Metaprogramming

These slides borrow heavily from Ben Wood's Fall '15 slides.

CS251 Programming Languages
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Lisp/Racket and Implementation (2)

Interpretation, Translation, and everything in between
Programs as Data
If time: Implementing Racket in Racket
- hands-on
- how Lisp was first implemented

How to implement a programming language

Interpretation

An **interpreter** written in the **implementation language** reads a program written in the **source language** and **evaluates** it.

Translation (a.k.a. compilation)

An **translator (**a.k.a. **compiler)** written in the **implementation language** reads a program written in the **source language** and **translates** it to an equivalent program in the **target language**.

But now we need implementations of:

implementation language

target language

How to implement a programming language

Can describe by deriving a "proof" of the implementation using these inference rules:

Interpreter Rule

$$\frac{\text{P-in-L program} \qquad \text{L interpreter machine}}{\text{P machine}}$$

Translator Rule

$$\frac{\text{P-in-S program} \qquad \text{S-to-T translator machine}}{\text{P-in-T program}}$$

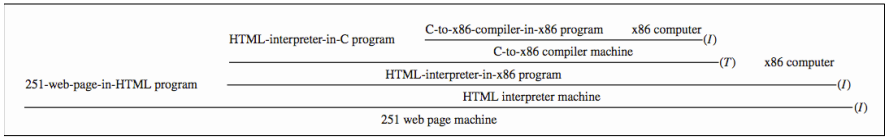
Implementation Derivation Example

Prove how to implement a "251 web page machine" using:

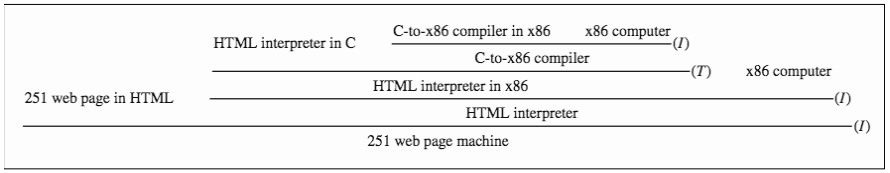
- 251-web-page-in-HTML program (a web page written in HTML)
- HTML-interpreter-in-C program (a web browser written in C)
- C-to-x86-translator-in-x86 program (a C compiler written in x86)
- x86 interpreter machine (an x86 computer)

No peaking ahead!

Implementation Derivation Example Solution



We can omit "program" and "machine":



Implementation Derivation Are Trees

And so we can represent them as nested structures, like nested bulleted lists:

- 251 web page machine (I)
  - 251-web-page-in-HTML program
  - HTML interpreter machine (I)
    - HTML-interpreter-in-x86 program (T)
      - HTML-interpreter-in-C program
      - C-to-x86 compiler machine (I)
        - C-to-x86-compiler-in-x86 program
        - x86 computer
    - x86 computer

Metacircularity and Bootstrapping

Many examples:

- Lisp in Lisp / Racket in Racket: eval
- Python in Python: PyPy
- Java in Java: Jikes RVM, Maxine VM
- …
- C-to-x86 compiler in C

How can this be possible?

Key insights to bootstrapping:

- The first implementation of a language **cannot** be in itself, but must be in some other language.
- Once you have one implementation of a language, you can implement it in itself.

Metacircularity Example 1

Suppose you are given:

- Racket-in-SML interpreter
- SML machine
- Racket-in-Racket interpreter

How do you run the Racket-in-Racket interpreter?

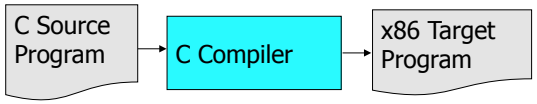
Metacircularity Example 2

Suppose you are given:

- C-to-x86-translator-in-x86 program (a C compiler written in x86)
- x86 interpreter machine (an x86 computer)
- C-to-x86-translator-in-C

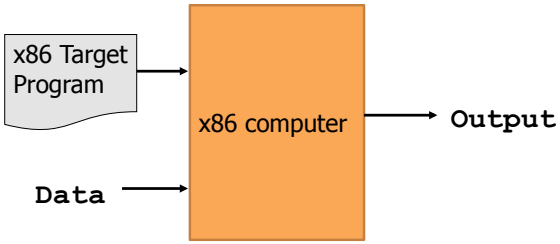
How do you compile the C-to-x86-translator-in-C ?

Compiler

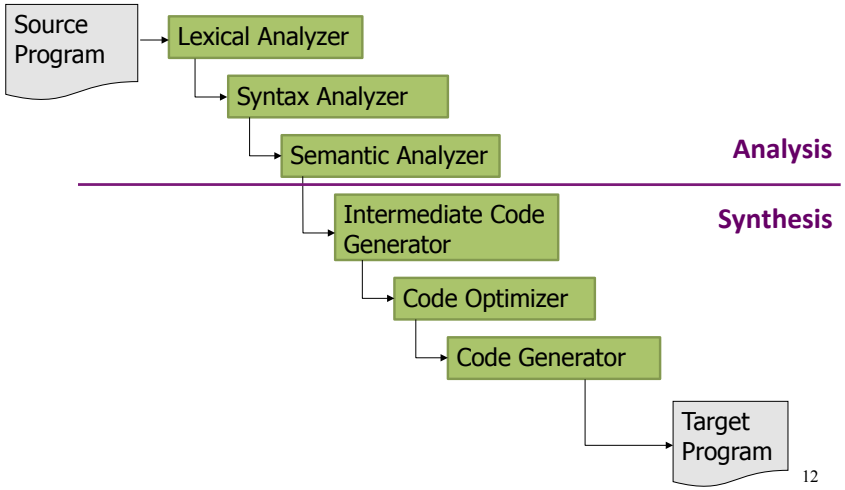



```
if (x == 0) {
  x = x + 1;
}
...
```

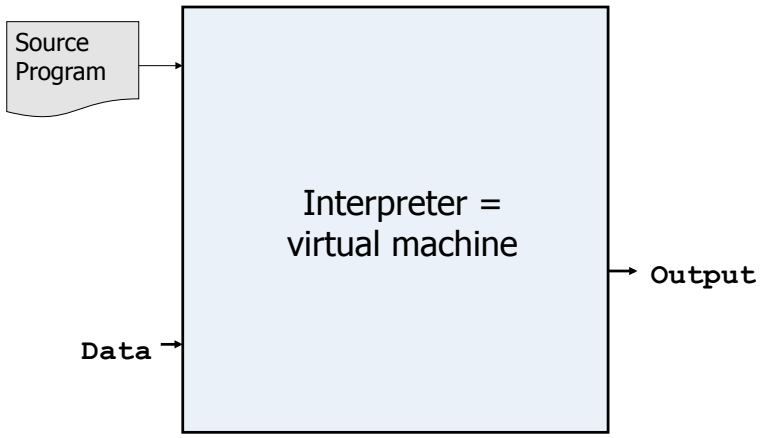
```
cmp (1000), $0
bne L
add (1000), $1
L:
...
```



Typical Compiler



Interpreters



Interpreters vs Compilers

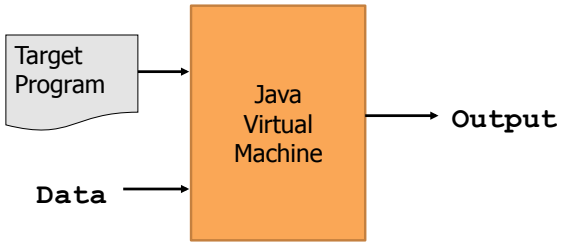
Interpreters

- No work ahead of time
- Incremental
- maybe inefficient

Compilers

- All work ahead of time
- See whole program (or more of program)
- Time and resources for analysis and optimization

Compilers... whose output is interpreted



Doesn't this look familiar?

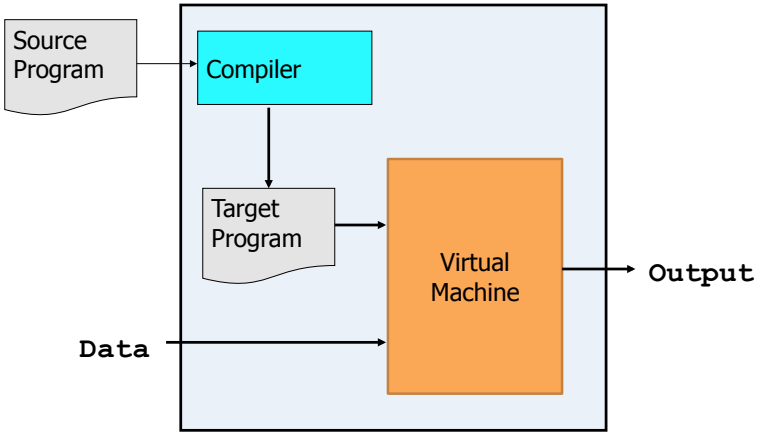
Java Compiler


```
if (x == 0) {
  x = x + 1;
}
...
```

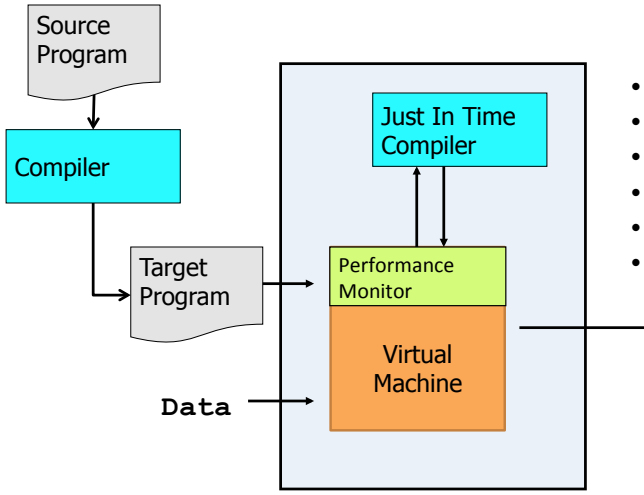
```
load 0
ifne L
load 0
inc
store 0
L:
...
```

(compare compiled C to compiled Java)

Interpreters... that use compilers.

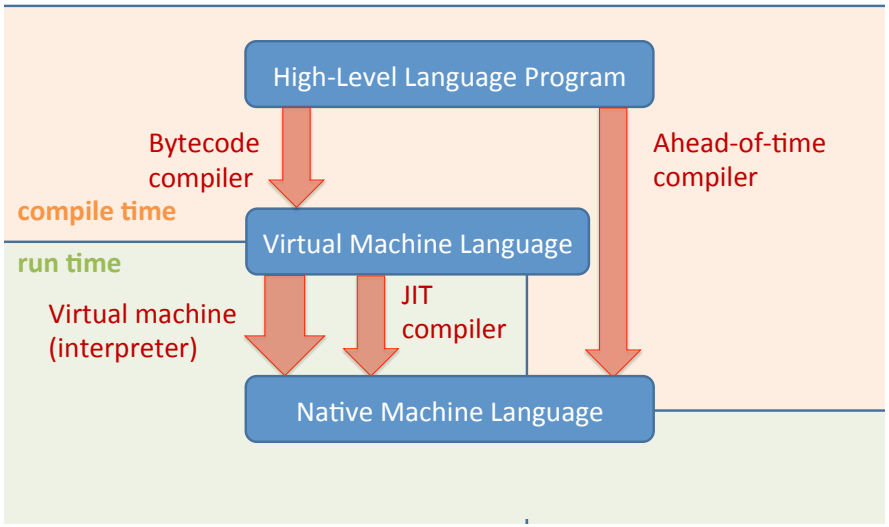


JIT Compilers and Optimization



- HotSpot JVM
- Jikes RVM
- SpiderMonkey
- v8
- Transmeta
- ...

Virtual Machine Model



Remember: language != implementation

- Easy to confuse "the way this language is usually implemented" or "the implementation I use" with "the language itself."
- Java and Racket can be compiled to x86
- C can be interpreted in Racket
- x86 can be compiled to JavaScript
- Can we compile C/C++ to Javascript? http://kripken.github.io/emscripten-site/

Next Topic: Metaprogramming in SML

- PostFix in SML (see `postfix.sml`)
- A sequences of expression languages implemented in SML that look closer and closer to Racket:
  - Intex
  - Bindex
  - Valex
  - HOFL (higher-order functional langauge)