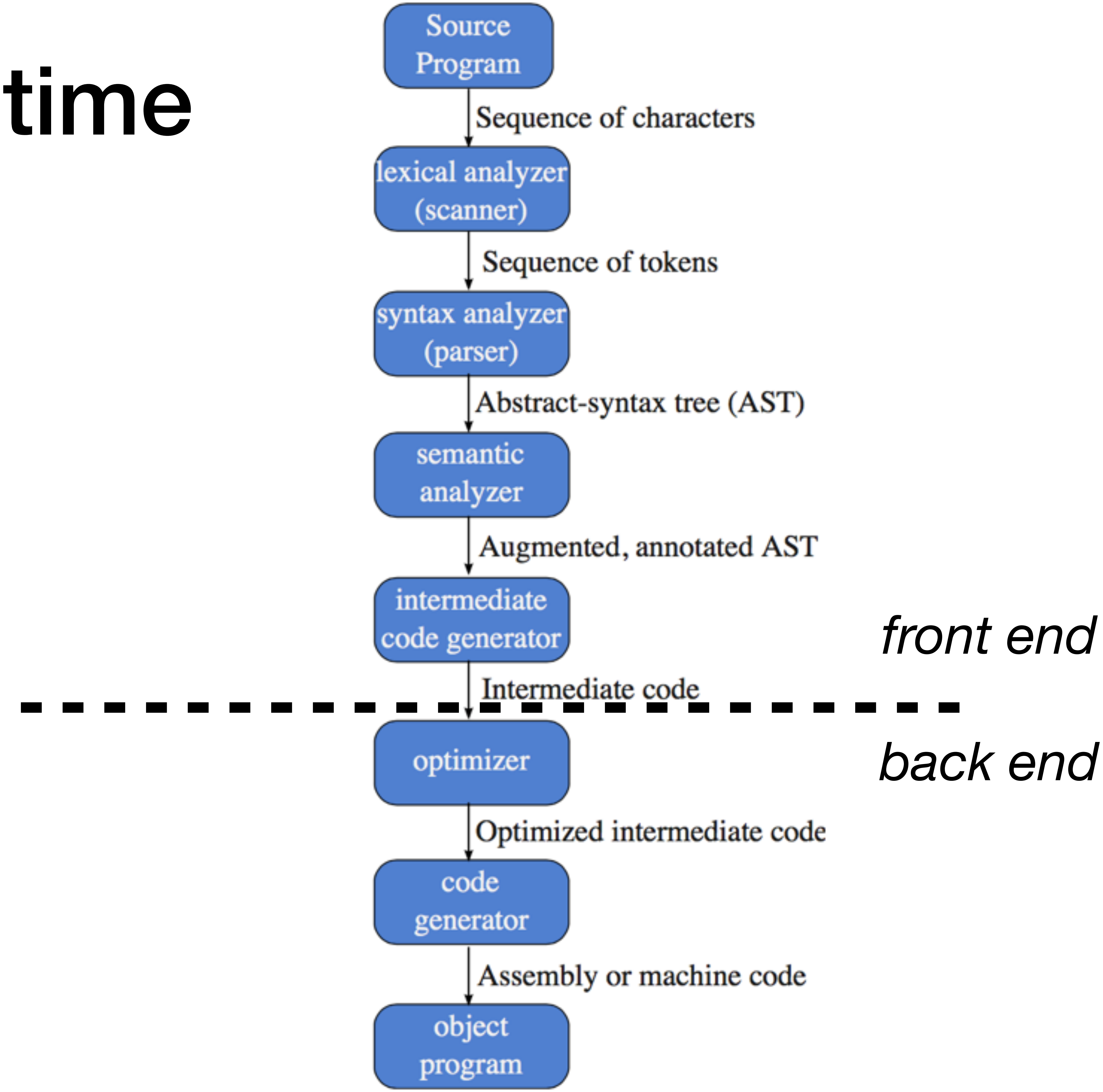
Finite-state machines

CS 536

Last time


Source Program
Sequence of characters
lexical analyzer (scanner)
Sequence of tokens
syntax analyzer (parser)
Abstract-syntax tree (AST)
semantic analyzer
Augmented, annotated AST
intermediate code generator
front end
Intermediate code
back end
optimizer
Optimized intermediate code
code generator
Assembly or machine code
object program

The scanner

Translates sequence of chars into sequence of tokens

Each time scanner is called it should:

- find longest sequence of chars corresponding to a token
- return that token

Scanner generator

Generates a scanner!!!

Needs one regular expression for each token

Needs regular expressions for things to ignore

- comments, whitespace, etc.

To understand how it works, we need FSMs

- finite state machines

FSMs: Finite State Machines

Aka finite automata

Input: string (seq of chars)

Output: accept / reject

i.e., input is legal in language

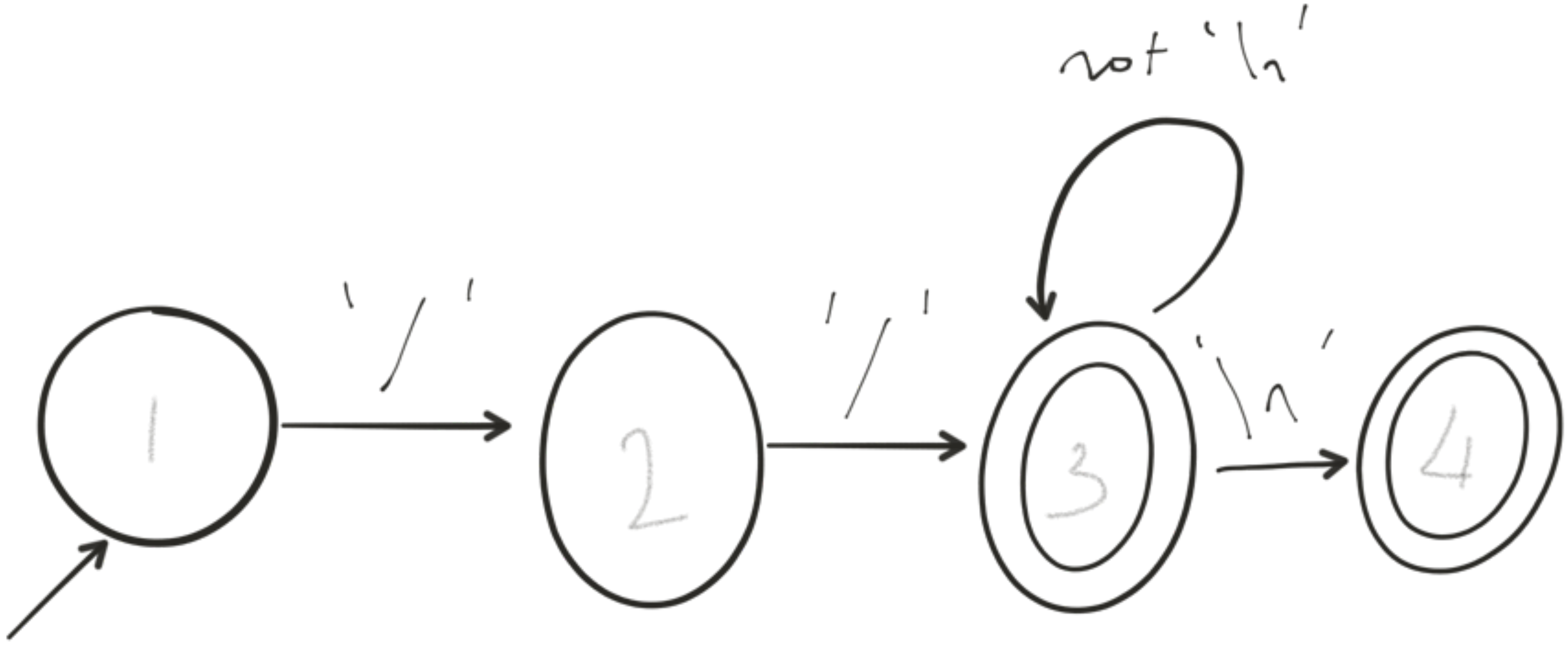
FSMs

Represent regular languages

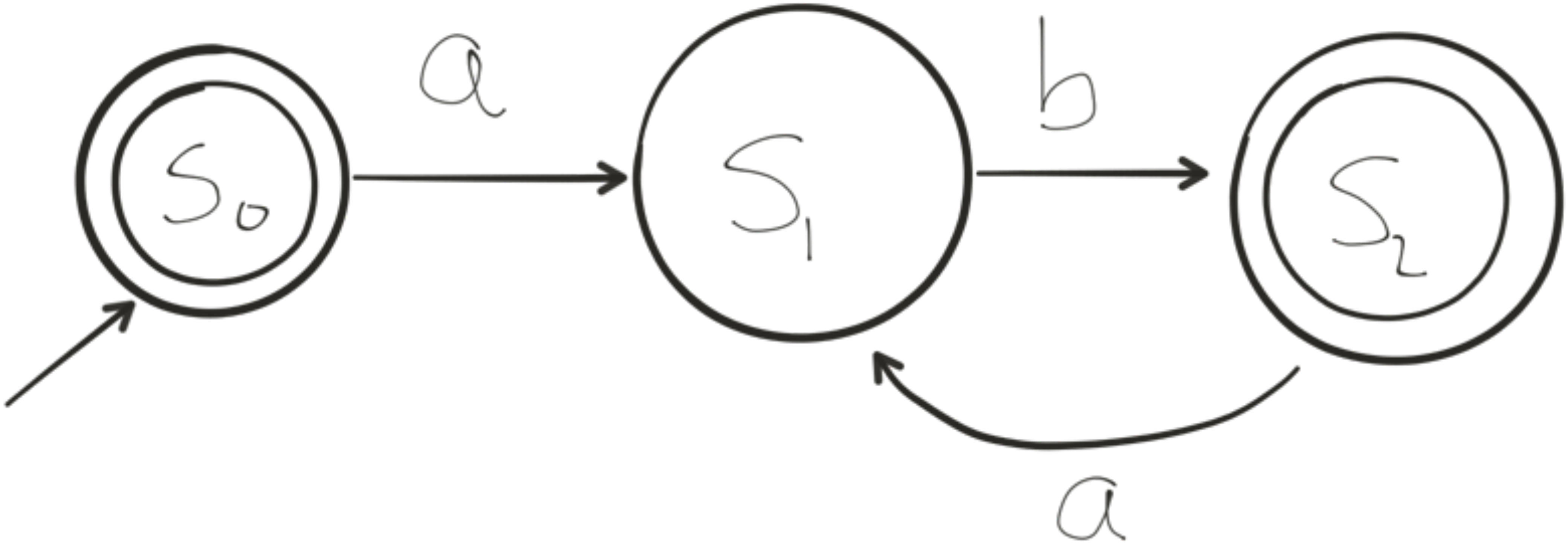
Good enough for tokens in PLs

Example 1

single line comments with //



Example 2



What language does this accept?

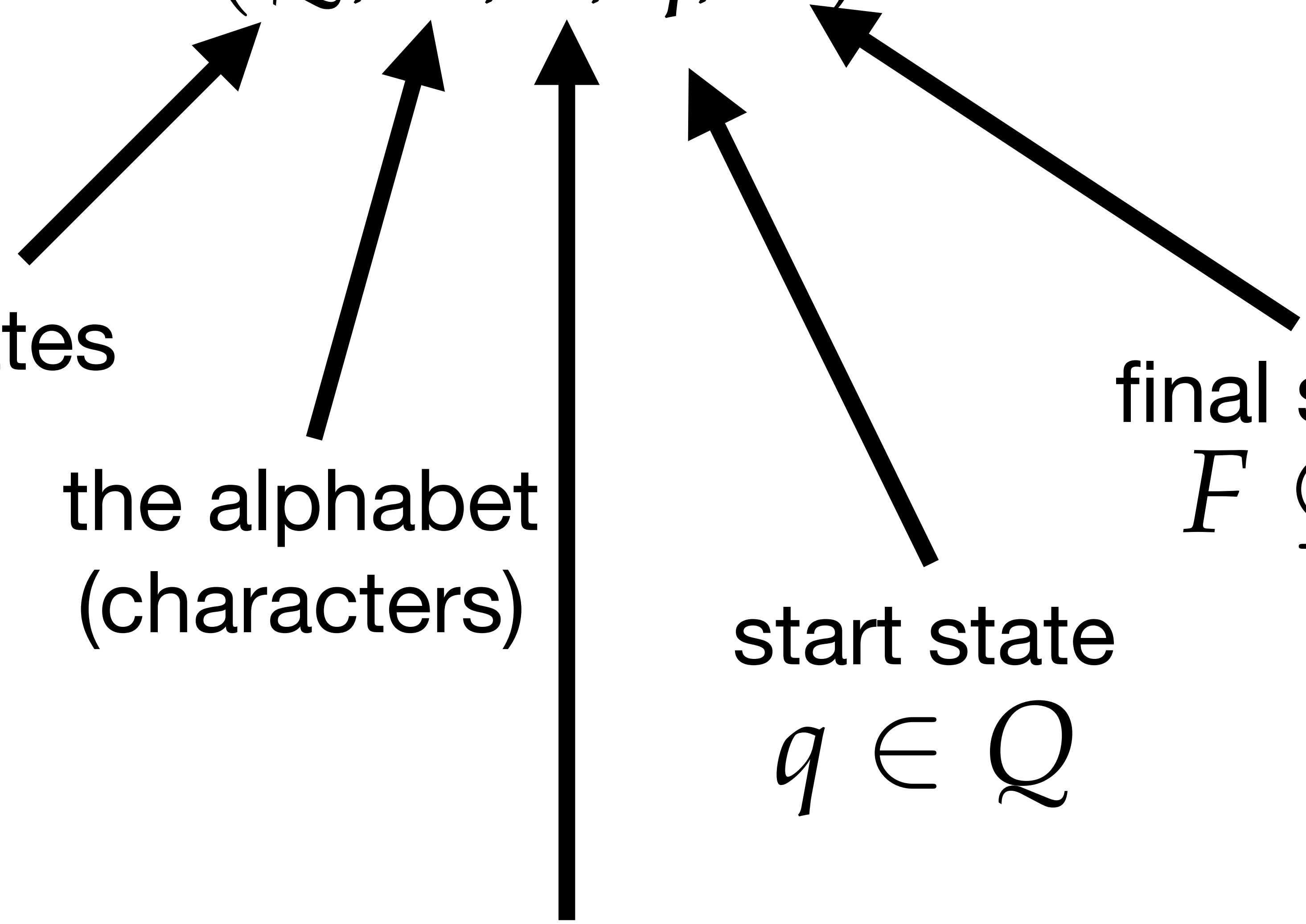
Can you find an equivalent, but smaller, FSM?

How an FSM works

```
curr_state = start_state

let in_ch = current input char

repeat

  if there is edge out of curr_state with label in_ch into next_state

    cur_state = next_state

    in_ch = next char of input

  o/w stuck // error condition

until stuck or input string is consumed

string is accepted iff entire string is consumed and cur_state = final_state
```

FSMs, formally

$$(Q, \Sigma, \delta, q, F)$$



finite set of states

the alphabet
(characters)

transition relation

$$\delta : Q \times \Sigma \to Q$$

start state

$$q \in Q$$

final states

$$F \subseteq Q$$

FSMs, formally

$$(Q, \Sigma, \delta, q, F)$$

FSM accepts string

$$x_1 x_2 x_3 \ldots x_n$$

$$\Longleftrightarrow$$

$$\delta(\ldots \delta(\delta(\delta(q, x_1), x_2), x_3) \ldots, x_n) \in F$$

The language of FSM *M* is the set of all words it accepts, denoted $L(M)$

FSM example, formally

$$(Q, \Sigma, \delta, q, F)$$

$$Q = \{s_0, s_1\}$$

$$\Sigma = \{a, b, c\}$$

$$q = s_0$$

$$F = \{s_0\}$$

$$\delta = s_0, a \rightarrow s_1$$
$$s_1, b \rightarrow s_0$$

	a	b	c
s0	s1		
s1		s0	

anything else, machine is stuck

Coding an FSM

```
curr_state = start_state
done = false
while (!done)
 ch = nextChar()
 next = transition[curr_state][ch]
 if (next == error || ch == EOF)
   done = true
 else
   curr_state = next
return curr_state == final_state
```

FSM types: DFA & NFA

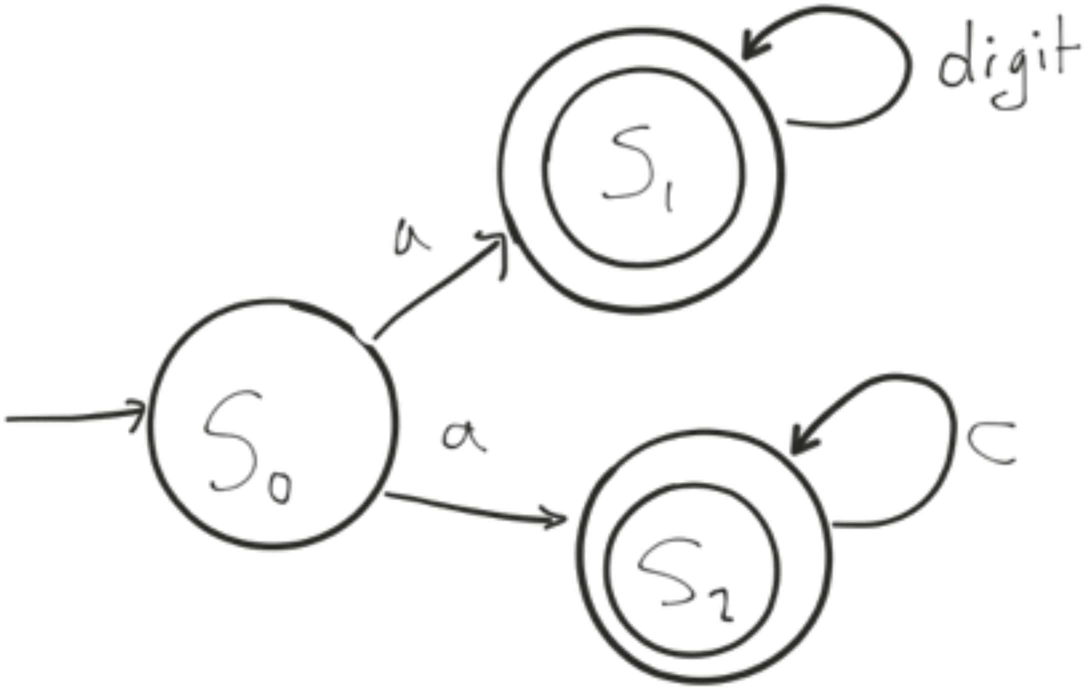
Deterministic

- no state has > 1 outgoing edge with same label

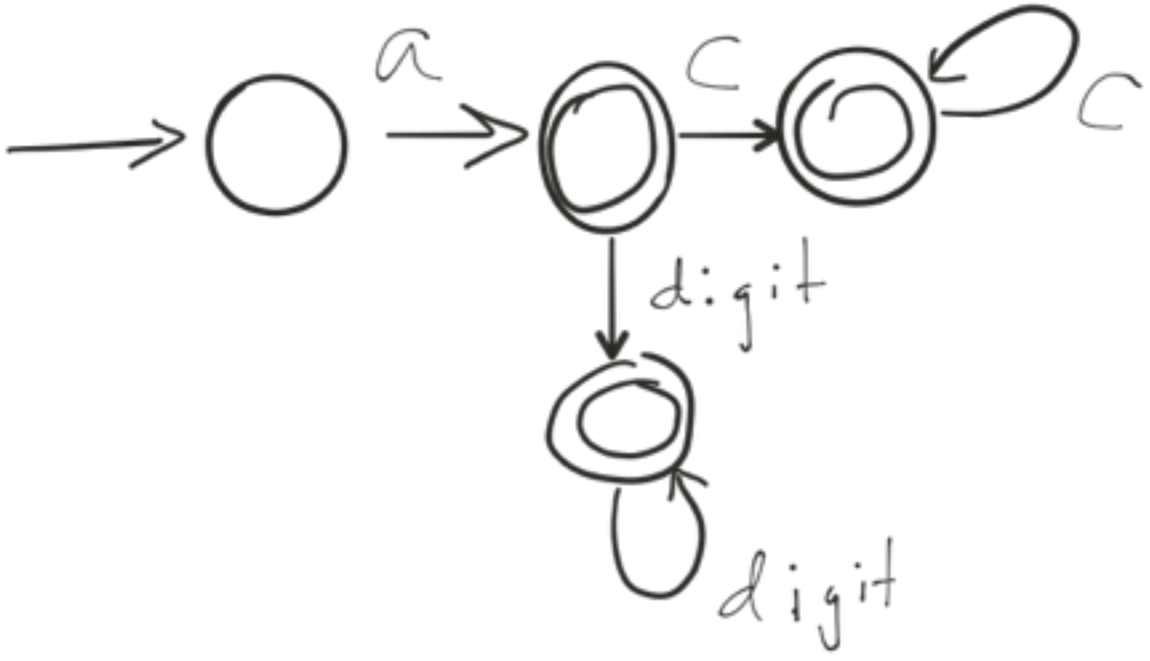
Nondeterministic

- states may have multiple outgoing edges with same label
- edges may be labelled with special symbol **ε** (empty string)
- **ε**-transitions can happen without reading input

NFA example

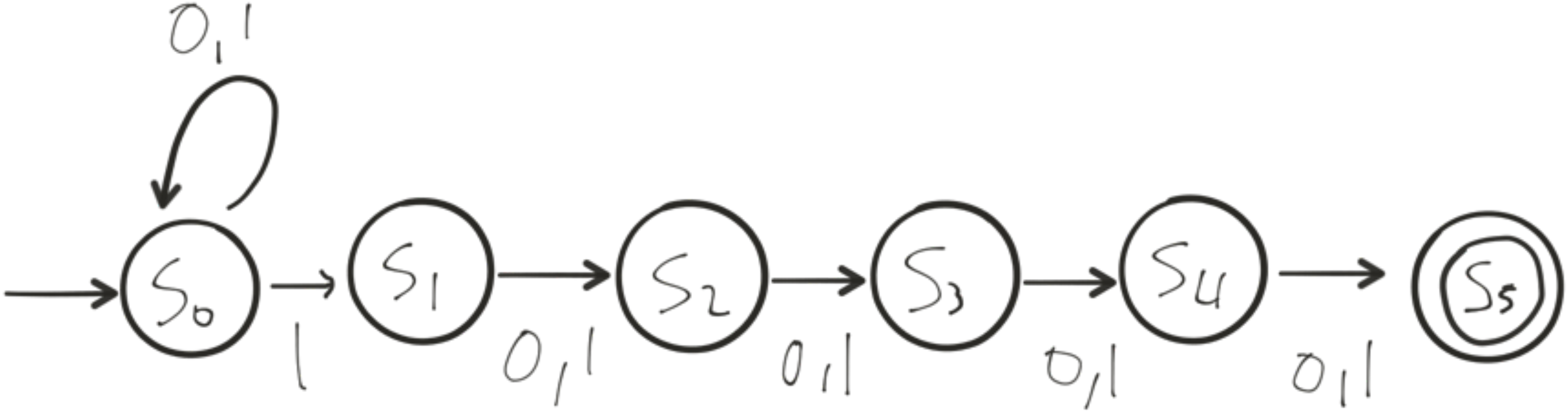


Equivalent DFA



Why NFA?

Much more compact



What does this accept?

An equivalent DFA needs 2^5 states

Extra example

Hex literals

- must start with 0x or 0X
- followed by at least one hex digit (0-9,a-f,A-F)
- can optionally have long specifier (l,L) at the end

Extra example

A C/C++ identifier is a sequence of one or more letters, digits, or underscores. It cannot start with a digit.

What if you wanted to add the restriction that it can't end with an underscore?

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Recap

The scanner reads stream of characters and finds tokens

Tokens are defined using regular expressions, which are finite-state machines

Finite-state machines can be non-deterministic

Next time: understand connection between deterministic and non-deterministic FSMs