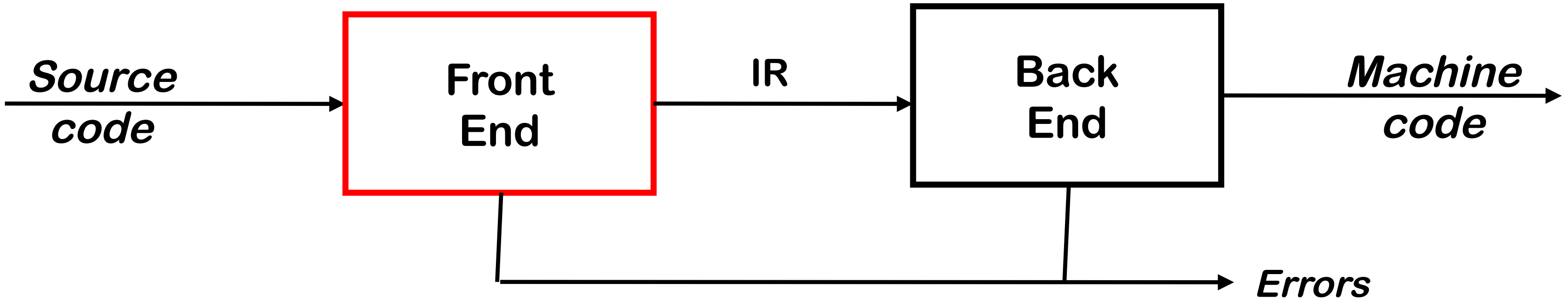
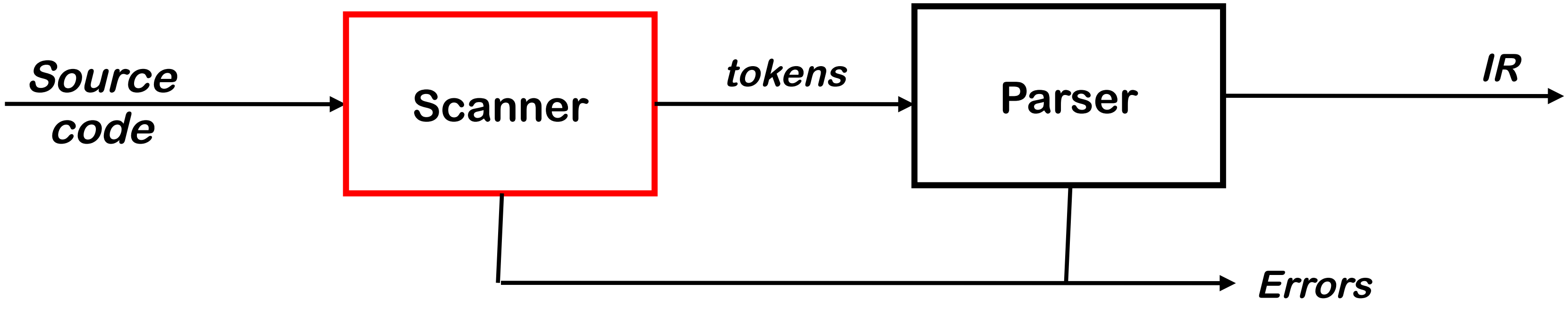
Lexical Analysis - An Introduction

The Front End



The front end is not monolithic

The Front End



Source code

Scanner

tokens

Parser

IR

Errors

Scanner

- Maps stream of characters into words
  - → Basic unit of syntax
  - → x = x + y ; *becomes set of tokens <type, lexeme>*

    <id,x> <eq,=> <id,x> <pl,+> <id,y> <sc,; >

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
- GREP
- Prototyping high-level languages
- JavaScript, Perl, Python

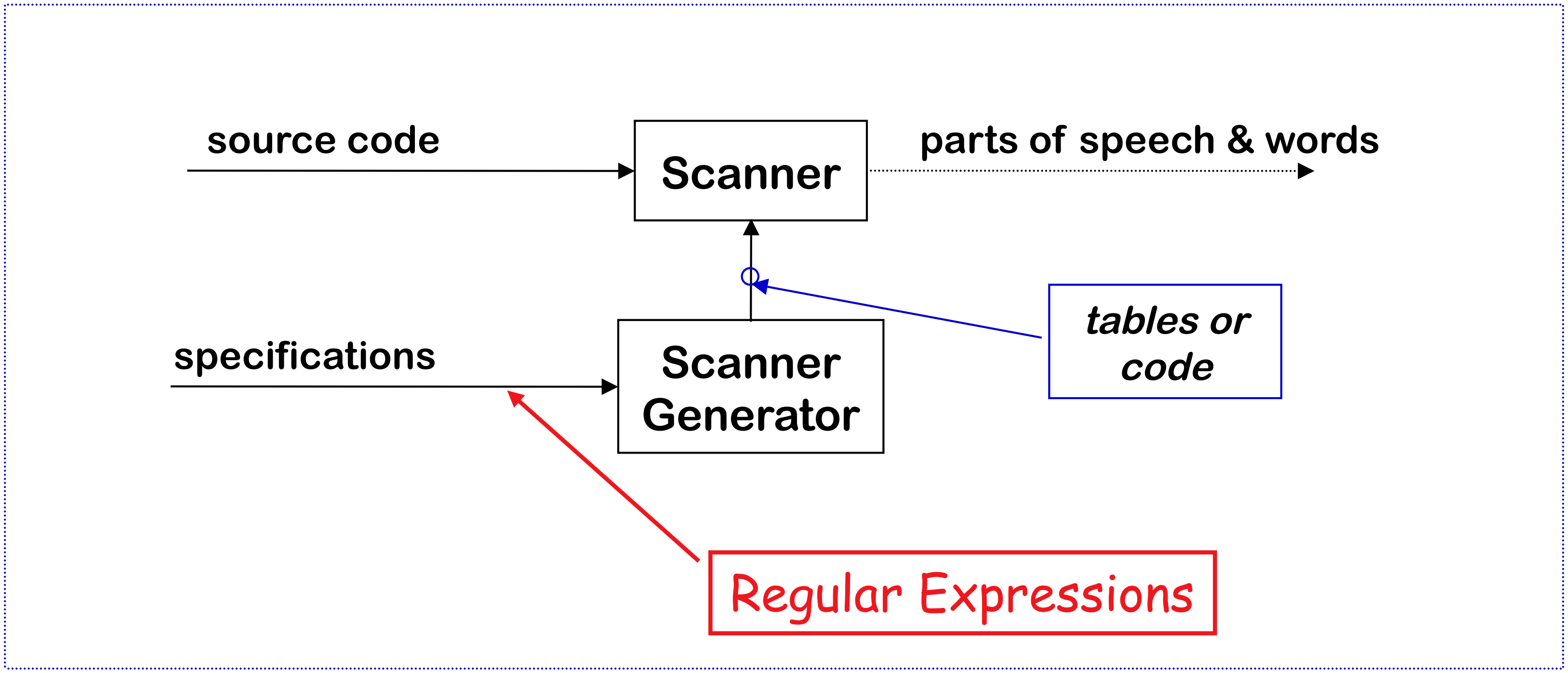
The Big Picture

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



Regular Expressions

Powerful notation to specify lexical rules

- Simplifies scanner construction
- Notation describes set of strings over some alphabet
- Entire set of strings called the **language**
- If r is an RE, L(r) is the language it specifies

Regular Expressions (more formally)

- Over some alphabet Σ
- ε is a RE denoting the empty set
- If $\underline{a}$ is in Σ, then $\underline{a}$ is a RE denoting $\{\underline{a}\}$

Regular Expressions (more formally)

Given sets R and S

- *Closure:* R^* is an RE denoting

$$\cup_{0 \leq i \leq \infty} \; R^i$$

- *Concatenation:* RS is an RE denoting

$$\{st \mid s \in R \text{ and } t \in S\}$$

- *Alternation:* $R \mid S$ is an RE denoting

$$\{s \mid s \in R \text{ or } s \in S\}$$

  - *Often written* $R \cup S$

Note: 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**))

Decimal → *Integer* . *Digit**

Real → (*Integer* | *Decimal*) $\underline{\text{E}}$ (+|-|ε) *Digit**

Complex → (*Real* , *Real*)

Numbers can get much more complicated!

Regular Expressions (the point)

REs are 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 (i.e. scanners)** from regular expressions

You may have seen this construction in a Automata Course

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

Regular Expression Class Problem?

What is the regular expression for a register name?

Examples: r1, r25, r999 ← These are OK.

r, s1, a25 ← These are <u>not</u> OK.

Register Name RE Solution

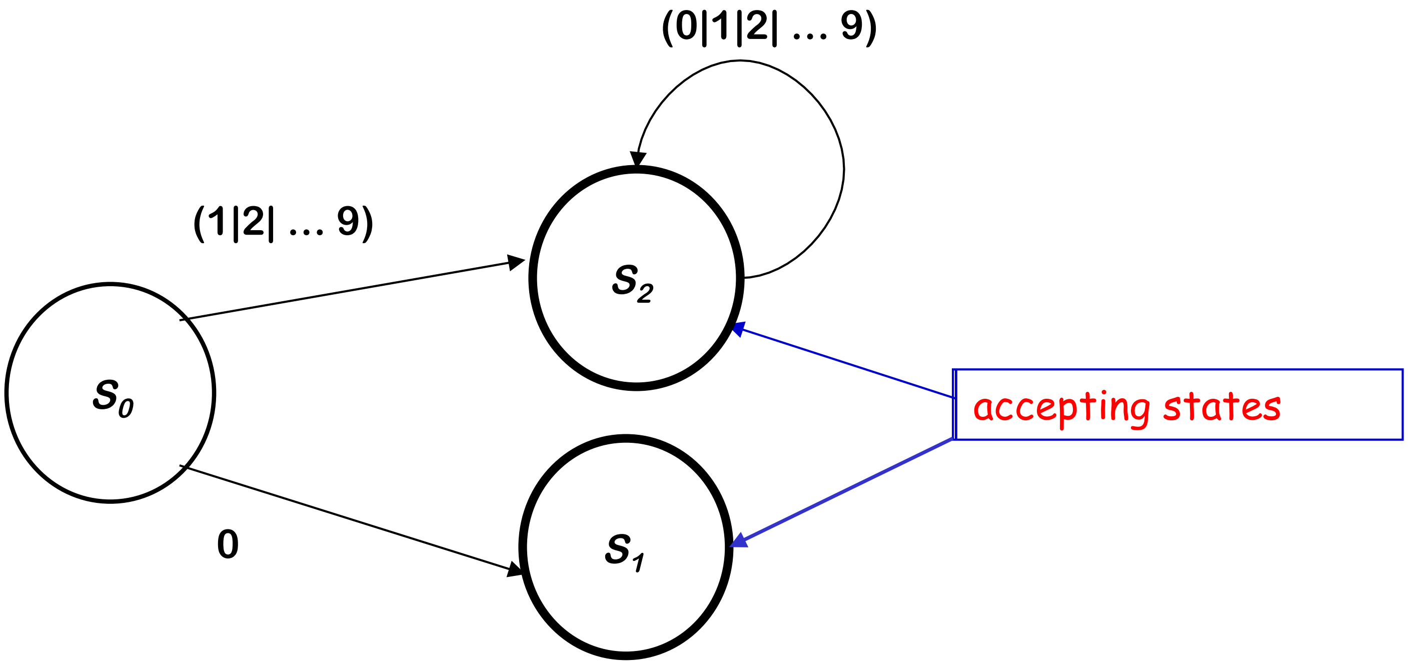
Consider the problem of recognizing register names

$\textit{Register} \rightarrow \mathrm{r}\ (0|1|2| \ldots | 9)\ (0|1|2| \ldots | 9)^*$

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

Finite Automaton (FA)

- An abstract machine that corresponds to a particular RE
- Recognizers can scan a stream of symbols to find words



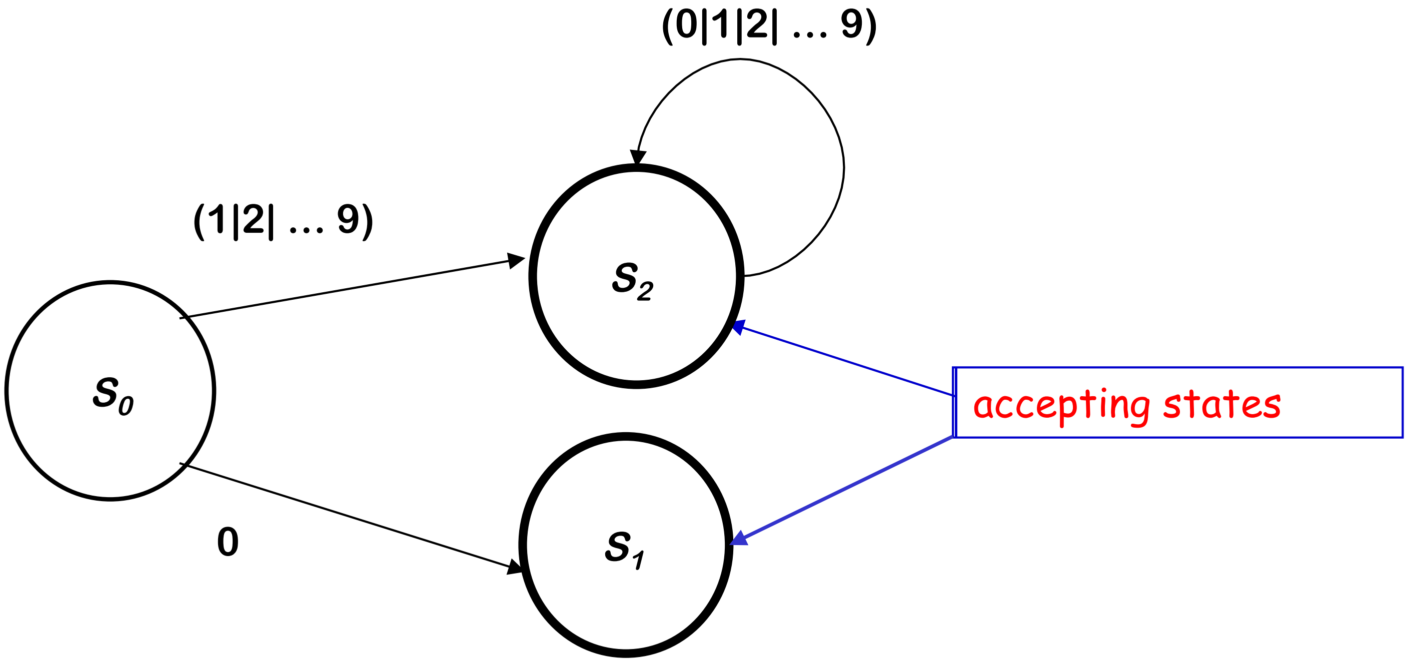
Transition Diagram for *Number*

Finite Automaton (FA)

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
  - takes a state and a character and returns new state
- s_0 is the start state
- S_F is the set of final states

Finite Automaton (FA)



Transition Diagram for *Number*

Register Name DFA Class Problem?

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

What does the DFA look like?

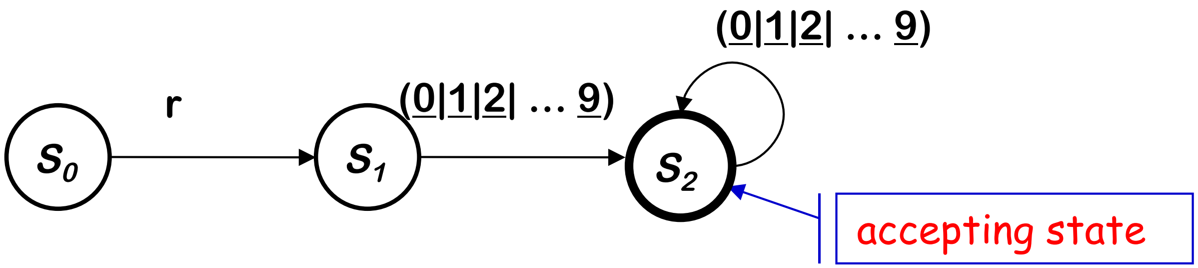
Register Name DFA Solution

Consider the problem of recognizing register names

$\textit{Register} \rightarrow \mathrm{r}\ (0|1|2|\ \ldots\ |\ 9)\ (0|1|2|\ \ldots\ |\ 9)^*$

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

RE corresponds to a recognizer (or DFA)



accepting state

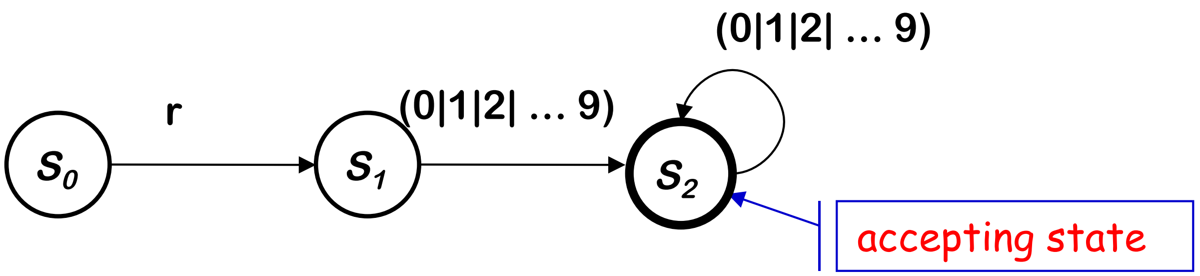
Recognizer for *Register*

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 <u>x</u> *iff* <u>x</u> leaves it in a final state (S_2)



Recognizer for *Register*

So,

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

Example (continued)

To be useful, recognizer must turn into code

```
Char ← next character
State ← $s_0$

while (Char ≠ EOF)
    State ← $\delta$(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 *Digit Digit** 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) (*Digit* | ε) | (4|5|6|7|8|9) | (3|30|31))
- → *Register* → r0|r1|r2| … |r31|r00|r01|r02| … |r09

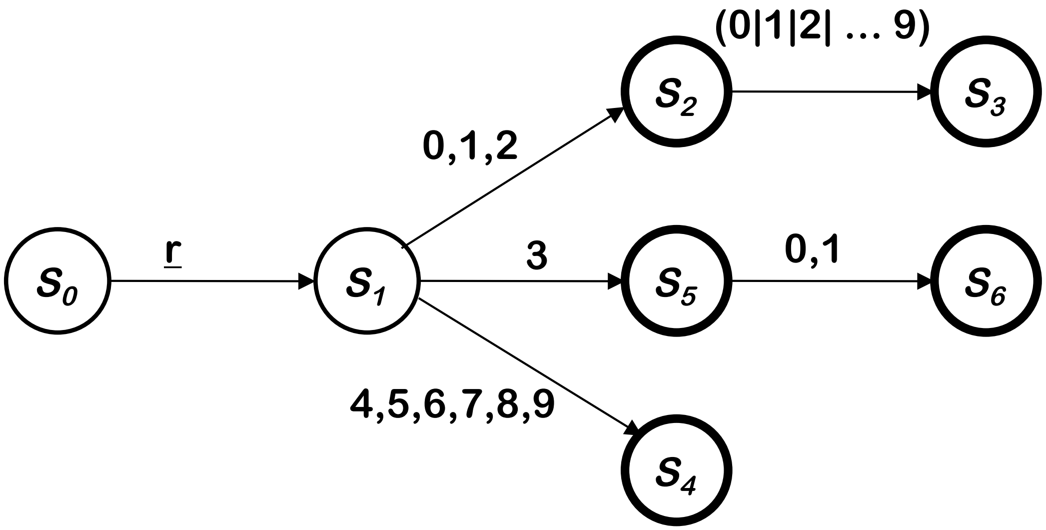
Produces a more complex DFA

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

Tighter register specification (continued)

The DFA for

Register → r ((0|1|2) (*Digit* | ε) | (4|5|6|7|8|9) | (3|30|31))



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

Tighter register specification (continued)

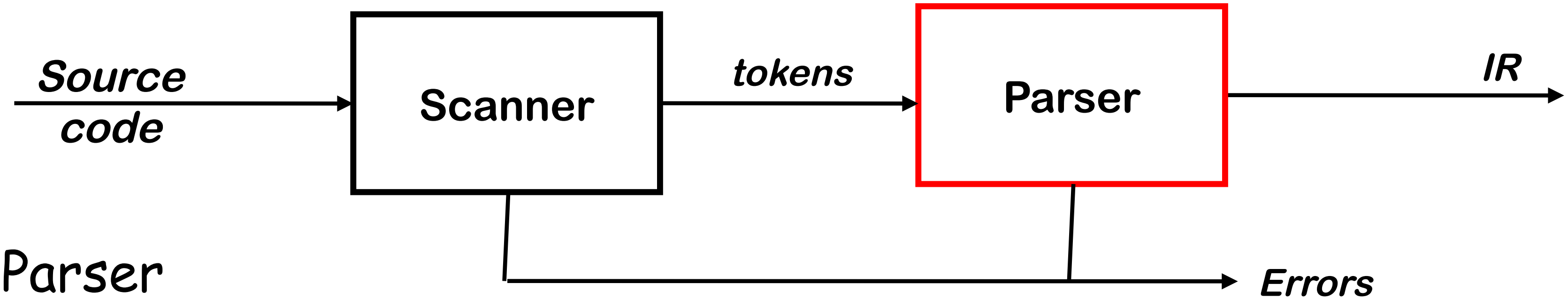
δ	r	0,1	2	3	4-9	All others
s_0	s_1	s_e	s_e	s_e	s_e	s_e
s_1	s_e	s_2	s_2	s_5	s_4	s_e
s_2	s_e	s_3	s_3	s_3	s_3	s_e
s_3	s_e	s_e	s_e	s_e	s_e	s_e
s_4	s_e	s_e	s_e	s_e	s_e	s_e
s_5	s_e	s_6	s_e	s_e	s_e	s_e
s_6	s_e	s_e	s_e	s_e	s_e	s_e
s_e	s_e	s_e	s_e	s_e	s_e	s_e

Runs in the same skeleton recognizer

Table encoding RE for the tighter register specification

Extra Slides

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

Set Operations

Operation	**Definition**
Union of L and M ***Written L | M***	$L \cup M = \{s / s \in L \text{ or } s \in M\}$
Concatenation of L and M ***Written LM***	$LM = \{st \mid s \in L \text{ and } t \in M\}$
Kleene closure of L ***Written L^****	$L^* = \bigcup_{0 \le i \le \infty} L^i$
Positive Closure of L ***Written L^+***	$L^+ = \bigcup_{1 \le i \le \infty} L^i$

These definitions should be well known