Context-free grammars

Roadmap

- Last time
  - Regex == DFA
  - 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…

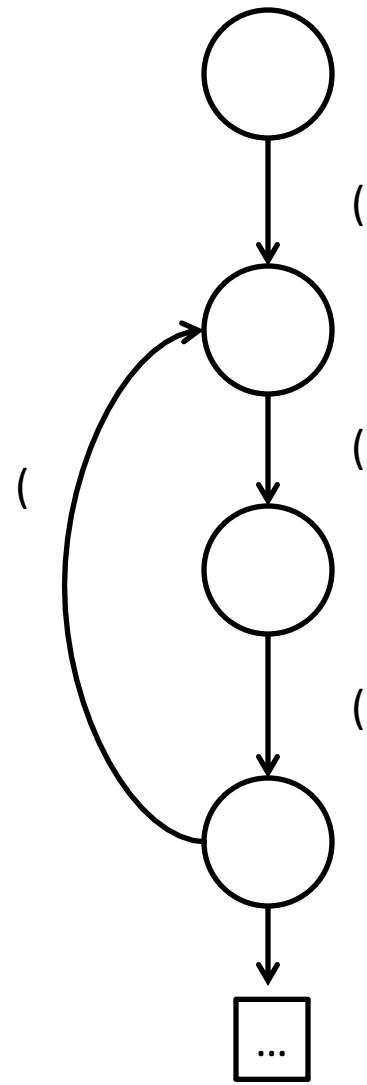
Limitations of RegExs: Balanced Parens

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 *pigeonhole* 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:

X	=	Y	+	Z
↑	↑	↑	↑	↑
ID	ASSIGN	ID	PLUS	ID

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

The Chomsky Hierarchy

Turing machine

LANGUAGE CLASS: power efficiency

Recursively enumerable

Context-Sensitive

Context-Free

Happy medium?

Regular

FSM

Noam Chomsky

Context Free Grammars (CFGs)

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

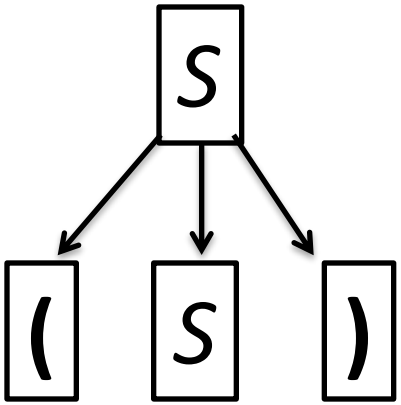
CFG: Intuition

$$\underbrace{S \rightarrow (\ S\ )}$$

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 trees 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)

占位符
Placeholder / interior nodes in the parse tree

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Tokens from scanner

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Rules for deriving strings

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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 as the start

Production Syntax

LHS → RHS

Single nonterminal symbol

Expression: Sequence of terminals and nonterminals

Production Shorthand

Nonterm → expression

Sequence of terms and nonterms

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

<u>Terminals</u>
begin
end
semicolon
assign
id
plus

An Example Grammar

For readability, bold and lowercase

Terminals

begin
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Terminals

begin } Program boundary
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Terminals

begin
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Program boundary

semicolon

Represents ";"
Separates statements

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Represents "+" expression

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<u>Nonterminals</u>

Prog
Stmts
Stmt
Expr

An Example Grammar

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begin
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For readability, Italics and UpperCamelCase

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For readability, Italics and UpperCamelCase

Nonterminals

Prog — Root of the parse tree
Stmts
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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
Expr

An Example Grammar

For readability, bold and lowercase

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Nonterminals

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

An Example Grammar

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Prog
Stmts
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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**

An Example Grammar

For readability, bold and lowercase

Terminals

begin } Program boundary
end
semicolon — Represents ";" Separates statements
assign — Represents "=" statement
id — Identifier / variable name
plus — Represents "+" expression

For readability, Italics and UpperCamelCase

Nonterminals

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

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Parse Tree

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Parse Tree

Derivation Sequence

Key

terminal

Nonterminal

Rule used

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Derivation Sequence

Prog ⇒ **begin** Stmts **end** 1

Parse Tree

Prog

Key

terminal

Nonterminal

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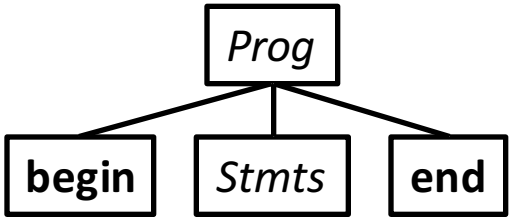
Parse Tree



Derivation Sequence

Prog ⇒ **begin** Stmts **end** 1

Key

terminal

Nonterminal

Rule used

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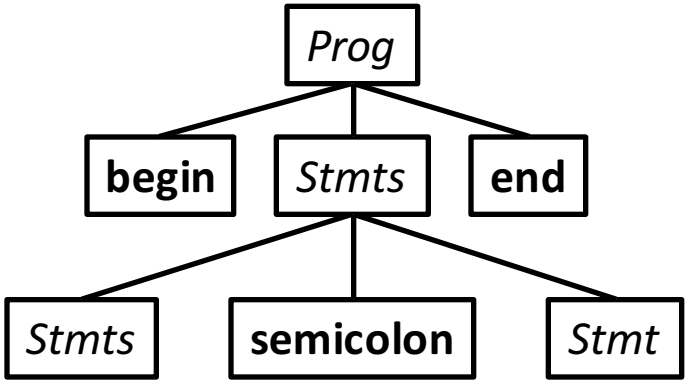

Derivation Sequence

Prog ⇒ **begin** Stmts **end** (1)

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

Key

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Rule used

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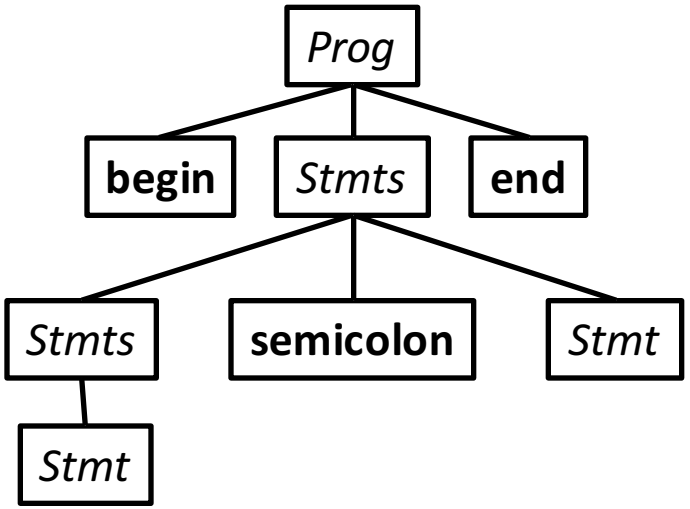

Derivation Sequence

Prog ⇒ **begin** Stmts **end** (1)

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Key

terminal

Nonterminal

Rule used

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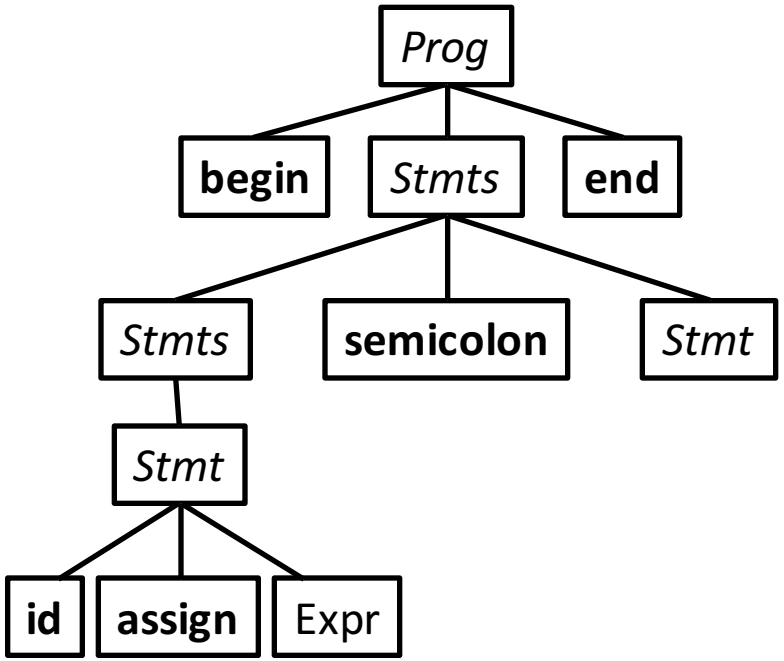

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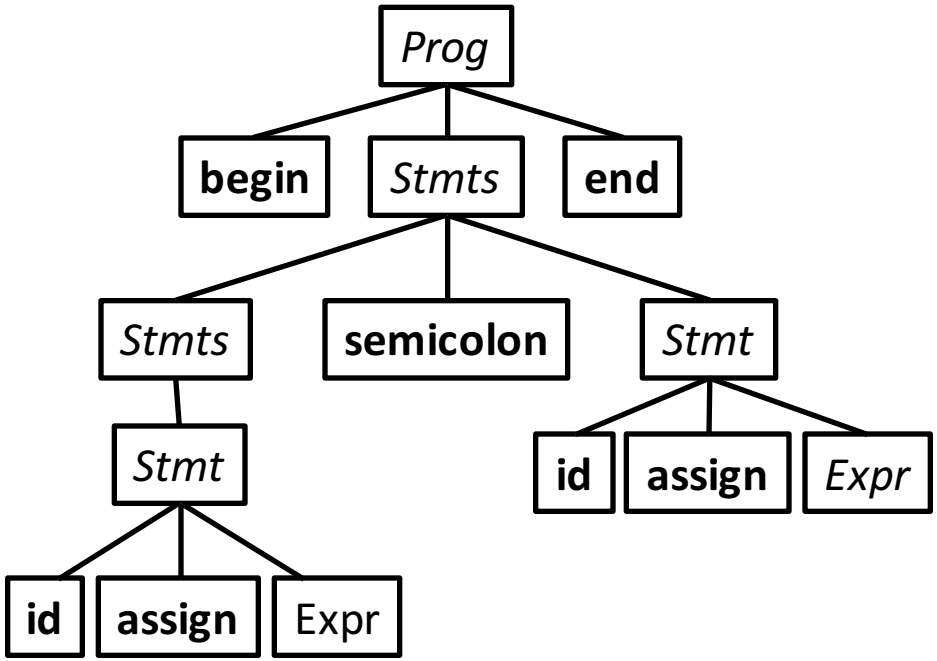

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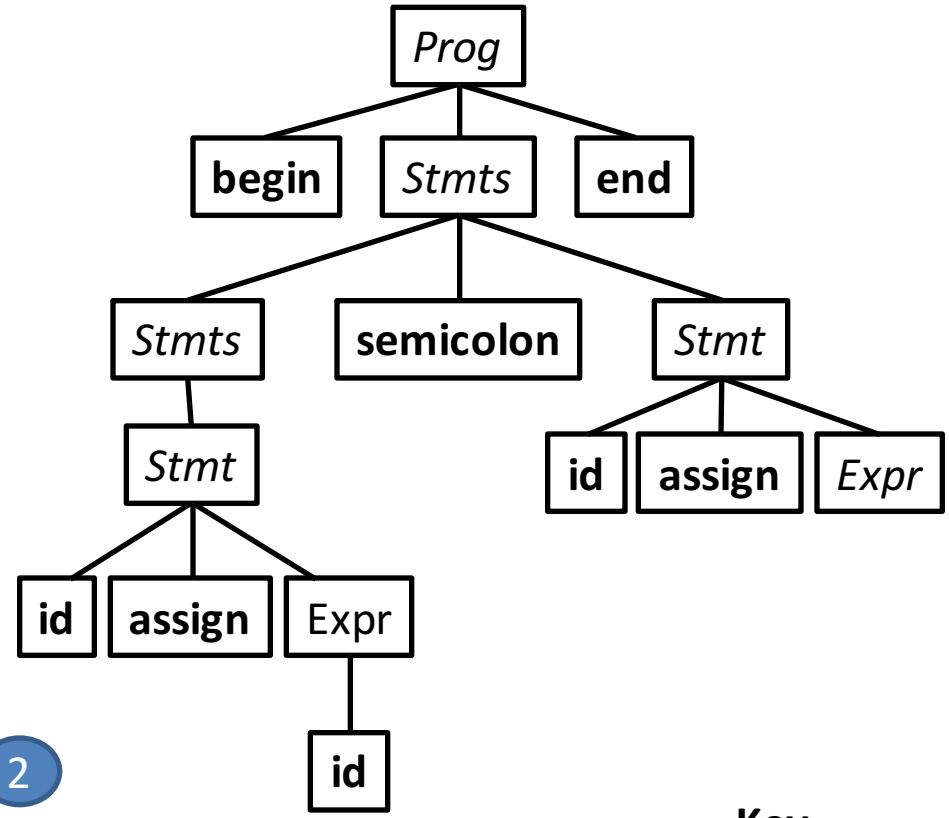

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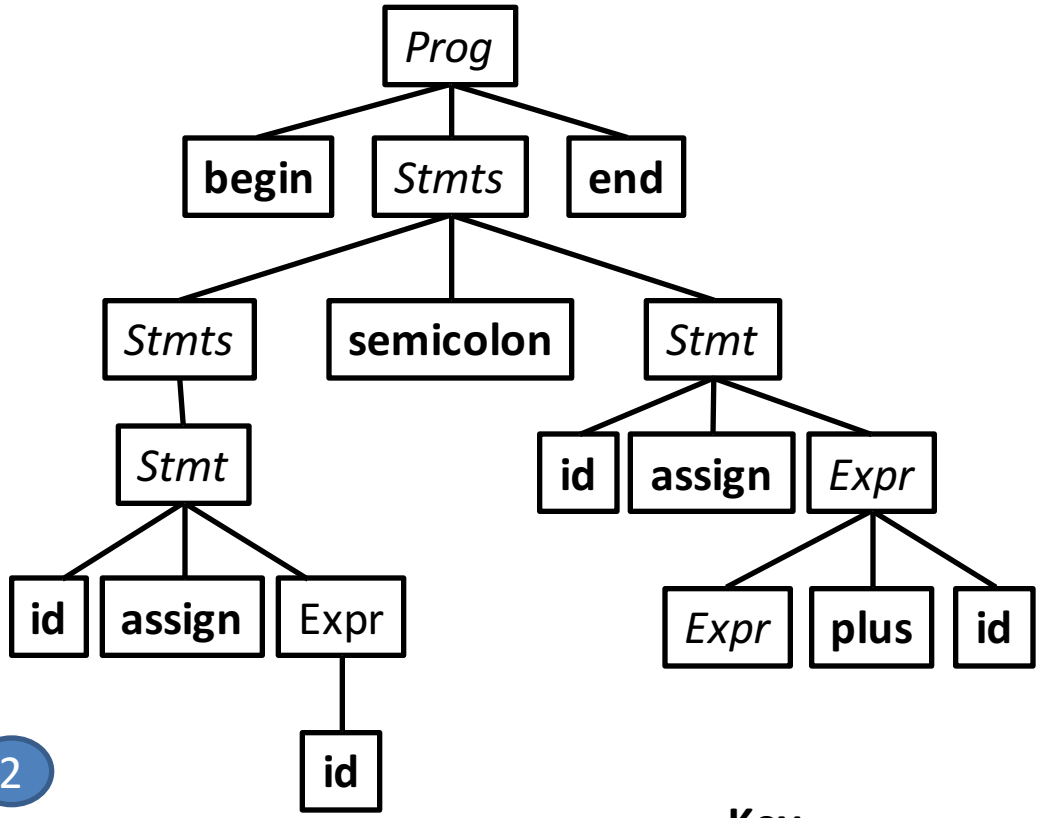

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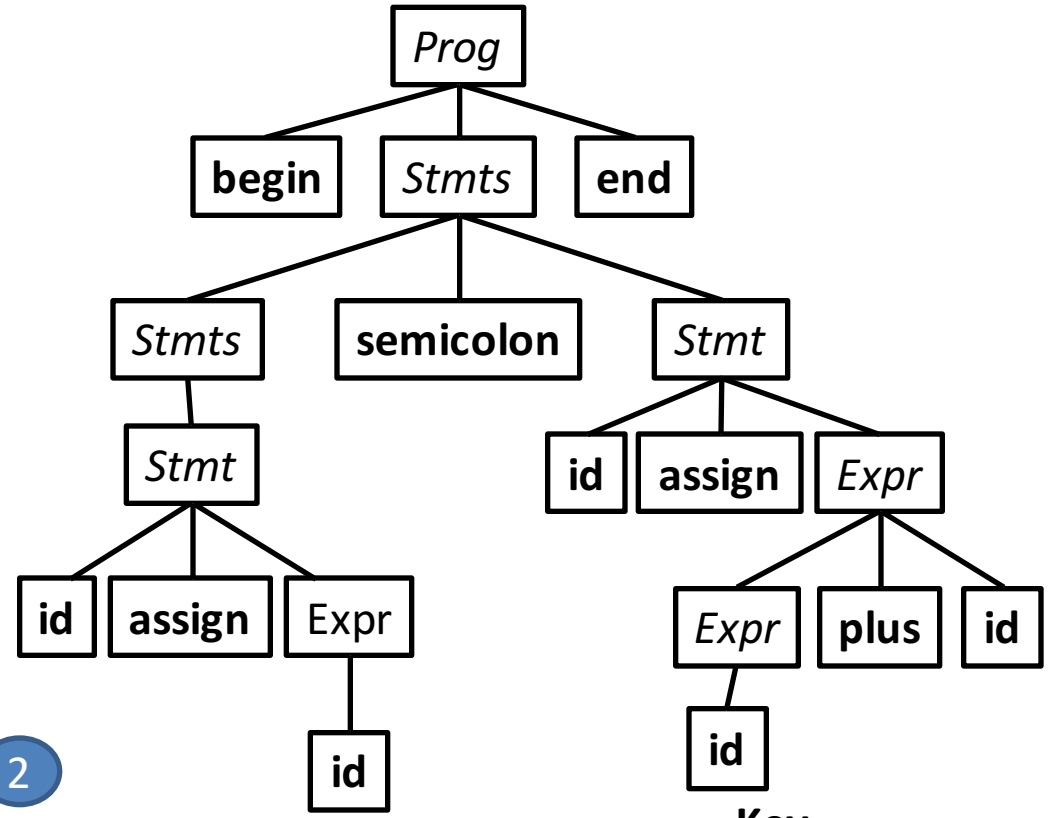

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terminal

Nonterminal

Rule used

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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Example

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

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

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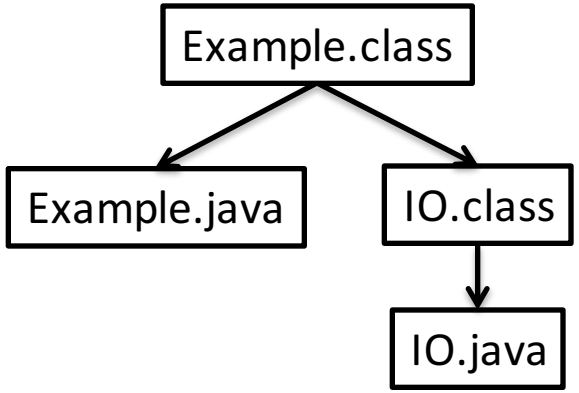

Example.class is generated by javac Example.java

Makefiles: Dependencies



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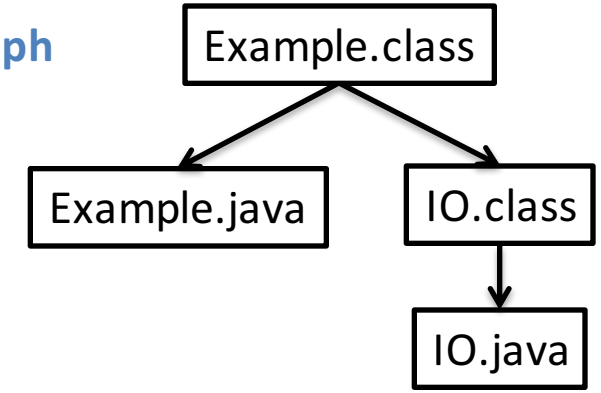
Makefiles: Dependencies

Internal Dependency graph



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Makefiles: Dependencies

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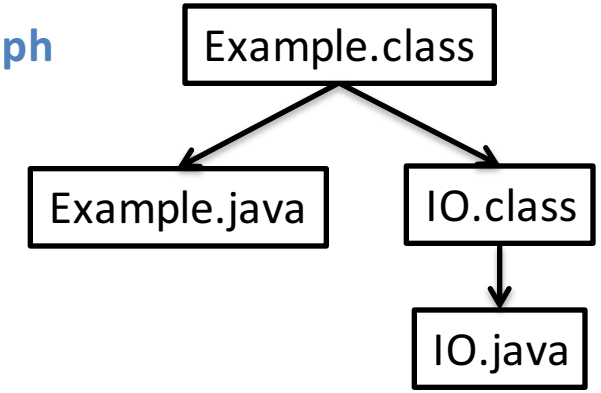

A file is rebuilt if one of it's dependencies changes

Example

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     javac Example.java

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```

Makefiles: Variables

You can thread common configuration values through your makefile

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<u>Example</u>

JC = /s/std/bin/javac

JFLAGS = -g

Makefiles: Variables

You can thread common configuration values through your makefile

Example

JC = /s/std/bin/javac

JFLAGS = -g **Build for debug**

Makefiles: Variables

You can thread common configuration values through your makefile

Example

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JFLAGS = -g **Build for debug**

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

IO.class: IO.java
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```

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- 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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	rm -f *.class
```

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

Example

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

Recap

- We've defined context-free grammars
  - More powerful than regular grammars
- Submit P1
- P2 will come out tonight
- Next time we'll look at grammars in more detail