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Unnatural Language Processing

COMPUTER SCIENCE AT
COLUMBIA UNIVERSITY

Keynote Presentation SSST-3
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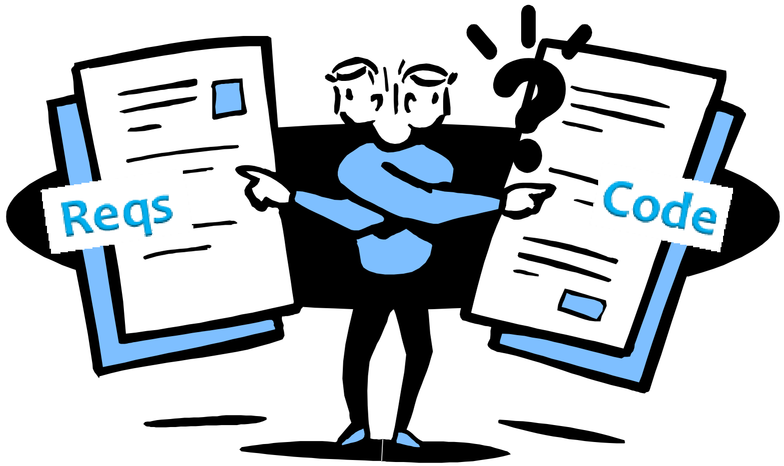
The Concern-Location Problem in Software

What program elements are relevant to a requirement?

More than 50% of the cost of developing a program is spent in maintenance.

More than 50% of the maintenance time is spent understanding the program.



NLP + PLP can help!

Natural Languages

A *natural language* is a form of communication peculiar to humankind. [Wikipedia]

Popular spoken natural languages:

Chinese	1,205m	Portuguese	178m
Spanish	322m	Bengali	171m
English	309m	Russian	145m
Arabic	206m	Japanese	122m
Hindi	108m	German	95m

[Wikipedia]

Ethnologue catalogs 6,912 known living languages.

Conlangs: Made-Up Languages

Okrent lists 500 invented languages including:

- **Lingua Ignota** [Hildegaard of Bingen, c. 1150]
- **Esperanto** [L. Zamenhof, 1887]
- **Klingon** [M. Okrand, 1984]
  Huq Us'pty G'm (I love you)
- **Proto-Central Mountain** [J. Burke, 2007]
- **Dritok** [D. Boozer, 2007]
  Language of the Drushek, long-tailed beings with large ears and no vocal cords

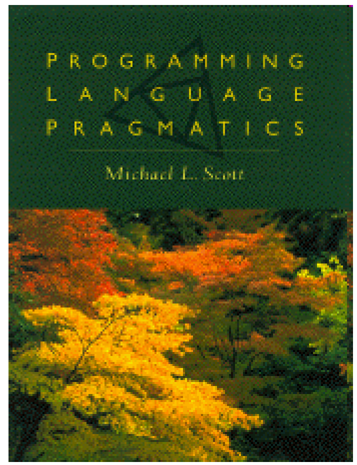
[Arika Okrent, *In the Land of Invented Languages*, 2009]
[http://www.inthelandofinventedlanguages.com]

Programming Languages

Programming languages are notations for describing computations to people and to machines.

Underlying every programming language is a model of computation:

- Procedural: C, C++, C#, Java
- Declarative: SQL
- Logic: Prolog
- Functional: Haskell
- Scripting: AWK, Perl, Python, Ruby



Programming Languages

There are many thousands of programming languages.

Tiobe's ten most popular languages for May 2009:

1. Java
2. C
3. C++
4. PHP
5. Visual Basic
6. Python
7. C#
8. JavaScript
9. Perl
10. Ruby

[http://www.tiobe.com]

http://www.99-bottles-of-beer.net has programs in 1,271 different programming languages to print out the lyrics to "99 Bottles of Beer."

“99 Bottles of Beer”

99 bottles of beer on the wall, 99 bottles of beer.
Take one down and pass it around, 98 bottles of beer on the wall.

98 bottles of beer on the wall, 98 bottles of beer.
Take one down and pass it around, 97 bottles of beer on the wall.

.
.
.

2 bottles of beer on the wall, 2 bottles of beer.
Take one down and pass it around, 1 bottle of beer on the wall.

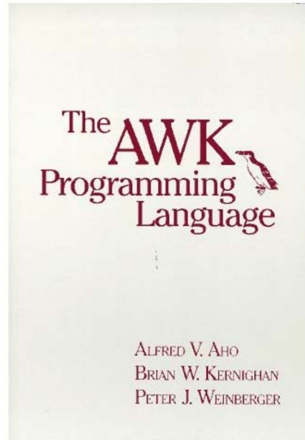
1 bottle of beer on the wall, 1 bottle of beer.
Take one down and pass it around, no more bottles of beer on the wall.

No more bottles of beer on the wall, no more bottles of beer.
Go to the store and buy some more, 99 bottles of beer on the wall.

[Traditional]

“99 Bottles of Beer” in AWK

```
BEGIN {
 for(i = 99; i >= 0; i--) {
  print ubottle(i), "on the wall,", lbottle(i) "."
  print action(i), lbottle(inext(i)), "on the wall."
  print
 }
}
function ubottle(n) {
 return sprintf("%s bottle%s of beer", n ? n : "No more", n - 1 ? "s" : "")
}
function lbottle(n) {
 return sprintf("%s bottle%s of beer", n ? n : "no more", n - 1 ? "s" : "")
}
function action(n) {
 return sprintf("%s", n ? "Take one down and pass it around," : \
                          "Go to the store and buy some more,")
}
function inext(n) {
 return n ? n - 1 : 99
}
```



[Osamu Aoki, http://people.debian.org/~osamu]

“99 Bottles of Beer” in Perl

```
  ''=~(        '(?{'       .('`'       |'%')       .('['       ^'-')
  .('`'        |'!')       .('`'       |',')       .'"'.       '\\$'
  .'=='        .('['       ^'+')       .('`'       |'/')       .('['
  ^'+')        .'||'       .(';'       &'=')       .(';'       &'=')
  .';-'        .'-'.       '\\$'       .'=;'       .('['       ^'(')
  .('['        ^'.')       .('`'       |'"')       .('!'       ^'+')
 .'_\\{'      .'(\\$'     .';=('.     '\\$=|'     ."\|".(     '`'^'.'
).(('`')|    '/').').'   .'\\"'.+(   '{'^'[').   ('`'|'"')   .('`'|'/'
).('['^'/') .('['^'/'). ('`'|',').( '`'|('%')). '\\".\\"'.( '['^('(')).
'\\"'.('['^ '#').'!!--' .'\\$=.\\"' .('{'^'['). ('`'|'/').( '`'|"\&").(
'{'^"\[").( '`'|"\"").( '`'|"\%").( '`'|"\%").( '['^(')')). '\\").\\"'.
('{'^'[').( '`'|"\/").( '`'|"\.").( '{'^"\[").( '['^"\/").( '`'|"\(").(
'`'|"\%").( '{'^"\[").( '['^"\,").( '`'|"\!").( '`'|"\,").( '`'|(',')).
'\\"\\}'.+( '['^"\+").( '['^"\)").( '`'|"\)").( '`'|"\.").( '['^('/')).
'+_,\\",'.( '{'^('[')). ('\\$;!').( '!'^"\+").( '{'^"\/").( '`'|"\!").(
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'[').("\["^ '+').("\`"| '!').("\["^ '(').("\["^ '(').("\{"^ '[').("\`"|
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'.').("\`"| '.').("\`"| '$')."\,".( '!'^('+')). '\\",_,\\"' .'!'.("\!"^
'+').("\!"^ '+').'\\"'. ('['^',').( '`'|"\(").( '`'|"\)").( '`'|"\,").(
'`'|('%')). '++\\$="})' );$:=('.')^ '~';$~='@'| '(';$^=')'^ '[';$/='`';
```

[Andrew Savage, http://search.cpan.org/dist/Acme-EyeDrops/lib/Acme/EyeDrops.pm]

“99 Bottles of Beer” in the Whitespace Language

[Edwin Brady and Chris Morris, U. Durham]

A Little Bit of Formal Language Theory

An *alphabet* is a finite set of symbols.

{0, 1}, ASCII, UNICODE

A *string* is a finite sequence of symbols.

ε (the empty string), 0101, dog, cat

A *language* is a countably infinite set of strings called *sentences*.

$\{ a^n b^n \mid n \geq 0 \}$, { *s* | *s* is a Java program }, { *s* | *s* is an English sentence }

A language has properties such as a *syntax* and *semantics*.

Language Translation

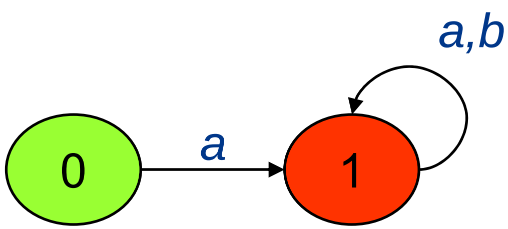
Given a source language *S*, a target language *T*, and a sentence *s* in *S*, map *s into* a sentence *t* in T that has the same meaning as *s*.

Specifying Syntax: Regular Sets

Regular expressions **generate the regular sets**

a*(*a*|*b*)* generates all strings of *a*'s and *b*'s beginning with an *a

Finite automata **recognize the regular sets**



Some Regular Sets

All words with the vowels in order

`facetiously`

All words with the letters in increasing lexicographic order

`aegilops`

All words with no letter occurring more than once

`dermatoglyphics`

Comments in the programming language C

```
/* any string without a star followed by a slash */
```

Some Regular Expression Pattern-Matching Tools

egrep

```
egrep 'a.*e.*i.*o.*u.*y' /usr/dict/words
```

AWK

C

Java

JavaScript

Lex

Perl

Python

Ruby

Context-Free Languages

Context-free grammars generate the CFLs

Let *G* be the grammar with productions $S \rightarrow aSbS \mid bSaS \mid \varepsilon$.

The language denoted by *G* is all strings of *a*'s and *b*'s with the same number of *a*'s as *b*'s.

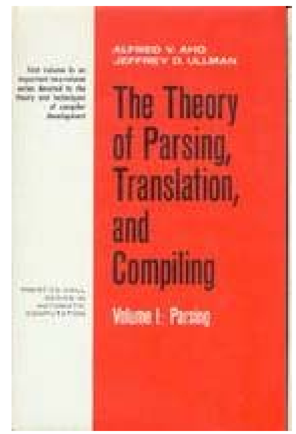
Parsing algorithms for recognizing the CFLs

Earley's algorithm

Cocke-Younger-Kasami algorithm

Top-down LL(k) parsers

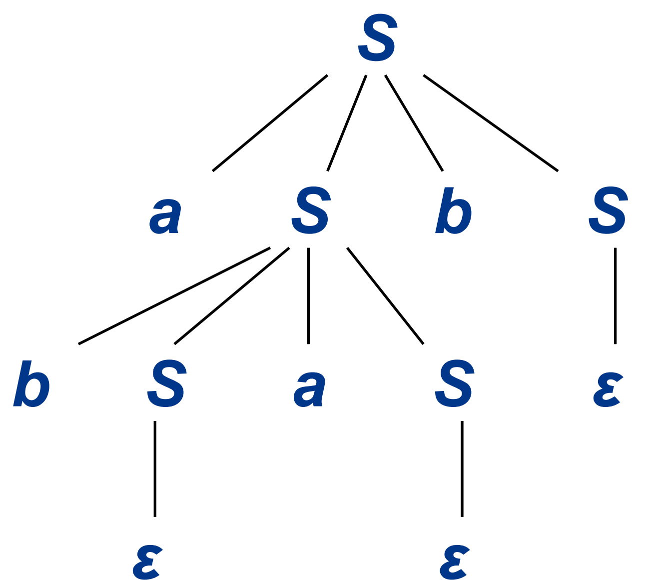
Bottom-up LR(k) parsers

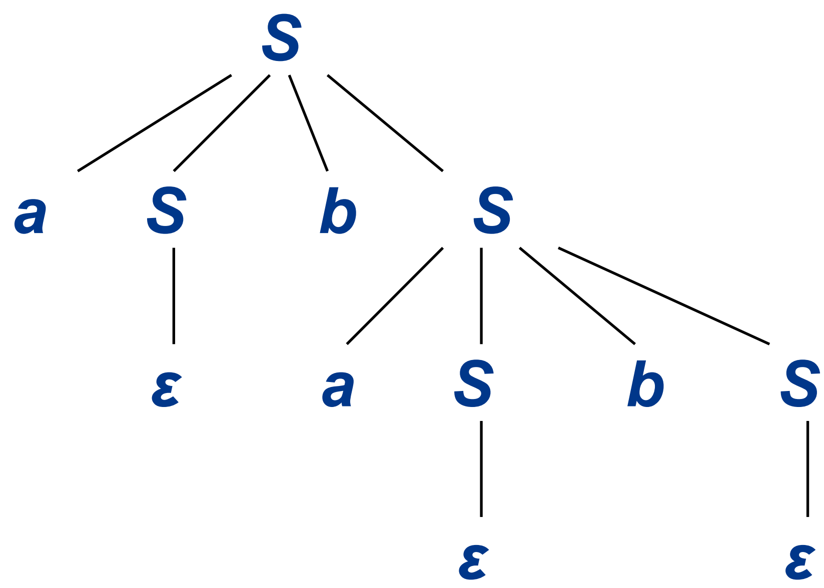


Ambiguity in Grammars

Grammar $S \rightarrow aSbS \mid bSaS \mid \varepsilon$ generates all strings of *a*'s and *b*'s with the same number of *a*'s as *b*'s.

This grammar is ambiguous: abab has two parse trees.





$(ab)^n$ has $\frac{1}{n+1}\binom{2n}{n}$ parse trees

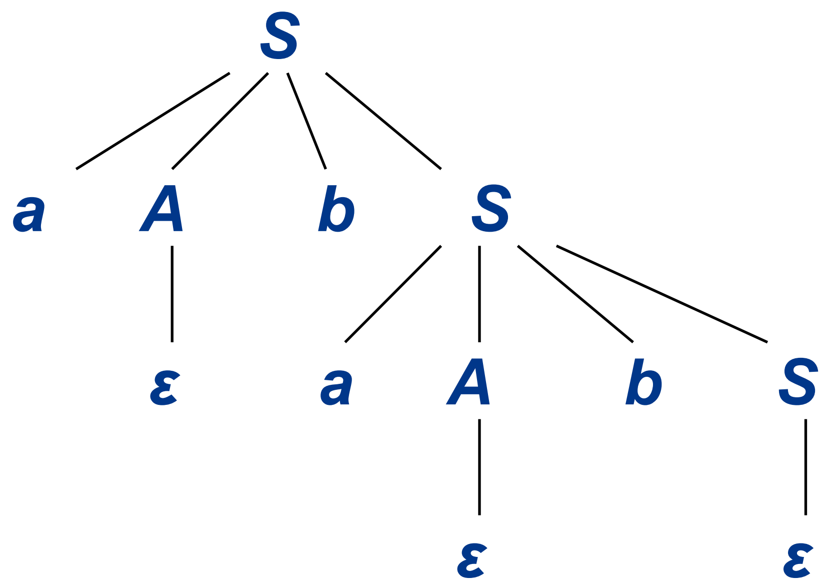
Programming Languages are not Inherently Ambiguous

The grammar *G* generates the same language

$S \rightarrow aAbS \mid bBaS \mid \varepsilon$

$A \rightarrow aAbA \mid \varepsilon$

$B \rightarrow bBaB \mid \varepsilon$



***G* is unambiguous and has only one parse tree for every sentence in *L*(*G*).**

Natural Languages are Inherently Ambiguous

I made her duck.

[5 meanings: D. Jurafsky and J. Martin, 2000]

One morning I shot an elephant in my pajamas. How he got into my pajamas I don't know.

[Groucho Marx, *Animal Crackers*, 1930]

List the sales of the products produced in 1973 with the products produced in 1972.

[455 parses: W. Martin, K. Church, R. Patil, 1987]

Methods for Specifying the Semantics of Programming Languages

Operational semantics

translation of program constructs to an understood language

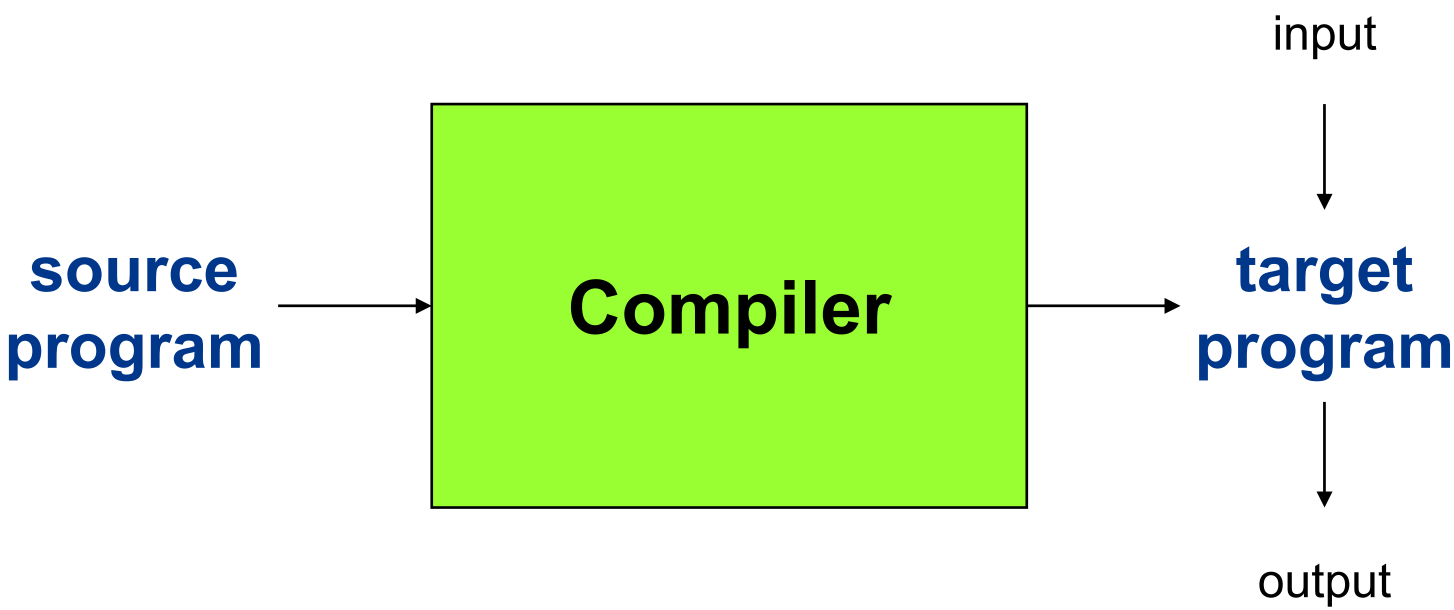
Axiomatic semantics

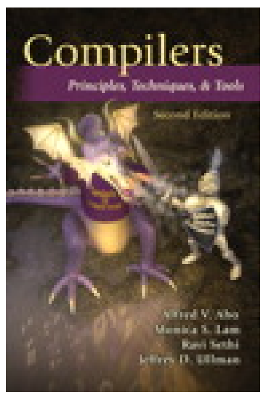
assertions called preconditions and postconditions specify the properties of statements

Denotational semantics

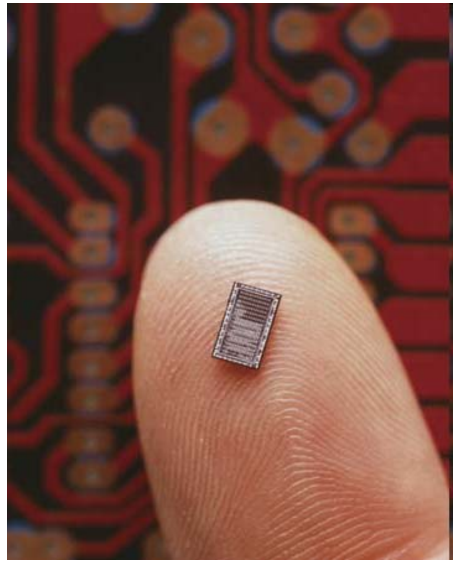
semantic functions map syntactic objects to semantic values

Translation of Programming Languages





Target Languages



Another programming language

CISCs

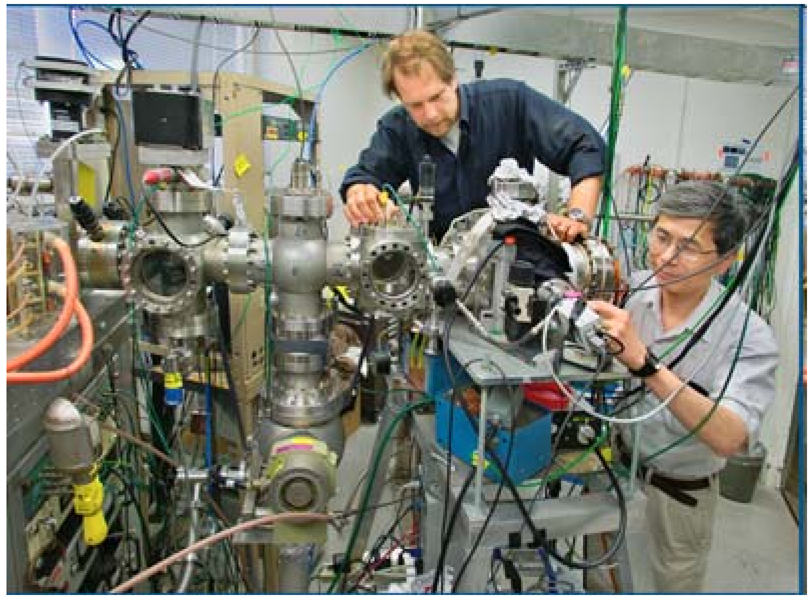
RISCs

Vector machines

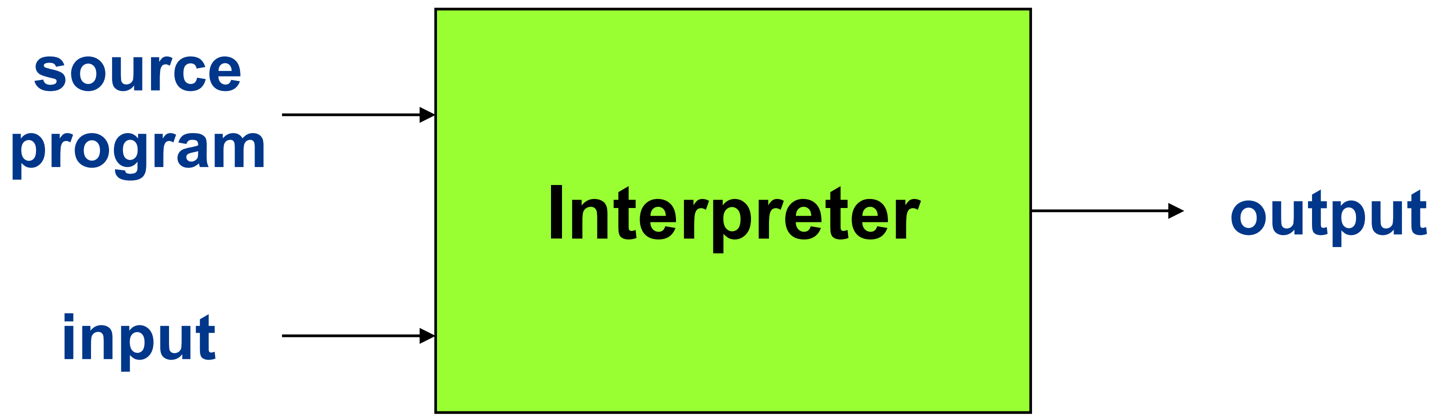
Multicores

GPUs

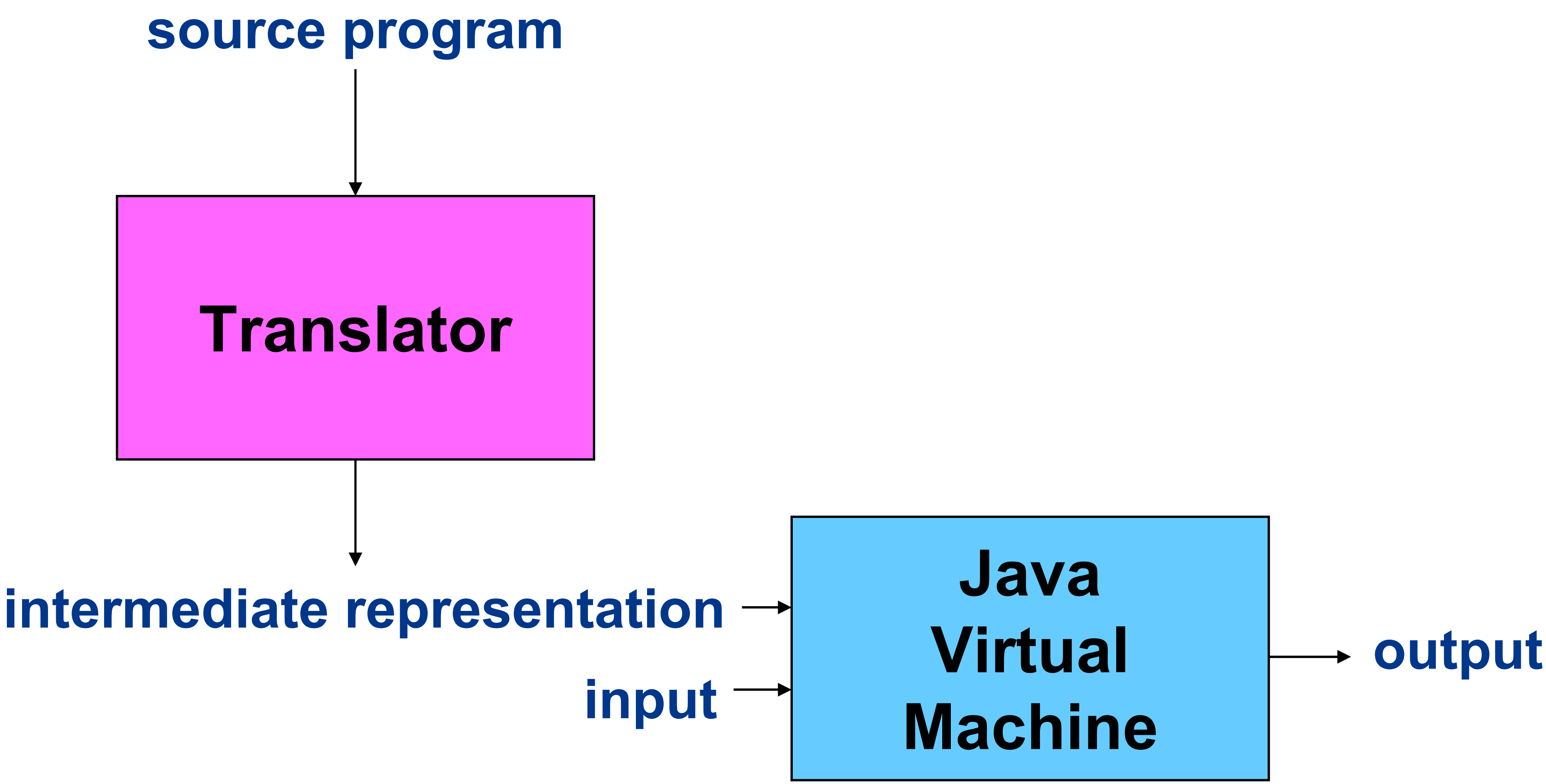
Quantum computers



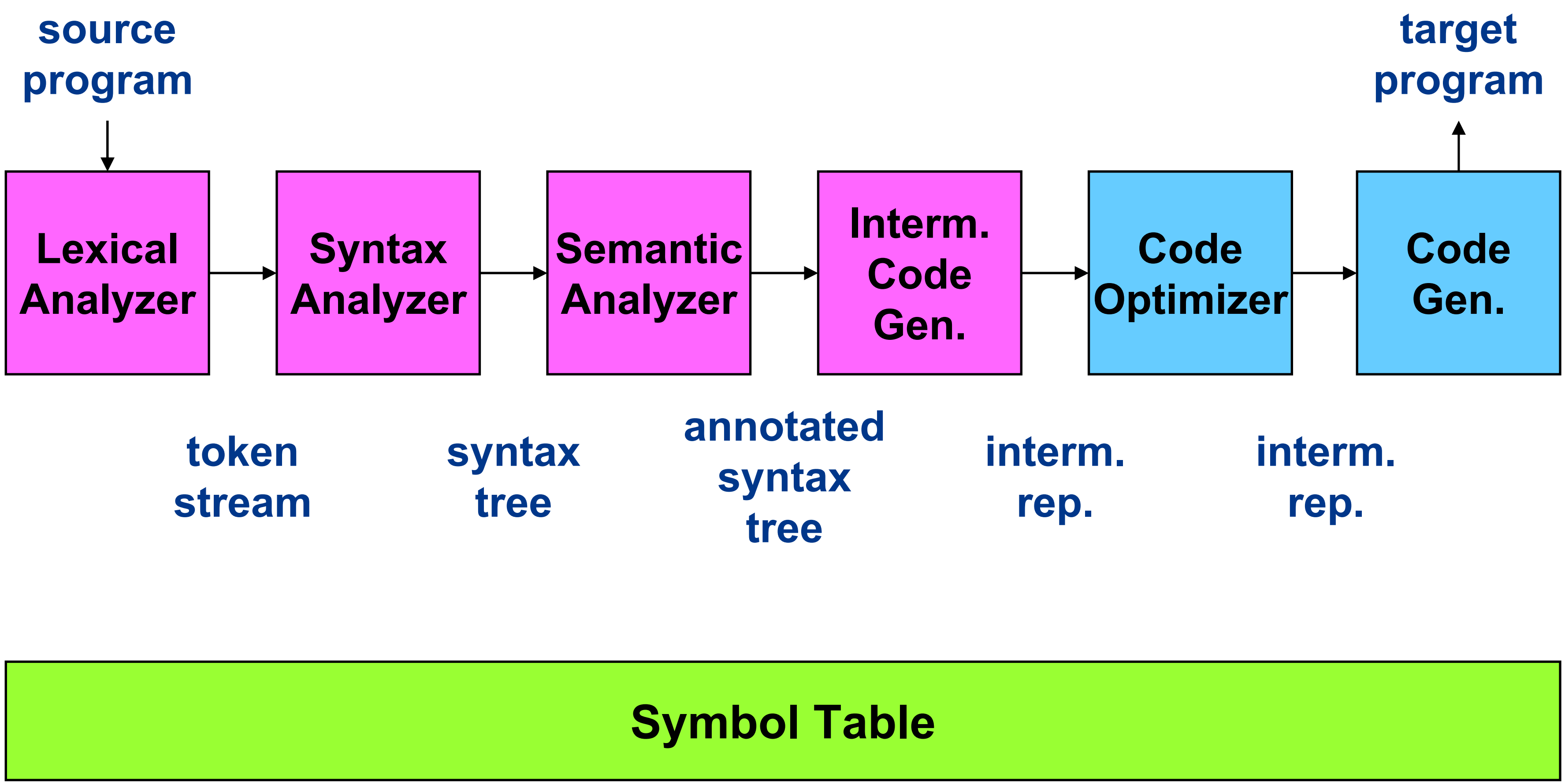
An Interpreter Directly Executes a Source Program on its Input



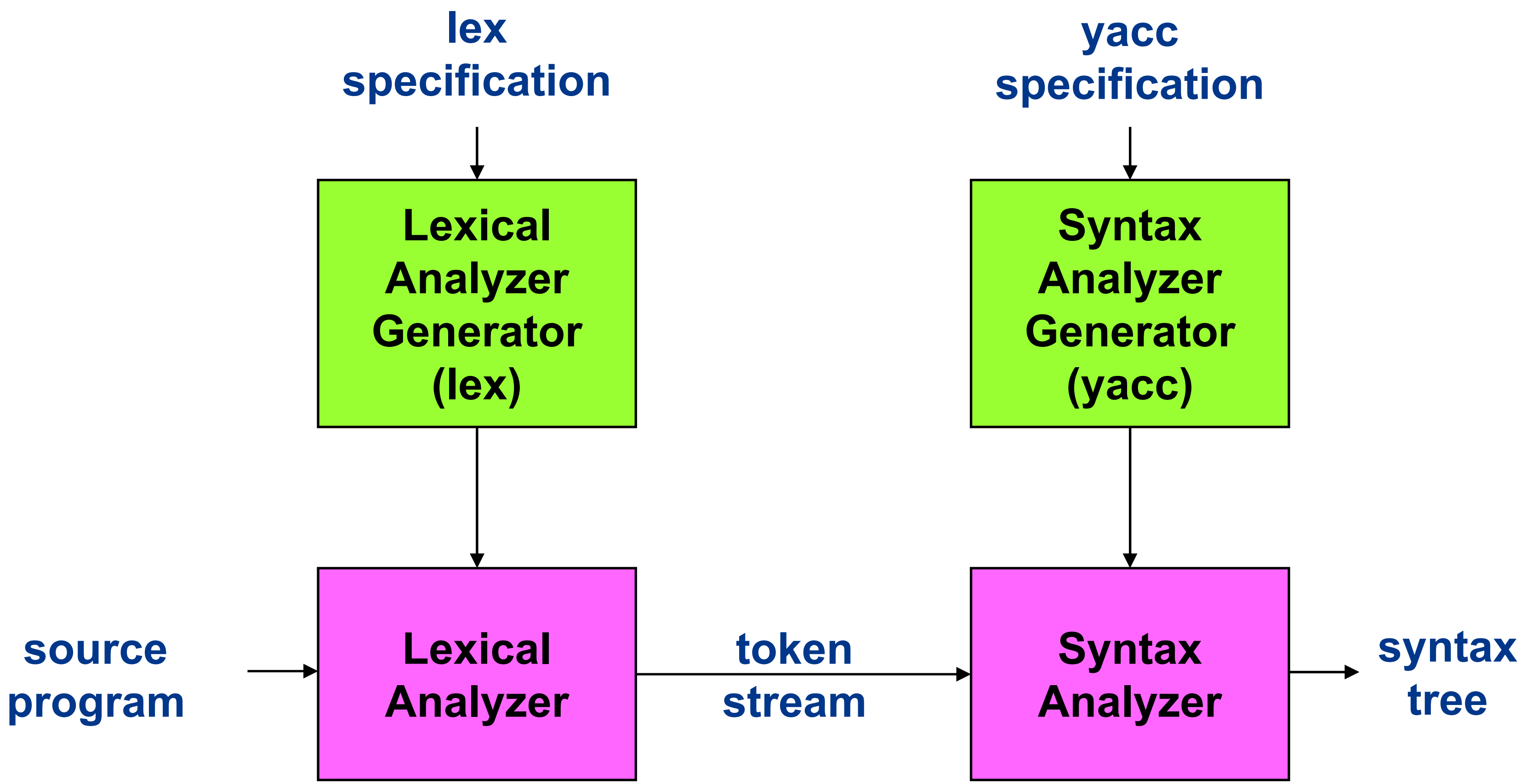
Java Compiler



Phases of a Classical Compiler



Compiler Component Generators



Lex Specification for a Desk Calculator

```
number      [0-9]+\.?|[0-9]*\.[0-9]+
%%
[ ]         { /* skip blanks */ }
{number}    { sscanf(yytext, "%lf", &yylval);
              return NUMBER; }
\n|.        { return yytext[0]; }
```

Yacc Specification for a Desk Calculator

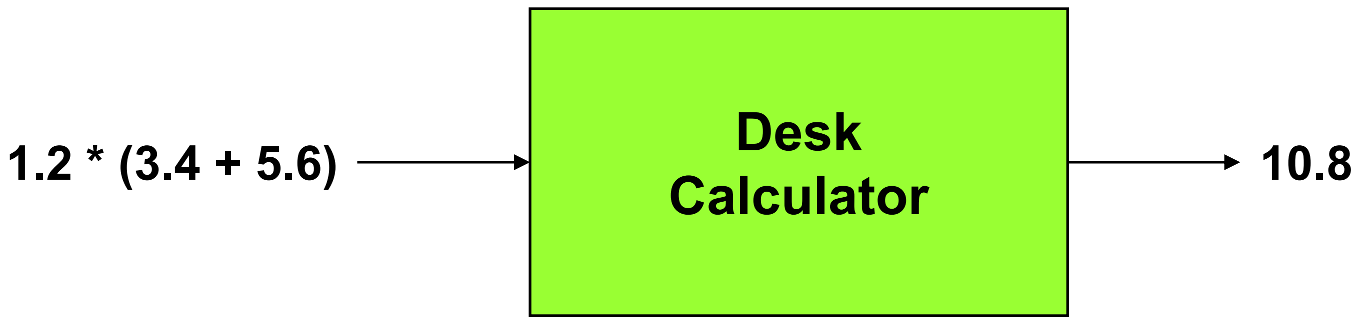
```
%token NUMBER
%left '+'
%left '*'
%%
lines : lines expr '\n' { printf("%g\n", $2); }
      | /* empty */
      ;
expr  : expr '+' expr   { $$ = $1 + $3; }
      | expr '*' expr   { $$ = $1 * $3; }
      | '(' expr ')'    { $$ = $2; }
      | NUMBER
      ;
%%
#include "lex.yy.c"
```

Creating the Desk Calculator

Invoke the commands

```
lex desk.l
yacc desk.y
cc y.tab.c –ly –ll
```

Result



The Compilers Course at Columbia University

Week	Task
2	Form a team of five and think of an innovative new language
4	Write a whitepaper on your proposed language modeled after the Java whitepaper
8	Write a tutorial patterned after Chapter 1 and a language reference manual patterned after Appendix A of Kernighan and Ritchie's book, *The C Programming Language*
14	Give a ten-minute presentation of the language to the class
15	Give a 30-minute working demo of the compiler to the teaching staff
15	Hand in the final project report

Some of the Languages Created in the Compilers Course in the Spring Semester 2009

AMFM: a fractal music composition language

GWAPL: a language for designing games with a purpose

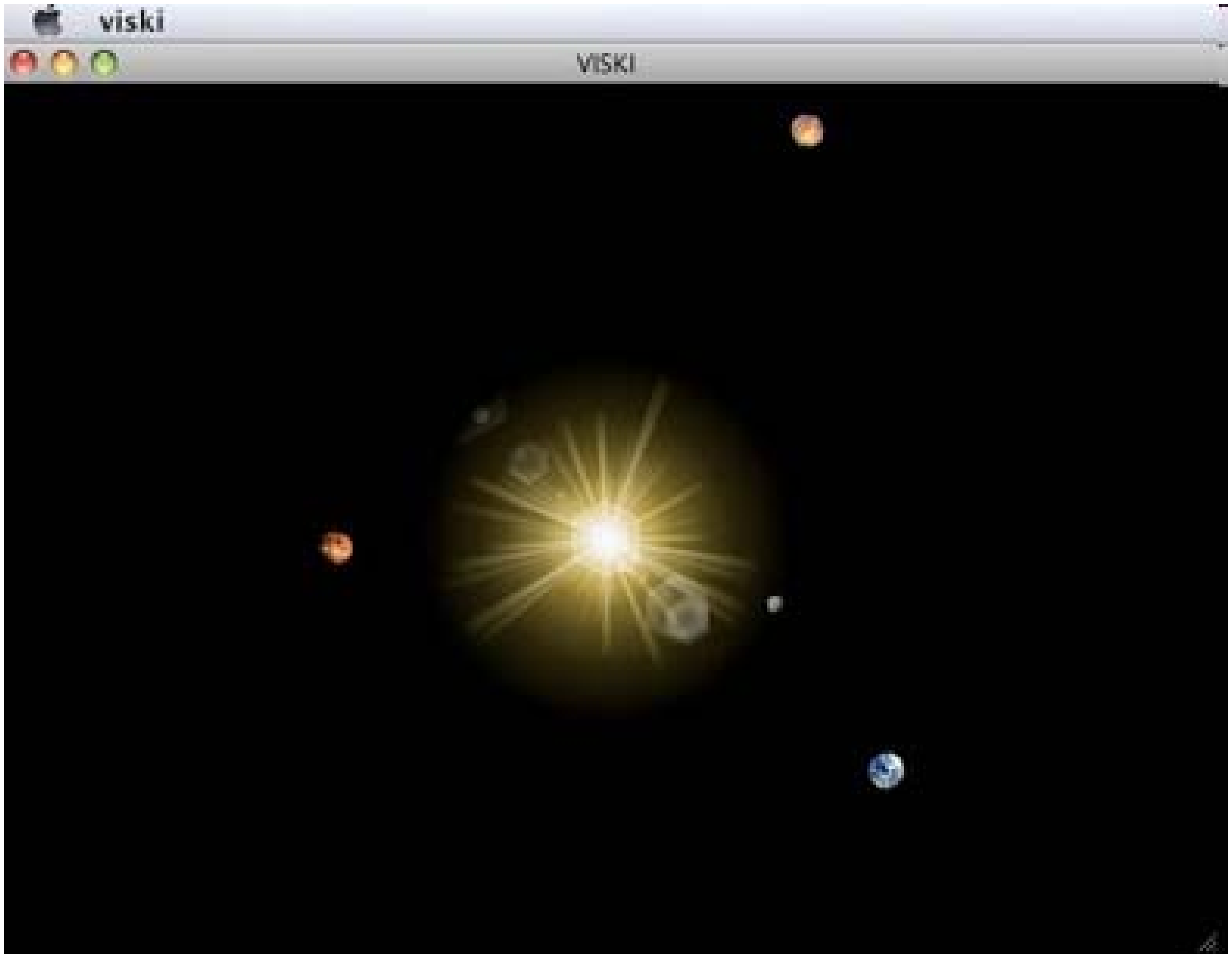
PIGASUS: a language for distributed computing

ROBOT: a language for learning programming

sn*w: a language for specifying genetic algorithms

viski: a language for 2d animations

viski simulation of the inner planets



[V. Narla, I. Deliz, S. Dey, K. Ramasamy, I. Greenbaum: http://www.viski2d.com/]

The Concern-Location Problem in Software

A concern is any consideration that can impact the implementation of a program.

What program elements are relevant to a concern?

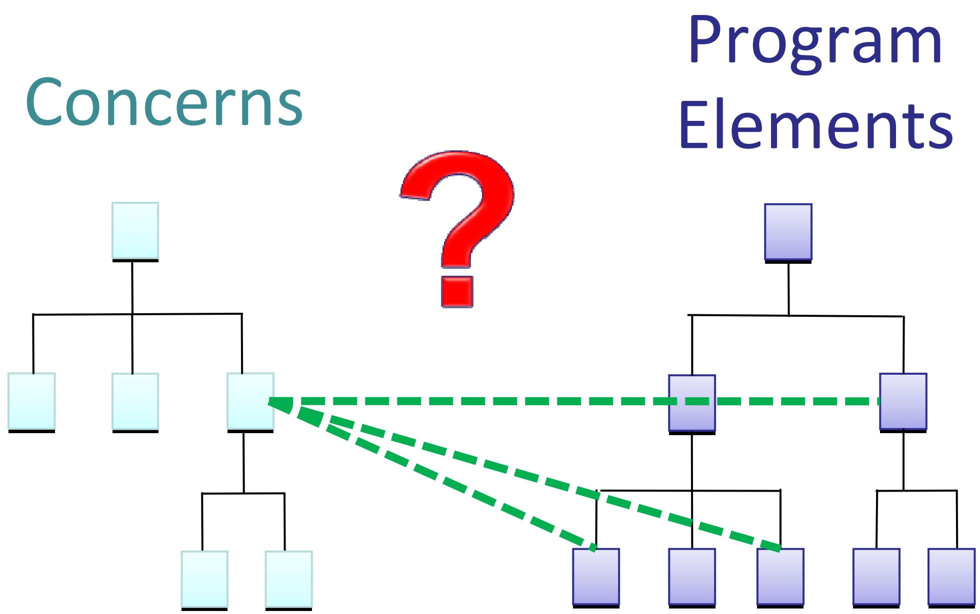
More than 50% of the cost of developing a program is spent in maintenance.

More than 50% of the maintenance time is spent understanding the program.

Natural language information retrieval and compiler program analysis techniques can help!

Concern-Location Problem

What program elements are relevant to a concern?



Concern location is vital for debugging, software evolution and systems maintenance.

Concern–code relationships are often undocumented.

How can we construct these relationships reliably?

Marc Eaddy's Prune Dependency Rule

A program element is relevant to a concern if the program element should be removed or otherwise altered when the concern is pruned.

Code dependent on removed code may need be altered to prevent compile errors.

Easy (but time consuming) for humans to apply.

[M. Eaddy, A. Aho, G. Murphy,
Identifying, Assigning, and Quantifying Crosscutting Concerns,
ICSE ACOM, 2007]

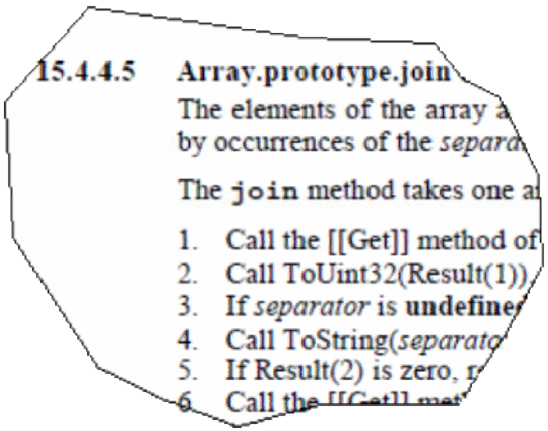
Concern-Location Problem Case Study

ECMAScript Language Specification ECMA-262 v3

International standard for JavaScript

172-page document written in English

360 concerns (“leaf” paragraphs)



15.4.4.5 Array.prototype.join

The elements of the array a
by occurrences of the *separa*

The `join` method takes one a

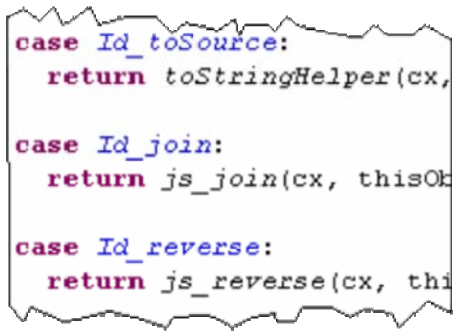
1. Call the [[Get]] method of
2. Call ToUint32(Result(1)).
3. If *separator* is **undefine**
4. Call ToString(*separato*
5. If Result(2) is zero, r
6. Call the [[Get]] met

RHINO JavaScript Interpreter Version 1.5R6

32,134 source lines of Java code

1,870 methods

1,339 fields



```
case Id_toSource:
  return toStringHelper(cx,

case Id_join:
  return js_join(cx, thisOb

case Id_reverse:
  return js_reverse(cx, thi
```

Manual Concern Location

Concern–code relationship determined by a human

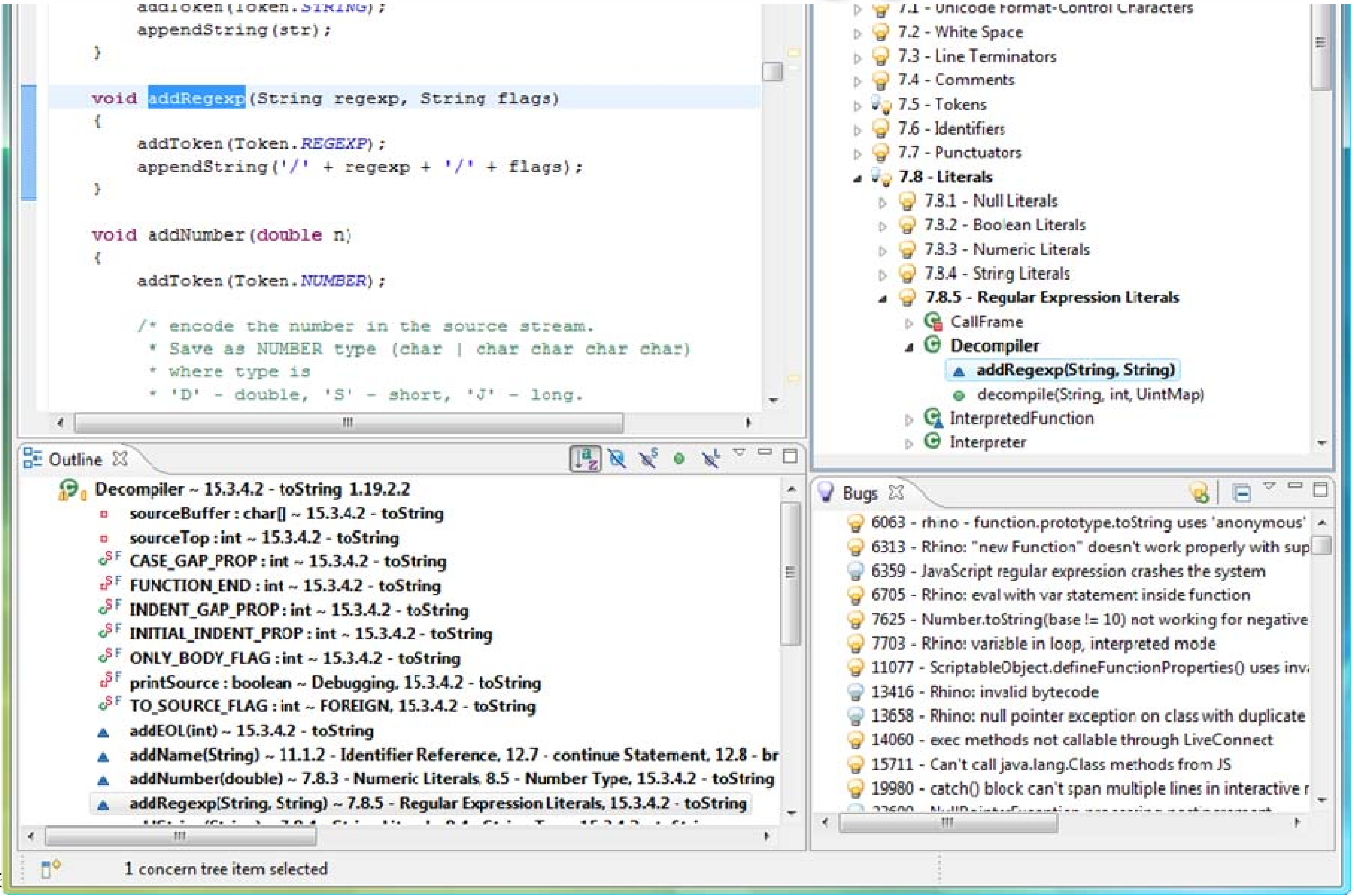
Existing tools were impractical for analyzing all concerns of a real system

- –Many concerns (>100)
- –Many concern–code links (>10K)
- –Hierarchical concerns

Eaddy's ConcernTagger System used to assign elements to concerns and determine coverage statistics.

[Eaddy, Zimmerman, Sherwood, Garg, Murphy, Nagappan, Aho
Do Crosscutting Concerns Cause Defects?
IEEE Trans. Software Engineering, 2008]

ConcernTagger



Manual Concern Location

Using ConcernMapper, for a prior study Marc Eaddy had manually determined 10,613 concern-code links between the 360 concerns in the ECMAScript Specification and the 32,134 lines of code in RHINO.

It took him 102 hours!

This extensive effort strongly motivated this work. ☺

Cerberus: Automated Concern Location

Concern–code relationship predicted by "experts"

Experts look for clues in documentation and code

Existing techniques only consult 1 or 2 experts

Cerberus is a system for automated concern location that combines

1. Information retrieval
2. Execution tracing
3. Prune dependency analysis

[Eaddy, Aho, Antoniol, Gueheneuc - *Cerberus: Tracing Requirements to Source Code Using Static, Dynamic, and Semantic Analysis*, IEEE ICPC 2008]

IR-based Concern Location

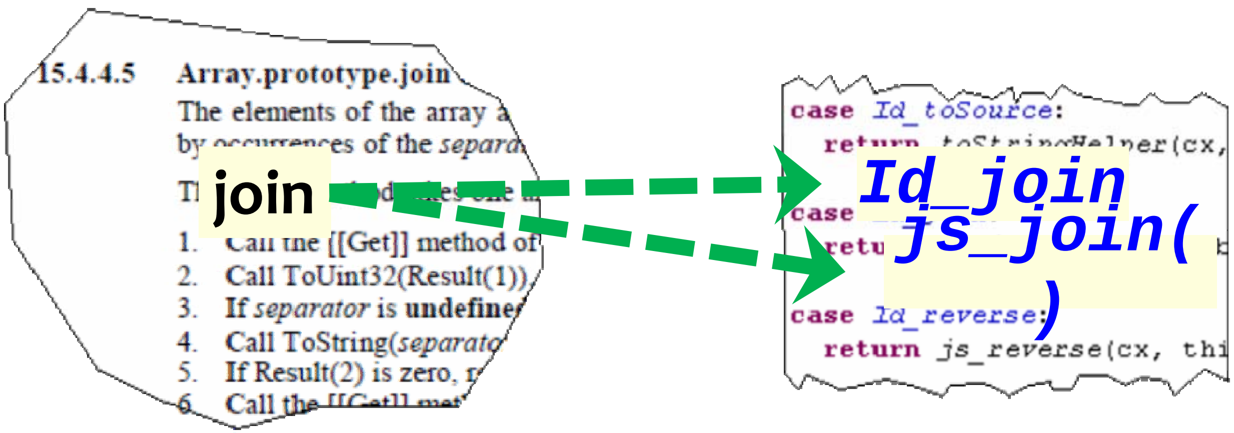
Goal: find locations of program entities relevant to a given requirement (concern)

Program entities are documents

Requirements are queries

Requirement "Array.join"

Source Code



Vector Space Model

Parsed code and requirements to extract term vectors

- NativeArray.js_join() method → "native," "array," "join"
- "Array.join" requirement → "array," "join"

Extensions

- Expanded abbreviations
  - numconns → number, connections, numberconnections
- Indexed field accesses

Term weights computed using standard *tf* × *idf* formula

- Term frequency (*tf*)
- Inverse document frequency (*idf*)

Calculated cosine distance to get similarity score

- Cosine distance between document and query vectors

Execution-tracing-based Concern Location

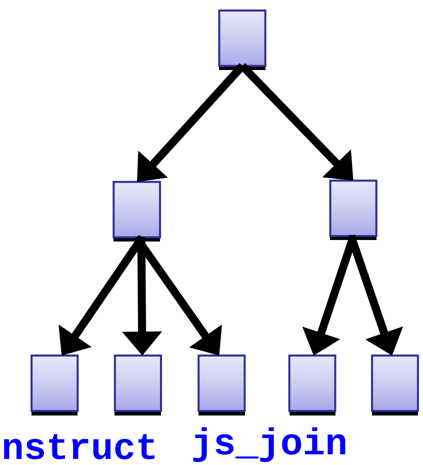
Observed elements activated when concerns executed

- –Analyzed run-time behavior of unit tests when each concern is exercised
- –Found elements uniquely activated by a concern

Unit Test for "Array.join"

```
[illegible]);
if (a.join(',') == "1,2")
{
   print "Test passed";
}
else {
   print "Test failed";
}
```

Call Graph



Execution-tracing-based Concern Location

Compared traces for a set of concerns to distinguish elements specific to a particular concern

Output is a list of methods ranked by their *Element Frequency–Inverse Concern Frequency* score:

$$EF\text{-}ICF = \frac{\#\,element\ activations\ by\ the\ concern}{total\ \#\,element\ activations} \times \log\left(\frac{\#\,concerns\ that\ activate\ any\ element}{\#\,concerns\ that\ activate\ the\ current\ element}\right)$$

Prune Dependency Analysis

Infer code elements related to concerns based on structural relationships to relevant seed elements

- Need to identify initial relevant seed elements

Prune dependency analysis

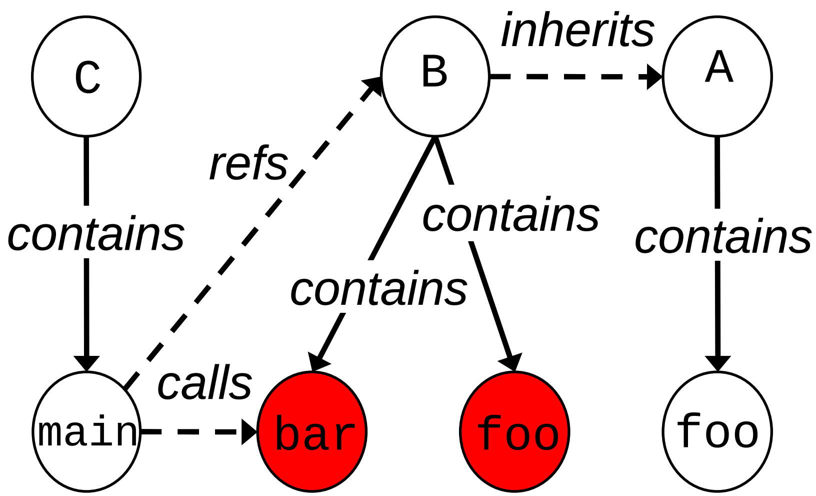
- Automates *prune dependency rule*
- Finds references to a given seed
- Finds superclasses and subclasses of that seed using the program dependency graph

PDA Example

Source Code

```
interface A {
  public void foo();
}
public class B implements A {
  public void foo() { ... }
  public void bar() { ... }
}
public class C {
  public static void main() {
    B b = new B();
    b.bar();
  }
```

Program Dependency Graph



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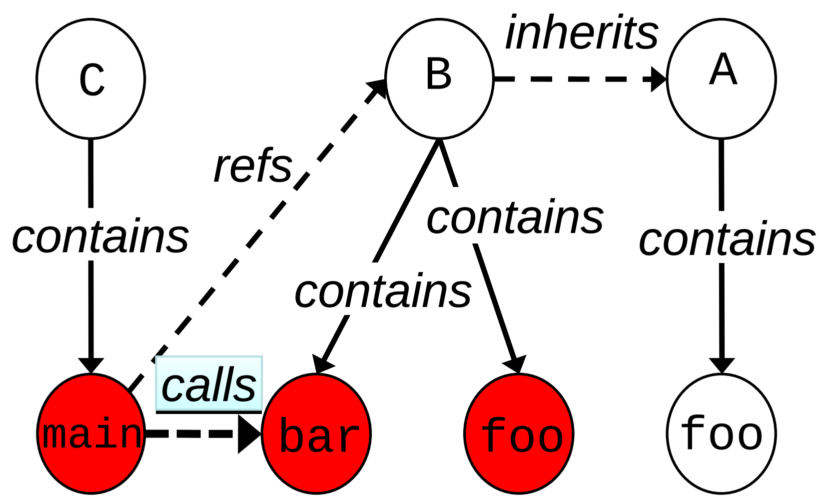

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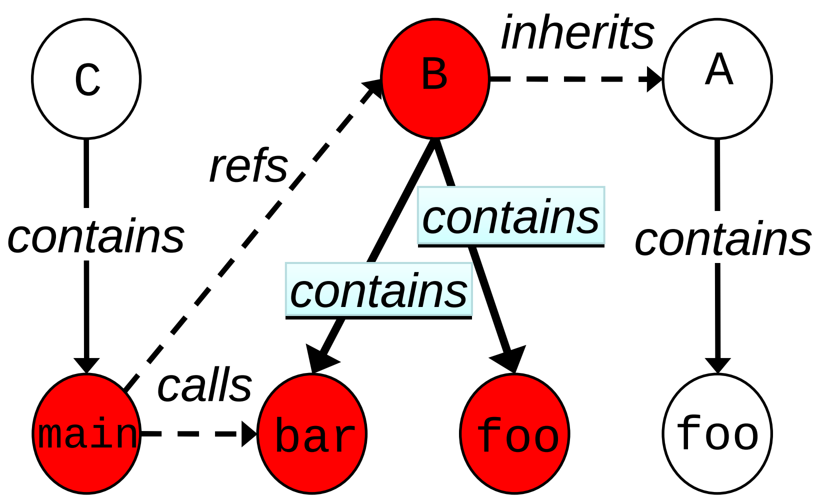
Program Dependency Graph



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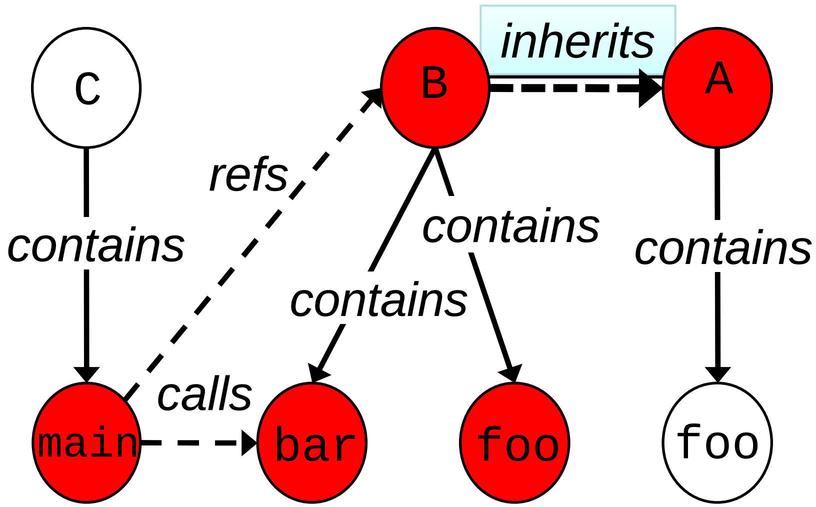
  public static void main() {
    B b = new B();
    b.bar();
  }
```

Program Dependency Graph

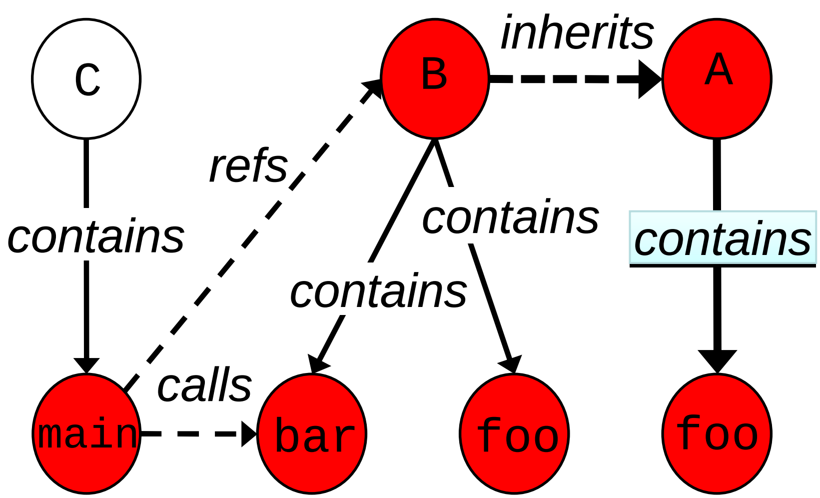


PDA Example

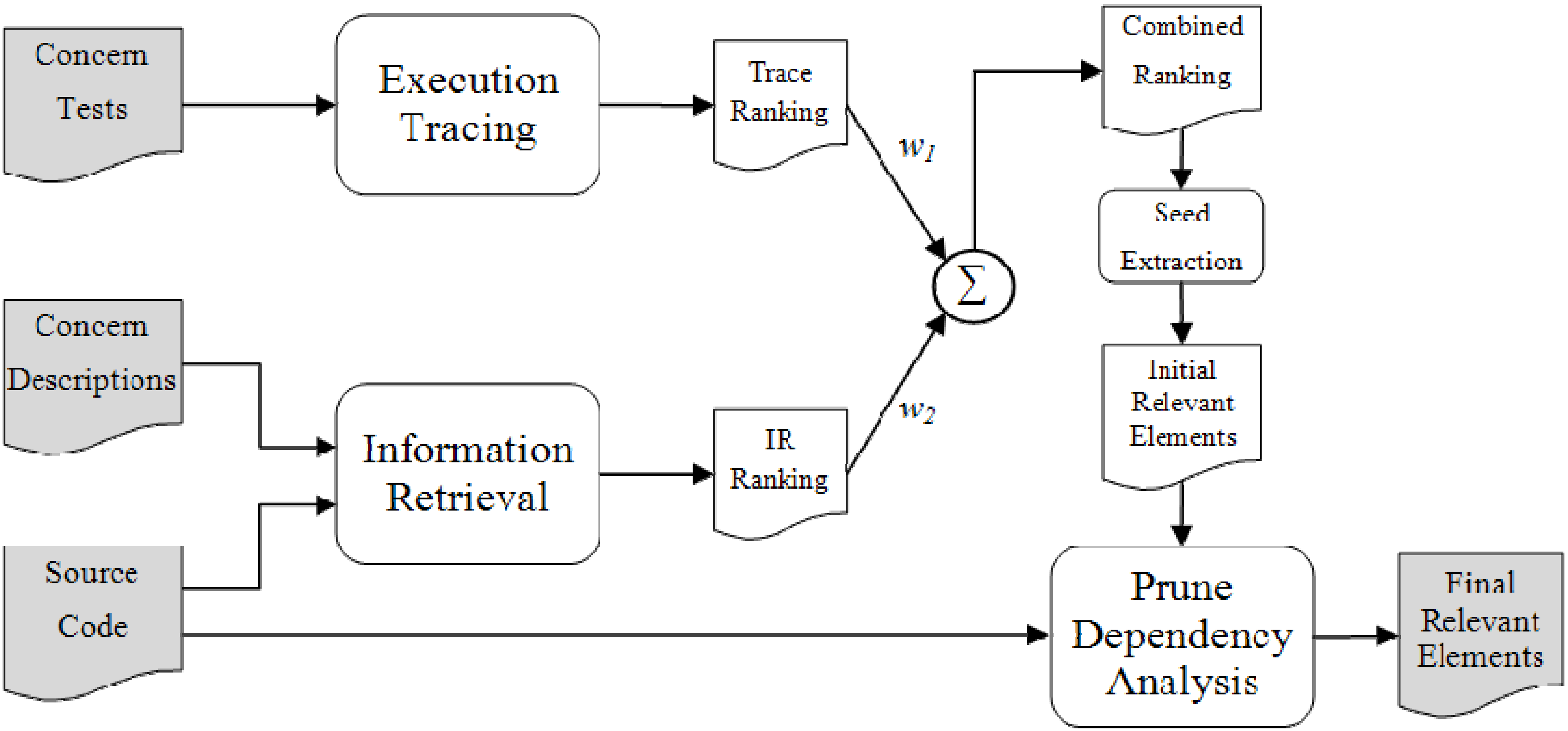
Source Code

```
interface A {
  public void foo();
}
public class B implements A {
  public void foo() { ... }
  public void bar() { ... }
}
public class C {
  public static void main() {
    B b = new B();
    b.bar();
  }
```

Program Dependency Graph



Cerberus System for Concern Location



[M. Eaddy, A. Aho, G. Antoniol, Y-G. Gueheneuc
Cerberus: Tracing Requirements to Source Code Using Static, Dynamic, and Semantic Analysis
IEEE ICPC 2008]

Effectiveness Measures

Precision

P = # relevant elements retrieved / total # retrieved

Recall

R = # relevant elements retrieved / total # relevant

F-Measure = $2PR / (P + R)$

Applying Cerberus to ECMAScript and RHINO

ECMAScript Specification

360 ECMAScript requirements (“concerns”)

939 tests in the ECMAScript test suite cover 67% of the concerns

RHINO Interpreter

4,530 unique RHINO source code terms

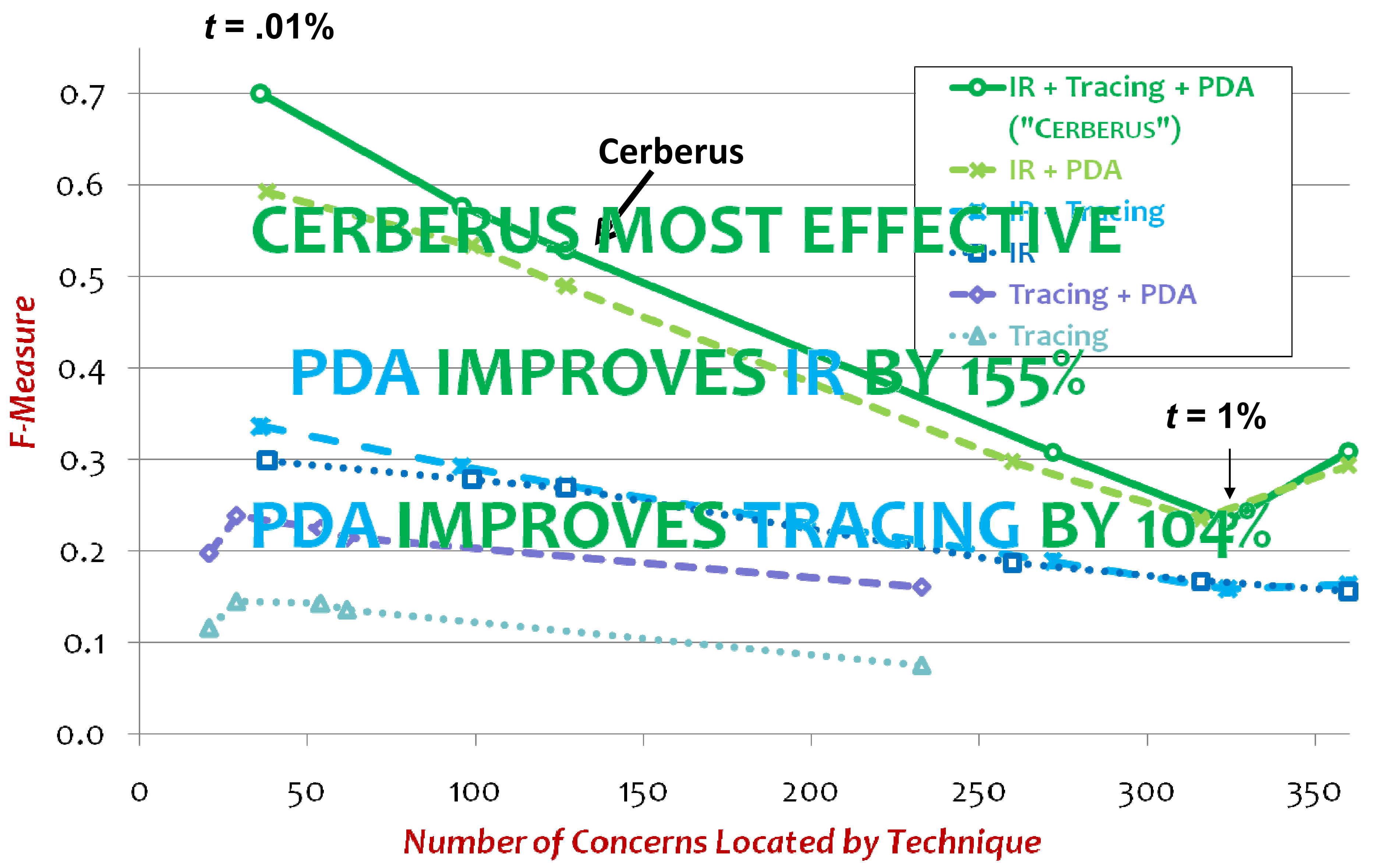
3,345 RHINO documents (one for every type, method, and field)

1,870 methods

Threshold *t*

Concern location technique produces a list of retrieved elements for each concern ranked by a relevance score. Elements whose relevance is below *t* are discarded.

Comparison of Technique Effectiveness



Summary

The combination of the three techniques is the most effective at locating concerns.

- combining expert judgments reduces the impact of “unqualified experts”

Each technique and technique combination is effective at locating concerns.

Prune dependency analysis is effective at boosting the performance of the other techniques.

Open Problems

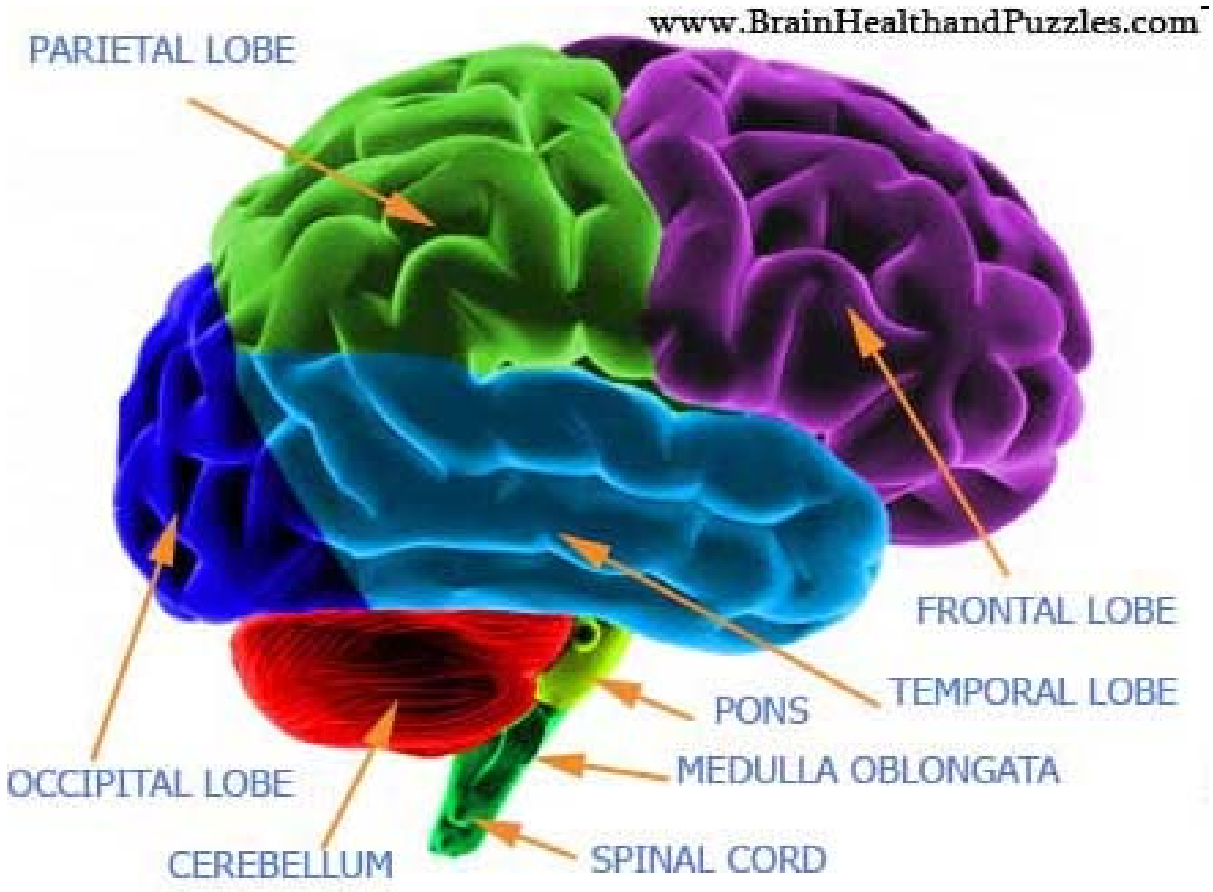
How well do these techniques work in other software domains?

Are there better combinations of techniques?

Is there an effective software engineering process for keeping track of concern-location relationships in requirements and code?

Can we use NLP + PLP techniques to produce better documentation for software?

Ultimate Open Problem: Is there a good computational model for the human brain?



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Thanks for Listening!

Unnatural Language Processing

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