Chart parsing with non-atomic categories

L545

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(With thanks to Detmar Meurers)

Altering a chart parser to handle unification

By utilizing unification as we parse, we can eliminate parses that don't work in the end

- e.g., eliminate NPs that don't match in agreement features with their VPs as we parse, instead of as a filter

Changes to the chart representation

Each state will be extended to include the LHS feature structure (FS), which can get augmented as it goes along

- i.e., Add a feature structure (in DAG form) to each state
  - So, S $\rightarrow$ • NP VP, [0,0]
  - Becomes S $\rightarrow$ • NP VP, [0,0], FS_S

The predictor, scanner, and completer have to pass the FS, so all three operations have to be altered

Earley parser with atomic categories

Prediction:

for each ${}_i[A \;\rightarrow\; \alpha \;\bullet_j\; B\,\beta]$ in chart
for each $B \rightarrow \gamma$ in rules
add ${}_j[B \;\rightarrow\; \bullet_j\; \gamma]$ to chart

Scanning:

let $w_1 \ldots w_j \ldots w_n$ be the input string
for each ${}_i[A \;\rightarrow\; \alpha \;\bullet_{j-1}\; w_j\,\beta]$ in chart
add ${}_i[A \;\rightarrow\; \alpha\; w_j \;\bullet_j\; \beta]$ to chart

Completion (fundamental rule of chart parsing):

for each ${}_i[A \;\rightarrow\; \alpha \;\bullet_k\; B\,\beta]$ and ${}_k[B \;\rightarrow\; \gamma \;\bullet_j\;]$ in chart
add ${}_i[A \;\rightarrow\; \alpha\; B \;\bullet_j\; \beta]$ to chart

Earley parser with unification

Prediction:

for each $_i[A \rightarrow \alpha \bullet_j B\, \beta]$ in chart
for each $B' \rightarrow \gamma$ in rules
add $_j[\sigma(B \rightarrow \bullet_j \gamma)]$ with $\sigma = \mathrm{mgu}(B, B')$ to chart

Completion (fundamental rule of chart parsing):

for each $_i[A \rightarrow \alpha \bullet_k B\, \beta]$ and $_k[B' \rightarrow \gamma \bullet_j]$ in chart
add $_i[\sigma(A \rightarrow \alpha\, B \bullet_j \beta)]$ with $\sigma = \mathrm{mgu}(B, B')$ to chart

Prediction

Prediction:

for each $_i[A \rightarrow \alpha \bullet_j B\, \beta]$ in chart
for each $B' \rightarrow \gamma$ in rules
add $_j[\sigma(B \rightarrow \bullet_j \gamma)]$ with σ = mgu(B, B') to chart

The predictor takes the specification of B (i.e., FS) and finds the **most general unifier (mgu)** of B with B'

- If B & B' do not unify, the rule for B' is not added to the chart
- Initially (i.e., at position 0), all that happens is that a dotted rule with a FS is added to the chart

Completion

Completion (fundamental rule of chart parsing):

for each ${}_i[A \rightarrow \alpha \bullet_k B\, \beta]$ and ${}_k[B' \rightarrow \gamma \bullet_j]$ in chart
add ${}_i[\sigma(A \rightarrow \alpha\, B \bullet_j \beta)]$ with $\sigma = \mathrm{mgu}(B, B')$ to chart

Again, a step of unification is added.

- B and B' must unify in order for the dot to move
- The resulting (more specific) FS is added to the chart

How to use a chart with feature structures

- Use **unification** to combine categories in completion or prediction
- Each time a rule or edge is used, a new **copy** is made
- But how about testing whether an entry already exists in the chart?
  - Currently, we simply check to see whether a state *unifies* with something already in the chart and do not add a new state if it is already there
  - But a more specific or a more general state may already be in the chart

The subsumption problem (based on Covington 1994)

- S → NP VP
- NP → Det N
- VP → V'(0)
- VP → V'(X) Comps(X)
- V'(X) → V(X)
- V'(X) → Adv V(X)
- Comps(1) → NP
- Comps(2) → NP NP

- Det → the
- N → dog
- N → cat
- Adv → often
- V(0) → sings
- V(1) → chases
- V(2) → gives

The subsumption problem (2)

What happens when we try to parse *the dog chases the cat*?

- At position 2 (between *dog* and *chases*), from 2 to 2, the parser predicts:
  - VP $\rightarrow \bullet$ V'(0)
  - V'(0) $\rightarrow \bullet$ V(0)
  - V'(0) $\rightarrow \bullet$ Adv V(0)
  - VP $\rightarrow \bullet$ V'(X) Comps(X)
- What happens when we scan *chases*?
  - We have a passive V(1) edge
  - But there is no predicted $V'(1)$ edge—only $V'(0)$

Using subsumption to check the chart

Subsumption check: Do not add a state to the chart if an equivalent or more general state is already there.

- In trying to add a singular determiner state at [x, y], if the chart already has a determiner state at [x, y] unspecified for number, do not add it
- Without a subsumption restriction, we could add two states at [x, y], one expecting to see a singular determiner, the other just a determiner.
  - On seeing a singular determiner, the parser advances the dot on both rules, creating two edges (since singular unifies with singular and with unspecified).
  - As a result, we would get duplicate edges.
- With subsumption, if either a singular or plural determiner is encountered, we advance the dot, creating only one edge (singular or plural) at [x, y]

Checking for subsumption

Case 1

Let's define a function `subsumes_chk` which takes 2 arguments: more general item & more specific item

No variables:

- `subsumes_chk(V'(1),V'(1)).` → yes
- `subsumes_chk(V'(1),V'(2)).` → no

Compound terms without variables are either identical or different, i.e., here: subsumption = unification

Checking for subsumption

Case 2

Variables only in more general term:

- `subsumes_chk(V'(X),V'(1)).` → yes
- `subsumes_chk(foo(X,X),foo(1,1)).` → yes
- `subsumes_chk(foo(X,X),foo(1,2)).` → no

Succeeds if a consistent variable assignment exists, i.e., here: subsumption = unification

Checking for subsumption

Case 3

Variables in both terms:

- `subsumes_chk(vbar(X),vbar(Y)).` → yes
- `subsumes_chk(vbar(X),vbar(foo(1,Y))).` → yes
- `subsumes_chk(vbar(foo(1,2)),vbar(foo(1,Y))).` → no

- Succeeds if terms can be unified without further instantiating more specific term; in other words:
  - Unification should not require a particular instantiation of a variable in the more specific term.
- Idea: Identify each variable in more specific term with a unique, variable-free term; then subsumption = unification.

The restriction problem

Shieber et al 1995: Grammar accepting ab^n with N being instantiated to the successor representation of n.

$$\begin{aligned}
&\textbf{start} \rightarrow \textbf{r}(0, N)\\
&\textbf{r}(X, N) \rightarrow \textbf{r}(s(X), N)\ \textbf{b}\\
&\textbf{r}(N, N) \rightarrow \textbf{a}
\end{aligned}$$

Prediction step with unification will loop:

1		${}_0[\textbf{start} \rightarrow\ \bullet_0\ \textbf{r}(0, N)]$
2	`pred` $\textbf{r}(0, N)$ `in 1`	${}_0[\textbf{r}(0, N) \rightarrow\ \bullet_0\ \textbf{r}(s(0), N)\ \textbf{b}]$
3	`pred` $\textbf{r}(s(0), N)$ `in 2`	${}_0[\textbf{r}(s(0), N) \rightarrow\ \bullet_0\ \textbf{r}(s(s(0)), N)\ \textbf{b}]$
4	`pred` $\textbf{r}(s(s(0)), N)$ `in 3`	${}_0[\textbf{r}(s(s(0)), N) \rightarrow\ \bullet_0\ \textbf{r}(s(s(s(0))), N)\ \textbf{b}$
5	`pred` $\textbf{r}(s(s(s(0))), N)$ `in 3`	${}_0[\textbf{r}(s(s(s(0))), N) \rightarrow\ \bullet_0\ \textbf{r}(s(s(s(s(0))))$
$\vdots$		

Using restriction to prevent prediction loops

- Prediction terminates for grammars with atomic categories, since a new item is only added to the chart if not already there and there is a finite number of atomic categories.
- Moving beyond atomic categories, there can be an infinite number of non-atomic categories.
- Prediction loop on left-recursive rules can be problem again.
- Solution: restrict number of predicted categories to finitely many cases

Prediction with restriction

for each $_i[A \rightarrow \alpha \bullet_j B\ \beta]$ in chart
  for each $B' \rightarrow \gamma$ in rules
    add $_j[\sigma(B \rightarrow \bullet_j \gamma)]$ with $\sigma = \mathit{restriction}(\mathit{mgu}(B, B'))$ to chart

$\mathit{restriction}(\mathit{mgu}(B, B'))$ can be any operation reducing the number of possible substitutions to finite classes:

- depth bound on term complexity
- elimination of terms that are known to grow indefinitely
- use of only selected terms known not to grow indefinitely

This is sound since prediction only creates a hypothesis to be completed!

Example

Grammar:

$$\begin{aligned} \textbf{start} &\rightarrow \textbf{r}(0, N) \\ \textbf{r}(X, N) &\rightarrow \textbf{r}(s(X), N)\ \textbf{b} \\ \textbf{r}(N, N) &\rightarrow \textbf{a} \end{aligned}$$

Parsing using a restrictor that replaces every term deeper than 2 with a variable:

1		${}_0[\textbf{start} \rightarrow\ \bullet_0\ \textbf{r}(0, N)]$
2	pred $\textbf{r}(0, N)$ in 1	${}_0[\textbf{r}(0, N) \rightarrow\ \bullet_0\ \textbf{r}(s(0), N)\ \textbf{b}]$
3	pred $\textbf{r}(s(0), N)$ in 2	${}_0[\textbf{r}(s(0), N) \rightarrow\ \bullet_0\ \textbf{r}(s(s(0)), N)\ \textbf{b}]$
4	pred $\textbf{r}(s(s(A)), N)$ in 3	${}_0[\textbf{r}(s(s(A)), N) \rightarrow\ \bullet_0\ \textbf{r}(s(s(s(A))), N)\ \textbf{b}]$
5	pred $\textbf{r}(s(s(A)), N)$ in 4	= edge 4
$\vdots$		