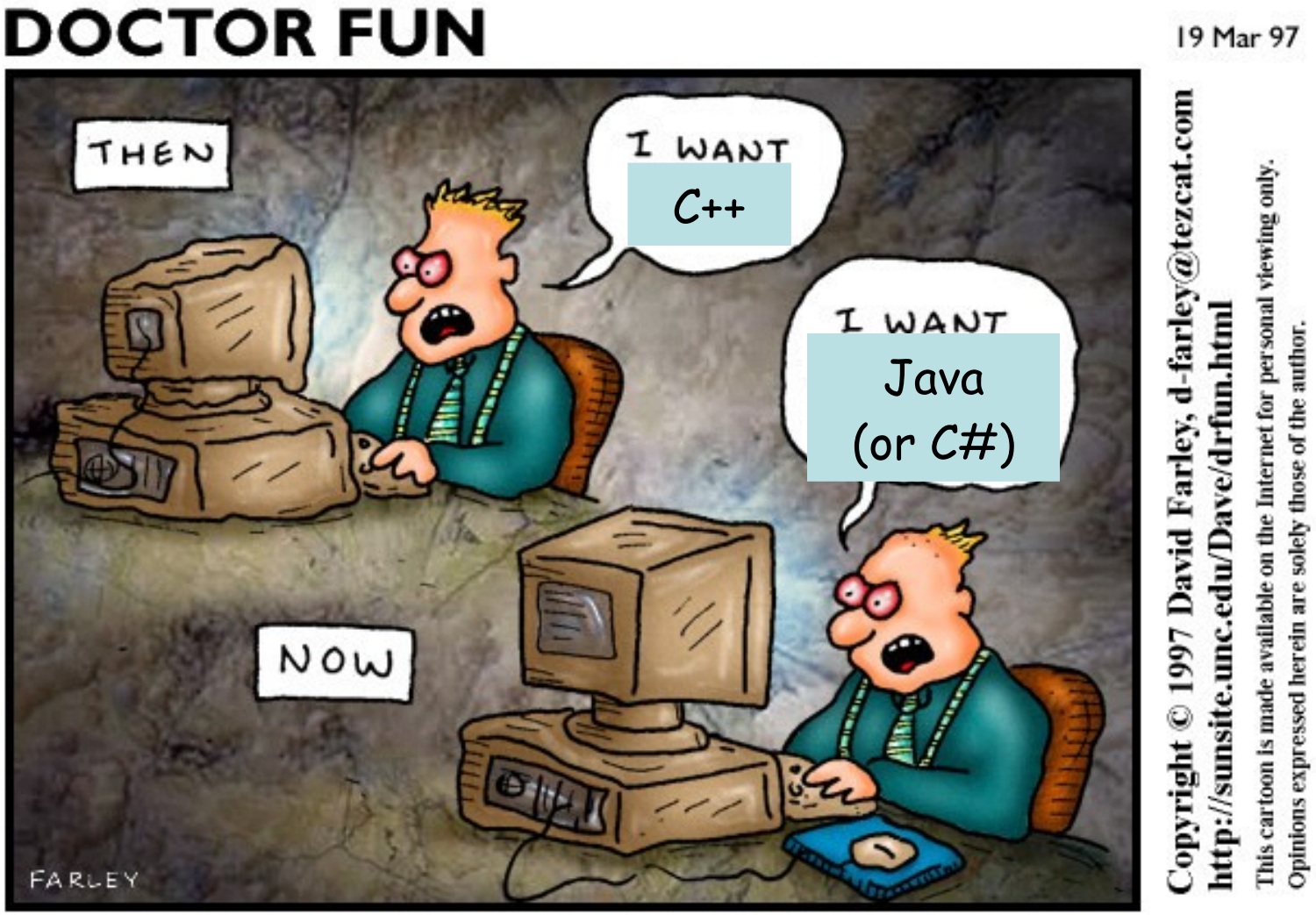
- Two major strategies:
  - Interpreters (take source code and run it)
  - Compilers (translate source code, run result)
  - Distinctions blurring (e.g., just-in-time compiler)
- Interpreters run programs “as is”
  - Little or no preprocessing
- Compilers do extensive preprocessing
  - Most implementations use compilers

Don’t We Already Have Compilers?



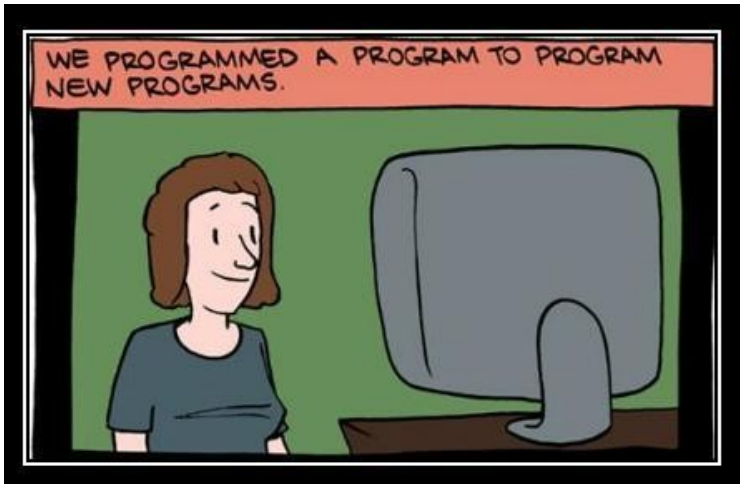
Progress

Dismal View Of Prog Languages

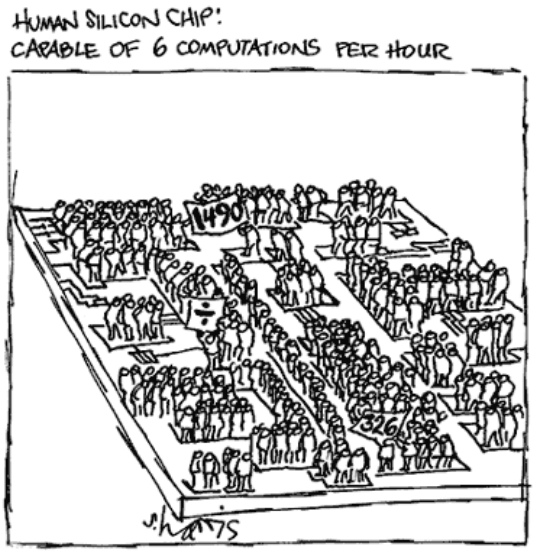


(Short) History of High-Level Languages

- 1953 IBM develops the 701 “Defense Calculator”
  - 1952, US formally ends occupation of Japan
  - 1954, Brown v. Board of Education of Topeka, Kansas
- **All programming done in assembly**
- **Problem: Software costs exceeded hardware costs!**
- John Backus: “Speedcoding”
  - An interpreter
  - Ran 10-20 times slower than hand-written assembly



FORTRAN I



- 1954 IBM develops the 704
- John Backus
  - Idea: translate high-level code to assembly
  - Many thought this impossible

- 1954-7 FORTRAN I project
- By 1958, >50% of all software is in FORTRAN
- Cut development time dramatically
  - (2 weeks → 2 hours)

FORTRAN I

- The first **compiler**
  - Produced code almost as good as hand-written
  - Huge impact on computer science
- Led to an enormous body of theoretical work
- Modern compilers keep the outlines of FORTRAN I

Real-World Languages

- This Indo-European language is associated with South Asian Muslims and is the lingua franca of Pakistan. It developed from Persian, Arabic and Turkic influences over about 900 years. Poetry in this language is particularly famed, and is a reported favorite of US President Barack Obama.
- Example: السلام عليكم

Interpreters	Compilers
Lexical Analysis	Lexical Analysis
Parsing	Parsing
Semantic Analysis	Semantic Analysis
Optimization (optional)	Optimization (optional)
Interpret The Program	Generate Machine Code
	Run that Machine Code

The first 3, at least, can be understood by analogy to how humans comprehend English.

Lexical Analysis

- First step: recognize words.
  - Smallest unit above letters

This is a sentence.

- Note the
  - Capital "T" (start of sentence symbol)
  - Blank " " (word separator)
  - Period "." (end of sentence symbol)

More Lexical Analysis

- Lexical analysis is not trivial. Consider:

  How d'you break "this" up?

- Plus, programming languages are typically more cryptic than English:

  ***p->f += -.12345e-6**

And More Lexical Analysis

- Lexical analyzer divides program text into "words" or tokens

if x == y then z = 1; else z = 2;

- Broken up:

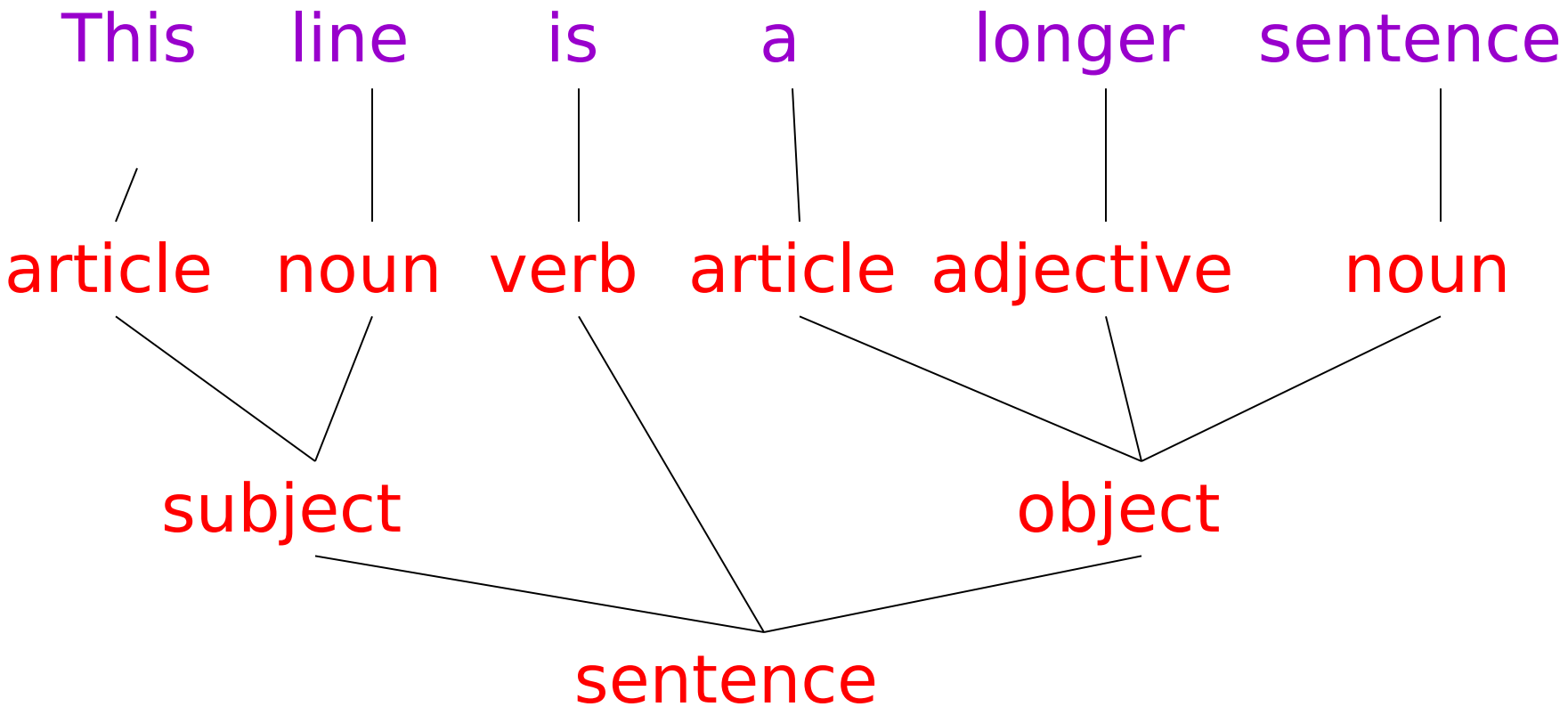
if, x, ==, y, then, z, =, 1, ;, else, z, =, 2, ;

Parsing

- Once words are understood, the next step is to understand sentence structure

- Parsing = Diagramming Sentences
  - The diagram is a tree
  - Often annotated with additional information

Diagramming a Sentence

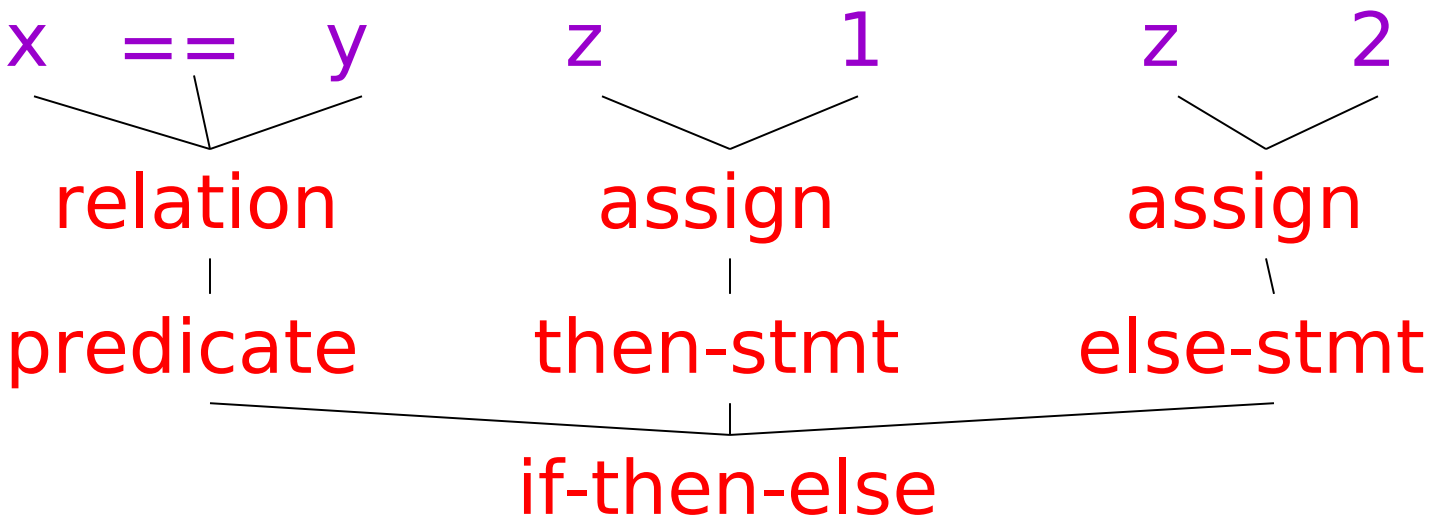


Parsing Programs

- Parsing program expressions is the same
- Consider:

  if x == y then z = 1; else z = 2;

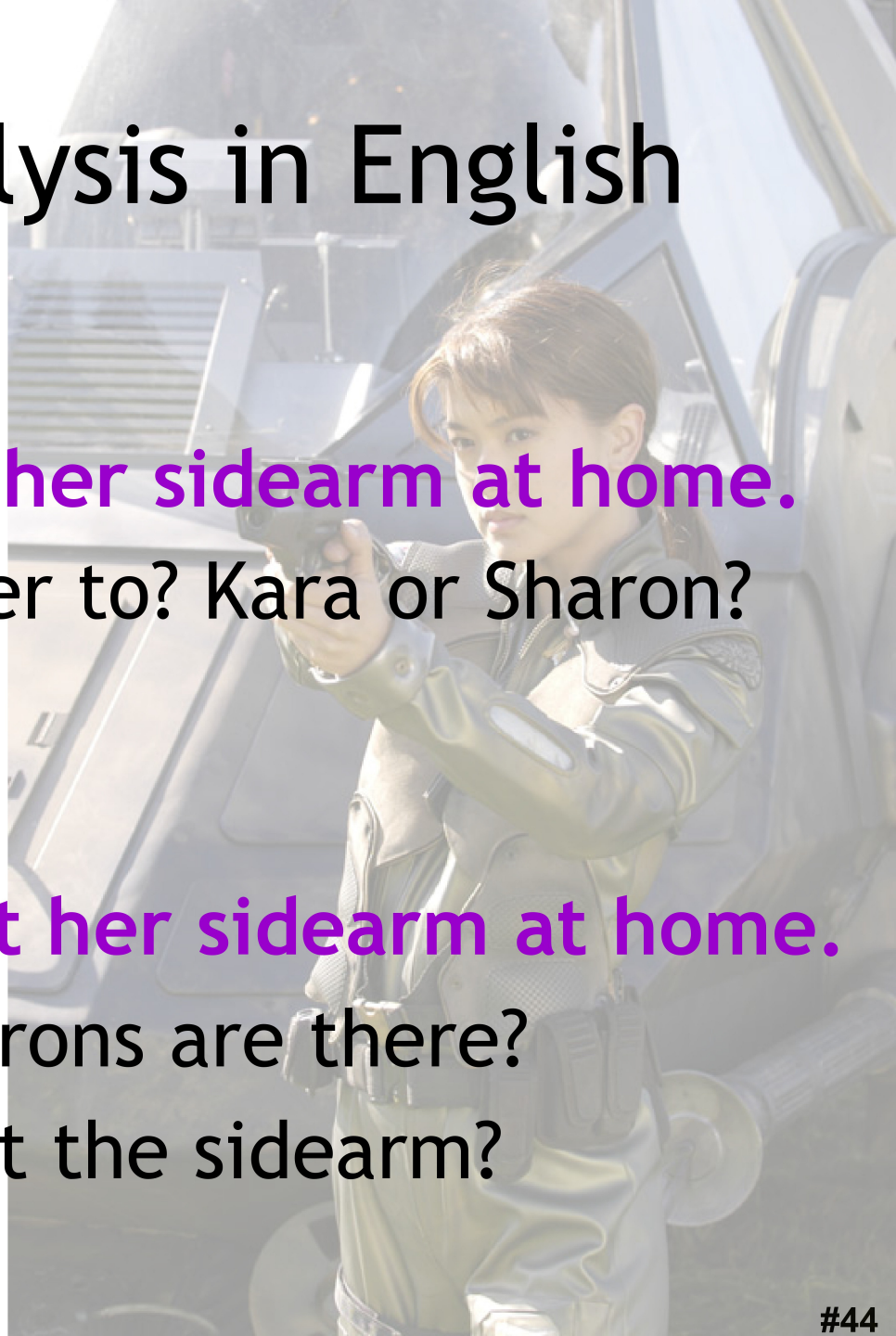
- Diagrammed:



Semantic Analysis

- Once sentence structure is understood, we can try to understand "meaning"
  - But meaning is too hard for compilers
- Compilers perform limited analysis to catch inconsistencies: reject bad programs early!
- Some do more analysis to improve the performance of the program

Semantic Analysis in English



- Example:

Kara said Sharon left her sidearm at home.

What does “her” refer to? Kara or Sharon?

- Even worse:

Sharon said Sharon left her sidearm at home.

How many Sharons are there?

Which one left the sidearm?

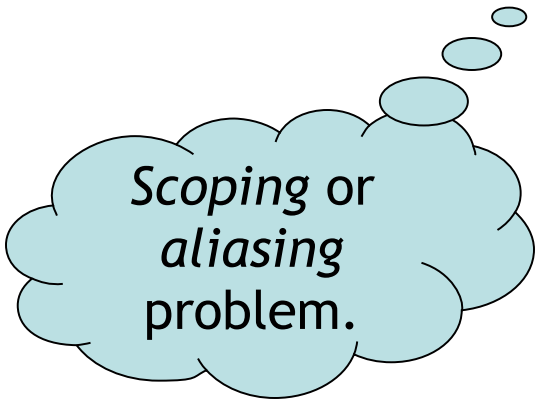
It's context-sensitive!

Semantic Analysis in Programming

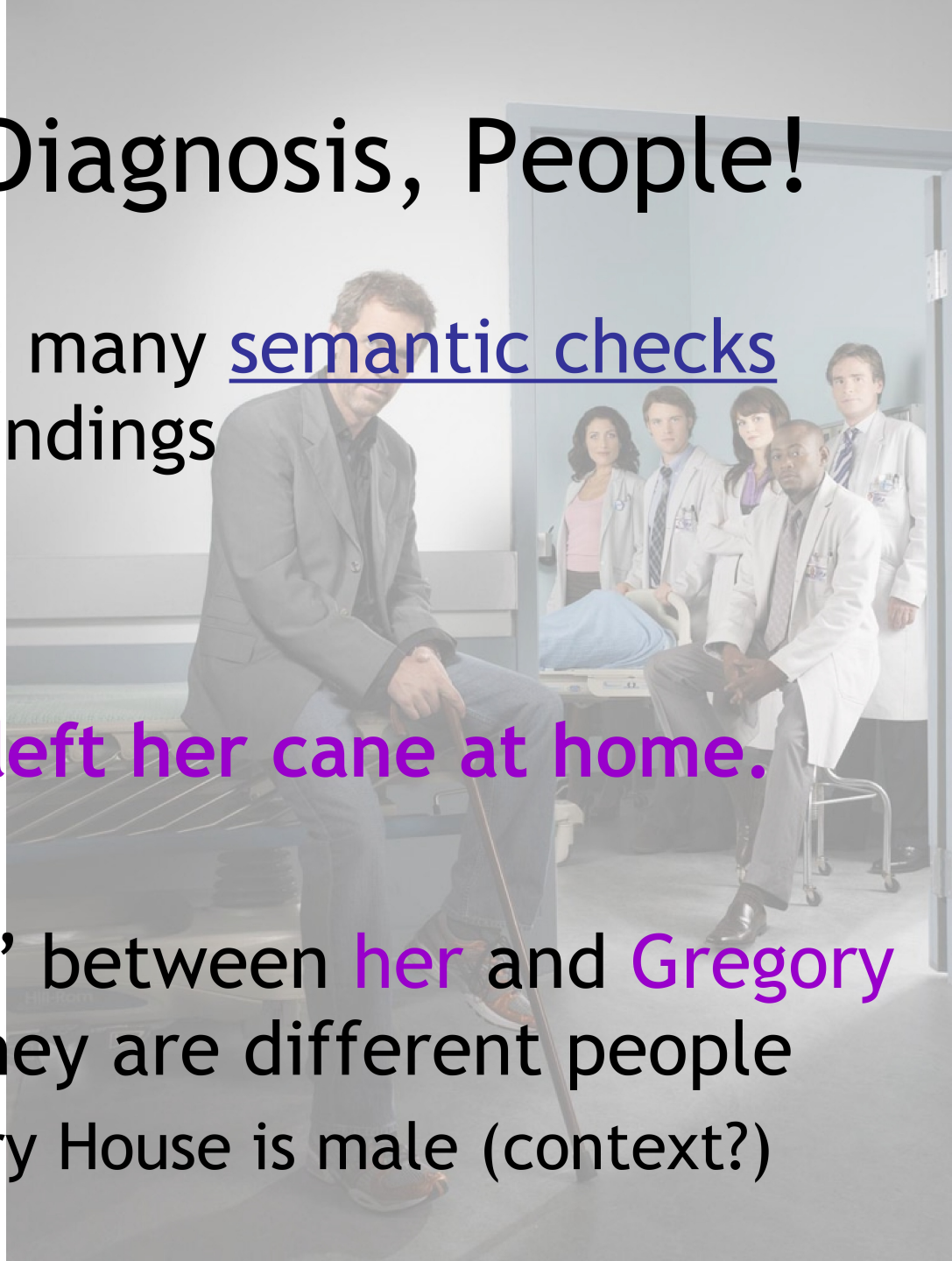
- Programming languages define strict rules to avoid such ambiguities

- This C++ code prints "4"; the inner definition is used

```
{
  int Sydney = 3;
  {
    int Sydney = 4;
    cout << Sydney;
  }
}
```



Differential Diagnosis, People!



- Compilers perform many semantic checks besides variable bindings

- Example:

  Gregory House left her cane at home.

- A "type mismatch" between her and Gregory House; we think they are different people
  - Presumably Gregory House is male (context?)

Optimization

- No strong counterpart in English, but akin to editing (cf. poems, short stories)

- Automatically modify programs so that they
  - Run faster
  - Use less memory
  - In general, conserve some resource

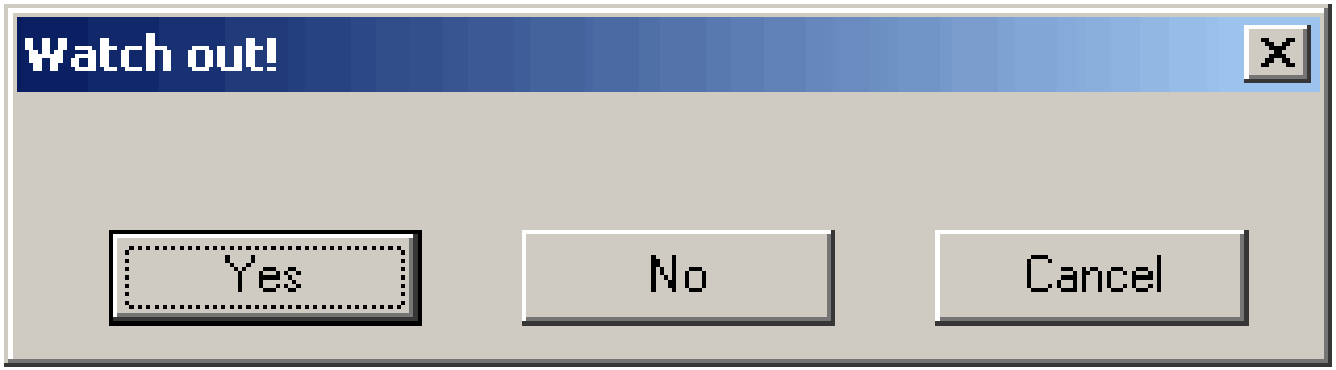
- “Compilers” studies Optimizations in depth

Code Generation

- Produces assembly code (usually)
  - which is then assembled into executables by an assembler
- A translation into another language
  - Analogous to human translation
- “Compilers”: produce machine code
  - Either “Java Bytecode” or x86-64 assembly

Issues

- Compiling and interpreting are almost this simple, but there are many pitfalls.
- Example: How are bad programs handled?
- Language design has big impact on compiler
  - Determines what is easy and hard to compile
  - Course theme: **trade-offs in language design**



Languages Today

- The overall structure of almost every compiler & interpreter follows our outline

- The proportions have changed since FORTRAN
  - Early: lexing, parsing most complex, expensive
  - Today: optimization dominates all other phases, lexing and parsing are cheap
  - Thus: this course puts no emphasis on ancient parsing optimizations (e.g., LL, LALR)

Trends in Languages

- Optimization for speed is less interesting. But:
  - scientific programs
  - advanced processors (Digital Signal Processors, advanced speculative architectures)
  - small devices where speed = longer battery life
- Ideas we'll discuss are used for improving code reliability:
  - memory safety
  - detecting concurrency errors (data races)
  - type safety
  - automatic memory management
  - …

Why Study Prog. Languages?

- Prepare for many good jobs
- Increase capacity of expression
- Improve understanding of program behavior
  - Know how things work "under the hood"
- Increase ability to learn new languages
- Learn to build a large and reliable system
- See many basic CS concepts at work
- Computers are the only tools that increase cognitive power, so learn to control them

What Will You Do In This Class?

- Reading (textbook, videos, outside sources)
- Learn about different kinds of languages
  - Imperative vs. Functional vs. Object-Oriented
  - Static typing vs. Dynamic typing
  - etc.
- Gain exposure to new languages (ML, Cool)

- Write an interpreter!

What Is This?

A lungo il mio cuore di tali ricordi ha voluto colmarsi!

Come un vaso in cui le rose sono state dissetate:

Puoi romperlo, puoi distruggere il vaso se lo vuoi,

Ma il porfumo delle rose sarà sempre tutt'intorno.

Długo, długo moje serce przepełnione było takimi wspomnieniami!

Były jak waza, w której kiedyś róże destylowały:

Możesz sprawić by pekła, możesz gruchotać waze jeśli chcesz,

Ale zapach róż bedzie wciaż czuć dookoła.

Mon coeur est brûlant rempli de tels souvenirs

Comme un vase dans lequel des roses ont été distillées:

Tu peux le briser, tu peux détruire le vase si tu le désires,

Mais la senteur des roses sera toujours là.

Lang, lang soll die Erinnerung in meinem Herzen klingen!

Gleich einer Vase, drin Rosen sich einst tränkten:

Lass sie zerbrechen, lass sie zerspringen,

Der Duft der Rose bleibt immer hängen.

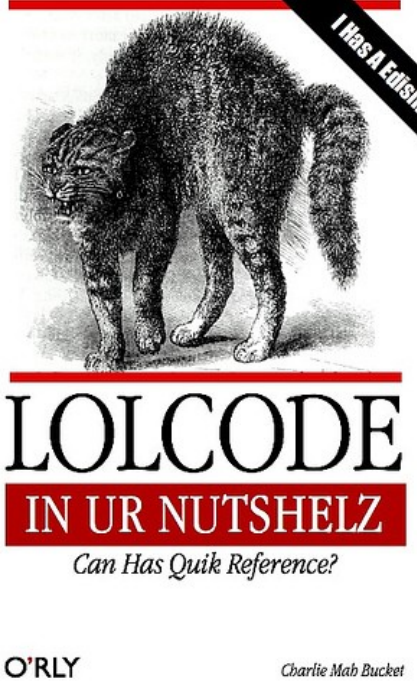
Muito, muito tempo seja meu coração preenchido com tais lembranças!

Tal qual o vaso onde rosas foram uma vez destiladas:

Pode quebrar, pode estilhaçar o vaso se o desejas,

Mas perdurará para sempre o aroma das rosas perfumadas.

The Rosetta Stone

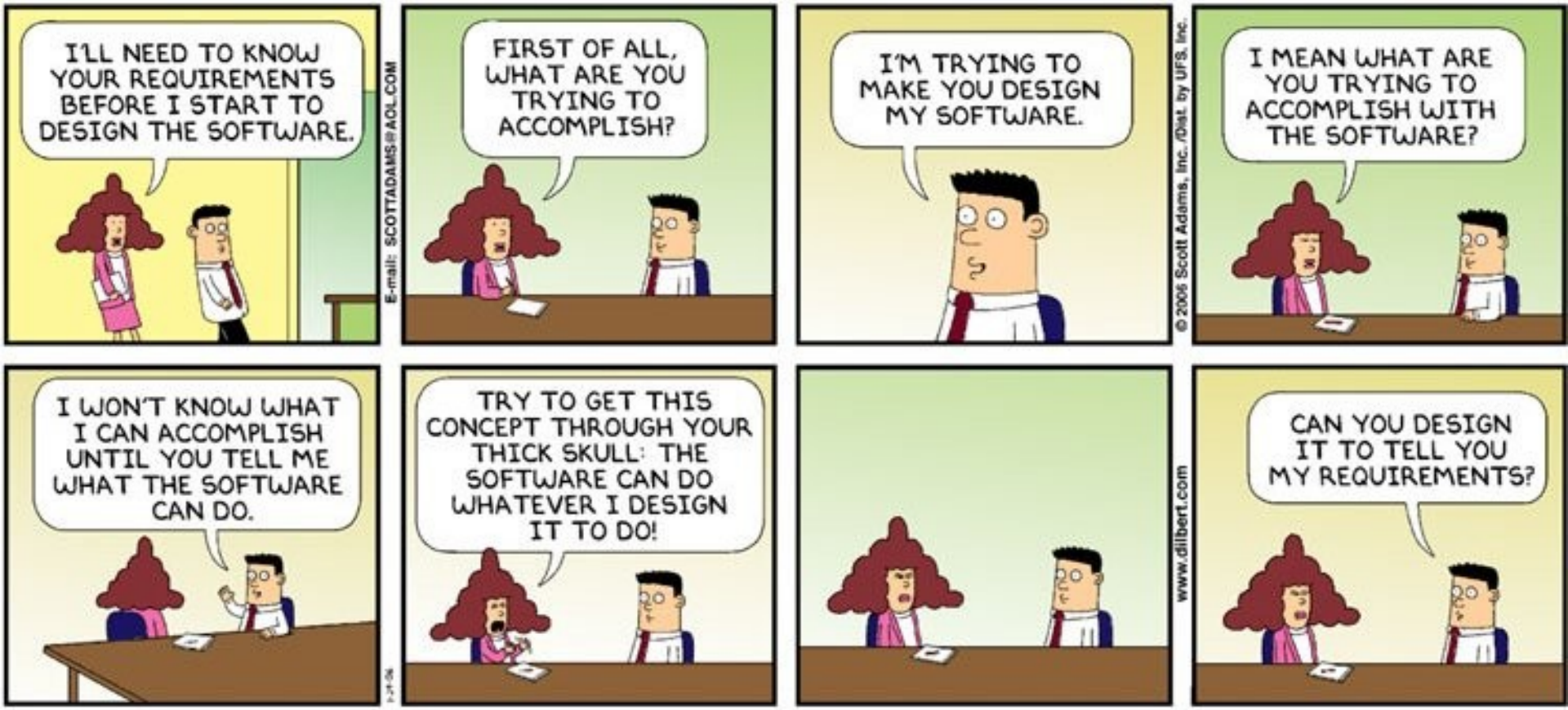


- The first programming assignment involves writing the same simple (50-75 line) program in two languages:
  - **Ocaml and Cool (with Ruby, Python, JavaScript, Haskell and C as Extra Credit)**
- PA1c, **due Thu Jan 28**, requires you to write the program in one language
- PA1, due subsequent Tue, requires both

Long, long be my heart with such memories fill'd!
Like the vase in which roses have once been distill'd:
You may break, you may shatter the vase if you will,
But the scent of the roses will hang round it still.
- Thomas Moore (Irish poet, 1779-1852)

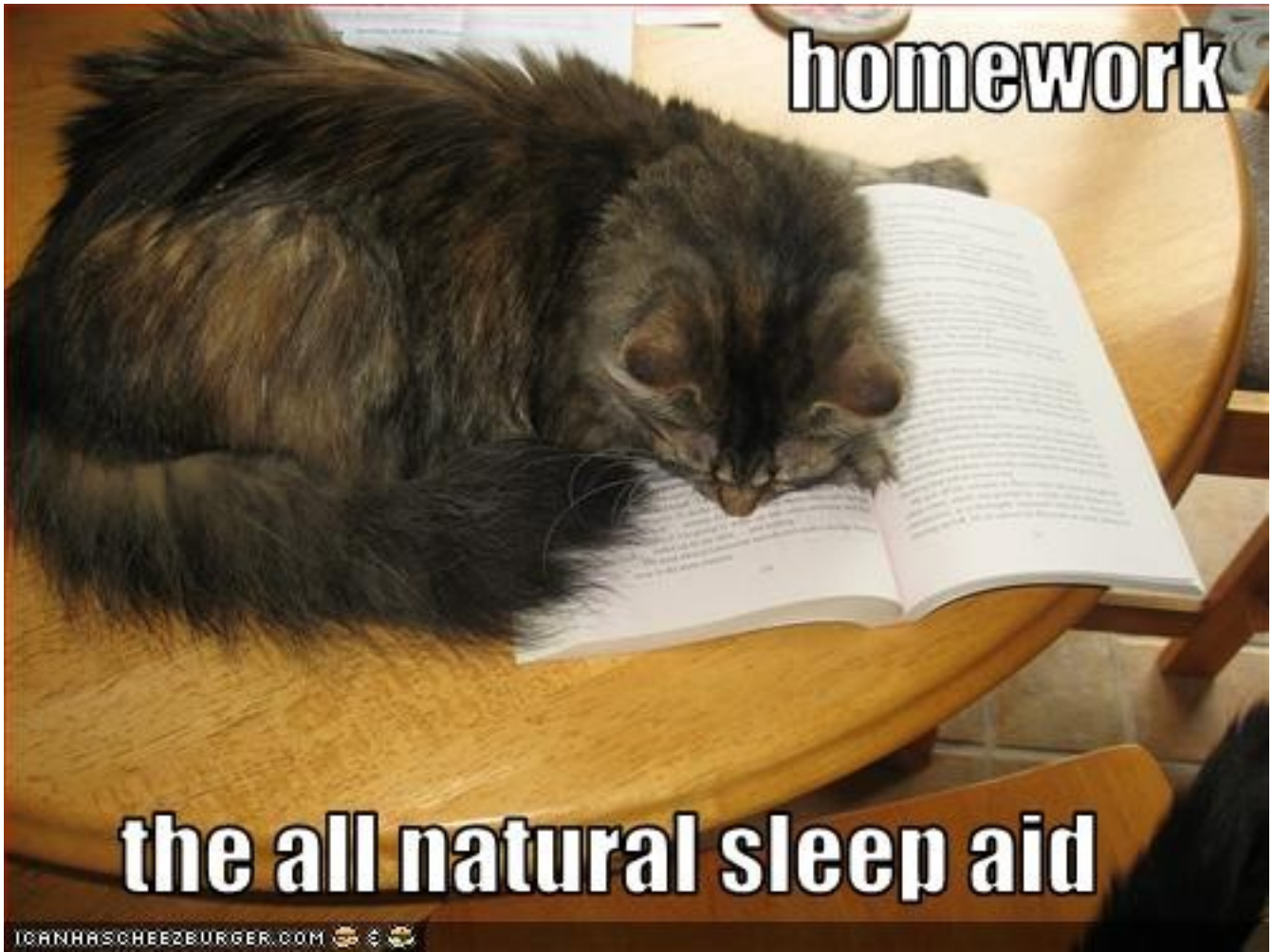
Live Submission Demo

- Let's visit the automated submission website



Start The Homework Now

- We can help you!



2-Credit “Sidecar” Course: Compilers Practicum

- The final project for the Compilers Practicum is a working **optimizing compiler** (code generator) that produces either bytecode or x86-64 assembly.
- At the end of this course, you will be acquainted with the fundamental concepts in code generation and optimization. In particular, you will understand the **theory** and **practice** of **code generation**, **stack layouts**, **calling conventions**, **dynamic dispatch**, **control flow graphs**, and **dataflow analyses**.

Compilers Practicum Section

- There will be one sixty-minute Compilers Section each week (about 10 sections)
  - Hosted by Kevin Leach
- When do those meet?
  - *Vote today* for times that everyone can make
  - Notes posted on web
- Course will fire if 12+ stay signed up

Homework

- Scott Book reading (for Tuesday)
- Get started on PA1c (due in 7 days)

Questions?