Computational Semantics
Day 4: Dominance Graphs, Round Two

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Overview

- Semantics construction for dominance graphs
- Implementation in our Prolog framework

- Solving dominance graphs
- Implementing the graph solver

Recap: Yesterday

Sentence ⟶ Syntax ⟶ USR

USR ⟶ semantic repres. 1

USR ⟶ semantic repres. 2

USR ⟶ semantic repres. 3

USR ⟶ semantic repres. 4

dominance graphs

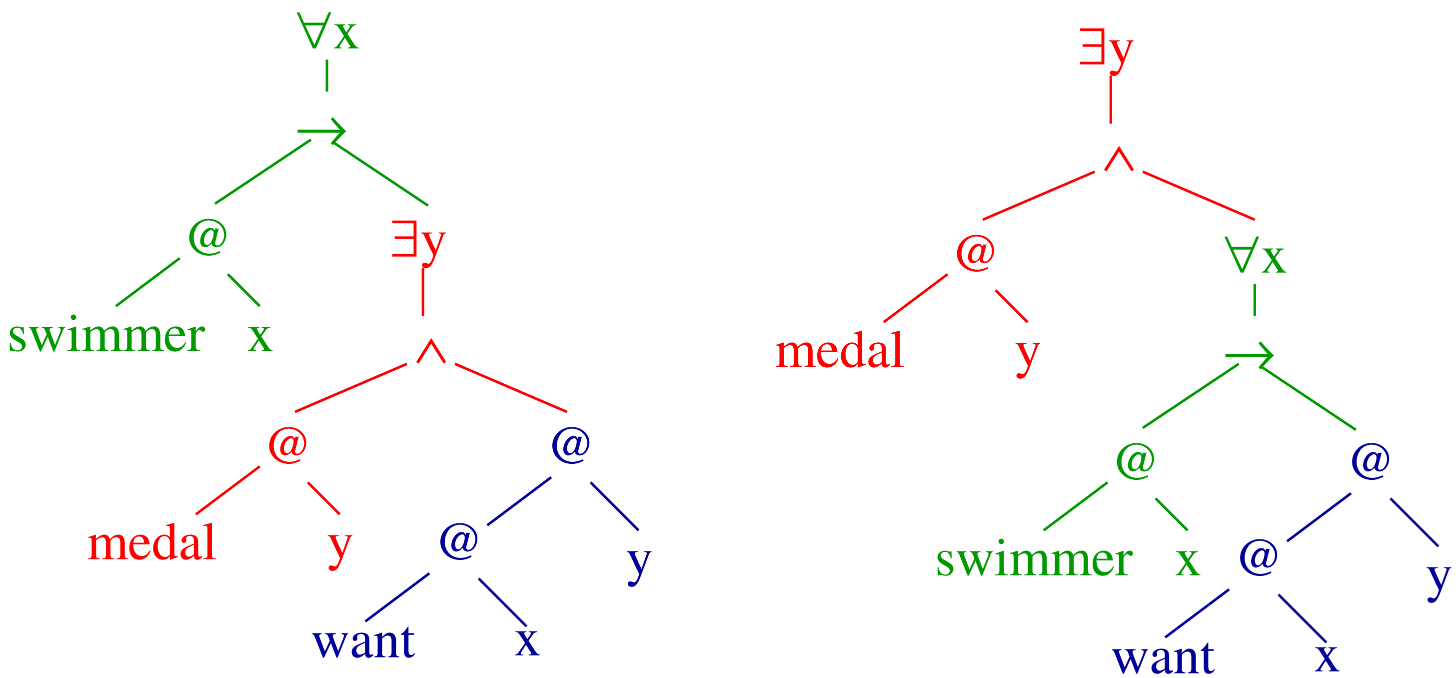
lambda structures

Recap: Yesterday

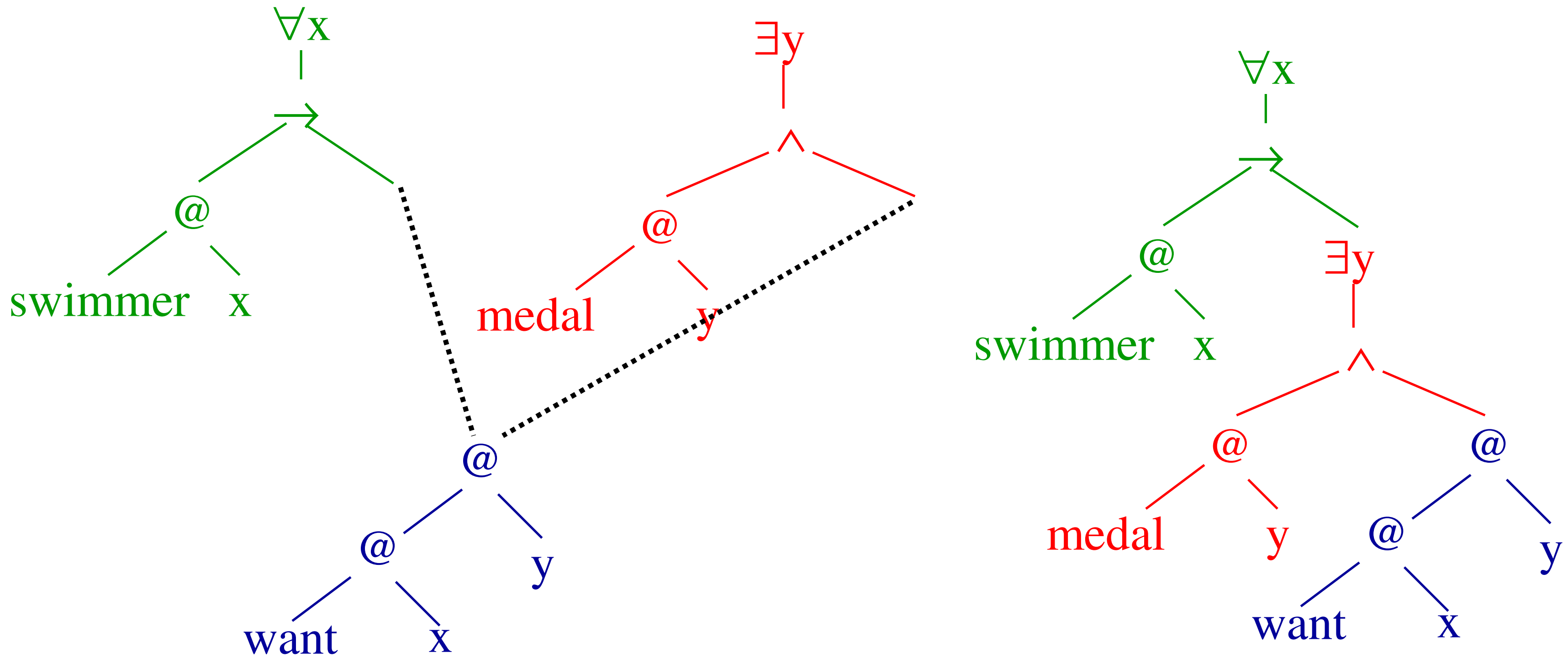
"Every swimmer wants a medal."

$\exists y\ \text{medal}(y) \wedge \forall x.\text{swimmer}(x) \rightarrow \text{want}(x,y)$

$\forall x.\text{swimmer}(x) \rightarrow \exists y\ \text{medal}(y) \wedge \text{want}(x,y)$



Recap: Yesterday



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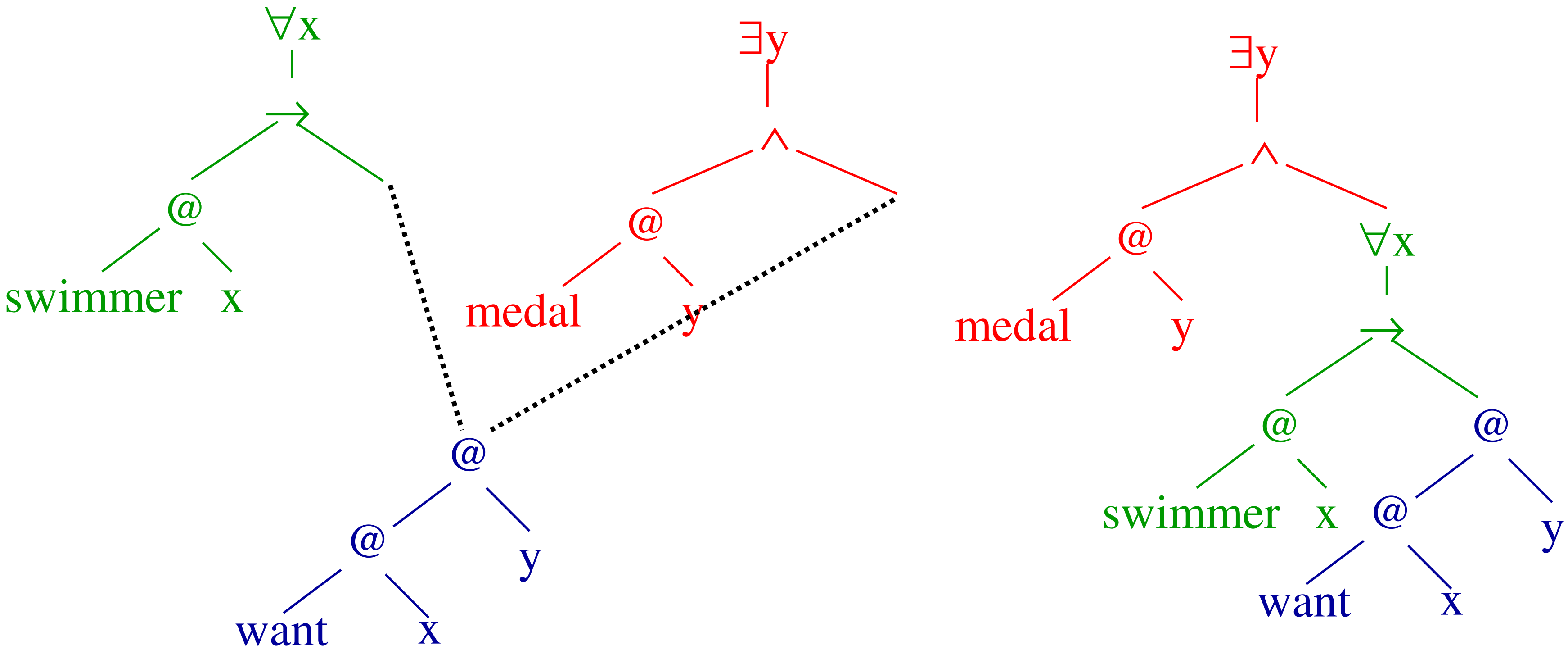
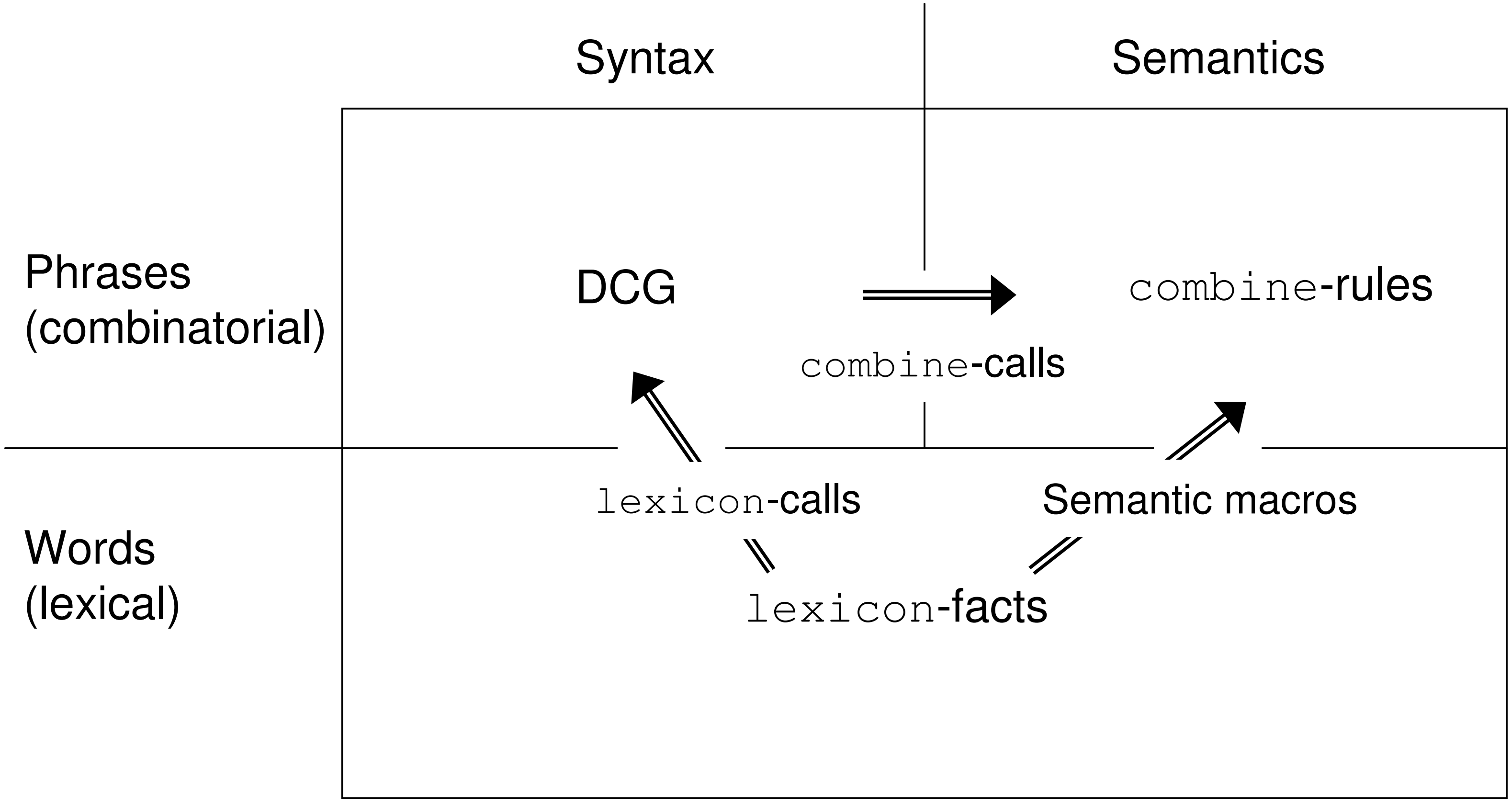


Semantics Construction

- First remaining question:
  - How do we construct a dominance graph from a syntactic analysis?
- We use Tuesday's modular syntax-semantics framework.
- Replace semantic macros and `combine` rules by new ones.

Semantics Construction Architecture



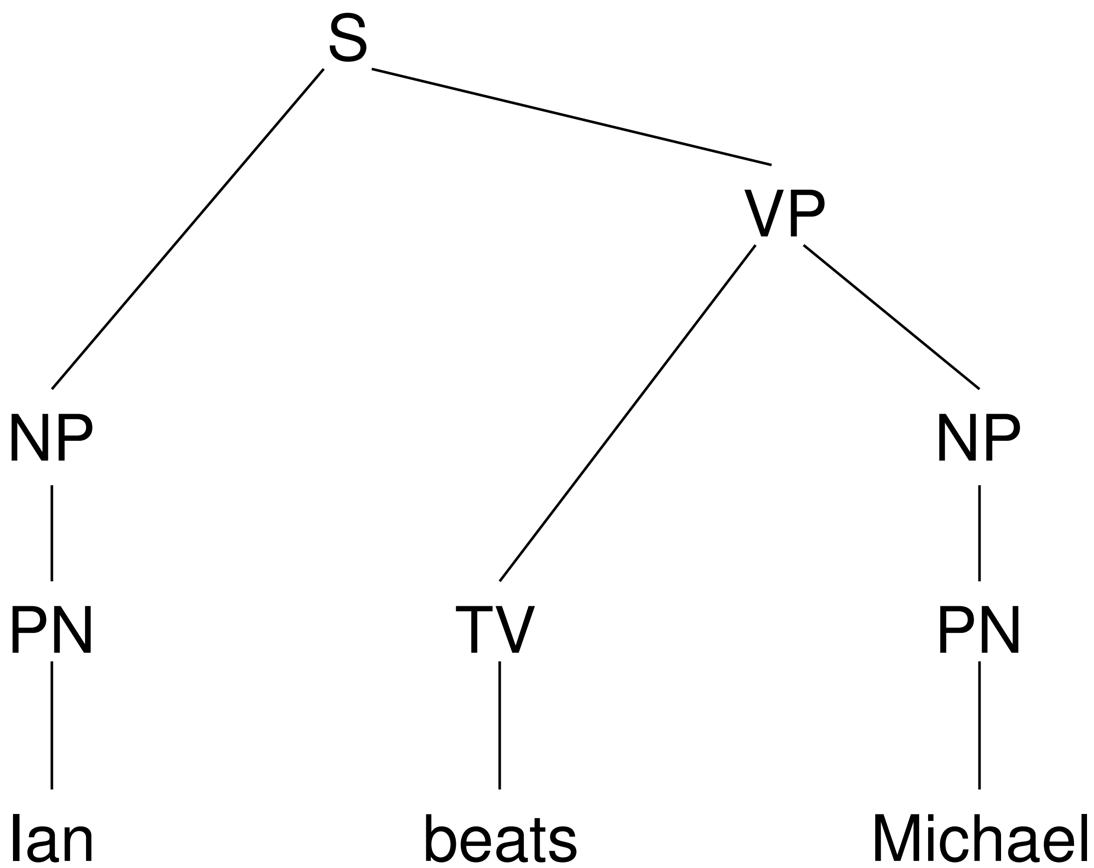
Semantics Construction: Principles

- We use exactly the same DCG grammar and lexicon facts as on Tuesday.
- For every node in the syntax tree, we derive a dominance graph that represents the semantic readings.
- Prolog representation of dominance graphs:

  `usr(Nodes, LCs, DCs, BCs)`

- First element of node list is the interface node (or root). Use this to connect the subgraph to other subgraphs.

A Simple Example



Semantic macros for the example

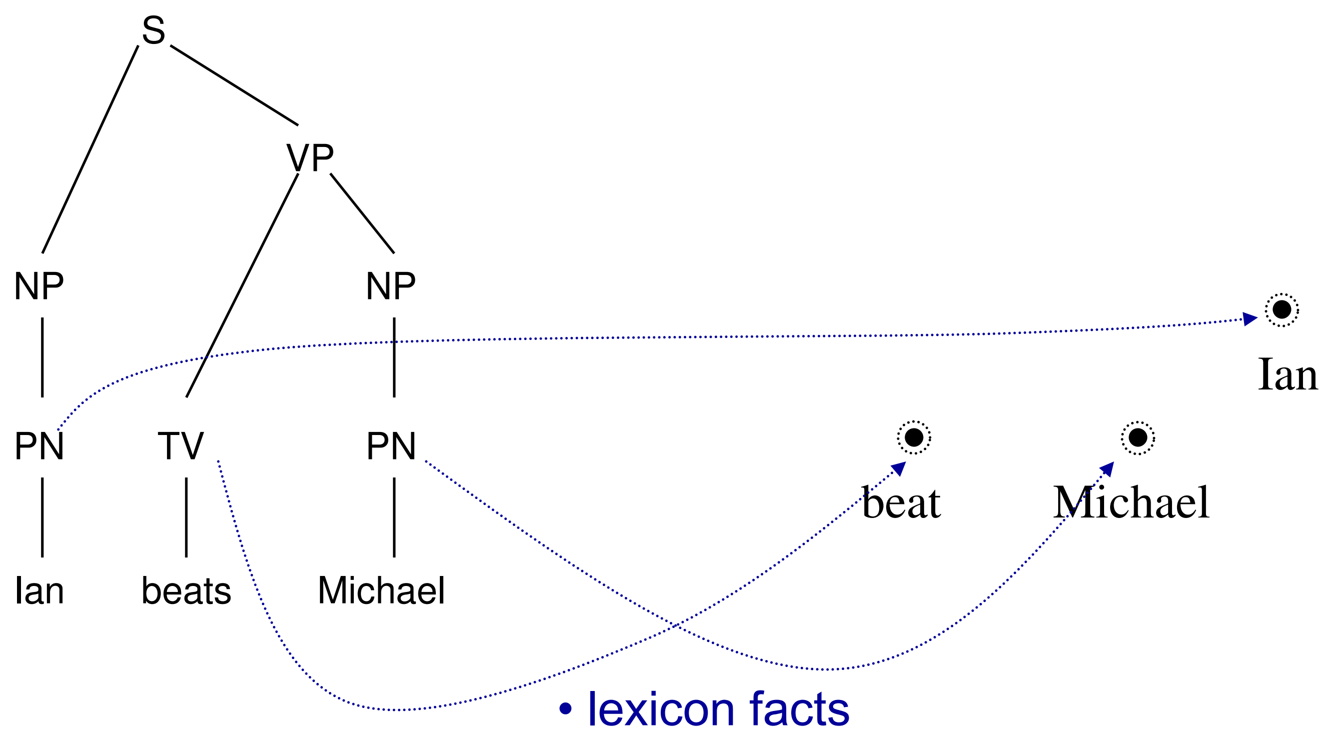
- Most semantic macros introduce graphs that have exactly one node, which is labelled by the "core semantics".
- Macro for proper names:

```
pnSem(Symbol,
        usr([Root],[Root:Symbol],[],[])).
```

- Macro for transitive verbs:

```
tvSem(Symbol,
        usr([Root],[Root:Symbol],[],[])).
```

Semantics construction: The simple example



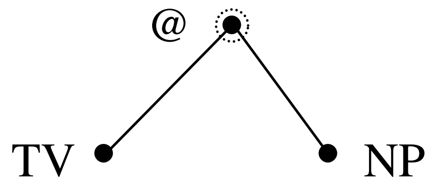
- lexicon facts
- semantic macros

Combining verbs and NPs

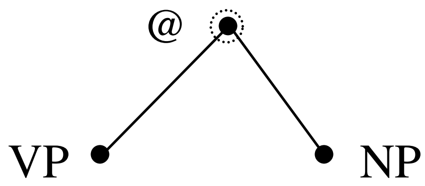
- General rule: The interface node of a graph for a noun phrase is the node that will be plugged into the verb as an argument.
- For proper names, this means we don't need to do any real work:

```
combine(np:NP, [pn:NP]).
```

Combine rules for verbs

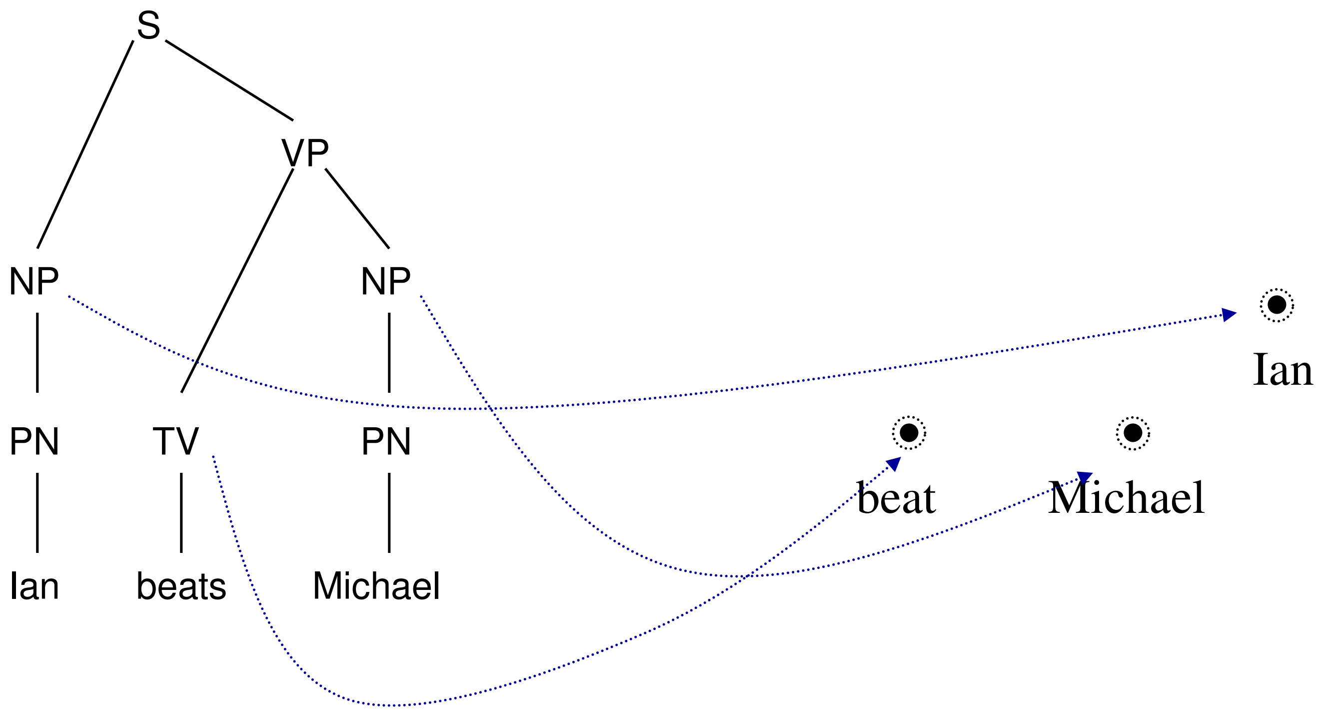



```
combine(vp:V,[tv:TV,np:NP]) :-
   TV = usr([TVRoot|_],_,_,_),
   NP = usr([NPRoot|_],_,_,_),
   NewUsr = usr([Root],[Root:(TVRoot@NPRoot)],
                 [],[]),
   mergeUSR([NewUsr,TV,NP],V).
```

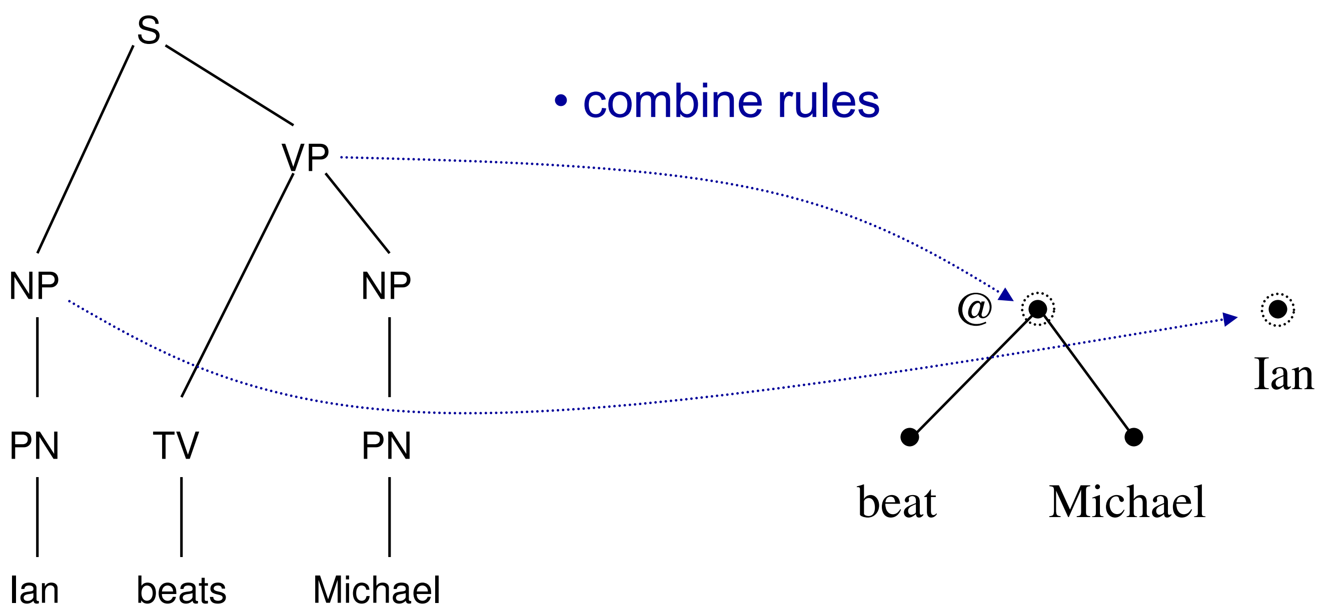



```
combine(s:S,[np:NP,vp:VP]) :-
   NP = usr([TVRoot|_],_,_,_),
   VP = usr([NPRoot|_],_,_,_),
   NewUsr = usr([Root],[Root:(VPRoot@NPRoot)],
                 [],[]),
   mergeUSR([NewUsr,NP,VP],S).
```

Semantics construction: The simple example

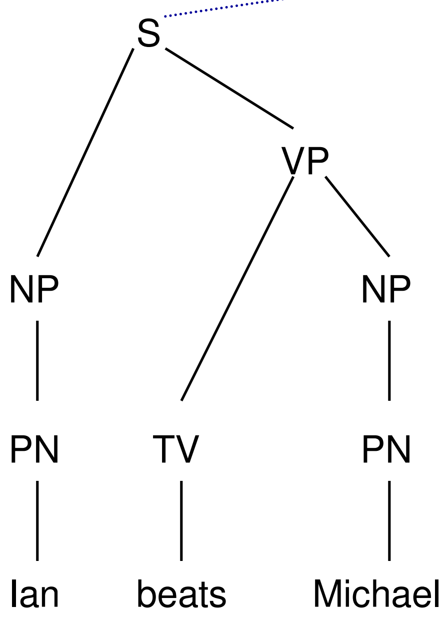


Semantics construction: The simple example

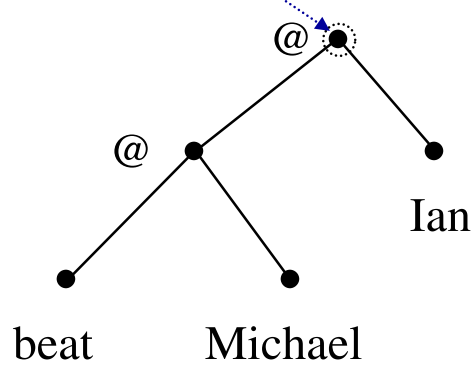


- combine rules

Semantics construction: The simple example

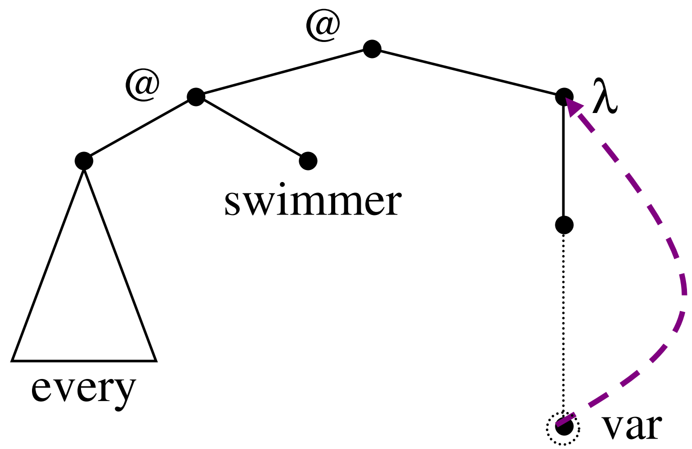


- combine rules



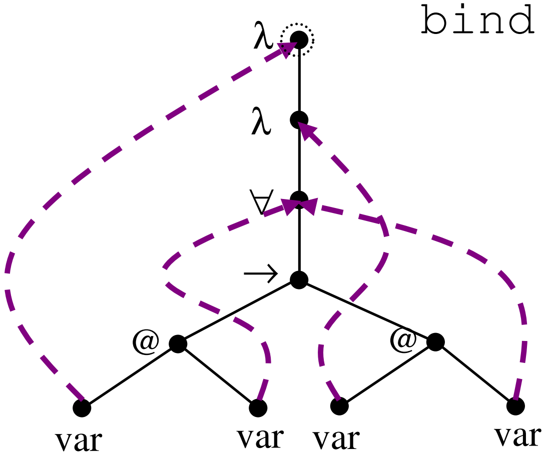
Quantifiers

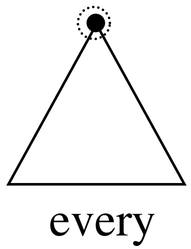
- The graph for a quantifier NP contains a variable node and its binder, linked by dominance and binding edges.
- The interface node of the graph is the variable node!



Semantic macro for determiners

```
detSem(uni,
          usr([Root,N1,N2,N3,N4,N5,N6,N7,N8,N9],
               [Root:lambda(N1),N1:lambda(N2),
                N2:forall(N3), N3:(N4 > N5),
                N4:(N6@N7), N5:(N8@N9), N6:var,
                N7:var, N8:var, N9:var],
               [],
               [bind(N6,Root),bind(N7,N2),
                bind(N8,N1),bind(N9,N2)])).
```

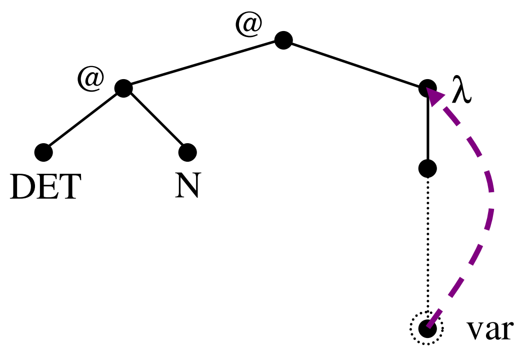




$\lambda P\ \lambda Q\ \forall x.(P@x \rightarrow Q@x)$

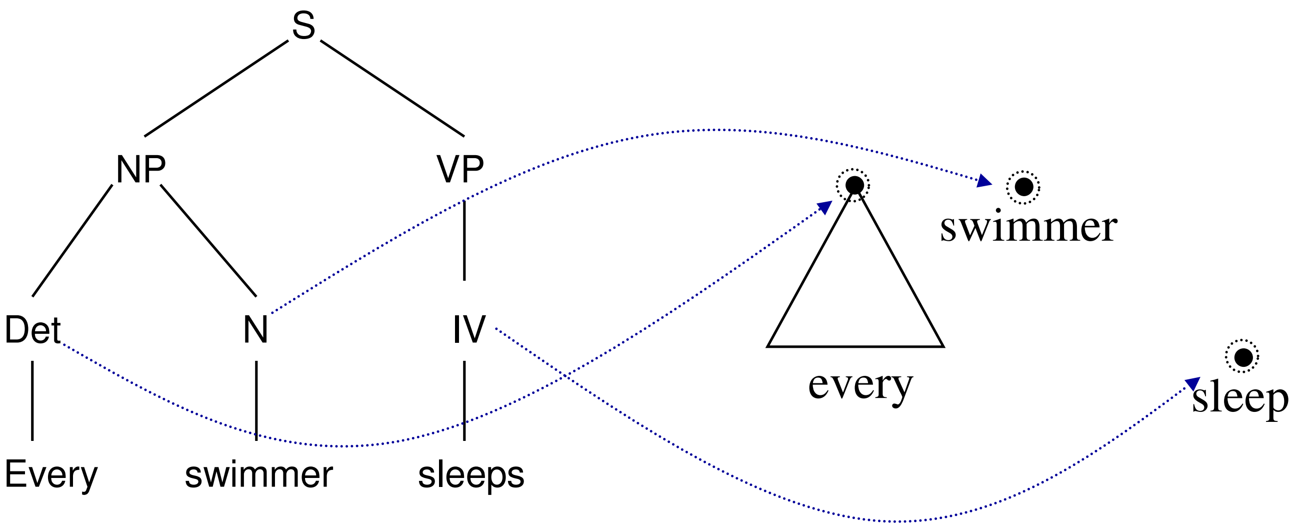
Combine rule for determiners

```
combine(np:NP,[det:DET,n:N]) :-
  DET = usr([DETRoot|_],_,_,_),
  N   = usr([NRoot|_],_,_,_),
  NewUsr = usr(........),
  mergeUSR([NewUsr,TV,NP],V).
```

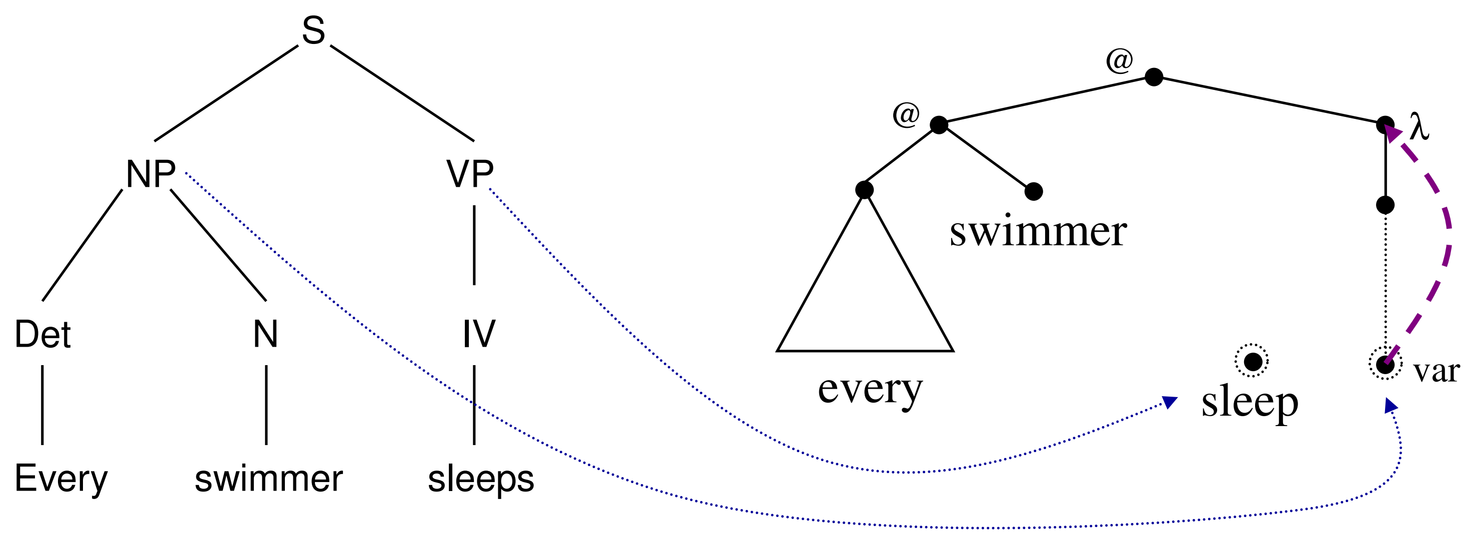


- This rule encodes Montague's Trick!

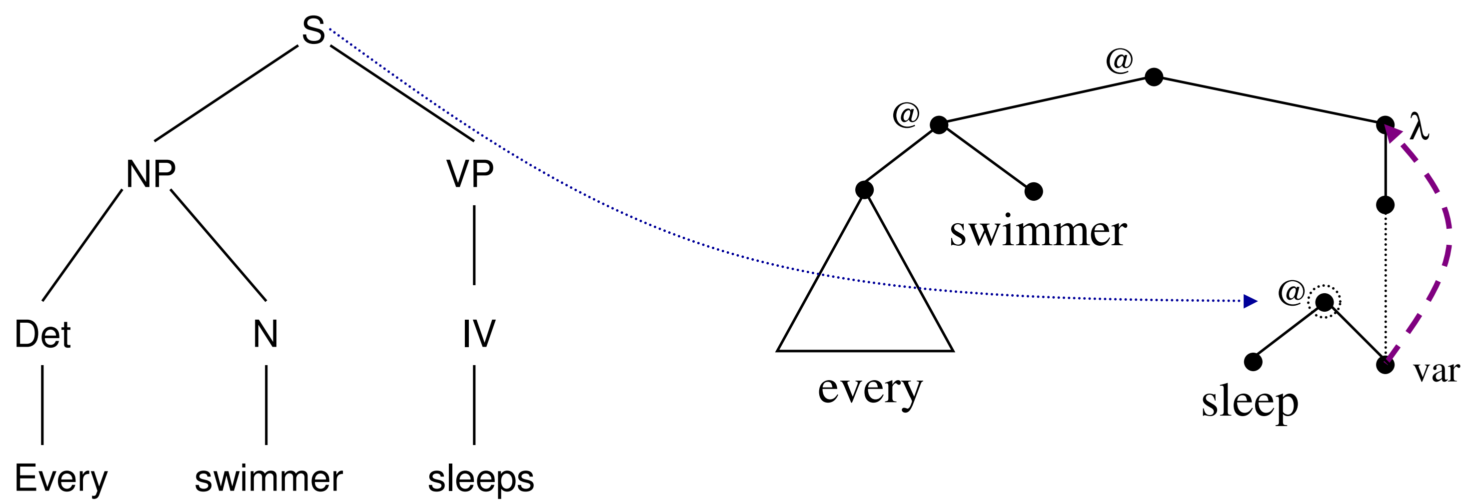
An example with determiners



An example with determiners

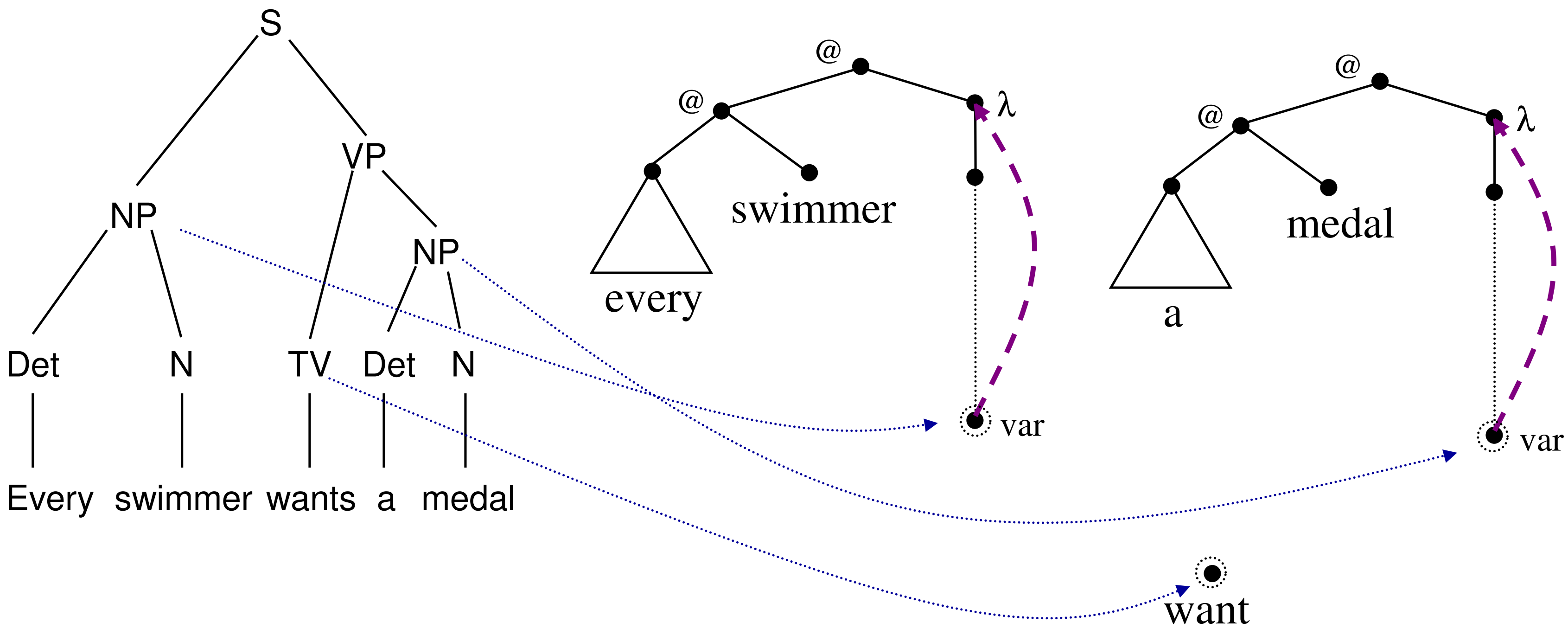


An example with determiners

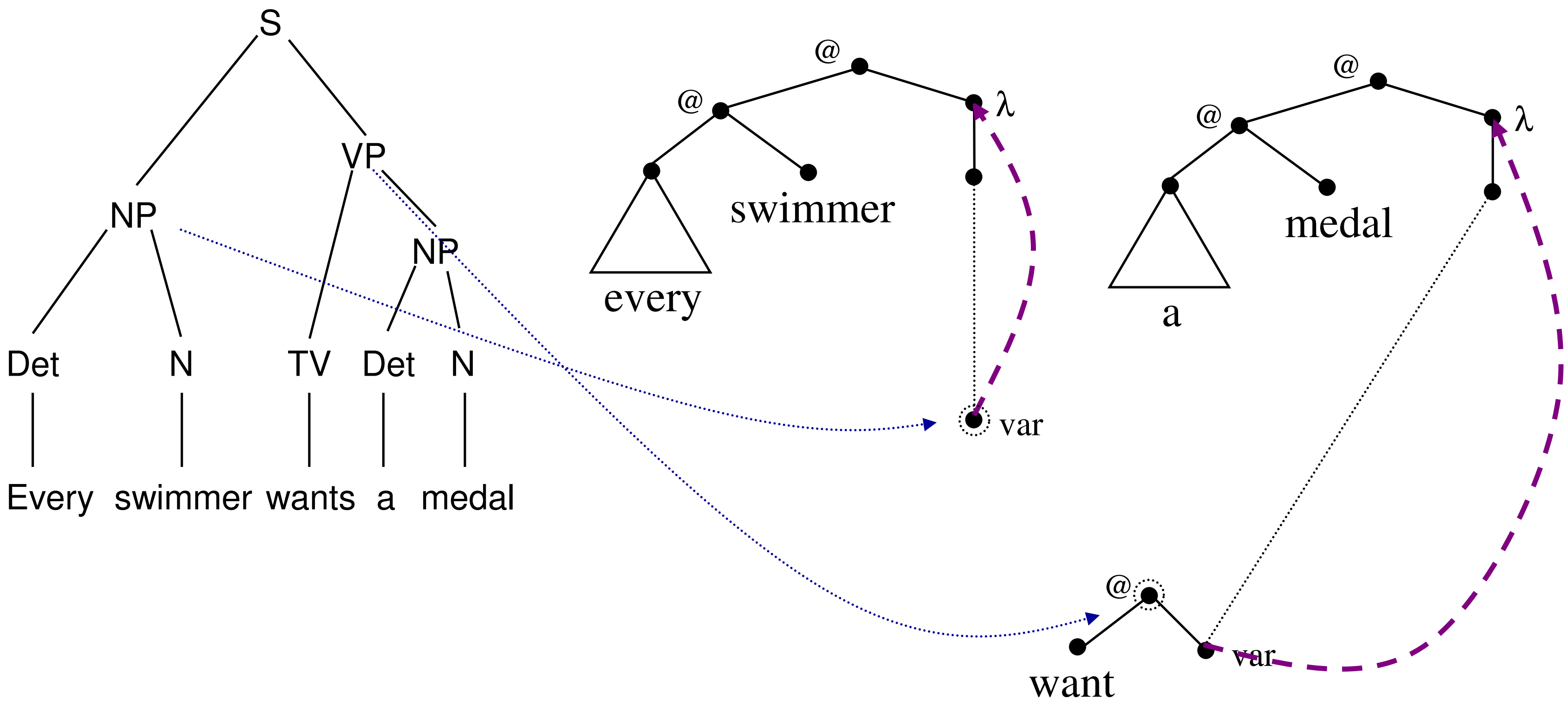


$$\lambda P\ \lambda Q\ \forall x.(P@x \rightarrow Q@x)$$
$$@\ swimmer$$
$$@\ (\lambda y.sleep@y)$$

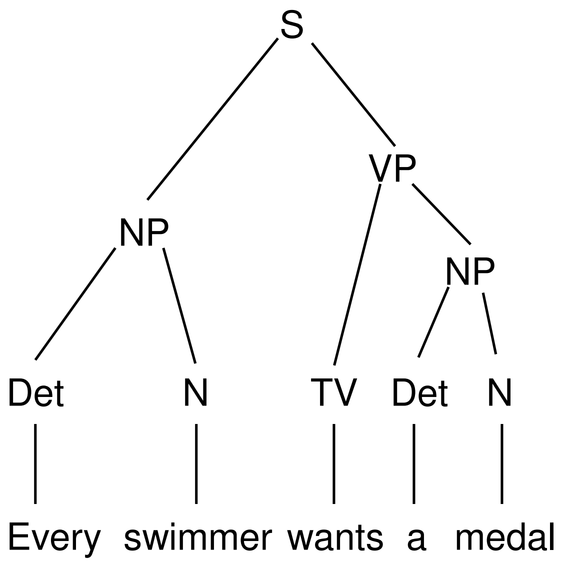
Scope ambiguities

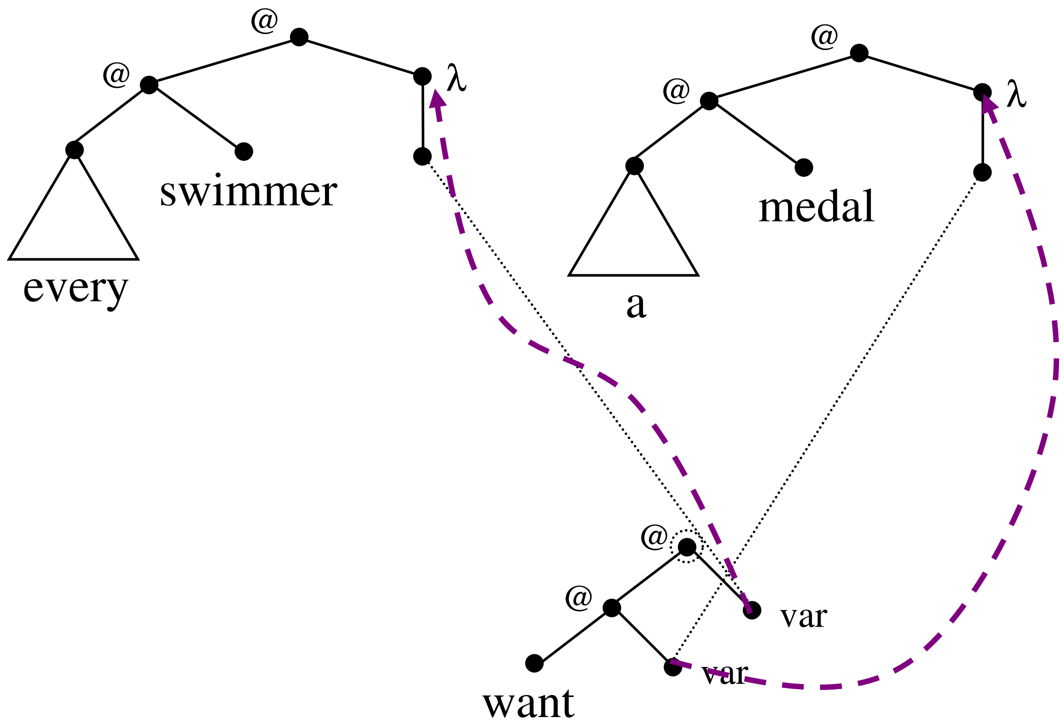


Scope ambiguities



Scope ambiguities





Semantics construction: Summary

- By plugging new rules into yesterday's syntax-semantics framework, we can compute dominance graphs for English sentences.
- Changed semantic macros to give us dominance graphs for lexicon entries.
- Combine rules plug subgraphs together by connecting their interface nodes.
- Always apply verb semantics to interface variable of an argument NP.

Underspecification in semantics construction

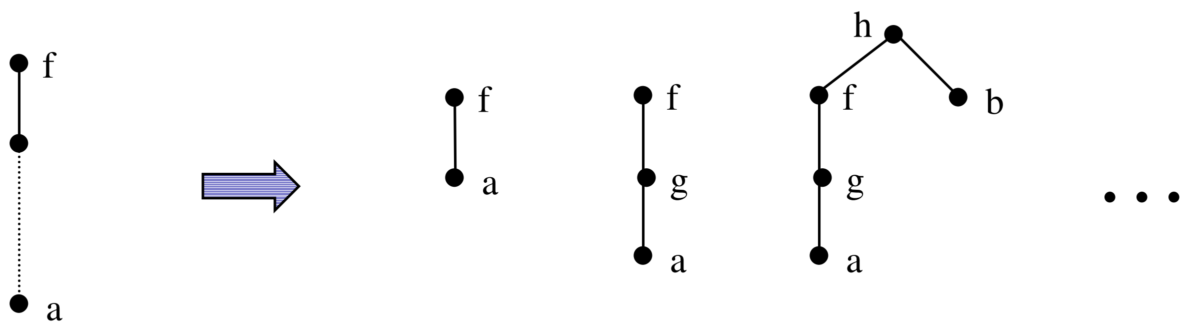
- Combine rule of determiners encodes Montague's Trick.
- Variable and binder are introduced together: No capturing necessary!
- Need fewer lambdas because we can now talk about positions in formulas explicitly.
- All large-scale grammars with semantics use some form of underspecification.

Solving Dominance Graphs

- Now we know
  - how to model scope ambiguities with dominance graphs
  - how to represent dominance graphs in Prolog
  - how to compute dominance graphs for English sentences.
- What's still missing: How to compute the trees (= formulas) that a graph represents?

Solved Forms

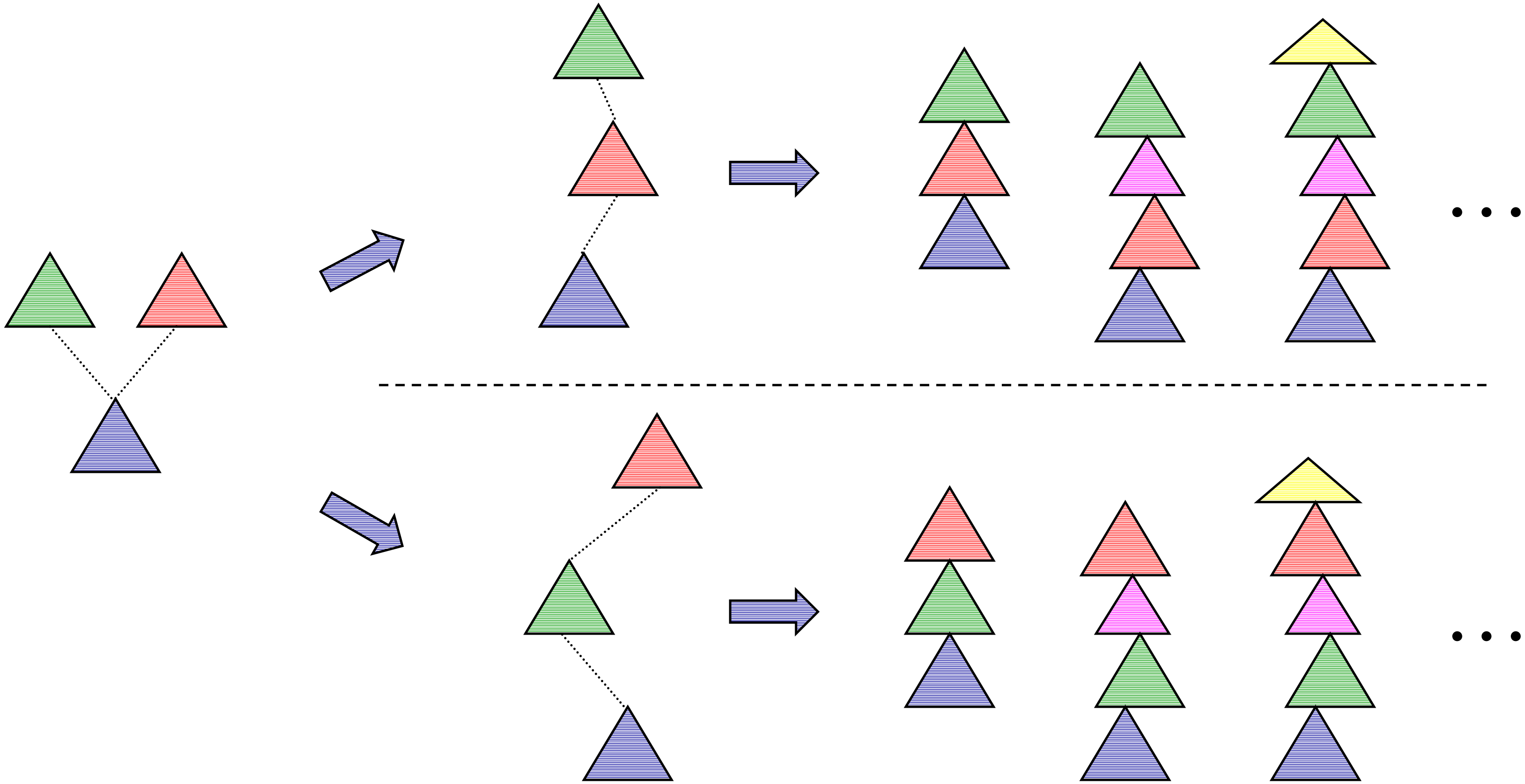
- We have seen yesterday that every solvable graph has an infinite number of solutions (= trees into which it can be embedded).



Solved Forms

- 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 are a forest.
- A graph G' is a solved form of G iff G' is in solved form and if 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



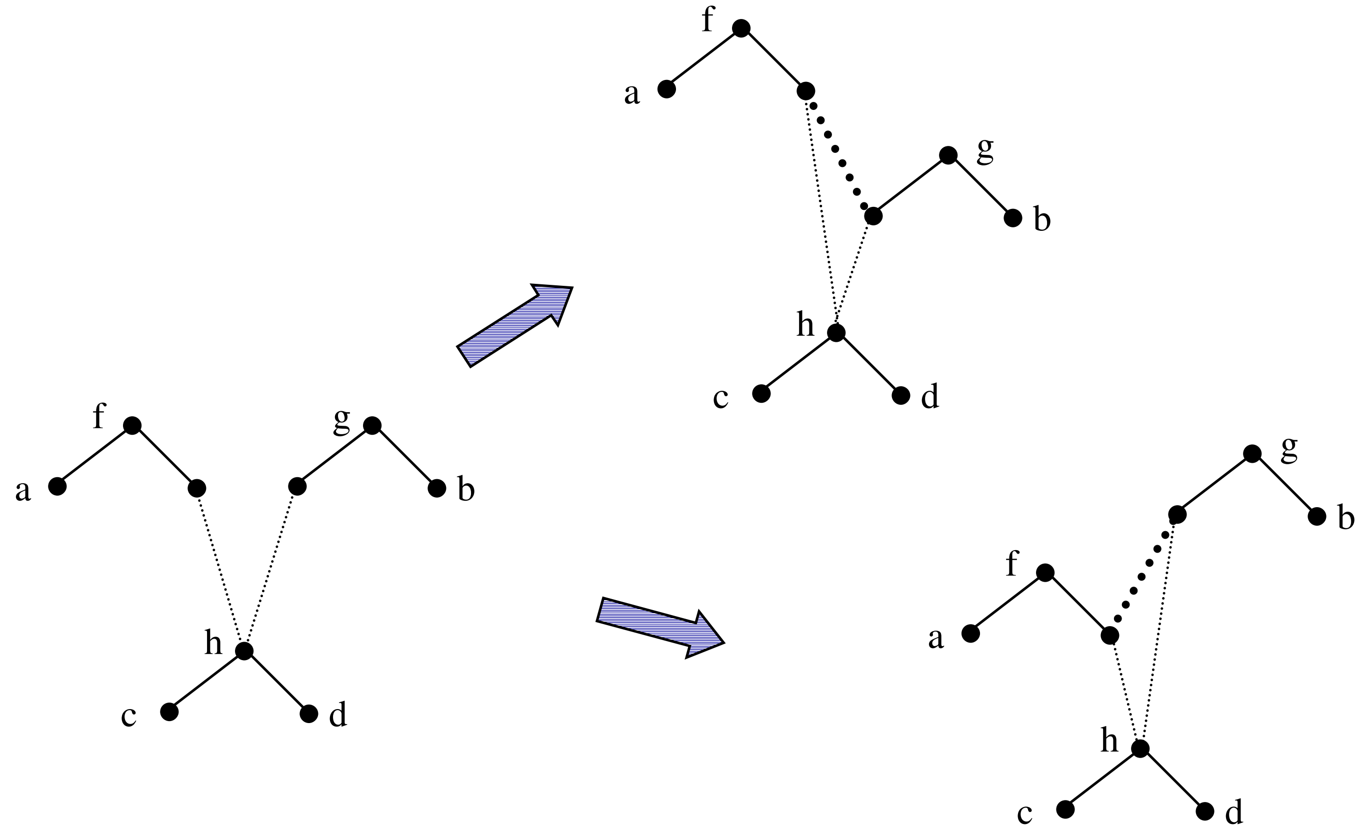
- Can consider solved forms as representatives of classes of solutions that only differ in "irrelevant details".

Solving Dominance Graphs

- Solver algorithm applies three graph simplification rules and then calls itself recursively:
  - Choice
  - Parent Normalisation
  - Redundancy Elimination
- Detect unsolvability: Test for cycles.
- Prolog implementation.

The Choice Rule

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

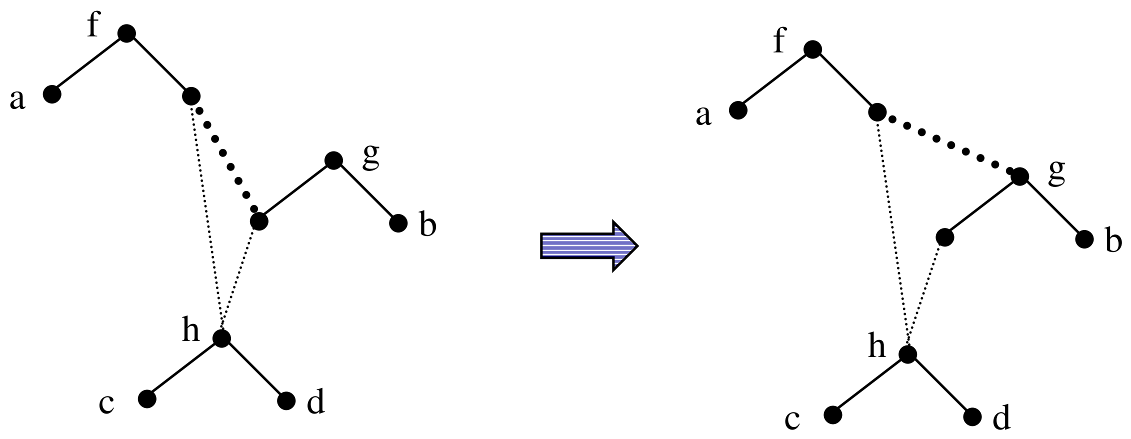


The Choice Rule

- Every application of Choice arranges the dominance parents of one node.
- Eventually, the dominance parents of all nodes will be arranged.
- Choice rule is sound: Every tree that satisfies original graph also satisfies one of the two possible results of the Choice application.

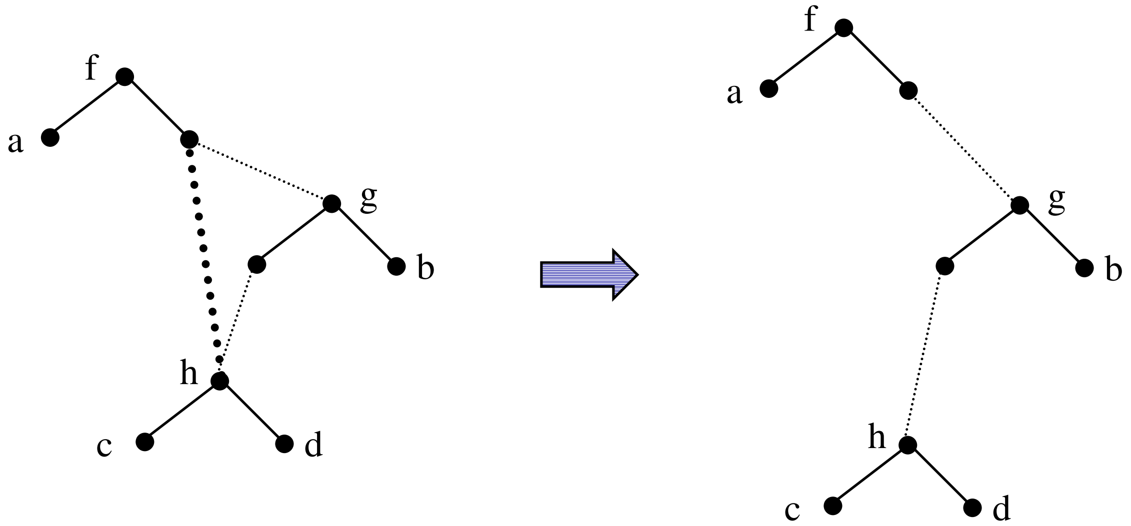
Cleaning Up I: Parent Normalisation

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



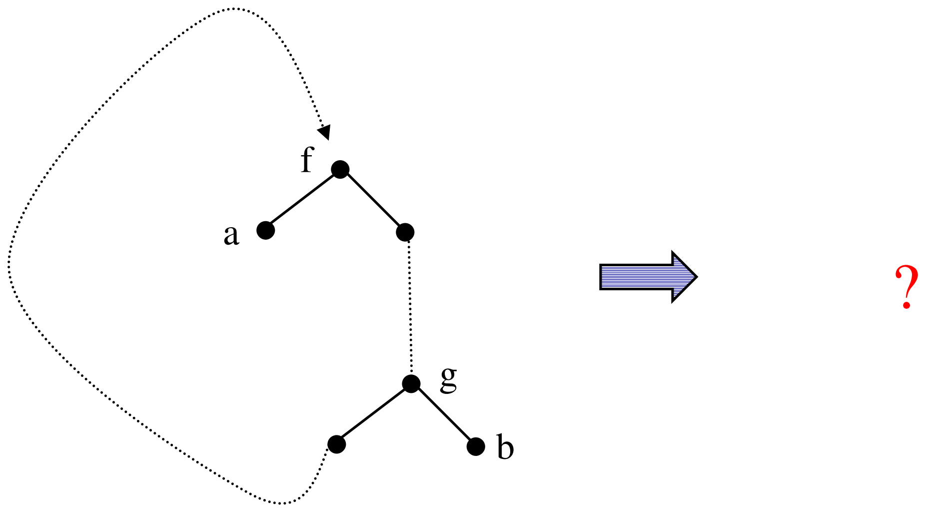
Cleaning Up II: Redundancy Elimination

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



Detecting Unsolvability

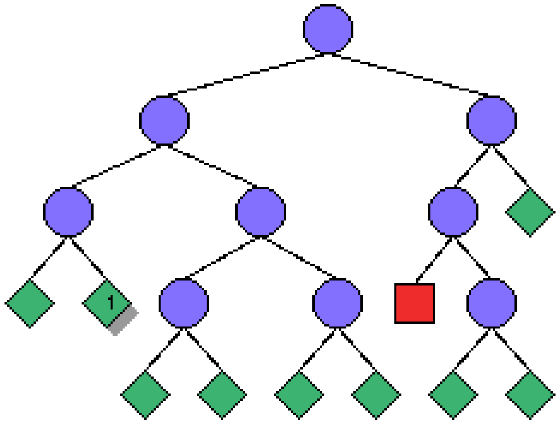
- Every dominance graph that has a cycle (using only tree and dominance edges) is unsolvable.



The Enumeration Algorithm

1. Apply Redundancy Elimination and Parent Normalisation exhaustively.
2. If the graph has a cycle, it is unsolvable.
3. If there is a node with two incoming dominance edges, pick one and apply Choice once. Then continue with Step 1 for each of the resulting graphs.
4. Otherwise, the dominance graph is in solved form.

Search Tree



The Algorithm in Prolog

Input:
An USR

Output:
List of solved forms

```
solve(Usr, SFs) :-
    normalize(Usr, NormalUsr),
    distribute(NormalUsr, Dist1, Dist2),
    solve(Dist1, SFs1),
    solve(Dist2, SFs2),
    append(SFs1, SFs2, SFs).
```

Case 1:
Choice applicable

```
solve(Usr, [NormalUsr]) :-
    normalize(Usr, NormalUsr),
    \+ hasCycle(NormalUsr).
```

Case 2:
Solved Form

```
solve(_Usr, []).
```

Case 3:
Cycle

Subroutines

- The algorithm uses some other predicates. These are all available on the course website.
- Here we look at
  - distribute
  - elimRedundancy

The predicate "distribute"

```
distribute(usr(Ns,LCs,DCs,BCs),
           usr(Ns,LCs,[dom(X,Y)|DCs],BCs),
           usr(Ns,LCs,[dom(Y,X)|DCs],BCs)) :-

   member(dom(X,Z), DCs),
   member(dom(Y,Z), DCs),
   X \== Y.
```

The predicate "elimRedundancy"

```
normalize(Usr, Normal) :-
    parentNormalization(Usr, Lifted),
    elimRedundancy(Lifted, Normal).



elimRedundancy(usr(Ns,LCs,DCs,BCs), Irr) :-
    select(dom(X,Y), DCs, DCsRest),
    reachable(Y,X,usr(Ns,LCs,DCsRest,BCs)),
    !,
    elimRedundancy(usr(Ns,LCs,DCsRest,BCs), Irr).

elimRedundancy(Usr,Usr).
```

A Note on Efficiency

- The implementation is correct, but:
  - checking for cycles is not a complete unsatisfiability test: Search space may be too large.
  - Redundancy Elimination, Choice, etc. are not implemented efficiently.
- Both problems can be solved. Best current implementations enumerate over 100.000 solved forms per second (Bodirsky et al. 2004).

A Note on Formalisms

- Dominance graphs are equivalent to normal dominance constraints (Althaus et al. 03; Egg et al. 01).
- Hole Semantics (Bos 96) can be encoded into normal dominance constraints (Koller et al. 03).
- MRS (Copestake et al. 99) can be encoded into normal dominance constraints (Niehren & Thater 03; Fuchss et al. 04).

Summary

- Semantics construction for dominance graphs:
  - use Tuesday's framework
  - use interface nodes to combine subgraphs
  - clean construction that introduces variables and binders together.
- Solving dominance graphs:
  - enumerate solved forms
  - driving force is Choice rule
  - Prolog implementation very concise
  - can be made efficient (not in Prolog)

State of the art in underspecification

- Well-understood formalisms.
- Efficient solvers are available.
- Large-scale grammars that compute underspecified semantic descriptions are available: e.g. English Resource Grammar (Copestake & Flickinger, 2000).
- Used, in one form or another, in most major grammars that define semantics.