Semantic Theory
Summer 2005
Underspecification II

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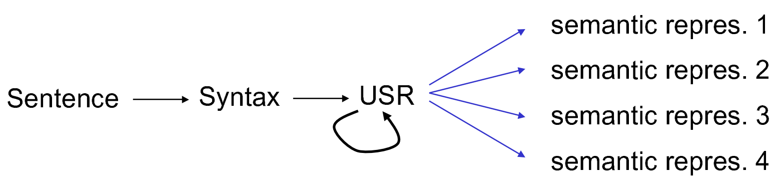
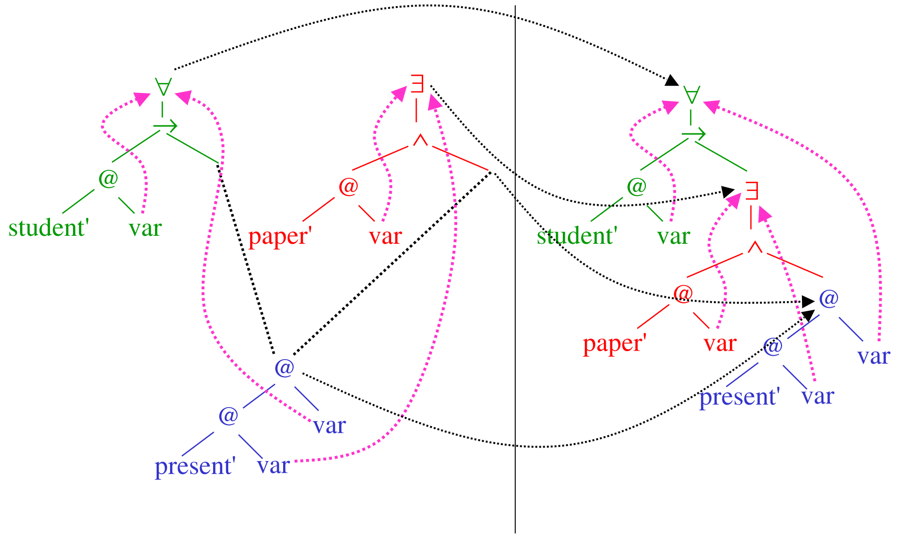
Underspecification: The big picture

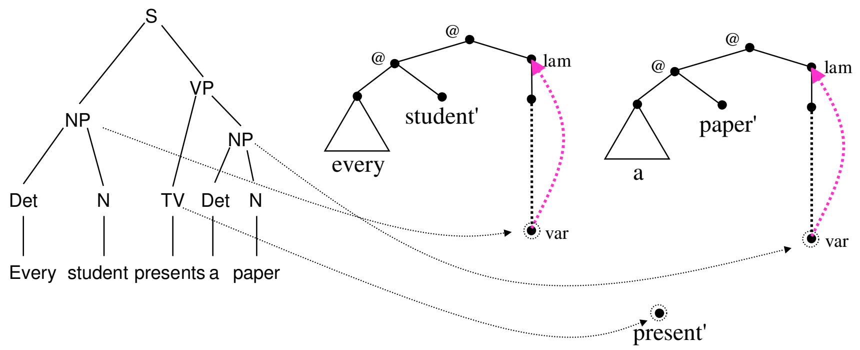


- Derive a single underspecified semantic representation (USR) from the syntactic analysis.
- Perform inferences on USR to eliminate readings excluded by the context.
- Enumerate readings by need.

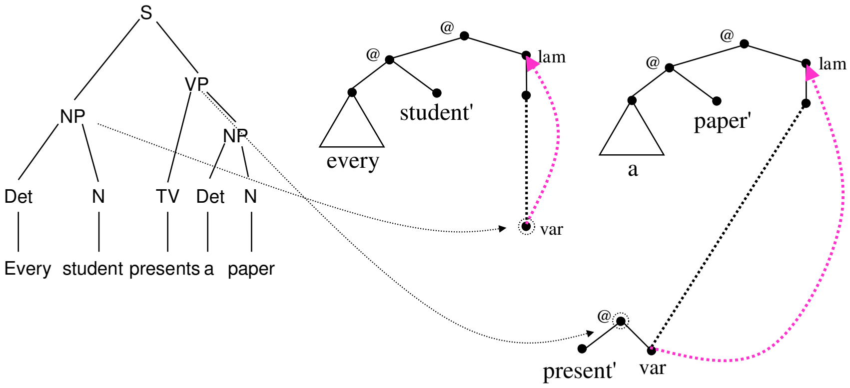
Solutions of dominance graphs



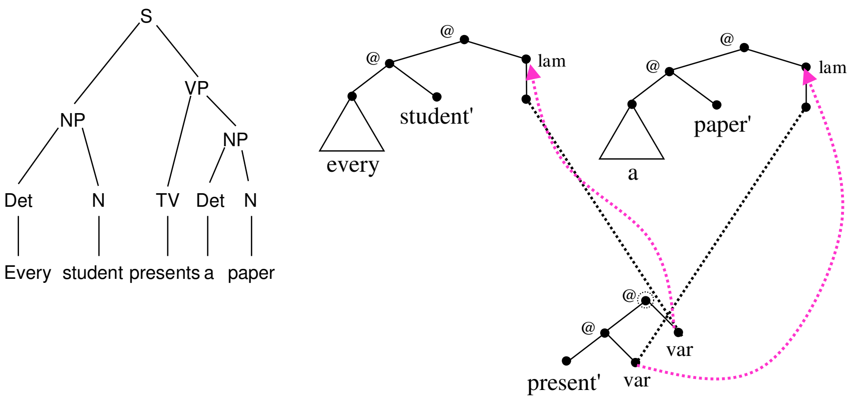
Semantics construction



Semantics construction

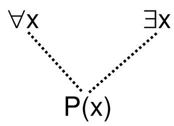


Semantics construction



Why binding edges?

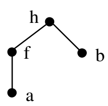
- In an underspecification context, variable names aren't always sufficient to indicate the binder for each variable:



- Problem could be solved by requiring that variables are named apart, but this breaks down for extensions of dominance graphs.
- Binding edges are a clean and simple way of doing it.

A small correction

- On Tuesday, I said that lambda terms and lambda structures correspond up to α-equivalence.
- It is true that every lambda term can be encoded as a lambda structure.
- Also, every lambda structure that encodes a lambda term encodes a unique lambda term up to α-equivalence.
- However, there are lambda structures that don't represent lambda terms, e.g.

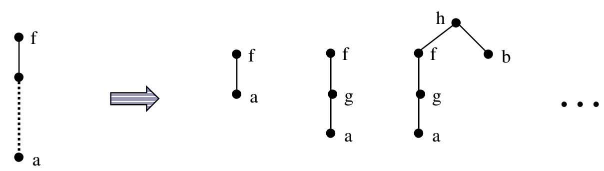


Solutions

- Question:
  How many solutions does a solvable dominance graph have?

Solutions

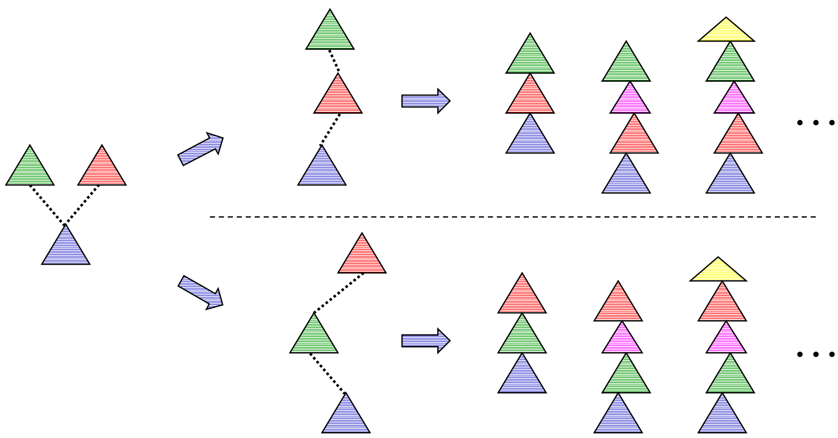
- Question:
  How many solutions does a solvable dominance graph have?
- Answer:
  An infinite number of solutions!



Solved Forms

- Enumerating all solutions of a graph is therefore hopeless (and not useful).
- Thus, we aim at enumerating all solved forms of a dominance graph and not all solutions.
- A dominance graph in solved form is a graph whose tree and dominance edges form a forest.
- A graph G' is a solved form of G iff G' is in solved form, G and G' have the same tree and binding edges, and whenever there is a path from u to v in G (over tree and dominance edges), there is also a path from u to v in G'.

Solved Forms and Solutions



Solved forms and solutions

- We can consider solved forms as representatives of classes of solutions that only differ in "irrelevant details".
- Every graph in solved form without binding edges has a solution.
- Every solution of a graph is also a solution of one of its solved forms.
- We will completely ignore binding edges today. The solver can be easily extended to deal with binding edges as they are generated e.g. by Tuesday's grammar.

Computational Questions

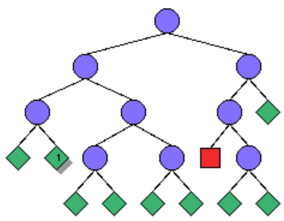
- Two computational questions arise in the context of dominance graphs.
  - The solvability problem: Does a given dominance graph have any solutions?
  - The enumeration problem: Enumerate the (minimal) solved forms of a dominance graph.
- The two questions are closely related.

Solving dominance graphs

- A solver for dominance graphs is an algorithm that solves the solvability and enumeration problems.
- There is a variety of different solvers for dominance graphs.
- The algorithm presented here is not the fastest one, but it is easiest to explain.

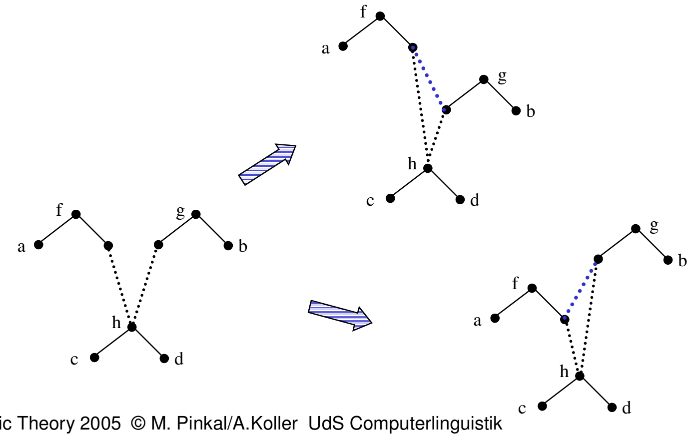
The solver: General architecture

- The solver is a search algorithm:
  - It recursively generates (simpler) new graphs by applying three simplification rules.
  - If none of the rules are applicable, it tests whether the graph is solvable.



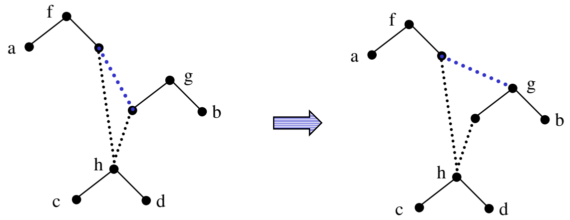
The Choice Rule

- Driving force behind solver is the Choice rule: Which of two trees comes first?



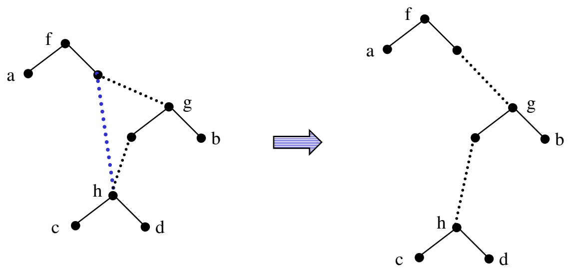
Cleaning Up I: Parent Normalisation

- Parent Normalisation changes a dominance edge (u,v) into a dominance edge (u,w), where w is the parent of v over a tree edge.



Cleaning Up II: Redundancy Elimination

- Redundancy Elimination deletes an edge (u,v) whenever there is a path from u to v that doesn't use this edge.

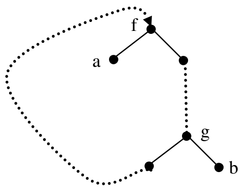


Correctness of the solver

- The rules are correct:
  - Every solved form of the original graph is a solved form of exactly one of the two results of Choice.
  - The original graph and the result of PN or RE have exactly the same solved forms.
- Every application of Choice (plus some applications of PN and RE) arranges the parents of one node.
- Eventually there will be no more nodes with two incoming edges left; so the algorithm terminates.

Detecting unsolvability

- It remains to check whether the end results are solvable or not.
- A dominance graph in which no node has two incoming edges is either a tree, or it has a cycle.
  - If it's a tree, then the graph is in solved form.
  - If it has a cycle, then it is unsolvable.



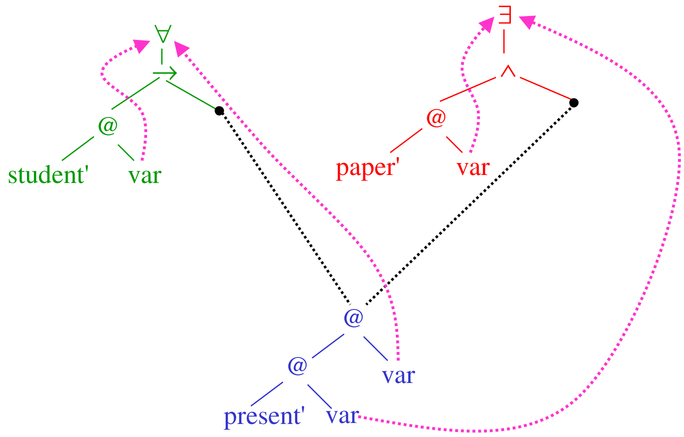
The complete solver

solve(G):

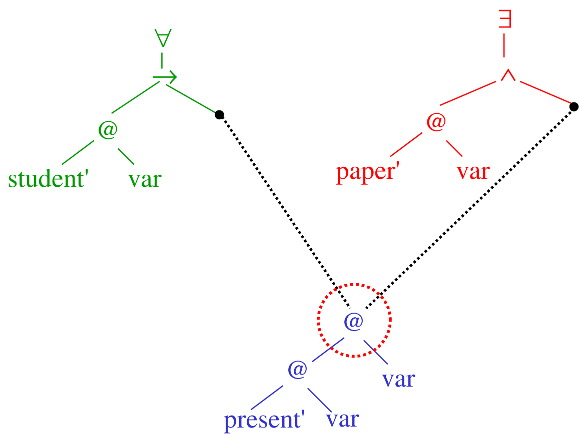
1. Apply Parent Normalisation and Redundancy Elimination exhaustively to G.
2. If there is a node v in G with two incoming dominance edges:

   apply Choice once; this gives new graphs H_1 and H_2
   solve(H_1)
   solve(H_2)
3. If there is no such node v, and if G has no cycle, then report G as a solved form of the original graph.

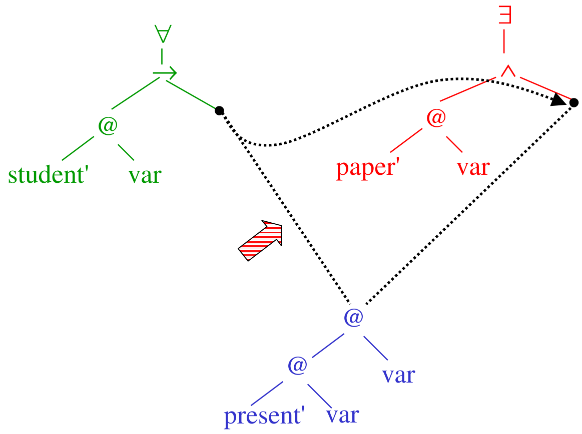
An example run of the solver



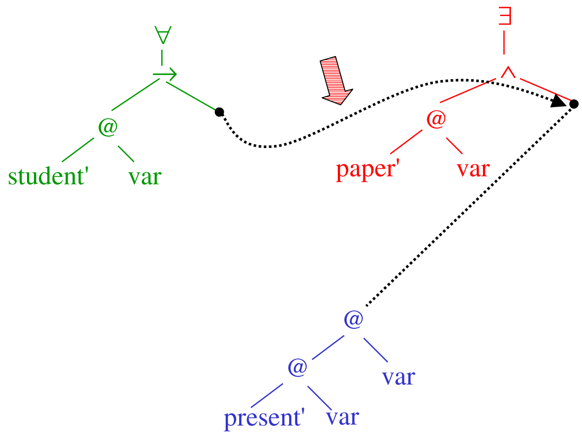
An example run of the solver



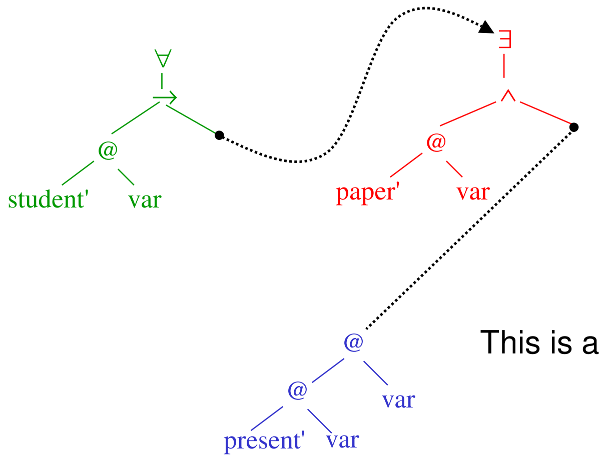
Choice 1



After Redundancy Elimination

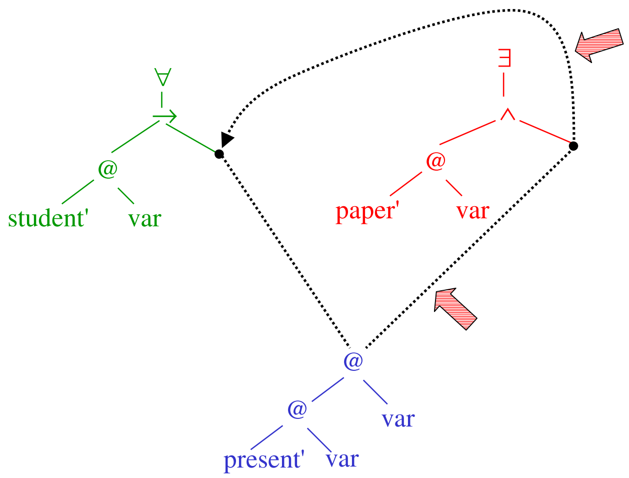


After Parent Normalisation (2 steps)

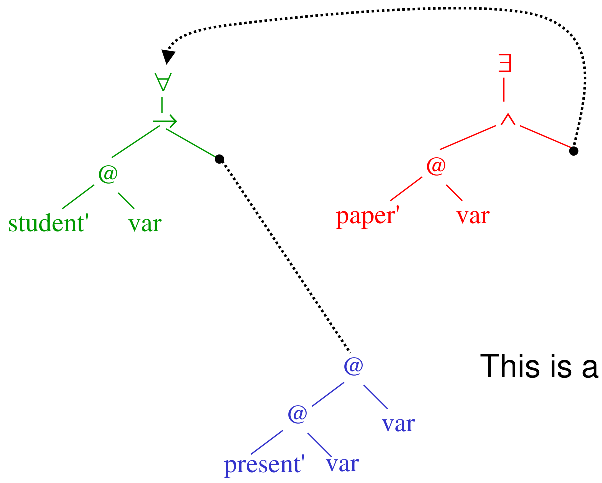


This is a solved form!

Choice 2

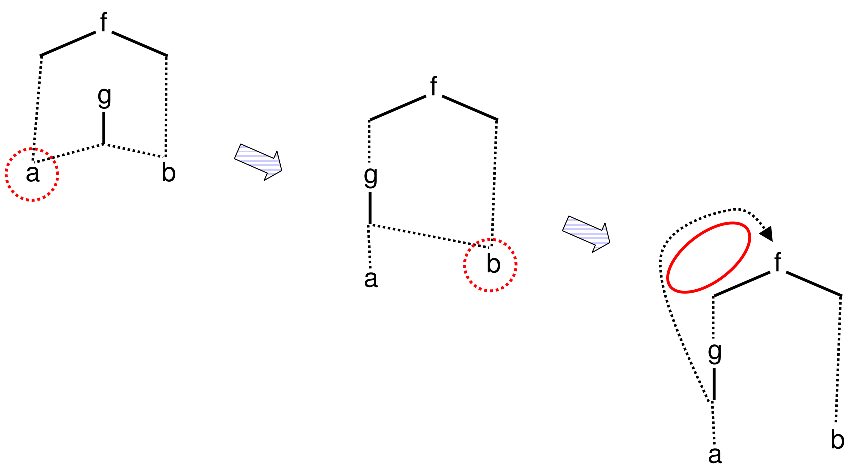


After RE and PN



This is a solved form!

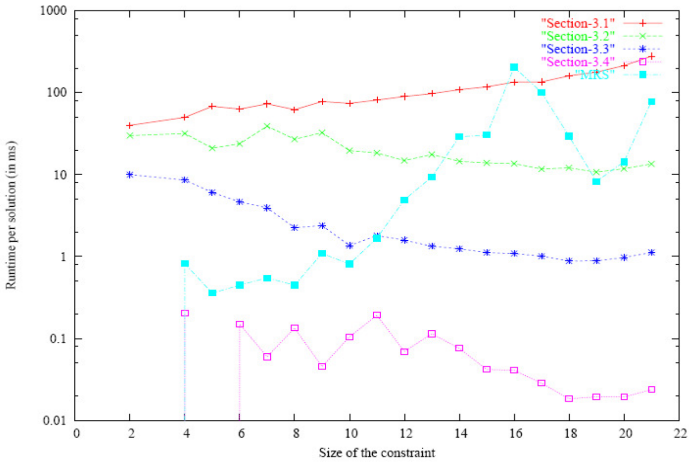
Running into unsolvability



The solver: Summary

- The solver is a search algorithm that computes a set of solved forms for a dominance graph.
- It doesn't enumerate all solved forms, but it does enumerate all minimal solved forms. Every solution of G solves exactly one minimal solved form of G.
- The algorithm may spend a lot of time trying to solve unsolvable graphs.
- This can be improved by a smarter unsolvability test.

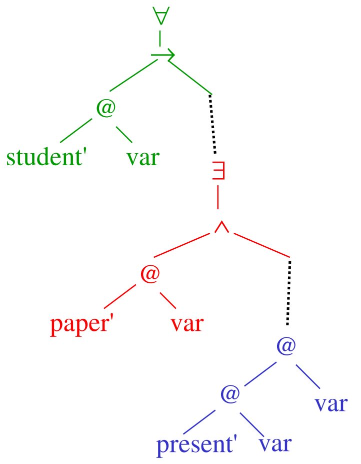
Comparison of different solvers



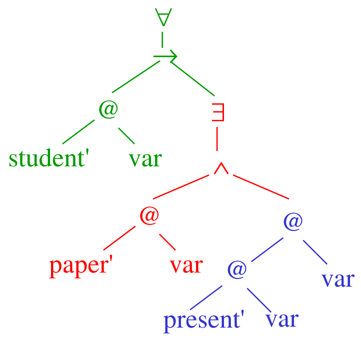
Constructive solutions

- Our initial idea was that solutions of a dominance graph should correspond to semantic representations.
- But now we know that there is generally an infinite number of solutions!
- We are really only interested in constructive solutions, i.e. solutions for which every node in the solution is the α-image of a labelled node in the graph.
- Can we always extract constructive solutions from solved forms?

Solved forms vs. constructive solutions

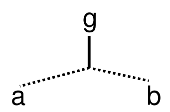


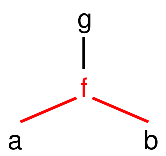
a graph in solved form ...



... and its unique constructive solution

Not all graphs *have* constructive solutions!





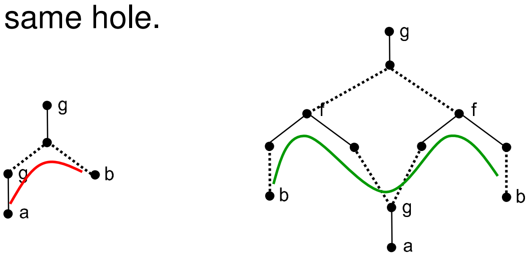
a graph in solved form ... ... and a smallest solution.

Constructive solvability

- In general, not all dominance graphs have constructive solutions.
- How can we tell which ones do?
- Can we somehow come up with a condition that guarantees constructive solvability, but which is also satisfied by all graphs that we need in underspecification?

Hypernormal paths

- A hypernormal path is an undirected path in a dominance graph that doesn't use two dominance edges out of the same hole.



- A dominance graph is hypernormally connected (or a net) iff every pair of nodes is connected by a hypernormal path.

Simple solved forms

- A solved form is called simple iff every hole has exactly one outgoing dominance edge.
- Every graph in simple solved form has exactly one constructive solution.
- All solved forms of a hypernormally connected graph are simple.

This is not obvious!

- By the way: A dominance graph is unsolvable iff it has a hypernormal (undirected) cycle.

Taking stock

- We know that every solved form of a hypernormally connected graph has exactly one constructive solution.
- This means that solved forms and the readings of the sentence correspond.

- Are the graphs that occur in practice actually hypernormally connected?

The Net Hypothesis

- Hypothesis: All dominance graph that occur in underspecification are hypernormally connected.
- This can be proved for (an extension of) Tuesday's grammar.
- Empirical verification (Flickinger et al., HPSG 2005):
  - Compute USRs for all 960 sentences in the Rondane Treebank using the English Resource Grammar.
  - Result: 90% are hypernormally connected.
  - The rest seem to be due to errors in grammar (but this is ongoing research).

The relevance of the Net Hypothesis

- If the Net Hypothesis is true, it has the following consequences:
  - solved forms correspond to readings
  - don't need to invent "semantic material" when enumerating readings (in any underspecification formalism)
  - an upper limit on the differences between syntactic and semantic structures
  - USRs in different formalisms (MRS, Hole Semantics) can be translated into dominance graphs

Summary

- Solving means enumeration of solved forms (not solutions).
- Solving dominance graphs:
  - search algorithm that is driven by the Choice rule
  - detect unsolvability via cyclicity test
- Hypernormally connected graphs (nets):
  - guarantee that solved forms have constructive solutions
  - it seems that every graph used in underspecification is a net