CS412/413

Introduction to Compilers

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Lecture 2: Lexical Analysis

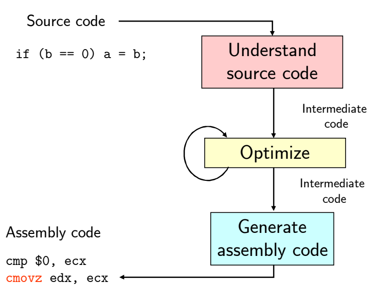
25 Jan 06

Outline

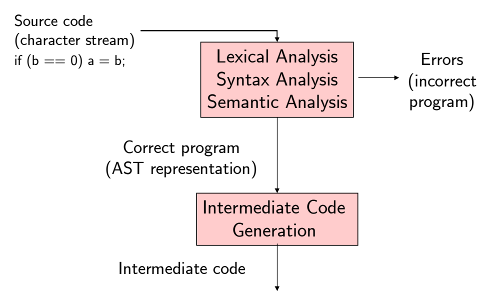
- Review compiler structure
- Compilation example

- What is lexical analysis?
- Writing a lexer
- Specifying tokens: regular expressions
- Writing a lexer generator

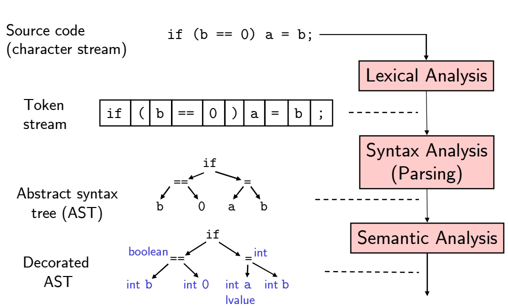
Simplified Compiler Structure



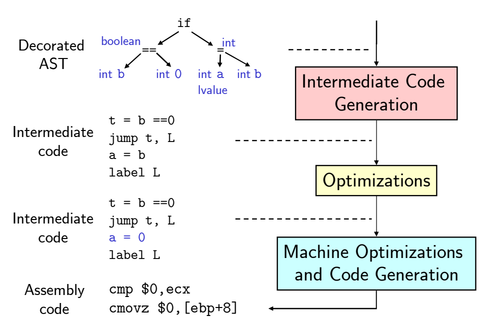
Front End Structure



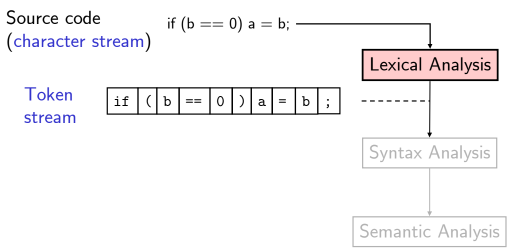
How It Works



How It Works



First Step: Lexical Analysis



Tokens

- Identifiers: `x y11 elsen _i00`
- Integers: `2 1000 -500 5L`
- Floating point: `2.0 0.00020 .02 1. 1e5 0.e-10`
- Strings: `"x" "He said, \"Are you?\""`
- Comments: `/** don't change this **/`
- Keywords: `if else while break`
- Symbols: `+ * { } ++ < << >=`

Ad-hoc Lexer

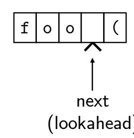
- Hand-write code to generate tokens
- How to read identifier tokens?

```
Token readIdentifier( ) {
  String id = "";
  while (true) {
   char c = input.read();
   if (!identifierChar(c))
      return new Token(ID, id);
   id = id + String(c);
  }
}
```


Look-ahead Character

- Use look-ahead character (next) to:
  - determine what kind of token to read and
  - when the current token ends

```
char next;
...
while (identifierChar(next)) {
  id = id + String(next);
  next = input.read ();
}
```



Ad-hoc Lexer: Top-level Loop

```
class Lexer {
  InputStream s;
  char next;
  Lexer(InputStream _s) { s = _s; next = s.read(); }

  Token nextToken( ) {
      if (identifierChar(next))
          return readIdentifier();
      if (numericChar(next))
          return readNumber();
      if (next == '\"')
          return readStringConst();
      ...
  }
}
```


Problems

- One character look-ahead might not be enough
  - What token is it if it begins with "i"?
  - What token is it if it begins with "2"?
  - Hard to write tokenizer correctly, harder to maintain
- Need a more principled approach: lexer generator that generates efficient tokenizer automatically (e.g., lex, flex, JFlex)

Issues

- How to describe tokens unambiguously

```
2.e0    20.e-01    2.0000
""      "x"        "\\"       "\"\""
```

- How to break text up into tokens

```
if (x == 0) a = x<<1;
if (x == 0) a = x<1;
```

- How to tokenize efficiently
  - tokens may have similar prefixes
  - avoid scanning (parts of the) input multiple times

How to Describe Tokens?

- Solution: use regular expressions
- A regular expression RE is defined inductively:

a	ordinary character stands for itself
ε	the empty string
$R\|S$	either R or S (alternation), where R, S are REs
RS	R followed by S (concatenation), where R, S are REs
$R*$	concatenate regular expression R zero or more times
	($R* = \varepsilon \mid R \mid RR \mid RRR \mid RRRR \ldots$)

Convenient RE Shorthands

$R+$	one or more strings from $L(R)$: $R(R*)$
$R?$	optional R: $(R\|\varepsilon)$
[abce]	one of the listed characters: (a|b|c|e)
[a-z]	one character from this range: (a|b|c|d|e|...|y|z)
[^ab]	anything but one of the listed chars
[^a-z]	one character not from this range

Simple Examples

- A regular expression R describes a set of strings of characters denoted $L(R)$
- $L(R)$ = the language defined by R
  - $L(\texttt{abc}) = \{$ `abc` $\}$
  - $L(\texttt{hello|goodbye}) = \{$ `hello, goodbye` $\}$
  - $L(\texttt{1(0|1)*})$ = all non-zero binary numbers
- We can define each kind of token using a regular expression

More Examples

Regular Expression R	Strings in $L(R)$
`digit = [0-9]`	"0" "1" "2" "3" ...
`posint = digit+`	"8" "412" ...
`int = -? posint`	"-42" "1024" ...
`real = int (. posint)?`	"-1.56" "12" "1.0"

- Lexer generators support such abbreviations
  - Abbreviations cannot be recursive

How To Break Up Text

- How do we tokenize "`elsen = 0;`" ?
- REs alone not enough: need rule for choosing
- Most languages: longest matching token wins
- Ties in length resolved by prioritizing tokens
- RE's + priorities + longest-matching token rule = lexer definition

Historical Issues

- PL/I
  - Keywords not reserved

```
IF IF THEN THEN = IF; ELSE ELSE = IF;
```

- FORTRAN
  - White-space insensitivity, limit identifier length:

```
DO 412 I = 1.25
DO412I = 1,25
INTEGERFUNCTIONFOO
```

- By and large, modern language design intentionally make scanning easier

Summary

- Lexical analyzer converts a text stream to tokens
- Ad-hoc lexers hard to get right, maintain
- For most languages, legal tokens conveniently, precisely defined using regular expressions
- Lexer generators generate lexer code automatically from token RE's, precedence
- Next lecture: how lexer generators work