CSCI 742 - Compiler Construction

Lecture 2

Describing Syntax

Instructor: Hossein Hojjat

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Compiler Phases

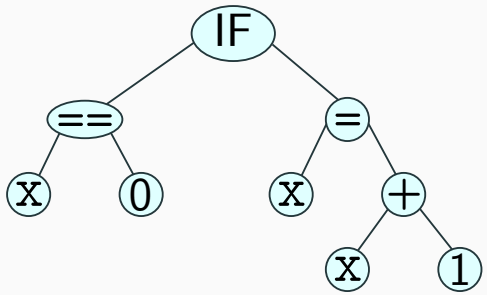
Source Code
(concrete syntax)

```
if (x==0) x=x+1;
```

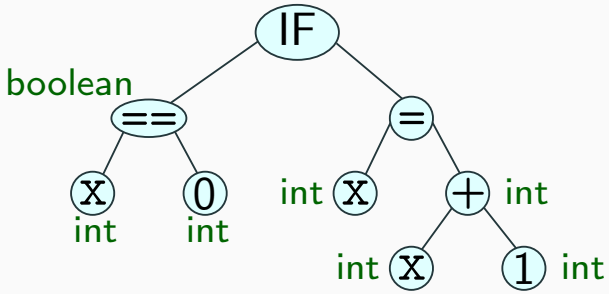
Token Stream

```
if ( x == 0 ) x = x + 1 ;
```

Abstract Syntex Tree
(AST)



Attributed AST



Machine Code

```
16: iload_2
17: ifne   24
20: iload_2
21: iconst_1
22: iadd
23: istore_2
24: ...
```

Lexical Analysis

Syntax Analysis
(Parsing)

Semantic Analysis
(Name Analysis,
Type Analysis, ...)

Code Generation

Error

Programming Language Description

How to describe a programming language?

- We need to provide:

1. **Syntax:**
   which strings of symbols are valid expressions in the language?
2. **Semantics:**
   what do valid expressions actually mean, or how do they behave?

Example

Some Java syntax rules:

- Use a semicolon (“;”) to separate two statements
- Enclose the condition of an IF expression inside parentheses

Some semantics rules for valid Java expressions:

- `x++` increment the value of variable x by 1
- `x + 1` calculate the sum of x and 1

Describing Syntax

- Informal description using natural languages (English)

  Pros.

  - Explain high-level concepts to beginners

  Cons.

  - Imprecise, vague, tedious and repetitive
  - Impossible to develop tools to analyze such descriptions

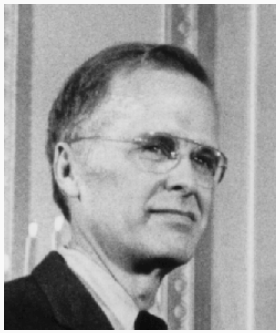
- List all valid programs

  Cons:

  - There exists arbitrarily long valid programs even for small languages

Describing Syntax

- **Formal languages and automata:**
  - Branch of CS that formalizes the properties of "languages" over strings and their syntax
- Benefits of precise descriptions based on formal languages theory
  - Document what programs a compiler should accept or reject
  - Develop compiler phases (lexer, parser) using compiler generating tools



John Backus was the first to employ a formal technique for specifying the syntax of programming languages (Algol 60)

While Language

- While-Language is a small language we use to illustrate basic concepts
- "While" because it has `while` and `if` as the only control statements
  - no procedures, no exceptions
- All variables are of type integer
- Variables not declared, they are initially zero
- No objects, No pointers, No arrays

Convert `if` to `while`

- How to express conditional statement

```
if (cond) {
  expr
}
```

- using a `while` statement?

Convert `if` to `while`

- While-language is Turing-complete! (although looks very simple)
- Does this program always terminate for any initial value of x?

```
while (x > 1) {
  if (x % 2 == 0) {
    x = x / 2;
  } else {
    x = 3 * x + 1;
  }
}
```

Convert `if` to `while`

- While-language is Turing-complete! (although looks very simple)
- Does this program always terminate for any initial value of x?

```
while (x > 1) {
  if (x % 2 == 0) {
    x = x / 2;
  } else {
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  }
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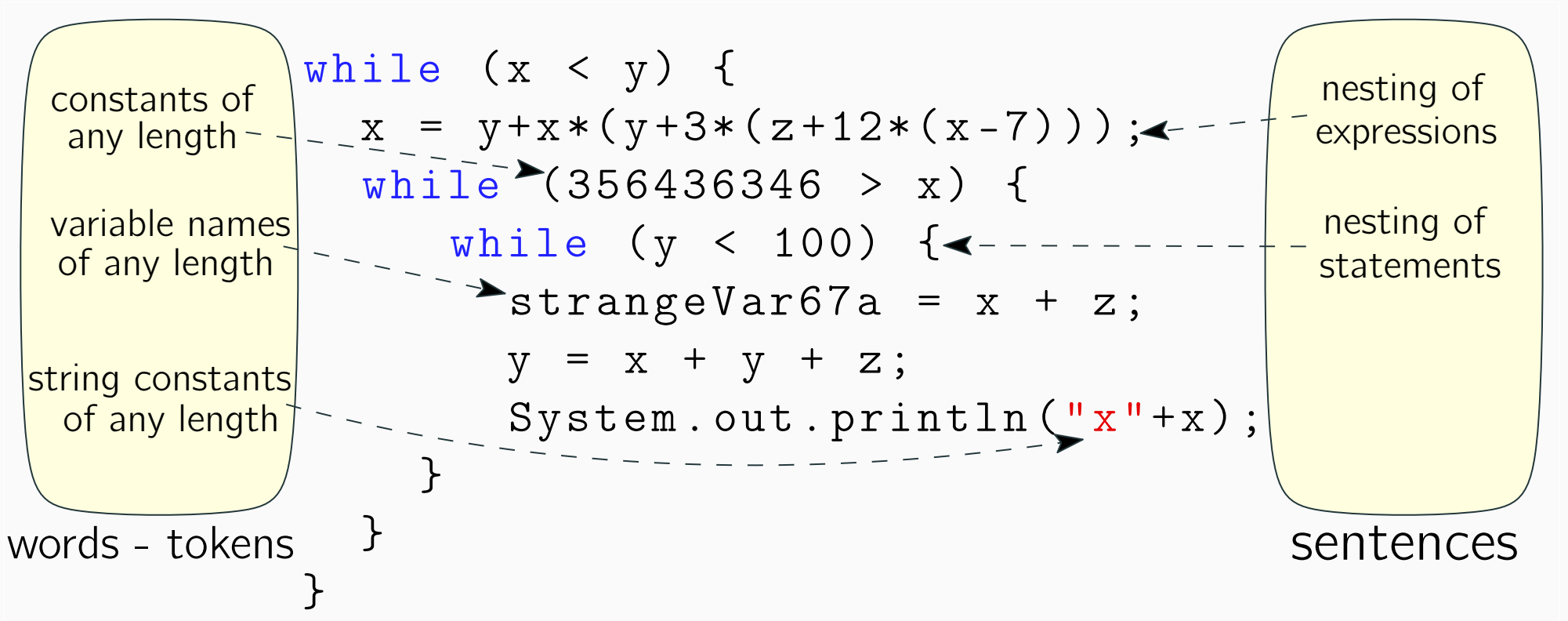
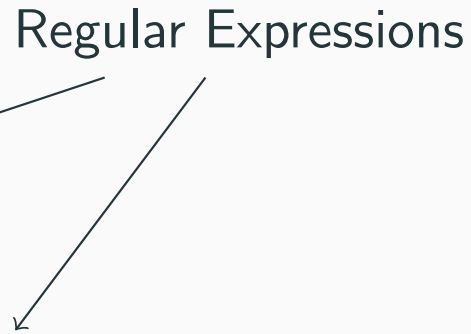
- Collatz Conjecture - open!
- Paul Erdős: "Mathematics may not be ready for such problems."

Reasons for Unbounded Program Size



Tokens (Words) of the While Language



Ident ::= letter (letter | digit)*

integerConst ::= digit digit*

stringConst ::= "AnySymbolExceptQuote*"

keywords ::=

if | else | while | println

special symbols ::=

( ) && < == + - * / % ! - { } ; ,

letter ::= a | b | c | ... | z | A | B | C | ... | Z

digit ::= 0 | 1 | ... | 8 | 9

Identifiers

```
while (x < y) {
   x = y+x*(y+3*(z+12*(x-7)));
   while (356436346 > x) {
      while (y < 100) {
         strangeVar67a = x + z;
         y = x + y + z;
         System.out.println("x"+x);
      }
   }
}
```

letter (letter | digit)*

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(concrete syntax)

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```

Regular Expressions for Tokens

Token Stream

```
if ( x == 0 ) x = x + 1 ;
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Abstract Syntex Tree
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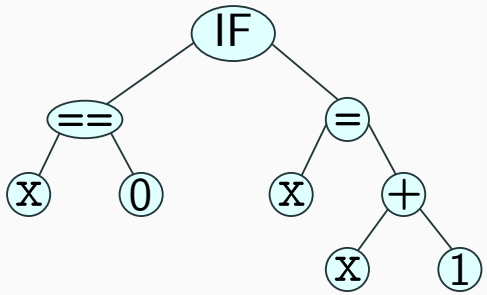

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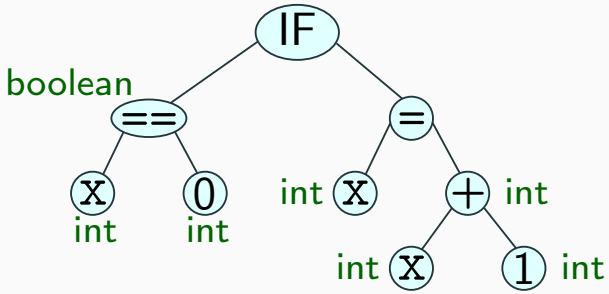

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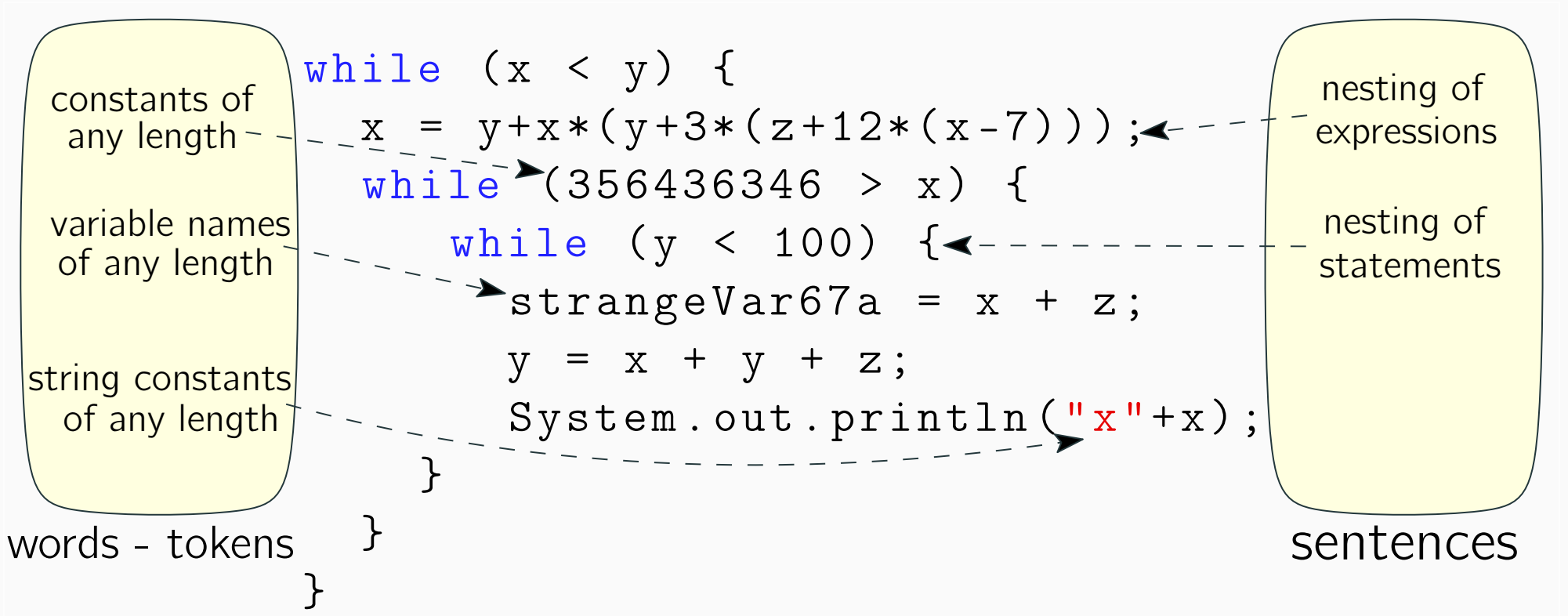

Sentences of the While Language

- Describe sentences using (possibly recursive) rules of a context-free grammar

```
program   ::=   statmt*
statmt    ::=   println( stringConst , ident )
            |   ident = expr
            |   if ( expr ) statmt (else statmt)?
            |   while ( expr ) statmt
            |   {statmt* }
expr      ::=   intLiteral | ident
            |   expr (&& | < | == | + | - | * | / | % ) expr
            |   ! expr   |   - expr
```

While Language without Nested Loops

```
statmt      ::=   println( stringConst , ident )
                | ident = expr
                | if ( expr ) statmt (else statmt)?
                | while ( expr ) statmtww
                | {statmt* }
statmtww    ::=   println( stringConst , ident )
                | ident = expr
                | if ( expr ) statmtww (else statmtww)?
                | {statmtww* }
```

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⇩ Regular Expressions for Tokens

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⇩ Context-Free Grammar

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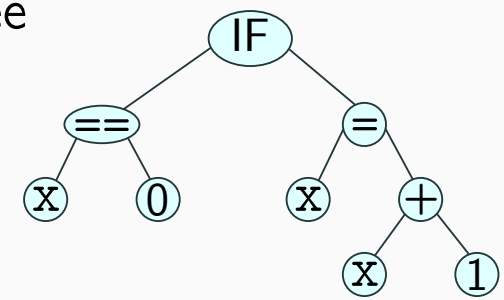

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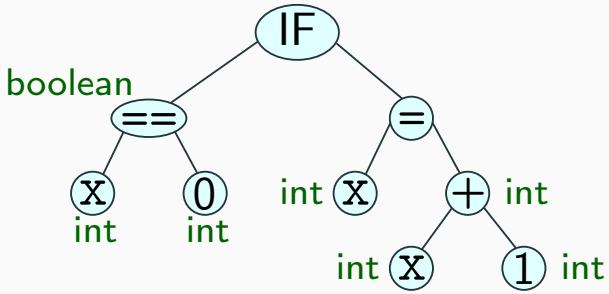

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Abstract Syntax Trees

To get abstract syntax trees:

- Start from context-free grammar for tokens
- Remove punctuation characters
- Interpret rules as tree descriptions, not string descriptions

statmt	::= println(stringConst , ident)	PRINT(string,ident)
	| ident = expr	ASSIGN(ident,expr)
	| if (expr) statmt (else statmt)?	IF(expr,statmt,statmt)
	| while (expr) statmt	WHILE(expr,statmt)
	| {statmt* }	BLOCK(List[statmt])