DAG Automata and DAG Transducers

Dagstuhl Seminar 17142 – Formal Methods of Transformations

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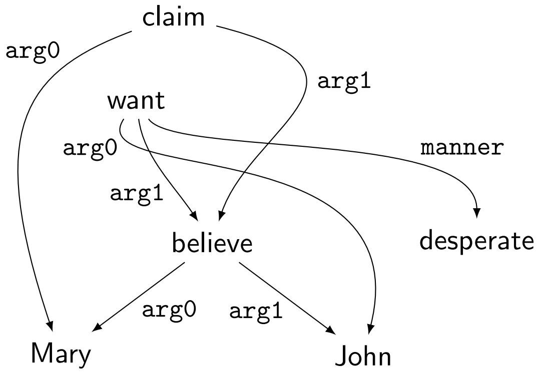
Overview

1. Why DAGs?
2. DAG automata
3. What a difference a root makes
4. DAG transducers – a proposal

DAG Automata

Motivation: Natural Language Semantics



"John desperately wants Mary to believe him, and she claims she does."

[inspired by Abstract Meaning Representation]

DAG Automata

Various earlier notions of DAG automata exist:

- Kamimura & Slutzki 1981
- Charatonik 1999 and Anantharaman et al. 2005
- Priese 2007
- Fujiyoshi 2010
- Quernheim & Knight 2012
- . . . and a few others.

None of them fits very well, and most are too powerful. We want a simple type of DAG automaton.

Design Decisions...

- Nodes have bounded rank
  [use symmetric version of first-child-next-sibling otherwise]
- Incoming/outgoing edges are totally ordered
  [no disadvantage, but makes determinism reasonable]
- Edges are unlabelled
  [can be encoded by auxiliary nodes]

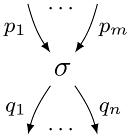
DAG Automata

Obvious idea: Computations assign states to edges.

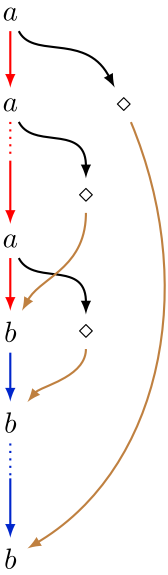
A DAG Automaton consists of states, node labels, and rules of the form

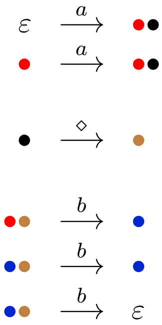
$$\overbrace{p_1 \cdots p_m}^{\substack{\text{incoming}\\ \text{states}\\ \downarrow}} \quad \overset{\substack{\text{node}\\ \text{label}\\ \downarrow}}{\xrightarrow{\ \sigma\ }} \quad \overbrace{q_1 \cdots q_n}^{\substack{\text{outgoing}\\ \text{states}\\ \downarrow}} .$$

A run is an assignment of states to edges. It is accepting if it locally coincides with a rule at each node:

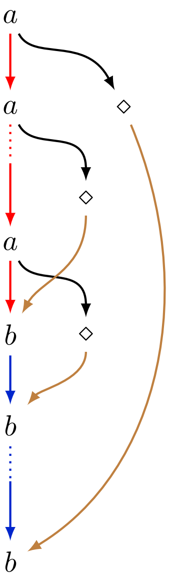


- The model is symmetric with respect to “up” and “down”.
- No initial/final states; use rules $\varepsilon \xrightarrow{\sigma} q_1 \cdots q_n$ and $p_1 \cdots p_m \xrightarrow{\sigma} \varepsilon$.
- The automata as such do not ensure/require acyclicity, but we do.
- We consider only nonempty connected DAGs because a disjoint union of DAGs is accepted iff each component is.
- In particular, this makes it meaningful to talk about emptiness and finiteness of accepted languages.
- Swapping targets of edges with the same state preserves acceptance.





$paths(L(A)) \cap a^*b^* = \{a^nb^n \mid n > 0\}$
(likewise for $a^nb^nc^n$ etc)



$$\varepsilon \xrightarrow{a} \textcolor{red}{\bullet}\bullet$$

$$\textcolor{red}{\bullet} \xrightarrow{a} \textcolor{red}{\bullet}\bullet$$

$$\bullet \xrightarrow{\diamond} \textcolor{brown}{\bullet}$$

$$\textcolor{red}{\bullet}\textcolor{brown}{\bullet} \xrightarrow{b} \textcolor{blue}{\bullet}$$

$$\textcolor{blue}{\bullet}\textcolor{brown}{\bullet} \xrightarrow{b} \textcolor{blue}{\bullet}$$

$$\textcolor{blue}{\bullet}\textcolor{brown}{\bullet} \xrightarrow{b} \varepsilon$$

~~$\mathit{paths}(L(A)) \cap a^*b^* = \{a^n b^n \mid n > 0\}$~~
~~(likewise for $a^n b^n c^n$ etc)~~

What a Difference a Root Makes

All (?) the previously proposed notions of DAG automata can restrict the number of roots.

	our model	restricted to single root
emptiness	polynomial	non-elementary
finiteness	polynomial	?
path languages	regular	? (but not context-free)
unfolding	regular tree language	? (but non-regular)
membership	NP-complete	NP-complete
Parikh image	?semi-linear?	

DAG Transducers – a Proposal

Desiderata

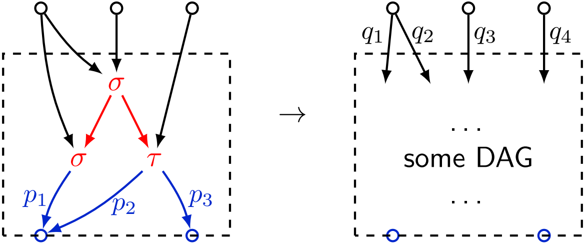
Possible uses:

- Turn syntax tree into semantic DAG (tree-to-DAG)
- Manipulate semantic DAG (DAG-to-DAG)
- Generate syntax tree from DAG (DAG-to-tree)

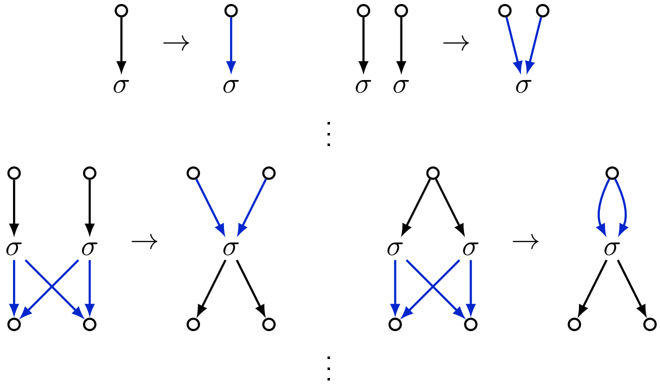
Ideally:

- "Natural" extension of the linear bottom-up tree transducer.
- Simple "local" rules to allow for training/learning.
- Extended rules should be covered.
- They should have some (un-)folding ability.
- Top-down should be the dual case.

Proposed Rule Type, Intuition

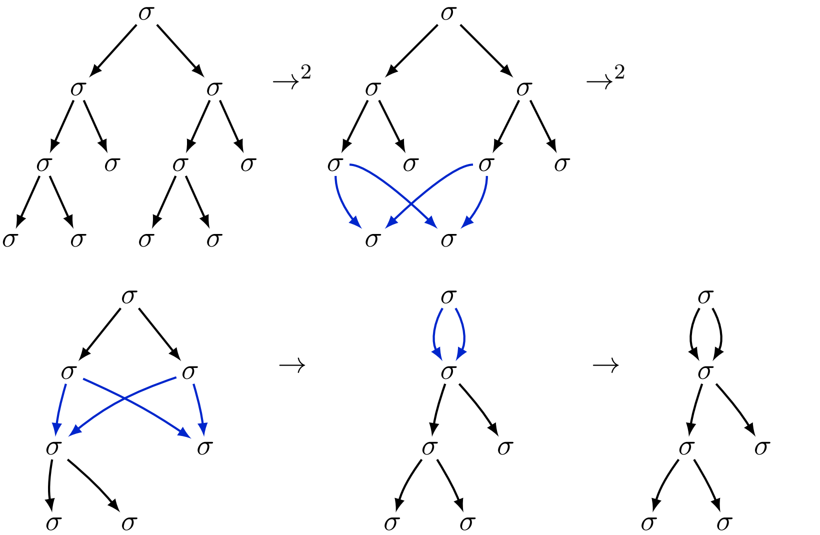


Example: Folding



(+ many more rules that don't fold)

Example: Folding



Concluding Remarks

- Origin information could be useful (comes naturally from training corpora).
- Symbolic versions can be of interest.
- I did not mention weights, but they are needed for NLP.
- Learning/training will be crucial.
- **It's fun, please join!**

Thank you!