CS 536 Announcements for Monday, January 29, 2024

Course websites:

`pages.cs.wisc.edu/~hasti/cs536`
`www.piazza.com/wisc/spring2024/compsci536`

Office hours

Paper copies of these overheads available at front

- Beck (in 5360 Comp Sci)
    - 2:00 – 3:00 pm Mondays
    - 9:00 – 10:30 am Tuesdays
    - 10:30 am – noon Fridays
- office hours for TAs are being determined

Programming Assignment 1

- test code due Sunday, Feb. 4 by 11:59 pm
- other files due Thursday, Feb. 8 by 11:59 pm

Reminders

- report exam conflicts using CS 536 Alternate Exam Request Form (link on Exam Information page)
- contact Beck within first 3 weeks of classes if
    - you participate in religious observances that may conflict with course requirements
    - you receive accommodations through the McBurney center

Last Time

- intro to CS 536
- compiler overview

Today

- start scanning
- finite state machines
    - formalizing finite state machines
    - coding finite state machines
    - deterministic vs non-deterministic FSMs

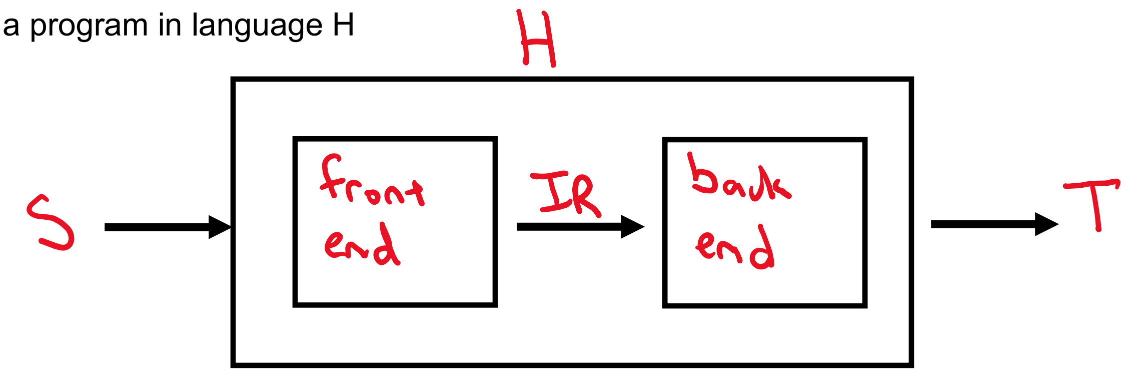
Next Time

- non-deterministic FSMs
- equivalence of NFAs and DFAs
- regular languages
- regular expressions

Recall

A compiler is

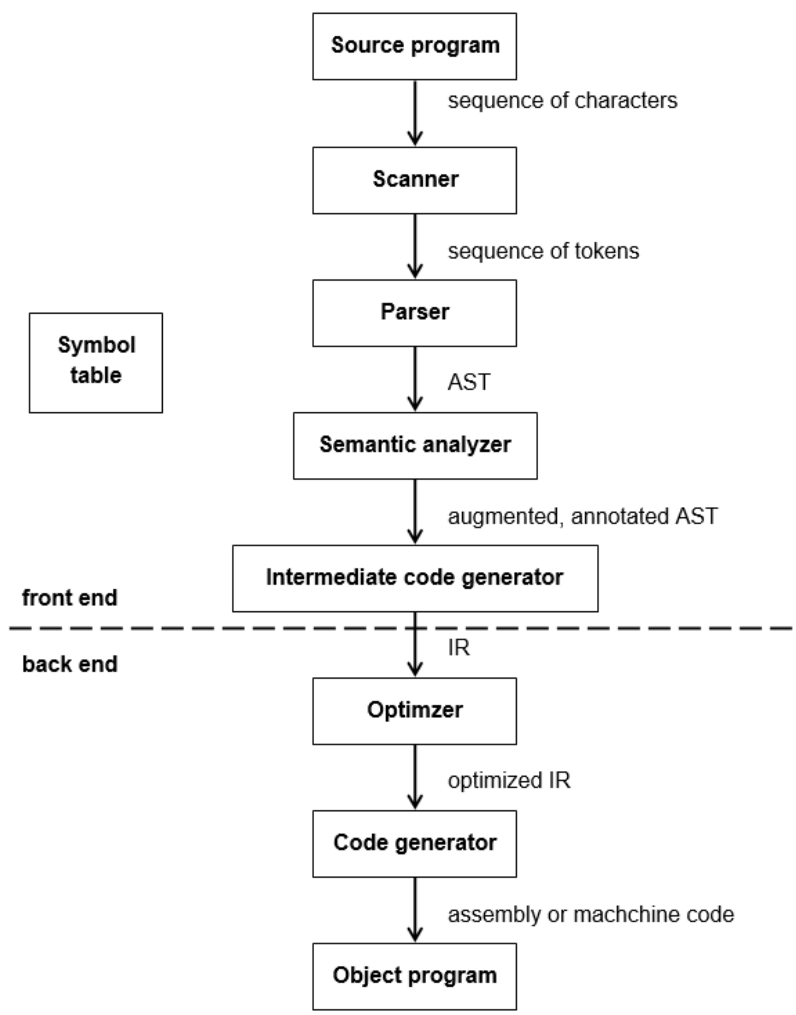
- recognizer of language S
- a translator from S to T
- a program in language H



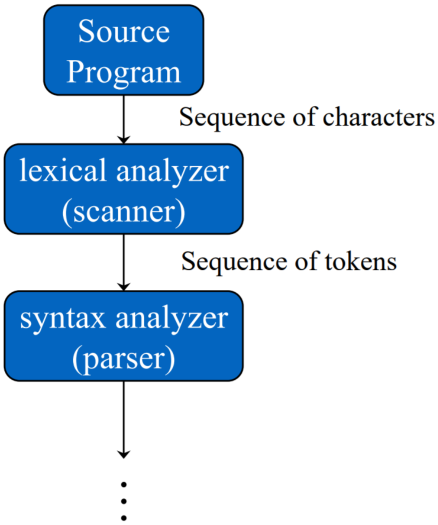
front end = understand source code S; map S to IR
IR = intermediate representation
back end = map IR to T

Why do we need a compiler?

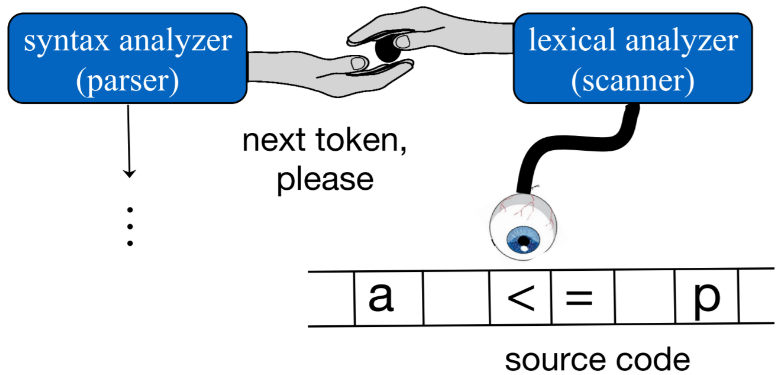
- processors can execute only binaries (machine-code/assembly programs)
- writing assembly programs will make you lose your mind
- allows you to write programs in nice(ish) high-level languages like C; compile to binaries



Special linkage between scanner and parser (in most compilers)



Conceptual organization



Scanning

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

avg += 7
ID (avg)
PLUSASG
INTLIT (7)

Scanner generator

- **Inputs**:
  - one regular expression for each token
  - one regular expression for each item to ignore (comments, whitespace, etc.)
- **Output**: scanner program

To understand how a scanner generator works, we need to understand FSMs

FA Finite-state machines FSM
(aka finite automata, finite-state automata)

- **Inputs**: string (sequence of characters) – finite length
- **Output**: accept / reject – is string in language L

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

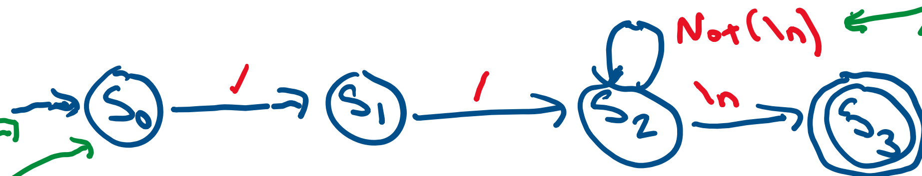
Compiler recognizes legal programs in source lang S

FSM recognizes legal strings in some lang L

Example 1:

Language: single-line comments starting with // (in Java / C++)

// stuff to end of line



shorthand for many transitions (1 for every char that is not \n)

Nodes are states

Edges are transitions

Start state has arrow point to it only 1

Final states are double circles can have multiple

Consider

//red\n ✓ //\n ✓ ///////\n ✓

//green X // blue EOF X //cyan\n teal X stuck

How a finite state machine works

```
curr_state = start_state
let in_ch= current input character
repeat
    if there is edge out of curr_state with
          label in_ch into next_state
       curr_state = next_state — follow transition
       in_ch = next char of input
    otherwise
       stuck // error condition
until stuck or input string is consumed
if entire string is consumed and
     curr_state is a final state
    accept string ✓
otherwise
    reject string ✗
```

Formalizing finite-state machines

alphabet (Σ) = finite, non-empty set of elements called **symbols**

string over Σ = finite sequence of symbols from Σ

language over Σ = set of strings over Σ

finite state machine $M = (Q, \Sigma, \delta, q, F)$ where

- Q = set of states – finite
- Σ = alphabet – finite (union of all edge labels)
- δ = state transition function $Q\times\Sigma\rightarrow Q$ given (state, symbol), return
- q = start state – only 1, $q \in Q$
- F = set of accepting (or final) states $F \subseteq Q$

L(*M*) = the language of FSM *M* = set of all strings *M* accepts – can be infinite

finite automata *M* **accepts** $x = x_1x_2x_3 \ldots x_n$ iff

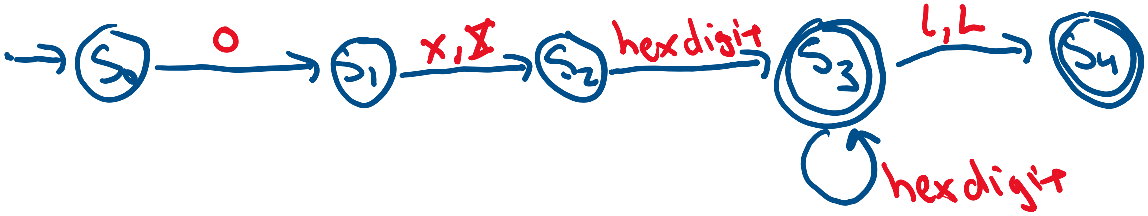
$$\delta(\delta(\delta(\ldots\ \delta(\delta(\delta(s_0, x_1), x_2), x_3), \ldots\ x_{n-2}), x_{n-1}), x_n) \in F$$

end in final state

Example 2: hexadecimal integer literals in Java

Hexadecimal integer literals in Java:

- must start 0x or 0X ← number 0 (not letter capital-o)
- followed by at least one hexadecimal digit (hexdigit)
  - hexdigit = 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, a, b, c, d, e, f, A, B, C, D, E, F
- optionally can add long specifier (`l` or `L`) at end



Example of accepted: 0x1f4d3

Stuck in start: 123

stuck in final state but not accepted: 0x4LX

$Q = \{S_0, S_1, S_2, S_3, S_4\}$

$\Sigma = \{0\text{-}9, a\text{-}f, A\text{-}F, x, X, l, L\}$

$\delta =$ use state transition table

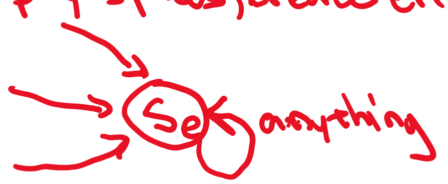
$q = S_0$

$F = \{S_3, S_4\}$

State transition table

	0	1 – 9	a – f	A – F	x	X	l	L
S_0	S_1	S_e	S_e	S_e	S_e	S_e	S_e	S_e
S_1					S_2	S_2		
S_2	S_3	S_3	S_3	S_3				
S_3	S_3	S_3	S_3	S_3			S_4	S_4
S_4								
S_e	S_e	S_e	S_e	S_e	S_e	S_e	S_e	S_e

To handle empty spaces, create error state S_e



Coding a state transition table

```
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 final_states.contains(curr_state) && next != error
```

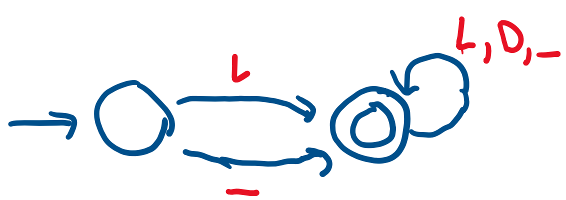
Works provided FSM is deterministic

Example 3: identifiers in C/C++

A C/C++ identifier

L D _

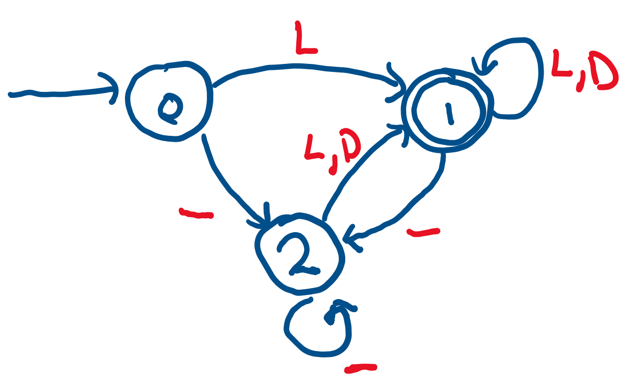
- is a sequence of one or more letters, digits, underscores
- cannot start with a digit



Legal but odd:

_ __ _0_

Add restriction: can't end in underscore



DFA NFA

Deterministic vs non-deterministic FSMs

deterministic

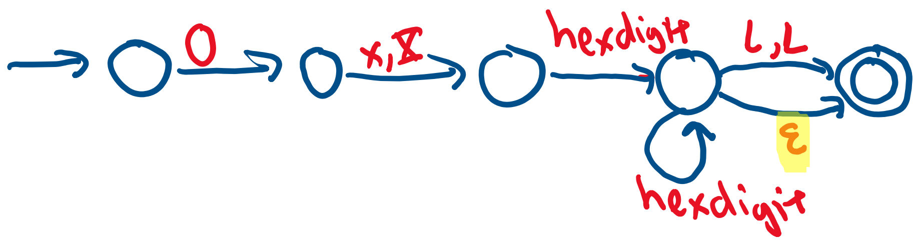
- no state has >1 outgoing edge with same label
- edges can only be labelled with elements of Σ

non-deterministic

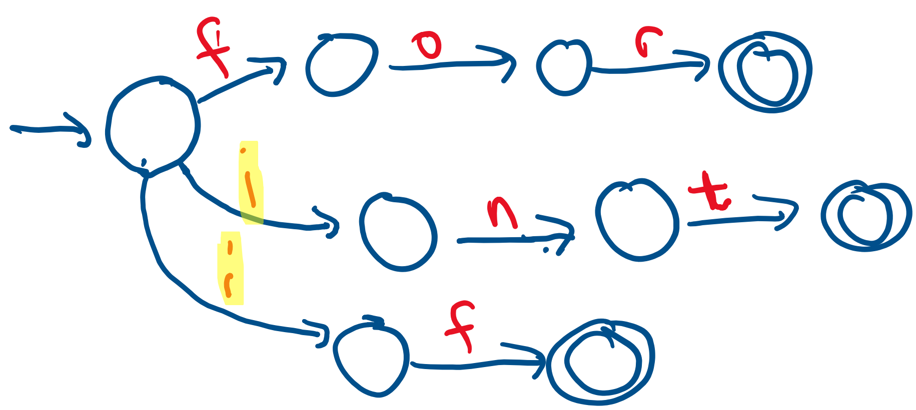
- states may have multiple outgoing edges with same label
- edges may be labelled with special symbol ε (empty string)

ε -transitions can happen without reading input

Example 2 (revisited): hexadecimal integer literals in Java



Example 4: FSM to recognize keywords `for`, `if`, `int`



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 (deterministic) FSMs
- FSMs can be non-deterministic