Bottom Up Parsing

Construct parse tree for input from leaves up
- reducing a string of tokens to single start symbol (inverse of deriving a string of tokens from start symbol)

"Shift-reduce" strategy:
- read ("shift") tokens until seen r.h.s. of "correct" production `xyzabcdef` A ::= **bc**.D
  ^
- reduce handle to l.h.s. nonterminal, then continue
- done when all input read and reduced to start nonterminal

LR(k)

- LR(k) parsing
  - **L**eft-to-right scan of input, **R**ightmost derivation
  - ***k*** tokens of look ahead
- Strictly more general than LL(*k*)
  - Gets to look at whole rhs of production before deciding what to do, not just first k tokens of rhs
  - can handle left recursion and common prefixes fine
  - Still as efficient as any top-down or bottom-up parsing method
- Complex to implement
  - need automatic tools to construct parser from grammar

LR Parsing Tables

Construct parsing tables implementing a FSA with a stack
- rows: states of parser
- columns: token(s) of lookahead
- entries: action of parser
  - shift, goto state `X`
  - reduce production "`X ::= RHS`"
  - accept
  - error

Algorithm to construct FSA similar to algorithm to build DFA from NFA
- each state represents set of possible places in parsing

LR(k) algorithm builds huge tables

LALR-Look Ahead LR

LALR(*k*) algorithm has fewer states ==> smaller tables
- less general than LR(*k*), but still good in practice
- size of tables acceptable in practice

- k == 1 in practice
  - most parser generators, including `yacc` and `jflex`, are LALR(1)

Global Plan for LR(0) Parsing

- Goal: Set up the tables for parsing an LR(0) grammar
  - Add S' --> S$ to the grammar, i.e. solve the problem for a new grammar with terminator
  - Compute parser states by starting with state 1 containing added production, S' --> .S$
  - Form closures of states and shifting to complete diagram
  - Convert diagram to transition table for PDA
  - Step through parse using table and stack

LR(0) Parser Generation

Example grammar:

```
S' ::= S $        // always add this production
S ::= beep | { L }
L ::= S | L ; S
```

- Key idea: simulate where input might be in grammar as it reads tokens
- "Where input might be in grammar" captured by set of items, which forms a state in the parser's FSA
  - LR(0) item: `lhs ::= rhs` production, with dot in rhs somewhere marking what's been read (shifted) so far
    - LR(k) item: also add *k* tokens of lookahead to each item
  - Initial item: `S' ::= . S $`

Closure

Initial state is **closure** of initial item

- closure: if dot before non-terminal, add all productions for that non-terminal with dot at the start
  - "epsilon transitions"

Initial state (1):

```
S'::= . S $
S ::= . beep
S ::= . { L }
```


State Transitions

Given set of items, compute new state(s) for each symbol (terminal and non-terminal) after dot
  - state transitions correspond to shift actions

New item derived from old item by shifting dot over symbol
  - do closure to compute new state Initial state (1):
    `S' ::= . S $ S ::= . beep S ::= .{ L }`
  - State (2) reached on transition that shifts `S`:
    `S' ::= S . $`
  - State (3) reached on transition that shifts **beep**:
    `S ::= beep .`
  - State (4) reached on transition that shifts **{**:

```
S ::= { . L }
L ::= . S
L ::= . L ; S
S ::= . beep
S ::= . { L }
```

Accepting Transitions

If state has `S' ::= ... . $` item,
then add transition labeled `$` to the accept action

Example:
`S' ::= S . $`
has transition labeled `$` to `accept` action

Reducing States

If state has *`lhs ::= rhs .`* item, then it has a `reduce` *`lhs ::= rhs`* action

Example:
`S ::=` **`beep`** `.`
has `reduce S ::=` **`beep`** action

No label; this state always reduces this production
- what if other items in this state shift, or accept?
- what if other items in this state reduce differently?

Rest of the States, Part 1

State (4): if shift **`beep`**, goto State (3)
State (4): if shift **`{`**, goto State (4)
State (4): if shift `S`, goto State (5)
State (4): if shift `L`, goto State (6)

State (5):
`L ::= S .`

State (6):
`S ::=` **`{`** `L .` **`}`**
`L ::= L . ; S`

State (6): if shift **`}`**, goto State (7)
State (6): if shift **`;`**, goto State (8)

Rest of the States (Part 2)

State (7):
`S ::=` **`{`** `L` **`}`** `.`

State (8):
`L ::= L ; . S`
`S ::= .` **`beep`**
`S ::= .` **`{`** `L` **`}`**

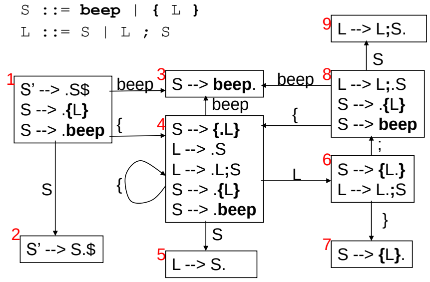
State (8): if shift **`beep`**, goto State (3)
State (8): if shift **`{`**, goto State (4)
State (8): if shift `S`, goto State (9)

State (9):
`L ::= L ; S .`

(whew)

LR(0) State Diagram

```
S'::= S $
S ::= beep | { L }
L ::= S | L ; S
```



Building Table of States & Transitions

Create a row for each state

Create a column for each terminal, non-terminal, and `$`

For every "state (*i*): if shift *X* goto state (*j*)" transition:

- if *X* is a terminal, put "shift, goto *j*" action in row *i*, column *X*
- if *X* is a non-terminal, put "goto *j*" action in row *i*, column *X*

For every "state (*i*): if `$` accept" transition:

- put "accept" action in row *i*, column `$`

For every "state (*i*): *`lhs ::= rhs.`*" action:

- put "`reduce lhs ::= rhs`" action in all columns of row *i*

Table of This Grammar

State	{	}	beep	;	S	L	$
1	s,g4		s,g3		g2		
2							a!
3	reduce S ::= beep						
4	s,g4		s,g3		g5	g6	
5	reduce L ::= S						
6		s,g7		s,g8			
7	reduce S ::= { L }						
8	s,g4		s,g3		g9		
9	reduce L ::= L ; S						

Example

```
S'::= S $
S ::= beep | { L }
L ::= S | L ; S
```

St	{	}	beep	;	S	L	$
1	s,g4		s,g3		g2		
2							a!
3	reduce S ::= beep						
4	s,g4		s,g3		g5	g6	
5	reduce L ::= S						
6		s,g7		s,g8			
7	reduce S ::= { L }						
8	s,g4		s,g3		g9		
9	reduce L ::= L ; S						

1	{ beep ; { beep } } $
1 { 4	beep ; { beep } } $
1 { 4 beep 3	; { beep } } $
1 { 4 S 5	; { beep } } $
1 { 4 L 6	; { beep } } $
1 { 4 L 6 ; 8	{ beep } } $
1 { 4 L 6 ; 8 { 4	beep } } $
1 { 4 L 6 ; 8 { 4 beep 3	} } $
1 { 4 L 6 ; 8 { 4 S 5	} } $
1 { 4 L 6 ; 8 { 4 L 6	} } $
1 { 4 L 6 ; 8 { 4 L 6 } 7	} $
1 { 4 L 6 ; 8 S 9	} $
1 { 4 L 6	} $
1 { 4 L 6 } 7	$
1 S 2	$
accept	

Problems In Shift-Reduce Parsing

Can write grammars that cannot be handled with shift-reduce parsing

Shift/reduce conflict:
- state has both shift action(s) and reduce actions

Reduce/reduce conflict:
- state has more than one reduce action

Shift/Reduce Conflicts

LR(0) example:

```
E ::= E + T | T
```

State: `E ::= E . + T`
`E ::= T .`

– Can shift `+`
– Can reduce `E ::= T`

LR(k) example:

```
S ::= if E then S |
      if E then S else S | ...
```

State: `S ::= if E then S .`
`S ::= if E then S . else S`

– Can shift `else`
– Can reduce `S ::= if E then S`

Avoiding Shift-Reduce Conflicts

Can rewrite grammar to remove conflict
– E.g. `Matched Stmt vs. Unmatched Stmt`

Can resolve in favor of shift action
– try to find longest r.h.s. before reducing
  works well in practice
  `yacc`, `jflex`, et al. do this

Reduce/Reduce Conflicts

Example:

```
Stmt ::= Type id ; | LHS = Expr ; | ...
...
LHS ::= id | LHS [ Expr ] | ...
...
Type ::= id | Type [] | ...
```

State: `Type ::= id .`
`LHS ::= id .`

Can reduce `Type ::= id`

Can reduce `LHS ::= id`

Avoid Reduce/Reduce Conflicts

- Can rewrite grammar to remove conflict
  - can be hard
    - e.g. C/C++ declaration vs. expression problem
    - e.g. MiniJava array declaration vs. array store problem
- Can resolve in favor of one of the reduce actions
  - but which?
  - `yacc`, `jflex`, et al. Pick reduce action for production listed textually first in specification

From CSE401 Wi08 48