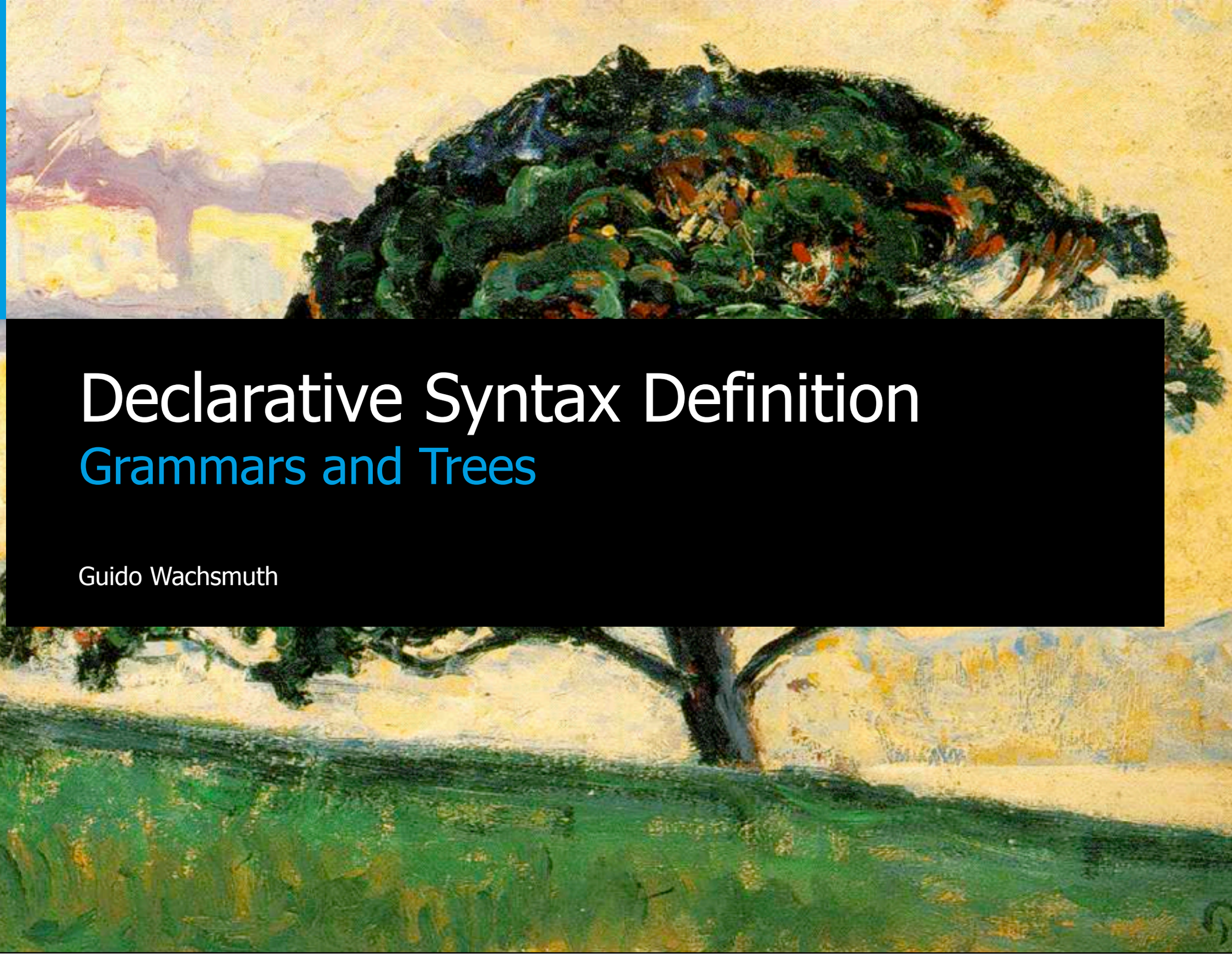


Declarative Syntax Definition

Grammars and Trees

Guido Wachsmuth

Assessment
last lecture

Identify three examples of polymorphism in the following Java expression: `"1" + ((2 + 4) + 3.5)`

- 1st and 2nd `+` symbolise different operations on different types
- 2nd and 3rd `+` symbolise same operation on different types
- `(2 + 4)` is of type `int`, but 3rd `+` requires a `float`
- `((2 + 4) + 3.5)` is of type `float`, but 1st `+` requires a `String`

What kinds of polymorphism do they represent?

- ad-hoc polymorphism, overloading
- ad-hoc polymorphism, type coercion, implicit conversion

What are the differences?

Assessment
last lecture

```
public class A {}

public class B extends A {}

public class C {
   public int m() { return 1 + 2; }
}

public class D {
   public String m() { return "1" + "2"; }
   public A m(A a1, A a2) { return a1; }
}

public class E extends D {
   public A m(B b1, B b2) { return b2; }
}
```

Type Systems
overriding

methods

- parameter types
- return type

covariance

- method in subclass
- return type: subtype of original return type

contravariance

- method in subclass
- parameter types: supertypes of original parameter types

Example: Java

overloading vs. overriding

```
public class F {
   public A m(B b) { System.out.println("F.m(B b)"); return b; }
}

public class G extends F {
   public A m(A a) { System.out.println("G.m(A a)"); return a; }
}

public class H extends F {
   public B m(B b) { System.out.println("H.m(B b)"); return b; }
}
```

```
A a = new A(); B b  = new B(); F f = new F(); G g = new G(); H h = new H();
               A ab = b;

f.m(b);
g.m(a); g.m(b); g.m(ab);
h.m(b);
```

Example: Java

invariance

```
public class X {
   public A a;
   public A    getA()    { return a ; }
   public void setA(A a) { this.a = a ; }
}

public class Y extends X {
   public B a;
   public B    getA()    { return a ; }
   public void setA(B a) { this.a = a ; }
}
```

```
A a = new A(); B b  = new B(); X y = new Y();

y.getA(); y.setA(b); y.setA(a);

String[] s = new String[3] ; Object[] o = s ; o[1] = new A();
```


PARENTAL
ADVISORY
THEORETICAL CONTENT

Overview
today's lecture

theory

- formal languages
- formal grammars
- decidability & complexity
- syntax trees

practice

- syntax definition for MiniJava

first assignment

I

generative grammar


infinite productivity

LA DEUXIÈME ANNÉE

DE LATIN

finite models

Théorie 250 pages.

227 Exercices 100 pages.

Lexiques

24 pages blanches pour notes et 4 cartes

Study of Language

linguistics and friends

philosophy

linguistics

- lexicology
- grammar
- morphology
- syntax
- phonology
- semantics

interdisciplinary

- applied linguistics
- computational linguistics
- historical linguistics
- neurolinguistics
- psycholinguistics
- sociolinguistics

computer science

- grammar
- semantics

A Theory of Language

formal languages

vocabulary Σ

finite, nonempty set of elements (words, letters)

alphabet

string over Σ

finite sequence of elements chosen from Σ

word, sentence, utterance

formal language λ

set of strings over a vocabulary Σ

$\lambda \subseteq \Sigma^*$

A Theory of Language
formal grammars

formal grammar G

derivation relation $\Rightarrow_G$

formal language $L(G) \subseteq \Sigma^*$

$L(G) = \{w \in \Sigma^* \mid S \Rightarrow_G^* w\}$

Decimal Numbers

morphology

G = (N, Σ, P, S)

Num → Digit Num
Num → Digit
Digit → "0"
Digit → "1"
Digit → "2"
Digit → "3"
Digit → "4"
Digit → "5"
Digit → "6"
Digit → "7"
Digit → "8"
Digit → "9"

Σ: finite set of terminal symbols

N: finite set of non-terminal symbols

S∈N: start symbol

P⊆(N×N∪Σ)*: set of production rules

Decimal Numbers

production

Num ⇒
Digit Num ⇒
4 Num ⇒
4 Digit Num ⇒
4 3 Num ⇒
4 3 Digit Num ⇒
4 3 0 Num ⇒
4 3 0 Digit ⇒
4 3 0 3

Num → Digit Num
Digit → “4”
Num → Digit Num
Digit → “3”
Num → Digit Num
Digit → “0”
Num → Digit
Digit → “3”

leftmost derivation

Decimal Numbers

production

Num ⇒	Num → Digit Num
Digit Num ⇒	Num → Digit Num
Digit Digit Num ⇒	Num → Digit Num
Digit Digit Digit Num ⇒	Num → Digit
Digit Digit Digit Digit ⇒	Digit → “3”
Digit Digit Digit 3 ⇒	Digit → “0”
Digit Digit 0 3 ⇒	Digit → “3”
Digit 3 0 3 ⇒	Digit → “4”
4 3 0 3	

rightmost derivation

Binary Expressions

syntax

G = (N, Σ, P, S)

Exp → Num
Exp → Exp "+" Exp
Exp → Exp "−" Exp
Exp → Exp "*" Exp
Exp → Exp "/" Exp
Exp → "(" Exp ")"

Σ: finite set of terminal symbols

N: finite set of non-terminal symbols

S∈N: start symbol

P⊆(N×N∪Σ)*: set of production rules

Binary Expressions
production

Exp ⇒

Exp + Exp ⇒

Exp + Exp * Exp ⇒

3 + Exp * Exp ⇒

3 + 4 * Exp ⇒

3 + 4 * 5

Exp → Exp “+” Exp

Exp → Exp “*” Exp

Exp → Num

Exp → Num

Exp → Num

A Theory of Language

formal grammars

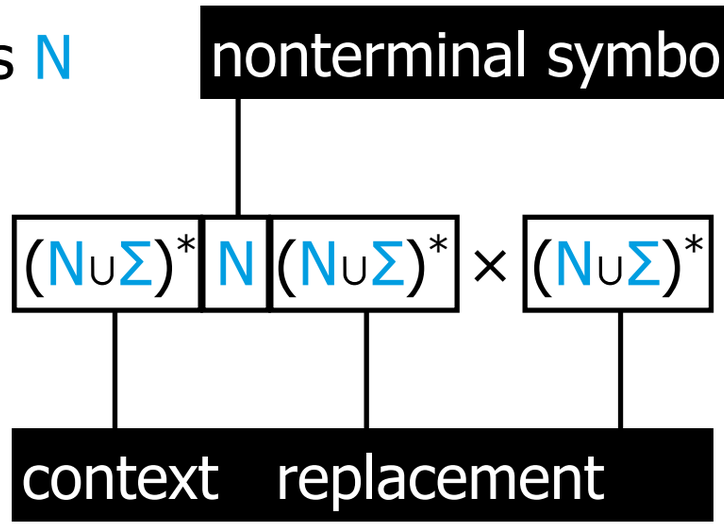
formal grammar $G = (N, \Sigma, P, S)$

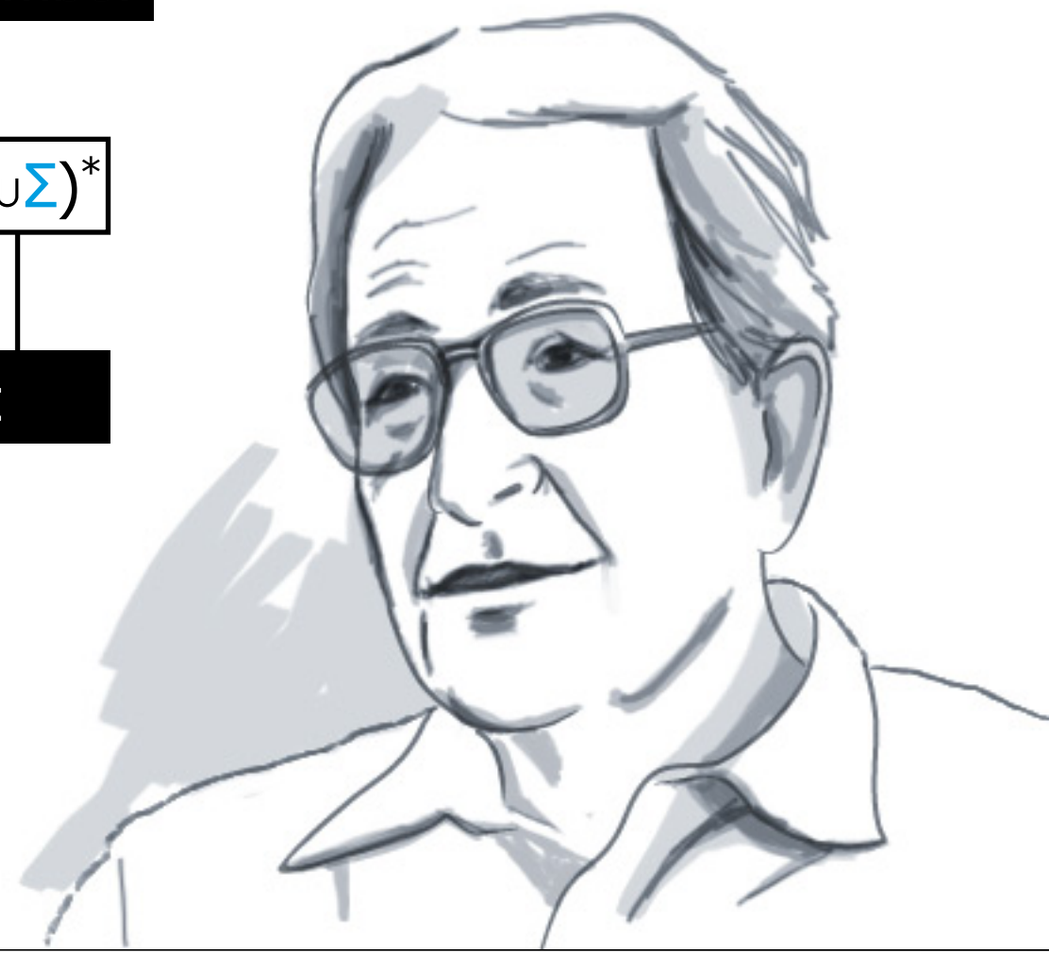
nonterminal symbols N

terminal symbols Σ

production rules $P \subseteq (N \cup \Sigma)^* N (N \cup \Sigma)^* \times (N \cup \Sigma)^*$

start symbol $S \in N$





A Theory of Language

grammar classes

type-0, unrestricted: $P \subseteq (N \cup \Sigma)^* \; N \; (N \cup \Sigma)^* \times (N \cup \Sigma)^*$

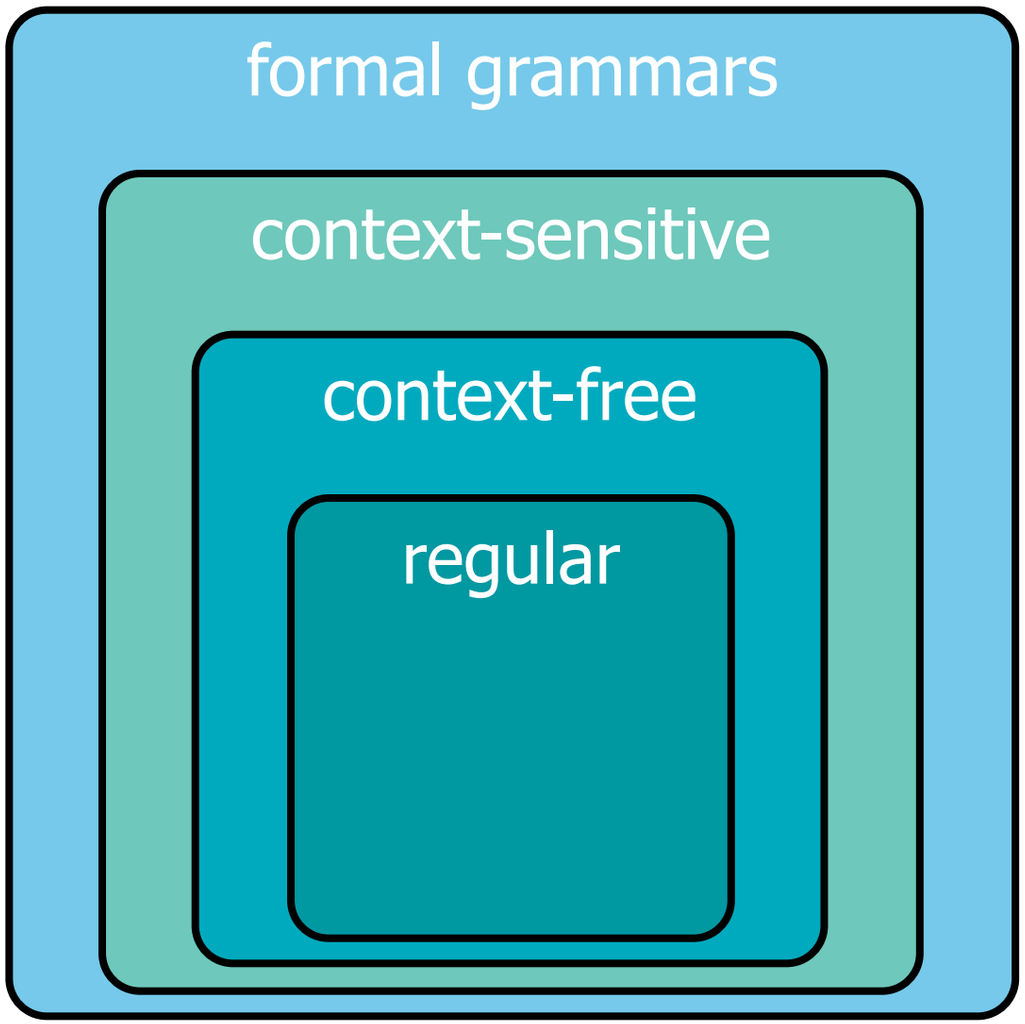
type-1, context-sensitive: (a A c, a b c)

type-2, context-free: $P \subseteq N \times (N \cup \Sigma)^*$

type-3, regular: (A, x) or (A, xB)

A Theory of Language

grammar classes



A Theory of Language

formal grammars

formal grammar G

derivation relation $\Rightarrow_G$

formal language $L(G) \subseteq \Sigma^*$

$L(G) = \{w \in \Sigma^* \mid S \Rightarrow_G^* w\}$

A Theory of Language
formal languages

formal grammar $G = (N, \Sigma, P, S)$

derivation relation $\Rightarrow_G \subseteq (N \cup \Sigma)^* \times (N \cup \Sigma)^*$

$w \Rightarrow_G w' \Leftrightarrow$

$\exists (p, q) \in P: \exists u, v \in (N \cup \Sigma)^*:$

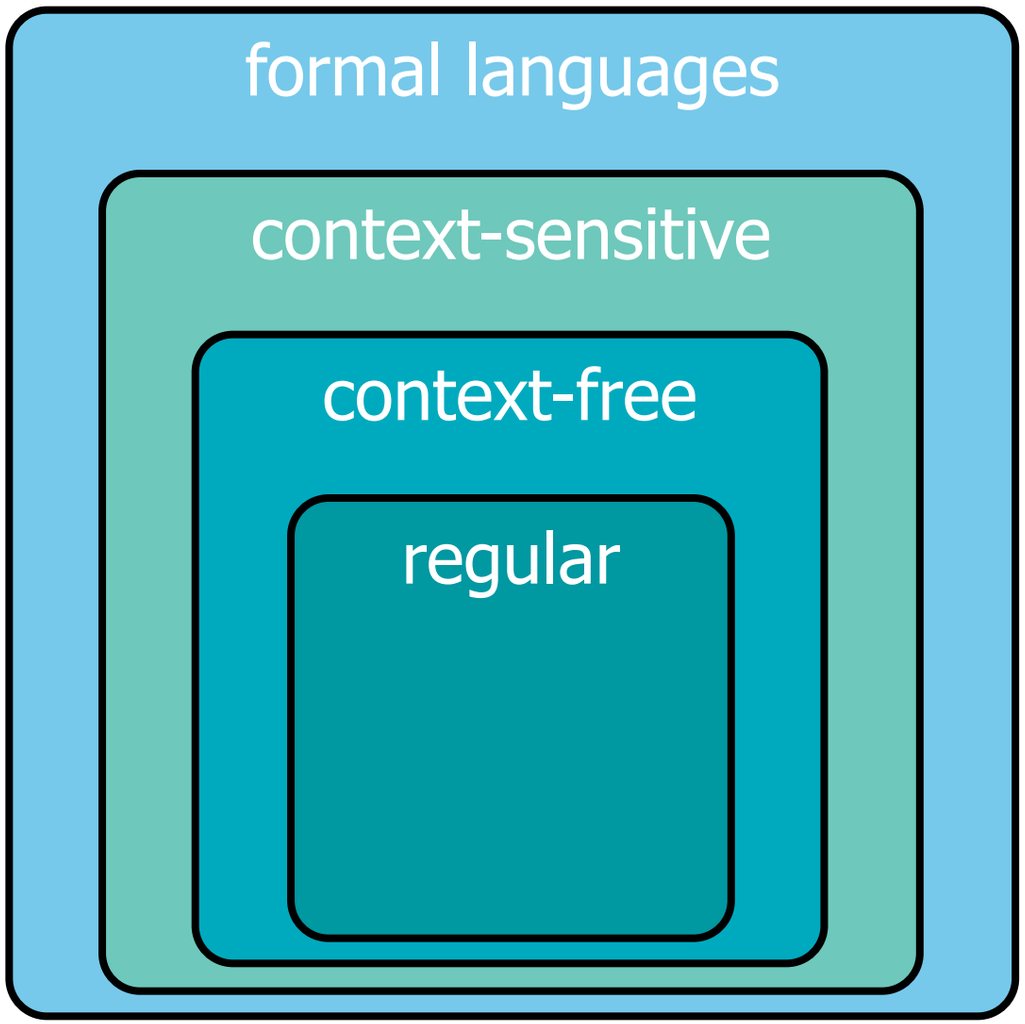
$w = u\ p\ v \wedge w' = u\ q\ v$

formal language $L(G) \subseteq \Sigma^*$

$L(G) = \{w \in \Sigma^* \mid S \Rightarrow_G^* w\}$

A Theory of Language

language classes



II

word problem

Theoretical Computer Science

decidability & complexity

word problem χ_L: $\Sigma^* \rightarrow \{0,1\}$

- $w \rightarrow 1$, if $w \in L$
- $w \rightarrow 0$, else

decidability

- type-0: semi-decidable
- type-1, type-2, type-3: decidable

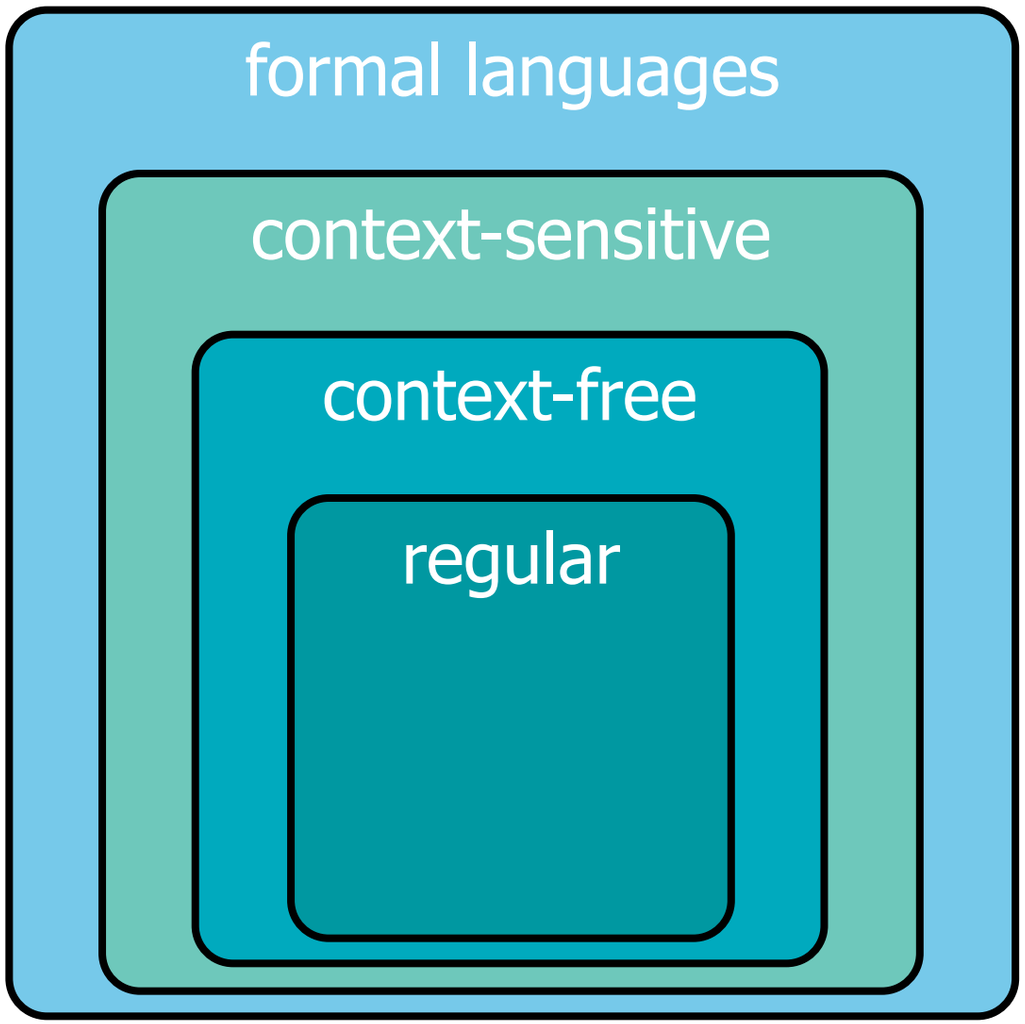
complexity

- type-1: PSPACE-complete
- type-2, type-3: P

$PSPACE \supseteq NP \supseteq P$

Theoretical Computer Science

decidability & complexity



Context-free Grammars

production vs. reduction rules

Exp → Num	Num → Exp
Exp → Exp “+” Exp	Exp “+” Exp → Exp
Exp → Exp “−” Exp	Exp “−” Exp → Exp
Exp → Exp “*” Exp	Exp “*” Exp → Exp
Exp → Exp “/” Exp	Exp “/” Exp → Exp
Exp → “(” Exp “)”	“(” Exp “)” → Exp
productive form	**reductive form**

Binary Expressions

reduction

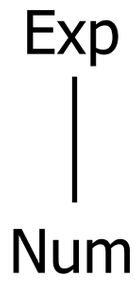
3 + 4 * 5 ⇒	Num → Exp
Exp + 4 * 5 ⇒	Num → Exp
Exp + Exp * 5 ⇒	Num → Exp
Exp + Exp * Exp ⇒	Exp "*" Exp → Exp
Exp + Exp ⇒	Exp "+" Exp → Exp
Exp	

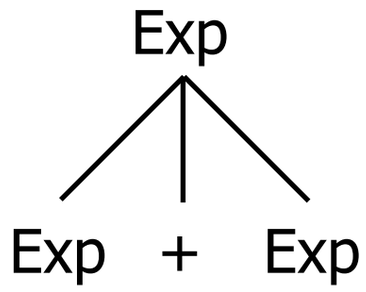
III

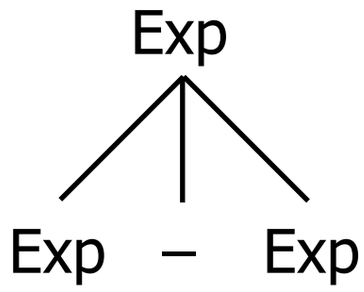
syntax trees

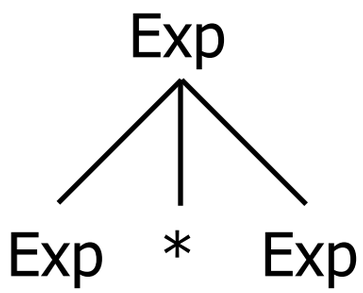
Context-free Grammars

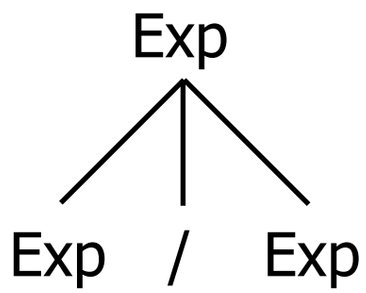
tree construction rules

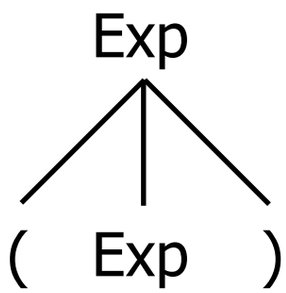






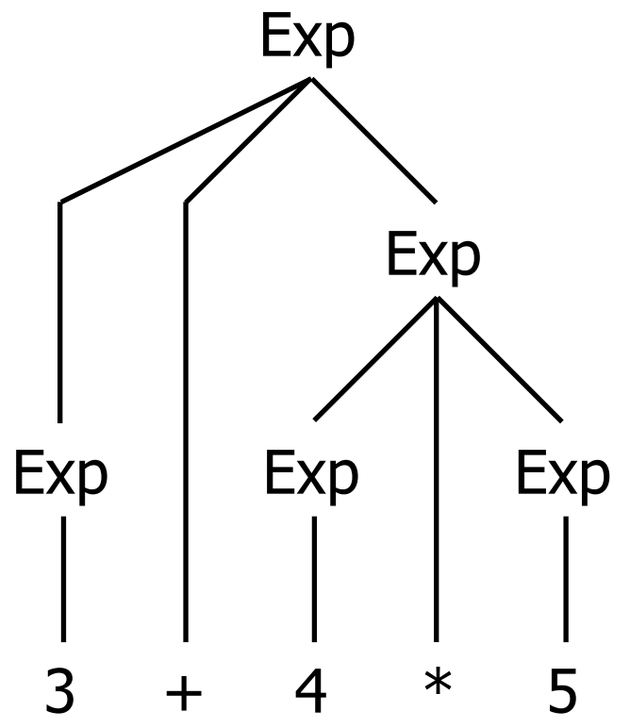






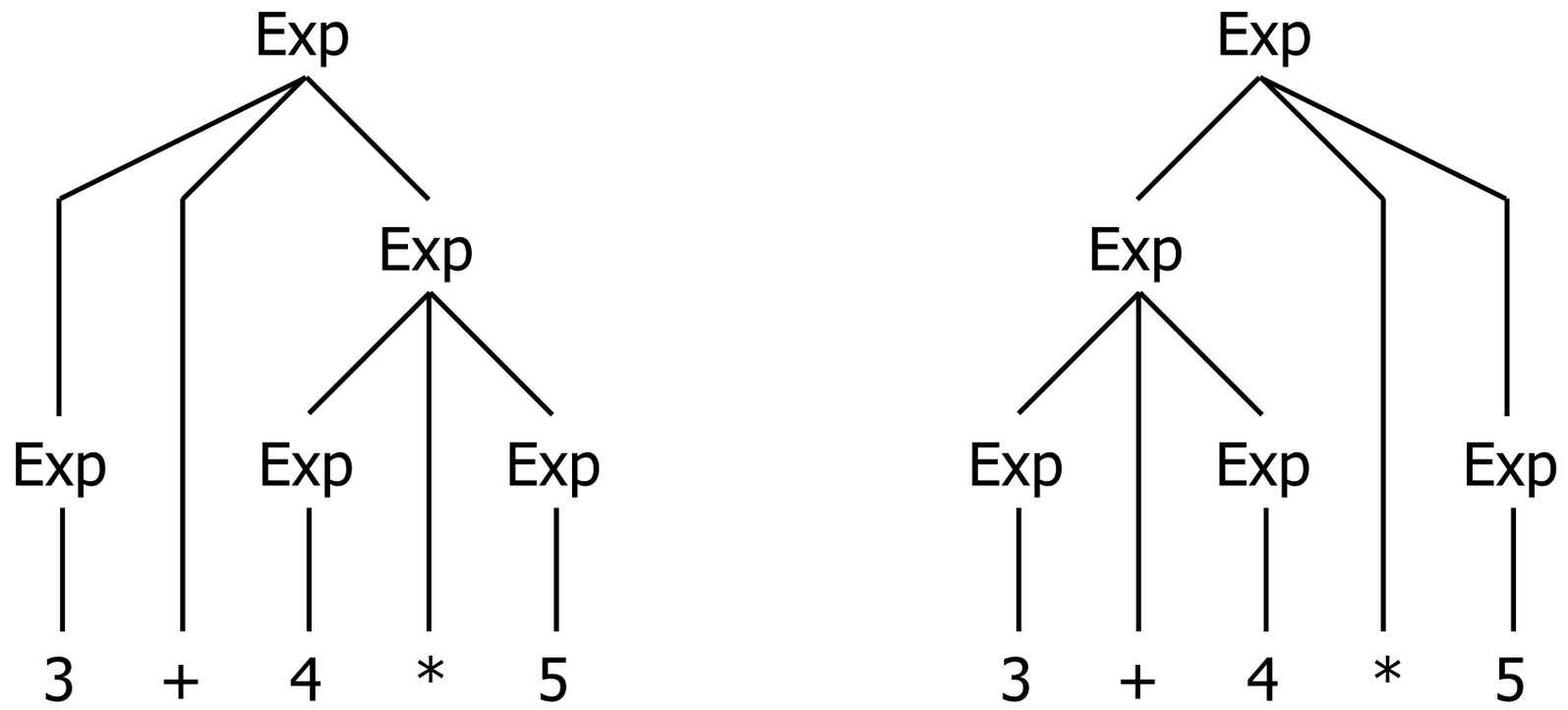
Binary Expressions

tree construction



Context-free Grammars

ambiguities



Abstract Syntax Trees

parse trees

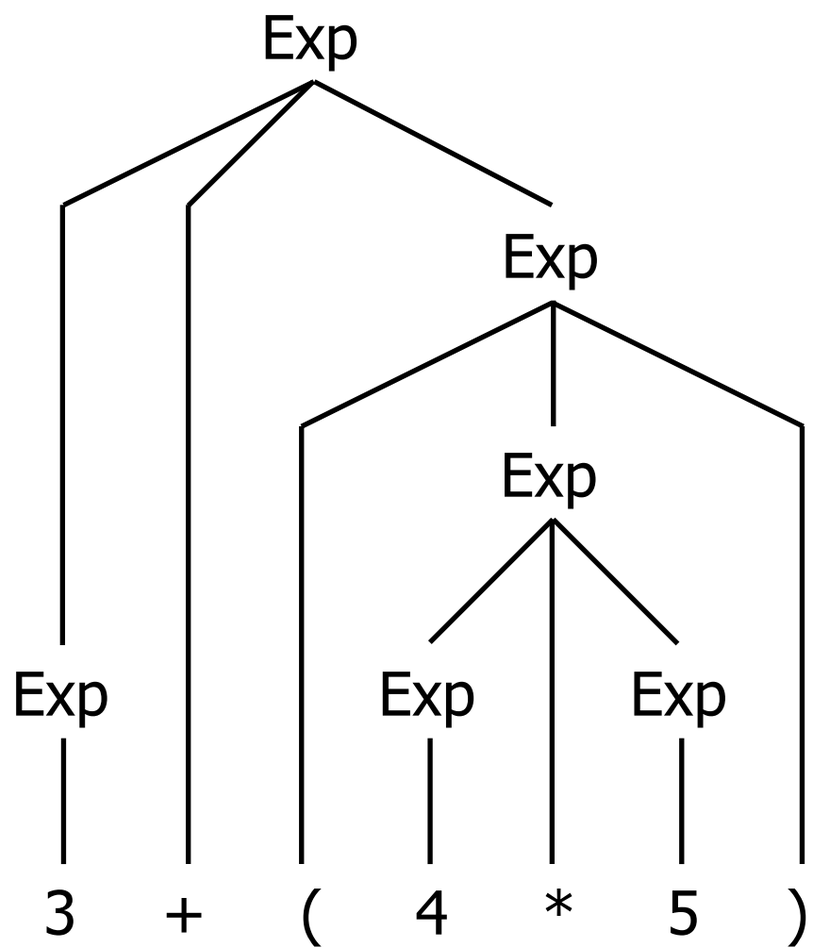
- parent node: nonterminal symbol
- children nodes: nonterminal and terminal symbols

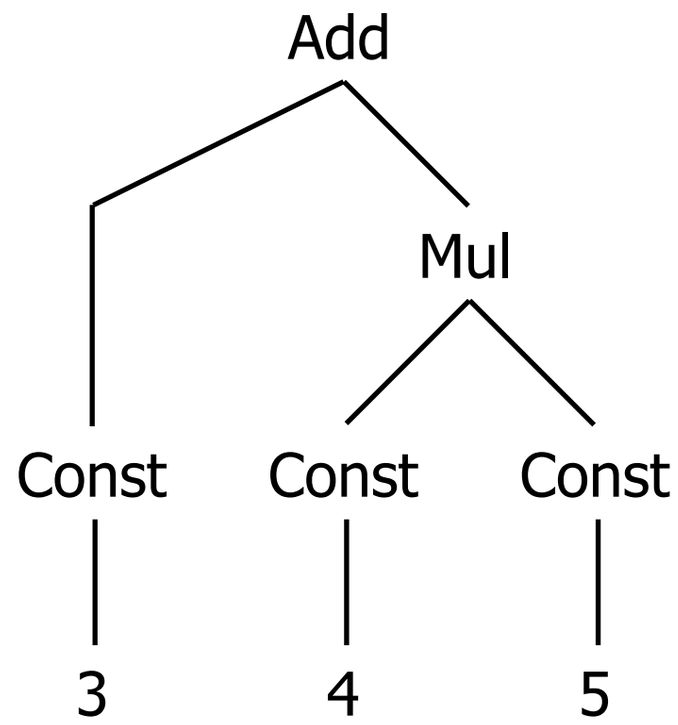
abstract syntax trees

- abstract over terminal symbols
- convey information at parent nodes
- abstract over injective production rules

Binary Expressions

abstract syntax trees





coffee break

Andrew W. Appel, Jens Palsberg: Modern Compiler Implementation in Java, 2nd edition

MiniJava

lexical syntax

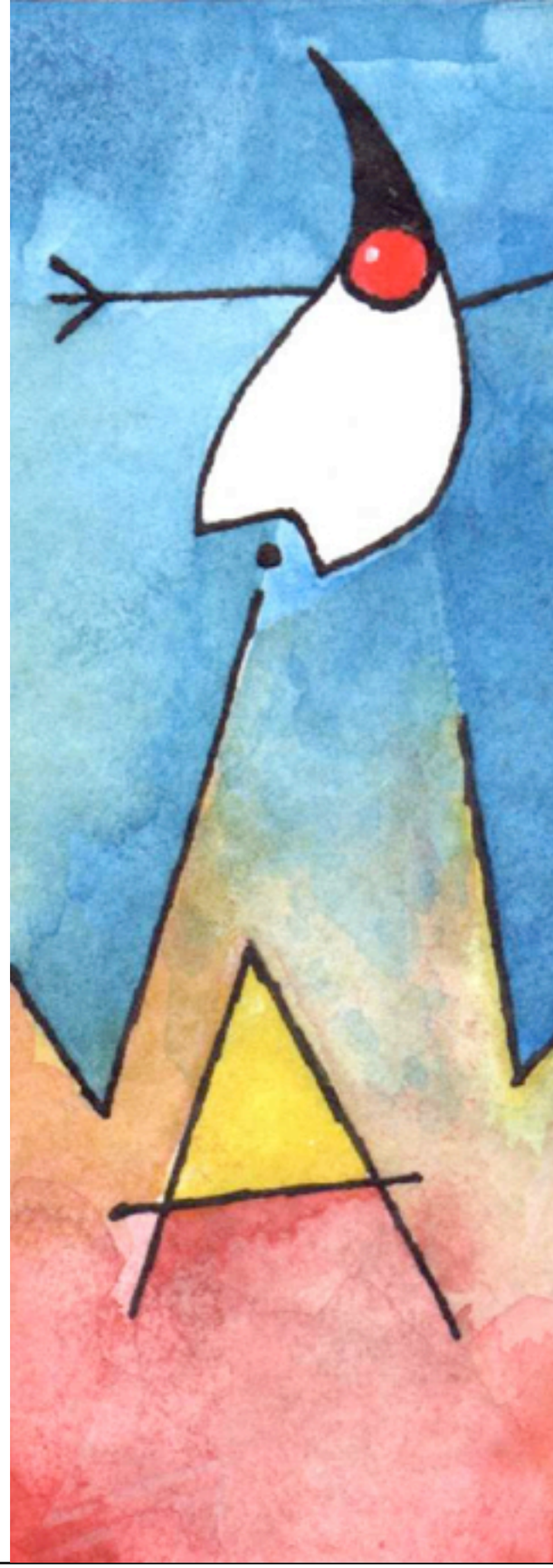
An identifier is a sequence of letters, digits, and underscores, starting with a letter. Uppercase letters are distinguished from lowercase.

A sequence of decimal digits is an integer constant that denotes the corresponding integer value.

A binary operator is one of

```
&&    <    +    -    *
```

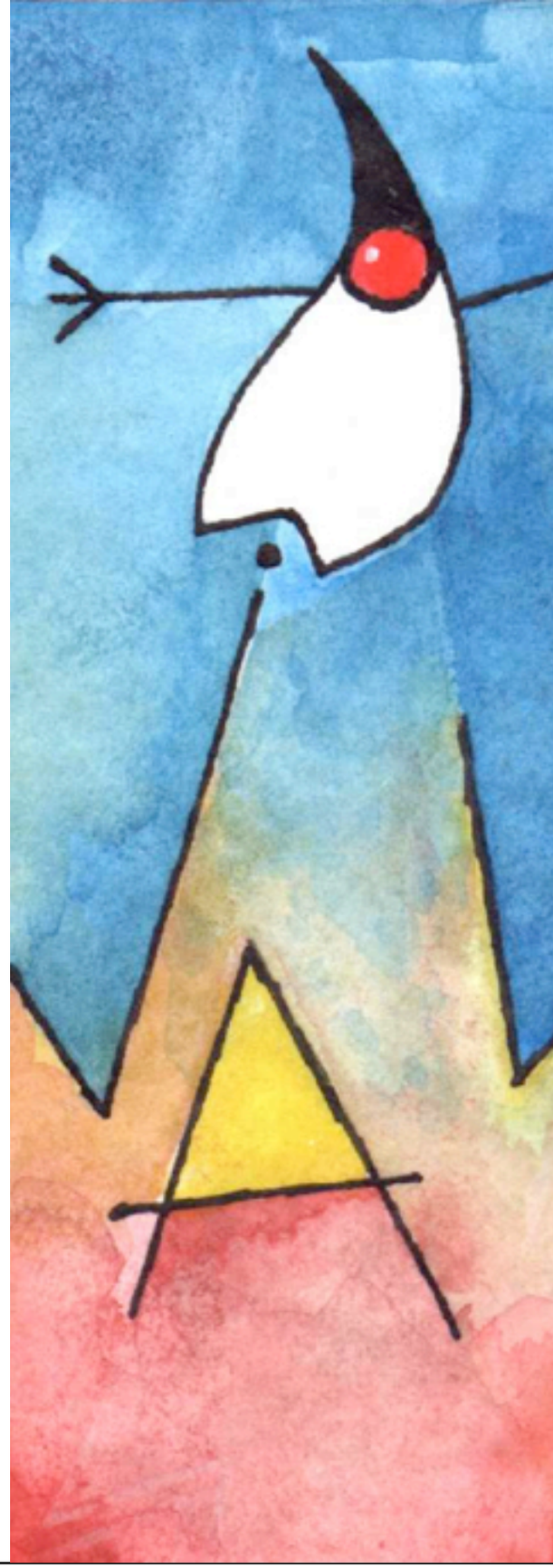
A comment may appear between any two tokens.There are two forms of comments: One starts with /*, ends with */, and may be nested; another begins with // and goes to the end of the line.



MiniJava Expressions

```
42
true
false
x
x*y
!x
(x)
```

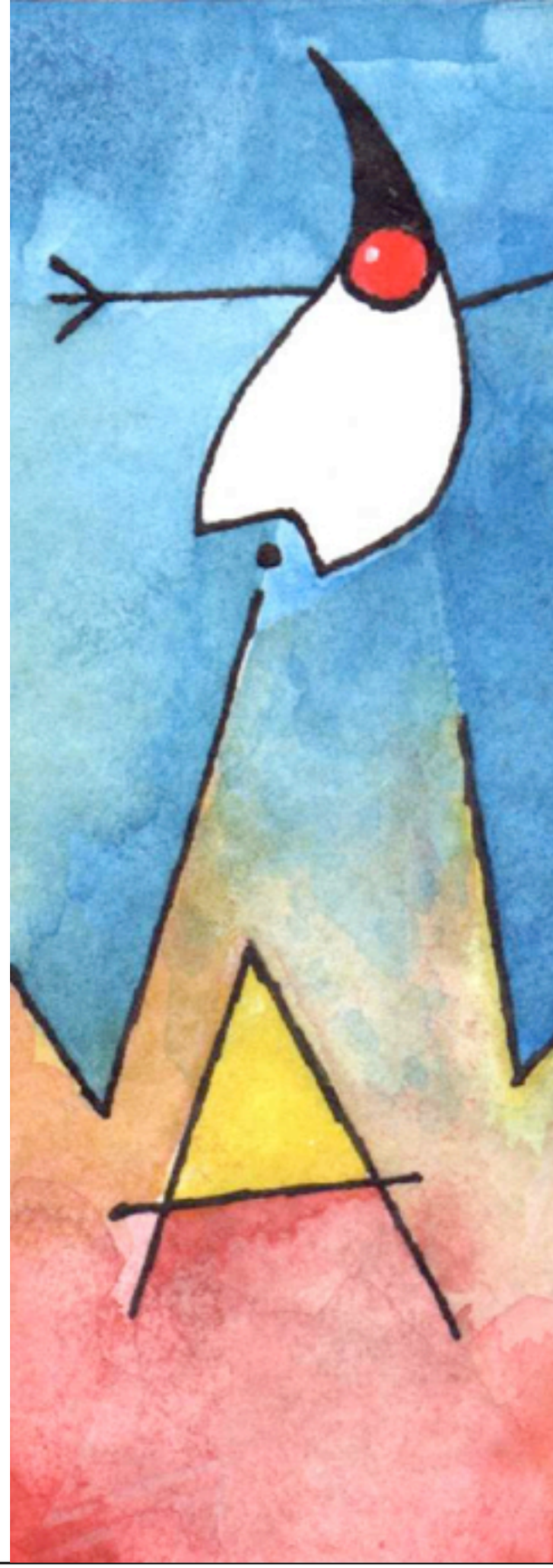
```
Exp → Int
    → "true"
    → "false"
    → Id
    → Exp Op Exp
    → "!" Exp
    → "(" Exp ")"
```



MiniJava Expressions

```
new int[42]
x[42]
x.length
new Class()
this
x.m(y, z)
```

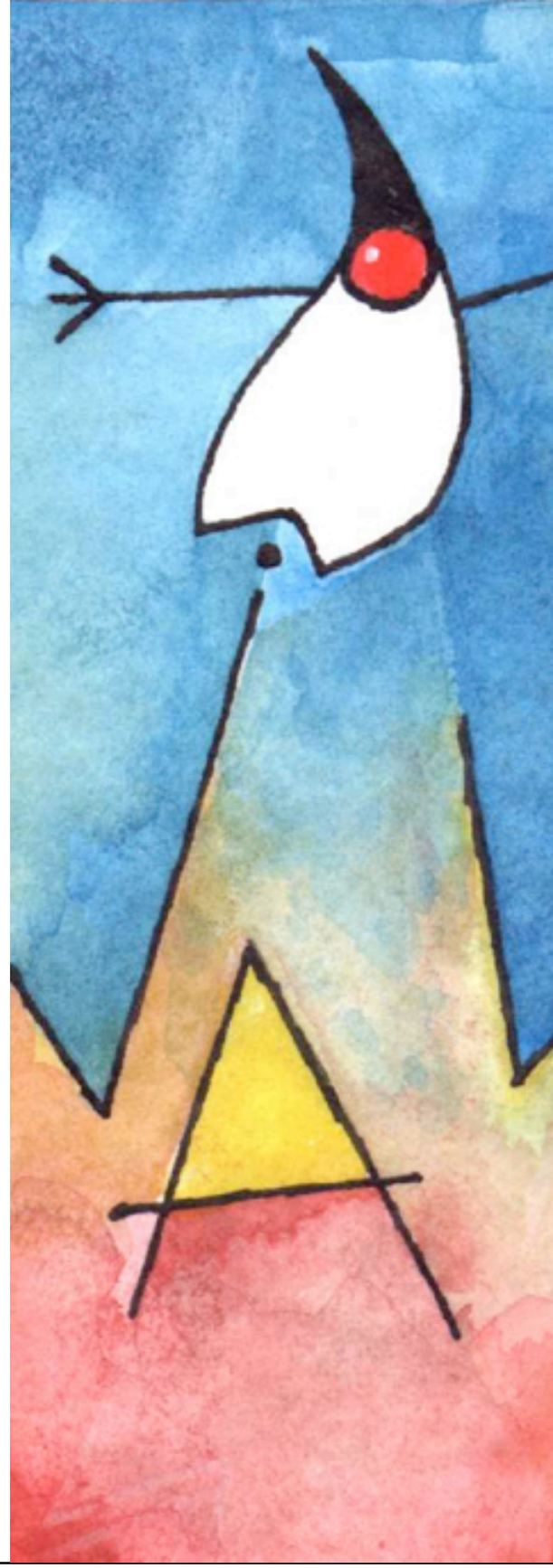
```
Exp → "new" "int" "[" Exp "]"
    → Exp "[" Exp "]"
    → Exp "." "length"
    → "new" Id "(" ")"
    → "this"
    → Exp "." Id "(" ExpList ")"
```



MiniJava Expressions

```
new int[42]
x[42]
x.length
new Class()
this
x.m(y, z)
```

```
ExpList → Exp ExpRest*
        →
ExpRest → "," Exp
```



MiniJava Statements

```
x = y ;
x[z] = y ;
if (b) x = y ; else y = x ;
while (x < 42) x = x+1 ;
System.out.println(x) ;
{ x = y ; y = z ; }
```

```
Statement → Id "=" Exp ";"
          → Id "[" Exp "]" "=" Exp ";"
          → "if" "(" Exp ")" Statement
            "else" Statement
          → "while" "(" Exp ")" Statement
          → "System.out.println" "(" Exp ")" ";"
          → "{" Statement* "}"
```

MiniJava Class Declarations

```
class Main {
   public static void main(String[] args) {
      System.out.println(new Fac().fac(10)) ;
   }
}

class Fac { … }
```

```
Program   → MainClass ClassDecl*
MainClass → "class" Id "{" "public" "static" "void"
            "main" "(" "String" "[" "]" Id ")"
            "{" Statement "}" "}"
ClassDecl → "class" Id "{" VarDecl* MethodDecl* "}"
          → "class" Id "extends" Id
            "{" VarDecl* MethodDecl* "}"
```

MiniJava Declarations

```
int x ;
public int id(int p) {int r ; r = p ; return r ; }
int
boolean
int[]
Class
```

```
VarDecl    → Type Id ";"
MethodDecl → "public" Type Id "(" FormalList ")" "{"
             VarDecl* Statement* "return" Exp ";" "}"
Type       → "int"
           → "boolean"
           → "int" "[" "]"
           → Id
```

MiniJava Declarations

```
int x ;
public int id(int p) {int r ; r = p ; return r ; }
int
boolean
int[]
Class
```

```
FormalList → Type Id FormalRest*
           →
FormalRest → "," Type Id
```

V

summary

Summary
lessons learned

What is a formal language?

- set of strings over a vocabulary

What is a formal grammar?

- quadruple of sets of nonterminal and terminal symbols, a set of productions, and a start symbol

What is a context-free grammar and how can you read it?

- formal grammar with a single nonterminal symbol at left-hand sides of production rules
- productive form, reductive form, tree construction rules

What is the syntax of MiniJava programs?

Literature

learn more

formal languages

Noam Chomsky: Three models for the description of language. 1956

Noam Chomsky: Syntactic Structures. 1957

J. E. Hopcroft, R. Motwani, J. D. Ullman: Introduction to Automata Theory, Languages, and Computation. 2006

MiniJava

Andrew W. Appel, Jens Palsberg: Modern Compiler Implementation in Java, 2nd edition. 2002

Outlook
coming next

declarative syntax definition

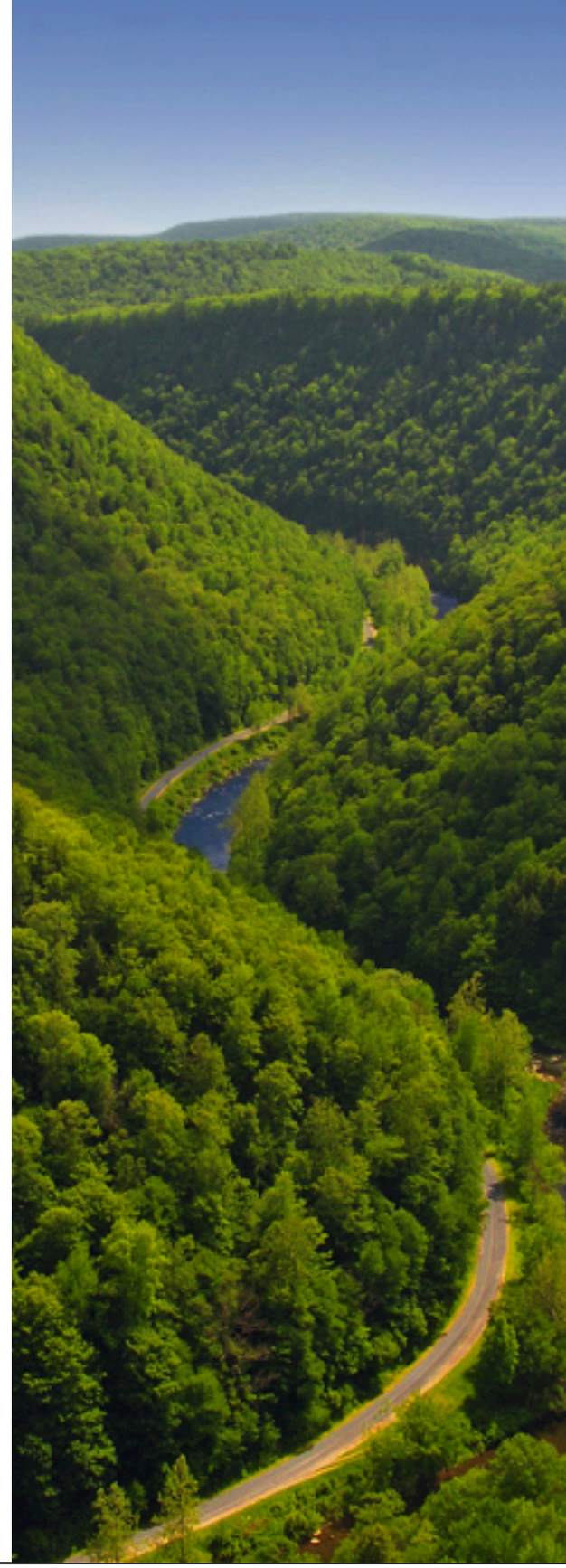
- Lecture 2: SDF and ATerms

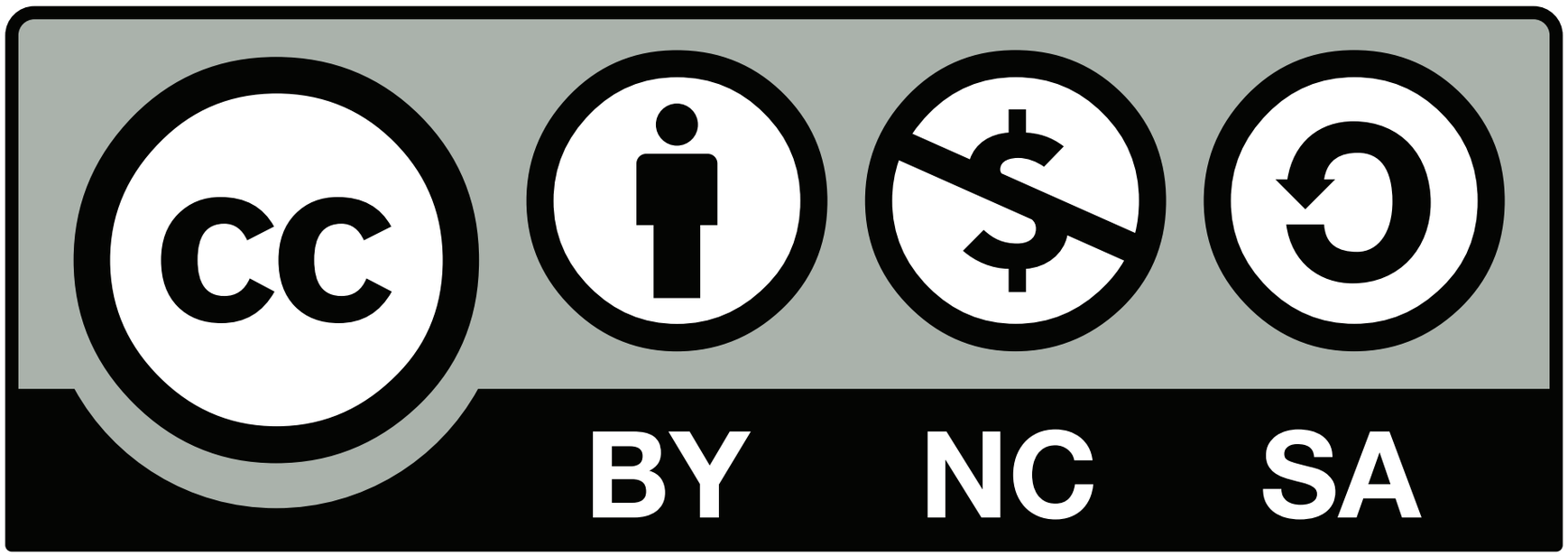
declarative semantics definition

- Lecture 3: Name Binding and Type Systems
- Lecture 4: Term Rewriting
- Lecture 5: Static Analysis and Error Checking
- Lecture 6: Code Generation

next 2 Labs

- install minimal MiniJava project
- write positive and negative test cases

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