CS 480
Fall 2015

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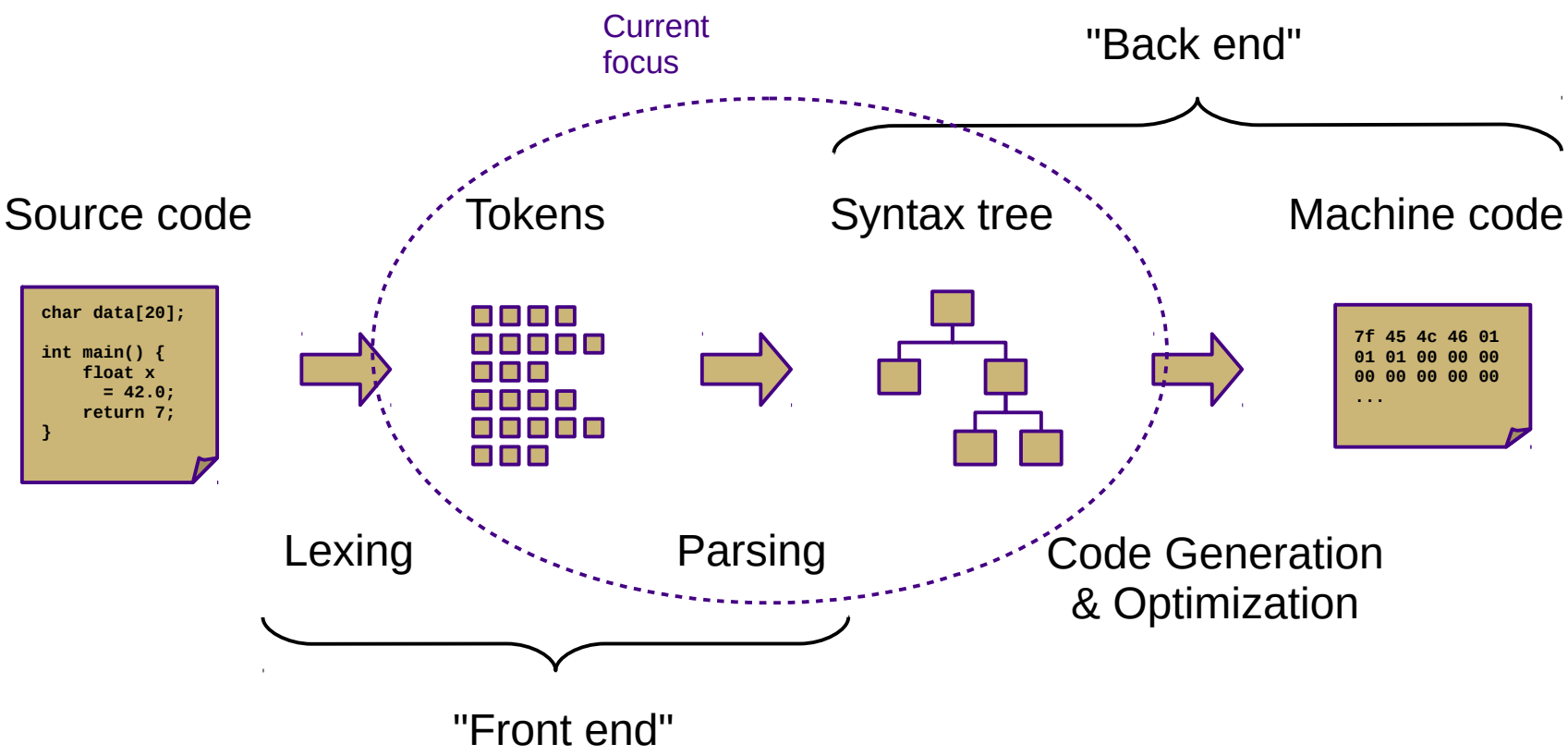
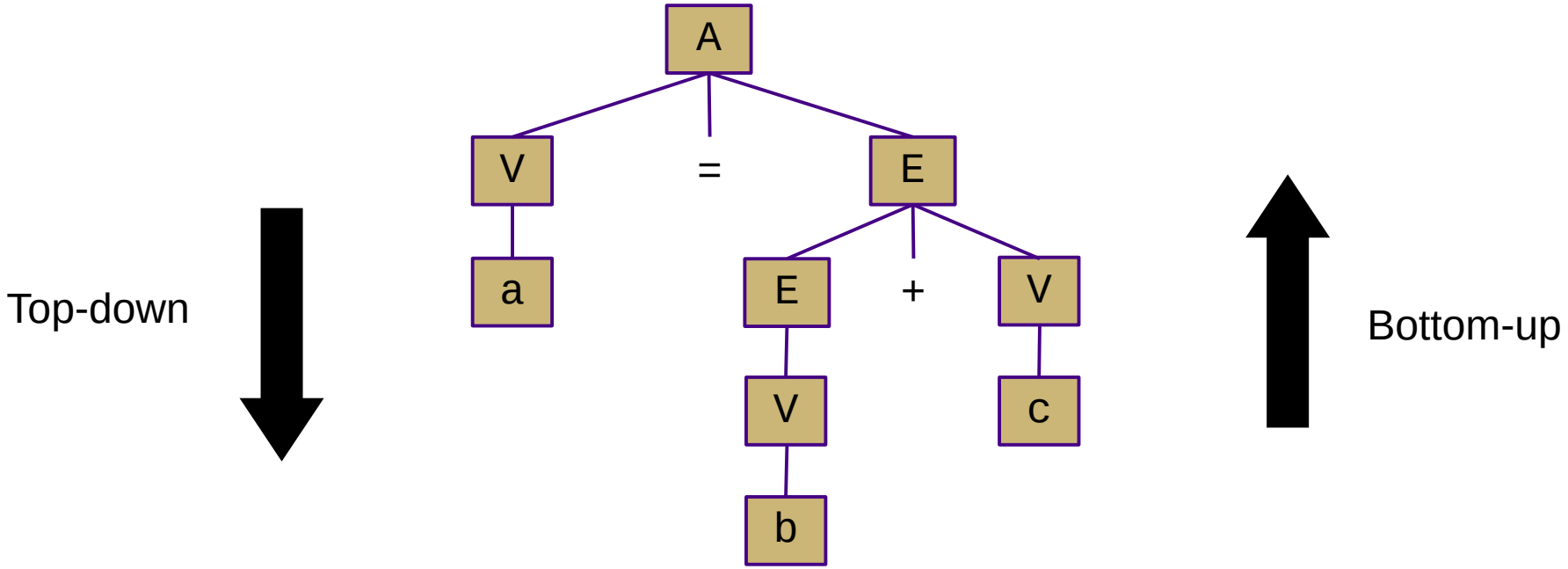
Bottom-Up (LR) Parsing

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

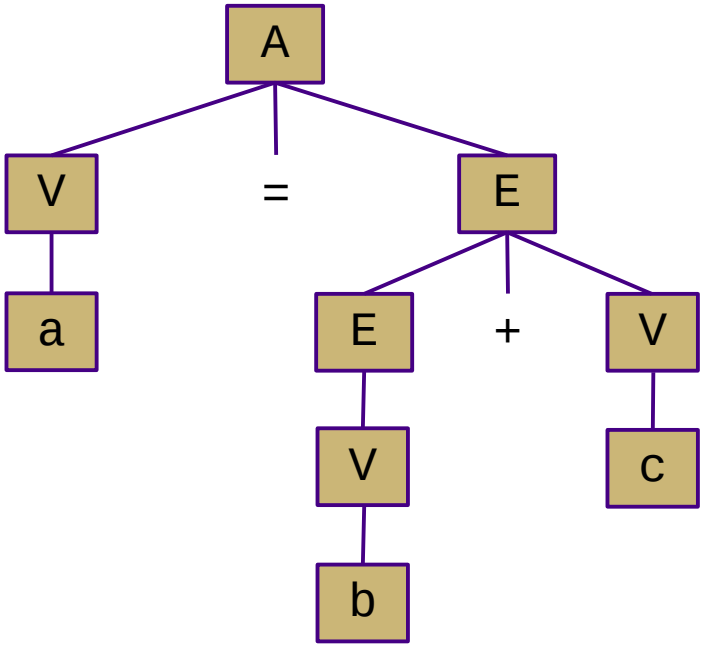


Shift-Reduce Parsing

- 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'
- <u>a</u>
  - reduce (V → a)
- V
  - shift '='
- V =
  - shift 'b'
- V = <u>b</u>
  - reduce (V → b)
- V = <u>V</u>
  - reduce (E → V)
- V = E
  - shift '+'
- V = E +
  - shift 'c'
- V = E + <u>c</u>
  - reduce (V → c)
- V = <u>E + V</u>
  - reduce (E → E + V)
- <u>V = E</u>
  - reduce (V = E)
-



A → V = E
E → E + V
| V
V → a | b | c

(handles are underlined)

LR Parsing

- Creating an LR parser
  - Build item sets ("canonical collections")
    - These represent closures of parser states
    - Use a dot (•) to represent status: "a • S b"
      - Dots on the left end: "possibilities"
      - Dots in the middle: "partially-complete"
      - Dots on the right end: "complete"
    - 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")
  - Productions from the grammar with a dot to indicate the current position
  - One for each position in each production
  - Take the closure and add more states if the dot lies to the left of a non-terminal
    - (Denoted here with "~")

```
S → a S b
  | a b
```

```
CC0:   S' → • S
    ~  S  → • a S b
    ~  S  → • a b

CC1:  S' → S •

CC2:  S  → a • S b
      S  → a • b
   ~  S  → • a S b
   ~  S  → • a b

CC3:  S  → a S • b

CC4:  S  → a S b •

CC5:  S  → a 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
    - 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)

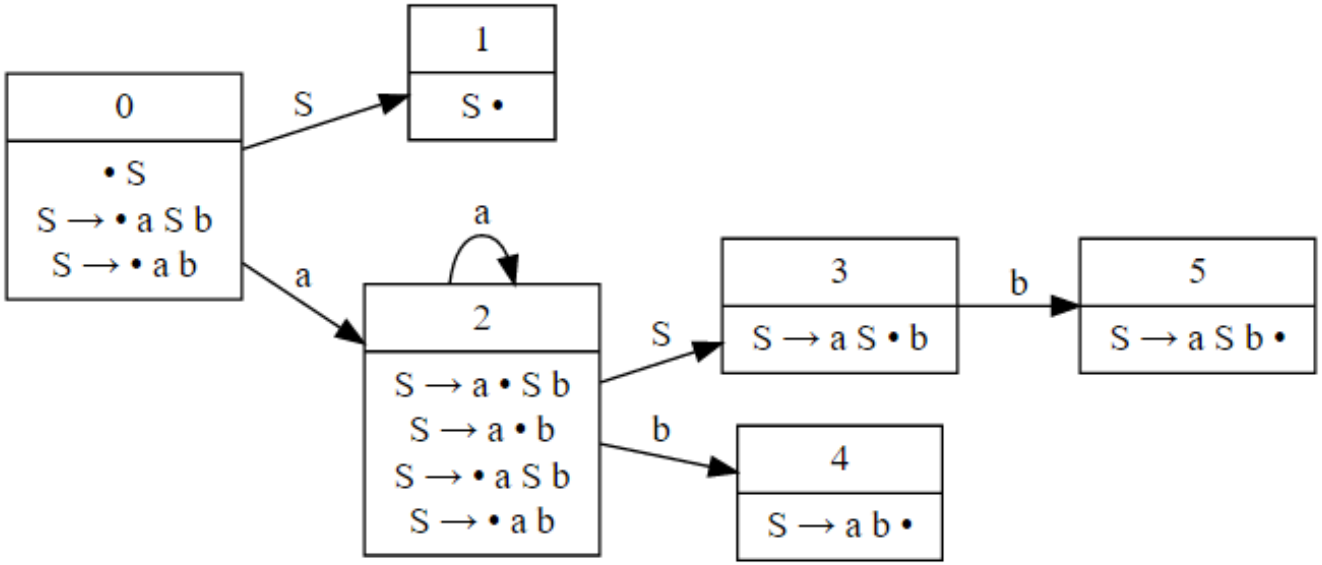
SLR Parsing

- *(Optional) Augment the grammar with* $S' \rightarrow s_0$
- 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 $\mathbf{A \rightarrow \beta \bullet c\ \gamma}$
      - **ACTION**(i, c) = "shift" to corresponding item set ("move the dot")
    - If an item matches $\mathbf{A \rightarrow \beta \bullet}$
      - **ACTION**(i, x) = "reduce $A \rightarrow \beta$" for all x in **FOLLOW**(A)
    - If an item matches $\mathbf{A \rightarrow \beta \bullet B\ \gamma}$
      - **GOTO**(i, B) = corresponding item set ("move the dot")
  - **ACTION**(S', $) = "accept"

SLR parsing

S → a S b
  | a b

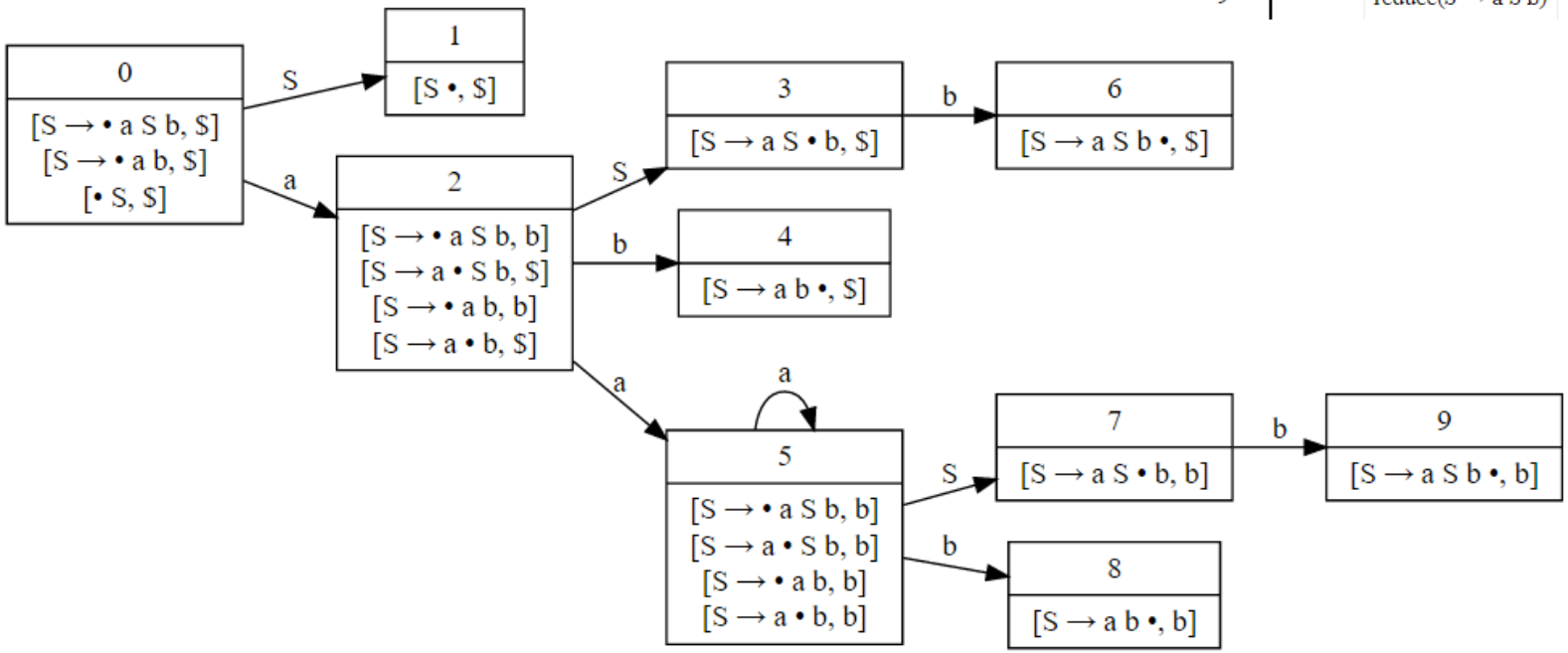
State	a	b	$	S
0	shift(2)			1
1			accept	
2	shift(2)	shift(4)		3
3		shift(5)		
4		reduce(S → a b)	reduce(S → a b)	
5		reduce(S → a S b)	reduce(S → a S b)	



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 -> B A x .
A -> .
B -> x .
```

Shift/reduce conflict (all LR)

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

Reduce/reduce conflict (all LR)