Finite-State Machines (FSMs)

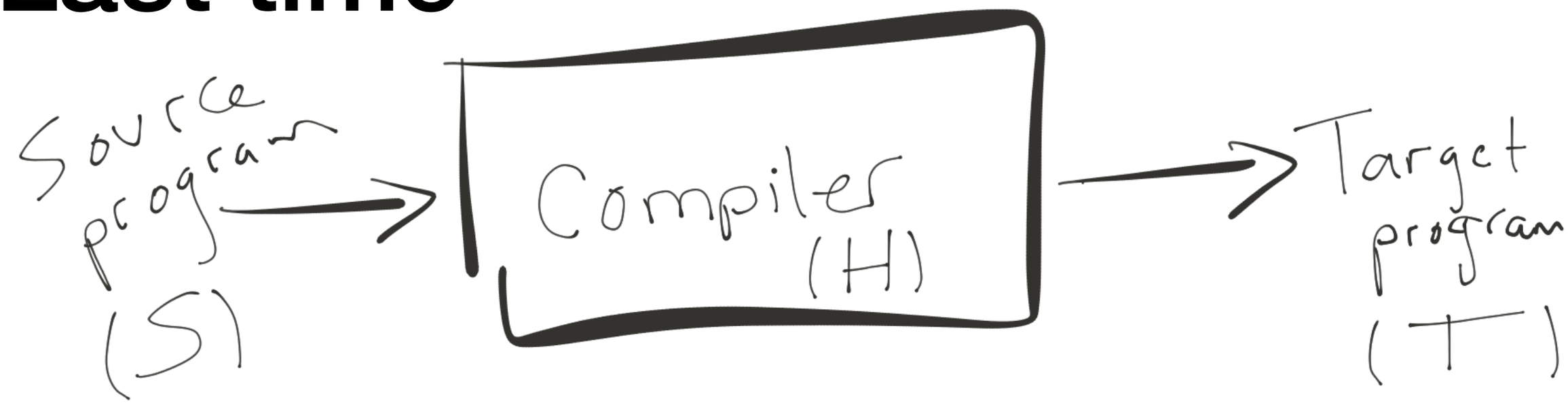
CS 536

Some announcements

P1

TA office hours

Last time



A compiler is a

recognizer of language *S* (Source)

a translator from *S* to *T* (Target)

a program in language *H* (Host)

For example, gcc: S is C, T is x86, H is C

Last time

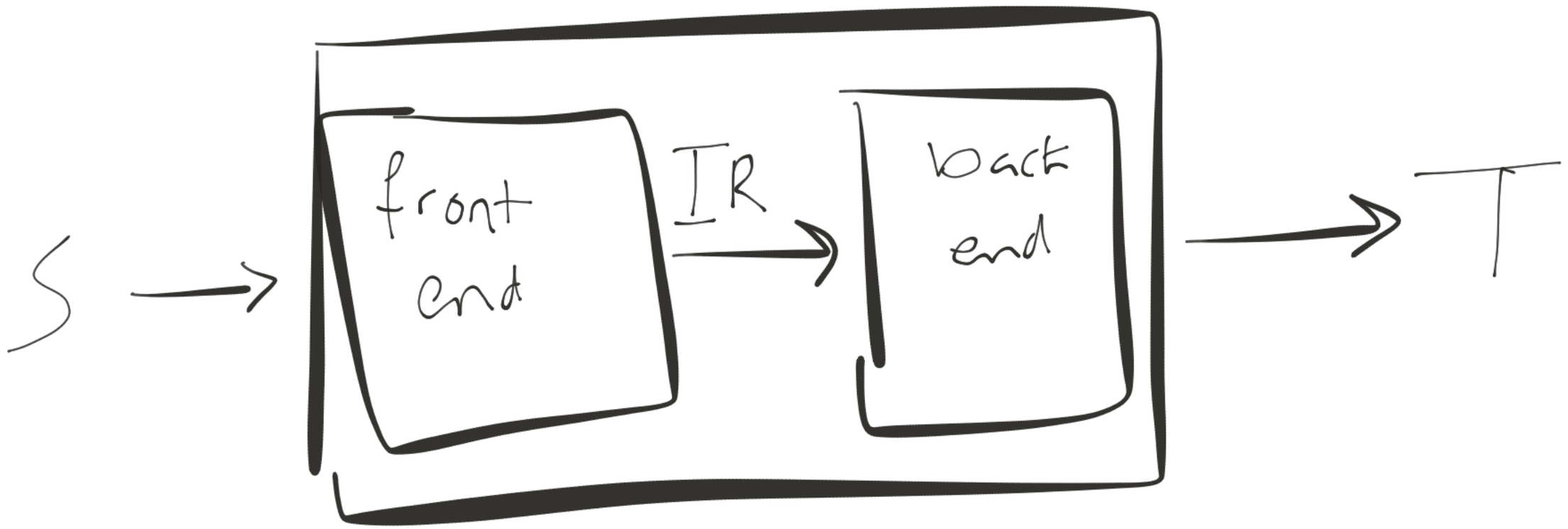
Why do we need a compiler?

- Processors can execute only binaries (machine-code/assembly programs)

- Writing assembly programs will make you lose your mind

- Write programs in a nice(ish) high-level language like C; compile to binaries

Last time



front end = understand source code *S*

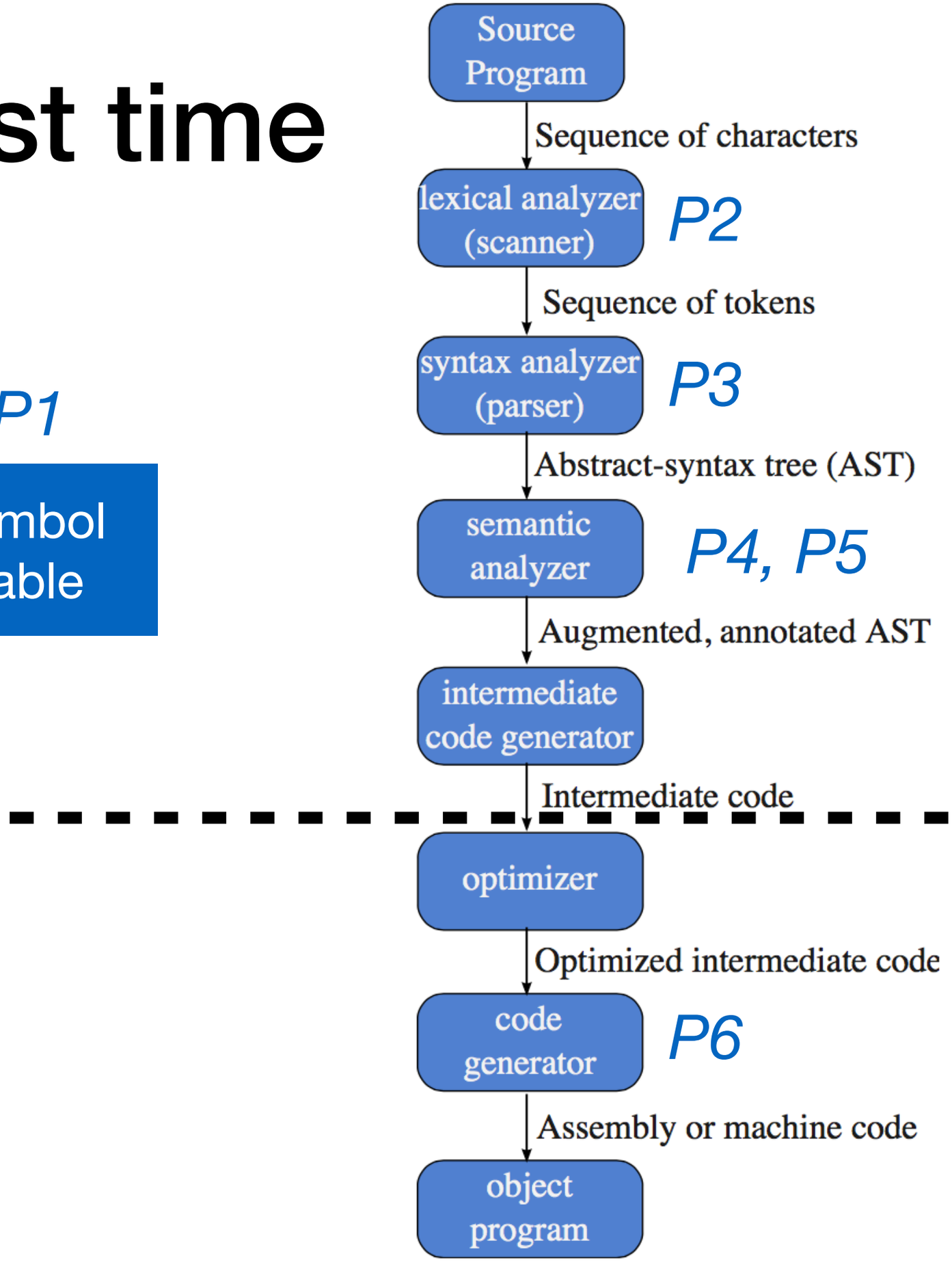
IR = intermediate representation

back end = map IR to T

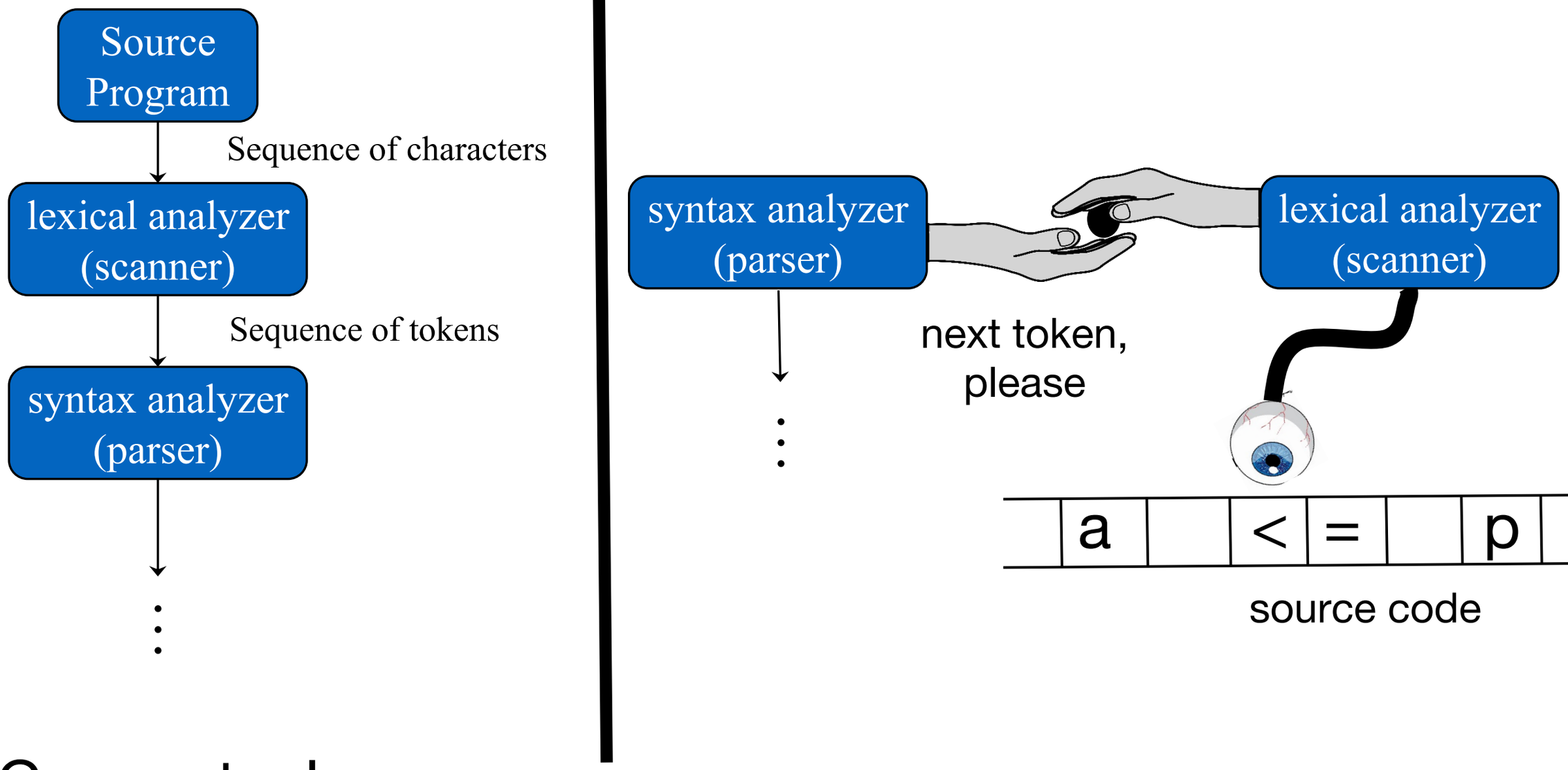
Last time

P1

Symbol table



Special linkage between scanner and parser in most compilers



Conceptual organization

The scanner

Translates sequence of chars into a sequence of tokens (ignoring whitespace)

```
a = 2 * b + abs(-71)
```

ident	asgn	int lit	times	ident	plus	ident	lparens	int lit	rparens
(a)		(2)		(b)		(abs)		(-71)	

Each time the scanner is called it should:

- find the longest prefix (lexeme) of the remaining input that corresponds to a token
- return that token

How to create a scanner?

- For every possible lexeme that can occur in source program, return corresponding token
- Inefficient
- Error-prone

Scanner generator

- Generates a scanner
- Inputs:
  - one regular expression for each token
  - one regular expressions for each item to ignore (comments, whitespace, etc.)
- Output: scanner program
- How does a scanner generator work?
  - Finite-state machines (FSMs)

FSMs: Finite State Machines

(A.k.a. finite automata, finite-state automata, etc.)

Input: string (sequence of chars)

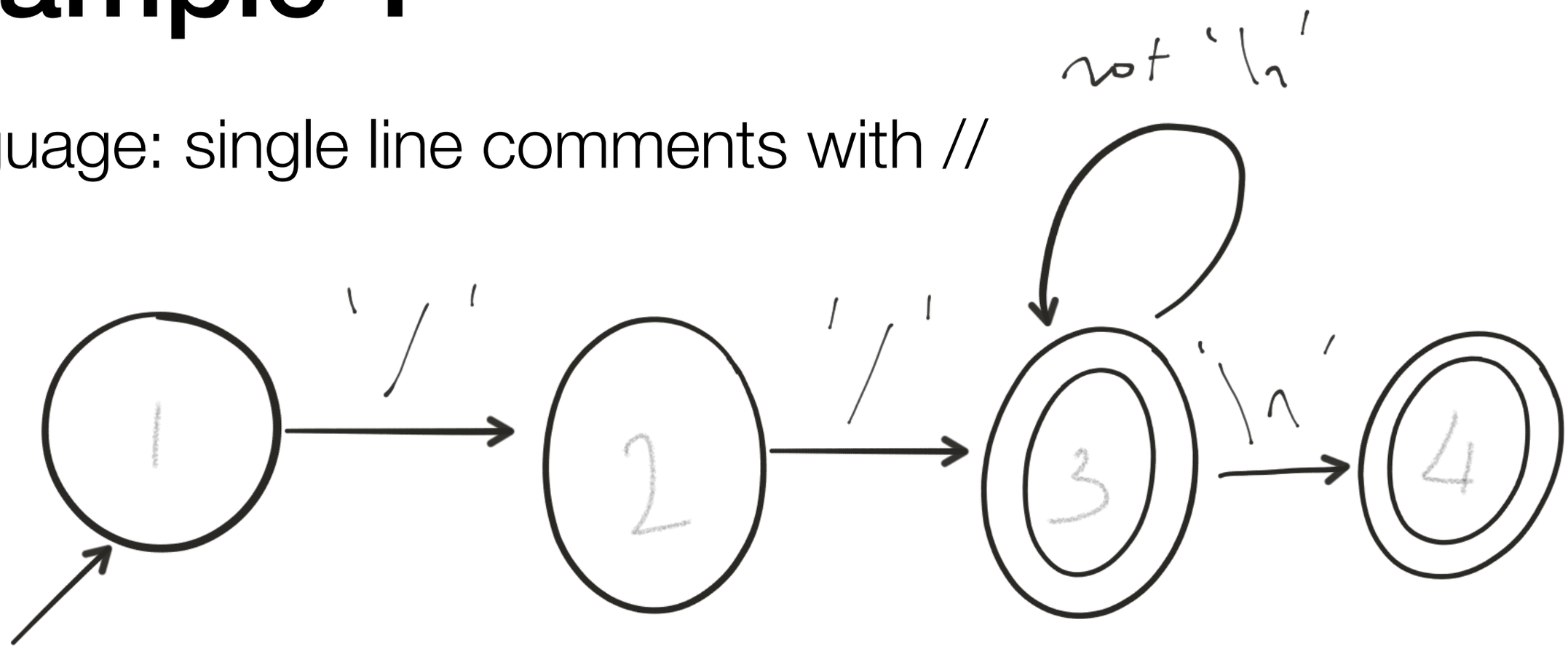
Output: accept / reject

i.e., input is legal in language

Language defined by an FSM is the set of strings accepted by the FSM

Example 1

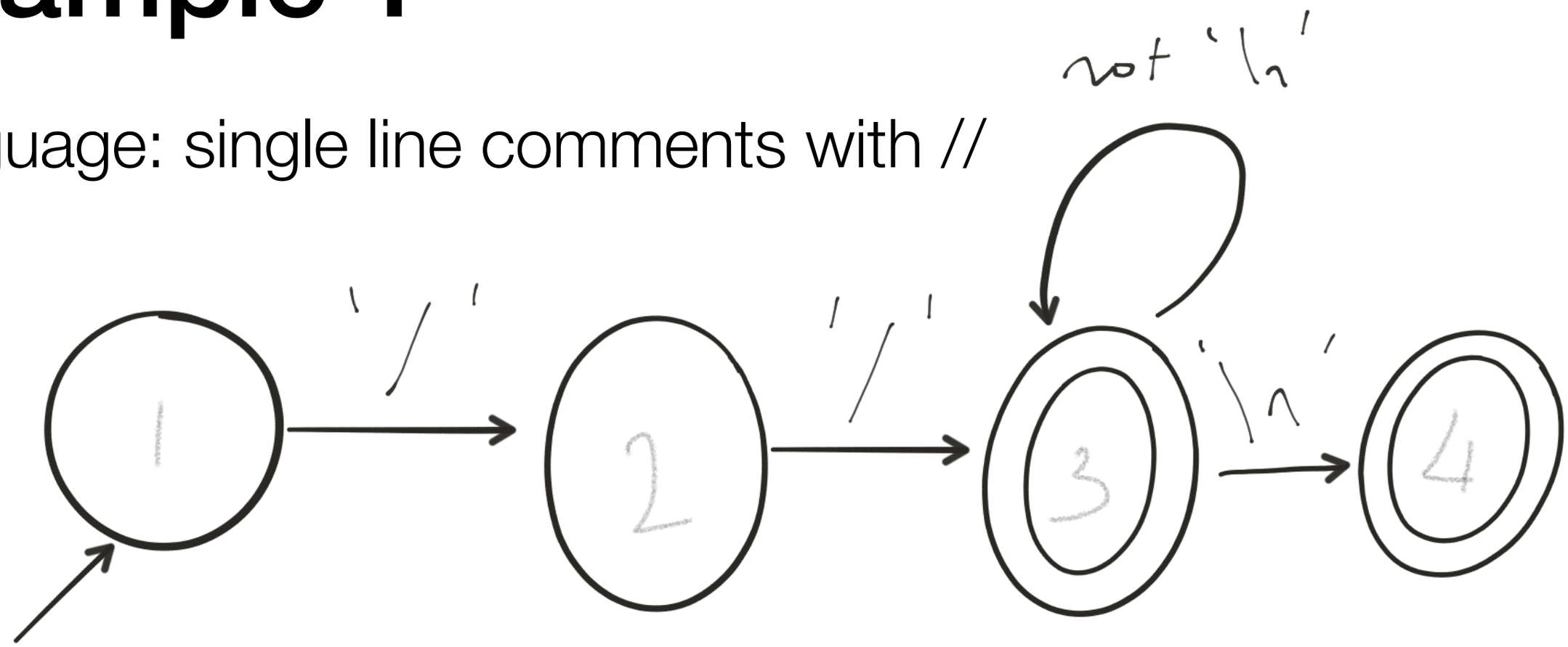
Language: single line comments with //



- Nodes are states
- Edges are transitions
- Start state has an arrow (only one start state)
- Final states are double circles (one or more)

Example 1

Language: single line comments with //

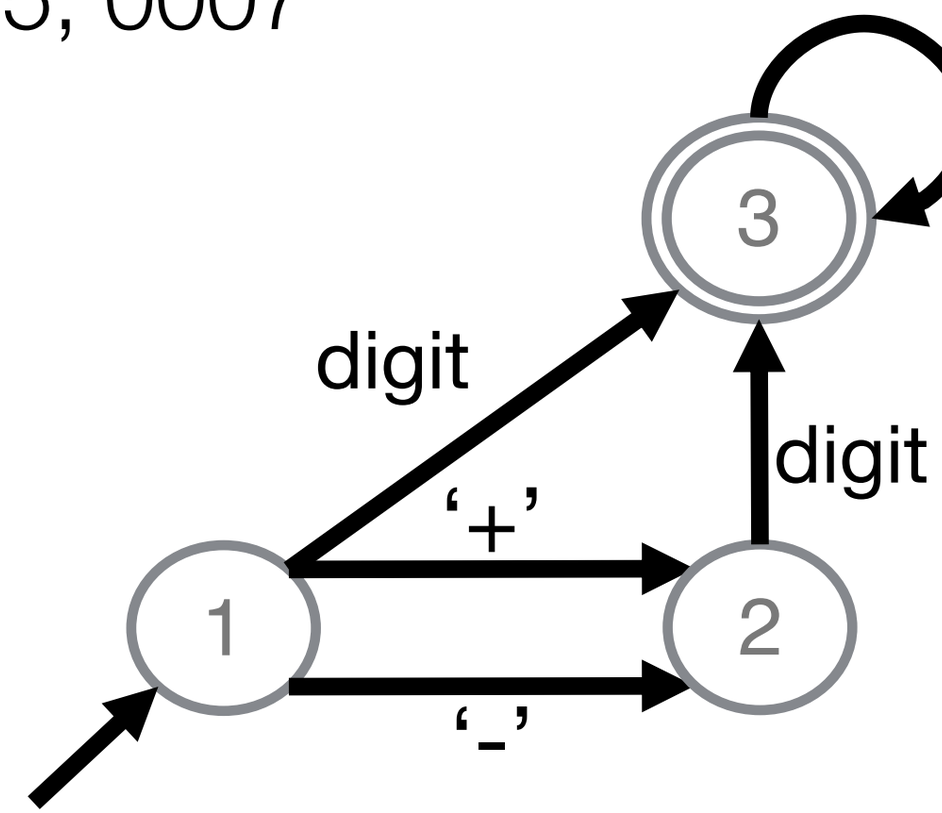


1. “// this is a comment.”
2. “/ / this is not.”
3. “// \n”
4. “Not // a comment”

Example 2

Language: Integer literals with an optional + or –
(token: int-lit)

e.g., -543, +15, 0007



FSMs, formally

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

$L(M)$ = set of integer literals

finite set of states

Q

the alphabet (characters)

Σ

start state

$q \in Q$

$F \subseteq Q$

transition function

$\delta : Q \times \Sigma \rightarrow Q$

	‘+’	‘-’	digit
1	2	2	3
2			3
3			3

FSM example, formally

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

What is $L(M)$?

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

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

$$q = s_0$$

$$F = \{s_0\}$$

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

$$s_1, b \rightarrow s_0$$

s0	s1		
s1		s0	

anything else, machine is stuck

$L(M)$ = {ε, ab, abab, abababab, abababababab, ... }

Coding an FSM

```
curr_state = start_state

done = false

while (!done)

 ch = nextChar()

 next = table[curr_state][ch]

 if (next == stuck || ch == EOF)

   done = true

 else

   curr_state = next

return final_states.contains(curr_state) &&

       next!=stuck
```

FSM types: DFA & NFA

Deterministic

no state has >1 outgoing edge with same label

Nondeterministic

states may have multiple outgoing edges with same label

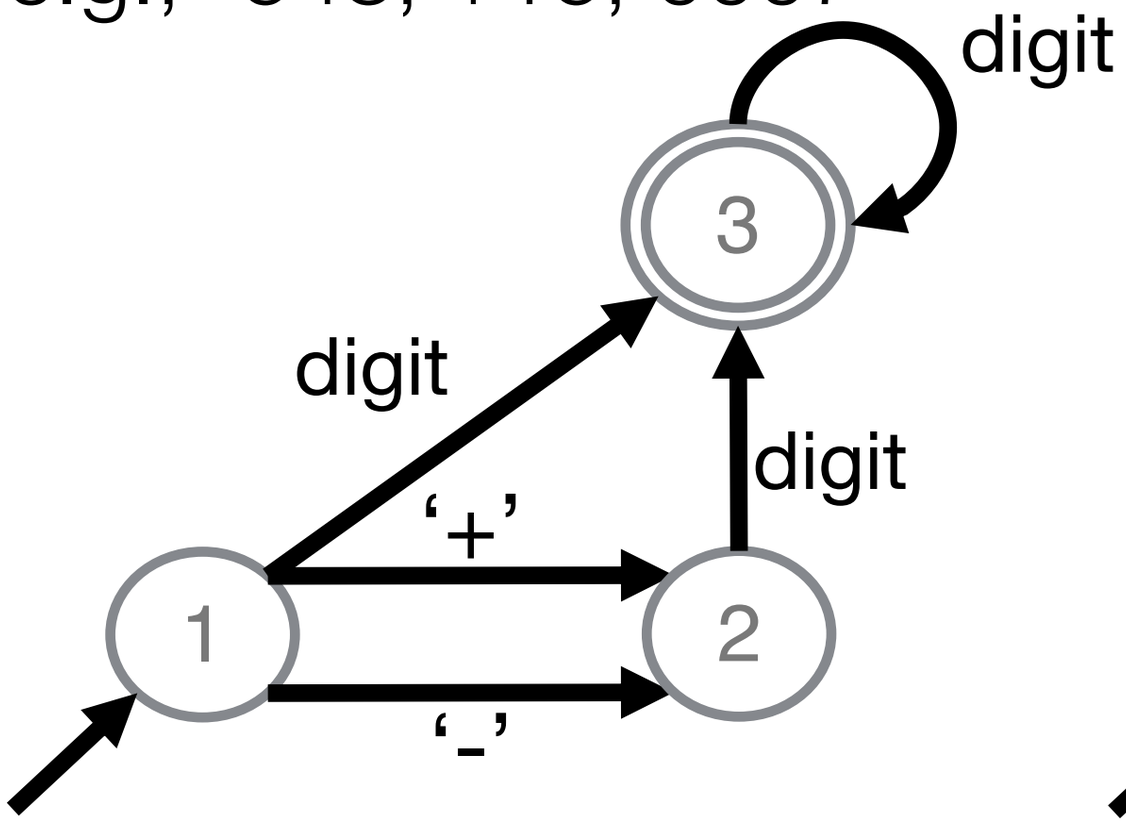
edges may be labelled with special symbol **ε** (empty string)

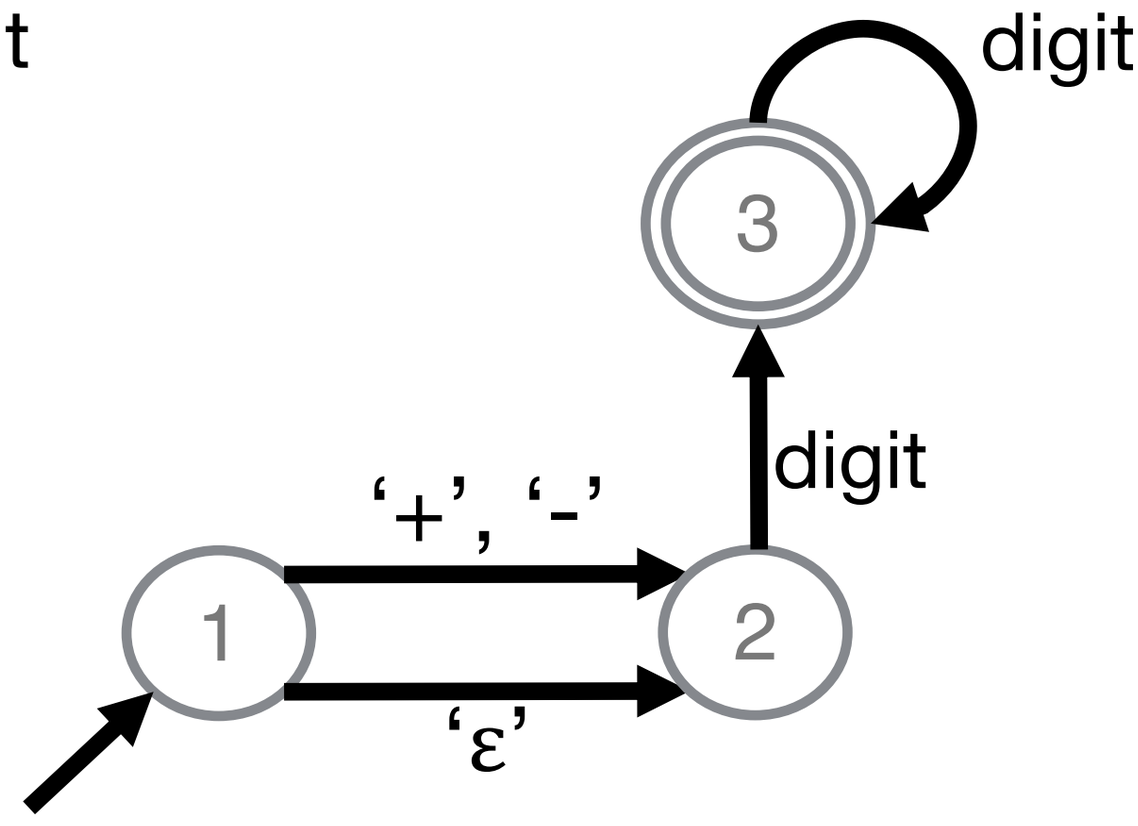
ε-transitions can happen without reading input

NFA Example

Language: Integer literals with an optional + or –
(token: int-lit)

e.g., -543, +15, 0007





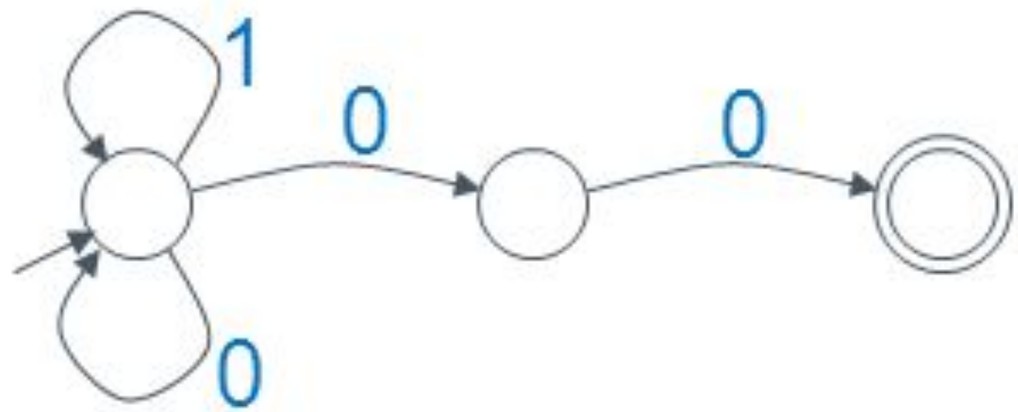
A string is accepted by an NFA if ***there exists*** a sequence of transitions leading to a final state

Why NFA?

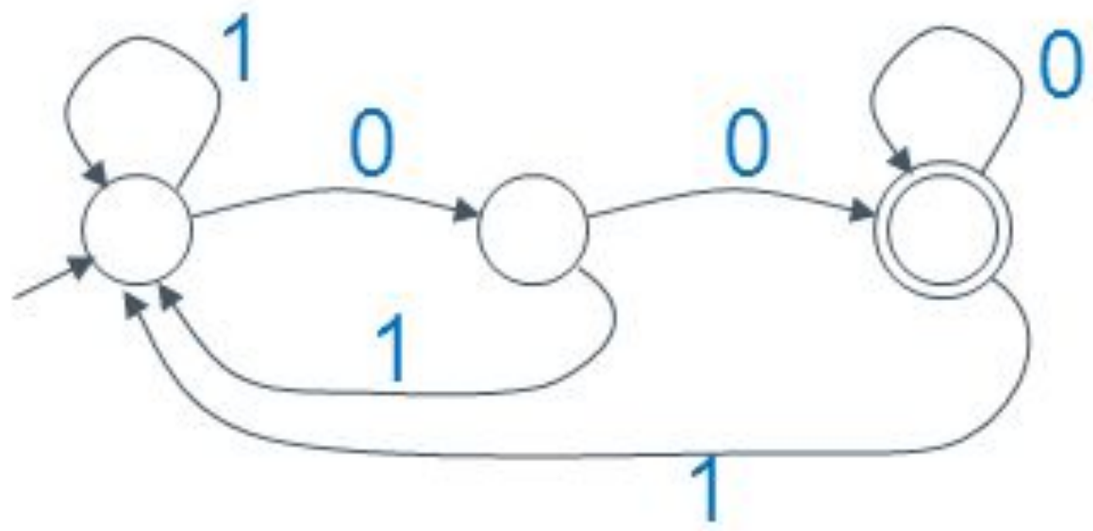
Simpler and more intuitive than DFA

Language: sequence of 0s and 1s, ending with 00

NFA



DFA

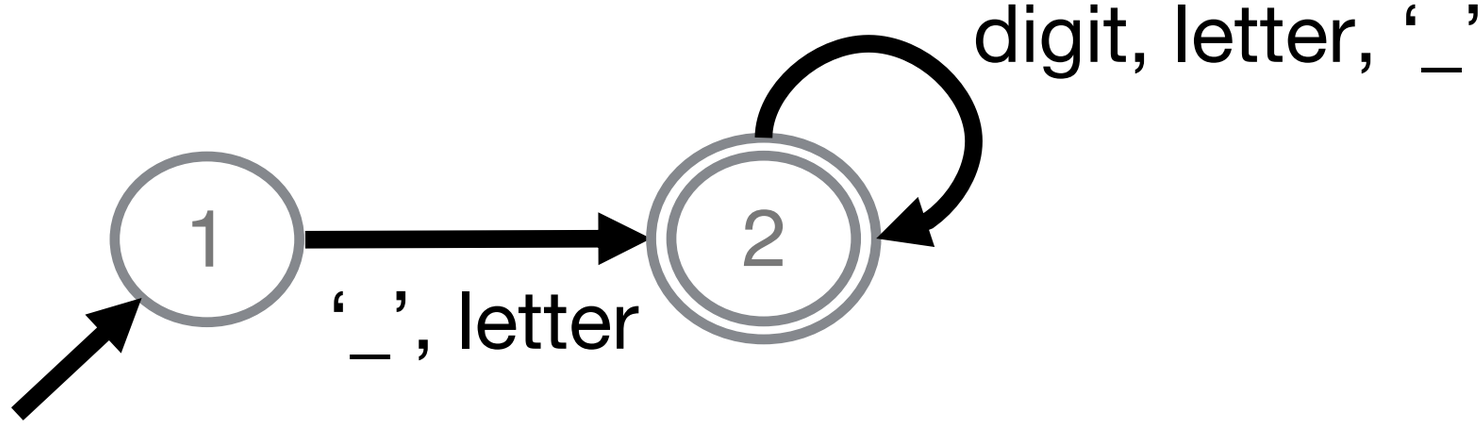


Extra example

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

Extra Example - Part 1

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



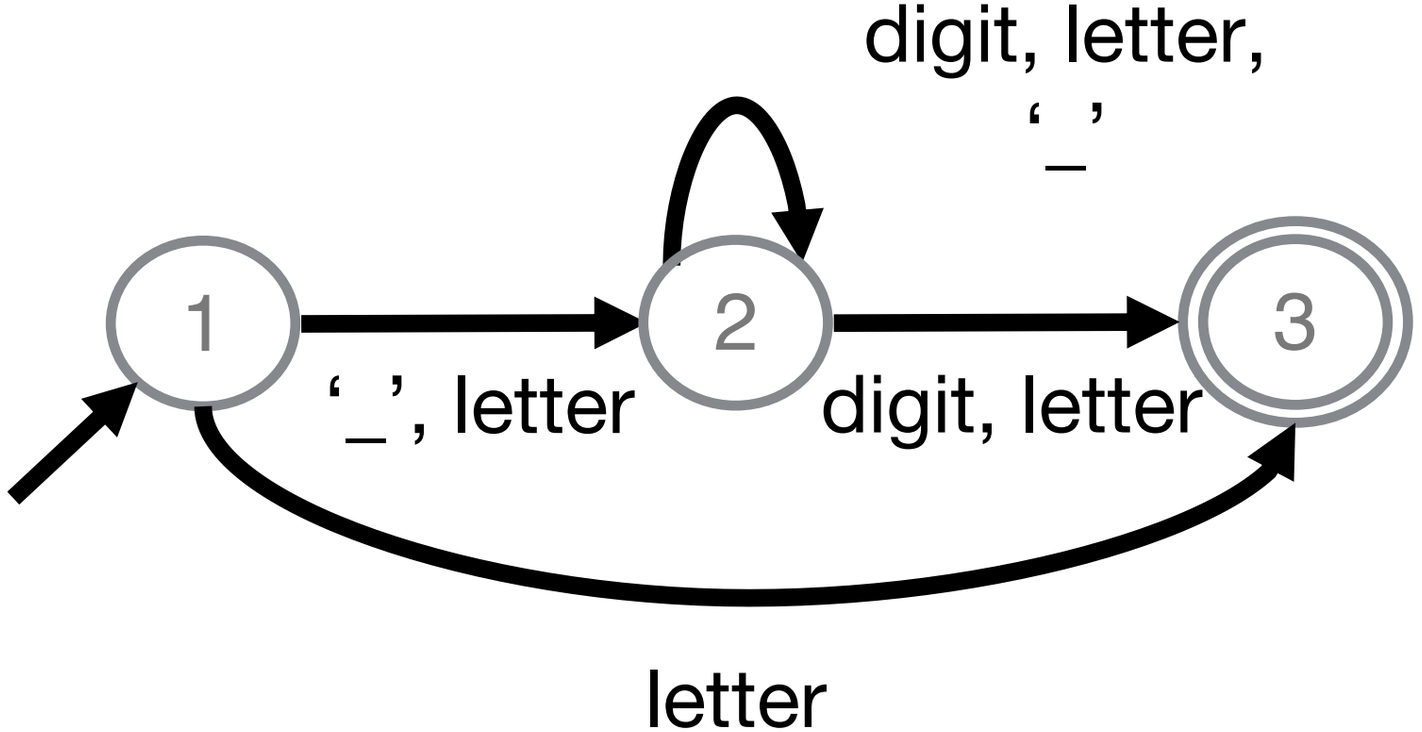
Extra example

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?

Extra Example - Part 2

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



Recap

The scanner reads a stream of characters and tokenizes it (i.e., finds tokens)

Tokens are defined using regular expressions, scanners are implemented using FSMs

FSMs can be non-deterministic

Next time: understand connection between DFA and NFA, regular languages and regular expressions

Play with automata!

automatatutor.com

Loris D’Antoni