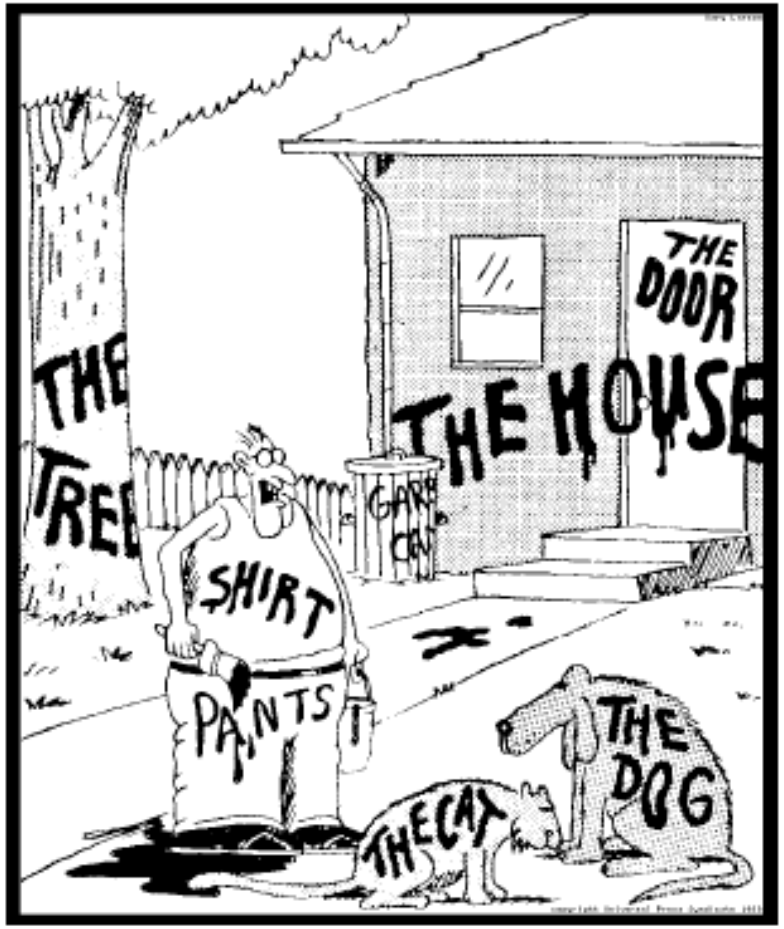
CS 381: Programming Language Fundamentals

Summer 2015

Types

July 13, 2015

Types



"Now! *That* should clear up a few things around here!"

Oregon State UNIVERSITY

Outline

Introduction

- Concepts and terminology
- The case for static typing

Implementing a static type system

- Basic typing relations
- Adding context

Types and type errors

Type: a set of syntactic terms (ASTs) that share the same behavior

- `Int`, `Bool`, `String`, `Maybe Bool`, `[[Int]]`, `Int->Bool`
- defines the **interface** for these terms — in what contexts can they appear?

Type error: occurs when a term cannot be assigned a type

- typically a violation of the type interface between terms
- if not caught/prevented, leads to a crash or unpredictable evaluation

Type safety

A **type system** detects and prevents/reports type errors

A language is **type safe** if an implementation can detect all type errors

- **statically**: by proving the absence of type errors
- **dynamically**: by detecting and reporting errors at runtime

Type safe languages

- Haskell, SML — *static*
- Python, Ruby — *dynamic*
- Java — *mixed*

Type unsafe languages

- C, C++ — *pointers*
- PHP, Perl, JavaScript — *conversions*

Implicit type conversions: strong vs. week typing

Many languages **implicitly convert** between types — is this safe?

Only if determined by the *types* and *not* the runtime values!

Java (safe)

```
int n = 42;
String s = “Answer: “ + n;
```

PHP/Perl (unsafe)

```
n = “4” + 2;
s = “Answer: “ + n;
```

Static vs. dynamic typing

Static typing

- types are associated with **syntactic terms**
- type errors are reported at **compile time**
- type checker **proves** that no type errors will occur at runtime

Dynamic typing

- types are associated with **runtime values**
- type errors are reported at **runtime**
- type checker is **integrated** into the runtime system

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Benefits of static typing

Usability and comprehension

1. **machine checked documentation**
   - guaranteed to be correct and consistent with implementation
2. **better tool support**
   - code completion, navigation, etc…
3. **supports high-level reasoning**
   - by providing named abstractions for shared behavior

Benefits of static typing (continued)

Correctness

4. **partial proof of correctness** — no runtime type errors
    - improves robustness, focus testing on more interesting errors

Efficiency

5. **improved code generation**
    - can apply type specific optimizations
6. **type erasure**
    - no need for type information or checking at runtime

Drawback of static typing

Conservative

Q: What is the type of the following expression?

```
if 3 > 4 then True else 5
```

A: Static typing: `type error`

Dynamic typing: `Int`

Q: What is the type of the following expression?

```
\x -> if x > 4 then True else x + 2
```

A: Static typing: `type error`

Dynamic typing: `???`

Undecidability of static typing

```
mayLoop :: Int -> Bool
f x = if mayLoop x then x + 1 else not x
```

`f` is *type correct* if `mayLoop x` yields `True`

`f` contains a *type error* if `mayLoop x` yields `False`

Static typing *approximates* by assuming a type error when type correctness cannot be shown — **proven**

Exercise: static vs. dynamic typing

What is the type of the following function under *static* and *dynamic typing*?

```
if True then 5 else False
```

Static typing: **type error**

Dynamic typing: **Int**

What is the type of the following function under *static* and *dynamic typing*?

```
f x = f (not x) × 2
```

Static typing: **Bool -> Int**

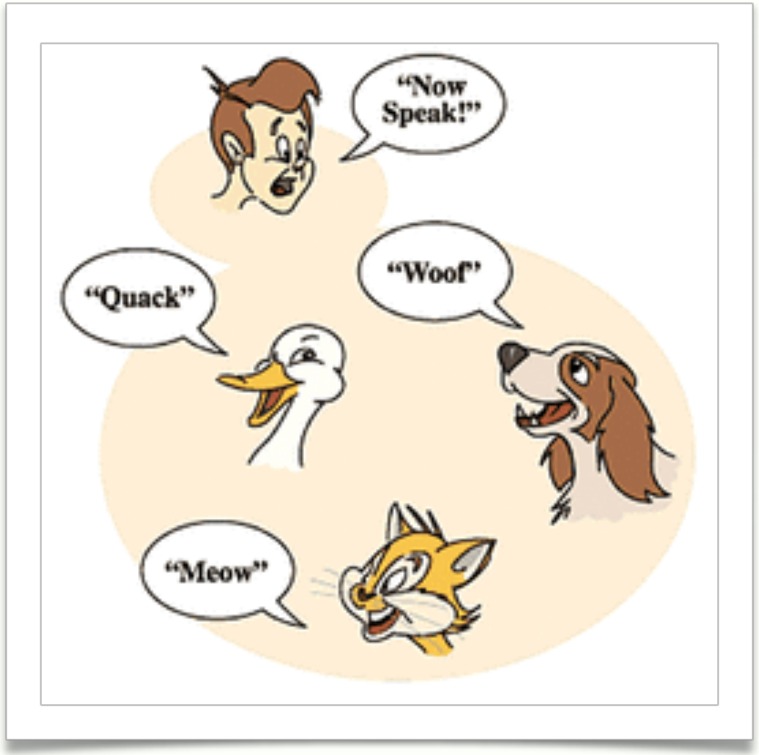
Dynamic typing: **???**
Bool -> Int

Polymorphism

A value (function, method, etc.) is **polymorphic** if it can have more than one value

Different forms of **polymorphism** can be distinguished based on:

- the *relationship* between the types
- the *implementation* of the functions



Forms of polymorphism

Parametric polymorphism

- polymorphic types match a common "type pattern"
- one implementation (e.g. there is only one function)

Ad hoc polymorphism (a.k.a **overloading**)

- polymorphic types are unrelated
- implementation differs for each type (e.g. different functions are referred to by the same name)

Subtype polymorphism

- types are related by a subtype relation
- one implementation

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Static typing is a "static semantics"

Dynamic semantics (a.k.a. **execution semantics**)

- *what is the meaning of this program?* `sem :: Expr → Val`
- relates an AST to a **value**
- describes what program does **at runtime**

Static semantics

- *which programs have meaning?* `typeOf :: Expr → Type`
- classifies/restricts programs based on structure
- describes what a program does **at compile time**

Typing is just semantics with a different kind of value!

Defining a static type system

IntBoolT.hs PairT.hs LetT.hs

Example encoding in Haskell:

1. Define the **abstract syntax**, ***E***

   the set of abstract syntax trees (ASTs)

```
data Exp = ...
```

2. Define the structure of **types**, ***T***

   another abstract syntax

```
data Type = ...
```

3. Define the **typing relation**, ***`E : T`***

   *the mapping from **ASTs** to **types***

```
typeOf :: Exp -> Type
```

Then, we can define a dynamic semantics that **assumes** there are no type errors

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Typing contexts

StackT.hs

Often we need to keep track of some information during typing

- types of top-level functions
- types of local variables
- an implicit program stack
- set of declared classes and their methods
- …

Put this information into the **typing context** (a.k.a. the **environment**)

```
typeOf :: Exp -> Env -> Type
```