CS251: Introduction to Language Processing

Lexical Analysis

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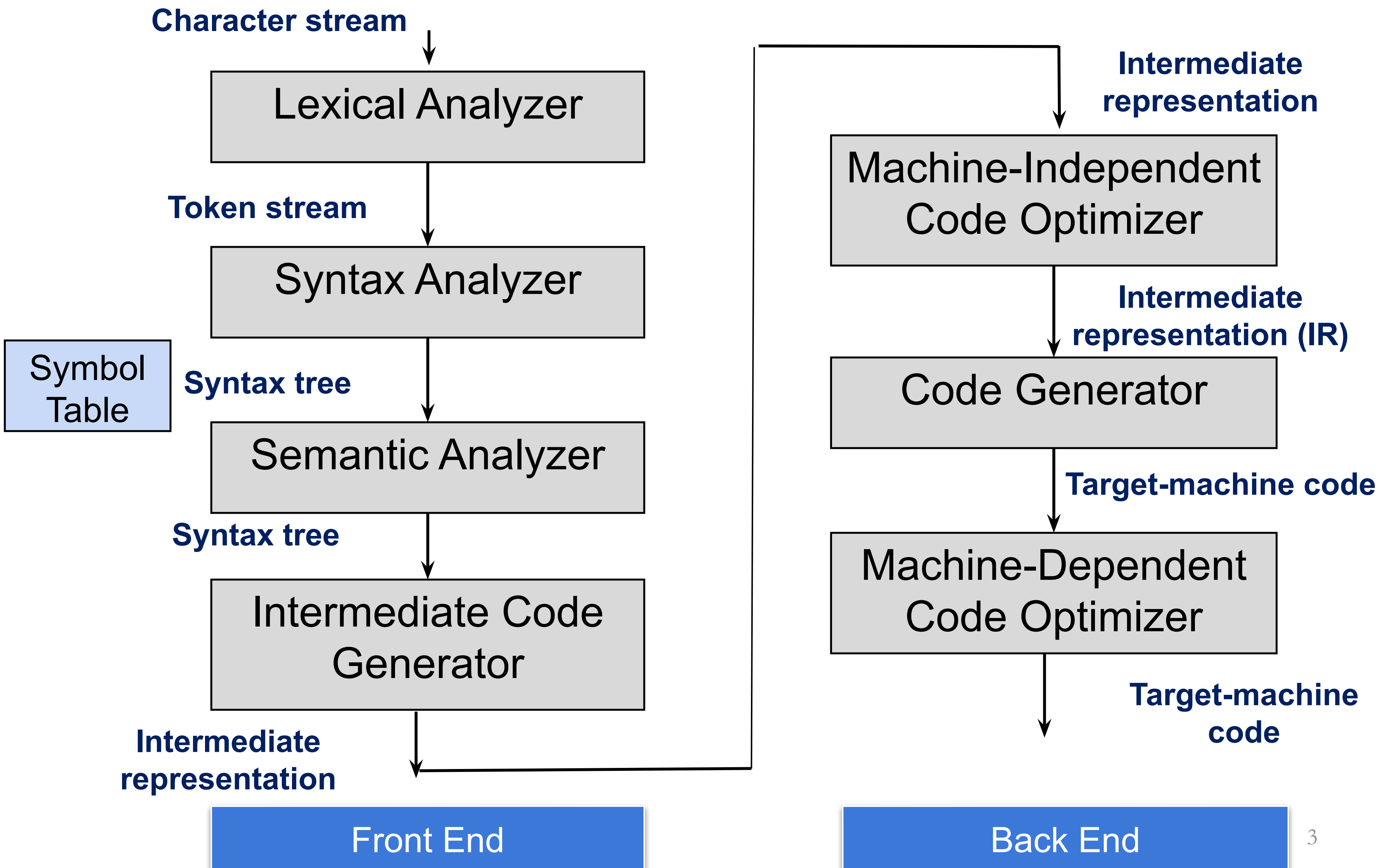
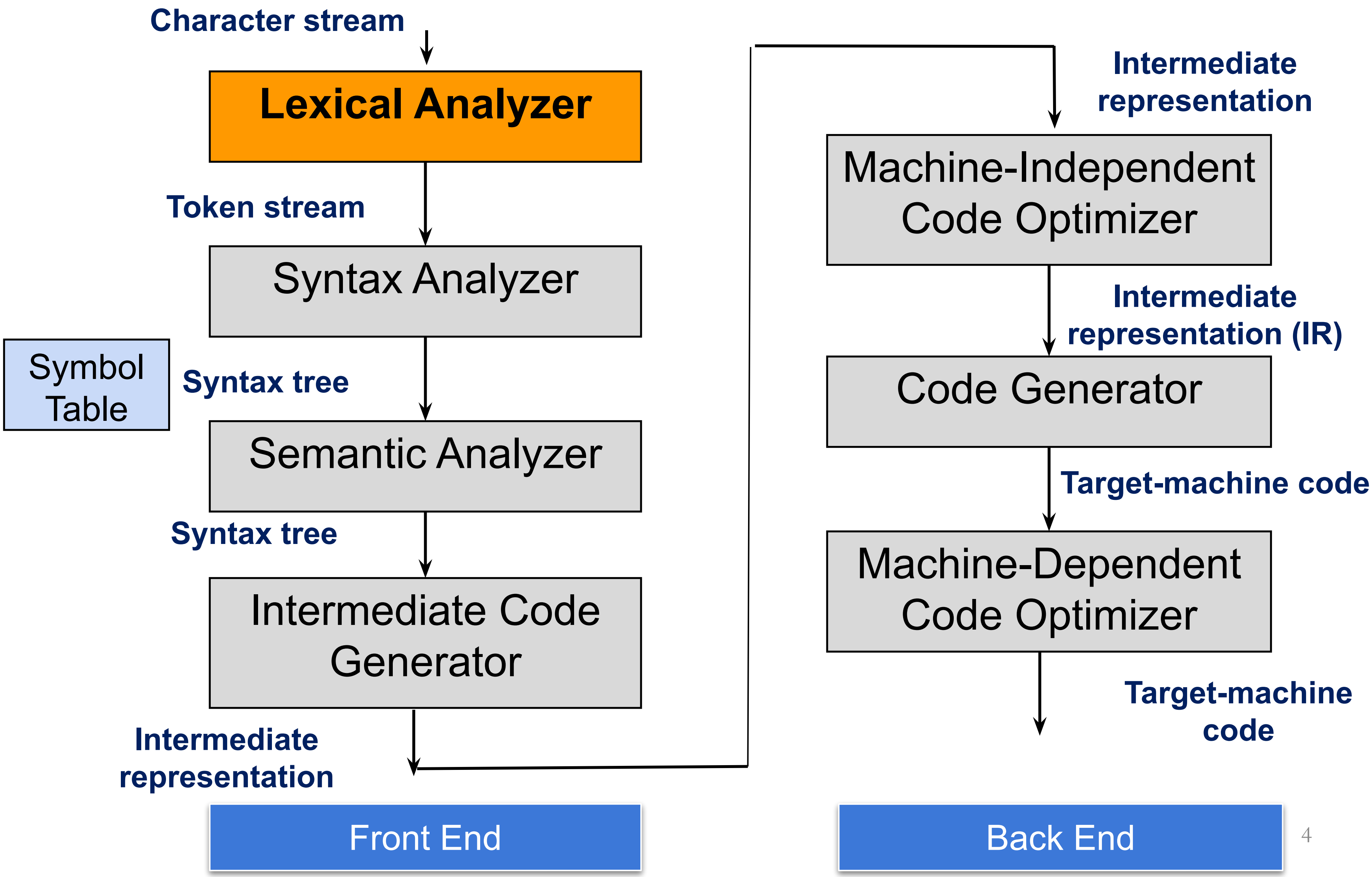
Acknowledgement

- References for today's slides
  - *Stanford University:*
    - *https://web.stanford.edu/class/archive/cs/cs143/cs143.1128/*
  - *Lecture notes of Prof. Amey Karkare (IIT Kanpur) and Late Prof. Sanjeev K Aggarwal (IIT Kanpur)*
  - *Suggested textbook for the course*

Compiler Design



Compiler Design



Lexical Analysis: Example

I eat banana

I → **Subject**

eat → **Verb**

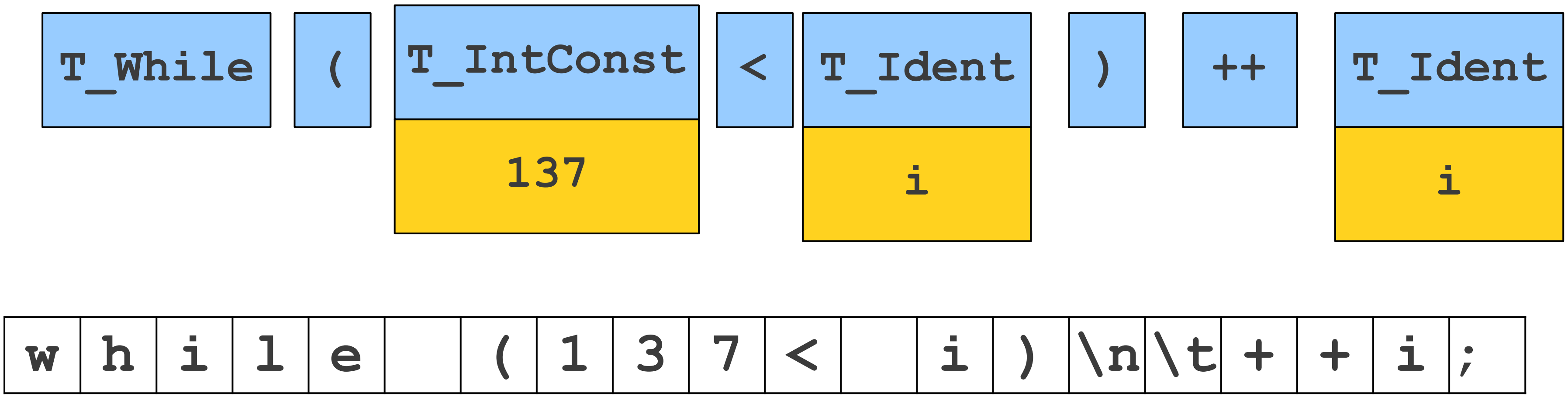
banana → **Object**

Tokens

```
while (13 < i)
    ++i;
```

w	h	i	l	e		(	1	3	7	<		i	)	\n	\t	+	+	i	;

```
while (13 < i)
    ++i;
```




```
while (137< i)
      ++i;
```

Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

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Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

T_While

Scanning a Source File

`w`	`h`	`i`	`l`	`e`		`(`	`1`	`3`	`7`		`<`		`i`	`)`	`\n`	`\t`	`+`	`+`	`i`	`;`

The piece of the original program from which we made the token is called a **lexeme**.

`T_While`

This is called a **token**. You can think of it as an enumerated type representing what logical entity we read out of the source code.

Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

`T_While`

Scanning a Source File

`w`	`h`	`i`	`l`	`e`		`(`	`1`	`3`	`7`		`<`		`i`	`)`	`\n`	`\t`	`+`	`+`	`i`	`;`

`T_While`

Scanning a Source File

`w`	`h`	`i`	`l`	`e`		`(`	`1`	`3`	`7`		`<`		`i`	`)`	`\n`	`\t`	`+`	`+`	`i`	`;`

`T_While`

Scanning a Source File

`w`	`h`	`i`	`l`	`e`		`(`	`1`	`3`	`7`		`<`		`i`	`)`	`\n`	`\t`	`+`	`+`	`i`	`;`

`T_While`

Sometimes we will discard a lexeme rather than storing it for later use.

Here, we ignore whitespace, since it has no bearing on the meaning of the program.

Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

`T_While`

Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

T_While

Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

`T_While`

Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

T_While	(

Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

T_While	(

Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

`T_While` `(`

Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

T_While	(

Scanning a Source File

w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

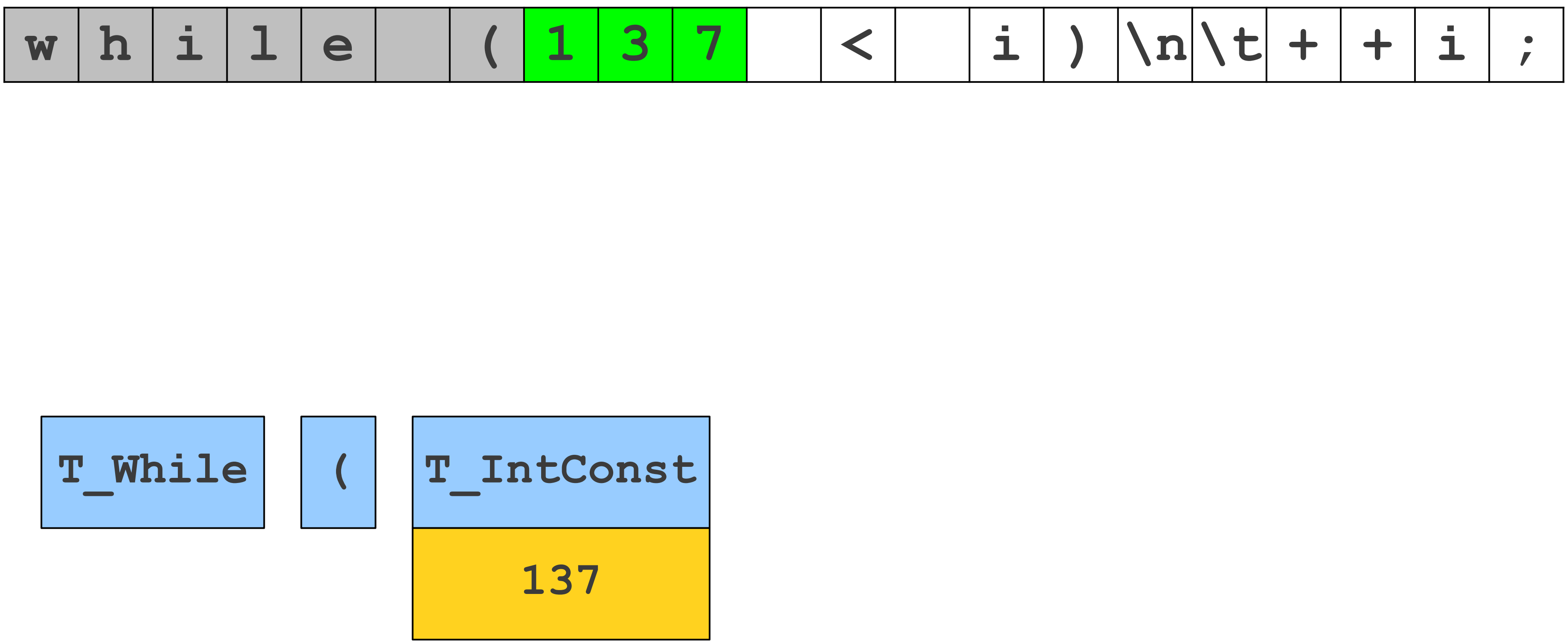
T_While	(

Scanning a Source File

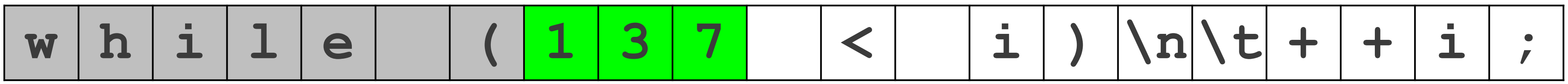
w	h	i	l	e		(	1	3	7		<		i	)	\n	\t	+	+	i	;

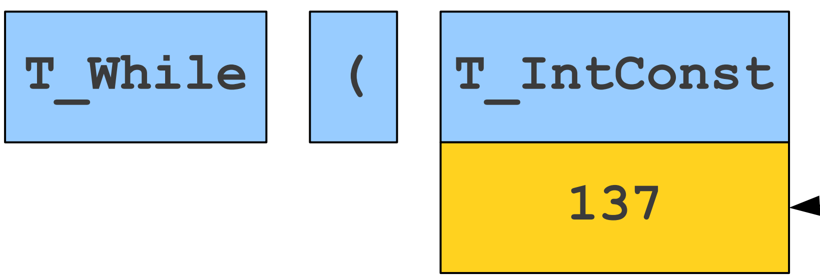
T_While	(

Scanning a Source File



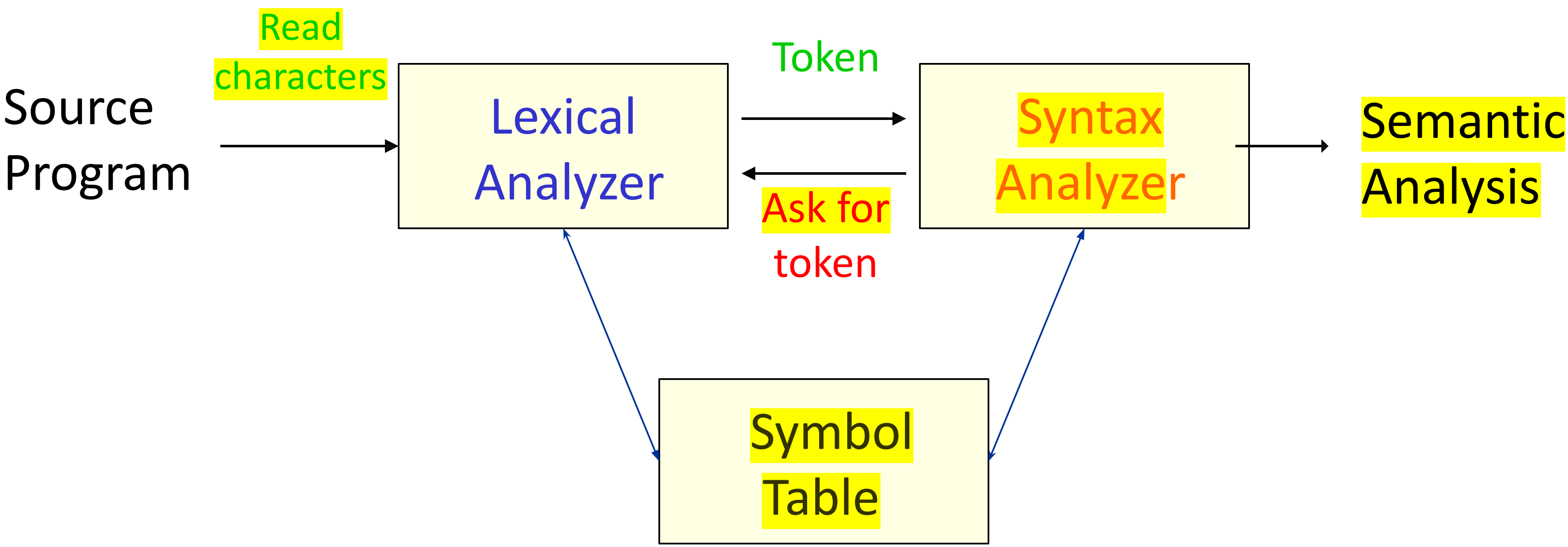
Scanning a Source File





Some tokens can have **attributes** that store extra information about the token. Here we store which integer is represented.

Overview



Read characters
Source Program
Lexical Analyzer
Token
Ask for token
Syntax Analyzer
Semantic Analysis
Symbol Table

Goals of Lexical Analysis

- Convert from physical description of a program into sequence of of **tokens**.
  - Each token represents one logical piece of the source file – a keyword, the name of a variable, etc.
- Each token is associated with a **lexeme**.
  - The actual text of the token: "137," "int," etc.
- Each token may have optional **attributes**.
  - Extra information derived from the text – perhaps a numeric value.
- The token sequence will be used in the parser to recover the program structure.

Choosing Tokens

What Tokens are Useful Here?

```
for (int k = 0; k < myArray[5]; ++k)
    {  myArray[k]++;
}
```

What Tokens are Useful Here?

```
for (int k = 0; k < myArray[5]; ++k)
    {  myArray[k]++;
}
```

```
for            {
int            }
=              ;
(              <
)              [
++             ]

Identifier
IntegerConstant
```

Choosing Good Tokens

- Very much dependent on the language.
- Typically:
  - Give keywords their own tokens.
  - Give different punctuation symbols their own tokens.
  - Group lexemes representing identifiers, numeric constants, strings, etc. into their own groups.
  - Discard irrelevant information (whitespace, comments)

Tokens

TOKEN	INFORMAL DESCRIPTION	SAMPLE LEXEMES
if	characters `i`, `f`	`if`
else	characters `e`, `l`, `s`, `e`	`else`
comparison	`<` or `>` or `<=` or `>=` or `==` or `!=`	`<=`, `!=`
id	letter followed by letters and digits	`pi`, `score`, `D2`
number	any numeric constant	`3.14159`, `0`, `6.02e23`
literal	anything but `"`, surrounded by `"`'s	`"core dumped"`

Describing Tokens

Lexemes and Tokens

- Tokens give a way to categorize lexemes by what information they provide.
- Some tokens might be associated with only a single lexeme:
  - Tokens for keywords like `if` and `while` probably only match those lexemes exactly.
- Some tokens might be associated with lots of different lexemes:
  - All variable names, all possible numbers, all possible strings, etc.

Sets of Lexemes

- Idea: Associate a set of lexemes with each token.
- We might associate the "number" token with the set { **`0`**, **`1`**, **`2`**, …, **`10`**, **`11`**, **`12`**, … }
- We might associate the "string" token with the set { `""`, **`"a"`**, **`"b"`**, **`"c"`**, … }
- We might associate the token for the keyword **`while`** with the set { **`while`** }.

How to describe tokens?

- Potentially infinite lexemes
- Programming language tokens can be described by regular languages
- Regular languages
  - Are easy to understand
  - There is a well understood and useful theory
  - They have efficient implementation
- Regular languages have been discussed in great detail in the "Theory of Computation" course

How to specify tokens

- Regular definitions
  - Let r_i be a regular expression and d_i be a distinct name
  - Regular definition is a sequence of definitions of the form

    $d_1 \rightarrow r_1$
    $d_2 \rightarrow r_2$
    …..
    $d_n \rightarrow r_n$
  - Where each r_i is a regular expression

Examples

- Identifier

  letter $\rightarrow$ a| b| …|z| A| B| …| Z

  digit $\rightarrow$ 0| 1| …| 9

  identifier $\rightarrow$ letter(letter|digit)*

Examples

- Email address
  cse@iitbhilai.ac.in

Write regular expression!

Examples

- Email address
  cse@iitbhilai.ac.in
- letter $\rightarrow$ a| b| …| z| A| B| …| Z
- name $\rightarrow$ letter$^+$
- address $\rightarrow$ name '@' name '.' name '.' name

Regular expressions in specifications

- Regular expressions describe many useful languages
- Regular expressions are only specifications; implementation is still required
- Given a string s and a regular expression R, does $s \in L(R)$?
- Solution to this problem is the basis of the lexical analyzers
- Goal: Partition the input into tokens

1. Write a regular expression for lexemes of each token
   - number -> $digit^+$
   - identifier -> $letter(letter|digit)^+$
2. Construct R matching all lexemes of all tokens
   - R = R1 + R2 + R3 + …..
3. Let input be $x_1 \ldots x_n$
   - for $1 \leq i \leq n$ check $x_1 \ldots x_i \in L(R)$
4. $x_1 \ldots x_i \in L(R)$ $x_1 \ldots x_i \in L(Rj)$ for some j
   - smallest such j is token class of $x_1 \ldots x_i$
5. Remove $x_1 \ldots x_i$ from input; go to (3)

- The algorithm gives priority to tokens listed earlier
  - Treats “if” as keyword and not identifier
- Regular expressions provide a concise and useful notation for string patterns

Examples

IF → if

ELSE → else

DOUBLE → double

identifier → letter(letter|digit)*

letter → a| b| …|z| A| B| …| Z

digit → 0| 1| …| 9

COMP_OP → >|<|>=|<=|==|!=

ARITH_OP → +|-|*|/

Recognizing Regular Expressions

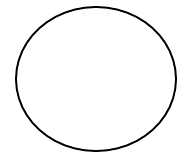
Transition Diagrams

- Regular expressions are declarative specifications
- Transition diagram is an implementation
- A transition diagram consists of
  - An input alphabet belonging to Σ
  - A set of states S
  - A set of transitions $\text{state}_i \xrightarrow{input} \text{state}_j$
  - A set of final states F
  - A start state n
- Transition $s1 \xrightarrow{a} s2$ is read:

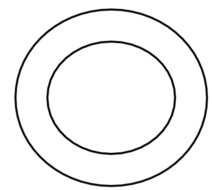
  in state s1 on input *a* go to state s2
- If end of input is reached in a final state then accept
- Otherwise, reject

Pictorial Notation

- A state

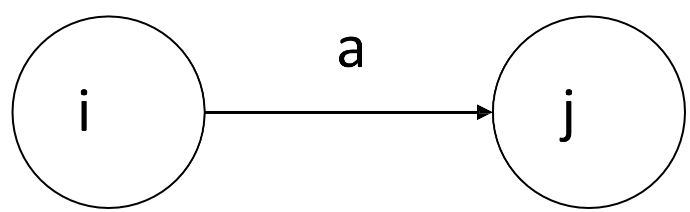


- A final state



- Transition

- Transition from state i to state j on an input a



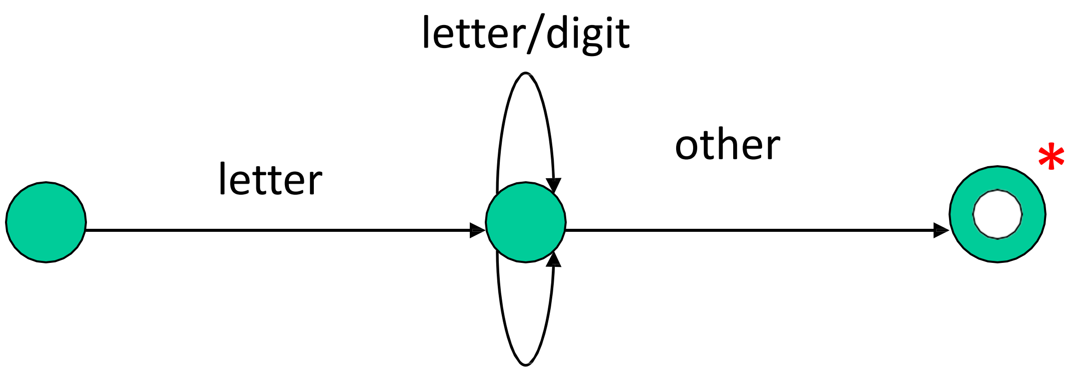
How to Recognize Tokens

- Consider

  id -> letter(letter|digit)*

- Construct an analyzer that will return <token, attribute> pairs

Transition diagram for identifier



Approaches to implementation

- Use assembly language

  Most efficient but most difficult to implement

- Use high level languages like C

  Efficient but difficult to implement

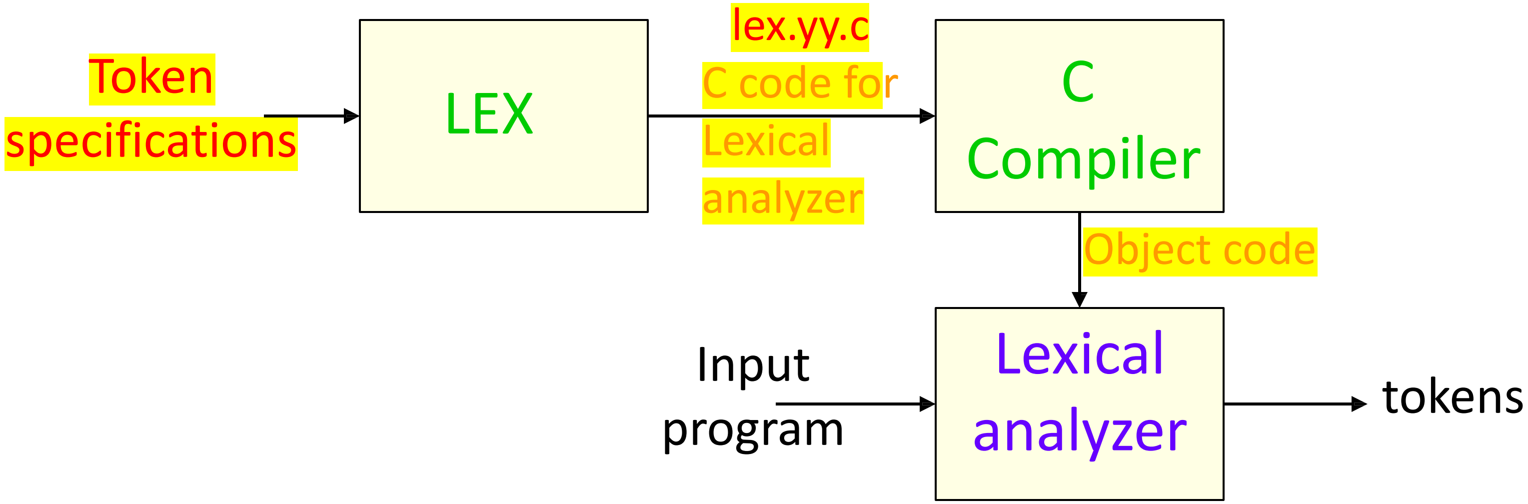
- Use tools like lex, flex

  Easy to implement

Implementation of transition diagrams

```
Token nexttoken() {
  while(1) {
     switch (state) {
          ......
          case 10: c=nextchar();
           if(isletter(c))
           state=10;  elseif
           (isdigit(c)) state=10;
           else state=11;
           break;
          ......
          }
     }
}
```

LEX: A lexical analyzer generator



Refer to LEX User's Manual

Lex: Program Structure

declarations

%%

transition rules

%%

auxiliary functions

LEX: A simple program

```
%{
	#include<stdio.h>
	#include<string.h>
	int i = 0;
%}
/* Rules Section*/
%%
	([a-zA-Z0-9])*    {i++;} /* Rule for counting  number of words*/
	"\n"              {printf("%d\n", i); i = 0;}
%%
	int yywrap(void){}
	int main()
	{
	    yylex();
	    return 0;
	}
```

Next Lecture:

Demo on Programming with Lex

Questions?