
"NOBODY UNDERSTANDS ME."

# Scoping and Type Checking

# Google speeds up Chrome by compiling JavaScript in the background

By **EMIL PROTALINSKI**, *Thursday, 13 Feb '14 , 06:44pm*


7 COMMENTS

PREVIOUS NEXT

Google today revealed a tweak it has made in the latest Chrome beta to further boost performance: concurrent compilation, which offloads a large part of the optimizing compilation phase to a background thread. Previously, Chrome compiled JavaScript on the main thread, where it could interfere with the performance of the JavaScript application.

As a result, Google says JavaScript applications remain responsive and performance gets a boost. This is all handled by V8, Chrome's JavaScript engine.

# Semantic Fever: Catch it!

# Course Goals and Objectives

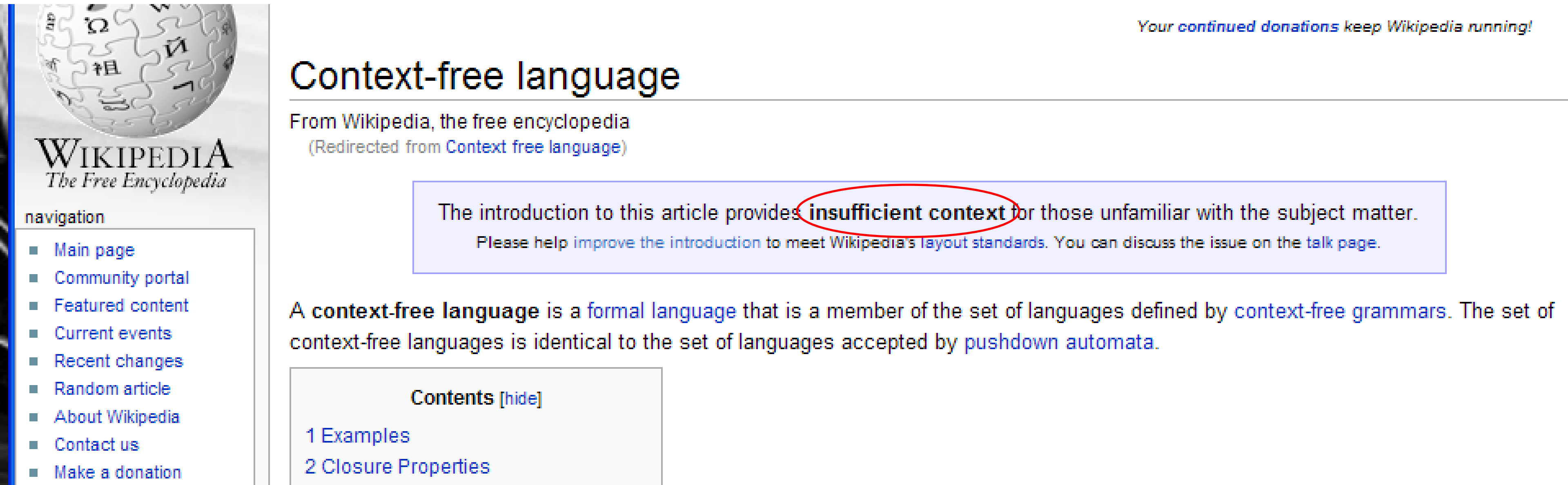
- At the end of this course, you will be acquainted with the fundamental concepts in the **design** and **implementation** of high-level programming **languages**. In particular, you will understand the **theory** and **practice** of **lexing**, **parsing**, **semantic** analysis, and **code** interpretation.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

# In One Slide

- **Scoping rules** match identifier uses with identifier definitions.
- A **type** is a set of values coupled with a set of operations on those values.
- A **type system** specifies which operations are valid for which types.
- **Type checking** can be done statically (at compile time) or dynamically (at run time).

# Lecture Outline

- The role of semantic analysis in a compiler
  - A laundry list of tasks
- Scope
- Types



# The Interpreter So Far

- Lexical analysis
  - Detects inputs with illegal tokens
- Parsing
  - Detects inputs with ill-formed parse trees
- **Semantic analysis**
  - Last “front end” phase
  - Catches more errors

# What's Wrong?

- Example 1

  let y: Int in x + 3

- Example 2

  let y: String ← "abc" in y + 3

# Why a Separate Semantic Analysis?

- Parsing cannot catch some errors
- Some language constructs are **not context-free**
  - Example: All used variables must have been declared (i.e. scoping)
  - Example: A method must be invoked with arguments of proper type (i.e. typing)

# What Does Semantic Analysis Do?

- Many checks! For example, **cool** checks:
  1. All identifiers are declared
  2. Static Types
  3. Inheritance relationships (no cycles, etc.)
  4. Classes defined only once
  5. Methods in a class defined only once
  6. Reserved identifiers are not misused

  And others . . .
- The requirements depend on the language
  - Which of these are checked by Python?

# Scope

- **Scoping rules** match identifier uses with identifier declarations
  - Important semantic analysis step in most languages
  - Including Cool and Java and C++ and C# and …
  - (Even Python has `global` …)

# Scope (Cont.)

- The **scope** of an identifier is the portion of a program in which that identifier is accessible

- The same identifier may refer to different things in different parts of the program
  - Different scopes for same name don't overlap

- An identifier may have restricted scope

# Static vs. Dynamic Scope

- Most languages have **static** scope
  - Scope depends only on the program text, not run-time behavior
  - Cool, Java, C++, C#, etc., have static scope
- Ancient history: **dynamically** scoped
  - Lisp, SNOBOL, Tex, Perl, PostScript
  - Lisp has changed to mostly static scoping
  - Scope depends on execution of the program

# Static Scoping Example

```
let x: Int <- 0 in
  {
      x;
      { let x: Int <- 1 in
            x; } ;
      x;
  }
```

# Static Scoping Example (Cont.)

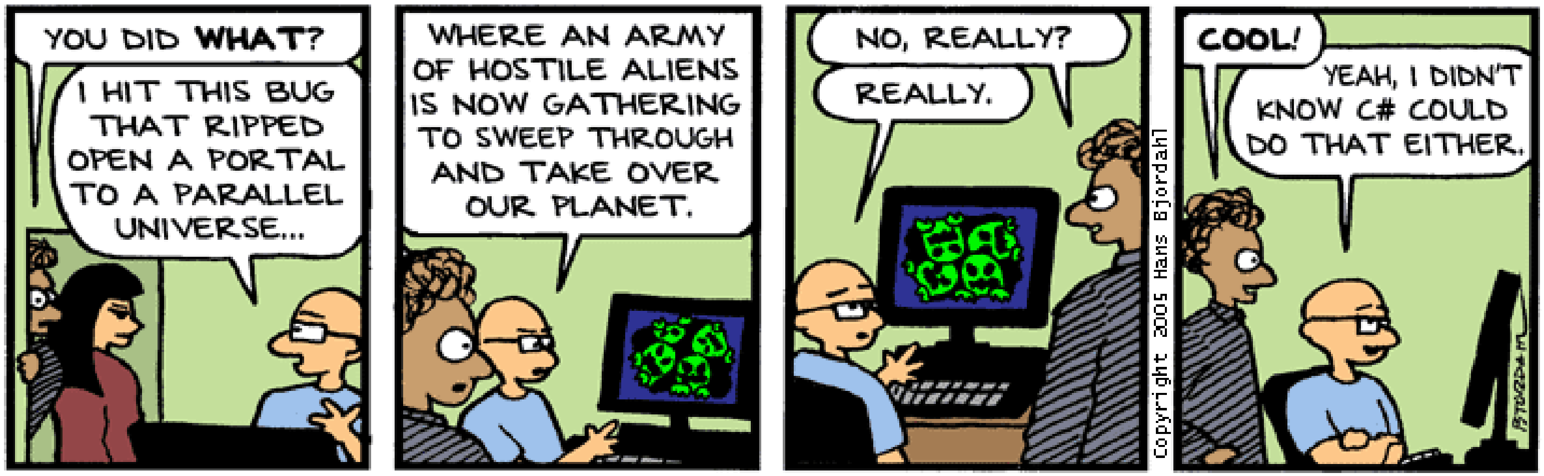
```
let x: Int <- 0 in
  {
     x;
     { let x: Int <- 1 in
          x; } ;
     x;
  }
```

Uses of x refer to closest enclosing definition

# Scope in Cool

- Cool identifier bindings are **introduced** by
  - Class declarations (introduce class names)
  - Method definitions (introduce method names)
  - Let expressions (introduce object id's)
  - Formal parameters (introduce object id's)
  - Attribute definitions in a class (introduce object id's)
  - Case expressions (introduce object id's)

# Implementing the Most-Closely Nested Rule




Bug Bash by Hans Bjordahl

http://www.bugbash.net/

- Much of semantic analysis can be expressed as a **recursive descent** of an AST
  - Process an AST node *n*
  - Process the children of *n*
  - Finish processing the AST node *n*

# Implementing . . . (Cont.)

- Example: the scope of let bindings is one subtree

**let x: Int ← 0 in e**


- x can be used in subtree e

# Symbol Tables

- Consider again: let x: Int ← 0 in e
- Idea:
  - Before processing e, add definition of x to current definitions, overriding any other definition of x
  - After processing e, remove definition of x and restore old definition of x
- A **symbol table** is a data structure that tracks the current bindings of identifiers
  - You'll need to make one for PA4
  - OCaml's Hashtbl is designed to be a symbol table

# Scope in Cool (Cont.)

- Not all kinds of identifiers follow the most-closely nested rule

- For example, class definitions in Cool
  - Cannot be nested
  - Are **globally visible** throughout the program

- In other words, a class name can be **used before it is defined**

# Example: Use Before Definition

Class Foo {

. . . let y: **Test** in . . .

};

Class **Test** {

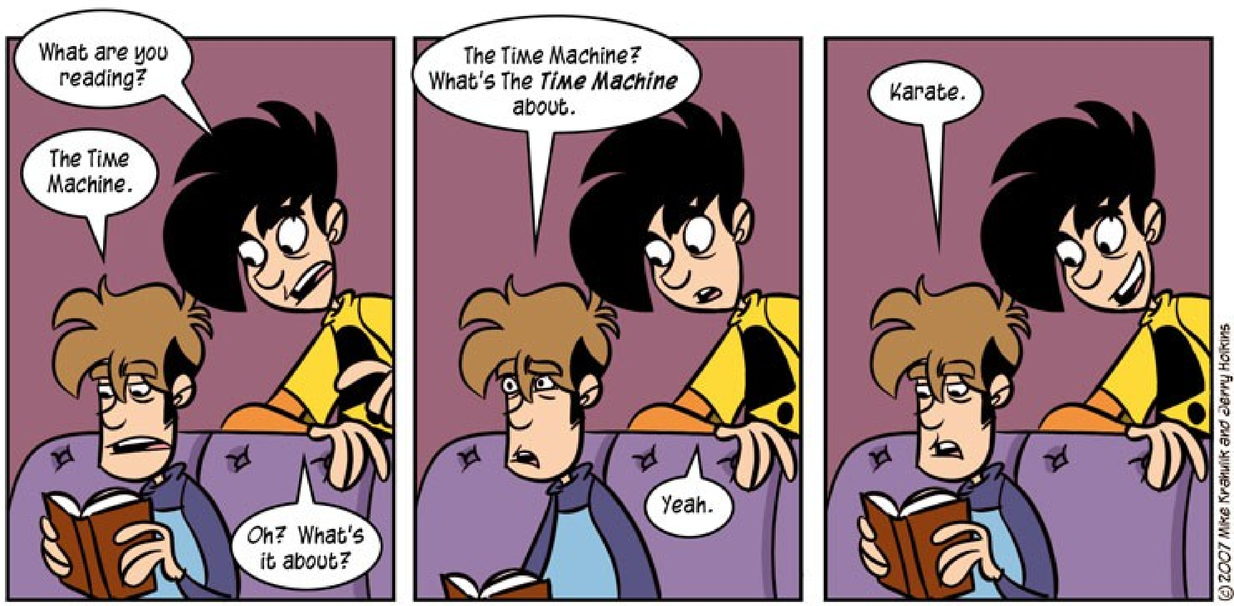
. . .

};

# More Scope in Cool

Attribute names are **global** *within* the class in which they are defined

```
Class Foo {
   f(): Int { tm };
   tm: Int ← 0;
}
```

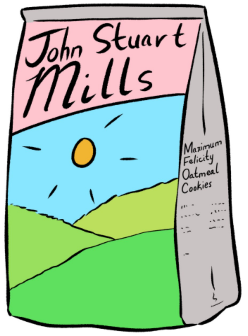


# More Scope (Cont.)

- Method and attribute names have complex rules
- A method need not be defined in the class in which it is used, but in some parent class
  - This is standard **inheritance**!
- Methods may also be redefined (overridden)

# Class Definitions

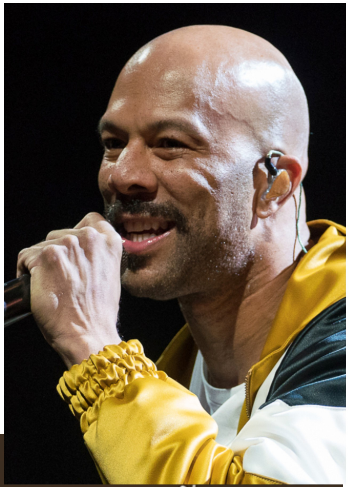
- Class names can be used before being defined
- We can't check this property
  - using a symbol table
  - or even in one pass :-(
- Solution
  - Pass 1: Collect all class names
  - Pass 2: Do the checking
  - ?
  - Pass 4: Profit!
- Semantic analysis needs **multiple passes**
  - Probably more than two

# Q: Advertising (832 / 842)

- Translate the last line in this French **M&Ms** jingle: *Nous sommes les M&Ms / Nous sommes les M&Ms / Des belles coleurs en choix / Des belles coleurs en choix / Tout le monde nous aime / C'est nous, les M&Ms / M&Ms fondent dans la bouche, pas dans la main*.

# Trivia: Hip Hop
(student "memorial")




- This rapper and activist has won three Grammies and an Academy Award. His award-winning sixth album, "Be", featured the single "Go!" and a mini-movie "Testify". He has feuded with Drake. He is known for positive lyrics and a spoken-word style.

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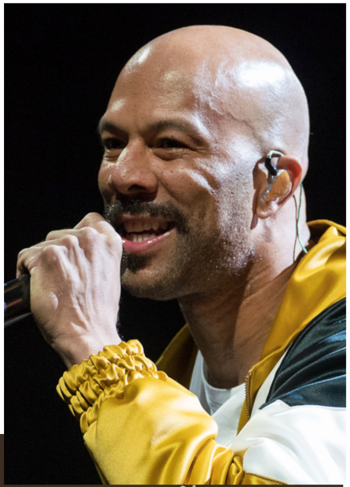


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# Trivia: State Capitals
(student "memorial")

- This Keystone State state capital sits on the Susquehanna River. It is infamous for the Three-Mile Island nuclear meltdown of 1979.

# Trivia: Mythology

(student "memorial")

- These supernatural evil creatures are cousins to the Yakshas in Hindu mythology. They are often depicted as shape-shifting, fanged human-eaters. They are the main antagonists of the epic Ramayana: they kidnap Sita, the wife of Rama.

# Real-World Languages

- This Asian language, sometimes called Siamese, is mutually intelligible with Lao and is spoken by 61+ million. It is tonal and has a complex writing system. The language's literature is influenced by India; its literature epic is a version of the Ramayana.
  - Example: สวัสดี

# Types

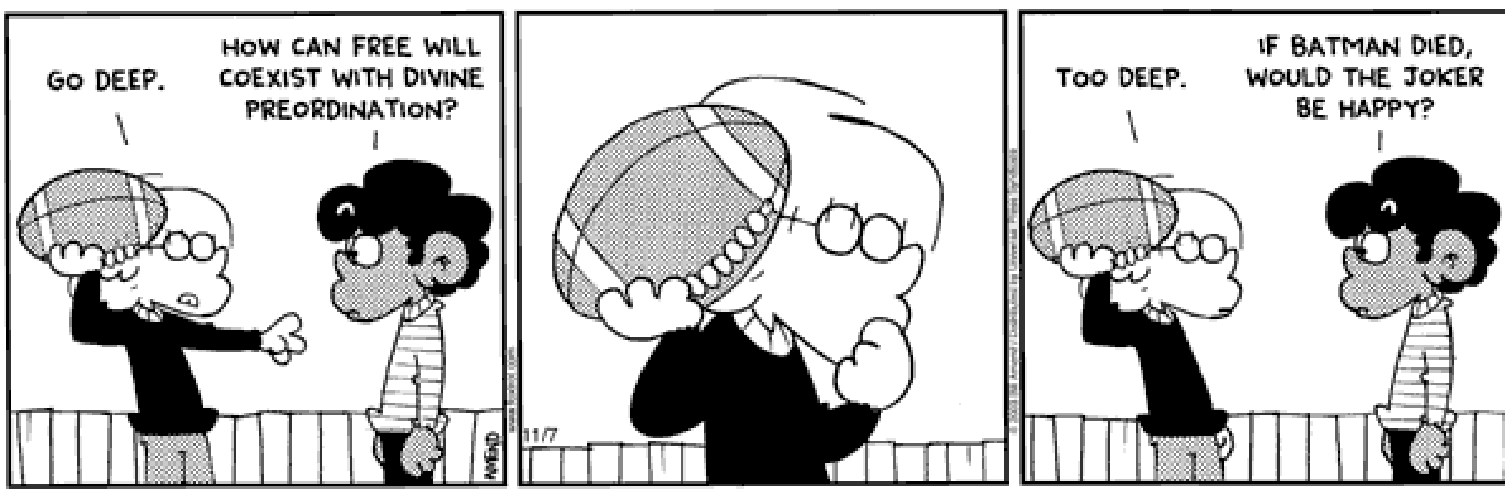
- What is a **type**?
  - The notion varies from language to language
- Consensus
  - A set of values
  - A set of valid operations on those values
- Classes are one instantiation of the modern notion of type

# Why Do We Need Type Systems?

Consider the assembly language fragment

add  r1 <- r2 + r3

What are the types of r1, r2, r3?



# Types and Operations

- Certain operations are **legal** or **valid** for values of each type
  - It doesn’t make sense to add a function pointer and an integer in C
  - It does make sense to add two integers
  - But both have the same assembly language implementation!

# Type Systems

- A language's **type system** specifies which operations are valid for which types
- The goal of type checking is to ensure that operations are used with the correct types
  - Enforces intended interpretation of values, because nothing else will!
    - Our last, best hope … for victory!
- Type systems provide a concise formalization of the semantic checking rules

# What Can Types do For Us?

- Can detect certain kinds of errors
- Memory errors:
  - Reading from an invalid pointer, etc.
- Violation of **abstraction** boundaries:

```
class FileSystem {
  open(x : String) : File {
      …
   }
…
}
```

```
class Client {
  f(fs : FileSystem) {
     File fdesc <- fs.open("foo")
     …
  } -- f cannot see inside fdesc !
}
```

# Type Checking Overview

- Three kinds of languages:
  - **Statically typed**: All or almost all checking of types is done as part of compilation (C, Java, Cool, OCaml, Haskell, C#, C++, ...)
  - **Dynamically typed**: Almost all checking of types is done as part of program execution (Scheme, Ruby, Python, PHP, JavaScript, …)
  - **Untyped**: No type checking (machine code)

# The Type Wars

- Competing views on static vs. dynamic typing
- Static typing proponents say:
  - Static checking catches many programming errors at compile time
  - Avoids overhead of runtime type checks
- Dynamic typing proponents say:
  - Static type systems are restrictive
  - Rapid prototyping is easier in a dynamic type system

# The Type Wars (Cont.)

- In practice, most code is written in statically typed languages with an “escape” mechanism
  - Unsafe casts in C, native methods in Java, unsafe modules in Modula-3
- Dynamic typing (sometimes called “duck typing”) is big in the scripting / glue world

# Cool Types


- The **types** are:
  - Class names
  - SELF_TYPE
- There are *no* unboxed base types (unlike int in Java)
- The user declares types for all identifiers
- The compiler **infers** types for expressions
  - Infers a type for *every* expression
  - Java and C and C++ and C# (etc.) do this too!

# Type Checking and Type Inference

- **Type Checking** is the process of verifying fully typed programs
- **Type Inference** is the process of filling in missing type information
- The two are different, but are often used interchangeably

# Rules of Inference

- We have seen two examples of formal notation specifying parts of a compiler
  - Regular expressions (for the lexer)
  - Context-free grammars (for the parser)

- The appropriate formalism for type checking is **logical rules of inference**

# Why Rules of Inference?

- **Inference rules** have the form

  *If Hypothesis is true, then Conclusion is true*

- Type checking computes via reasoning

  *If $E_1$ and $E_2$ have certain types,*

  *then $E_3$ has a certain type*

- **Rules of inference** are a compact notation for "If-Then" statements

# From English to an Inference Rule

- The notation is easy to read (with practice)
- Start with a simplified system and gradually add features
- Building blocks
  - **Symbol $\wedge$ is "and"**
  - **Symbol $\Rightarrow$ is "if-then"**
  - **$x{:}T$ is "$x$ has type $T$"**

# English to Inference Rules (2)

If $e_1$ has type Int and $e_2$ has type Int,
then $e_1 + e_2$ has type Int

($e_1$ has type Int $\wedge$ $e_2$ has type Int) $\Rightarrow$
$e_1 + e_2$ has type Int

**($e_1$: Int $\wedge$ $e_2$: Int) $\Rightarrow$ $e_1 + e_2$: Int**

# English to Inference Rules (3)

The statement

$$(e_1\text{: Int} \;\wedge\; e_2\text{: Int}) \Rightarrow e_1 + e_2\text{: Int}$$

is a special case of

$$(\text{ Hypothesis}_1 \wedge \ldots \wedge \text{Hypothesis}_n\text{ }) \Rightarrow \text{Conclusion}$$

This is an inference rule

# Notation for Inference Rules

- By tradition inference rules are written

$$\frac{\vdash \text{iHypothesis}_1 \quad \ldots \quad \vdash \text{Hypothesis}_n}{\vdash \text{Conclusion}}$$

- Cool type rules have hypotheses and conclusions of the form:

$$\vdash e : T$$

- $\vdash$ means "we can prove that . . ."

# Two Rules

$$\frac{}{\vdash i : \text{Int}}\ [\text{Int}]$$

*(i is an integer)*

$$\frac{\vdash e_1 : \text{Int} \qquad \vdash e_2 : \text{Int}}{\vdash e_1 + e_2 : \text{Int}}\ [\text{Add}]$$

# Two Rules (Cont.)

- These rules give templates describing how to type integers and + expressions
- By filling in the templates, we can produce complete typings for expressions
- We can fill the template with *any* expression!

$$\frac{\vdash \text{true} : \text{Int} \qquad \vdash \text{false} : \text{Int}}{\vdash \text{true} + \text{false} : \text{Int}}$$

# Example: 1 + 2

$$\dfrac{\dfrac{}{\vdash 1 : \text{Int}} \qquad \dfrac{}{\vdash 2 : \text{Int}}}{\vdash 1 + 2 : \text{Int}}$$

# Homework

- PA4t Due Today
  - Why? We really don't want students to fall behind on PA4 or put it off until after the break.
- PA4c Before Break