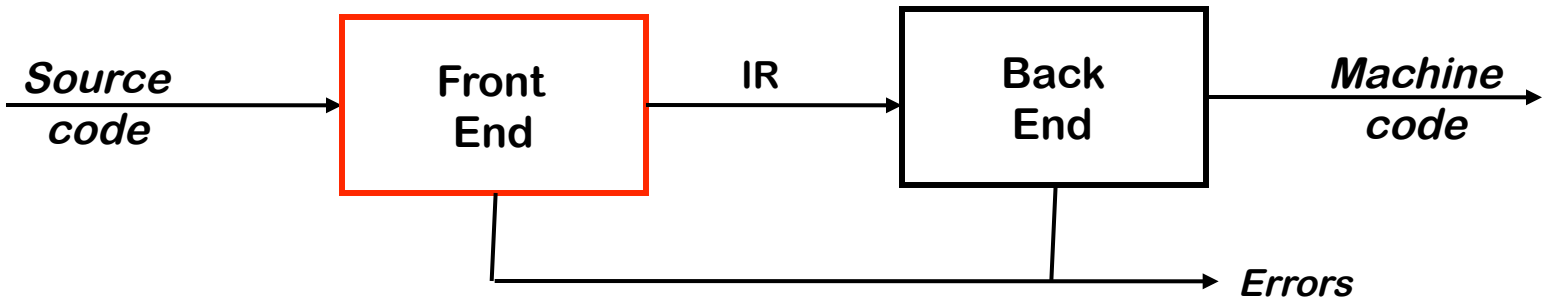
Lexical Analysis - An Introduction

The Front End

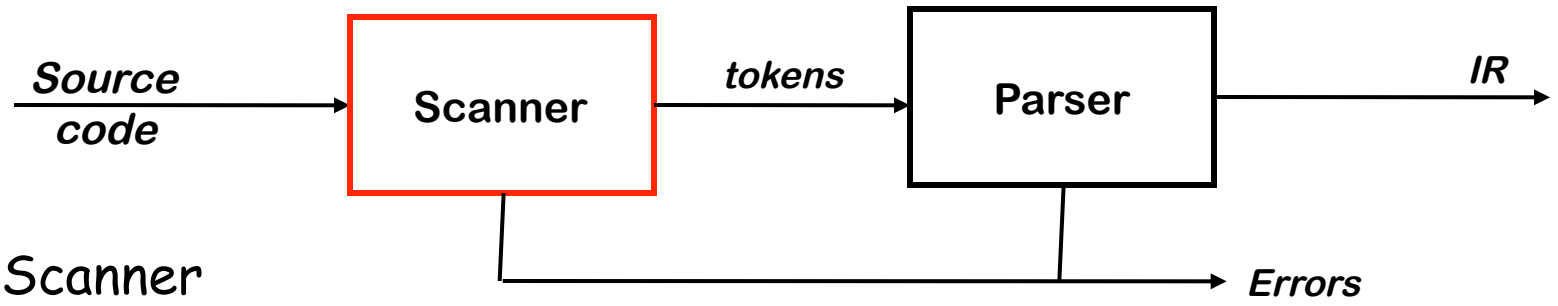


The purpose of the front end is to deal with the input language

- Perform a membership test: code ∈ source language?
- Is the program well-formed (semantically) ?
- Build an IR version of the code for the rest of the compiler

The front end is not monolithic

The Front End



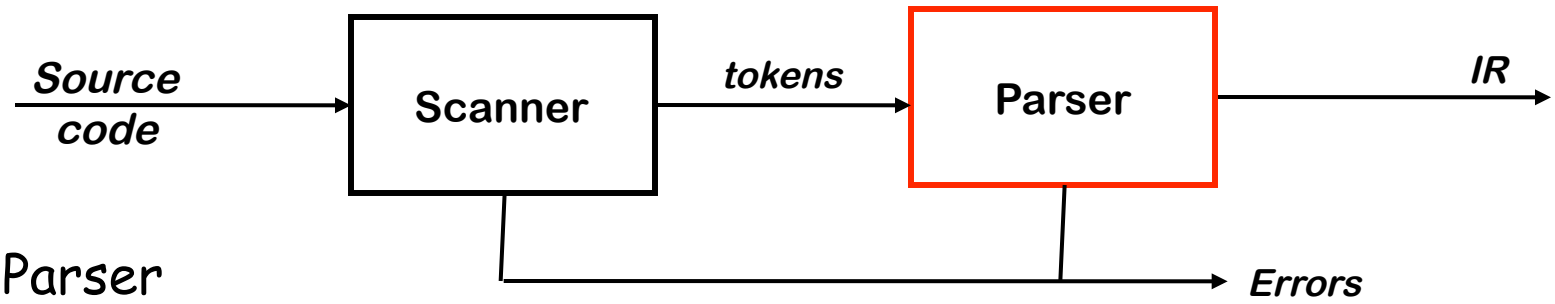
Scanner

- Maps stream of characters into words
  - → Basic unit of syntax
  - → x = x + y ; *becomes*
    <id,x> <eq,=> <id,x> <pl,+> <id,y> <sc,; >
- Characters that form a word are its *lexeme*
- Its *part of speech* (or *syntactic category*) is called its *token type*
- Scanner discards white space & (often) comments

Speed is an issue in scanning

⇒ use a specialized recognizer

The Front End



Parser

- Checks stream of classified words (*parts of speech*) for grammatical correctness
- Determines if code is syntactically well-formed
- Guides checking at deeper levels than syntax
- Builds an IR representation of the code

We'll come back to parsing in a couple of lectures

The Big Picture

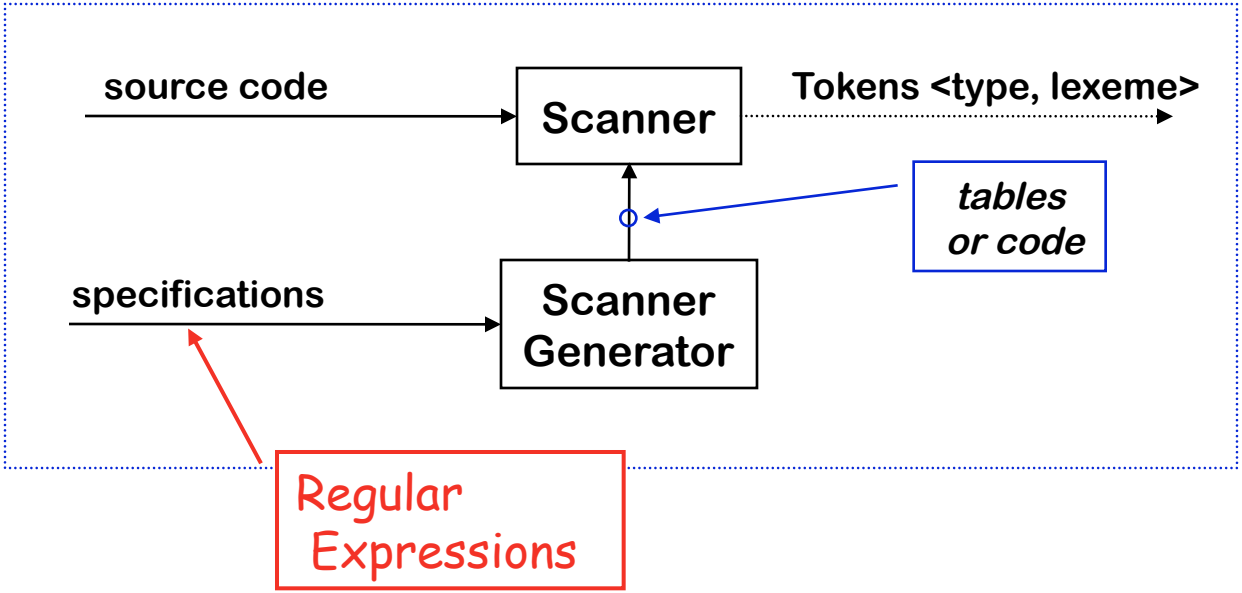
Why study lexical analysis?

- We want to avoid writing scanners by hand
- We want to harness the theory from classes like CISC 303

Goals:

→ To simplify specification & implementation of scanners

→ To understand the underlying techniques and technologies

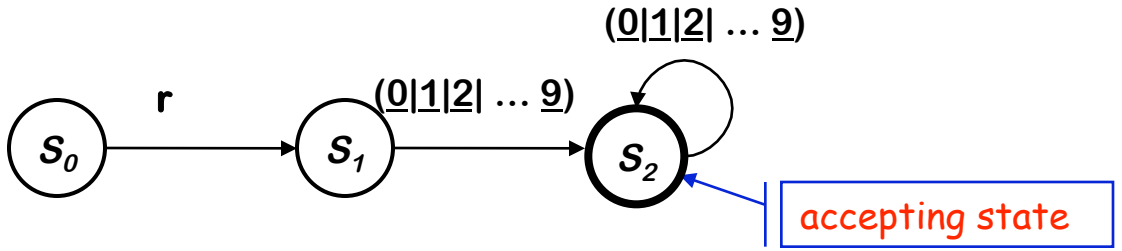


Where is Lexical Analysis used?

- For traditional languages but where else…
- Web page "compilation"
  - Lexical Analysis of HTML, XML, etc.
- Natural Language Processing
- Game Scripting Engines
- OS Shell Command Line
- Find
- Prototyping high-level languages
  - JavaScript, Perl, Python

Recognizing Words

- Finite Automaton (FA) – recognizers that can scan a stream of symbols to find lexemes (words)



Recognizer for *Register*

- An FA is a five-tuple $(S,\Sigma,\partial,s_0,S_F)$ where
  - S is the set of states
  - Σ is the alphabet
  - ∂ a set of transition functions where each takes a state and a character and returns another state
  - s_0 is the start state
  - S_F is the set of final states

Regular Expressions

Regular expressions (REs) describe regular languages

Regular Expression (over alphabet Σ)

- ε is a RE denoting the set $\{\varepsilon\}$
- If a is in Σ, then a is a RE denoting {a}
- If *x* and *y* are REs denoting *L(x)* and *L(y)* then
  - → *Alternation : x | y* is an RE denoting $L(x) \cup L(y)$
  - → *Concatenation: xy* is an RE denoting *L(x)L(y)*
  - → *Closure: x** is an RE denoting *L(x)**

Precedence is *closure*, then *concatenation*, then *alternation*

Examples of Regular Expressions

Identifiers:

Letter → (a|b|c| … |z|A|B|C| … |Z)

Digit → (0|1|2| … |9)

Identifier → *Letter* (*Letter* | *Digit*)*

Numbers:

Integer → (+|-|ε) (0| (1|2|3| … |9)(*Digit* *))

Fraction → *Integer* / *Integer*

Decimal → *Integer* . *Digit* *

Real → (*Integer* | *Decimal*) E (+|-|ε) *Digit* *

Numbers can get much more complicated!

Regular Expressions (the point)

Regular expressions can be used to specify the words to be translated to parts of speech by a lexical analyzer

Using results from automata theory and theory of algorithms, we can automatically build recognizers from regular expressions

Some of you may have seen this construction for string pattern matching

⇒ We study REs and associated theory to automate scanner construction !

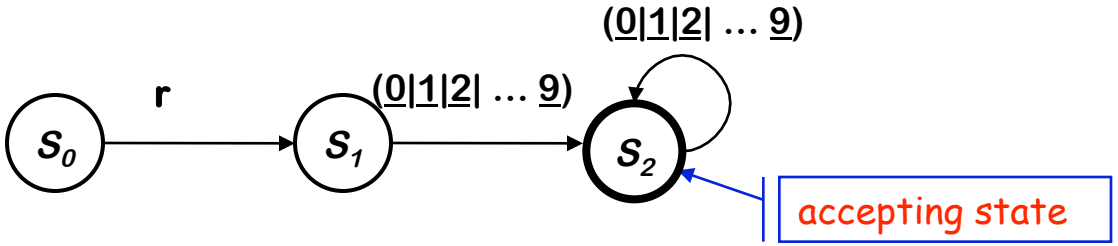
Example

Consider the problem of recognizing register names

Register → r (0|1|2| … | 9) (0|1|2| … | 9)*

- Allows registers of arbitrary number
- Requires at least one digit

RE corresponds to a recognizer (or DFA)



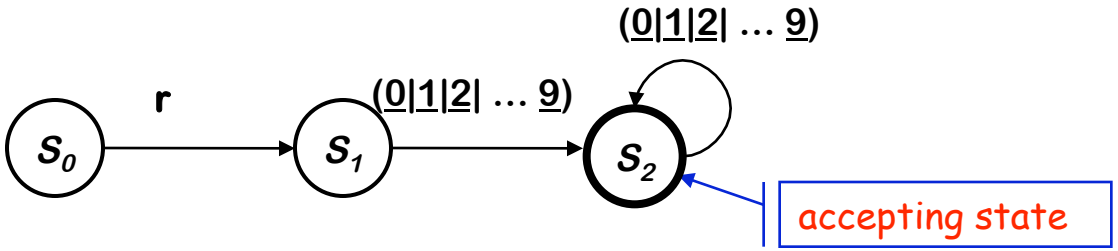
Recognizer for *Register*

Transitions on other inputs go to an error state, s_e

Example (continued)

DFA operation

- Start in state S_0 & take transitions on each input character
- DFA accepts a word *x iff* x leaves it in a final state (S_2)



Recognizer for *Register*

So,

- r17 takes it through s_0, s_1, s_2 and accepts
- r takes it through s_0, s_1 and fails
- a takes it straight to s_e

Example (continued)

To be useful, recognizer must turn into code

```
Char ← next character
State ← s0
while (Char ≠ EOF)
    State ← δ(State,Char)
     Char ← next character
if (State is a final state )
    then report success
    else  report failure
```

Skeleton recognizer

δ	r	0,1,2,3,4, 5,6,7,8,9	*All others*
s_0	s_1	s_e	s_e
s_1	s_e	s_2	s_e
s_2	s_e	s_2	s_e
s_e	s_e	s_e	s_e

Table encoding RE

What if we need a tighter specification?

r (0|1|2| … | 9) (0|1|2| … | 9)* allows arbitrary numbers

- Accepts r00000
- Accepts r99999
- What if we want to limit it to r0 through r31 ?

Write a tighter regular expression

→ *Register* → r ((0|1|2) (*[0…9]* | ε) | (4|5|6|7|8|9) | (3(0|1|ε)))

→ *Register* → r0|r1|r2| … |r31|r00|r01|r02| … |r09

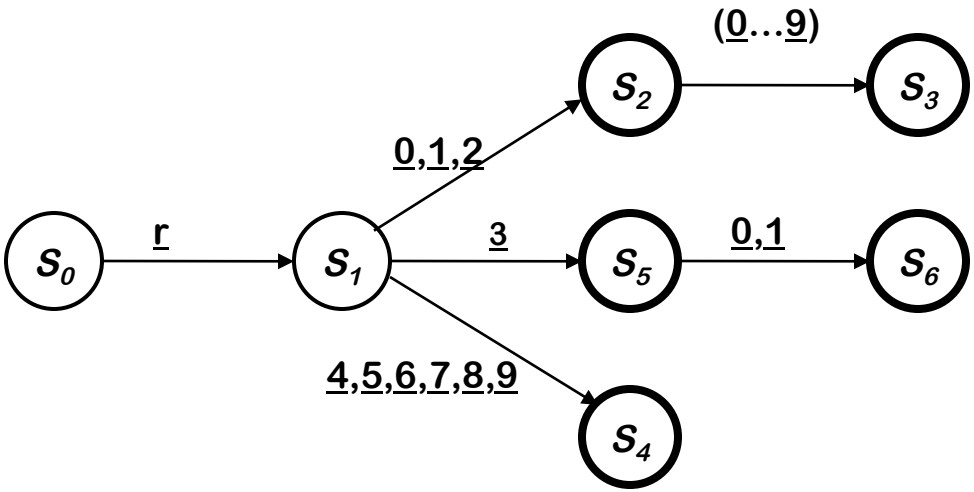
Produces a more complex DFA

- Has more states
- Same cost per transition
- Same basic implementation

Tighter register specification (continued)

The DFA for

Register → r ((0|1|2) (*[0…9]* |ε) | (4|5|6|7|8|9) | (3(0|1|ε)))



- Accepts a more constrained set of registers
- Same set of actions, more states

Tighter register specification (continued)

δ	r	0,1	2	3	4-9	All others
s_0	s_1	s_e	s_e	s_e	s_e	s_e
s_1	s_e	s_2	s_2	s_5	s_4	s_e
s_2	s_e	s_3	s_3	s_3	s_3	s_e
s_3	s_e	s_e	s_e	s_e	s_e	s_e
s_4	s_e	s_e	s_e	s_e	s_e	s_e
s_5	s_e	s_6	s_e	s_e	s_e	s_e
s_6	s_e	s_e	s_e	s_e	s_e	s_e
s_e	s_e	s_e	s_e	s_e	s_e	s_e

Runs in the same skeleton recognizer

Table encoding RE for the tighter register specification