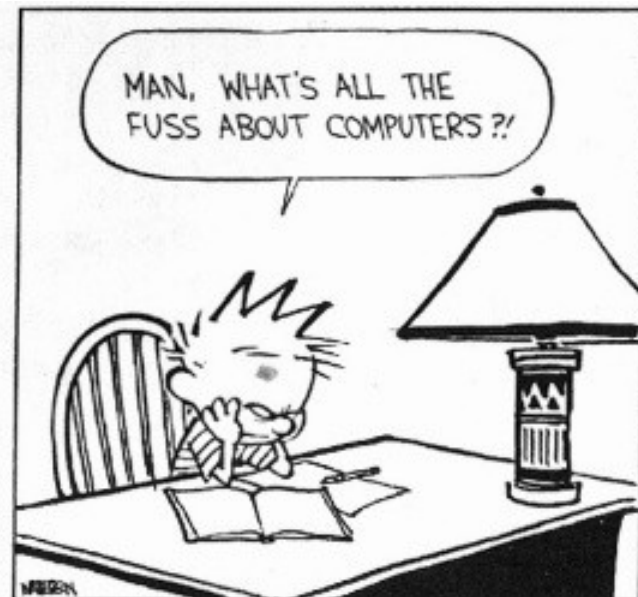
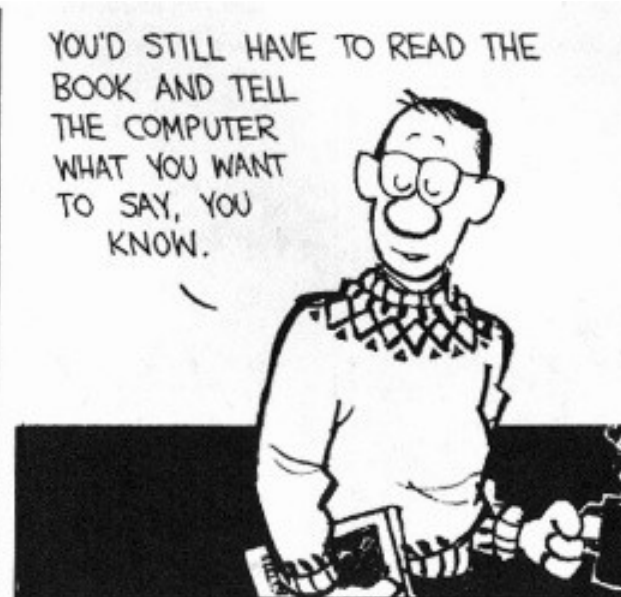
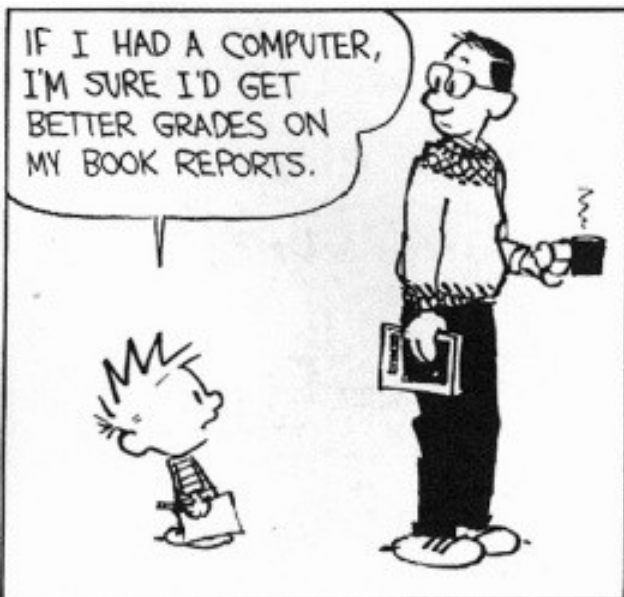


Programming Language Design and Implementation

Wes Weimer

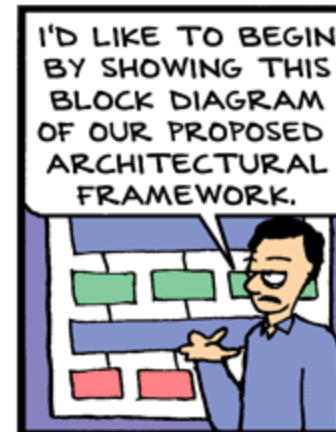
MW 2:00 - 3:15

Thornton E-303



Cunning Plan

- Who Are We?
 - Wes, Kevin Leach, undergrad TAs
- Administrivia
- What Is This Class About?
- Brief History Lesson
- Understanding a Program in Stages



Course Home Page

- google: virginia cs 4610
- <http://www.cs.virginia.edu/~weimer/4610>
- 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

Course Options

- Three options are available:
 - Take *only* CS 4610 (Programming Languages) for 3 credits
 - Take CS 4610 (Programming Languages) for 3 credits *and also* take CS 4501 (Compilers Practicum) for 2 credits
 - Take *neither* (this is actually the best choice)
- CS 4501 Compilers Practicum
 - Must attend CS 4610 PL lectures
 - Has additional lectures, homeworks, tests

Should I Take This Course?

- Beg for more mid-assignment checkpoints. Also, beg that the optional two-credit class only be opened just before the withdrawal deadline so you don't have to decide early on before you understand what you've decided to do to yourself. Finally, beg for mercy. :)
- Professor Weimer is very engaging in his lectures, which kept me awake and interested even through the most boring or difficult sections of the class. **And some of the class material WAS boring. And it was most DEFINITELY difficult.** While the assignments were **VERY** time-consuming and **difficult (sometimes ridiculously so)**, I felt great accomplishment after completing them, and I feel that I may have learned more from this class than any I have ever taken before.

Should I Take This Course?

- Easily the most time-consuming class that I have taken at UVA. There were times that I got very little sleep at all. In addition, the assignments require a deep understanding of the material, in order to do well on them. Nevertheless, I learned a lot from this class.
- On top of this, Professor Weimer is extremely knowledgeable and teaches in such a way that even very difficult concepts become much easier to grasp. This being said, **do not take Programming Languages, because you will put in over 9,000 hours into the class.**
- The hardest class that I've taken at UVA. Although it's worth 5 credits, the extra 2 credits are essentially worthless, since all of the credit requirements are for classes worth 3 credits each.

Should I Take This Course?

- **This course was the hardest course I have taken thus far,** but Professor Weimer made it very enjoyable. **The amount of work at times was a little overwhelming,** but I definitely learned a lot from it. Weimer was one of the best lecturers I have had in the Engineering school and he truly wanted the students to understand the material.
- This was a great course. **A ridiculous amount of work** but that was known information from the first day of the course. The instructor was enthusiastic and taught very well.
- **I don't know what you should do, but this class had ruined my life. I have spent more time on this class than the rest of my classes combined this semester.** However, knowing what I know now I would take this class again!

Should I Take This Course?

- Best professor ever, period! Be aware that by taking this class, your other classes should be: Music, Language, PE, etc... any classes that don't require your brain!!!!!! Because this should be a [***] 300000 credit class! I never go to Office Hours because I thought I was smart. But for Weimer's class don't miss his office hours!!!!
- This course involved far too much work for it to be a worthwhile course. While the professor warns the class of the amount of work he assigns, I do not think that it is right, and it is probably downright deceptive, to allot 3 credits to this course. However, the professor does know how to teach.

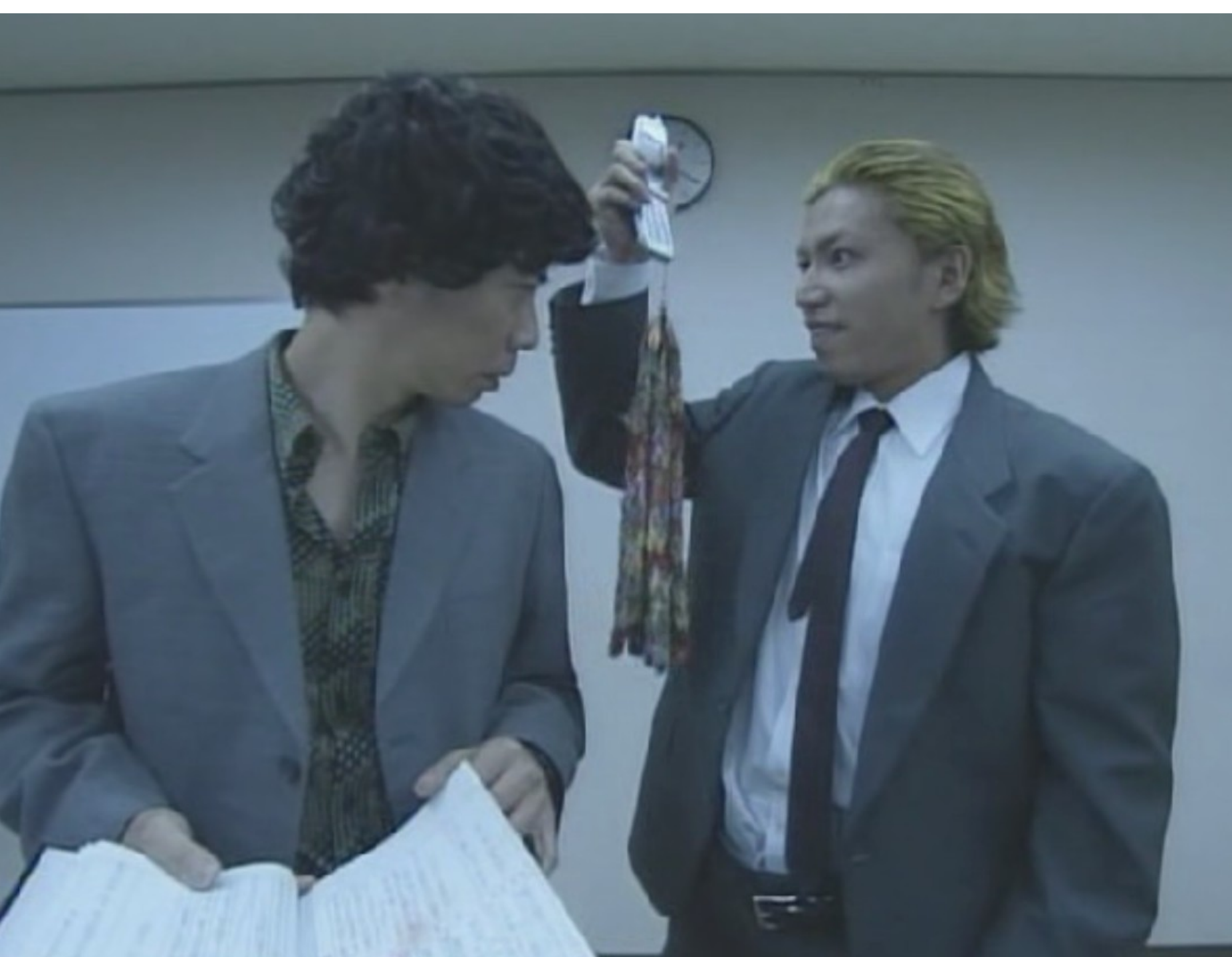
Happiness

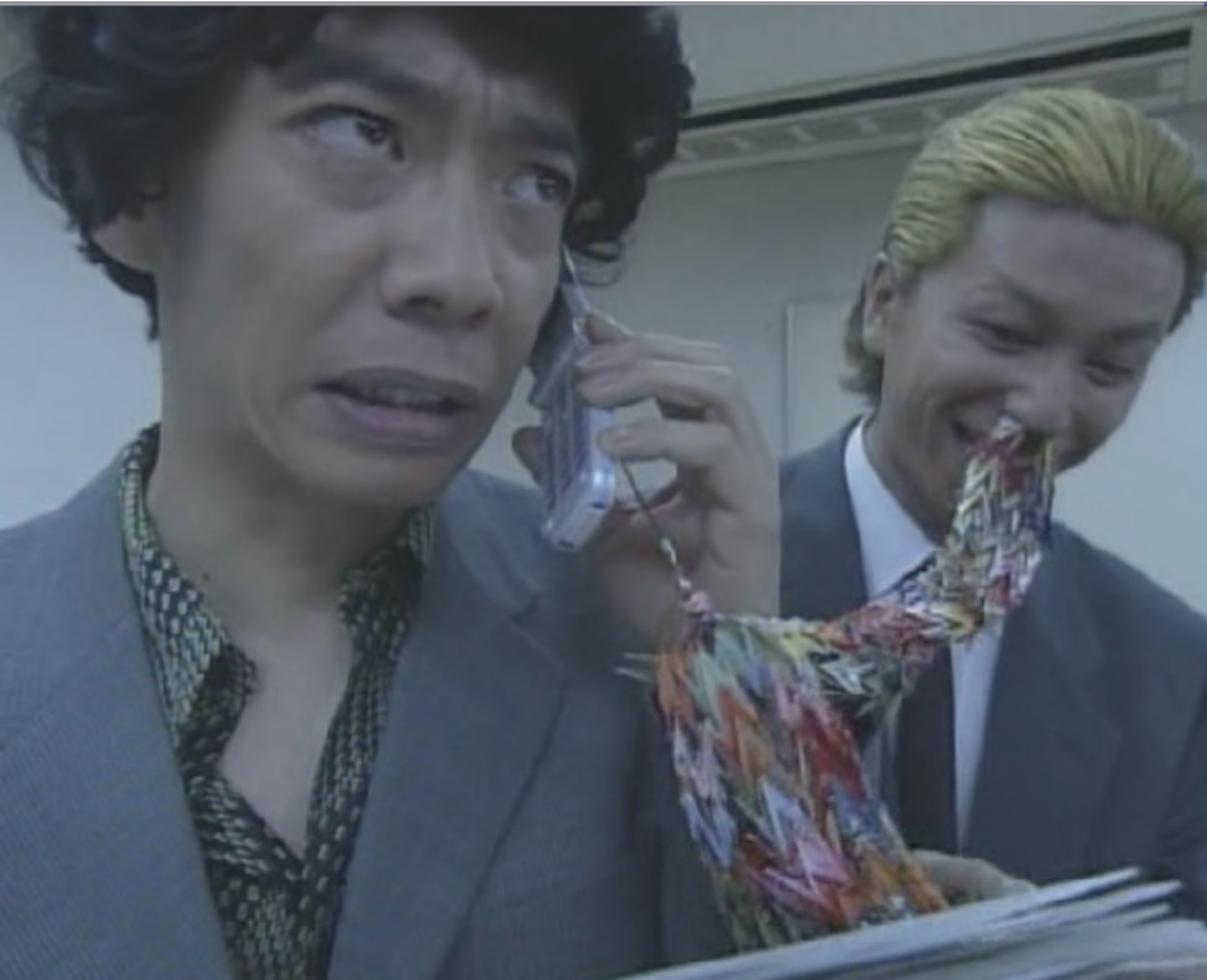
- Unhappiness is related to unrealized desires
 - cf. “Must take this to graduate”, “Must have good grades”, “Must have free time”.
- I have failed students in 4610.
- Currently open:
 - CS 4414 - Operating Systems
 - CS 4501-6 - Computer Vision
 - CS 4810 - Computer Graphics
 - CS 4993 - Independent Study (!) (e.g., survey 20 papers)
 - CS 5503-2 - Big Data and Visual Search
 - (And CS 4750 Databases will open up to a total of 160 students.)



Compilers Practicum Sections

- There will be one sixty-minute Compilers Section each week (about 10 sections)
 - Hosted by Kevin Leach
- When do those meet?
 - The current explicit time is actually a scheduling typo.
 - We *may* be able to vote for times that everyone in Compilers can make
 - If you cannot make the Section, you must drop Compilers. Sorry.
 - Notes posted on web.



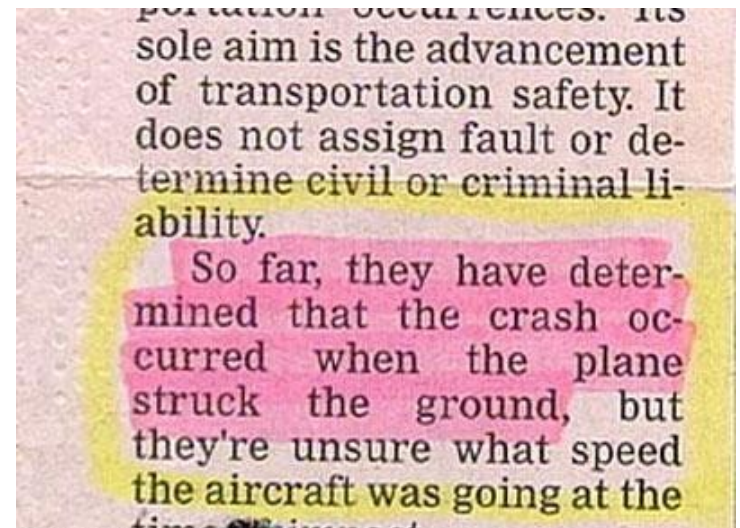
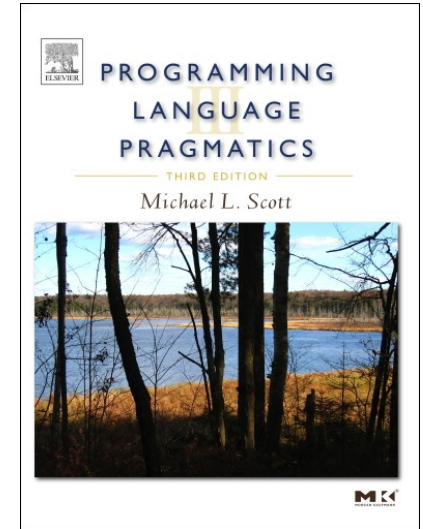


Course Structure

- Course has **theoretical** and **practical** aspects
 - Best of both worlds!
- Need both in programming languages!
- **Reading = both**
 - Many external and optional readings
- **Written assignments = theory**
 - Class hand-in, right before lecture, 0-5 points
- **Programming assignments = practice**
 - Electronic hand-in
- **Strict deadlines**
 - Ask me why ...

Resources

- Textbook
 - Programming Language Pragmatics
 - Michael L. Scott, third edition
- Free Online Materials
 - Udacity CS 262 (same instructor)
- Optional Readings



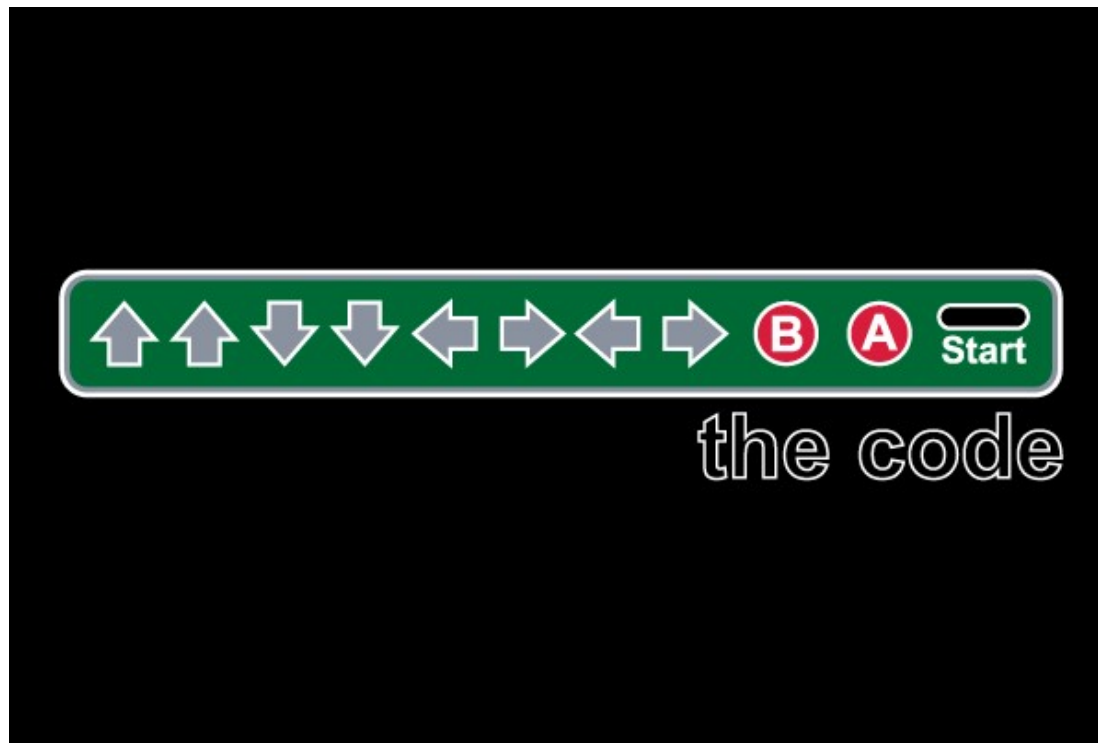
Academic Honesty

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



Academic Honesty

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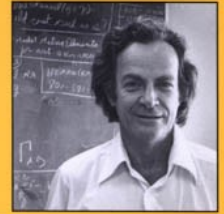


PL Course Project

- A big project: an Interpreter!
- ... in four easy parts
- Start early!

SIX EASY PIECES

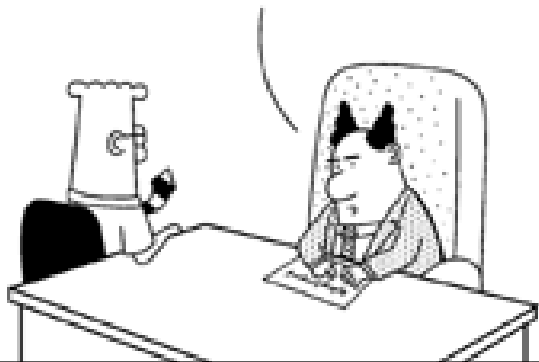
*Essentials of
Physics
Explained by
Its Most
Brilliant
Teacher*



**RICHARD P.
FEYNMAN**

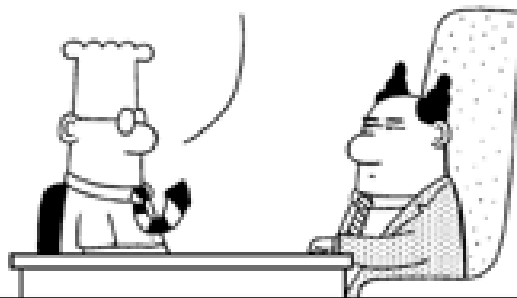
*Introduction by Paul Davies
Author of The Mind of God*

WHAT DOES MFU2
MEAN ON YOUR
TIMELINE?



www.dilbert.com
scottadams@aol.com

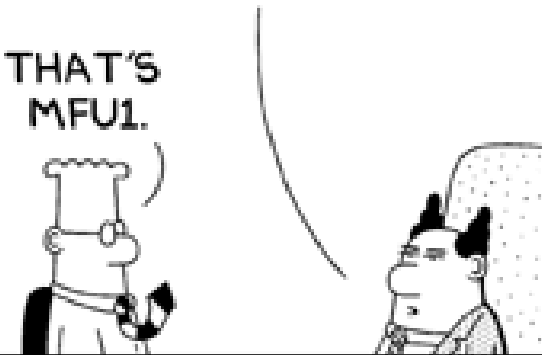
THAT'S MANAGEMENT
FOUL-UP NUMBER TWO.
IT USUALLY HAPPENS
AROUND THE THIRD
WEEK.



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WE DON'T ANTICIPATE
ANY MANAGEMENT
MISTAKES.

THAT'S
MFU1.



PL 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 multiple **different languages**.

Compilers Project & Course Goals

- 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.**

“Killing Unicorns”

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



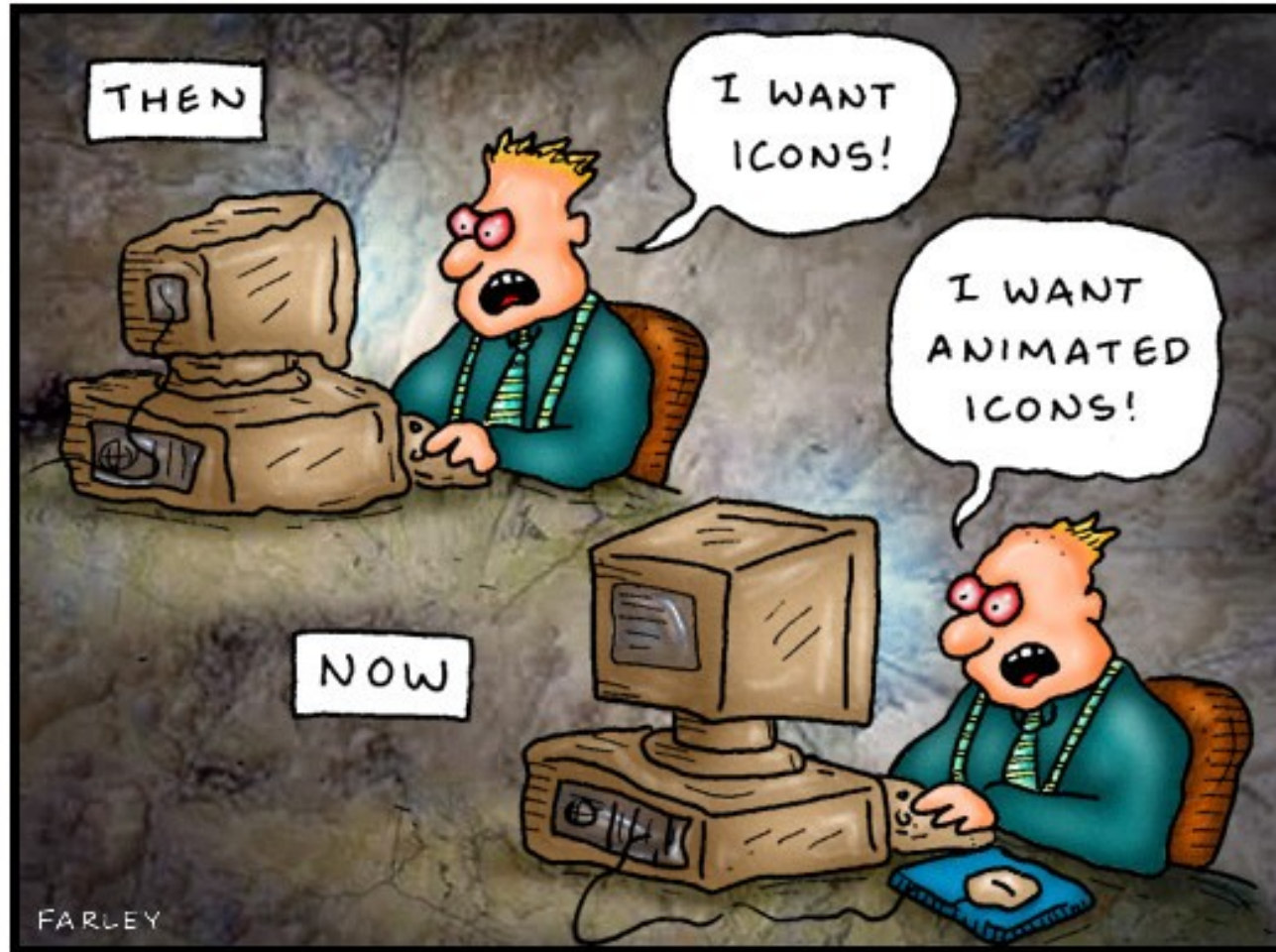
How are Languages Implemented?

- 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?

DOCTOR FUN

19 Mar 97



Copyright © 1997 David Farley, d-farley@tezcat.com
<http://sunsite.unc.edu/Dave/drfun.html>

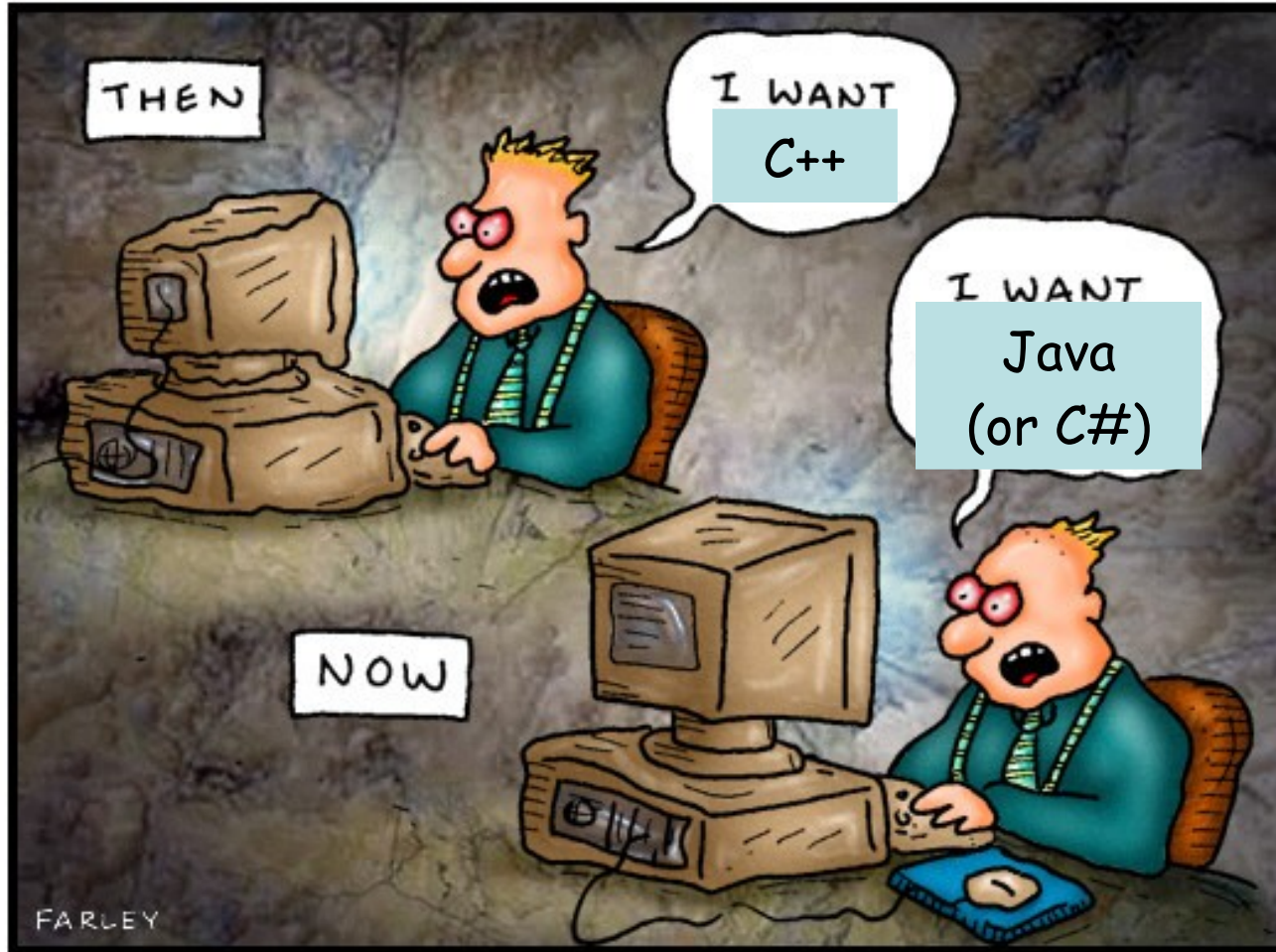
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Opinions expressed herein are solely those of the author.

Progress

Dismal View Of Prog Languages

DOCTOR FUN

19 Mar 97



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<http://sunsite.unc.edu/Dave/drfun.html>

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Progress

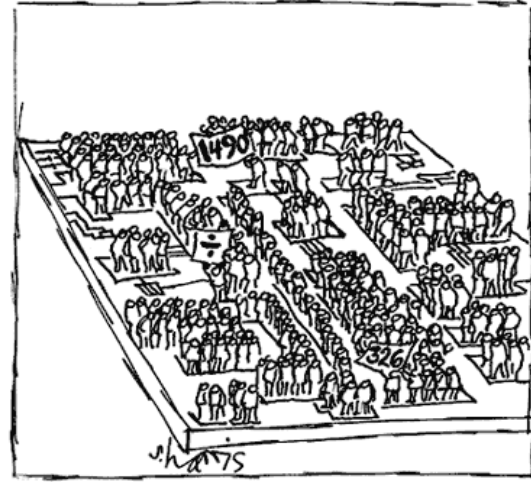
(Short) History of High-Level Languages

- 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

HUMAN SILICON CHIP:
CAPABLE OF 6 COMPUTATIONS PER HOUR



- 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

Lexical Analysis

Parsing

Semantic Analysis

Optimization (optional)

Interpret The Program

Compilers

Lexical Analysis

Parsing

Semantic Analysis

Optimization (optional)

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
- Blank
- Period

“T” (start of sentence symbol)

“ ” (word separator)

“.” (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:

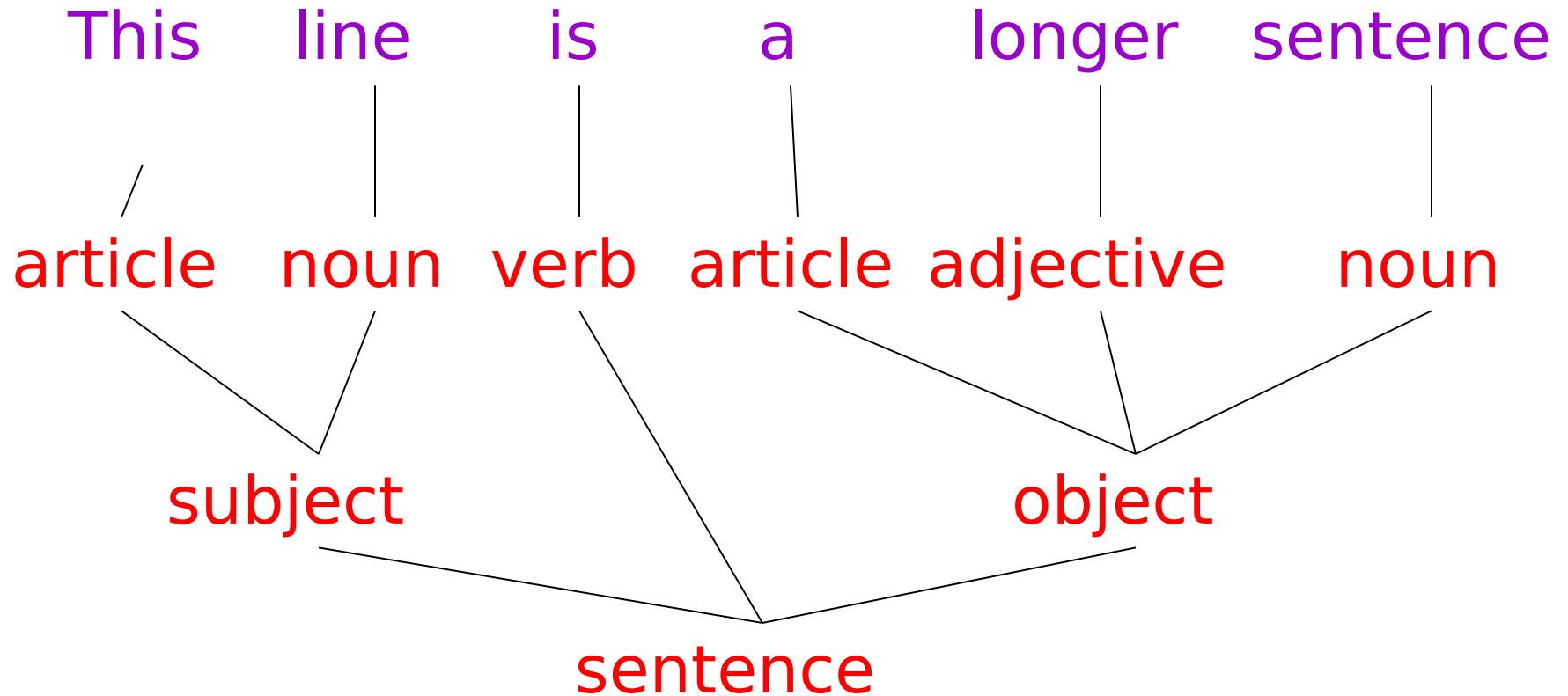
if, x, ==, y, then, z, =, 1, ;, else, z, =, 2, ;

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

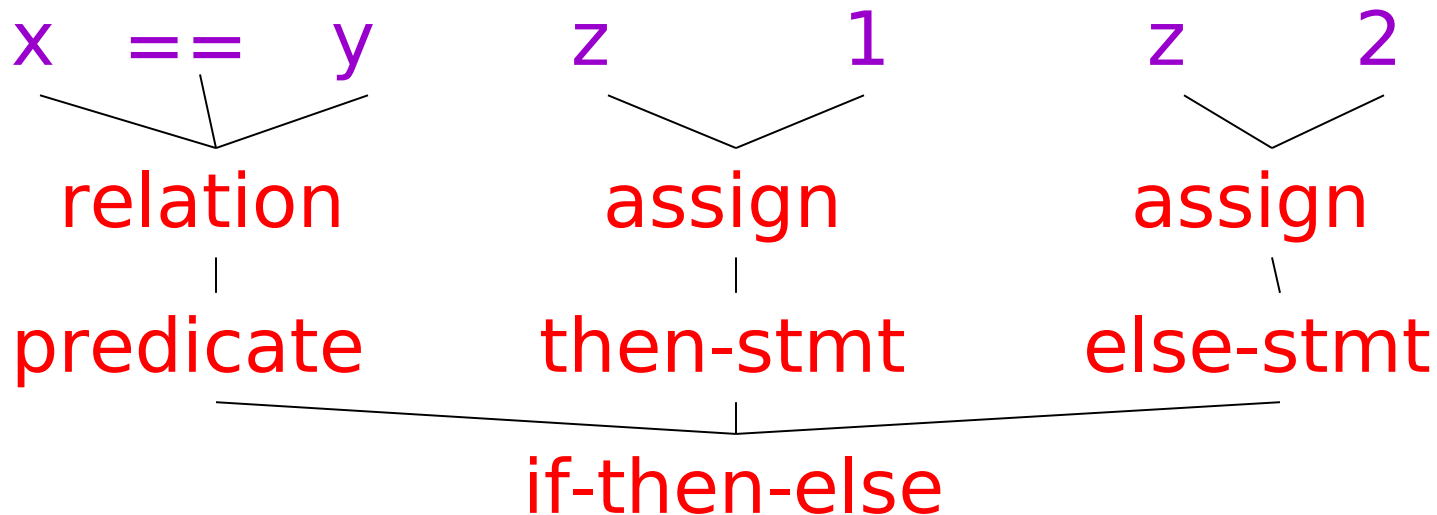


Parsing Programs

- 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?

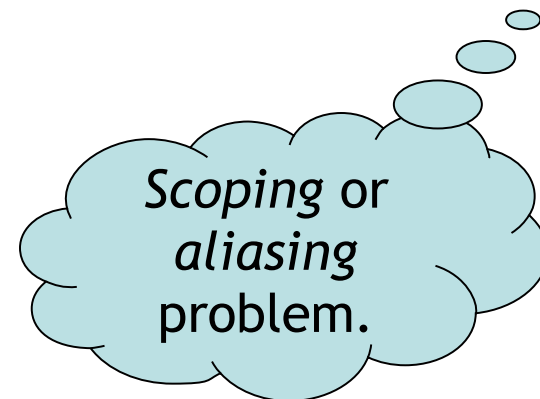
Which one left the sidearm?

It's
context-
sensitive!

Semantic Analysis in Programming

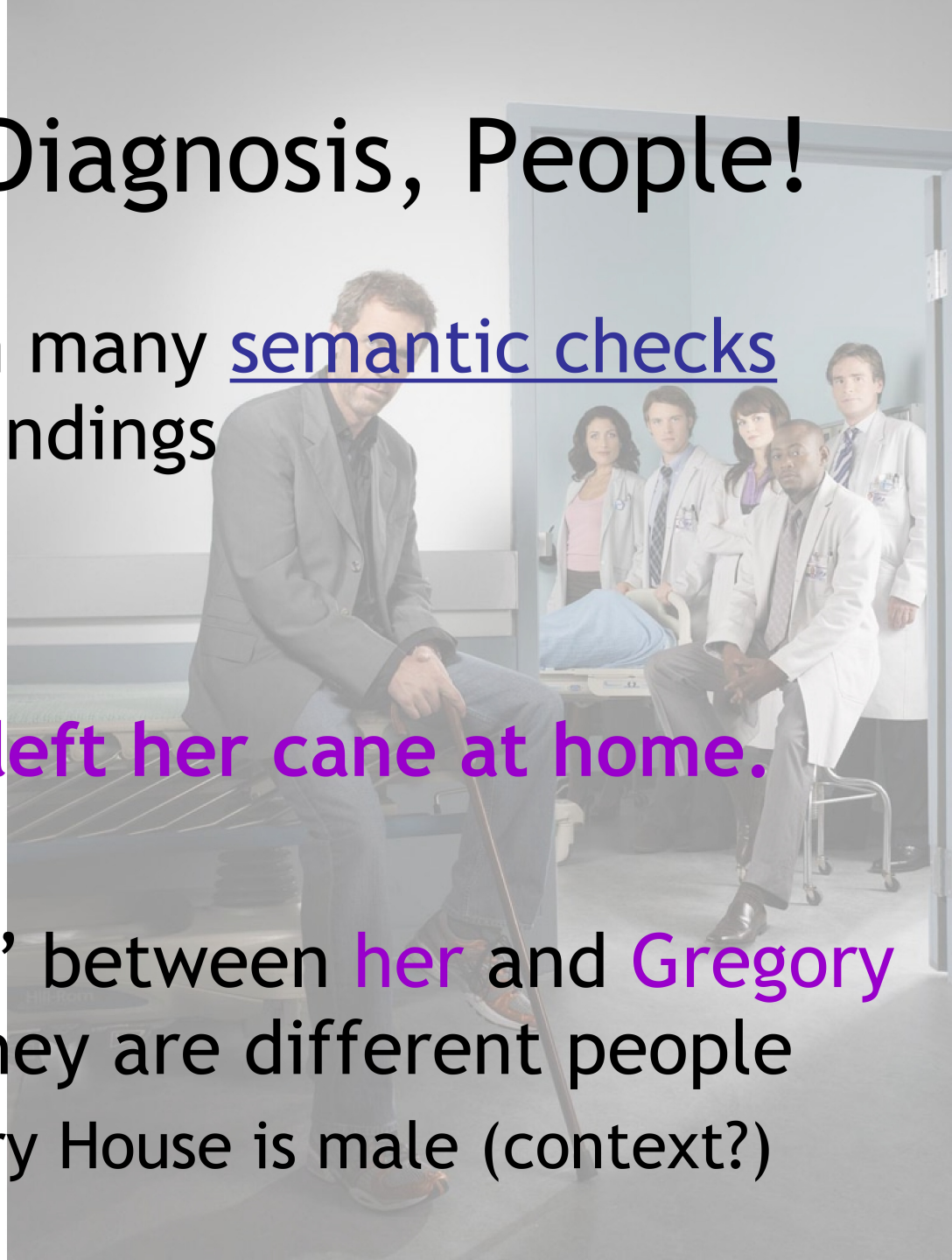
- Programming languages define strict rules to avoid such ambiguities
- This C++ code prints “4”; the inner definition is used

```
{  
  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

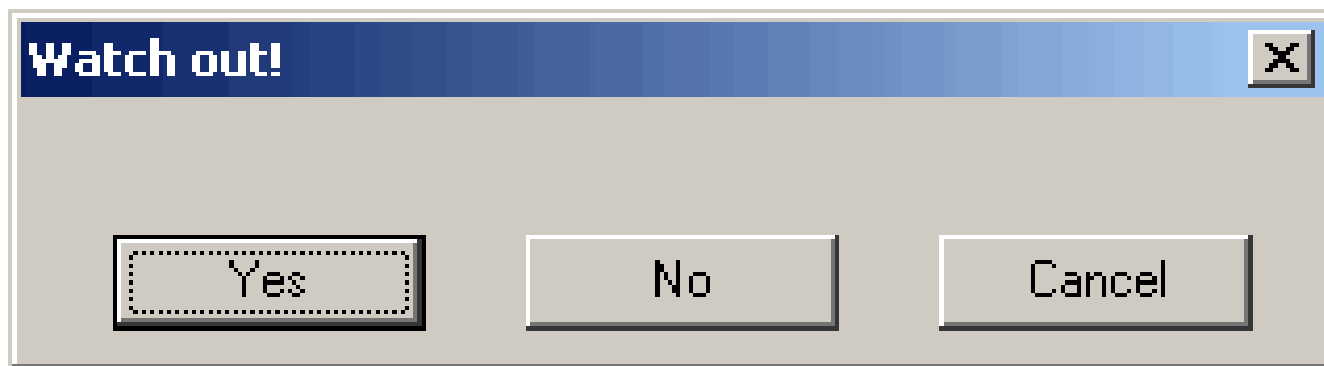
- No strong counterpart in English, but akin to editing (cf. poems, short stories)
- **Automatically modify programs** so that they
 - Run faster
 - Use less memory
 - In general, conserve some resource
- CS 4501 has an Optimization assignment

Code Generation

- Produces assembly code (usually)
 - which is then assembled into executables by an assembler
- A translation into another language
 - Analogous to human translation
- CS 4501: 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 a lesser emphasis on ancient parsing techniques (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?

- Increase capacity of expression
 - See what is possible
- 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.
- **Learn to program** in different languages
 - Python, Ruby, JavaScript, ML, Haskell, “Cool”
- **Complete homework assignments**
- **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 profumo delle rose sarà sempre tutt'intorno.

Długo, długo moje serce przepelnione było takimi wspomnieniami!

Były jak waza, w której kiedyś róże destylowały:

Możesz sprawić by pękła, możesz gruchotać wazę jeśli chcesz,

Ale zapach róż będzie wciąż 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 preencho com tais lembranças!

Tal qual o vaso onde rosas foram uma vez destiladas:

Pode quebrar, pode estilhaçar o vaso se o desejas,

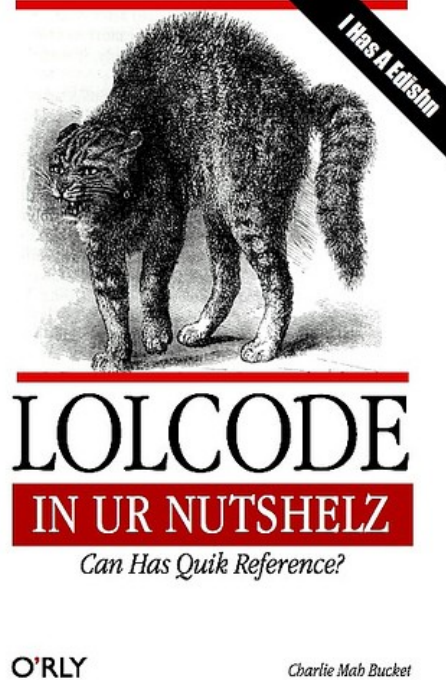
Mas perdurará para sempre o aroma das rosas perfumadas.

The Rosetta Stone

- The first programming assignment involves **writing the same simple (50-75 line) program in:**
 - Ruby, Python, JavaScript, OCaml, Haskell, Cool and C
- PA1c, **due Mon Jan 19** (MLK), requires you to write the program in four languages (you pick)
- PA1, due one week later, requires all seven

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)



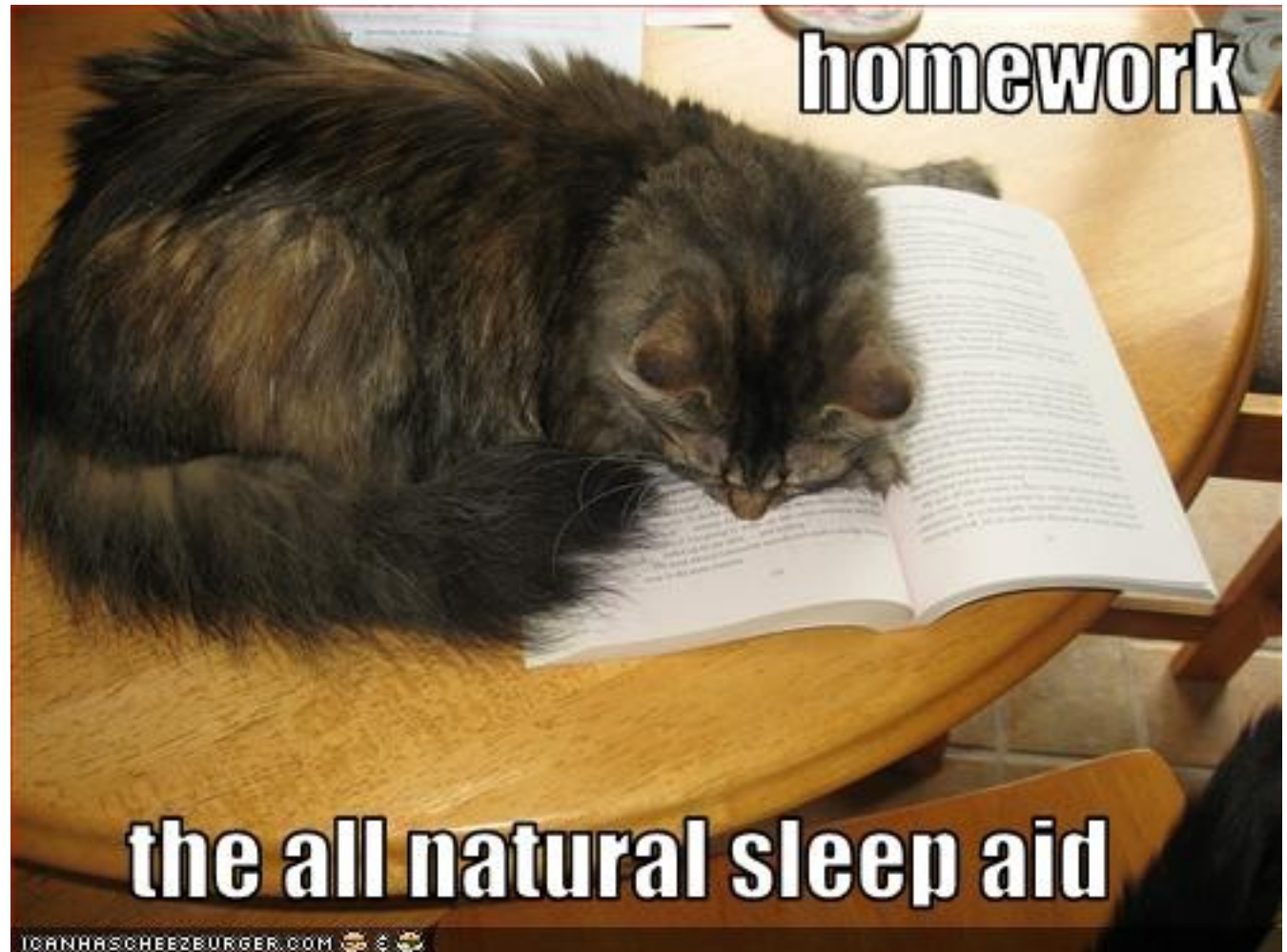
Live Submission Demo

- Let's visit the automated submission website



Start The Homework Now

- It may help you decide whether to stay in this course



homework

the all natural sleep aid

Homework

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

Questions?

