Dynamically-typed Languages

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Dynamically-typed Language

- Everything is a value
- No type declarations
- Examples of dynamically-typed languages
  - APL, Io, JavaScript, Lisp, Lua, Objective-C, Perl, PHP, Python, Ruby, Scheme, Smalltalk

Dynamic vs. Static

Static	Dynamic
▪Types are associated with variables	▪Types are associated with runtime values
▪Each variable is of only one type during its lifetime	▪Variables may point to values of differing types during their lifetime
▪Variable types declared or inferred	▪Often no variable declaration
▪Type checking done at compile time	▪Type checking often done at run-time

Dynamic vs. Static (In Practice)

Static	Dynamic
▪Most often occurs in compiled languages	▪Most often occurs in interpreted languages
▪Well suited for class-based OO programming	▪Well suited for prototype-based OO programming
▪Usually results in faster compiled code, but often takes longer to compile	▪May allow compilers and interpreters to run faster, but produces slower (compiled) code
▪Easier to optimize	▪More difficult to optimize
▪Code generally more verbose	▪Code generally more succinct
▪Meta-programming more cumbersome to write	▪Well suited for meta-programming

Dynamic vs. Static (In Practice)

Double Layered Hash Table:

C# 1.0

```
Hashtable ht = new Hashtable();
ht["something"] = new Hashtable();
((Hashtable)ht["something"])["someObj"] = new SomeObj();
((SomeObj)((Hashtable)ht["something"])["someObj"]).SomeMethod();
```

Python

```
ht = {}
ht["something"] = {}
ht["something"]["someObj"] = SomeObj()
ht["something"]["someObj"].SomeMethod();
```

Type Inference

- Optional type declaration
  - Allow variables to be declared so as to enable optimization of the (compiled) code
- Standard type inference
  - Use standard type inferencing techniques to determine static type information
- Type prediction
  - Use usage patterns to “guess” what type a variable (an object?) is based on what operation it is used in

Python

- Supports structured and prototype based(?) object oriented programming
- Uses Duck Typing
  - No type checking at compile time. Instead, an operation on an object fails at runtime if it does not support that operation
- Strongly typed

PyPy – Python Compiler

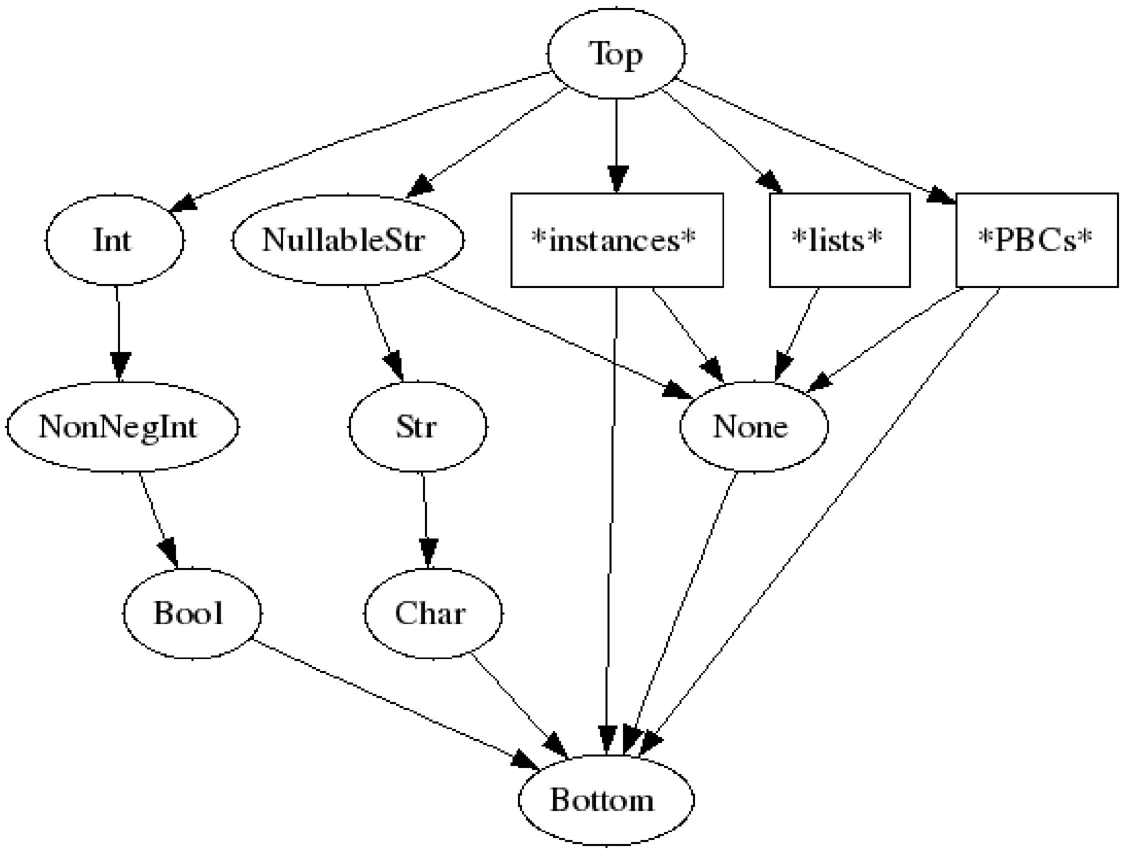
- Compiler analyses “live” programs
  - Programs are read into the Python interpreter and initialized
- Flow Object Space used to construct the control flow graphs by running through each possible control path of the code and recording operations performed on abstract objects
- Flow graphs are in Static Single Information (SSI) form
  - Extension of Static Single Assignment form in which each variable is used in only one basic block
  - All variables that are not dead at the end of a block are explicitly carried over and renamed
- Resulting flow graphs are passed to the annotator that performs type inferencing

PyPy’s Type Annotator

- Assigns annotations to each variable in the control flow graph
  - Annotations describe the possible run-time objects that a variable can contain
- Flows annotations forward
  - Type of a variable in Python can only be deduced by how it is produced, not by how it is used
  - Starting from an entry function, with user-specified annotations for it’s arguments, annotations are flowed through the blocks following calls recusively
  - Used fixed point algorithm in situation of loops – if previously annotated variables are too restrictive, generalize them and process the loop again

PyPy's Type Annotator

Lattice of annotations



PyPy's Type Annotator

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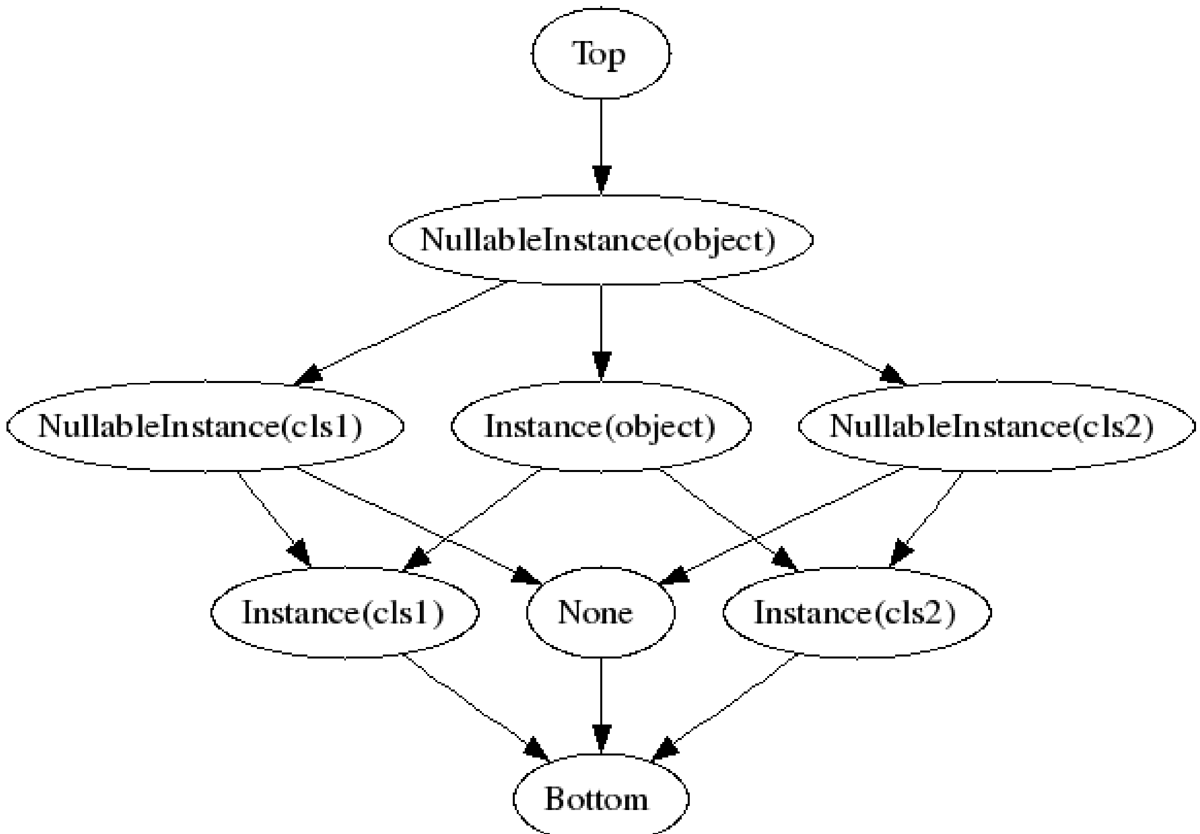

Self

- Prototype based Object Oriented language
- Implements full messages passing
- Objects consist of named slots, each of which contain a reference to another object
- Objects with source code associated with them are called methods
- When a message is sent to an object (called a “receiver”) the slots of the object (and recursively, parents of the object) are search for a match
  - If found, its content is evaluated and returned as the result of the message send
- Primitive operations have succeed and fail cases
  - Flow of control normally rejoins after the result is computed

Self Code Example

Self code:

```
sumTo: upperBound = (
        | sum <- 0 |
        to: upperBound Do: [
                | :index |
                sum: sum + index ].
        sum )
```

C code:

```
int sumTo(int self, int upperBound) {
        int sum = 0;
        int index;
        for (index = self; index <= upperbound; index++)
                sum = sum + index;
        return sum;
}
```

SELF Compiler

- Extracts static type information
- Compiles several copies of a procedure, each customized for a specific receiver type
- Splits calls after a join, placing a copy on each control path optimized for a particular receiver type
- Predicts types that are likely but unknown by static type inference and inserts run-time tests to verify predictions
- Implements other standard optimization techniques
  - compile-time message lookup, aggressive procedure inlining, etc. …

SELF Compiler – Customized Compilation

- Provides type information for any calls to self (assuming no dynamic inheritance)
- Compiles copies of a method customized by characteristics of the calling site
- All subsequent calls to the method sharing the same characteristic, call the copy optimized for that calling site

SELF Compiler – Message Splitting

- Provides type information for the successful results of primitive operations
- When control paths merge with different result types for each path, a subsequent message can be “split”
  - The messages send is “push” up past the merge point
  - Each copy of the message send can then be further optimized

SELF Compiler – Type Prediction

- Provides type information for some messages not covered by customized compilations or message splitting
- Certain messages are more likely to be sent to some types of receivers than others
- From benchmarking measurements, types of receivers can be predicted
  - eg. 90% of the time operators +, -, and < have integer arguments
- A run-time type check is inserted and the message is split with a copy compiled on each branch
  - The “success” message is inlined while the “fail” message remains a full message send