CS 432
Fall 2016

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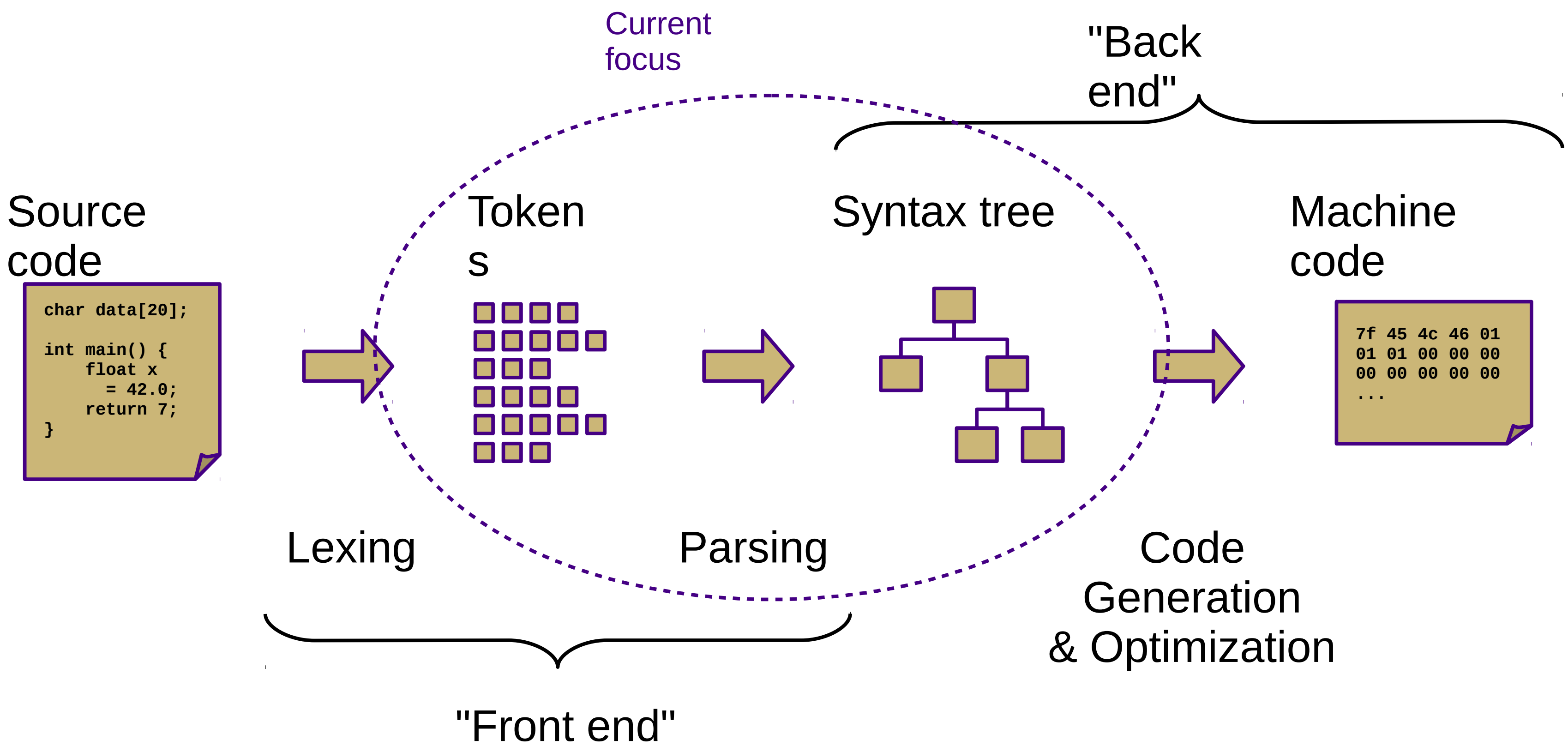
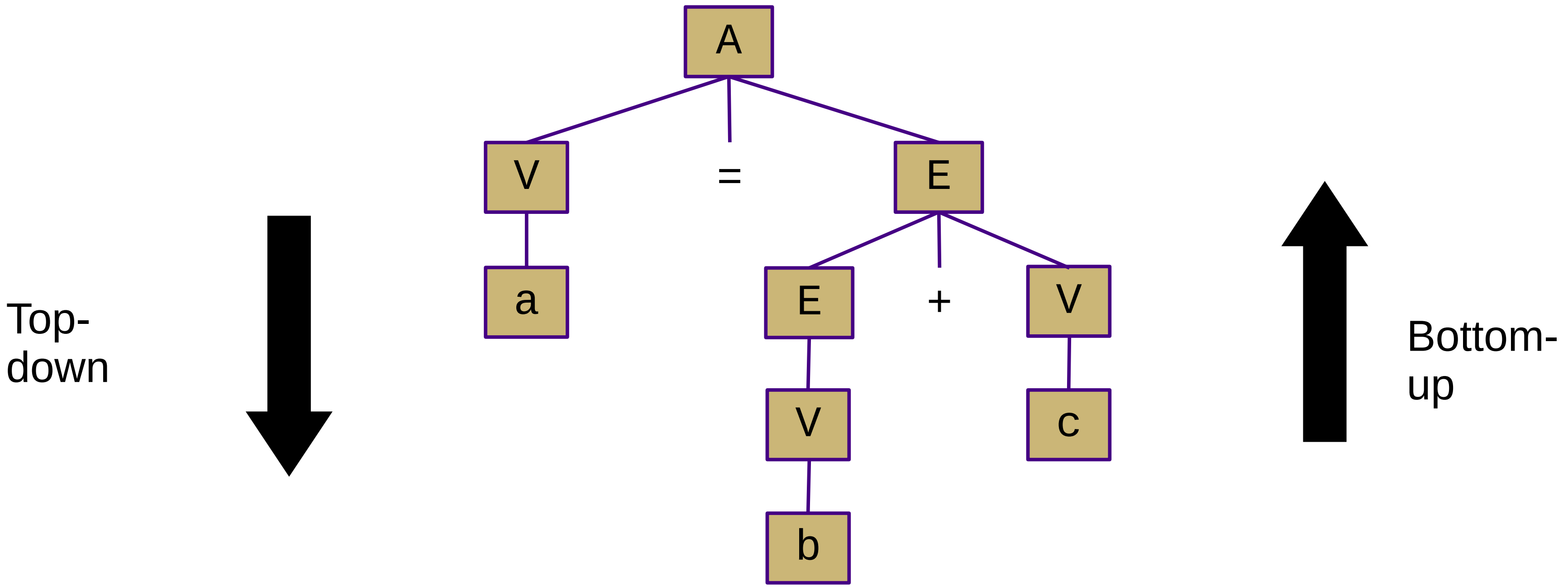
Bottom-Up (LR) Parsing

Compilation



Overview

- Two general parsing approaches
  - Top-down: begin with start symbol (root of parse tree), and gradually expand non-terminals
  - Bottom-up: begin with terminals (leaves of parse tree), and gradually connect using non-terminals



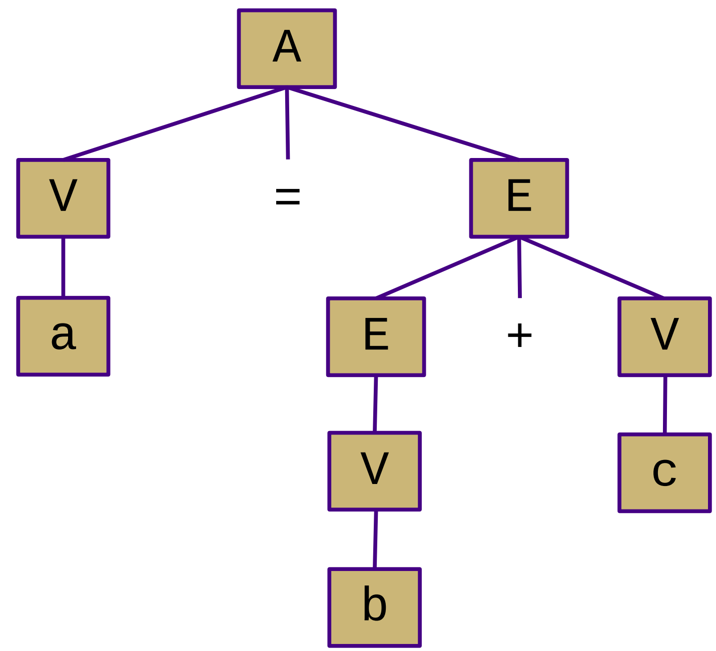
Shift-Reduce Parsing

- Top-down (LL) parsers
  - Left-to-right scan, Leftmost derivation
  - Recursive routines, one per non-terminal (*recursive descent*)
  - Implicit stack (system call stack)
  - Requires more restrictive grammars
  - Simpler to understand and possible to hand-code
- Bottom-up (LR) parsers
  - Left-to-right scan, (reverse) Rightmost derivation
  - "Shift"/push terminals and non-terminals onto a stack
  - "Reduce"/pop to replace *handles* with non-terminals
  - Less restrictive grammars
  - Harder to understand and nearly always auto-generated
  - Very efficient

Shift-Reduce Parsing

-
  - shift 'a'
- a
  - reduce (V → a)
- V
  - shift '='
- V =
  - shift 'b'
- V = b
  - reduce (V → b)
- V = V
  - reduce (E → V)
- V = E
  - shift '+'
- V = E +
  - shift 'c'
- V = E + c
  - reduce (V → c)
- V = E + V
  - reduce (E → E + V)
- V = E
  - reduce (V = E)
- A
  - accept

(handles are underlined)



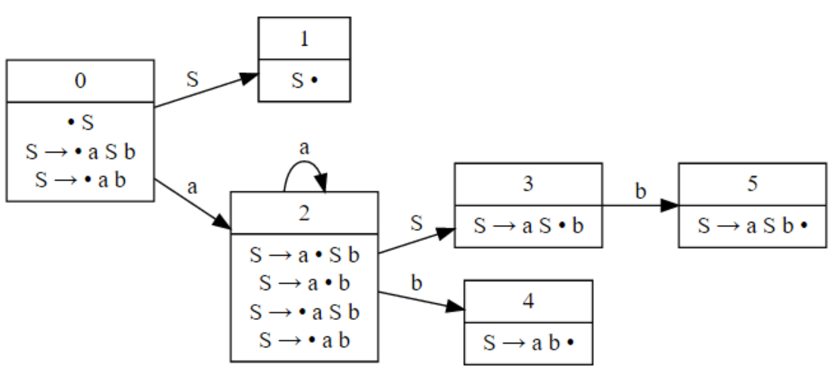
$$
\begin{aligned}
A &\rightarrow V = E \\
E &\rightarrow E + V \\
&\mid V \\
V &\rightarrow a \mid b \mid c
\end{aligned}
$$

LR Parsing

- Creating an LR parser
  - Build item sets ("canonical collections")
    - An item uses a dot (•) to represent parser status: "A → a • S b"
      - Dots on the left end: "possibilities"
      - Dots in the middle: "partially-complete"
      - Dots on the right end: "complete"
    - Item sets represent closures of parser states
    - Similar to NFA state collections in subset construction
  - Build **ACTION** / **GOTO** tables
    - Encodes handle reduction decisions
    - **ACTION**(state, terminal) = { *shift*, *reduce*, *accept* }
    - **GOTO**(state, non-terminal) = state

LR Parsing

- Item sets ("canonical collections")
  - Grammar productions with a dot to indicate the current position
  - Form new sets by "moving the dot"
  - Take the closure to add more states if the dot lies to the left of a non-terminal
    - (Denoted here in green)
  - Can be converted to an automaton
    - Each set becomes a state
    - "Moving the dot" = transition between states



S → a S b
   | a b

CC_0: S' → • S
S → • a S b
S → • a b

CC_1: S' → S •

CC_2: S → a • S b
S → a • b
S → • a S b
S → • a b

CC_3: S → a S • b

CC_4: S → a b •

CC_5: S → a S b •

LR Parsing

- How much lookahead do we need?
  - Depends on how complicated the grammar is
  - LR(k) – multiple lookaheads (not necessary)
  - LR(1) – single lookahead (*our textbook covers this!*)
    - Very general and very powerful
    - Lots of item sets; tedious to construct by hand
  - LALR – special case of LR(1) that merges some states
    - Less powerful, but easier to manage
  - **SLR** – special case of LR(1) w/o explicit lookahead
    - Uses **FOLLOW** sets to disambiguate
    - Even less powerful, but much easier to understand
  - LR(0) – no lookahead
    - Severely restricted; most "interesting" grammars aren't LR(0)

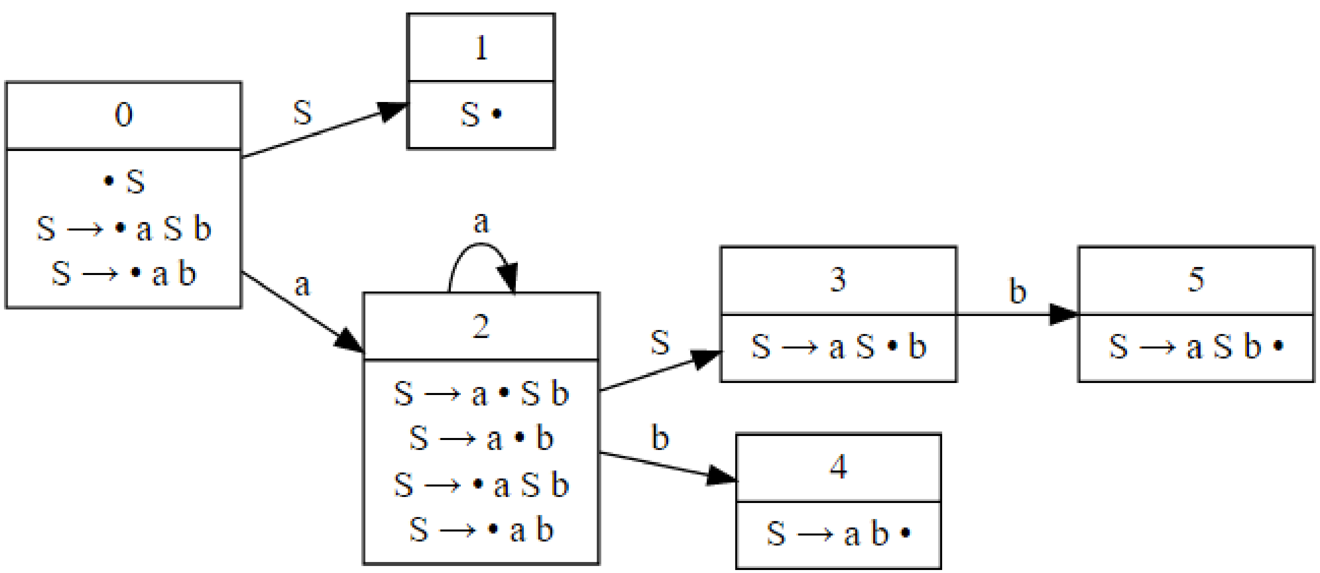
SLR Parsing

- *(Optional) Augment the grammar with S' → S*
- Construct LR(0) item sets and automaton
  - Keep track of transitions ("moving the dot")
- Create **ACTION** and **GOTO** tables
  - For each item set i
    - If an item matches **A → β • c γ**
      - **ACTION**(i, c) = "shift" to corresponding item set ("move the dot")
    - If an item matches **A → β •**
      - **ACTION**(i, x) = "reduce A → β" for all x in **FOLLOW**(A)
    - If an item matches **A → β • B γ**
      - **GOTO**(i, B) = corresponding item set ("move the dot")
  - **ACTION**(S', $) = "accept"

SLR parsing

$S \rightarrow a\ S\ b$
$\quad |\ a\ b$

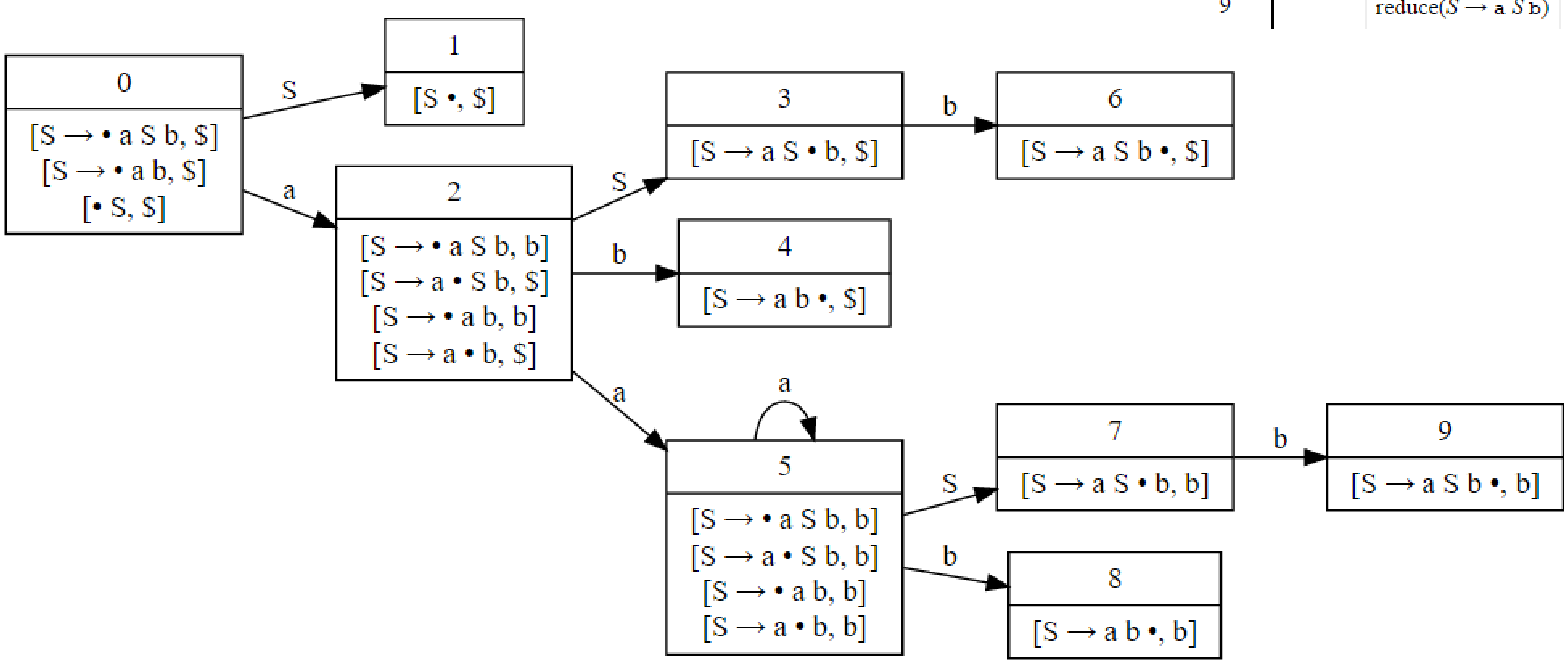
	ACTION			GOTO
State	a	b	$	*S*
0	shift(2)			1
1			accept	
2	shift(2)	shift(4)		3
3		shift(5)		
4		reduce($S \rightarrow$ a b)	reduce($S \rightarrow$ a b)	
5		reduce($S \rightarrow$ a S b)	reduce($S \rightarrow$ a S b)	



LR(1) parsing

S → a S b
  | a b

State	a	b	$	S
0	shift(2)			1
1			accept	
2	shift(5)	shift(4)		3
3		shift(6)		
4			reduce(S → a b)	
5	shift(5)	shift(8)		7
6			reduce(S → a S b)	
7		shift(9)		
8		reduce(S → a b)		
9		reduce(S → a S b)		



LR Conflicts

- Shift/reduce
  - Can be resolved by always shifting or by grammar modification
- Reduce/reduce
  - Requires grammar modification to fix

```
A -> V = E
E -> E + V
E -> V
V -> a | b | c
```

Shift/reduce conflict in LR(0)

```
A -> x A x
A ->
```

Shift/reduce conflict (all LR)

```
A -> B | C
B -> x
C -> x
```

Reduce/reduce conflict (all LR)

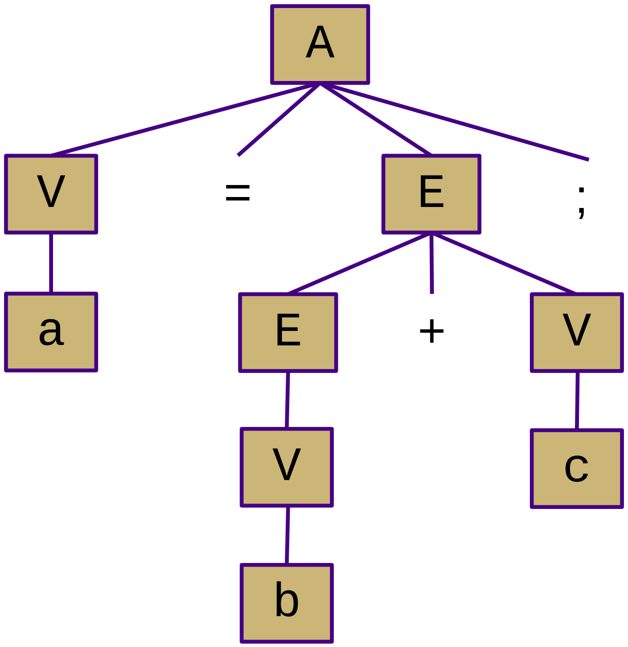
Observation: none of these languages are LL(1) either!

Aside: abstract syntax trees

Grammar:

A → V = E ;
E → E + V
  | V
V → a | b | c

Parse tree:



Abstract syntax tree: