LING/C SC 581:

Advanced Computational Linguistics

Lecture 13

Administrivia

- I'll be away next week (and the following week)
- Week after next is Spring Break anyway
- Lecture 14 will be pre-recorded and posted on the course website
- There will be a homework for Lecture 14 (*easy*)

Today's Topics

- Homework 6
- Context-Free Parsing:
  - Dotted rules
  - the Shift Reduce Parsing Algorithm

Homework 6

- Rewrite nl5.prolog below into a file nl5.txt (for nltk's grammar formalism)
  - implement NUM agreement using the nonterminal name (*see Lecture 7*)
  - ignore the parse tree representation (Prolog term)
  - don't worry about the left recursive rules
- nl5.prolog:

```
s(s(NP, VP)) --> np(NP), vp(VP).
np(np(DET, NN)) --> det(DET, NUM), nn(NN, NUM).
np(np(NNP)) --> nnp(NNP).
np(np(NP,PP)) --> np(NP), pp(PP).
pp(pp(IN,NP)) --> in(IN), np(NP).
det(dt(the), sg) --> [the].
det(dt(the), pl) --> [the].
det(dt(a), sg) --> [a].
nn(nn(man), sg) --> [man].
nn(nn(boy), sg) --> [boy].
nn(nn(telescope), sg) --> [telescope].
nn(nn(limp), sg) --> [limp].
nn(nn(men), pl) --> [men].
nn(nn(ball), sg) --> [ball].
vp(vp(VTR, NP)) --> vtr(VTR), np(NP).
vp(vp(VP,PP)) --> vp(VP), pp(PP).
vtr(vbd(kick_ed)) --> [kicked].
vtr(vbd(hit_ed)) --> [hit].
vtr(vbd(see_ed)) --> [saw].
in(in(with)) --> [with].
nnp(nnp(john)) --> [john].
nnp(nnp(mary)) --> [mary].
```

Homework 6

- Documentation:
- `string = open("nl5.txt").read()`

https://www.nltk.org/howto/grammar.html

https://www.nltk.org/api/nltk.grammar.html

```
>>> grammar = CFG.fromstring("""
... S -> A B
... A -> 'a'
... # An empty string:
... B -> 'b' | ''
... """)
```

```
>>> from nltk import CFG
>>> grammar = CFG.fromstring("""
... S -> NP VP
... PP -> P NP
... NP -> Det N | NP PP
... VP -> V NP | VP PP
... Det -> 'a' | 'the'
... N -> 'dog' | 'cat'
... V -> 'chased' | 'sat'
... P -> 'on' | 'in'
... """)
```

Homework 6

- Test your grammar on the following examples (*making sure you get all parses*) with the nltk chart parser:
  1. the boy kicked a ball
  2. *a men kicked a ball
  3. a man kicked the ball
  4. John saw a man with a telescope
  5. a man saw the boy with a ball with a telescope
  - * = ungrammatical

Homework 6

- Submit to sandiway@arizona.edu
- SUBJECT: 581 Homework 6 *YOUR NAME*
- One PDF file (for grading)
  - include your grammar code and nltk screenshots in your answer
- Attach (if I need to run your code):
  - source code for your grammar
- Deadline:
  - midnight Monday
  - we will review the homework next lecture (**recorded**)

Dotted Rules

Dot (●) indicates where we are in a grammar rule

- Examples:
  - `S -> ● NP VP        [the, man, saw, the, dog]`
  - `S -> NP ● VP        [saw, the, dog]`
  - `S -> NP VP ●        []`

  - `VP -> ● V NP        [saw, the, dog]`
  - `VP -> V ● NP        [the, dog]`
  - `VP -> V NP ●        []`

  - `NP -> ● DT NN       [the, man, saw, the, dog]`
  - `NP -> DT ● NN       [man, saw, the, dog]`
  - `NP -> DT NN ●       [saw, the, dog]`

Bottom-Up Parsing

- *We've already seen the CKY algorithm*
- ***LR(0) parsing***
  - An example of **bottom-up** tabular parsing
  - 0 = zero symbols of lookahead, generally *N* (*a bit like the left corner idea*)
  - Similar to the **top-down Earley algorithm** described in the textbook in that it uses the idea of dotted rules
  - *finite state automata revisited…*

Tabular Parsing

- **e.g. LR(*k*)** (Knuth, 1960)
  - *invented for efficient parsing of programming languages*
  - **disadvantage**: a potentially huge number of states can be generated when the number of rules in the grammar is large
  - *can be applied to natural languages* (Tomita 1985)
  - build a Finite State Automaton (FSA) from the grammar rules, then add a stack
- **tables encode the grammar (FSA)**
  - grammar rules are compiled, we no longer interpret the grammar rules directly
- **Parser = Table + Push-down Stack**
  - table entries contain instruction(s) that tell what to do at a given state

    … *possibly factoring in lookahead*
  - stack data structure deals with maintaining the history of computation and recursion

Tabular Parsing

- **Shift-Reduce Parsing**
  - an example is **LR(0)**
    - left to right = LR
    - **bottom-up**
    - (0) no lookahead (*input word*)
  - **Three possible machine actions**
    - ***Shift***: read an input word
      - i.e. advance current input word pointer to the next word
    - ***Reduce***: complete a nonterminal
      - i.e. complete parsing a grammar rule
    - ***Accept***: complete the parse
      - i.e. start symbol (e.g. S) derives the terminal string

Tabular Parsing

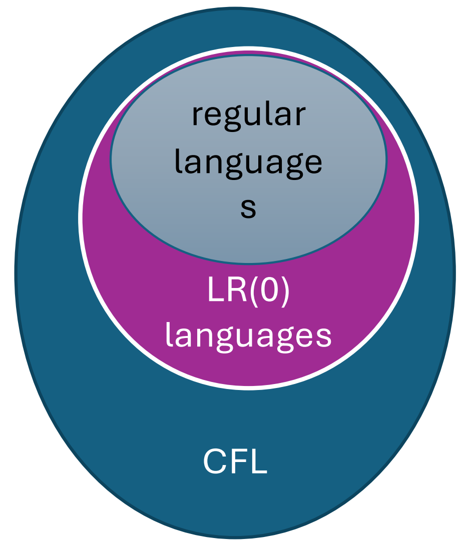
- **LR(0) Parsing**
  - L(G) = LR(0)
    - *i.e. the language generated by grammar G is LR(0)*

      if there is a unique instruction per state

      (or no instruction = error state)

      LR(0) is a proper subset of context-free languages (CFL)

      deterministic!
  - **note**
    - human language tends to be ambiguous
    - there are likely to be multiple or conflicting actions per state
    - *if we are using Prolog, we can let Prolog's computation rule handle it*
      - *via Prolog backtracking*



Tabular Parsing

- **Dotted rule notation**
  - "dot" *used to track the progress of a parse through a phrase structure rule*
- **Examples:**
  - `vp --> vbd . np`

    means we've seen *v* and predict *np*
  - `np --> . dt nn`

    means we're predicting a *dt* (followed by *nn*)
  - `vp --> vp pp.`

    means we've completed a *vp* (with *pp* modification)

- **state**
  - a set of dotted rules encodes the state of the parse
  - *set of dotted rules = name of the state*
- **kernel**
  - `vp --> vbd . np`
  - `vp --> vbd .`
- **completion** (of predict NP)
  - `np --> . dt nn`
  - `np --> . nnp`
  - `np --> . np cp`

Tabular Parsing

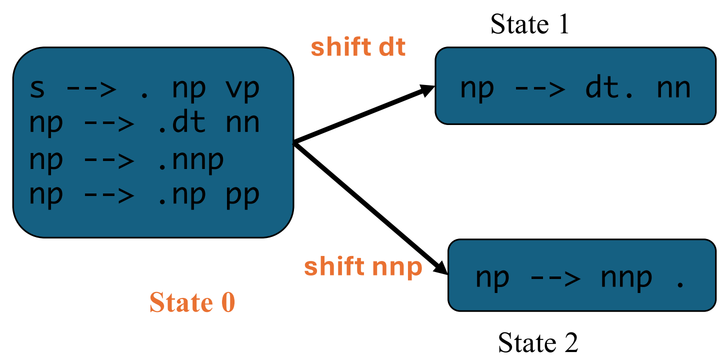
compute all possible states through advancing the dot

- **Example**:
- (Assume *dt is* next in the input)
  - `vp --> vbd . np`
  - `vp --> vbd .          (eliminated)`
  - `np --> dt . nn`
  - `np --> . nnp   (eliminated)`
  - `np --> . np cp`

Tabular Parsing

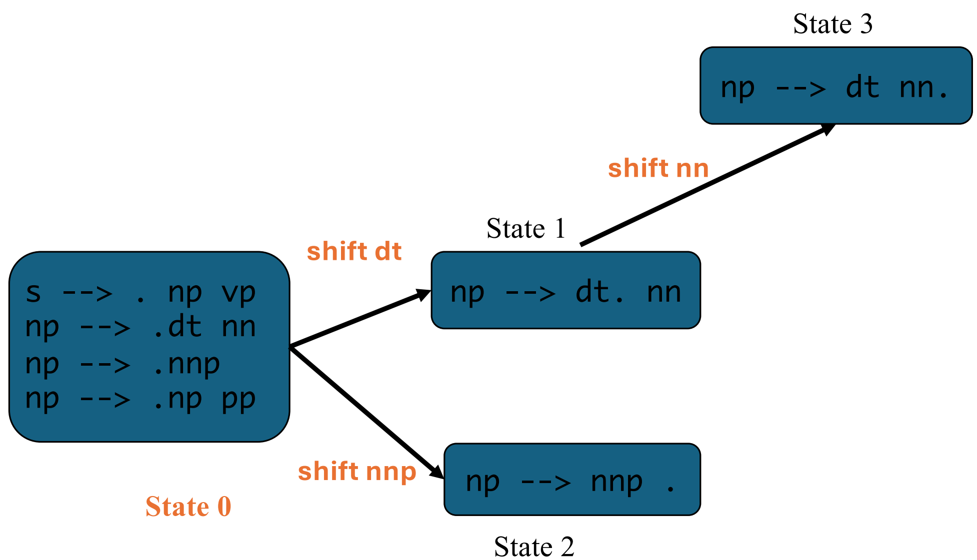
- **Dotted rules**
- **Example:**
  - **State 0**:
  - `s   --> .np vp`
  - `np --> .dt nn`
  - `np --> .nnp`
  - `np --> .np pp`
  - **possible actions**
    - **shift** *dt* and go to new state
    - **shift** *nnp* and go to new state

- Creating new states



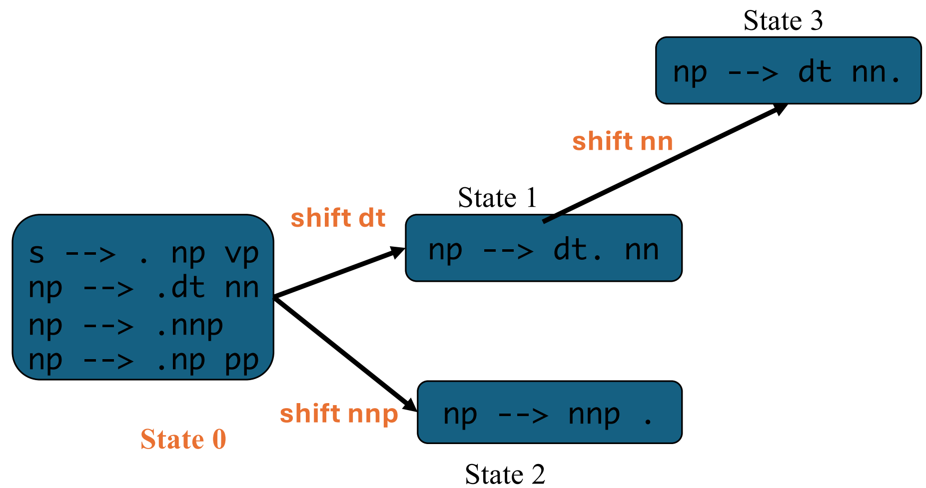
Tabular Parsing

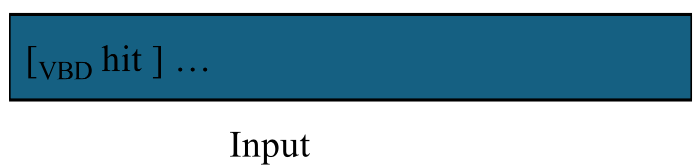
- **State 1: Shift *nn*, goto State 3**

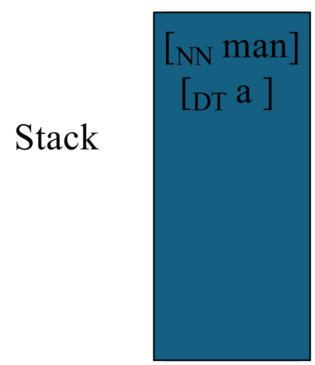


Tabular Parsing

- **Shift**
  - take input word, and
  - put it on the stack





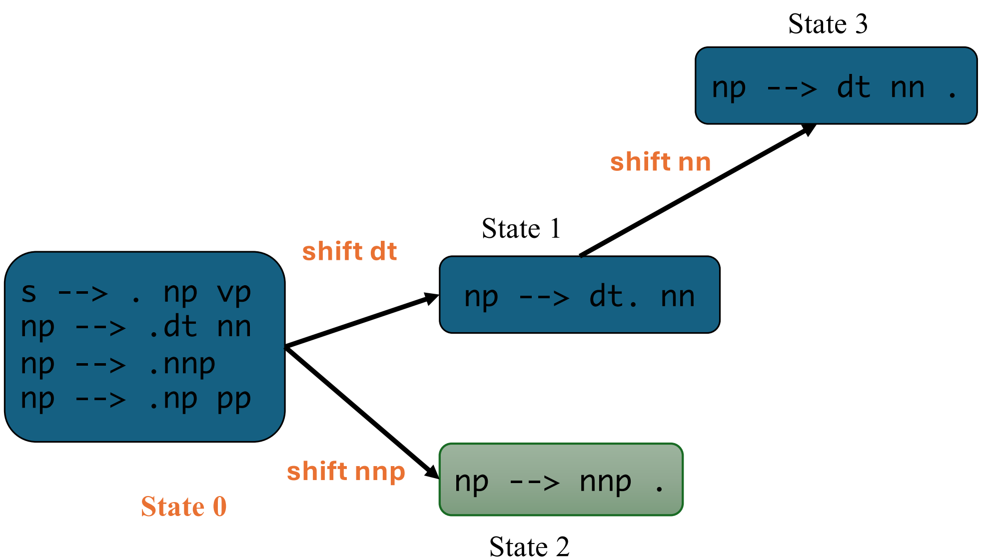


- **state 3**

(Powerpoint animation)

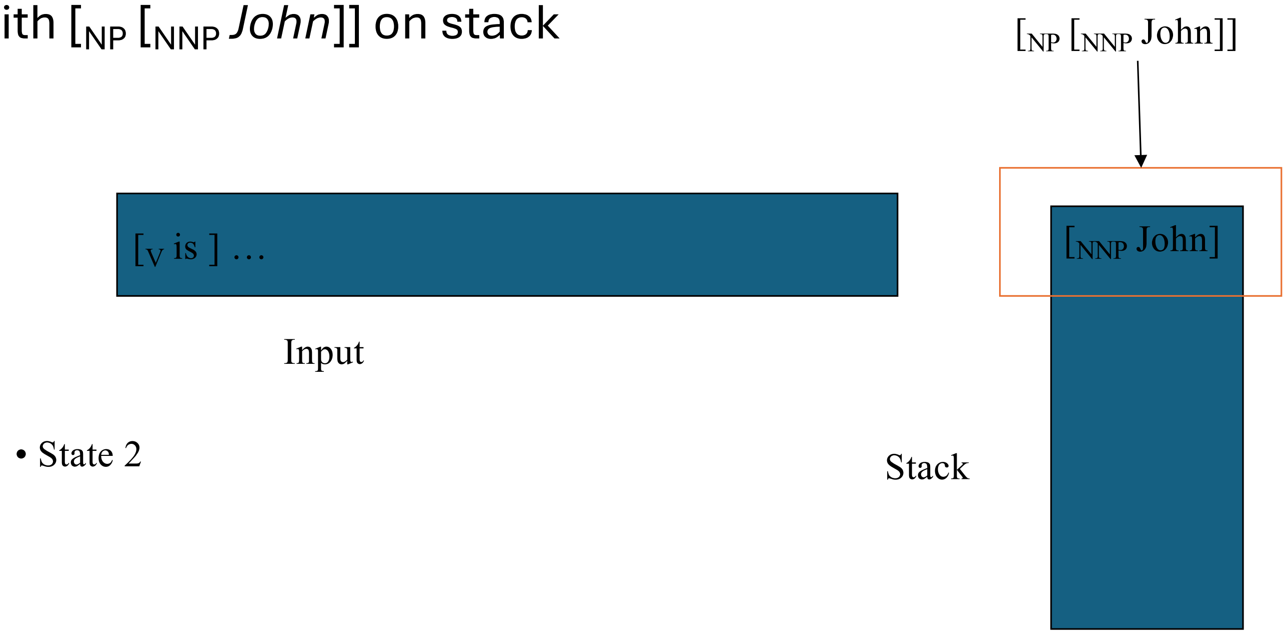
Tabular Parsing

- **State 2**: Reduce action np --> nnp .



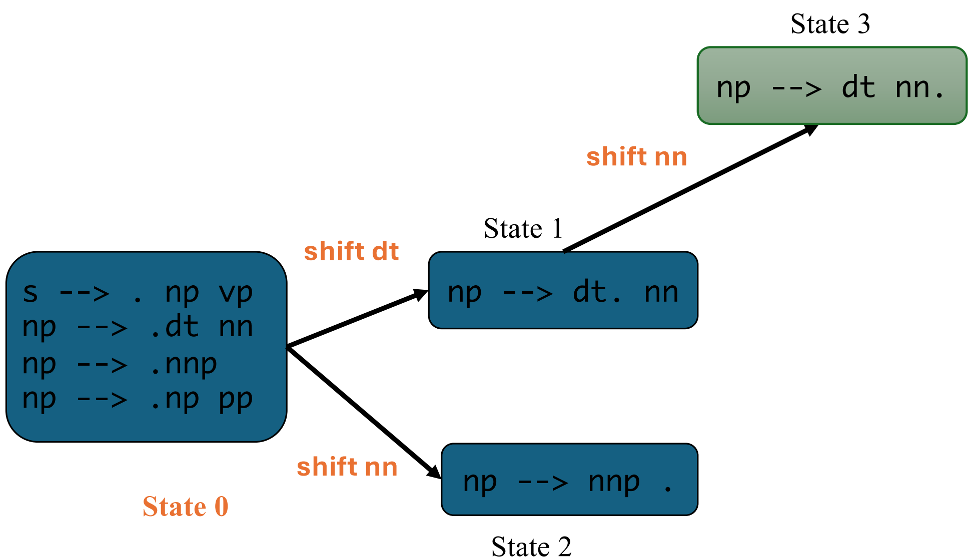
Tabular Parsing

- **Reduce** NP -> NNP .
  - pop [$_{NNP}$ *John*] off the stack, and
  - replace with [$_{NP}$ [$_{NNP}$ *John*]] on stack



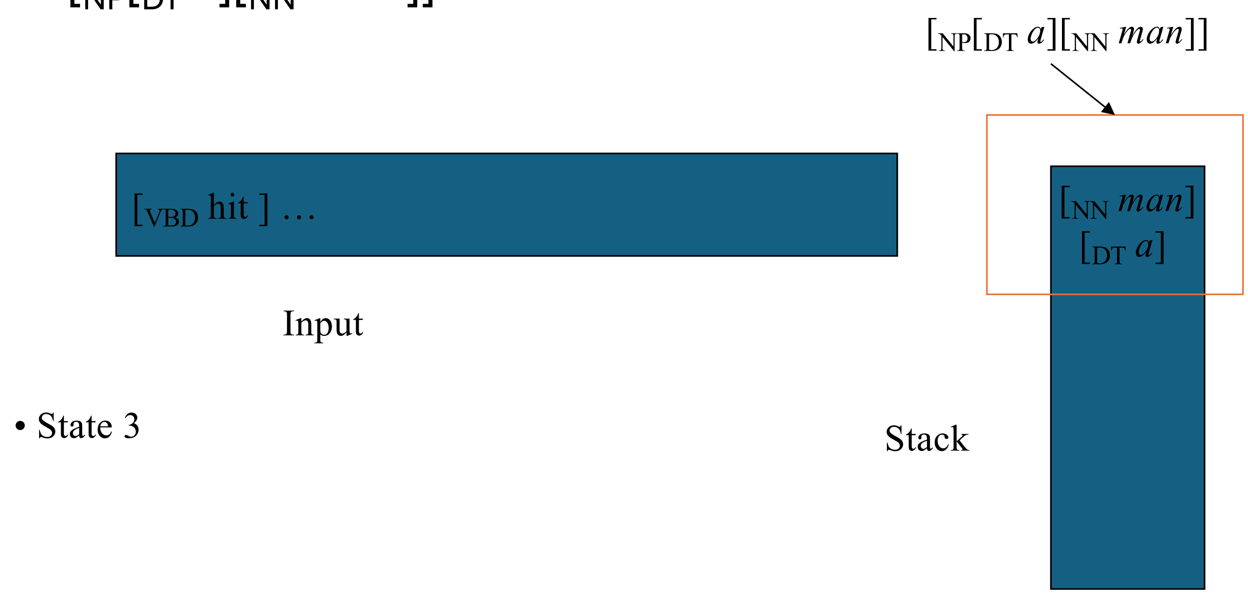
Tabular Parsing

- **State 3:** Reduce np --> dt nn.



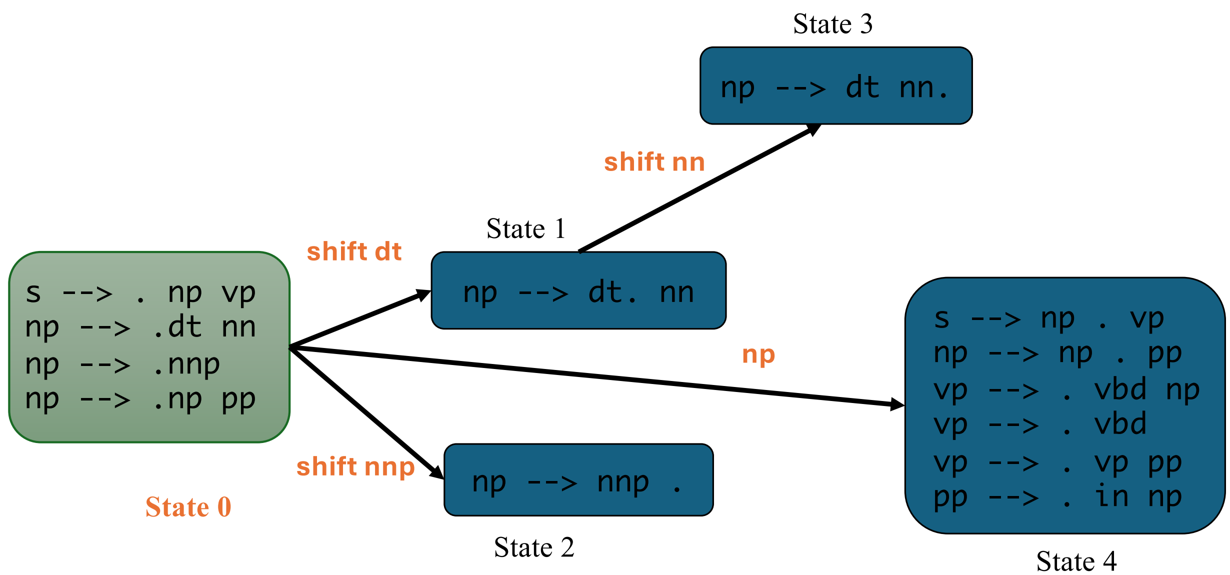
Tabular Parsing

- **Reduce** NP -> DT NN .
  - pop [$_{NN}$ *man*] and [$_{DT}$ *a*] off the stack
  - replace with [$_{NP}$[$_{DT}$ *a*][$_{NN}$ *man*]]



Tabular Parsing

- **State 0:** Transition NP



Tabular Parsing

- **for both states 2 and 3**
  - NP -> NNP .   (reduce NP -> NNP)
  - NP -> DT NN .   (reduce NP -> DT NN)
- **after Reduce NP operation**
  - **goto** state 4

- **notes**:
  - states are unique
  - grammar is finite
  - procedure generating states must terminate since the number of possible dotted rules is finite
  - no left recursion problem (*bottom-up means input driven*)

Tabular Parsing

- It's a table! (= **FSA**)

State	Action	Goto
0	Shift DT Shift NNP	1 2
1	Shift NN	3
2	Reduce NP --> NNP	4
3	Reduce NP --> DT NN	4
4	…	…

Tabular Parsing

- **Observations**
  1. ***table is sparse***
     - **Example:**
       - State 0, Input: [$_{VBD}$ ..]
       - parse fails immediately
  2. ***in a given state, input may be irrelevant***
     - **Example:**
       - State 2 (there is no shift operation)
  3. ***there may be action conflicts***
     - **Example:**
       - State 0: shift DT, shift NNP (*only if word is ambiguous*…)
     - **more interesting cases**
       - shift-reduce and reduce-reduce conflicts

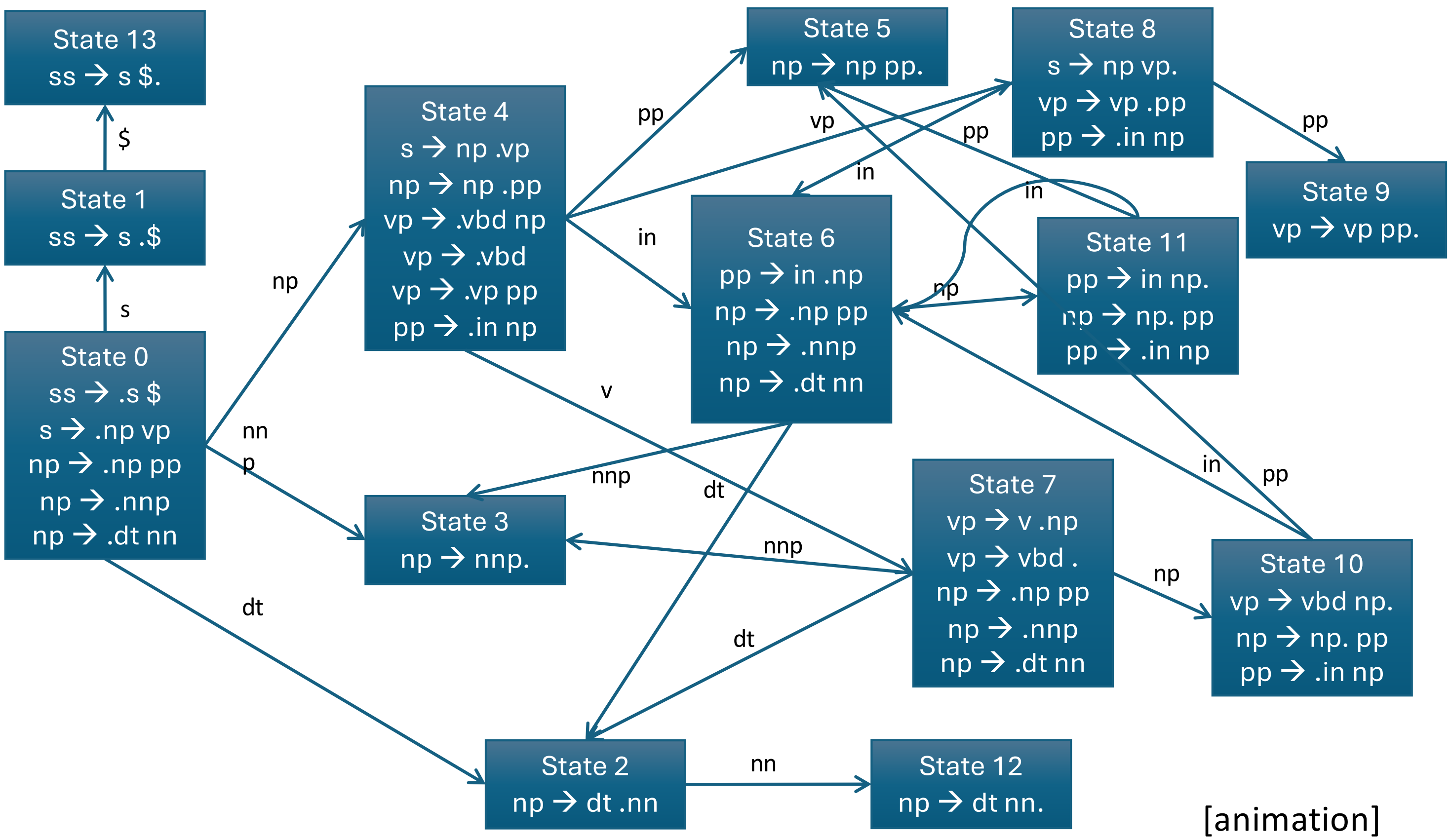
Tabular Parsing

- **finishing up**
  - an extra initial rule is usually added to the grammar
  - `SS --> S . $`
    - `SS` = start symbol
    - `$` = end of sentence marker
  - **input:**
    - *milk is good for you $*
  - **accept action**
    - discard $ from input
    - return element at the top of stack as the parse tree

LR Parsing in Prolog

- **Recap**
  - **finite state machine technology + a stack**
    - *each state represents a set of dotted rules*
    - **Example:**
      - `s --> . np vp`
      - `np --> .dt nn`
      - `np --> .nnp`
      - `np --> .np pp`
    - we transition, i.e. move, from state to state by advancing the “dot” over the possible terminal and nonterminal symbols

LR State Machine



[animation]

Build Actions

- **two main actions**
  - ***Shift***
    - move a word from the input onto the stack
    - Example:
      - *read a word with POS tag d*
      - `np --> .dt nn`
  - ***Reduce***
    - build a new constituent
    - Example:
      - *build a new NP*
      - `np --> dt nn.`

Lookahead

- **LR(1)**
  - a shift/reduce tabular parser
  - *using one (terminal) lookahead symbol*
  - *(like the left corner idea)*
- **decide on whether to take a reduce action depending on**
  - *state* x *next input symbol*
    - **Example**
      - *select the valid reduce operation consulting the next word*
      - cf. LR(0): *select an action based on just the current state*

Lookahead

- **potential advantage**
  - the input symbol may partition the action space
  - resulting in fewer conflicts
    - *provided the current input symbol can help to choose between possible actions*
- **potential disadvantages**
  1. larger finite state machine
     - more possible dotted rule/lookahead combinations than just dotted rule combinations
  2. might not help much
     - depends on the grammar
  3. more complex (off-line) computation
     - building the LR machine gets more complicated

Lookahead

- **formally**
  - `X --> α.Yβ, L`
    - `L` = lookahead set
    - `L` = set of possible terminals that can follow `X`
    - α,β (possibly empty) strings of terminal/non-terminals
- **Example:**
  - *State 0*
    - `ss-->.s $        [[]]`
    - `s-->.np vp       [$]`
    - `np-->.dt nn      [in, vbd]`
    - `np-->.nnp        [in, vbd]`
    - `np-->.np pp      [in, vbd]`

Lookahead

- **Central Idea**
    - *for propagating lookahead in state machine*
  - if dotted rule is complete,
  - **lookahead** informs parser about what the next terminal symbol should be

- **Example:**
  - `NP --> Dt NN. , L`
  - *reduce by NP rule only if current input symbol is in lookahead set* `L`

LR Parsing

- **In fact**
  - LR-parsers are generally acknowledged to be the fastest parsers
    - *especially when combined with the **chart technique** (table: dynamic programming)*
  - **reference**
    - (Tomita, 1985)
  - **textbook**
    - **Earley's algorithm**
    - uses chart
    - but follows the dotted-rule configurations **dynamically at parse-time**
    - instead of ahead of time (*so slower than LR*)