CSCI 742 - Compiler Construction

Lecture 2

Describing Syntax

Instructor: Hossein Hojjat

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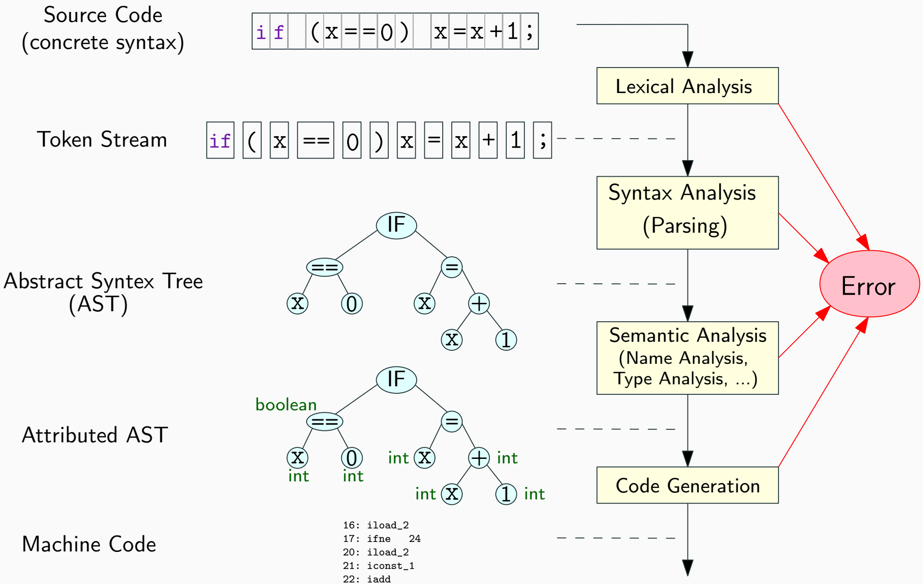
Compiler Phases



Source Code (concrete syntax)

`i f   ( x = = 0 )   x = x + 1 ;`

Lexical Analysis

Token Stream

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

Syntax Analysis (Parsing)

Abstract Syntex Tree (AST)

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

Attributed AST

Code Generation

Machine Code

Error

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

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

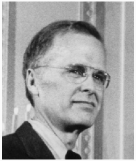
- List all valid programs

  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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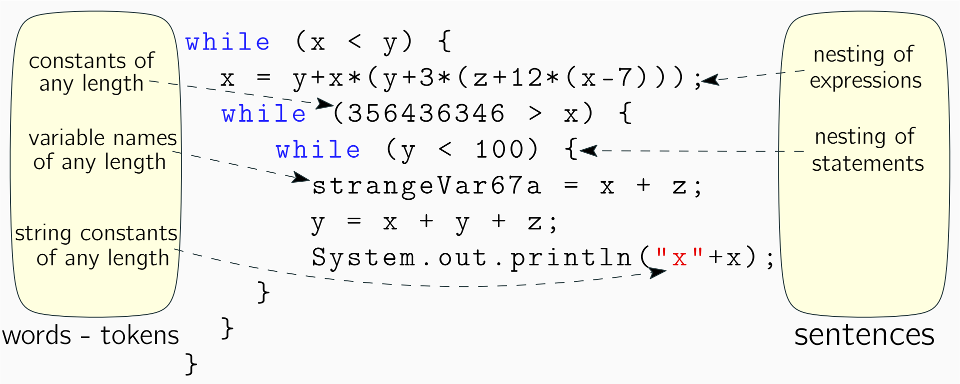
```

- Collatz Conjecture - open!
- Paul Erdős: "Mathematics may not be ready for such problems."

Reasons for Unbounded Program Size



```
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);
    }
  }
}
```

constants of any length

variable names of any length

string constants of any length

words - tokens

nesting of expressions

nesting of statements

sentences

Tokens (Words) of the While Language

Regular Expressions

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;
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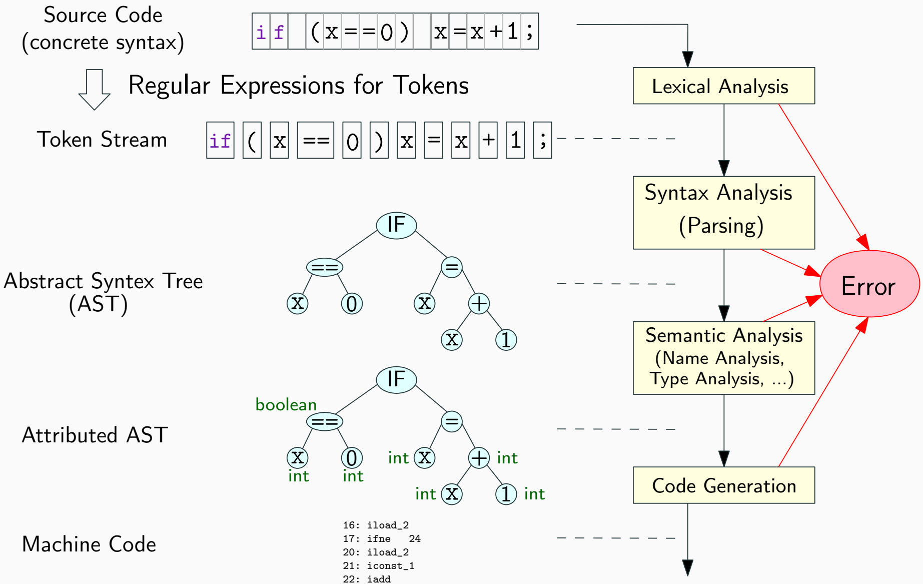
    }
  }
}
```

letter (letter | digit)*

Compiler Phases



Source Code
(concrete syntax)

i f (x = = 0) x = x + 1 ;

Regular Expressions for Tokens

Token Stream

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

Abstract Syntex Tree
(AST)

Attributed AST

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(Parsing)

Semantic Analysis
(Name Analysis,
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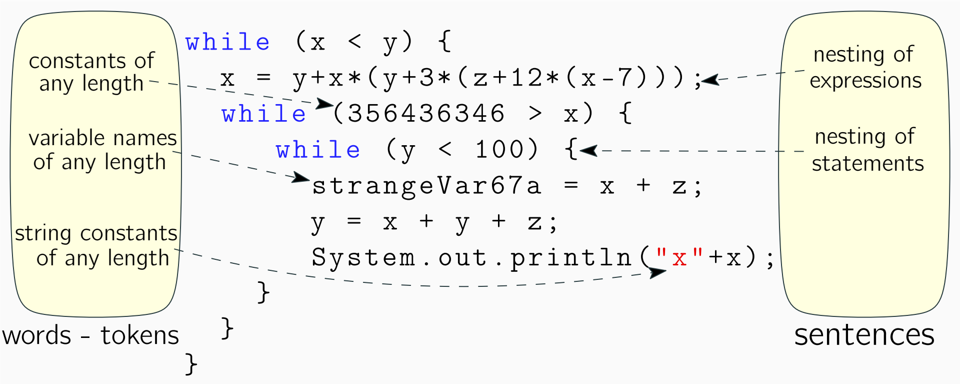

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    }
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```

nesting of expressions

nesting of statements

sentences

Sentences of the While Language

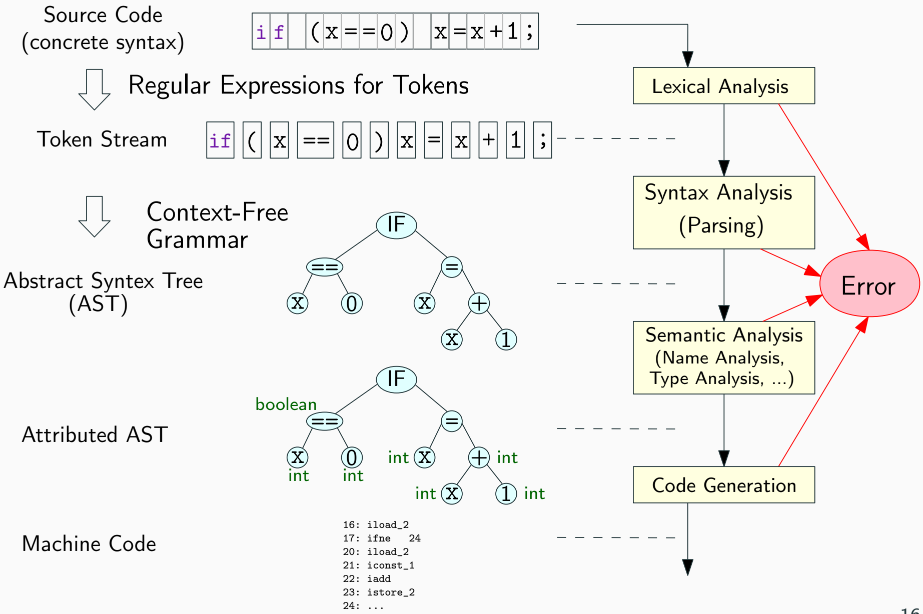
- Describe sentences using (possibly recursive) rules of a context-free grammar

```
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* }
```

Compiler Phases



Source Code
(concrete syntax)

Regular Expressions for Tokens

Token Stream

Context-Free
Grammar

Abstract Syntex Tree
(AST)

Attributed AST

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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])
```