Towards a Grand Unified Theory of Scope Underspecification

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joint work with
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Overview

- Ambiguity and underspecification
- Dominance graphs
- Are different underspecification formalisms equivalent?
- Encoding of MRS nets into dominance nets
- Relevant descriptions are nets
- Harvesting

Ambiguity

- Natural language sentences often have more than one possible meaning, syntactic structure, etc.
- Example: (syntactic) attachment ambiguity:
  John watched the man with the telescope.
- This phenomenon is called ambiguity.
- Ambiguity is one of the great challenges for natural language processing today.

Scope ambiguities

- Scope ambiguity is a kind of semantic ambiguity.
- Example:
  "Every student reads a book."

1. ..., namely, the one their professor wrote.
   $\exists y\ \text{book}(y) \wedge (\forall x\ \text{student}(x) \rightarrow \text{read}(x,y))$

2. ..., but not necessarily the same one.
   $\forall x\ \text{student}(x) \rightarrow (\exists y\ \text{book}(y) \wedge \text{read}(x,y))$

Explosion of Readings

- A sentence with more than one scope ambiguity can have an enormous number of readings:

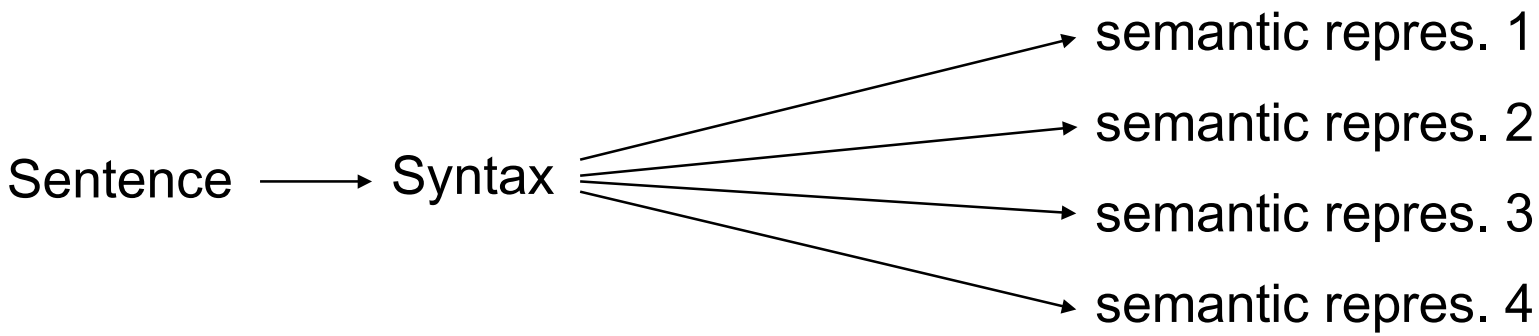
  Most politicians can fool most voters on most issues most of the time, but no politician can fool every voter on every single issue all of the time.
  (ca. 600 readings, Hobbs)

- Modern large-scale grammars predict a lot of scope readings even for harmless-looking sentences:

  But that would give us all day Tuesday to be there.
  (ca. 65.000 readings, according to ERG grammar)

- In general, scope ambiguities contribute a number of readings exponential in the number of quantifiers (and other scope bearers).

Semantics construction



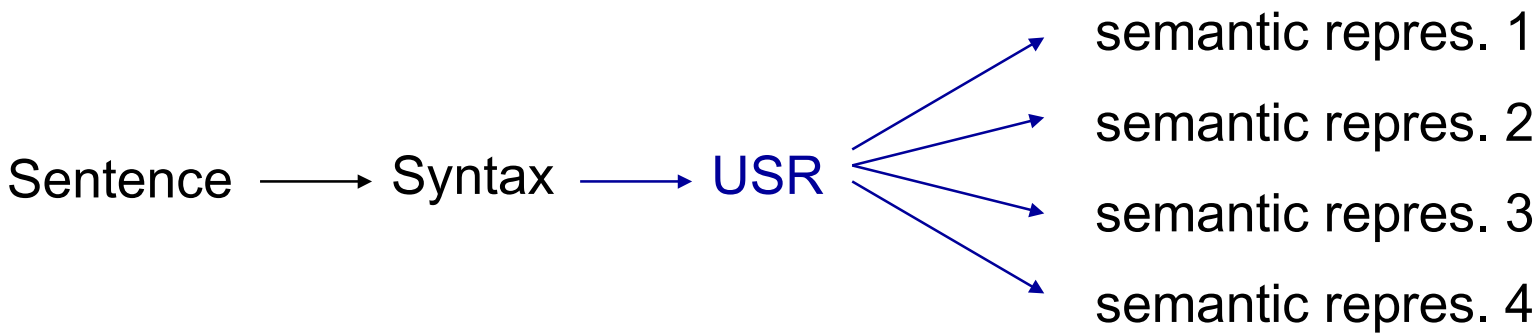
Enumerating readings is expensive

- We'd like to avoid enumerating these many readings.
- Most of the readings were not meant by the speaker.
- Do people enumerate readings of a scope ambiguity?

Scope Underspecification

- So let's avoid enumerating the readings for as long as we can.
- Take a single syntactic analysis and derive a single underspecified semantic representation from it.
- Possibly perform inferences on underspecified descriptions to remove unwanted readings.
- Then enumerate readings from description by need.

Scope Underspecification: The big picture



Dominance graphs

- Semantic representations are e.g. formulas of first-order logic.
- Read these formulas as trees.
- Describe these trees using graphs that can be embedded into them.
- Use special graph edges to represent variable binding (not shown here).
- Equivalent to normal dominance constraints, i.e. both graph view and logic view available.

Describe Trees Using Graphs

"Every student reads a book."

$\exists y\ book(y) \wedge \forall x.student(x) \rightarrow read(x,y)$

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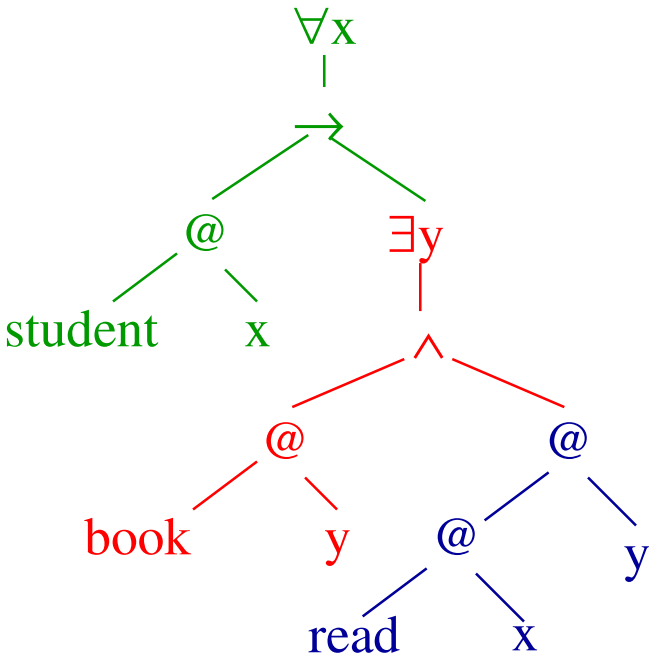

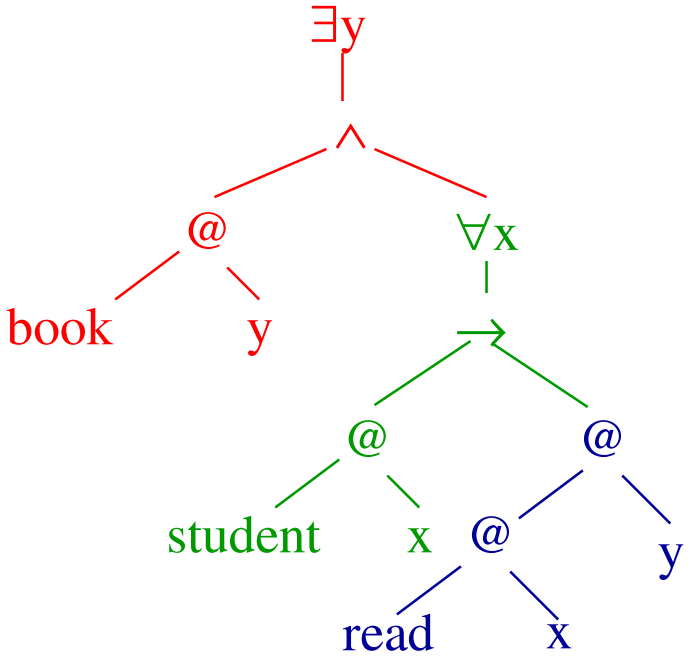

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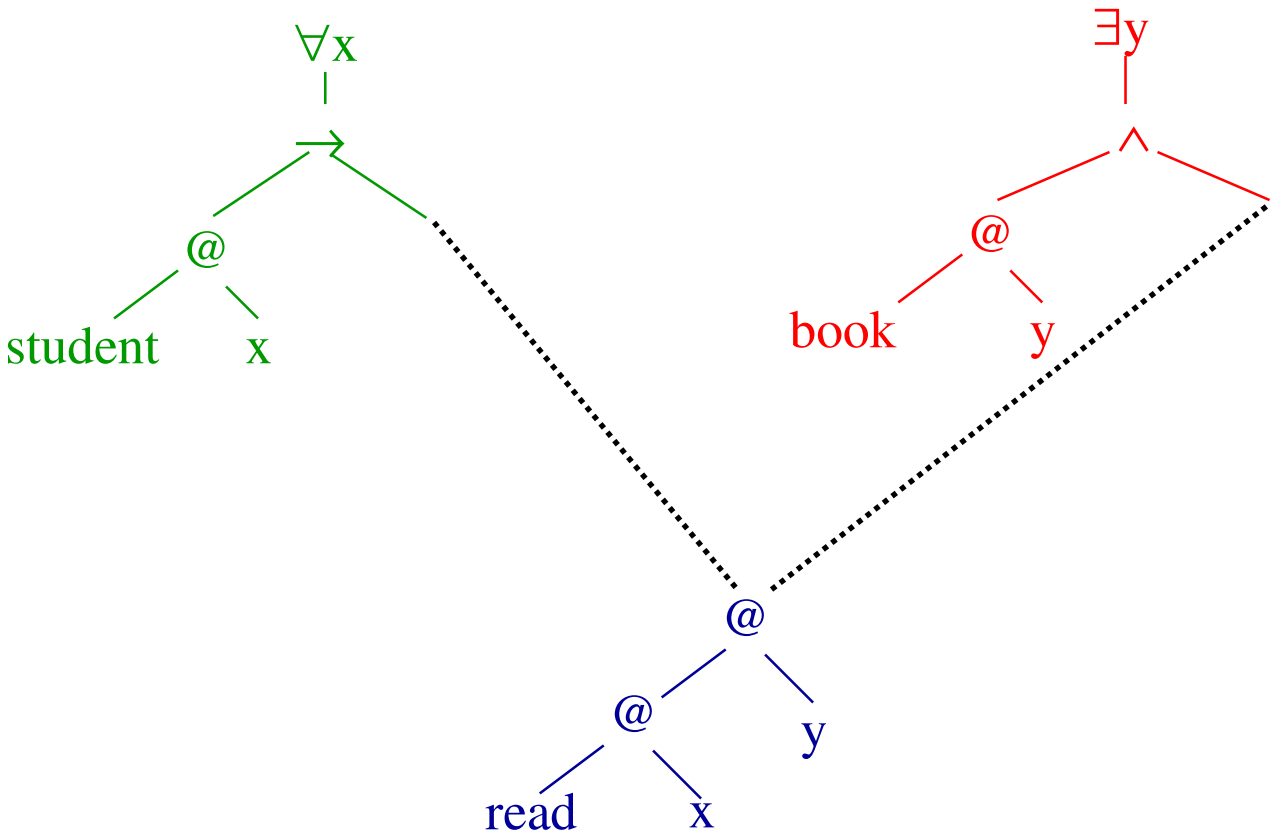
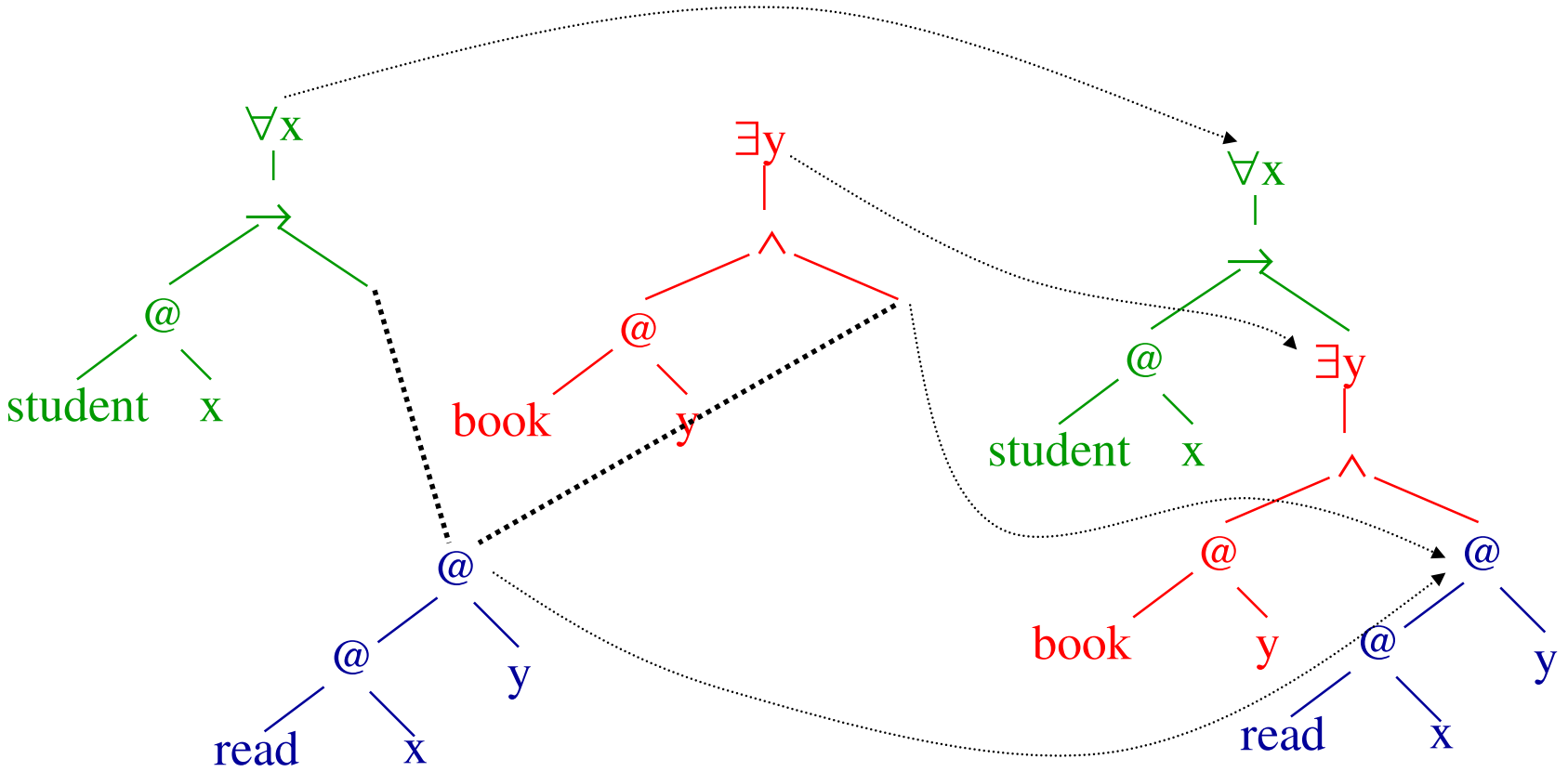


Solutions of dominance graphs



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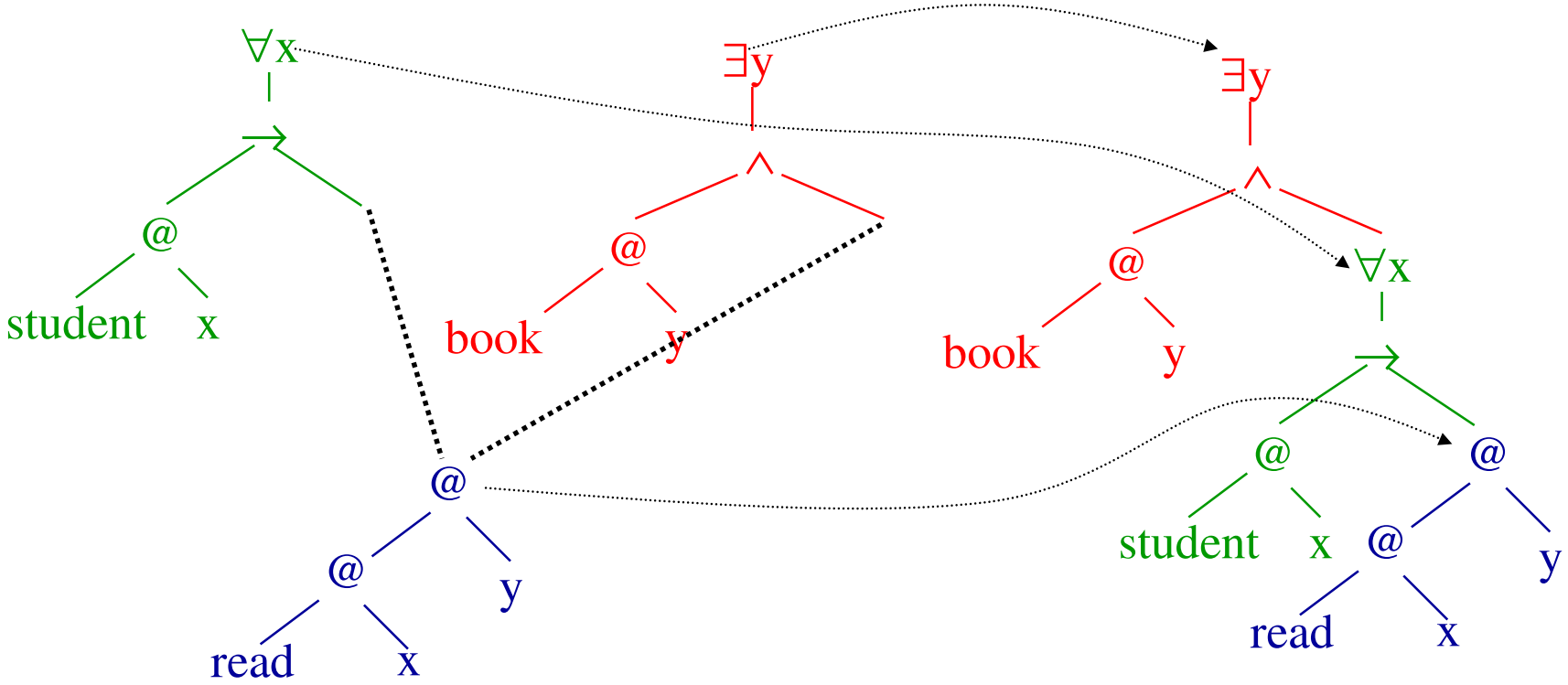
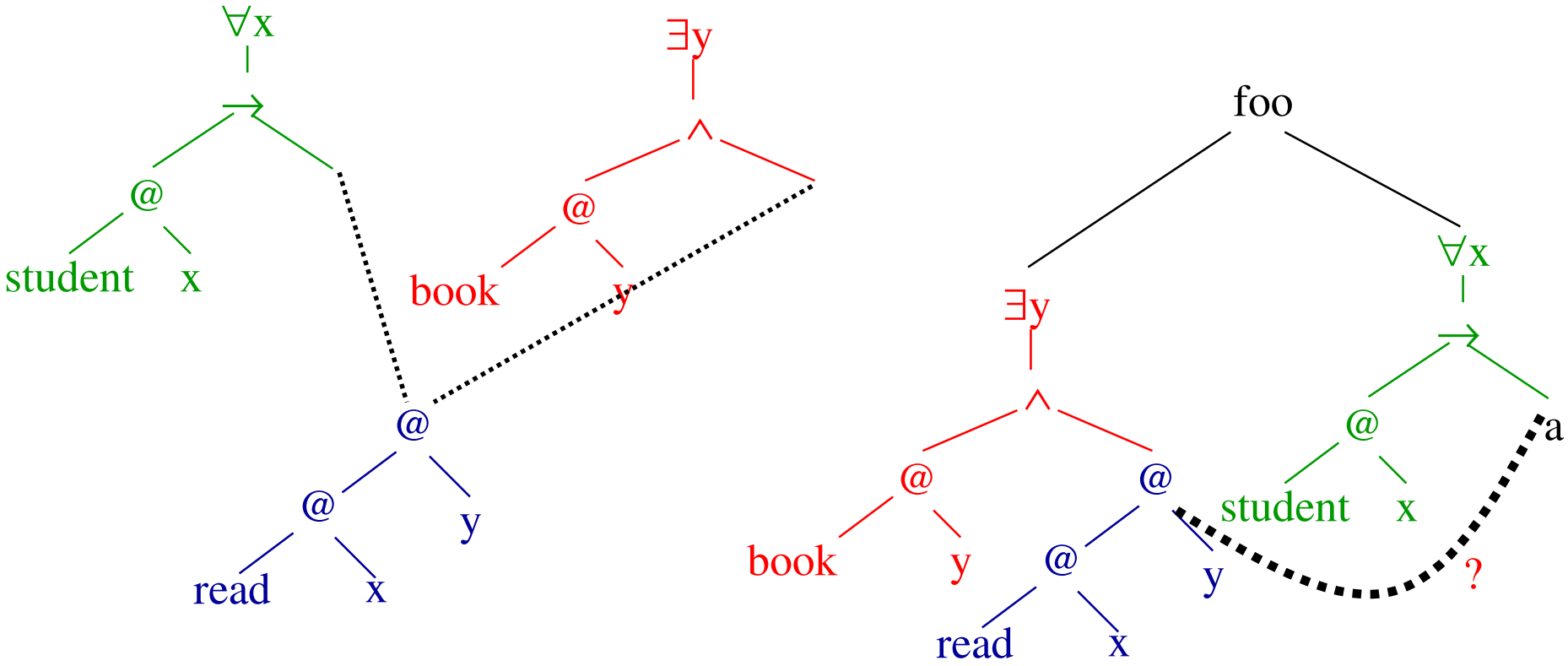
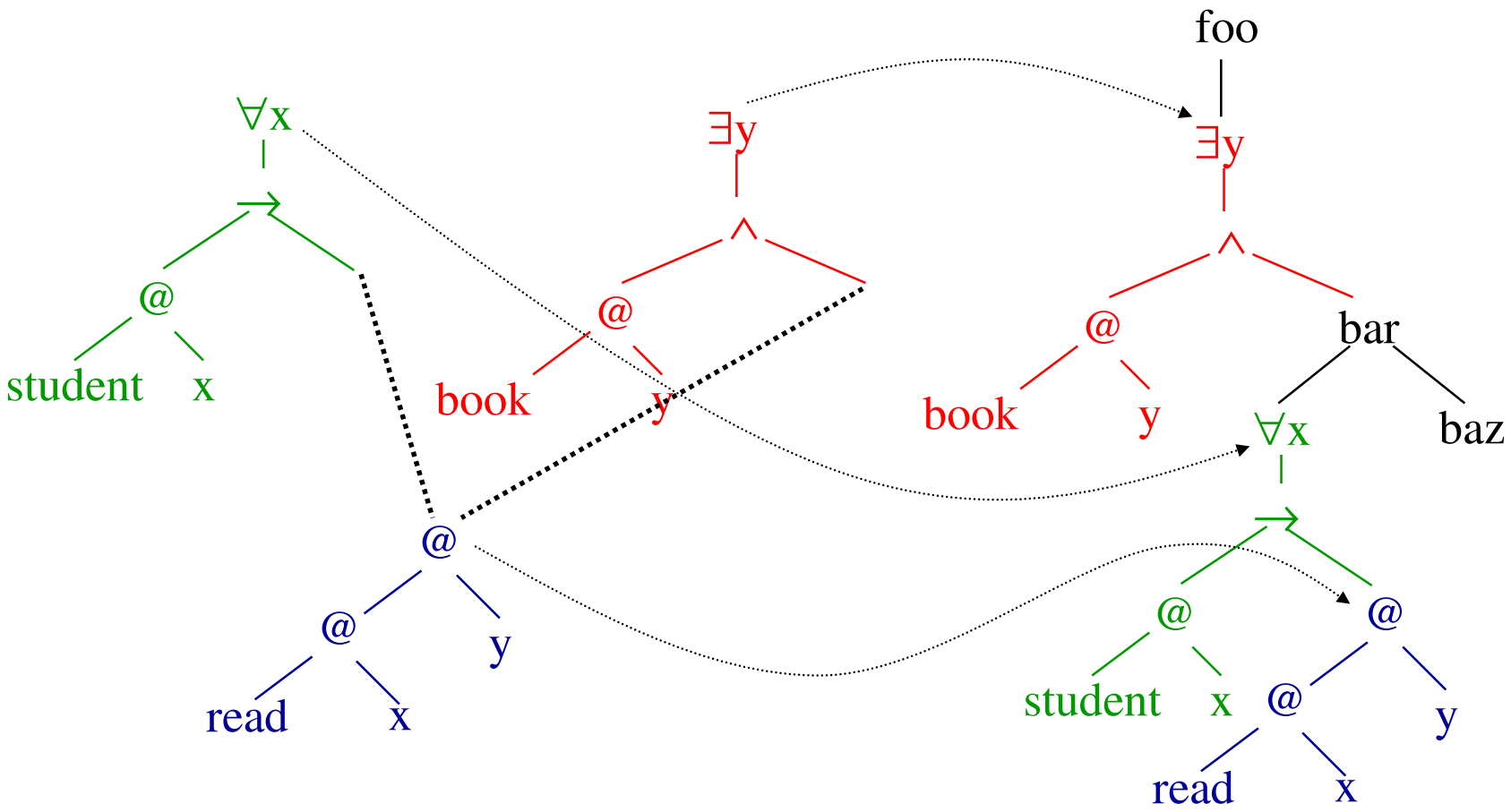


Not a solution



Solutions can be larger than graph



Solutions vs. configurations

- A solution is a tree into which the graph can be embedded.
- A configuration is a tree into which the graph's fragments can be configured, i.e. arranged without adding new nodes.

Underspecification Formalisms

QLF
(Alshawi & Crouch 92)

Hole Semantics
(Bos 96)

UDRT
(Reyle 93)

Dominance constraints/graphs
(Koller et al. 00)

LDG
(Muskens 95)

MRS
(Copestake et al. 99)

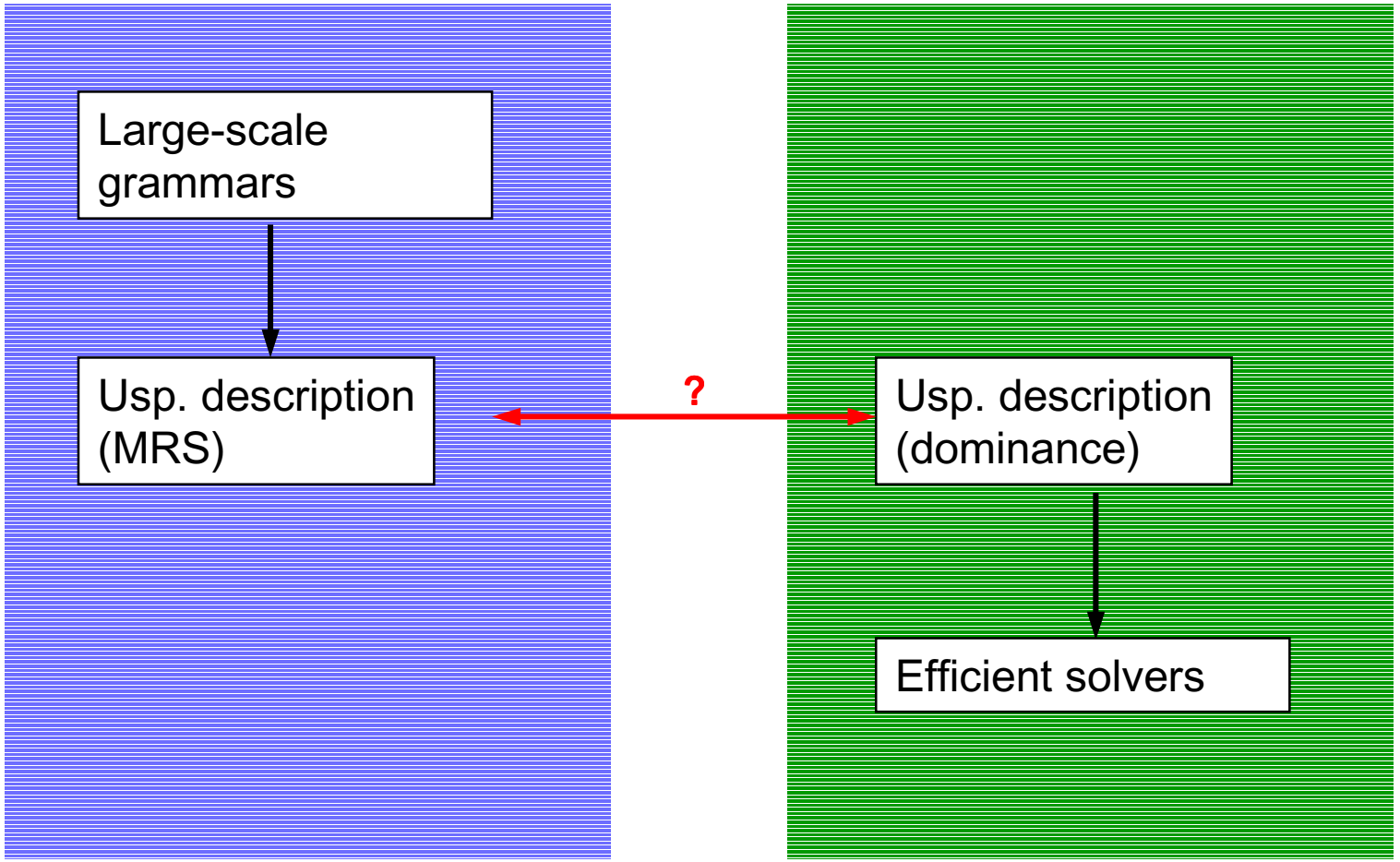
CLLS
(Egg et al. 98)

. . .

Grand Unified Theory?

- Underspecified descriptions in many of these formalisms look very similar.
- What are the formal relations between them?
- Are the formalisms equivalent?
- At least on some useful fragment of language?

Resource Sharing



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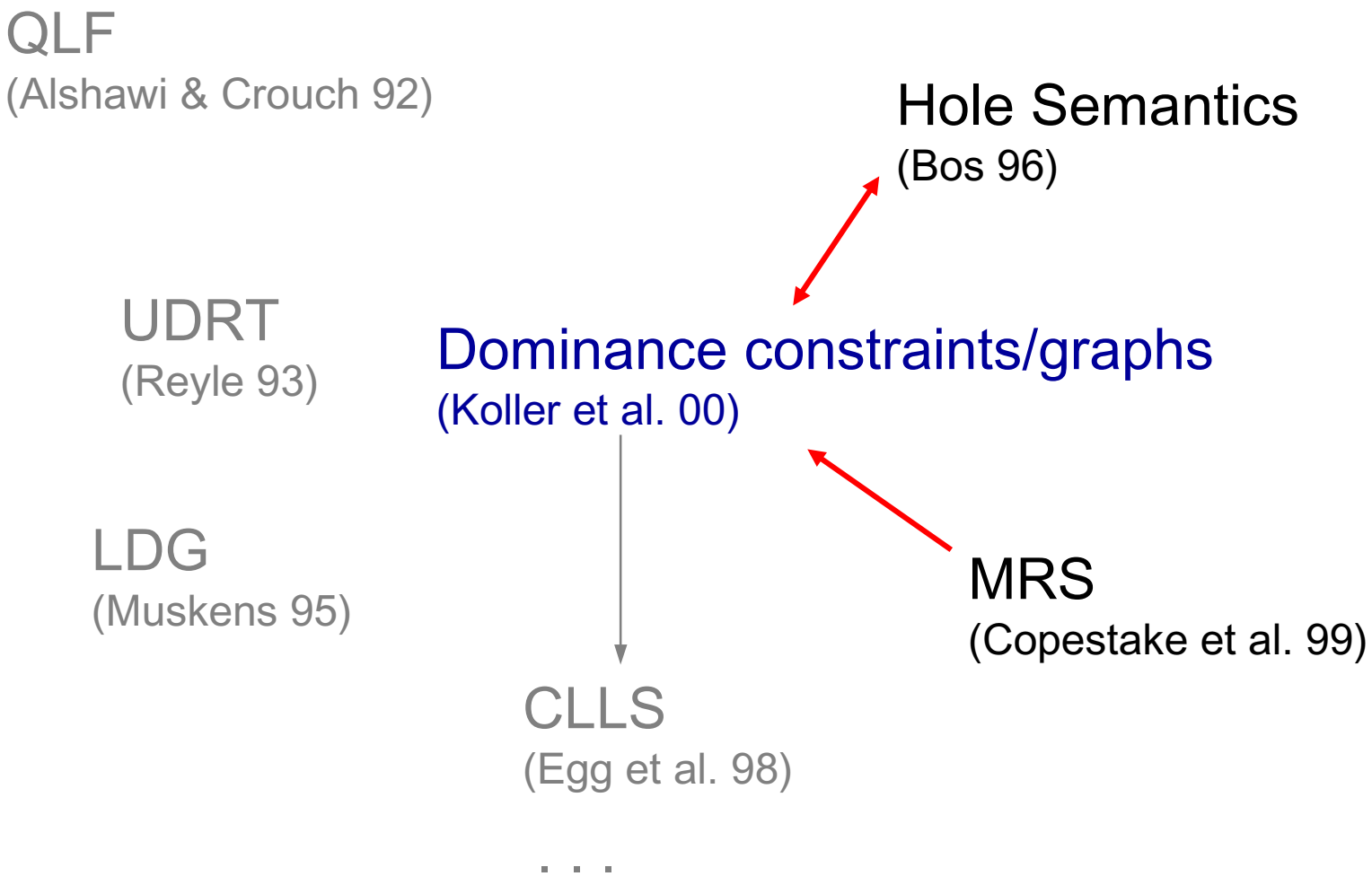
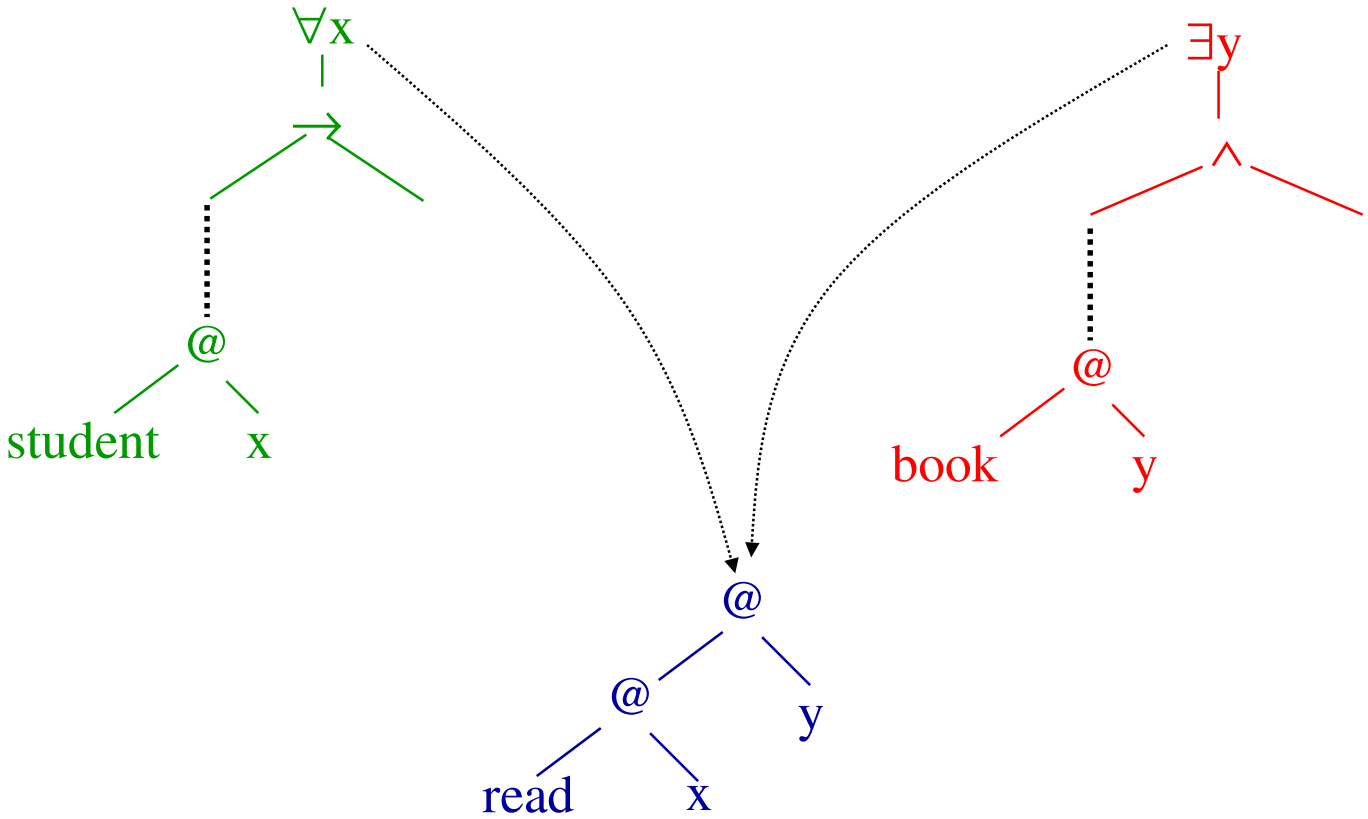


MRS (simplified)

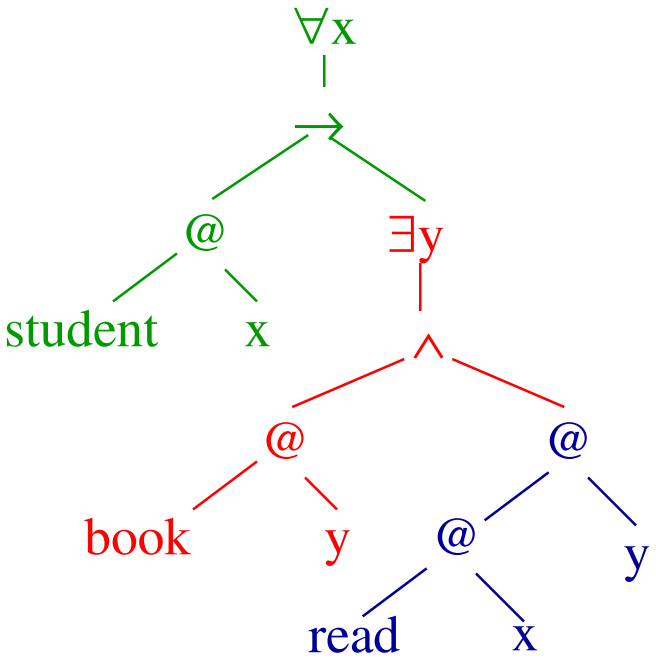
- Underspecified descriptions can be seen as graphs.
- Configure nodes into a tree such that dominance wishes are respected.
- All holes must be "plugged".
- A node can have more than one label.

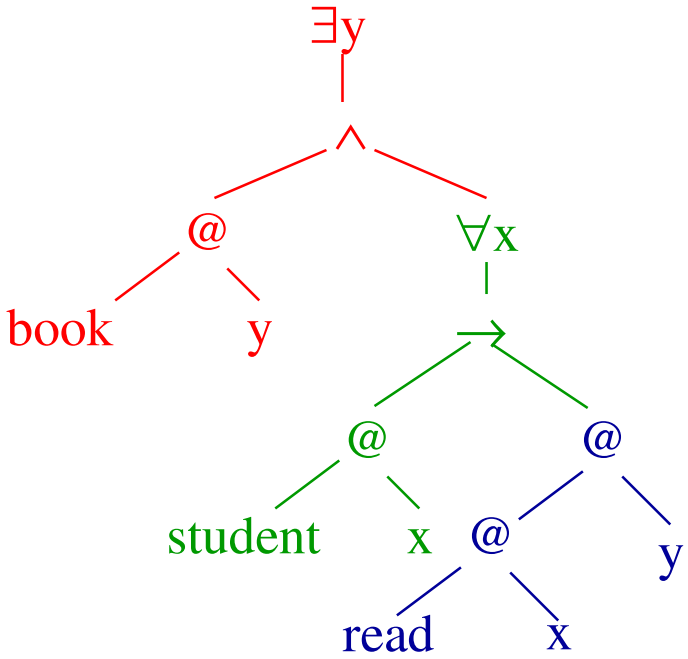
The example in MRS

"Every student reads a book."



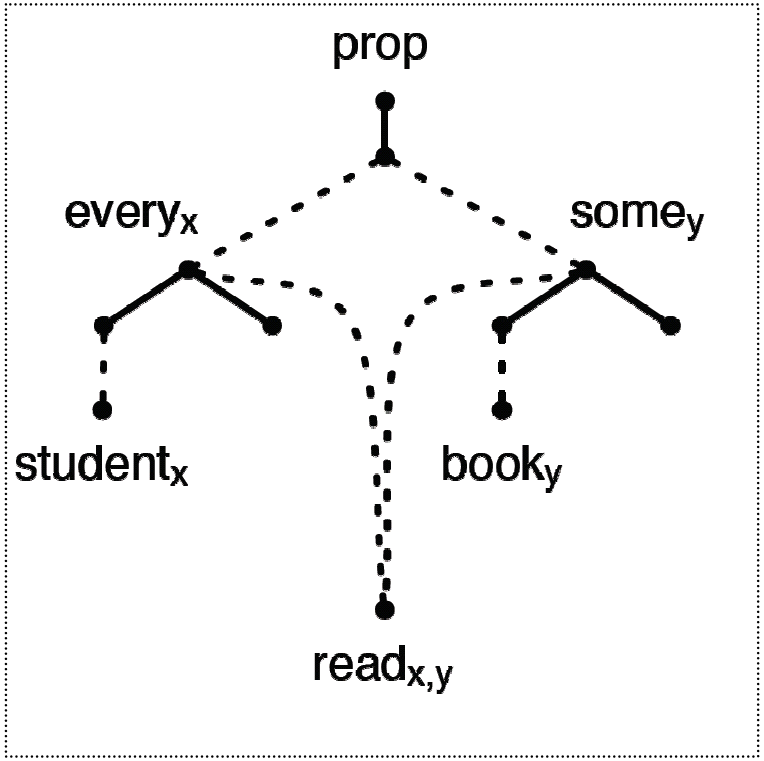
Description has exactly two solutions

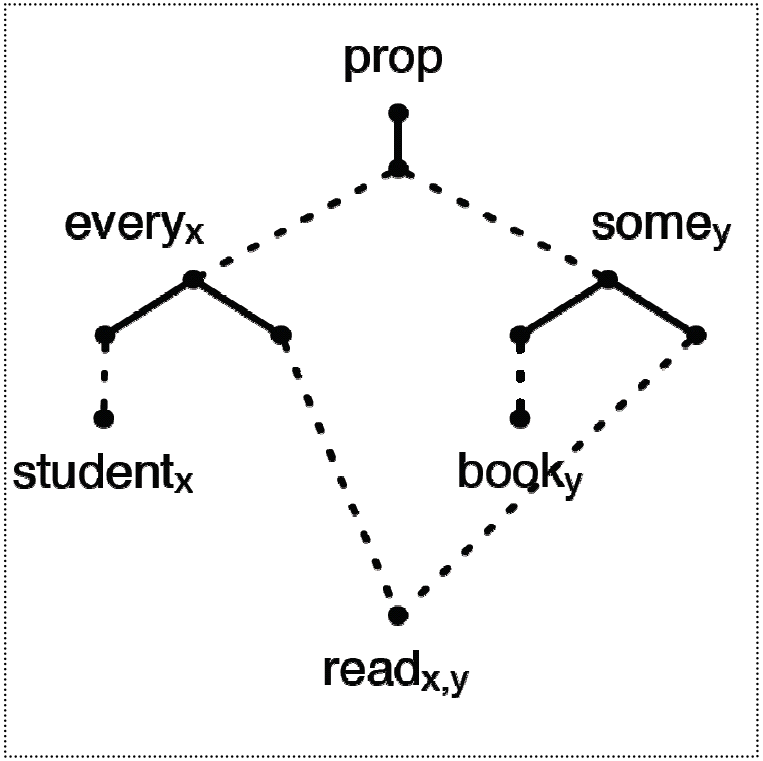




Translating MRS to dominance graphs

Usp. description (MRS) → Usp. description (dominance)

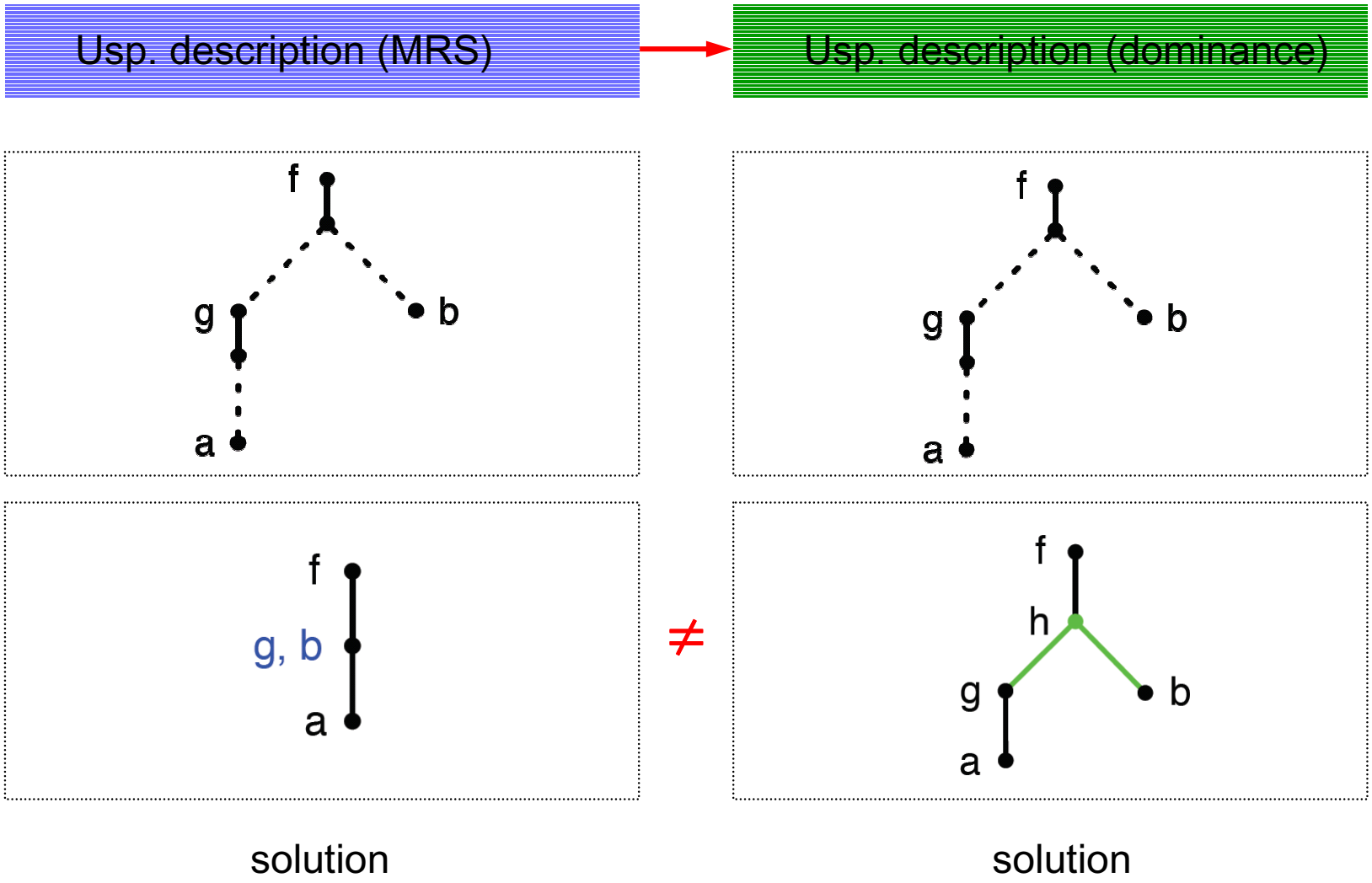




Almost correct ...

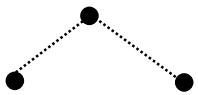
- Solutions of the MRS description correspond to configurations of the dominance graph.
- This is pretty nice.
- But: Configurations are not the standard notion of solutions for which e.g. dominance solvers are defined.

... but not quite



Why not?

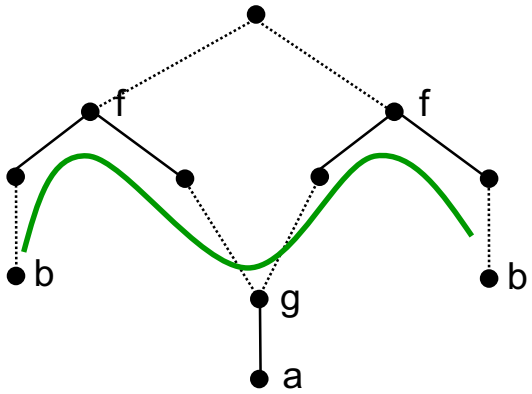
- So, strictly speaking, the translation is not correct!
- Crucial case: Graph contains subgraph of the following kind:

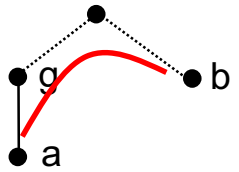


- Does this situation ever occur in practice? (If no, the translation works well enough!)

Nets

- A dominance graph is hypernormally connected (or a net) iff every pair of nodes is connected by a simple hypernormal path.
- Hypernormal paths: undirected paths that do not use adjacent dominance edges out of the same leaf:

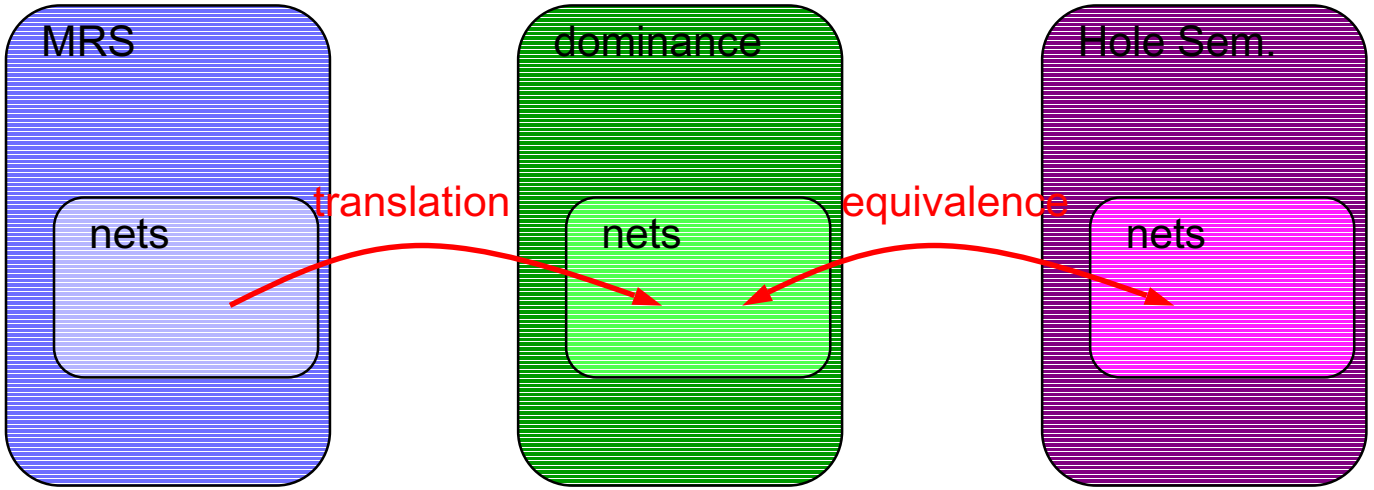




Equivalence of Nets

K., Niehren, Thater EACL 2003
Niehren & Thater ACL 2003

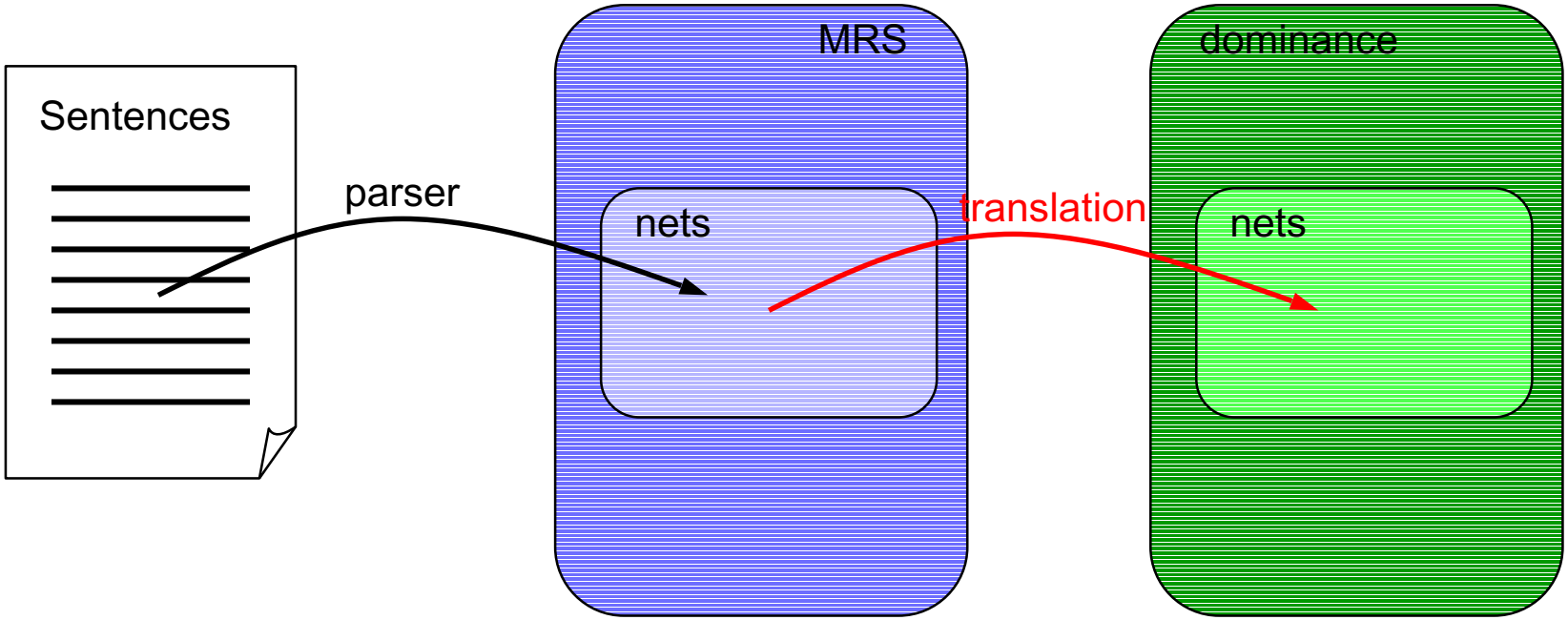
- The MRS-to-dominance translation is correct on all nets.
- The Hole Semantics-to-dominance translation and its reverse are correct on all nets.



Are real descriptions nets?

- Equivalence results very satisfying, but: Are the equivalent fragments practically relevant?
- For small fragments of English, this can be proved (K., Niehren, Thater 2003).
- For large-scale grammars, proof is infeasible.
- But: Empirical evaluation.

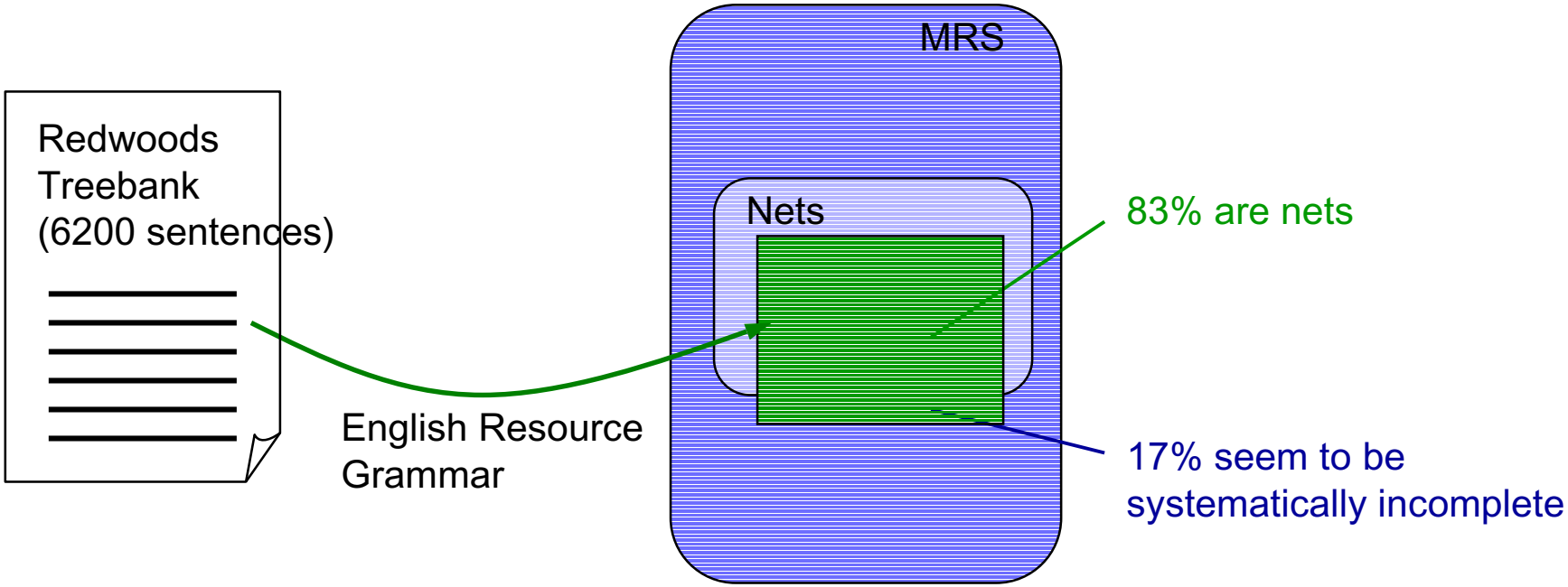
The Net Hypothesis



- Net hypothesis: All useful underspecified descriptions are hypernormally connected.

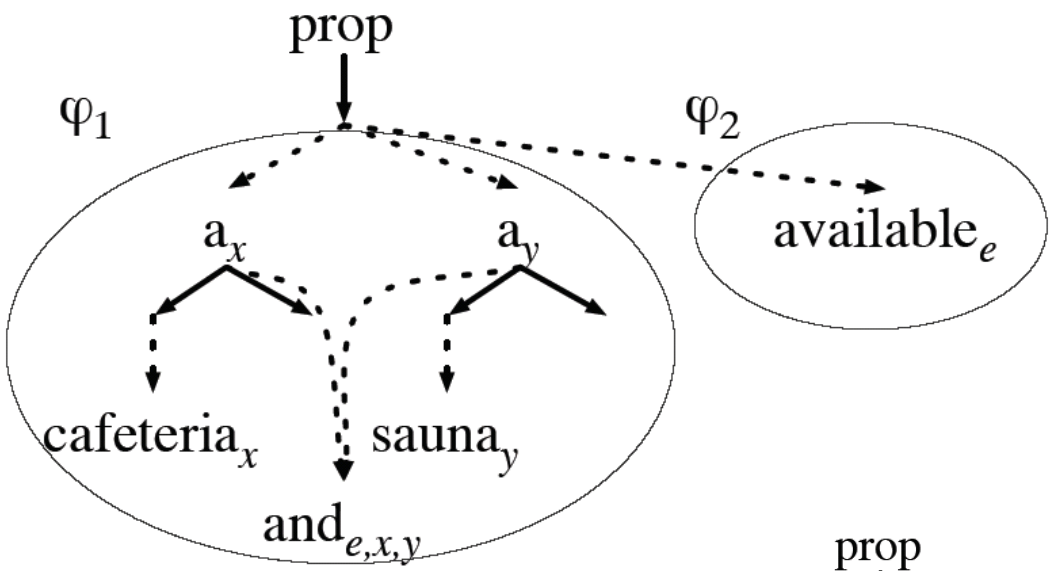
Evaluation of the Net Hypothesis

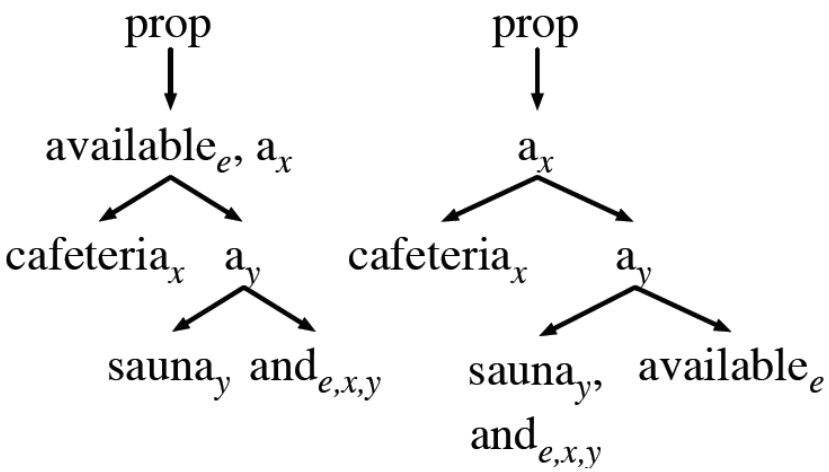
Fuchss et al., ACL 2004



Non-nets seem to be incomplete

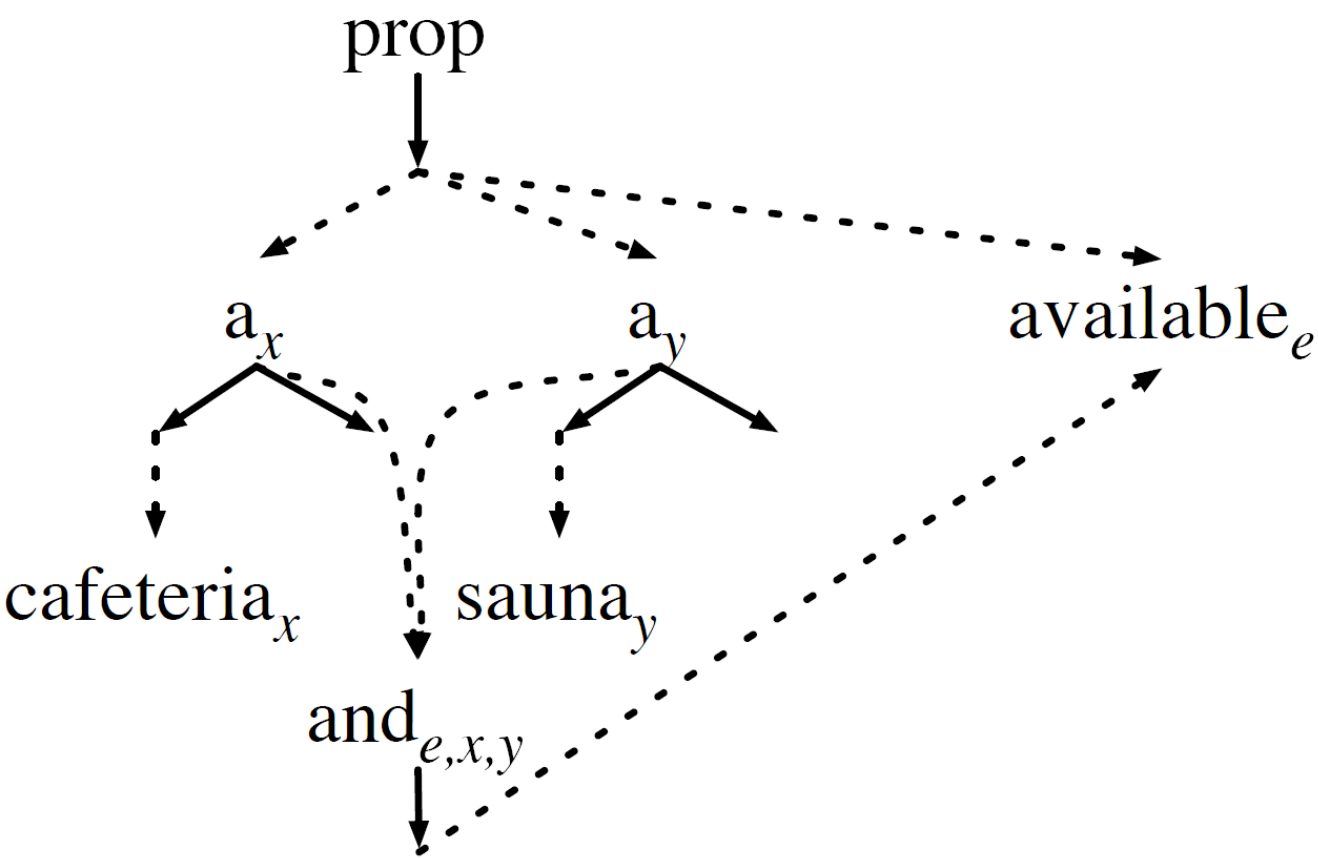
"A cafeteria and a sauna are available."





Completions are nets

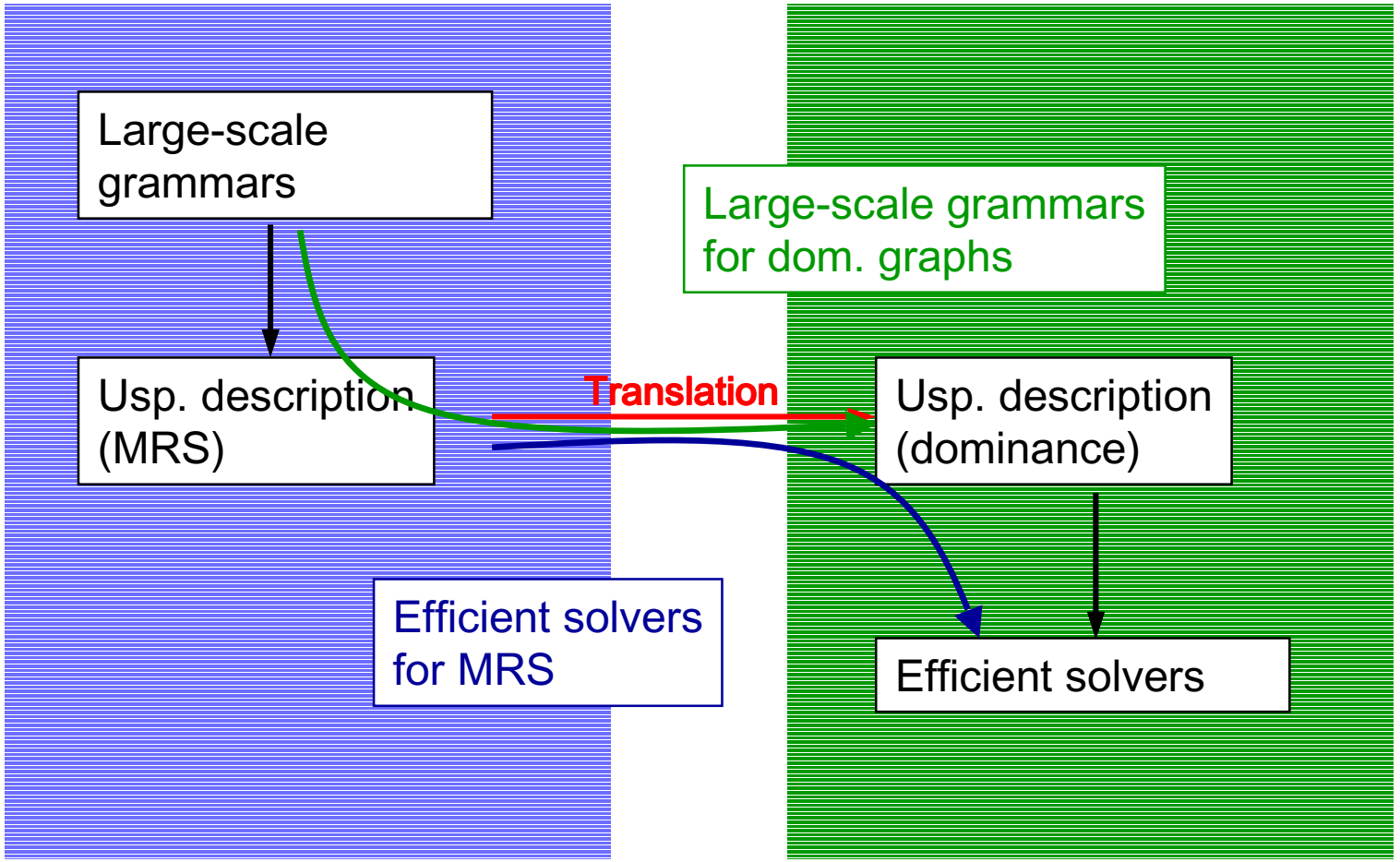
"A cafeteria and a sauna are available."



Taking stock

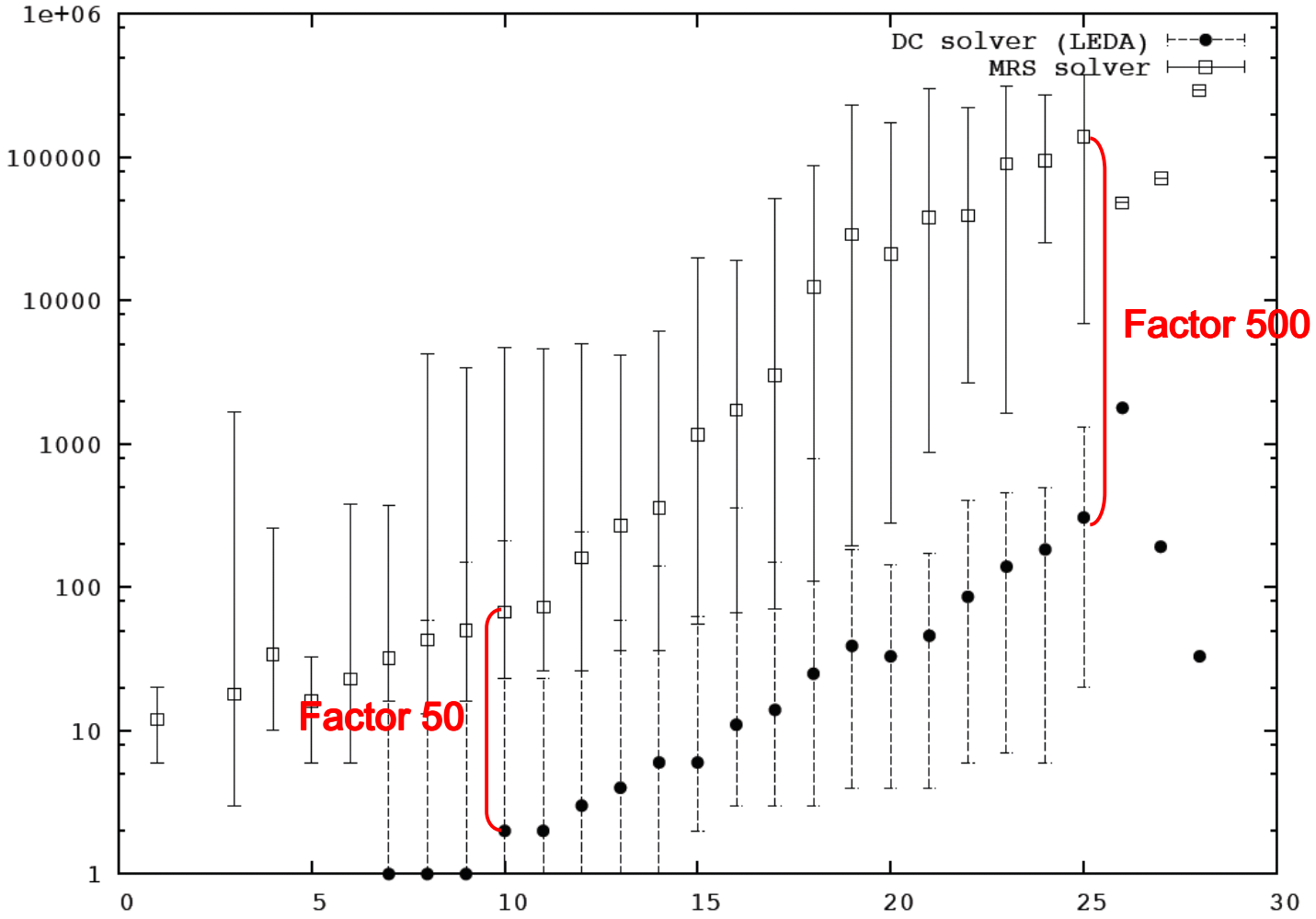
- Equivalence results for the hypernormally connected fragments of dominance graphs, MRS, and Hole Semantics.
- Most (or all!) relevant underspecified descriptions are indeed hypernormally connected.
- What does this give us?

Harvesting 1: Sharing resources



Efficient solving

Fuchss et al., ACL 2004



Harvesting 2: Grammar verification

- When developing a large grammar, it is not trivial to keep track of interdependencies and long-range effects of changes.
- Semantic output is hard to verify.
- If all correct underspecified descriptions are hnc, non-nets may be a warning sign for errors in the grammar's semantics component.

Harvesting 3: Expressivity of atoms

- Different usp. formalisms use different atoms to talk about formulas.
- MRS can express things that dominance graphs can't:
  - "equality up to quantifiers" (restricted form of dominance): empirically shown to be unnecessary
  - can label the same node with multiple labels: never necessary in nets

Conclusion

- Underspecification: deal with (scope) ambiguity by delaying enumeration of readings.
- Many different underspecification formalisms - but are they really different?
- Yes, they are!
- But relevant fragments (nets) of dominance graphs, MRS, and Hole Semantics are indeed equivalent.
- Sharing of resources.

Future Work

- Extend equivalence results to other underspecification formalisms.
- Develop and implement efficient test for hypernormal connectedness, and re-run evaluation on new version of grammar.
- Closer inspection of non-nets from the treebank.
- Let's get on with underspecification work, instead of inventing new formalisms!