Announcements

Working in pairs is only allowed for programming assignments and not for homework problems

H3 has been posted

Syntax Directed Translation

CFGs so Far

- CFGs for Language *Definition*
  - The CFGs we've discussed can generate/define languages of valid strings
  - So far, we **start** by building a parse tree and **end** with some valid string
- CFGs for Language *Recognition*
  - Start with a string and end with a parse tree for it

CFGs for Parsing

Language Recognition isn't enough for a parser

- We also want to *translate* the sequence

Parsing is a special case of *Syntax-Directed Translation*

- Translate a sequence of tokens into a sequence of actions

Syntax-directed translation (SDT) takes a parse tree and output something else. This can be string, a integer value, etc. When the output is an abstract-syntax tree, this process is parsing.

The abstract-syntax tree is the output of parsing, used in the next phase of compiling.

Syntax Directed Translation

Augment CFG rules with translation rules (at least 1 per production)

A translation rule

Define translation of LHS nonterminal as function of

- Constants
- RHS nonterminal translations
- RHS terminal value

Assign rules bottom-up

To translate a input string into an abstract-syntax tree:
(1) build the parse tree;
(2) apply the translation rules to compute the translation value for each non-terminals in the tree, working bottom up (since a nonterminal's value may depend on the value of the symbols on the right-hand side, you need to work bottom-up so that those values are available).

SDT Example

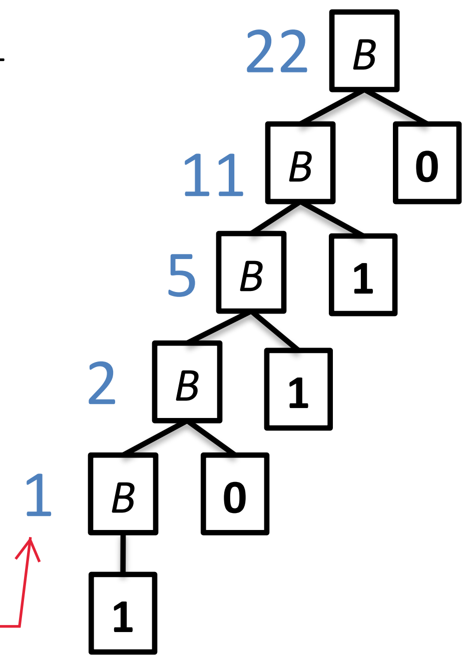
".trans" means translation.

CFG	Rules
B -> 0	B.trans = 0
| 1	B.trans = 1
| B 0	B.trans = B_2.trans * 2
| B 1	B.trans = B_2.trans * 2 + 1

Input string

10110

Assume that we already have the parse tree.



B.trans

Translation is the value of the input

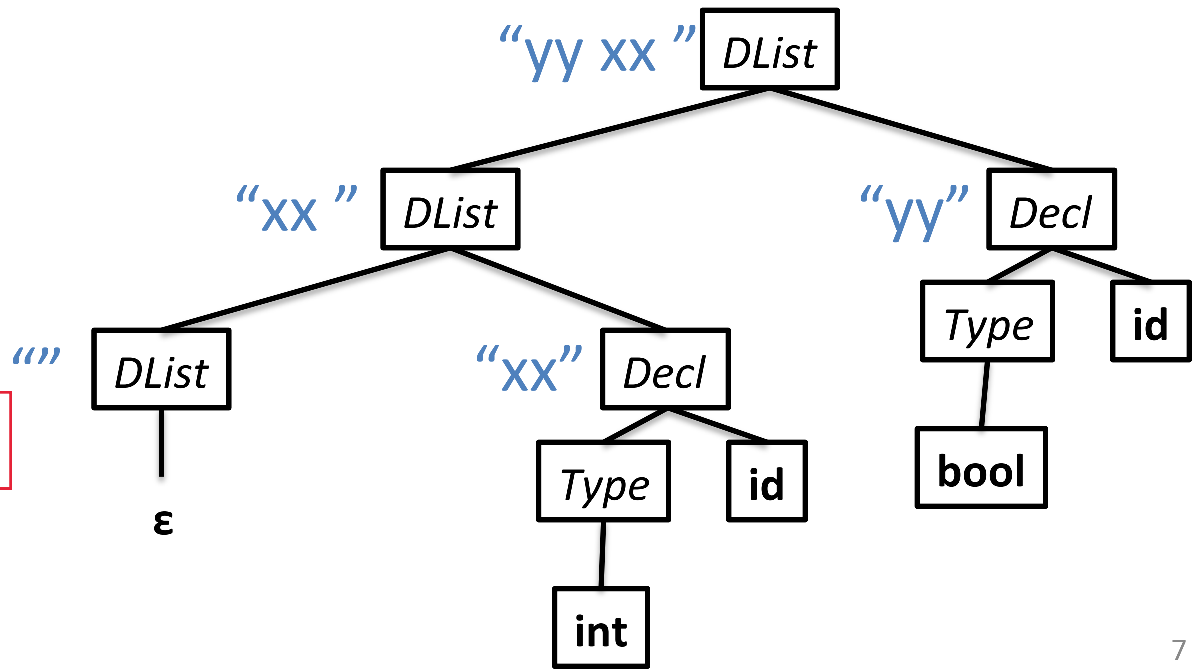
SDT Example 2: Declarations

Translation is a
String of ids

CFG

DList	→	ε	Dlist.trans = ""
	|	*DList Decl*	*DList.trans* = *Decl.trans* + " " + DList_2.trans
Decl	→	*Type* **id**	*Decl*.trans = **id**.value
Type	→	int	
	|	bool	

DList.tra



Input string
int xx;
bool yy;

Syntax directed translation:
get something from the parse tree.

Exercise Time

Only add declarations of type int to the output String.

Augment the previous grammar:

<u>CFG</u>			<u>Rules</u>
DList	$\rightarrow$	**ε**	*DList*.trans = “”
	|	*DList Decl*	*DList.trans* = *Decl.trans* + “ “ + DList_2.trans
Decl	$\rightarrow$	*Type* **id ;**	*Decl*.trans = **id**.value
Type	$\rightarrow$	**int**	
	|	**bool**	

Different nonterms can have different types

Rules can have conditionals

SDT Example 2b: ints only

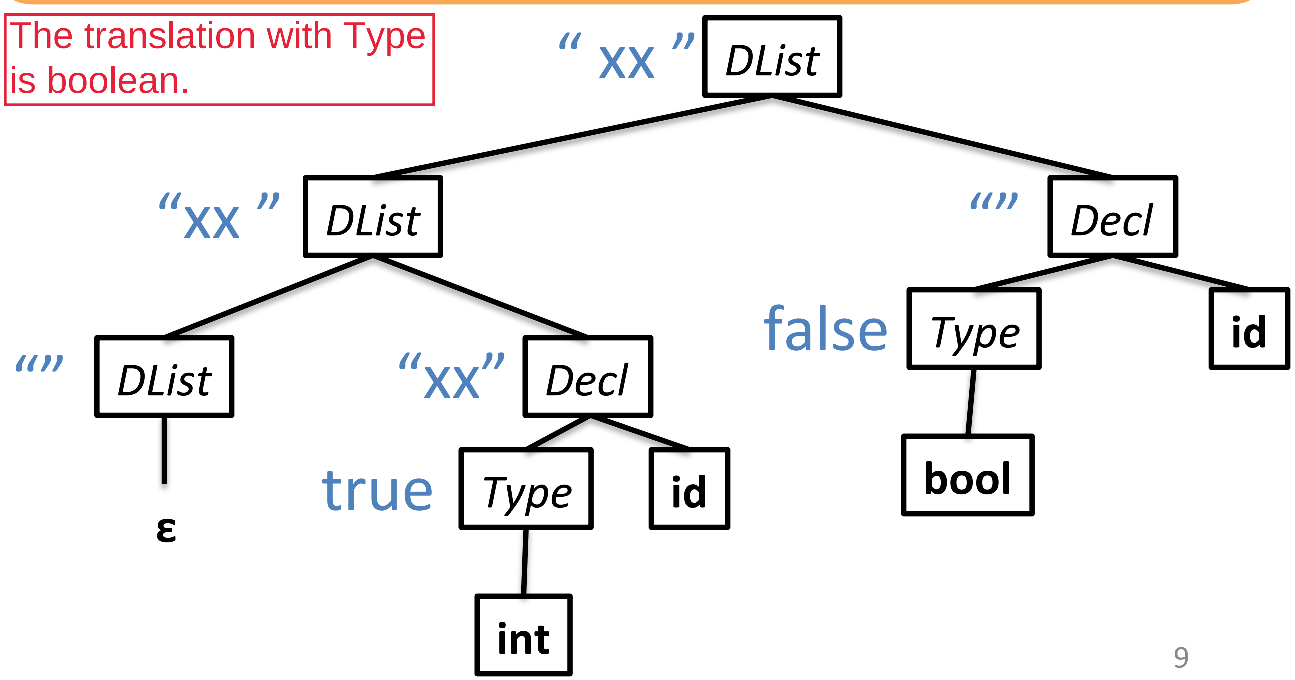
Translation is a String of **int** ids only

<u>CFG</u>			<u>Rules</u>
DList	→	ε	*DList*.trans = “”
	|	*Decl DList*	*DList.trans* = *Decl.trans* + “ “ + DList_2.trans
Decl	→	*Type* **id** ;	if (Type.trans) {*Decl*.trans = **id**.value} else {*Decl*.trans = “”}
Type	→	int	*Type*.trans = true
	|	bool	*Type*.trans = false

Why not return the string directly? It is ok though, but strings are expensive. Booleans are better :).

The translation with Type is boolean.

<u>Input string</u>
int xx;
bool yy;



Different nonterms can have different types

Rules can have conditionals

SDT for Parsing

In the previous examples, the SDT process assigned different types to the translation:

- Example 1: tokenized stream to an **integer value**
- Example 2: tokenized stream to a (java) **String**

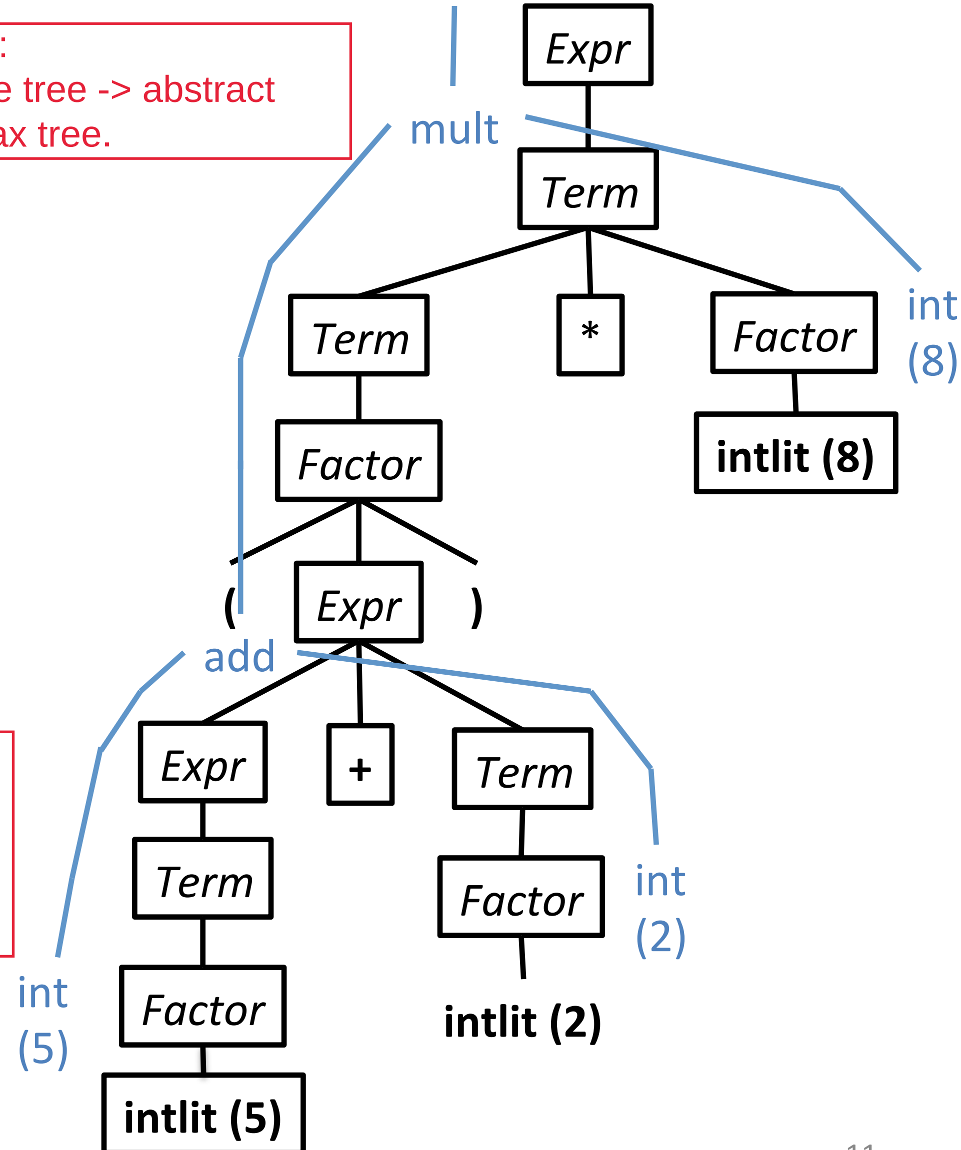
For parsing, we'll go from tokens to an Abstract-Syntax Tree (AST) abstract syntax tree vs parse tree

Abstract Syntax Trees

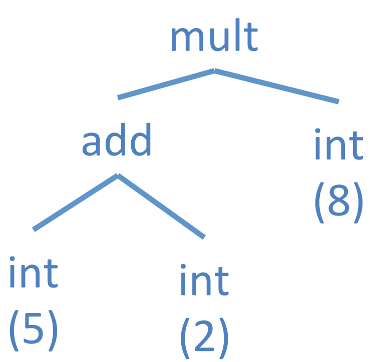
- A condensed form of the parse tree
- Operators at internal nodes (not leaves)
- Chains of productions are collapsed
- Syntactic details omitted

Goal:
parse tree -> abstract syntax tree.

Parse Tree



Example: (5+2)*8



Should the translation does type checking?
No. Not in this phase.

Exercise #2

- Show the AST for:

  (1 + 2) * (3 + 4) * 5 + 6

Expr -> Expr + Term
      | Term
Term -> Term * Factor
      | Factor
Factor -> intlit MkIntNode(intlit.value)
      | (Expr)

Expr -> Expr + Term *Expr1*.trans = MkPlusNode(*Expr2*.trans, *Term*.trans)

AST for Parsing

In previous slides we did our translation in two steps

- Structure the stream of tokens into a parse tree
- Use the parse tree to build an abstract syntax tree, throw away the parse tree

In practice, we will combine these into 1 step

Question: Why do we even need an AST?

- More of a “logical” view of the program
- Generally easier to work with than the parse tree.

AST Implementation

How do we actually represent an AST in code?

ASTs in Code

Note that we've assumed a field-like structure in our SDT actions:

$$\textit{DList}.\text{trans} = \textit{Decl}.\text{trans} + \text{`` ``} + \text{DList}_2.\text{trans}$$

In our parser, we'll define classes for each type of nonterminal, and create a new nonterminal in each rule.

- In the above rule we might represent DList as

```
public class DList{
   public String trans;
}
```

- For ASTs: when we execute an SDT rule
  - we construct a new node object for the RHS
  - propagate its fields with the fields of the LHS nodes

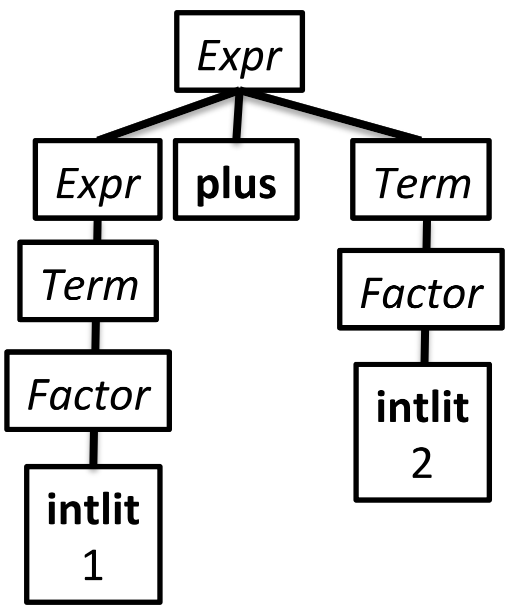
Thinking about implementing ASTs

Consider the AST for a simple language of Expressions

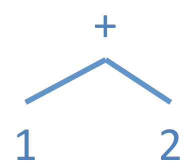
<u>Input</u>
1 + 2

<u>Tokenization</u>
intlit plus intlit

<u>Parse Tree</u>



<u>AST</u>



<u>Naïve AST Implementation</u>

```
class PlusNode
        IntNode left;
        IntNode right;
}
```

You cannot have 1+ 2 + 3.

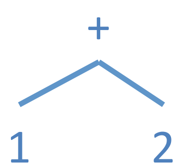
```
class IntNode{
        int value;
}
```

Thinking about implementing ASTs

Consider AST node classes

- We'd like the classes to have a common inheritance tree

AST

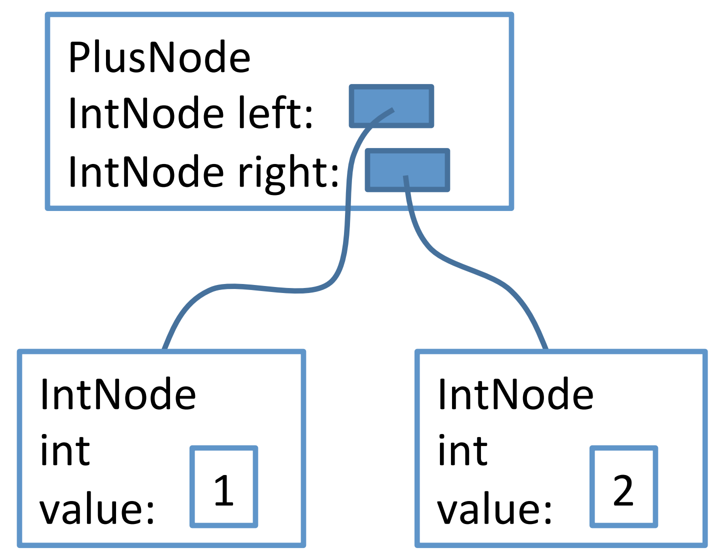


Naïve AST Implementation

```
class PlusNode
{       IntNode left;
        IntNode right;
}


class IntNode
{       int value;
}
```

Naïve java AST

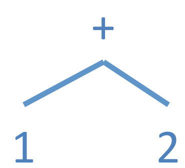


Thinking about implementing ASTs

Consider AST node classes

– We'd like the classes to have a common inheritance tree

AST



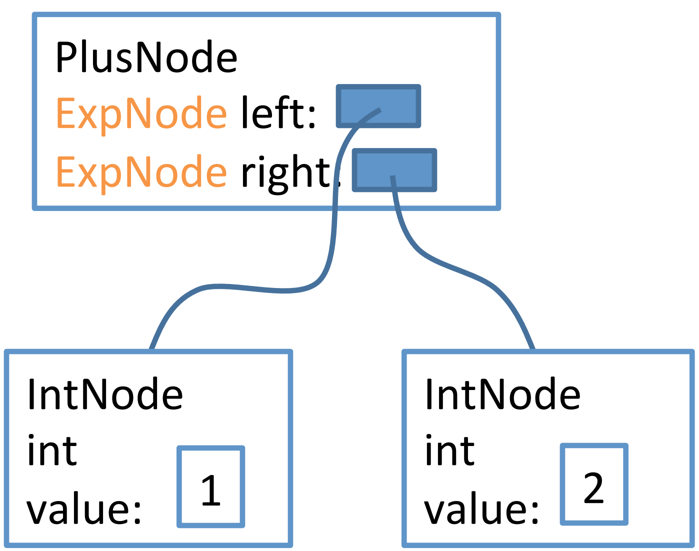
Naïve AST Implementation

```
class PlusNode
{       IntNode left;
        IntNode right;
}
```

```
class IntNode
{       int value;
}
```

Make these extend ExpNode

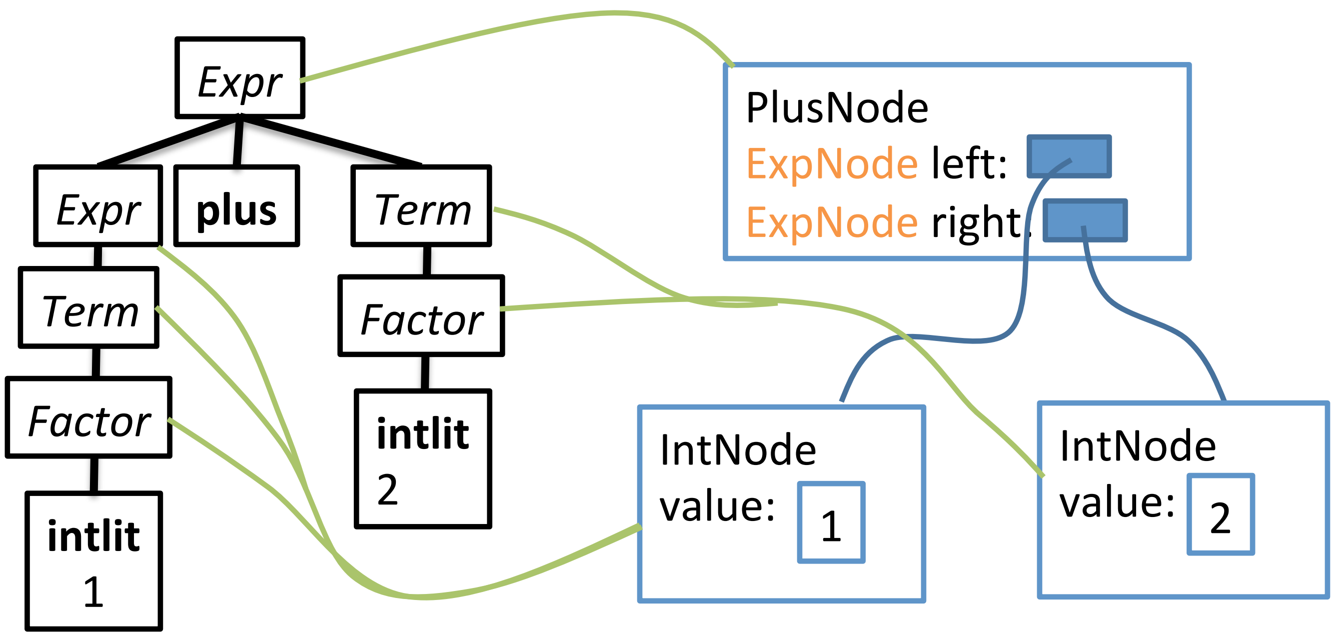
Better java AST



Implementing ASTs for Expressions

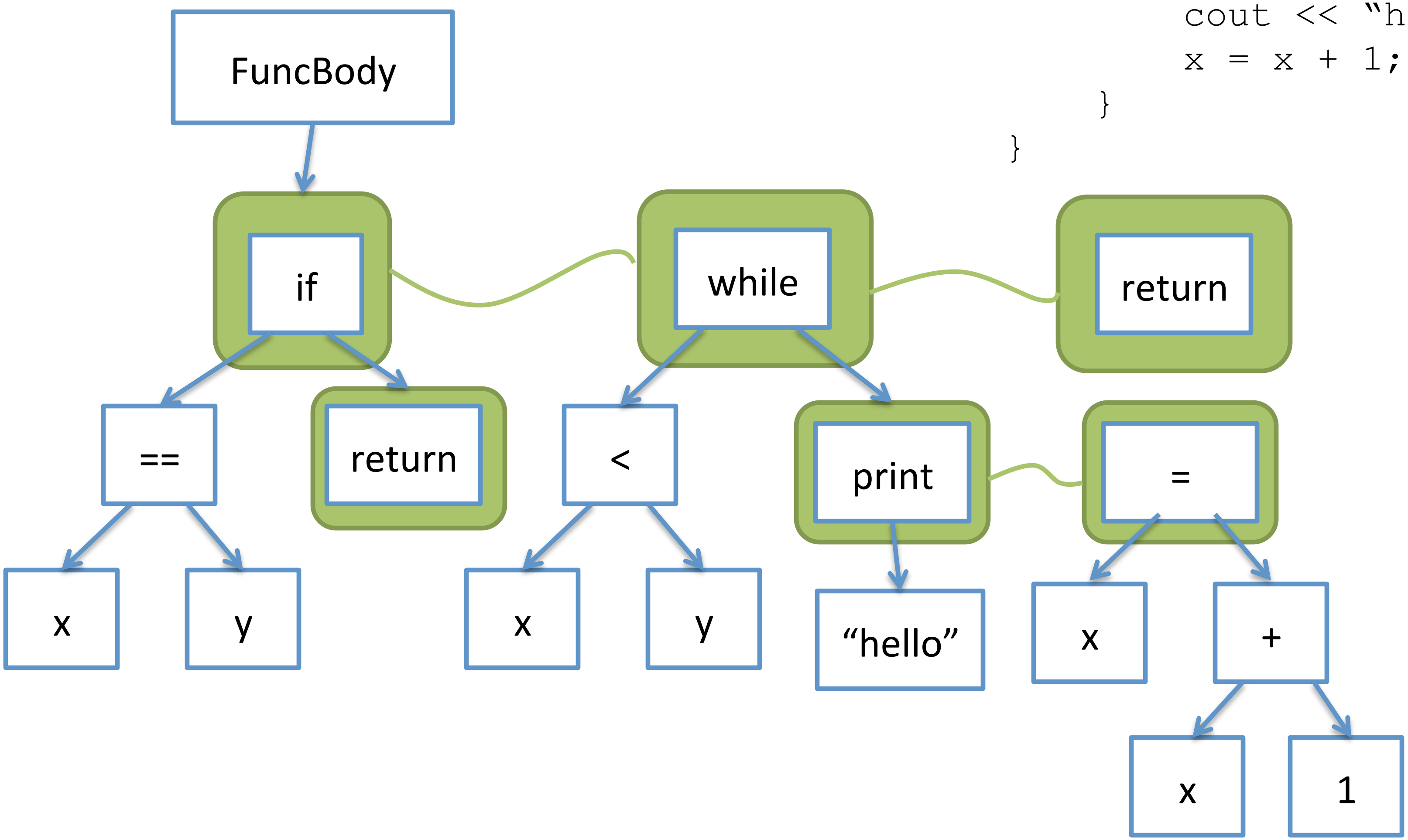
<u>CFG</u>			<u>Translation Rules</u>
Expr	->	Expr + Term	*Expr1*.trans = new PlusNode(*Expr2*.trans, *Term*.trans)
	|	Term	*Expr*.trans = Term.trans
Term	->	Term * Factor	*Term1*.trans = new TimesNode(Term2.trans, *Factor*.trans)
	|	Factor	*Term*.trans = *Factor*.trans
Factor	->	intlit	*Factor*.trans = new IntNode(**intlit**.value)
	|	(Expr)	*Factor*.trans = *Expr*.trans

Example: 1 + 2



An AST for a code snippet

```
void foo(int x, int y){
    if (x == y){
        return;
    }
    while ( x < y){
        cout << "hello";
        x = x + 1;
    }
}
```



Summary (1 of 2)

Today we learned about

- Syntax-Directed Translation (SDT)
  - Consumes a parse tree with actions
  - Actions yield some result
- Abstract Syntax Trees (ASTs)
  - The result of SDT for parsing in a compiler
  - Some practical examples of ASTs

Summary (2 of 2)

Scanner

Language abstraction: RegEx
Output: Token Stream
Tool: JLex
Implementation: DFA walking via table

Parser

Language abstraction: CFG
Output: AST by way of Parse Tree
Tool: Java CUP
Implementation: ???

Next time

Build a tree from a string and a grammar.

Next week