COMP 520 - Compilers

Lecture 6 (Tue Feb 1, 2022)

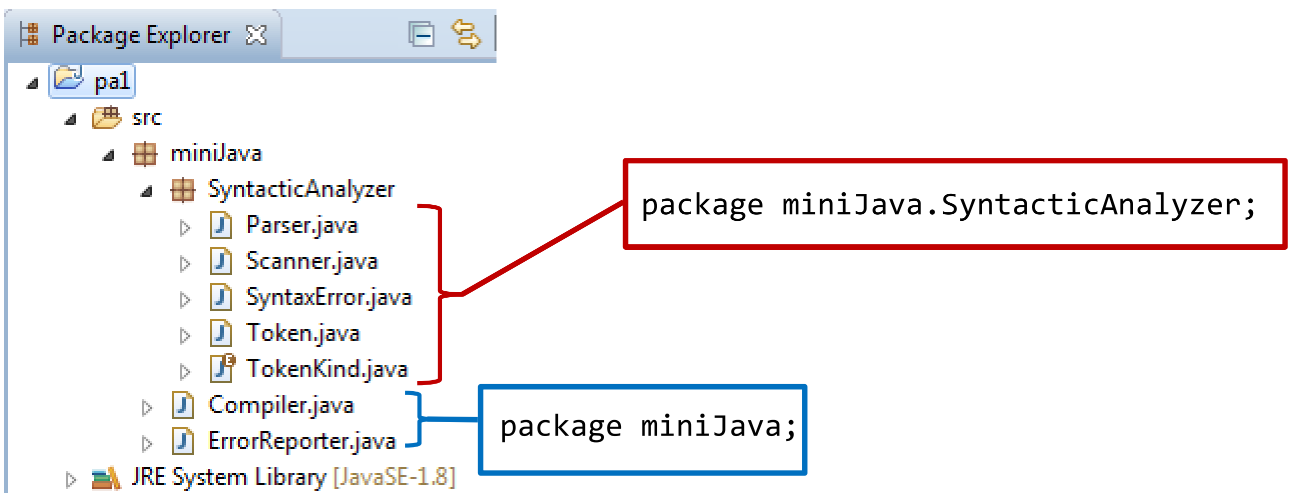
Structure and Operation of Compilers

- PA1 due date: extended to Wed Feb 2, 11.59 PM
  - Submission instructions on slides 2 – 5 below

- Reading assignment for Thu Feb 3
  - Skim secn 4.4 pp 109 -118 (Abstract Syntax Trees)

PA1 submission

- Java project structure for pa1
  - Package names
    - `miniJava`
    - `miniJava.SyntacticAnalyzer`
  - Main class
    - `Compiler.java` in package `miniJava`



Sample compiler.java

```
package miniJava;

import java.io.FileInputStream;
import java.io.FileNotFoundException;
import java.io.InputStream;

import miniJava.SyntacticAnalyzer.Parser;
import miniJava.SyntacticAnalyzer.Scanner;

public class Compiler {

    public static void main(String[] args) {
        InputStream inputStream = null;
        try {
            inputStream = new FileInputStream(args[0]);
        } catch (FileNotFoundException e) {
            System.out.println("Input file " + args[0] + " not found");
            System.exit(1);
        }

        ErrorReporter errorReporter = new ErrorReporter();
        Scanner scanner = new Scanner(inputStream, errorReporter);
        Parser parser = new Parser(scanner, errorReporter);

        System.out.println("Syntactic analysis ... ");
        parser.parse();
        System.out.print("Syntactic analysis complete:  ");
        if (errorReporter.hasErrors()) {
            System.out.println("Invalid miniJava program");
            System.exit(4);
        }
        else {
            System.out.println("Valid miniJava program");
            System.exit(0);
        }
    }

}
```

return exit code 1
if unable to open
input file

return these exit codes
for invalid / valid
miniJava programs

Project submission on server

- Submission instructions
  1. You do not have a home directory on comp520-1sp22.cs.unc.edu
     so run the simple readiness check `pa1.pl` on your own machine or a department server. You'll receive either
     - an indication that your submission passes the top level check – Great! you're all set!
     - an error in one of several simple miniJava programs -- correct this and rerun
  2. Copy your miniJava directory and subdirectories directly into your pa1 submission folder (once it has been created)
     - `scp –pr miniJava comp520-1sp22.cs.unc.edu/home/submit/onyen/pa1`

- Advice
  – try uploading something before the 11.59 pm deadline to avoid unwelcome surprises
  – The grader will run sometime after the deadline and will generate a test report in your pa1 submission directory

- Note: check Piazza for info/updates

How compilers are organized

- Today's topics
  - Steps in the compilation process
  - Illustration of the steps for a Triangle program
  - parts of the compiler and their relation to the compiler specification
  - a bird's eye view of implementation

Phases of compilation

Front end: lexical analysis through Contextual analysis; Back end: Optimization and Code generation

Unified in PLPJ text: lexical analysis, syntactic analysis

Phase	Input	Output
lexical analysis (scanner)	character stream	tokens
syntactic analysis (parser)	tokens	abstract syntax tree (AST)
Contextual analysis (type checker / identifier resolution)	AST	decorated AST
optional Optimization	decorated AST	decorated AST
Code generation	decorated AST	machine instructions

FE: Lexical Analysis (Triangle)

- Recognize the meaningful units in the source code
  - input: character stream

```
! this is part of a Triangle program
while  b  do
   begin
      n := 0;
      b := false
   end
```

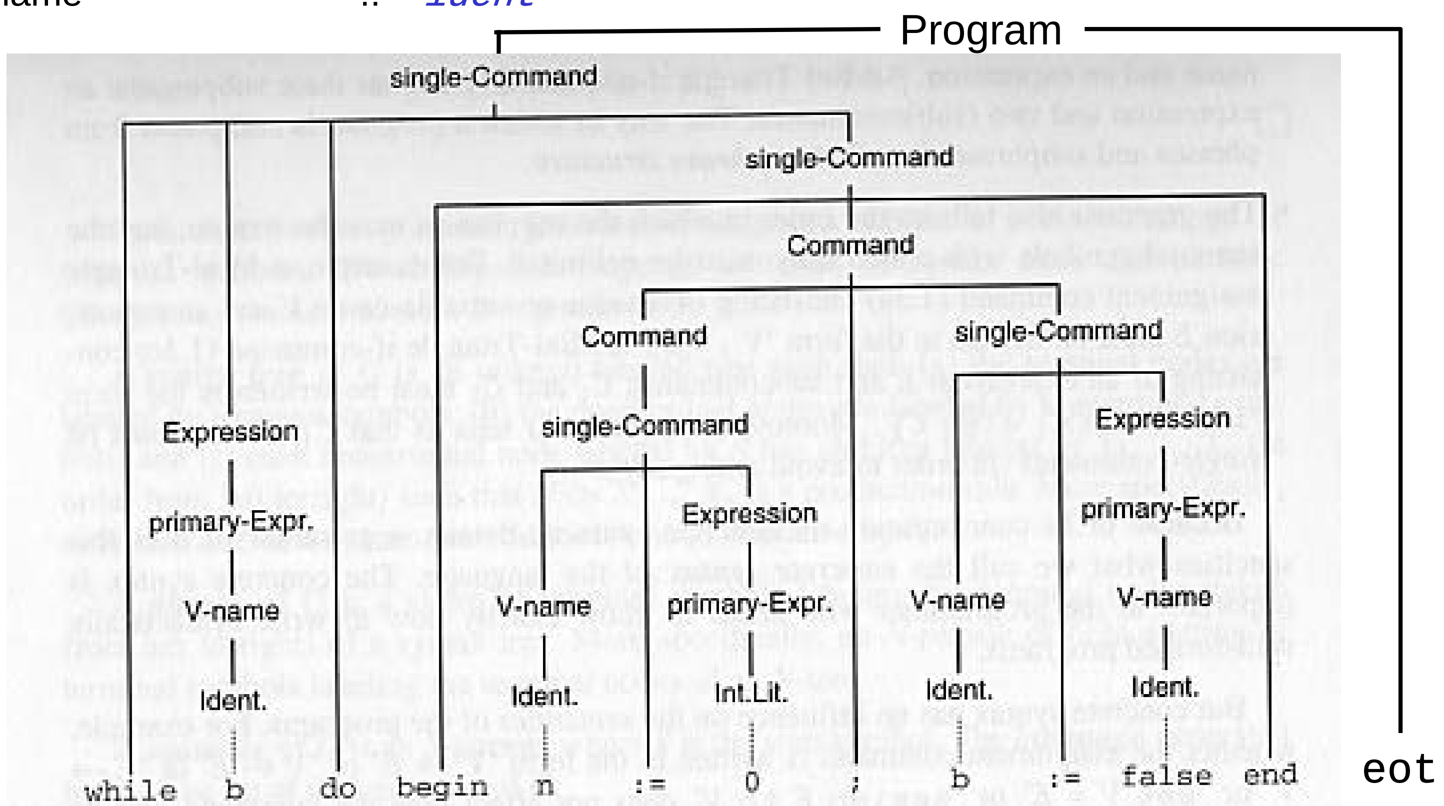
  - output: token stream

while	b	do	begin	n	:=	0	;	b	:=	false	end	
while	*ident* b	do	begin	*ident* n	:=	*inLit* 0	;	*ident* b	:=	*ident* false	end	eot

FE: Syntactic Analysis (Triangle)

- Use Triangle grammar to parse token stream into (concrete) syntax tree

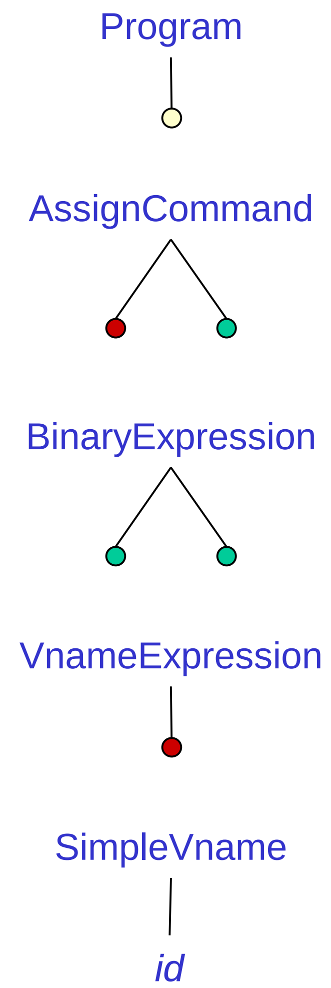
Program ::= Single-Command *eot*
Command ::= Single-Command | Command ; Single-Command
Single-Command ::= while Expression do Single-Command | V-name := Expression
| begin Command end | ...
Expression ::= Primary-Expression | ...
Primary-Expression ::= *intLit* | V-name | ...
V-name ::= *ident*



FE: Construct Abstract Syntax Tree

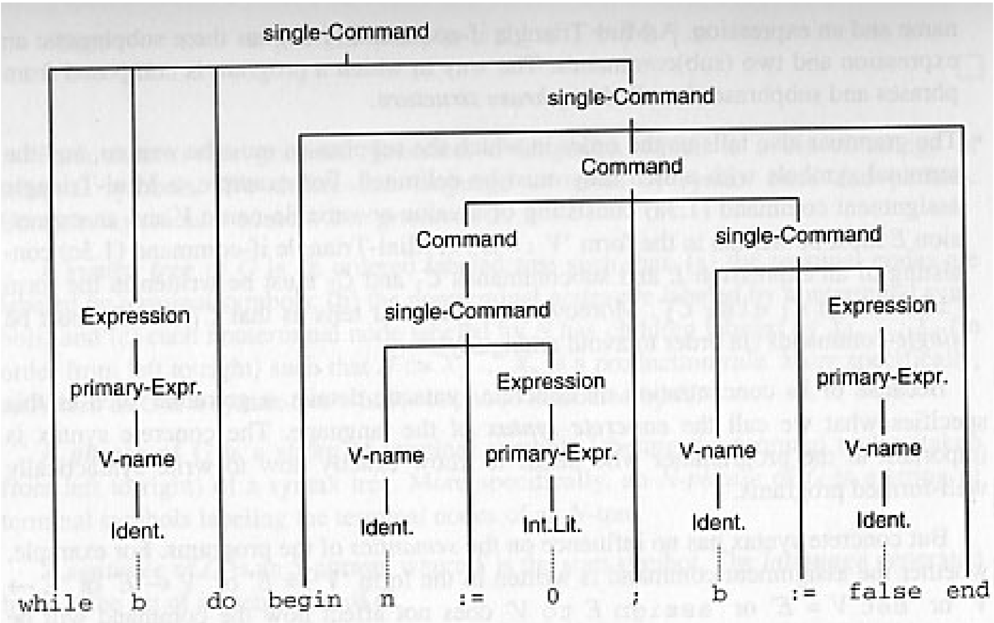
- While parsing concrete syntax tree, construct the abstract syntax tree

Program	::=	Command	Program	(1.14)
Command	::=	V-name **:=** Expression	AssignCommand	(1.15a)
	|	Identifier **(** Expression **)**	CallCommand	(1.15b)
	|	Command **;** Command	SequentialCommand	(1.15c)
	|	**if** Expression **then** Command **else** Command	IfCommand	(1.15d)
	|	**while** Expression **do** Command	WhileCommand	(1.15e)
	|	**let** Declaration **in** Command	LetCommand	(1.15f)
Expression	::=	Integer-Literal	IntegerExpression	(1.16a)
	|	V-name	VnameExpression	(1.16b)
	|	Operator Expression	UnaryExpression	(1.16c)
	|	Expression Operator Expression	BinaryExpression	(1.16d)
V-name	::=	Identifier	SimpleVname	(1.17)
Declaration	::=	**const** Identifier **~** Expression	ConstDeclaration	(1.18a)
	|	**var** Identifier **:** Type-denoter	VarDeclaration	(1.18b)
	|	Declaration **;** Declaration	SequentialDeclaration	(1.18c)
Type-denoter	::=	Identifier	SimpleTypeDenoter	(1.19)



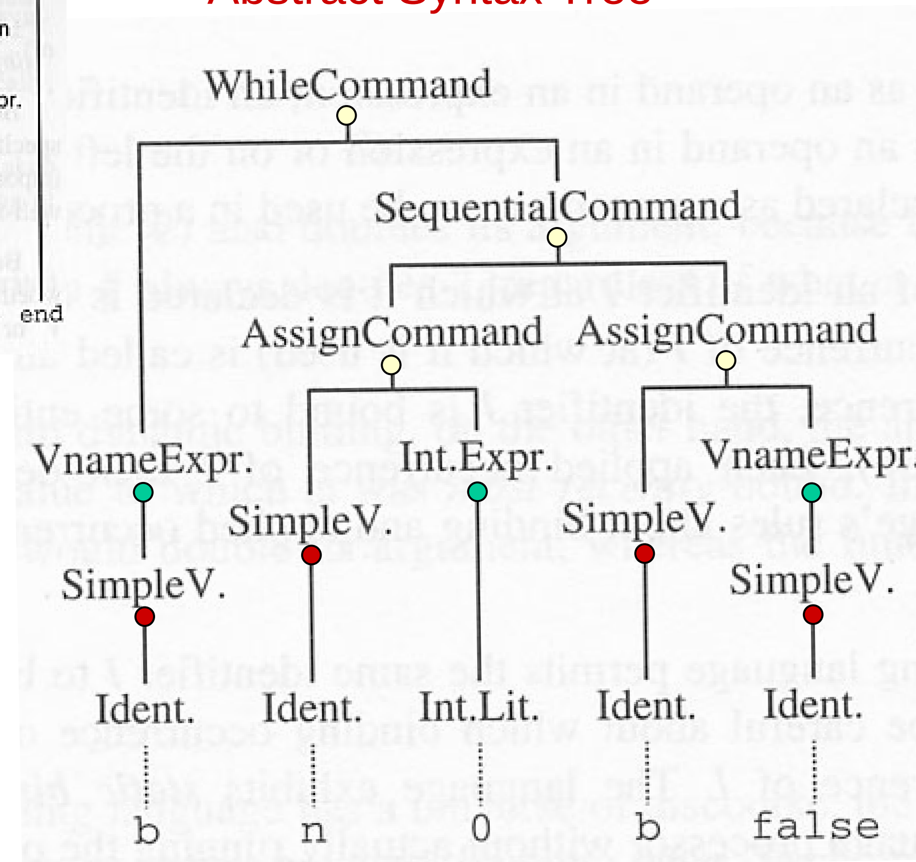
AST “grammar” for mini-Triangle

FE: Construct Abstract Syntax Tree (Triangle)



Concrete Syntax Tree

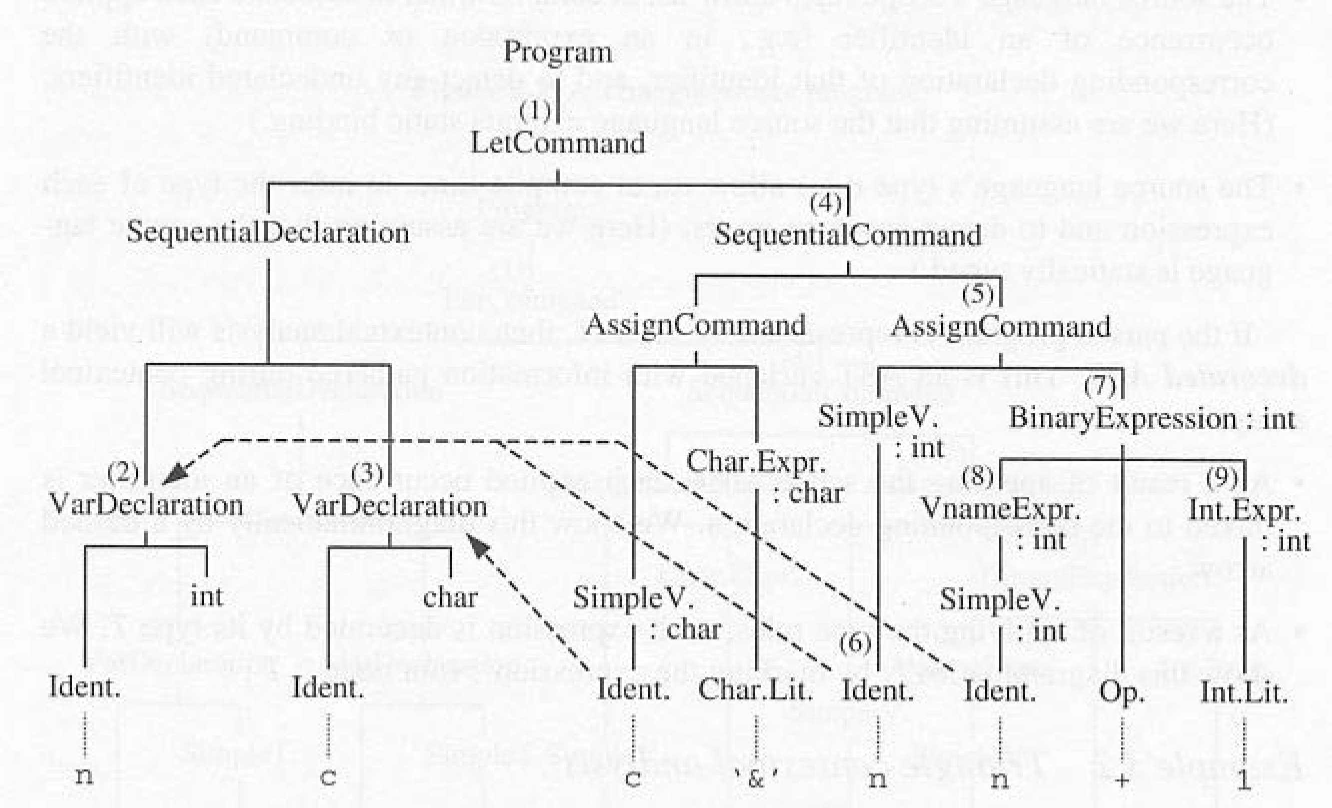
Abstract Syntax Tree



FE: Contextual analysis

- Traverse AST
  - determine the declaration associated with each identifier referenced
  - determine the type of all expressions
  - record in AST

```
let
   var n: Integer;
   var c: Char
in
   begin
     c := '&';
     n := n + 1
   end
```



Decorated AST for sample program

BE: Optimization

- Restructure AST so that it corresponds to an equivalent but more efficient program
  - simple example: constant folding

    `x := y * 0` $\Rightarrow$ `x := 0`

  - introduce temporaries to hold previously computed values

```
f[i] := f[i] + (m[i] * m[j]) / pow(x[i] – x[j], 2);
f[j] := f[j] - (m[i] * m[j]) / pow(x[i] – x[j], 2);
```

BE: Code Generation

- Produce machine code
  - for abstract machine or physical machine

- Issues
  - location of program variables (stack, heap)
  - instruction selection and register allocation
  - linkage conventions (ABI: Application Binary Interface)

Triangle

```
let
   var n: Integer
   var c: Char
in
   begin
     c := ‘&’;
     n := n + 1
   end
```

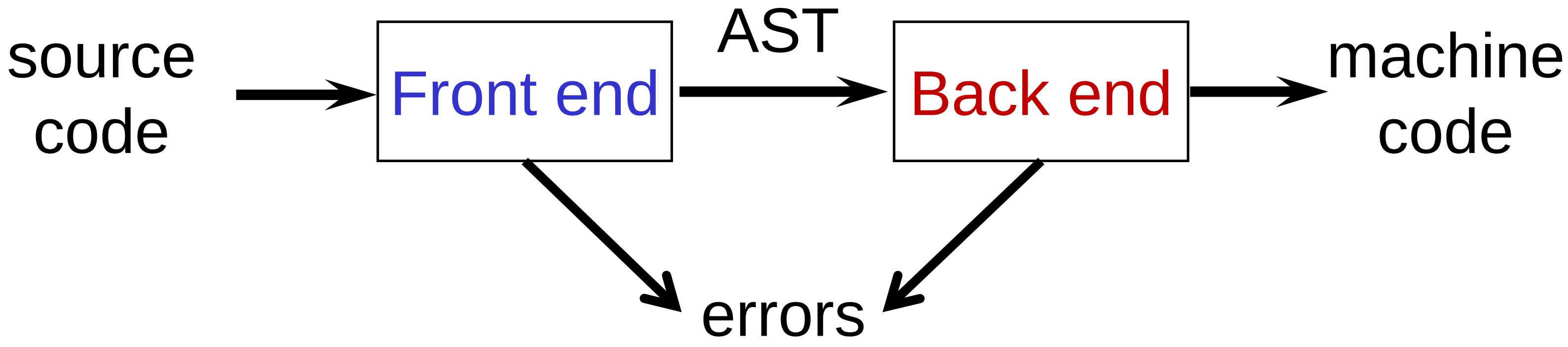
TAM instructions

```
PUSH   2
LOADL  38
STORE  1[SB]
LOAD   0[SB]
LOADL  1
CALL   add
STORE  0[SB]
POP    2
HALT
```

Implementation of multiple phases

- Single-pass compiler
  - economical in time and space
  - limited ability to implement language features and optimizations
- Multi-pass compiler
  - conceptually simpler and more versatile
  - requires more space and time
- Wirth’s design principle
  - design programming languages so that their compilers are simple
    - Pascal
    - C + “.h” header files
- Programmers design principle
  - but not too simple!

Traditional Two-Pass Compiler



- Front end creates AST
  - time complexity O(*n*) or O(*n* log *n*) where *n* is size of the program in characters
- Back end translates AST to target machine
  - O(*n*) or O(*n* log *n*) time complexity for simple code generation
  - but most back end optimization problems are NP-hard

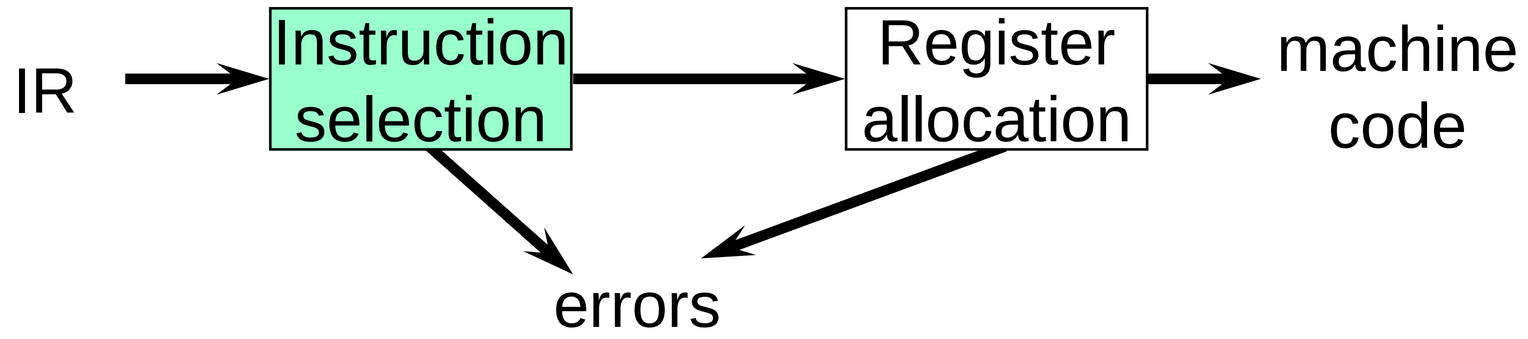
UNCOL: the universal AST?

- Suppose we have
  - *n* programming languages
  - *m* target machines
  - do we really need to construct *n* * *m* compilers ?

- A *universal* AST would allow us to
  - construct *n* front-ends
  - construct *m* back ends
  - *n* + *m* components: much less work!

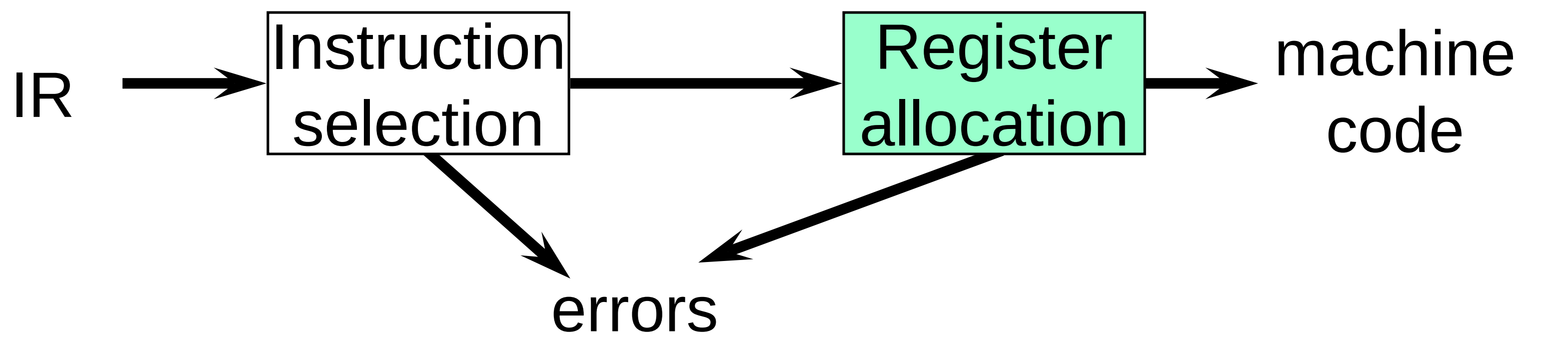
- The *Universal Computer Oriented Language*: an elusive goal since 1960
  - variation (evolution) in programming languages
  - variation (evolution) in hardware architecture
  - but hope springs eternal: JVM ? .NET ?

Back End (Instruction Selection)



- Produce compact, fast code
- Use available addressing modes
- Pattern matching problem
  - *ad hoc* techniques
  - tree pattern matching
  - dynamic programming

Back End (Register Allocation)



- performance advantage if a register is used instead of memory
- but we have a limited number of registers
  - which values to keep in a register?
- optimal allocation difficult
  - NP-complete for $k \geq 1$ registers

Compilers and Instruction Set Architecture

- Compiler benefits from simple instruction set
  - Difficult to deal with complex operations in instruction set
    - example: VAX instruction INDEX(base-addr, i, low, high)
      - if (low ≤ i ≤ high) return base-addr + 4 * i
      - 2 comparisons, 1 multiply, 1 add
    - Typical program
      - Only one test necessary
        - » loop bounds guarantee all values of i are valid indices
      - No multiplications necessary
        - » AddressOf(a[i+1]) == AddressOf(a[i])+4
      - better to avoid INDEX operation

```
int a[10];
int s = 0;
for (i=0; i < 10; i++)
    s += a[i];
end
```

- Current processor architectures
  - "orthogonal" RISC instruction set
    - easy for compiler to generate and optimize
    - easy to implement in hardware with superior performance