Announcements

- Project 2 Assigned
  - JLex for C Flat
  - Find a partner if you want
- Reminder: Homework 2
  - Due 9/23 (Tuesday)

Roadmap

- Last time
  - JLex for generating Lexers
- This time
  - CFGs, the underlying abstraction for Parsers

RegExs Are Great!

- Perfect for tokenizing a language
- They do have some limitations
  - Limited class of language that cannot specify all programming constructs we need
  - No notion of structure
- Let's explore both of these issues

Limitations of RegExs

- Cannot handle “matching”
  - Eg: language of balanced parentheses

    L = **{** $(^x)^x$ where x > 1**}**

    cannot be matched
  - Intuition:

    An FSM can only handle a finite depth of parentheses that we can handle

    let’s see a diagram…

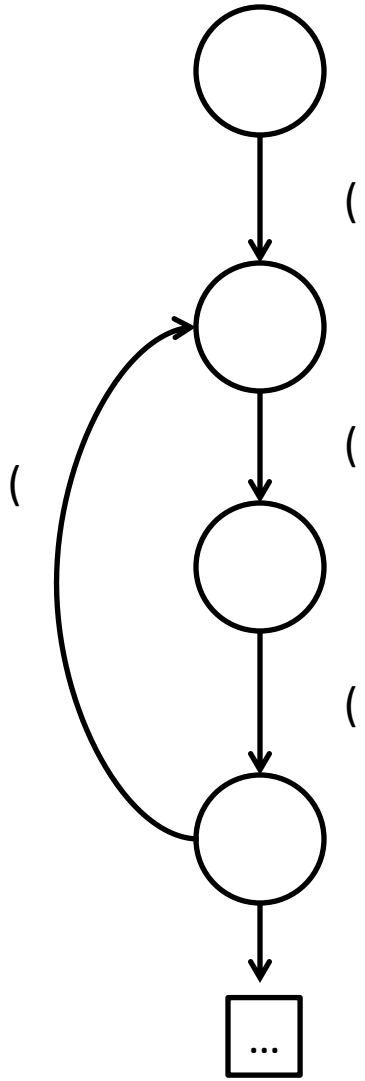
Limitations of RegExs: Balanced Parens

Assume F is an FSM that recognized L. Let N be the number of states in F'.

Feed N+1 left parens into N

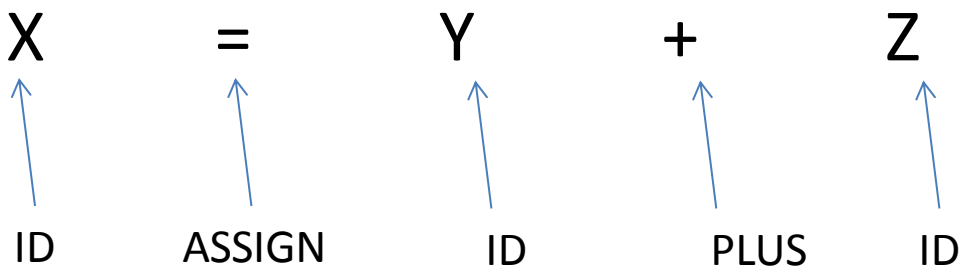
By the pidgeonhole principle, we must have revisited some state s on two input characters i and j.

By the definition of F, there must be a path from s to a final state. But this means that it accepts some suffix of closed parens at input i and j, but both cannot be correct



Limitations of RegEx: Structure

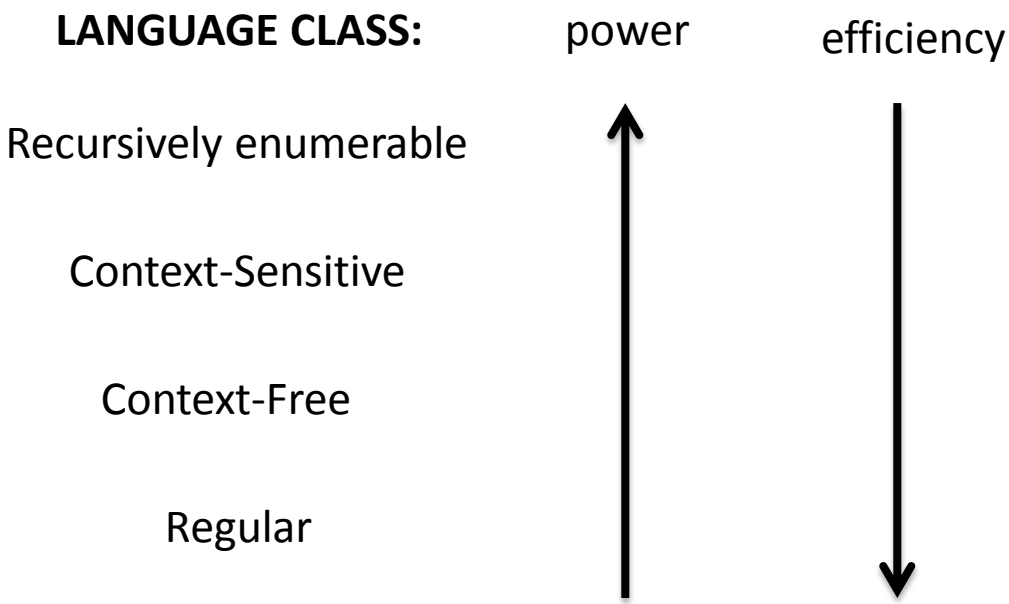
- Our Enhanced-RegEx scanner can emit a stream of tokens:



… but this doesn't really enforce any order of operations

We need more power than RegExs can provide

The Chomsky Hierarchy



The Chomsky Hierarchy

LANGUAGE CLASS:

Recursively enumerable

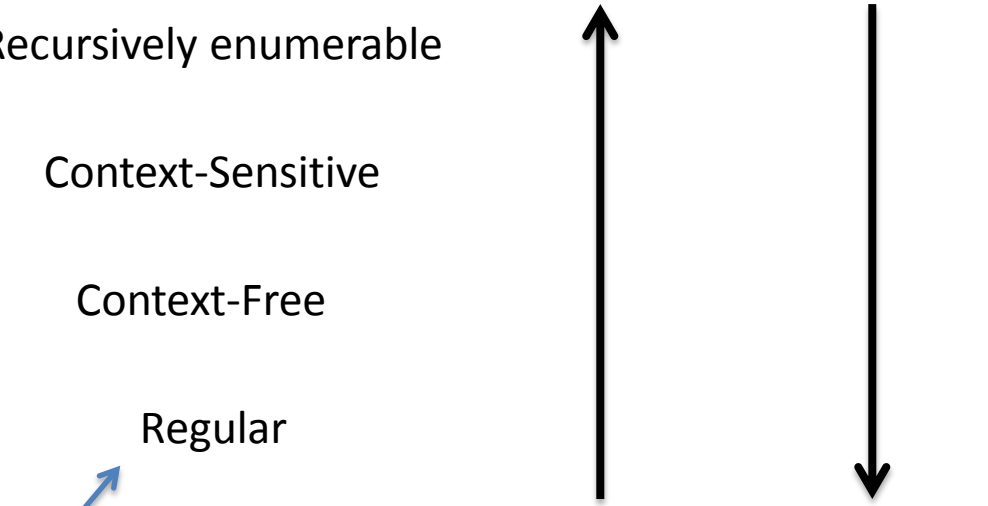
Context-Sensitive

Context-Free

Regular

power

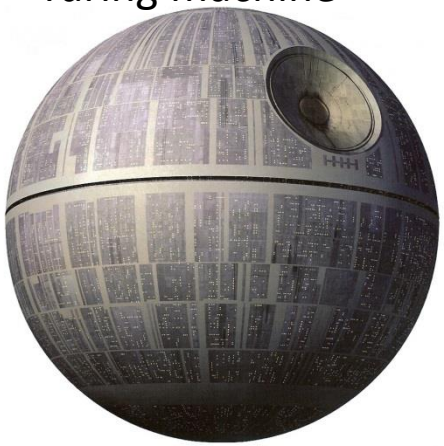
efficiency



FSM

The Chomsky Hierarchy

Turing machine



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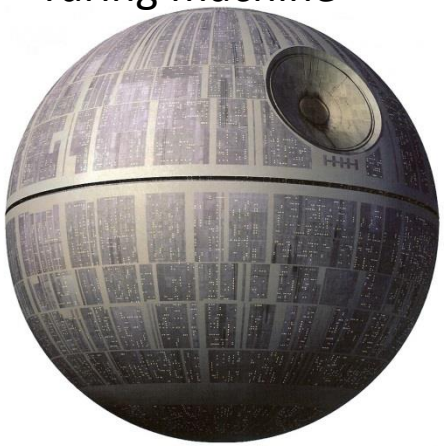

LANGUAGE CLASS:

Recursively enumerable

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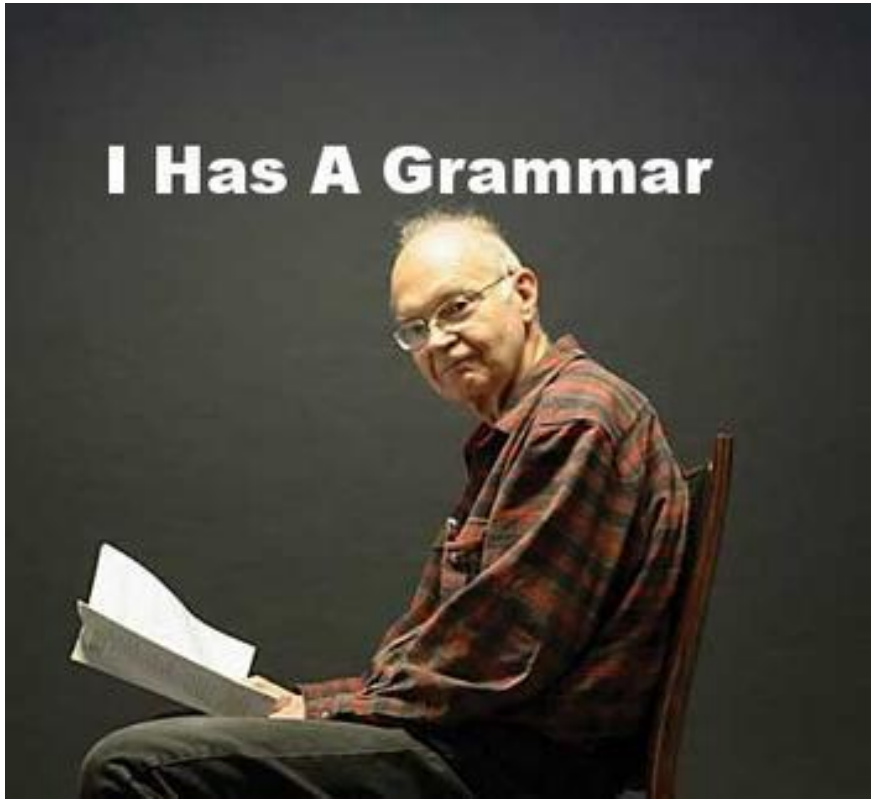
efficiency

Happy medium?

FSM

Context Free Grammars (CFGs)

- A set of (recursive) rewriting rules to generate patterns of strings
- Can envision a “parse tree” that keeps structure

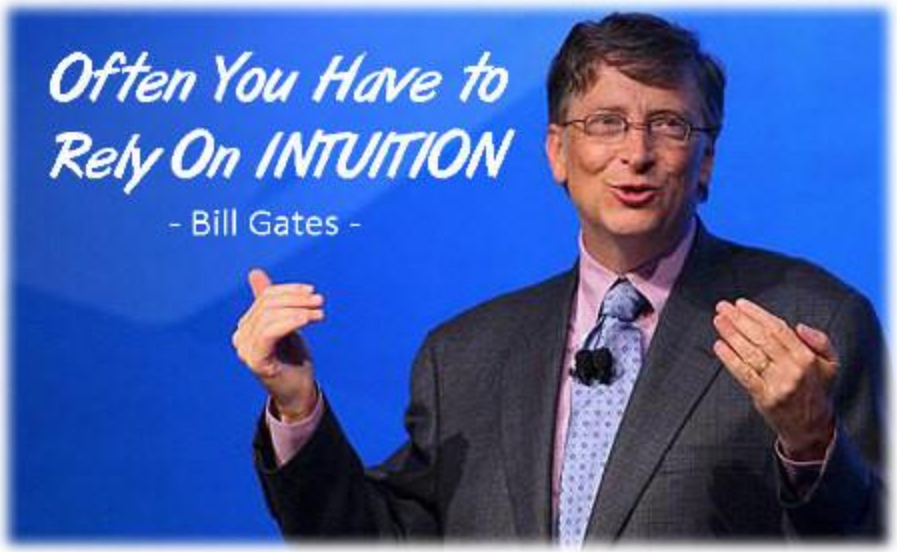


Don Knuth

CFG: Intuition

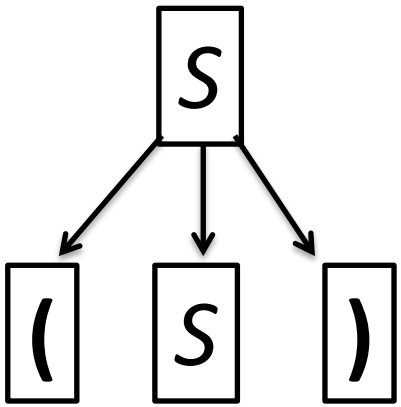
$S \rightarrow (S)$

A *rule* that says that you can rewrite S to be an S surrounded by a single set of parens



Before applying rule

After applying rule



CFGs recognize the language of tree where all the leaves are terminals

Context Free Grammars (CFGs)

- Formally, a 4-tuple:
  - N is the set of nonterminal symbols
  - $\sum$ is the set of terminal symbols
  - P is the set of productions
  - S is the start nonterminal in N

Context Free Grammars (CFGs)

Placeholder / interior nodes in the parse tree

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Placeholder / interior nodes in the parse tree

Tokens from scanner

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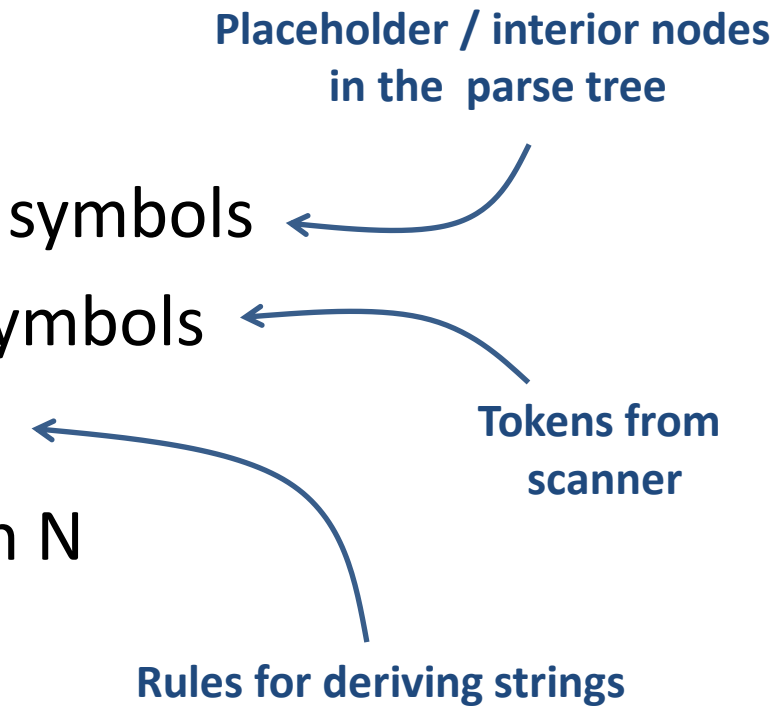

Context Free Grammars (CFGs)

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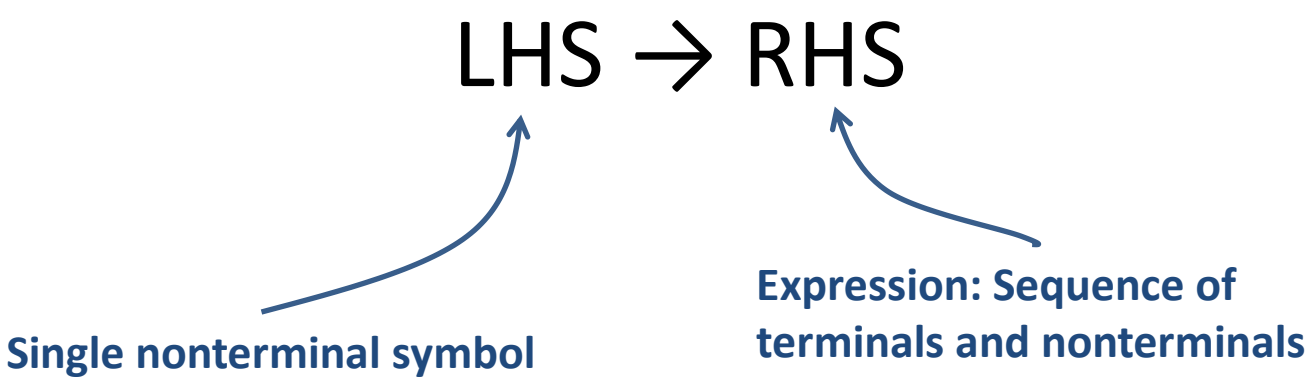
Placeholder / interior nodes in the parse tree

Tokens from scanner

Rules for deriving strings

If not otherwise specified, use the non-terminal that appears on the LHS of the first production is the start

Production Syntax



Production Shorthand

Nonterm → expression

Nonterm→ ε

equivalently:

Nonterm → expression

| ε

equivalently:

Nonterm → expression | ε

Derivations

- To derive a string:
  - Start by setting "*Current Sequence*" to the start symbol
  - Repeat:
    - Find a Nonterminal X in the Current Sequence
    - Find a production of the form $X \rightarrow \alpha$
    - "Apply" the production: create a new "current sequence" in which α replaces X
  - Stop when there are no more nonterminals

Derivation Syntax

- We'll use the symbol $\Rightarrow$ for *derives*
- We'll use the symbol $\overset{+}{\Rightarrow}$ for *derives in one or more steps*
- We'll use the symbol $\overset{*}{\Rightarrow}$ for *derives in zero or more steps*

An Example Grammar

An Example Grammar

Terminals
begin
end
semicolon
assign
id
plus

An Example Grammar

For readability, bold and lowercase

Terminals

begin
end
semicolon
assign
id
plus

An Example Grammar

For readability, bold and lowercase

Terminals

begin } Program
end } boundary

semicolon

assign

id

plus

An Example Grammar

For readability, bold and lowercase

Terminals

begin
end

Program boundary

semicolon

Represents ";"
Separates statements

assign
id
plus

An Example Grammar

For readability, bold and lowercase

Terminals

begin
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Program boundary

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Represents ";" Separates statements

assign

id

plus

Represents "=" statement

An Example Grammar

For readability, bold and lowercase

Terminals

begin } Program
end } boundary

semicolon — Represents ";" Separates statements

assign — Represents "=" statement

id — Identifier / variable name

plus

An Example Grammar

For readability, bold and lowercase

Terminals

begin } Program
end } boundary

semicolon — Represents ";" Separates statements

assign — Represents "=" statement

id — Identifier / variable name

plus — Represents "+" expression

An Example Grammar

For readability, bold and lowercase

Terminals

begin
end
semicolon
assign
id
plus

Nonterminals

Prog
Stmts
Stmt
Expr

An Example Grammar

For readability, bold and lowercase

Terminals

begin
end
semicolon
assign
id
plus

For readability, Italics and UpperCamelCase

Nonterminals

Prog
Stmts
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Expr

An Example Grammar

For readability, bold and lowercase

Terminals

begin
end
semicolon
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For readability, Italics and UpperCamelCase

Nonterminals

Prog — Root of the parse tree
Stmts
Stmt
Expr

An Example Grammar

For readability, bold and lowercase

Terminals

begin
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For readability, Italics and UpperCamelCase

Nonterminals

Prog — Root of the parse tree
Stmts — List of statements
Stmt
Expr

An Example Grammar

For readability, bold and lowercase

Terminals

begin
end
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For readability, Italics and UpperCamelCase

Nonterminals

Prog — Root of the parse tree
Stmts — List of statements
Stmt — A single statement
Expr

An Example Grammar

For readability, bold and lowercase

Terminals

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For readability, Italics and UpperCamelCase

Nonterminals

Prog — Root of the parse tree
Stmts — List of statements
Stmt — A single statement
Expr — A mathematical expression

An Example Grammar

For readability, bold and lowercase

Terminals

begin
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plus

For readability, Italics and UpperCamelCase

Nonterminals

Prog
Stmts
Stmt
Expr

Defines the syntax of legal programs

Productions

Prog → **begin** Stmts **end**

Stmts → Stmts **semicolon** Stmt

| Stmt

Stmt → **id assign** Expr

Expr → **id**

| Expr **plus id**

Productions

1. *Prog* → **begin** *Stmts* **end**
2. Stmts → *Stmts* **semicolon** *Stmt*
3. | *Stmt*
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Derivation Sequence

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Parse Tree

Derivation Sequence

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Parse Tree

Derivation Sequence

Key

terminal

Nonterminal

Rule used

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Derivation Sequence

Prog

Parse Tree

Prog

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Derivation Sequence

Prog ⇒ **begin** Stmts **end** (1)

Parse Tree

Key

terminal

Nonterminal

Rule used

Productions

1. *Prog* → **begin** *Stmts* **end**
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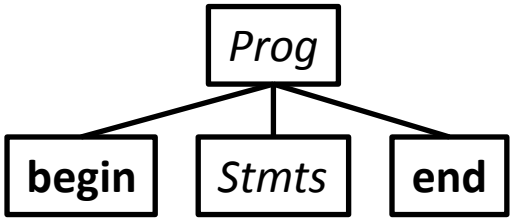
Parse Tree



Derivation Sequence

Prog ⇒ **begin** Stmts **end** (1)

Key

terminal

Nonterminal

Rule used

Productions

1. *Prog* → **begin** *Stmts* **end**
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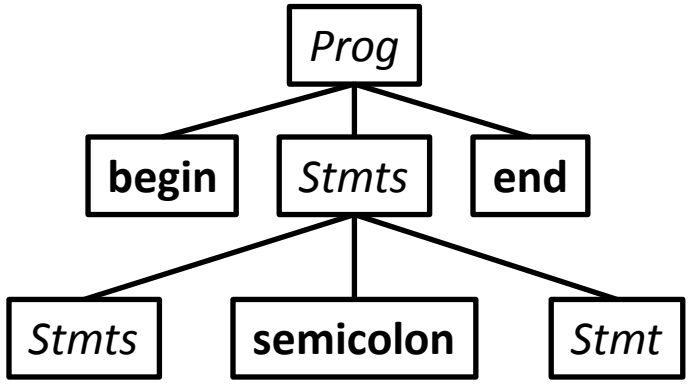
Parse Tree



Derivation Sequence

Prog ⇒ **begin** Stmts **end** (1)

⇒ **begin** Stmts **semicolon** Stmt **end** (2)

Key

terminal

Nonterminal

Rule used

Productions

1. *Prog* → **begin** *Stmts* **end**
2. Stmts → *Stmts* **semicolon** *Stmt*
3. | *Stmt*
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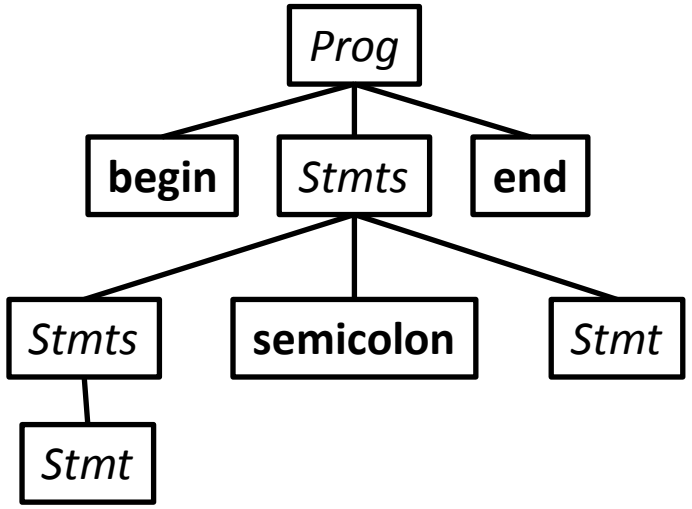
Parse Tree



Derivation Sequence

Prog ⇒ **begin** Stmts **end** (1)

⇒ **begin** Stmts **semicolon** Stmt **end** (2)

⇒ **begin** Stmt **semicolon** Stmt **end** (3)

Key

terminal

Nonterminal

Rule used

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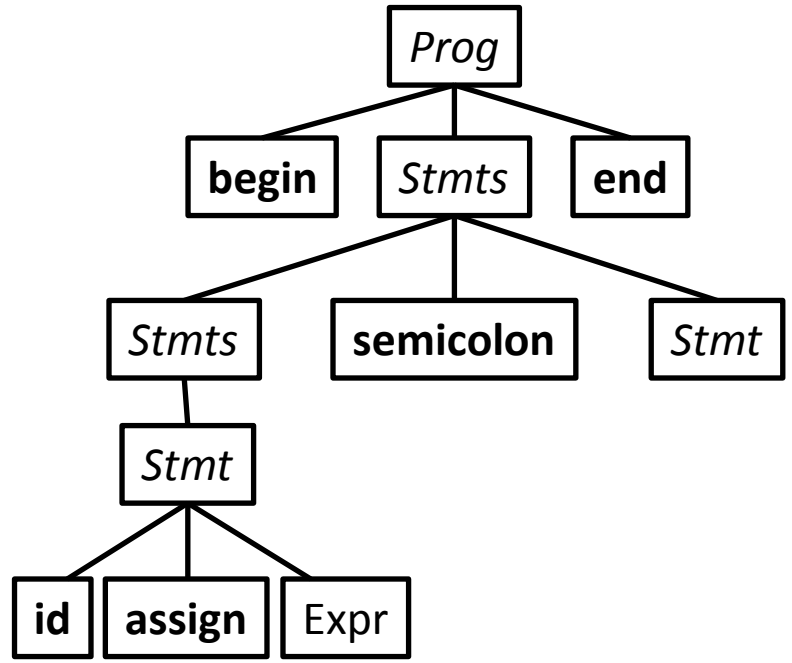

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⇒ **begin id assign** Expr **semicolon** Stmt **end** (4)

Key

terminal

Nonterminal

Rule used

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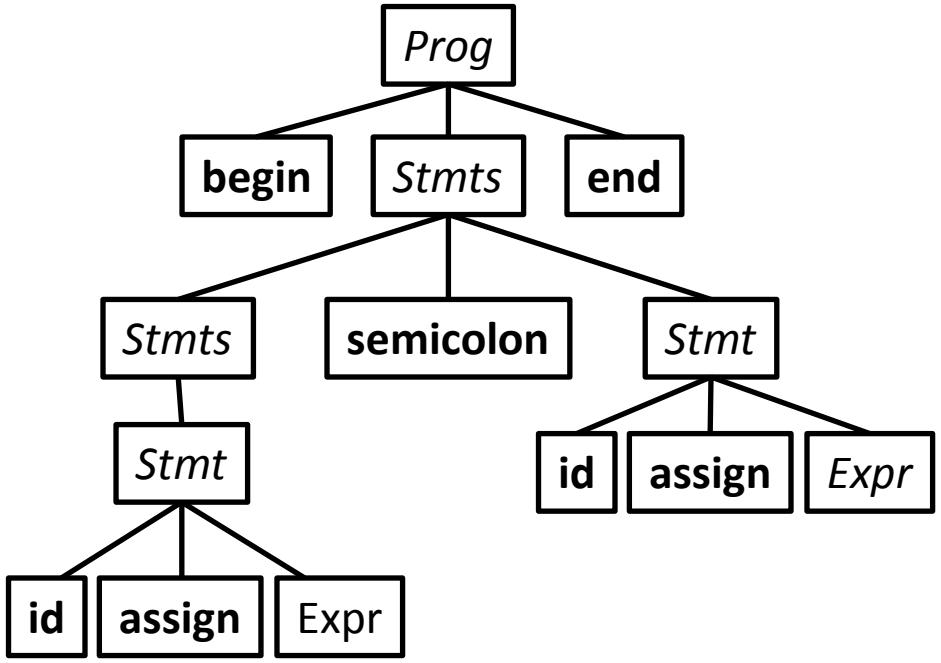
Parse Tree



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Rule used

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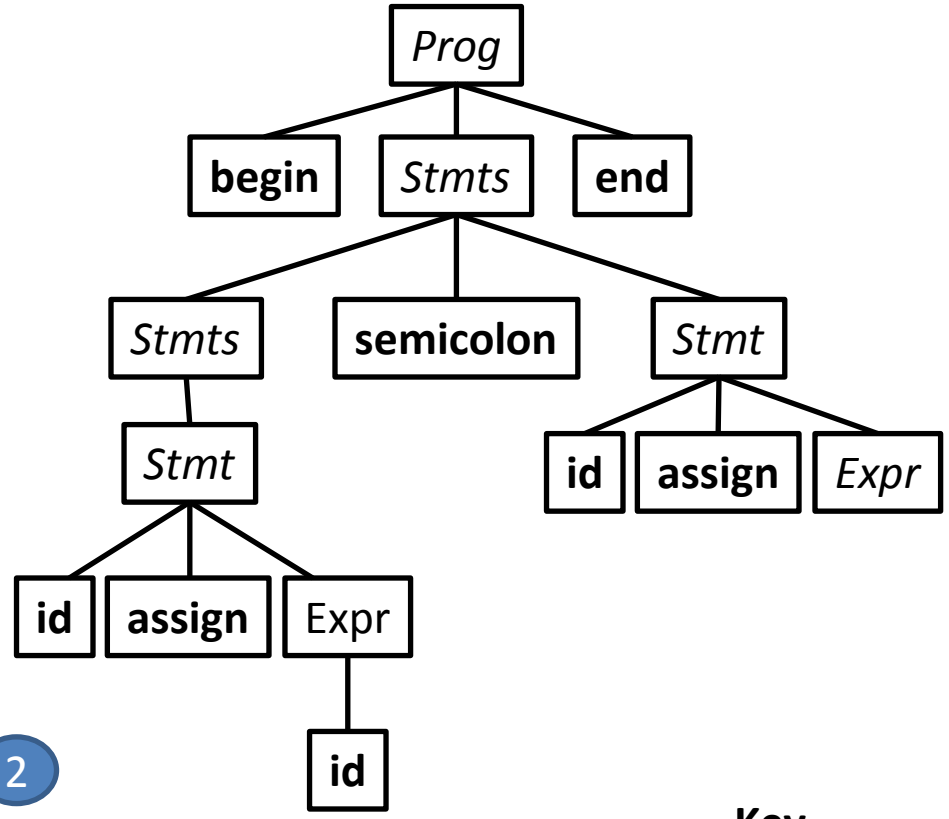

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⇒ **begin id assign** Expr **semicolon id assign** Expr **end** (4)

⇒ **begin id assign id semicolon id assign** Expr **end** (5)

Key

terminal

Nonterminal

Rule used

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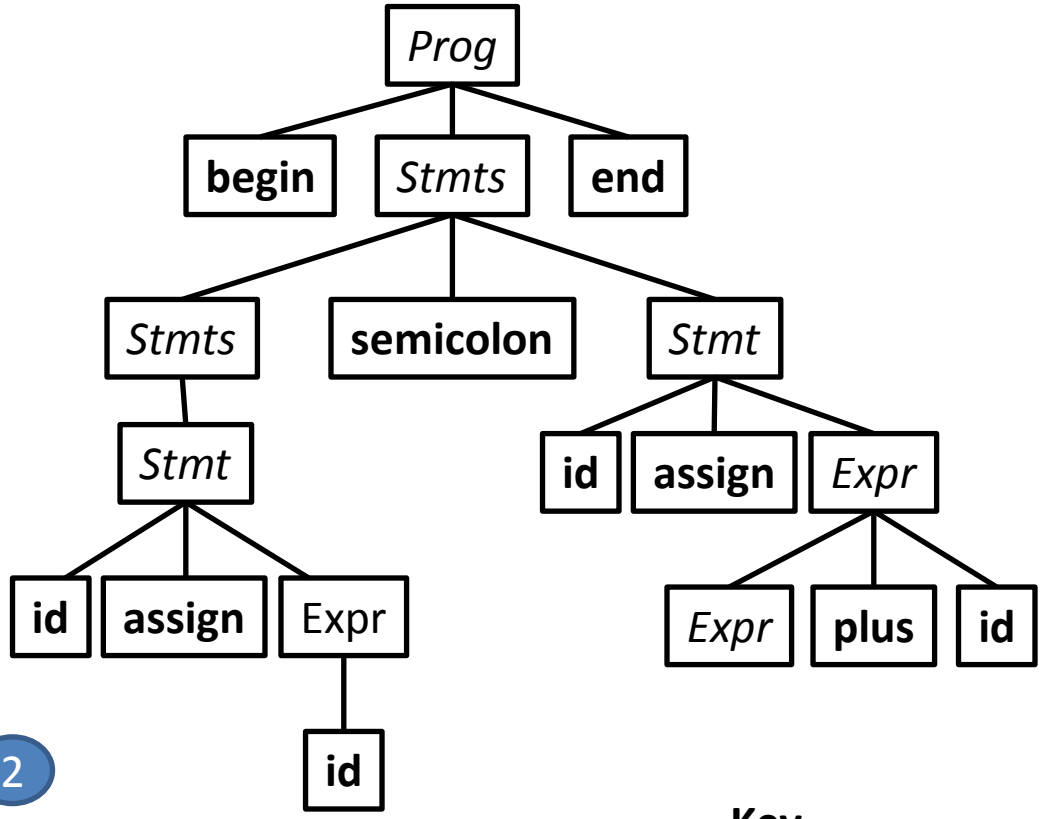

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⇒ **begin id assign id semicolon id assign** Expr **plus id end** (6)

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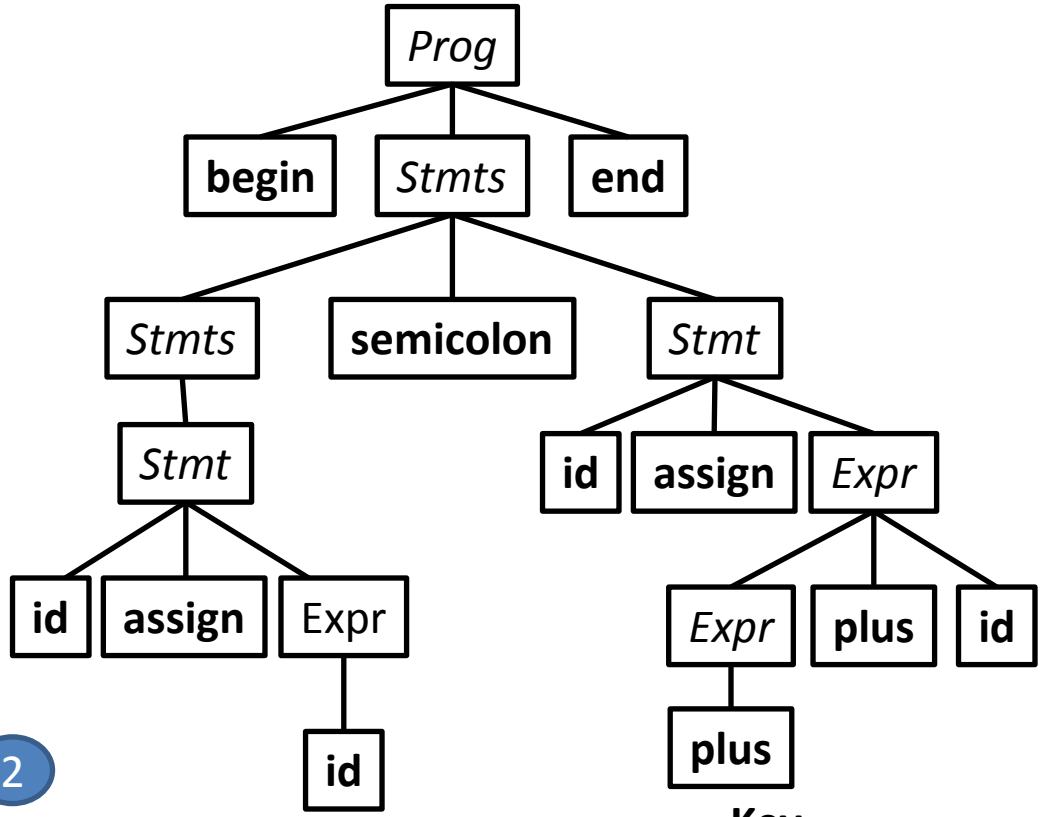

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⇒ **begin id assign id semicolon id assign** Expr **plus id end** (6)

⇒ **begin id assign id semicolon id assign id plus id end** (5)

Key

terminal

Nonterminal

Rule used

Switching Gears: Makefiles

Makefiles: Motivation

- Typing the series of commands to generate our code can be tedious
  - Multiple steps that depend on each other
  - Somewhat complicated commands
  - May not need to rebuild everything
- Makefiles solve these issues
  - Record a series of commands in a script-like DSL
  - Specify dependency rules and Make generates the results

Makefiles: Basic Structure

<target>: <dependency list>

(tab) <command to satisfy target>

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<target>: <dependency list>

(tab) <command to satisfy target>

Example

```
Example.class: Example.java IO.class
     javac Example.java

IO.class: IO.java
     javac IO.java
```

Makefiles: Basic Structure

<target>: <dependency list>

(tab) <command to satisfy target>

Example

Example.class depends on example.java and IO.class

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Example.class: Example.java IO.class
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Example

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IO.class: IO.java
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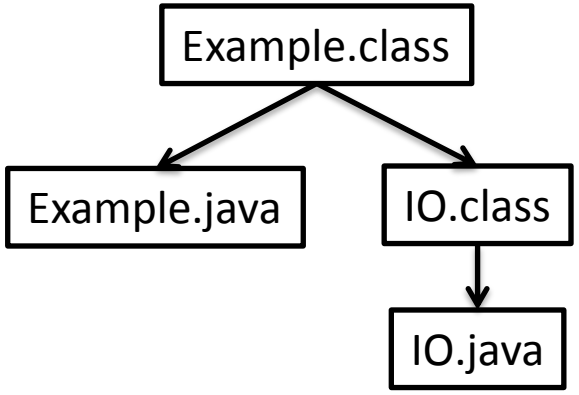
Example.class is generated by javac Example.java

Makefiles: Dependencies



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IO.class: IO.java
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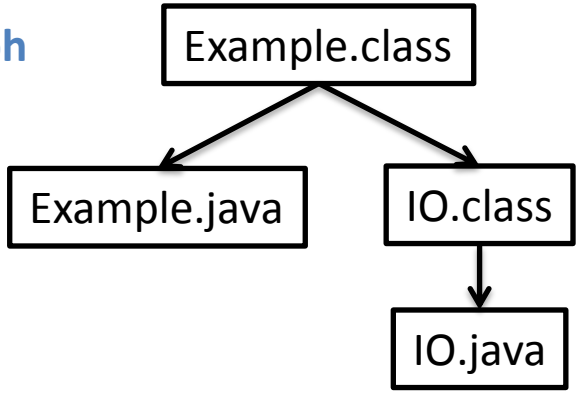
Makefiles: Dependencies

Internal Dependency graph



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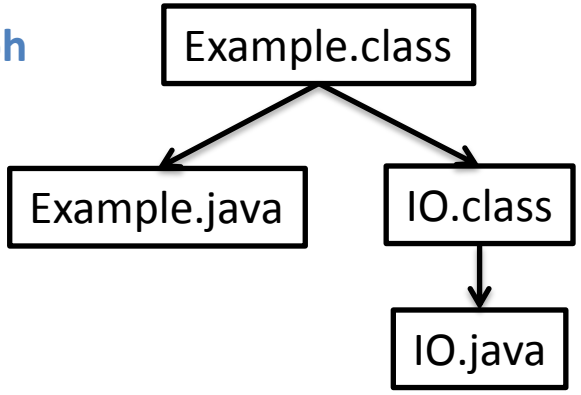
Makefiles: Dependencies

Internal Dependency graph



A file is rebuilt if one of it's dependencies changes

Example

```
Example.class: Example.java IO.class
    javac Example.java

IO.class: IO.java
    javac IO.java
```

Makefiles: Variables

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Example

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```
Example.class: Example.java IO.class
	$(JC) $(JFLAGS) Example.java

IO.class: IO.java
	$(JC) $(JFLAGS) IO.java
```

Makefiles: Phony Targets

- You can run commands through make.
  - Write a target with no dependencies (called phony)
  - Will cause it to execute the command every time

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  - Write a target with no dependencies (called phony)
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Example

```
clean:
	rm –f *.class
test:
	java –cp . Test.class
```

P2 Walkthrough