Logic-Based Parsing with Neural Networks

Compositional Models of Vector-based Semantics

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☮ Certified

no military applications/funding

The agenda

- exploring Æthel
- parsing with graph learning machinery

Types

ILL$_{\multimap}$ plus $\Diamond, \Box$ modalities for *dependency domain demarkation*.

$\mathbb{T}$ inductively defined as:

$$\mathbb{T} := A \mid T \multimap T \mid \Diamond^d T \mid \Box^d T \qquad A \in \mathbb{A}, T \in \mathbb{T}$$

- $\mathbb{A}$ – closed set of base types
- $\multimap$ – linear function builder
- $\Diamond$ – reserved for "necessary arguments", i.e. complements
- $\Box$ – reserved for "optional functors", i.e. adjuncts

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Rules & Terms

- 😃 function/argument structures

$$\frac{}{\mathtt{c} : T \vdash \mathtt{c} : T}\ Lex \qquad \frac{\Gamma \vdash \mathtt{s} : T_1 \multimap T_2 \quad \Delta \vdash \mathtt{t} : T_1}{\Gamma, \Delta \vdash \mathtt{s}\ \mathtt{t} : T_2} \multimap E$$

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- ☺ simple dependency demarkation

$$\frac{\Gamma \vdash \texttt{t} : T}{\langle \Gamma \rangle^d \vdash \triangle^d\, \texttt{t} : \Diamond^d T}\ \Diamond^d I \qquad \frac{\Gamma \vdash \texttt{s} : \Box^d T}{\langle \Gamma \rangle^d \vdash \blacktriangledown^d \texttt{s} : T}\ \Box^d E$$

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😐 hypothetical reasoning

$$\frac{}{\mathtt{x} : T \vdash \mathtt{x} : T}\ Ax \qquad \frac{\Gamma, \mathtt{x} : T_1 \vdash \mathtt{s} : T_2}{\Gamma \vdash \lambda \mathtt{x}.\mathtt{s} : T_1 \multimap T_2} \multimap I$$

Rules & Terms

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😱 cosmic horror from the great beyond

$$\frac{\langle \Gamma \rangle^d \vdash \mathtt{s} : T}{\Gamma \vdash \blacktriangle^d \mathtt{s} : \Box^d T}\ \Box^d I \qquad \frac{\Gamma[\langle \mathtt{x} : T_1 \rangle^d] \vdash \mathtt{t} : T_2 \qquad \Delta \vdash \mathtt{s} : \Diamond^d T_1}{\Gamma[\Delta] \vdash \mathtt{t}[\mathtt{x} \mapsto \triangledown^d \mathtt{s}] : T_2}\ \Diamond^d E$$

Rules & Terms

Bonus:

ad-hoc extraction

$$\frac{\langle \Gamma, \langle \mathtt{x} : T_1 \rangle^{\mathsf{X}}, \Delta \rangle^{d} \vdash \mathtt{s} : T_2}{\langle \Gamma, \Delta \rangle^{d}, \langle \mathtt{x} : T_1 \rangle^{\mathsf{X}} \vdash \mathtt{s} : T_2} \; \mathsf{X}$$

Today's Example

alt-tab

Formula Decomposition: Types ≡ Trees

The type assignment of *"where"*:

$$\diamondsuit^{relcl}(\diamondsuit^{x}\square^{x}\diamondsuit^{mod}\square^{mod}(ppart \multimap ppart) \multimap ssub) \multimap \square^{mod}(np \multimap np)$$

Formula Decomposition: Types ≡ Trees

The type assignment of *"where"*:

$$\Diamond^{relcl}(!^{x}!^{mod}(ppart \multimap ppart) \multimap ssub) \multimap \Box^{mod}(np \multimap np)$$

$$!(_) := \Diamond\Box(_)$$

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$\multimap$

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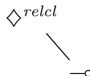

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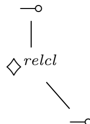

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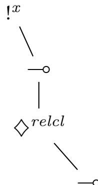

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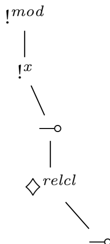

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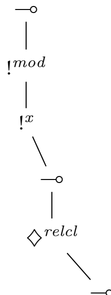

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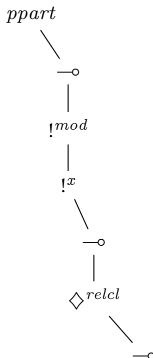

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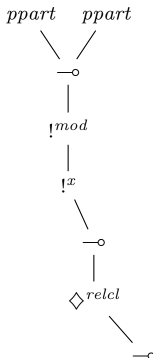

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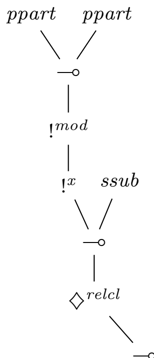

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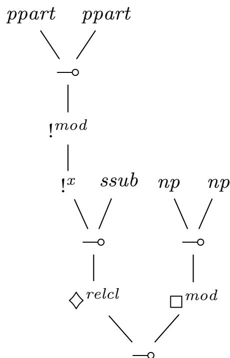
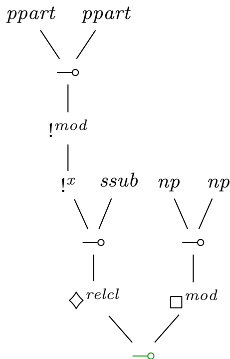


Formula Decomposition: Polarity Induction

subtree polarity (*preserved* to the right, *inverted* to the left)

+ we have
- we miss



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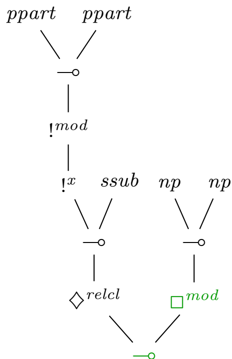

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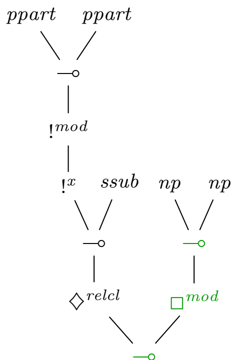

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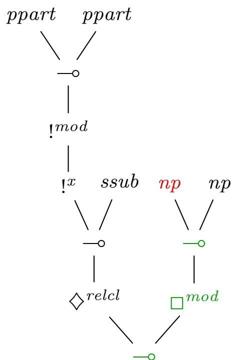

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$ppart$ $ppart$

$\multimap$

$!^{mod}$

$!^{x}$ $ssub$ np np

$\multimap$ $\multimap$

$\Diamond^{relcl}$ $\Box^{mod}$

$\multimap$

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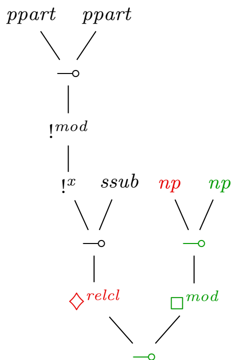

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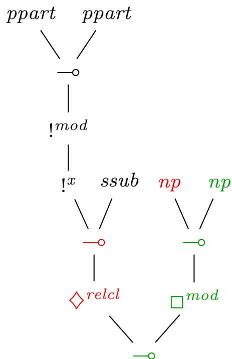

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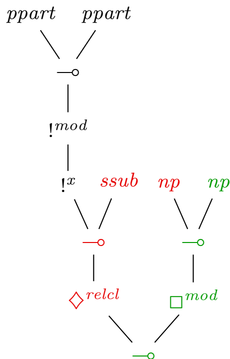

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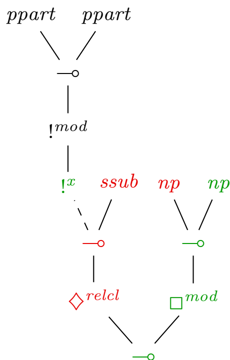

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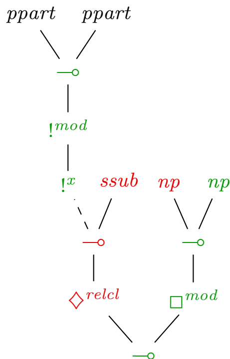

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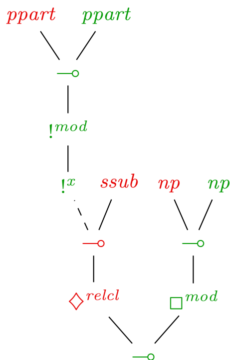
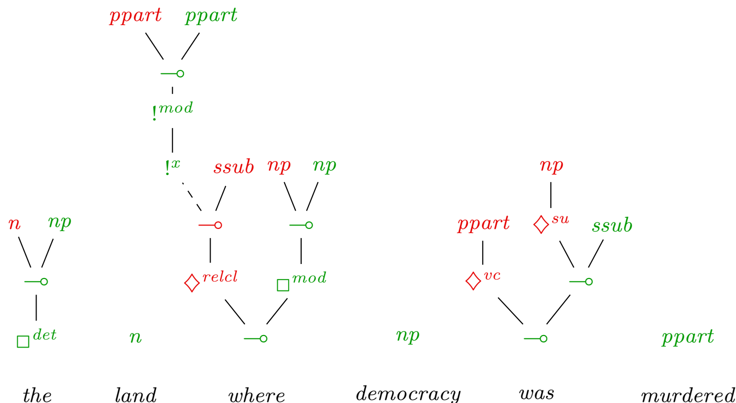


Proof Frames



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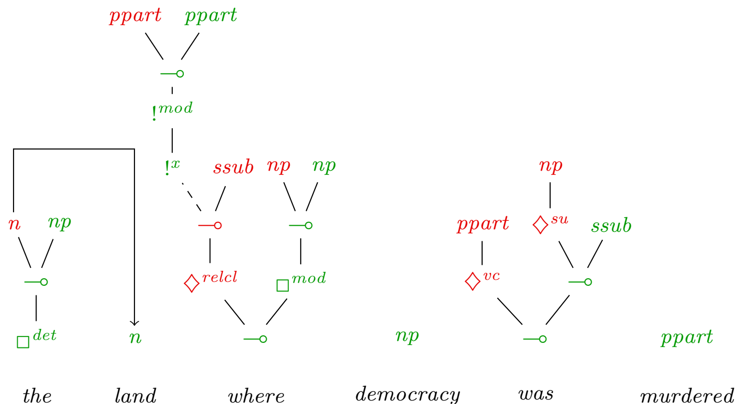

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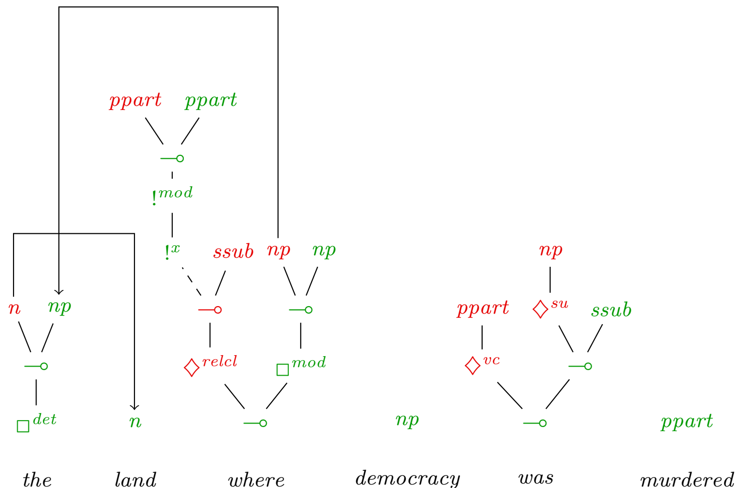

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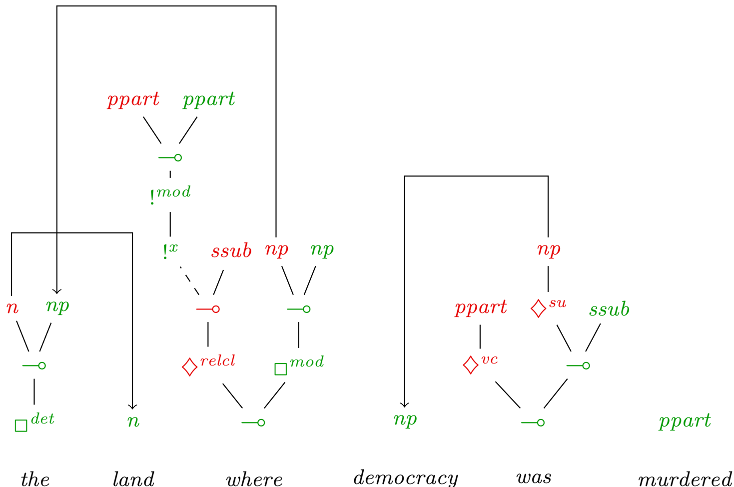

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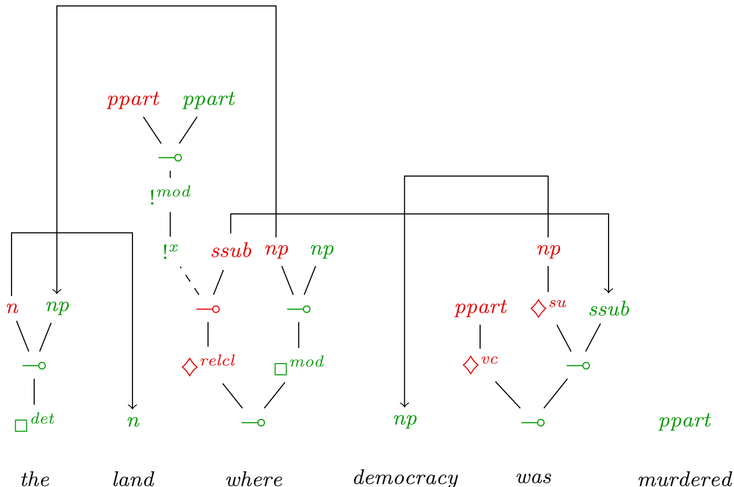

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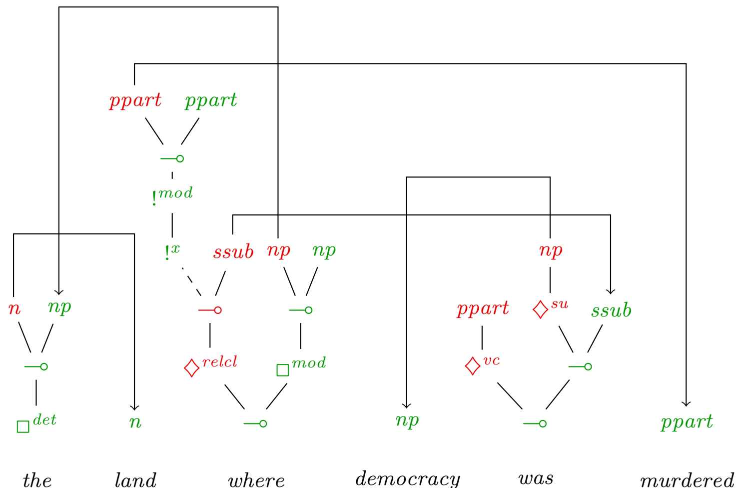

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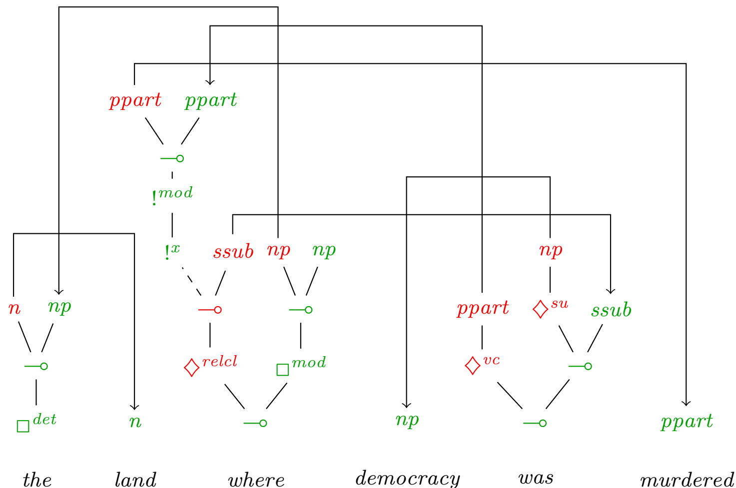

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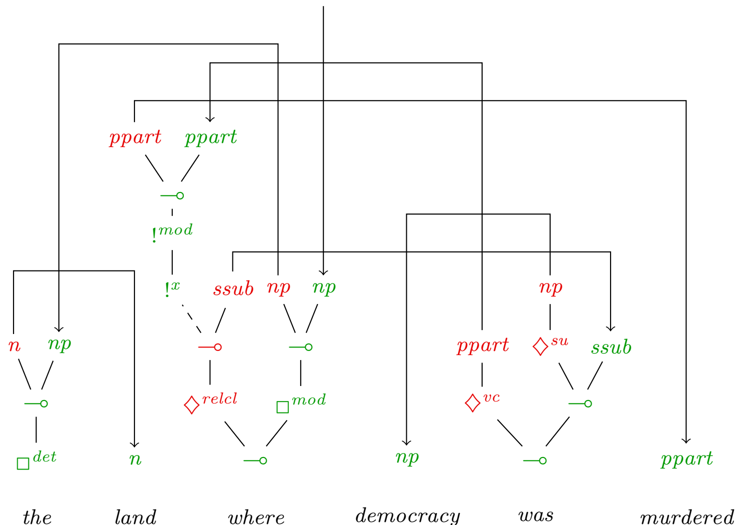
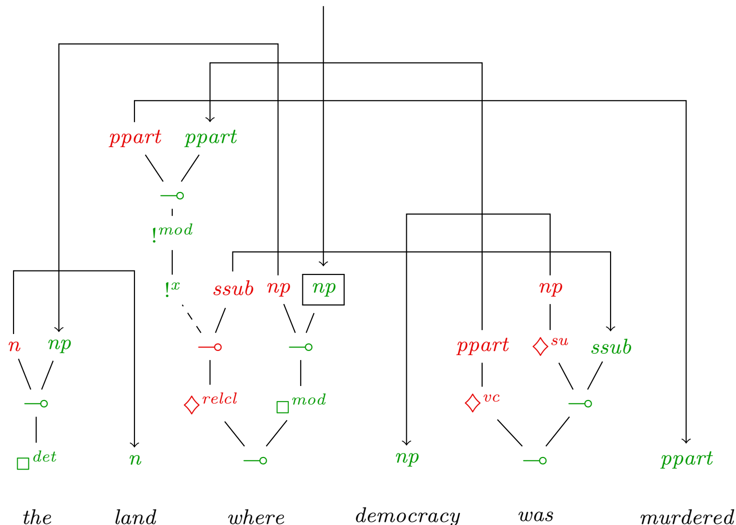


Proof ~~Frames~~ Structures



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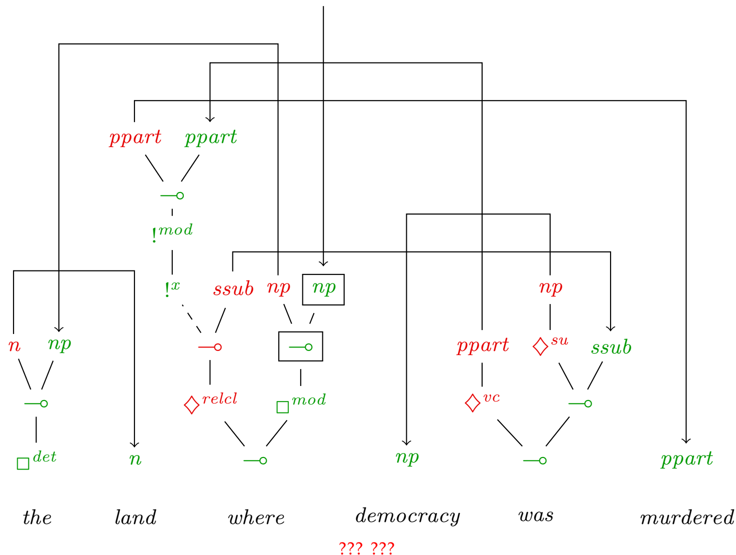

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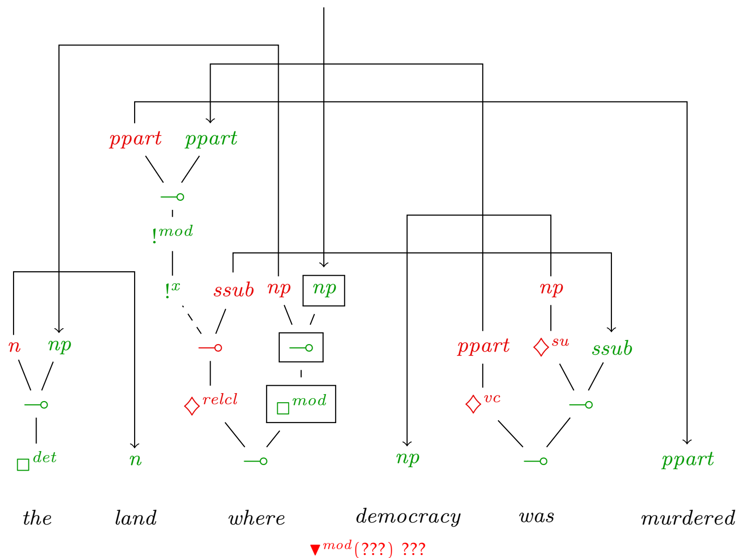

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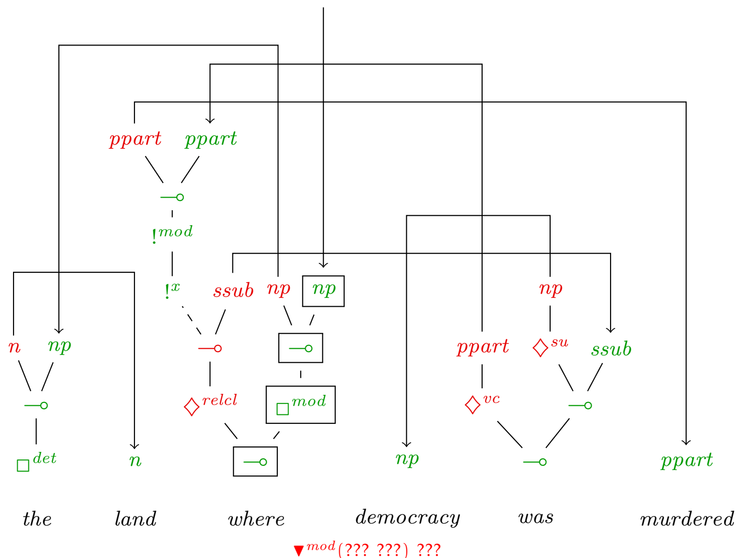

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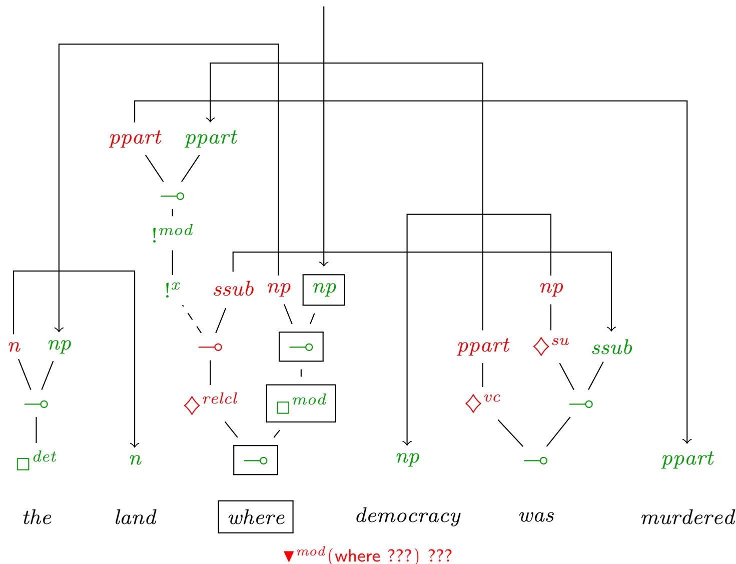

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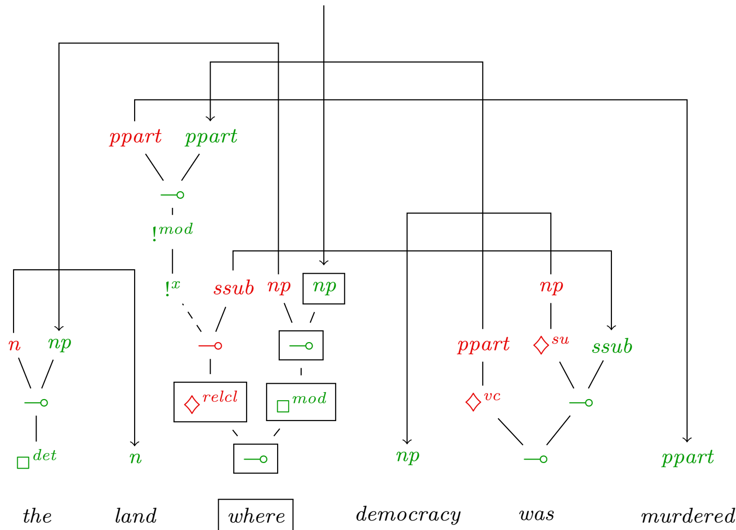

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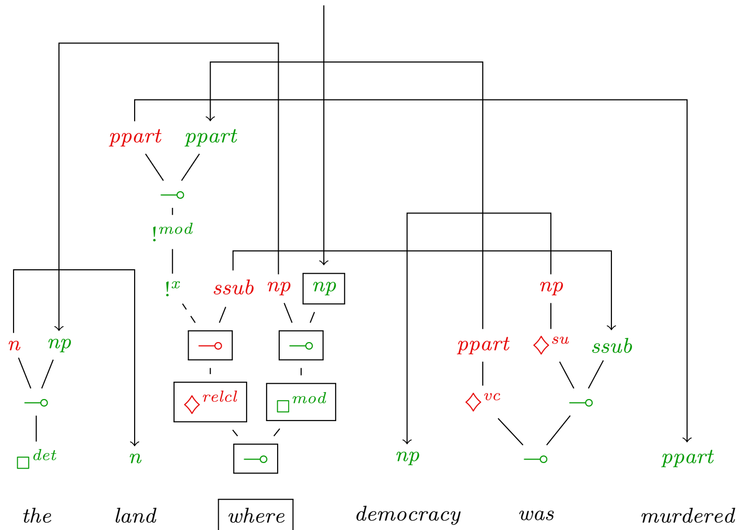
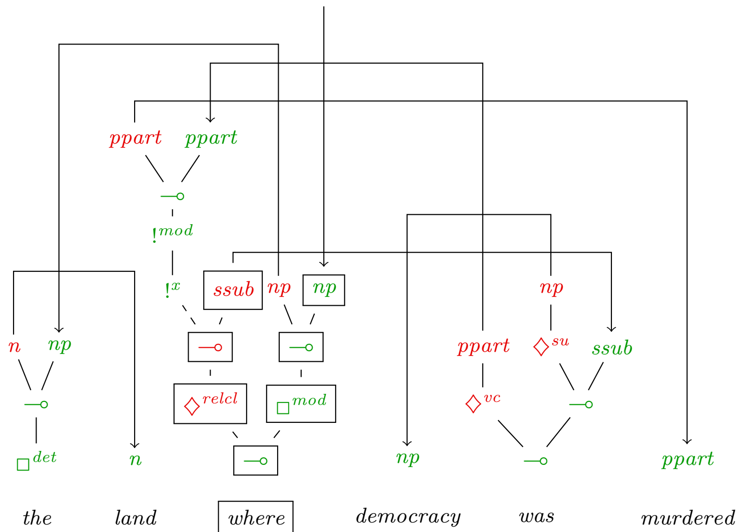


$\blacktriangledown^{mod}$(where $\triangle^{relcl}$ $(\lambda x_0.(???)))$???

Proof ~~Frames~~ Structures



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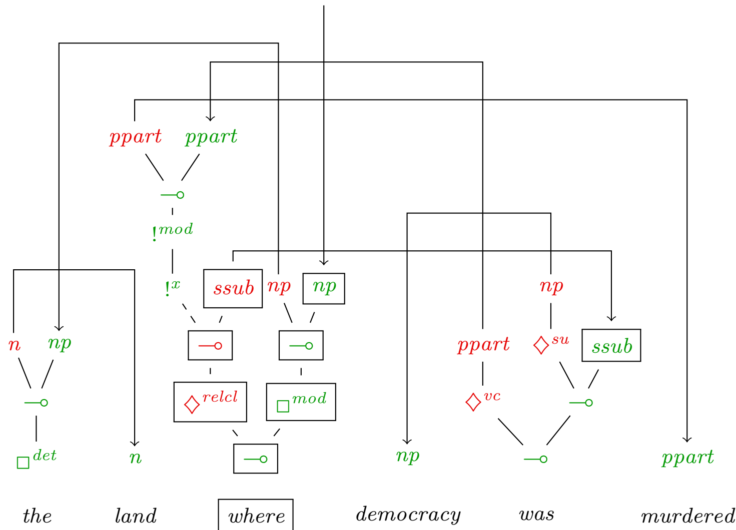


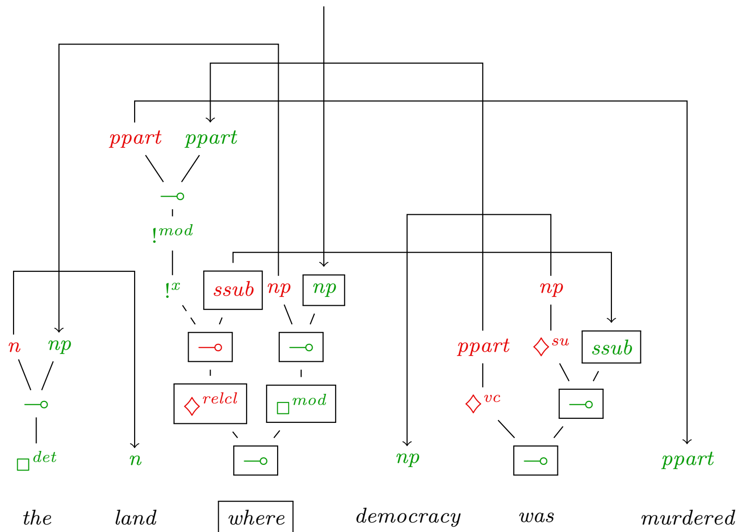
Proof ~~Frames~~ Structures

ppart ppart
$!^{mod}$
$!^{x}$ ssub np np
n np
ppart $\Diamond^{su}$ ssub
np
$\Diamond^{relcl}$ $\Box^{mod}$
$\Diamond^{vc}$
$\Box^{det}$ n np ppart

the *land* *where* *democracy* *was* *murdered*

$\blacktriangledown^{mod}$(where $\triangle^{relcl}$ (λx_0.(??? ???))) ???

Proof ~~Frames~~ Structures



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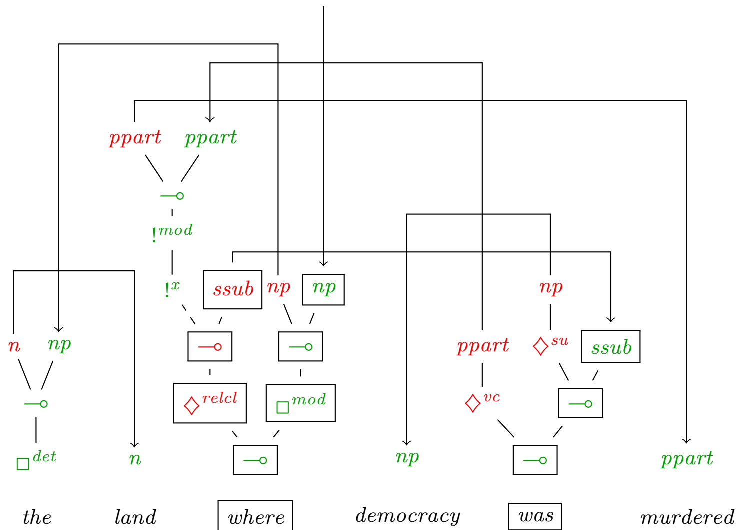

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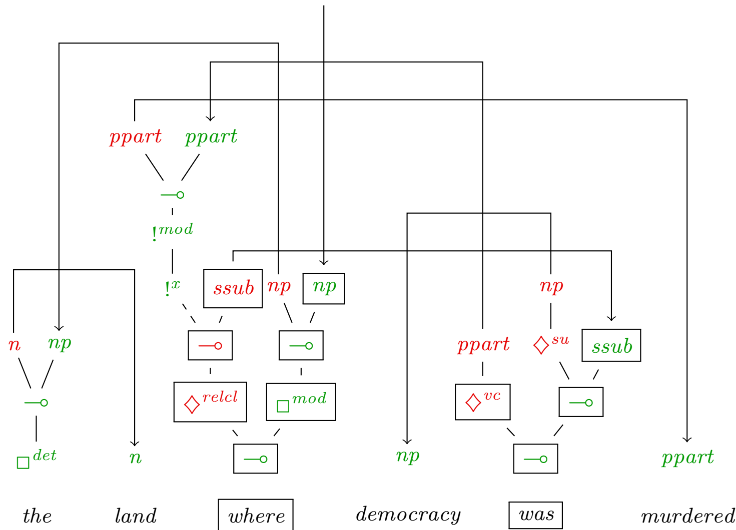

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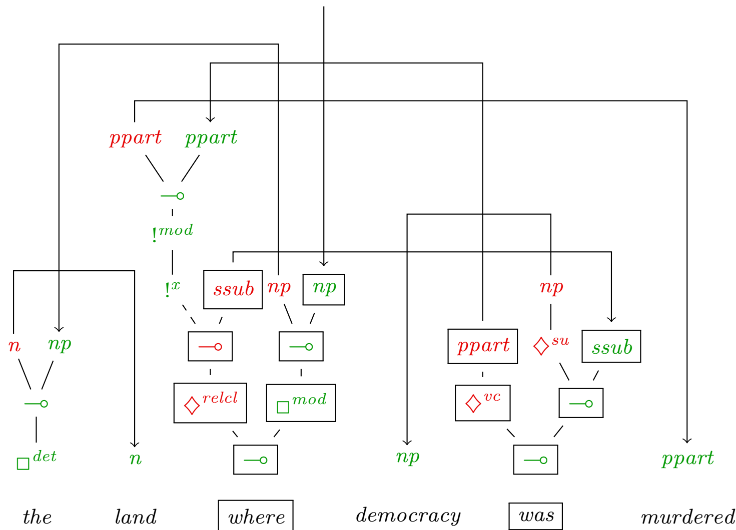

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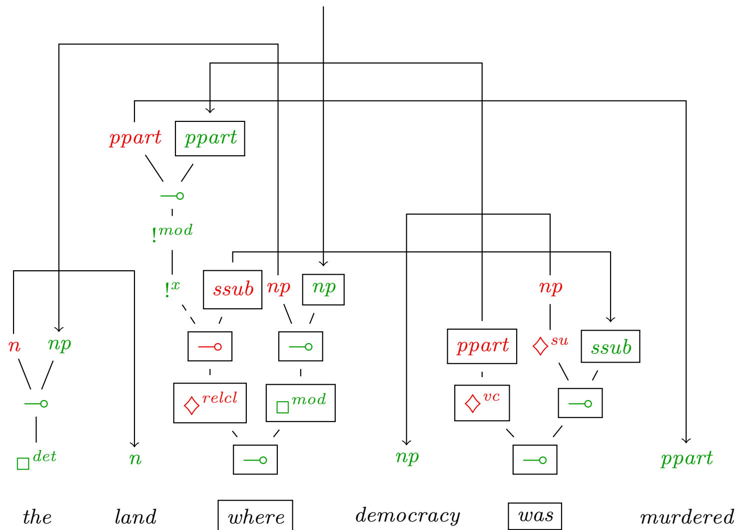
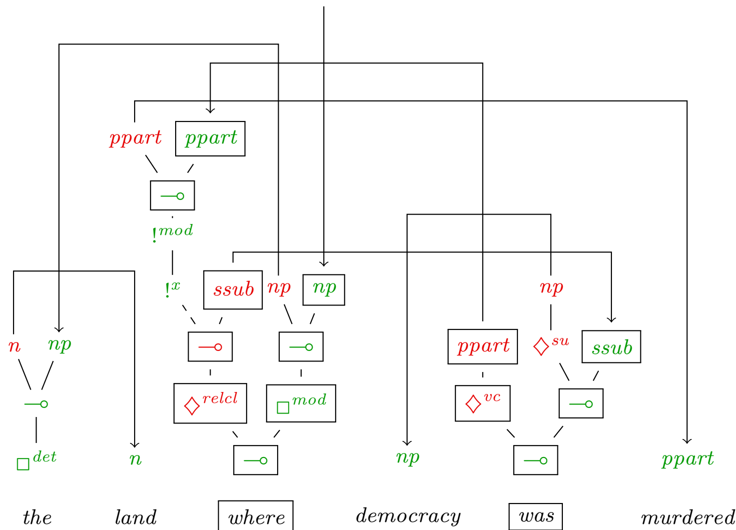


$\blacktriangledown^{mod}$(where $\triangle^{relcl}$ (λx_0.(was $\triangle^{vc}$ (???) ???))) ???

Proof ~~Frames~~ Structures



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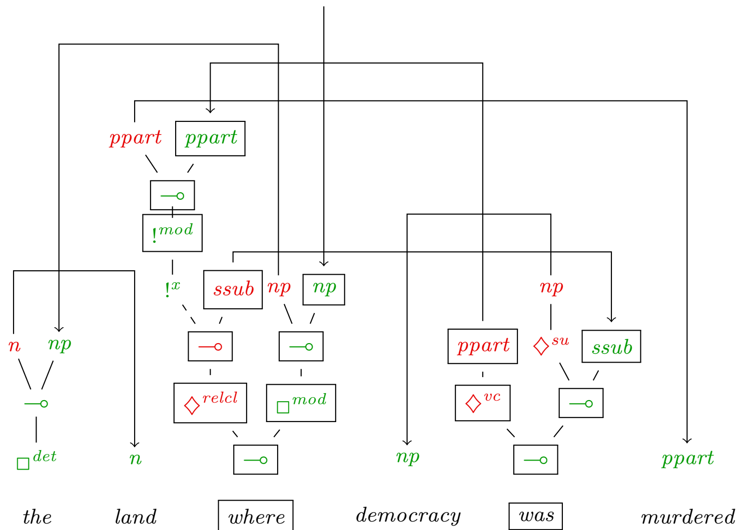

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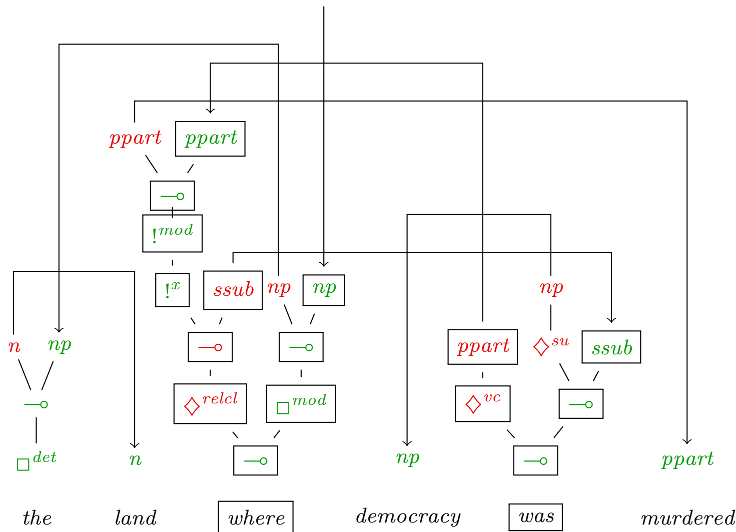

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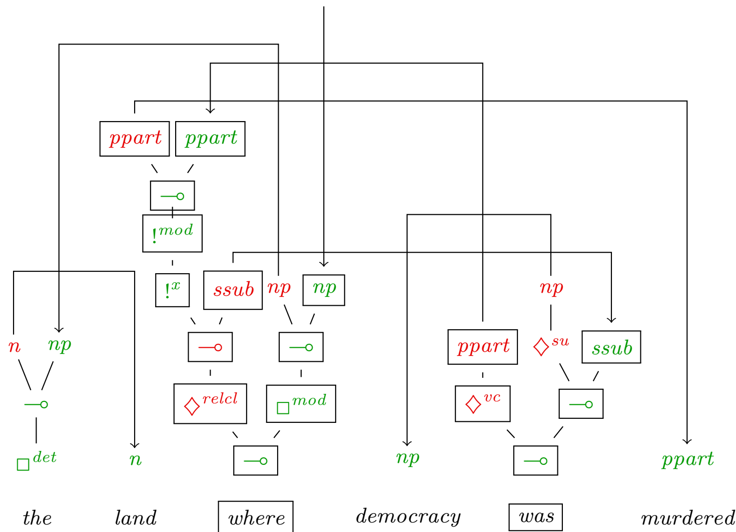

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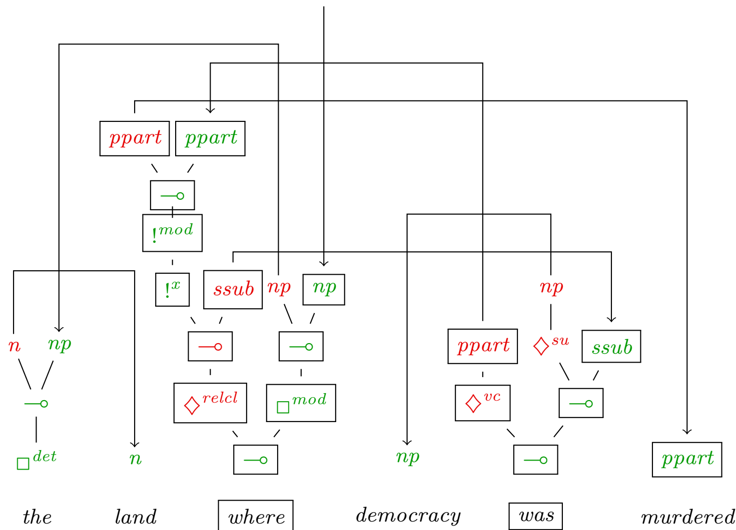

Proof ~~Frames~~ Structures

the *land* *where* *democracy* *was* *murdered*

$\blacktriangledown^{mod}$(where $\triangle^{relcl}$ (λx_0.(was $\triangle^{vc}$ ($\blacktriangledown^{mod}\triangledown^{mod}\blacktriangledown^{x}\triangledown^{x}x_0$ murdered) ???))) ???

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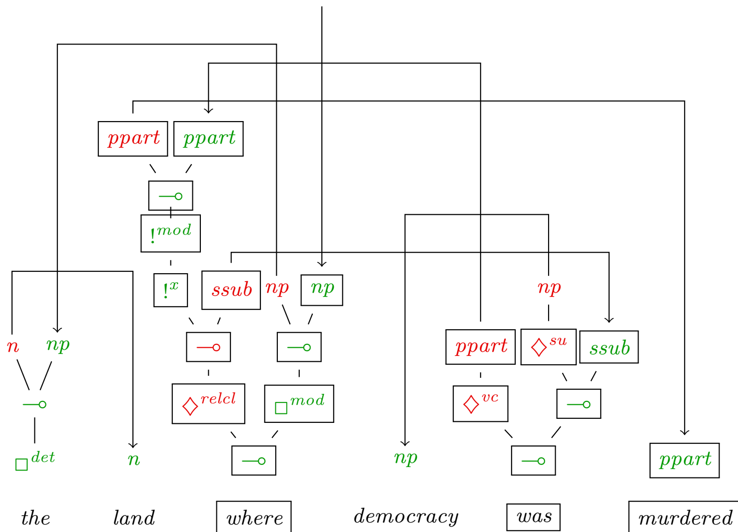

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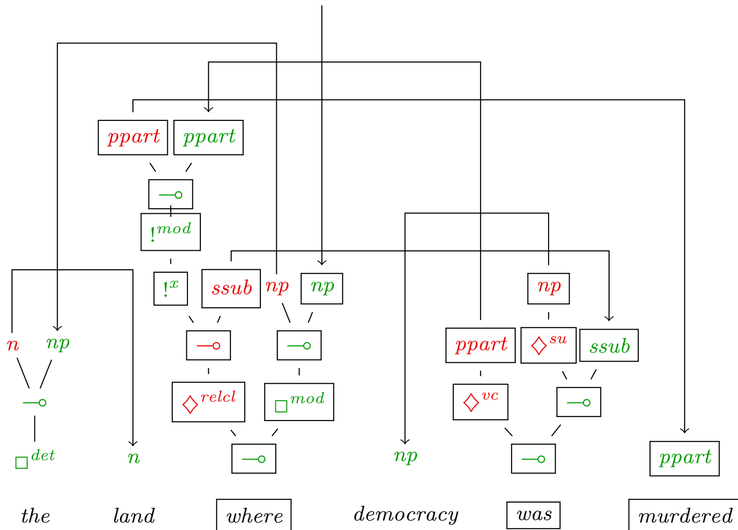

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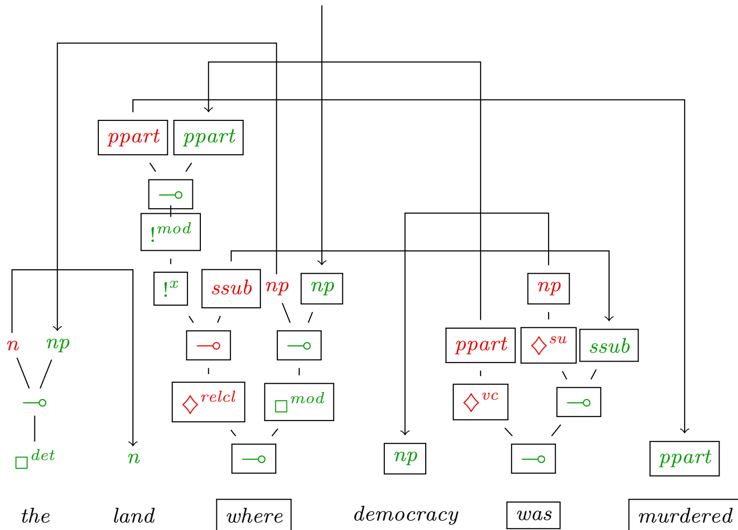

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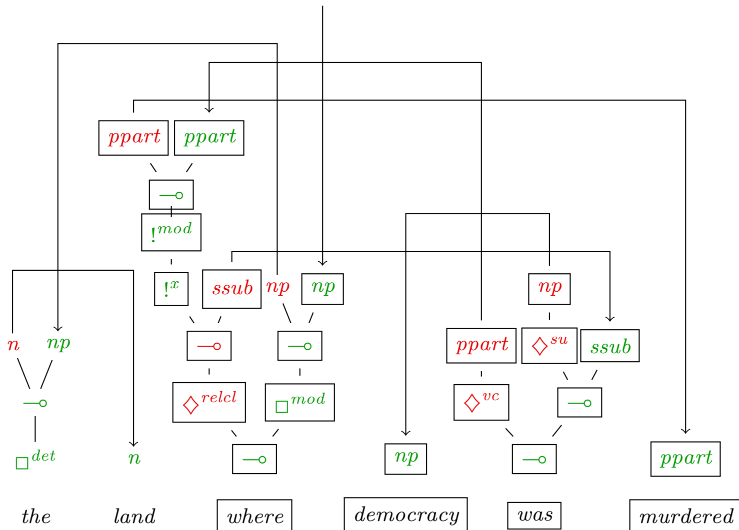

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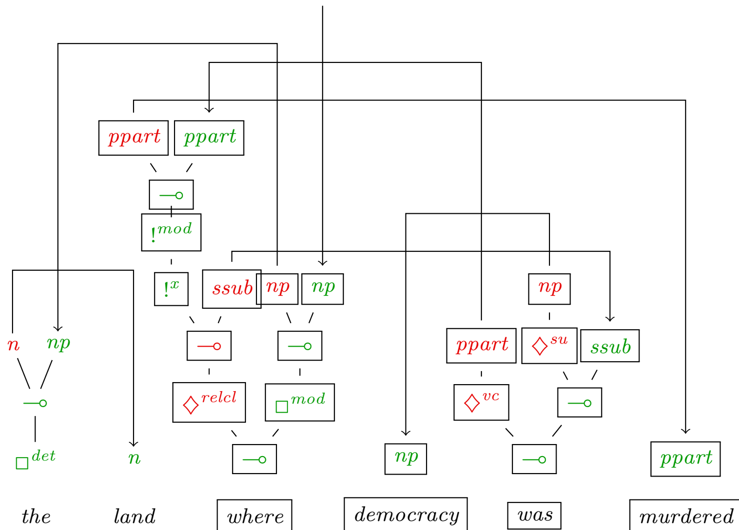
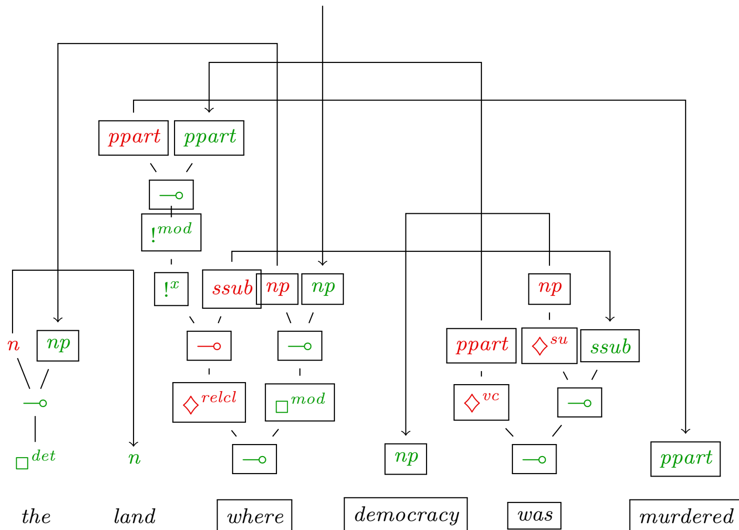


▼mod(where △relcl (λx0.(was △vc (▼mod▽mod▼x▽xx0 murdered) △su democracy))) ???

Proof ~~Frames~~ Structures



Proof ~~Frames~~ Structures

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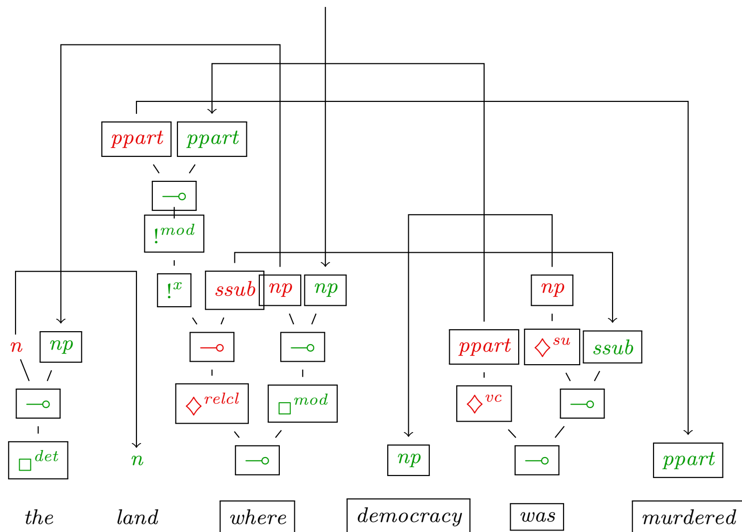

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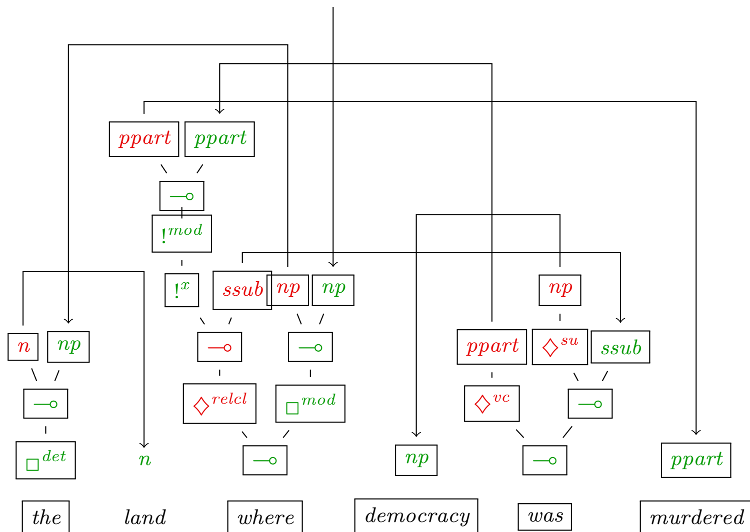

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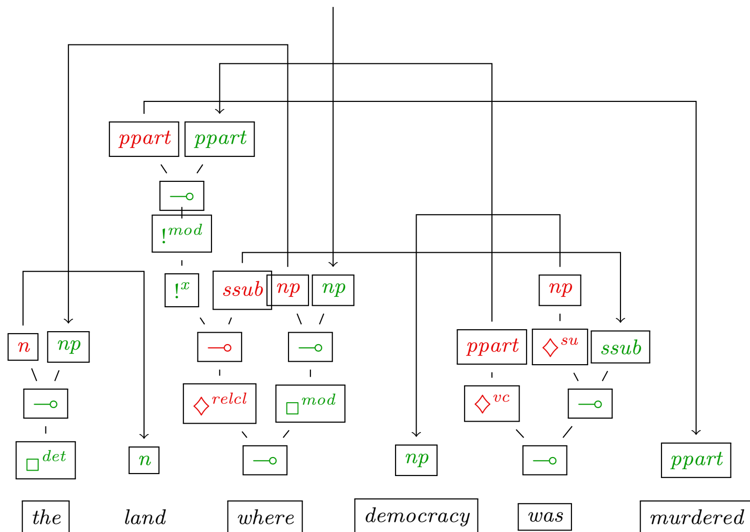

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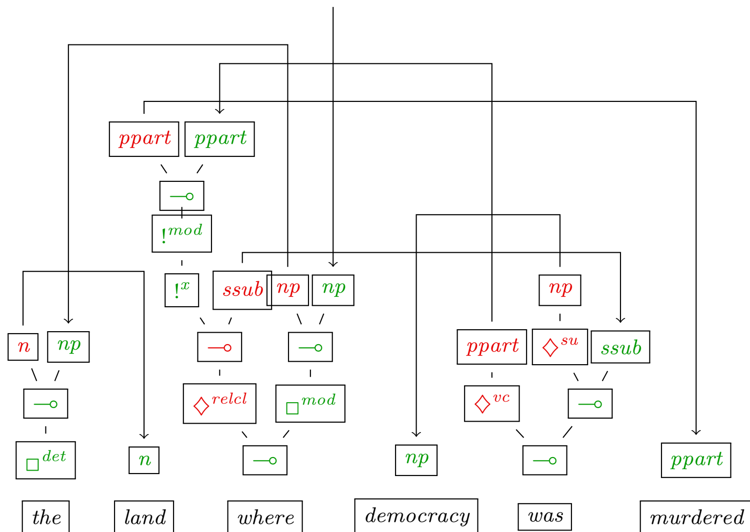
Proof ~~Frames Structures~~ Nets



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written and directed by

KOKOS

"Lets neural sh!t up"
– Alonzo Church, 1973

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– Alonzo Church, 1973

disclaimer: not an actual quote

Main ingredients

- Type assignment (supertagging)
  parallel tree decoding with dynamic graph convolutions
- Axiom linking (neural bijections)
  optimal transport with Sinkhorn iterations
- Formal verification
  proof net traversal

Supertagging 101

goal

maximize $p(T_1, \ldots T_n)$ conditional on some input $(w_1, \ldots w_n)$

the catch

types are sparse $\implies$ fixed vocabulary classification = no good

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Supertagging as parallel graph completion

???	???	???	???	???	???
the	land	where	democracy	was	murdered

Supertagging as parallel graph completion

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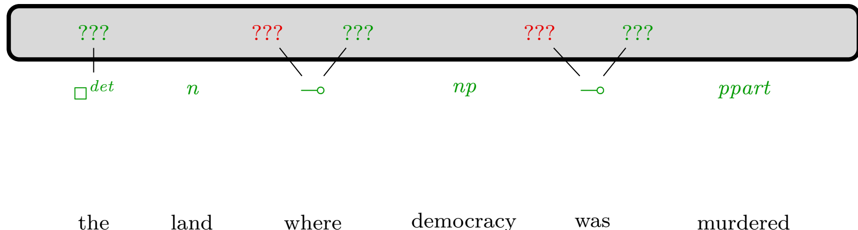
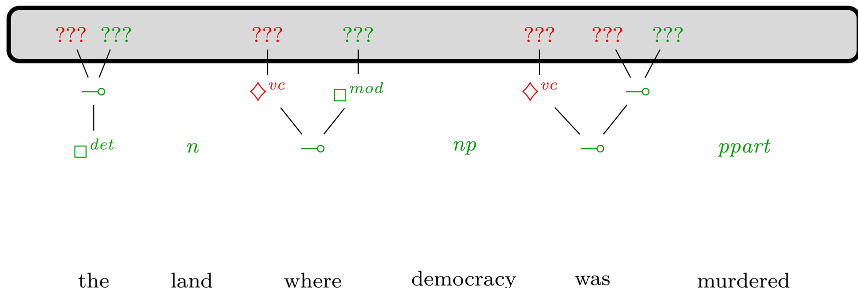
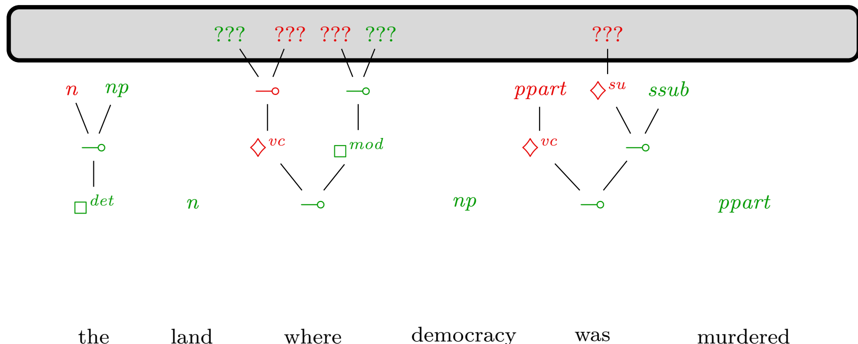
Supertagging as parallel graph completion



Supertagging as parallel graph completion



Supertagging as parallel graph completion



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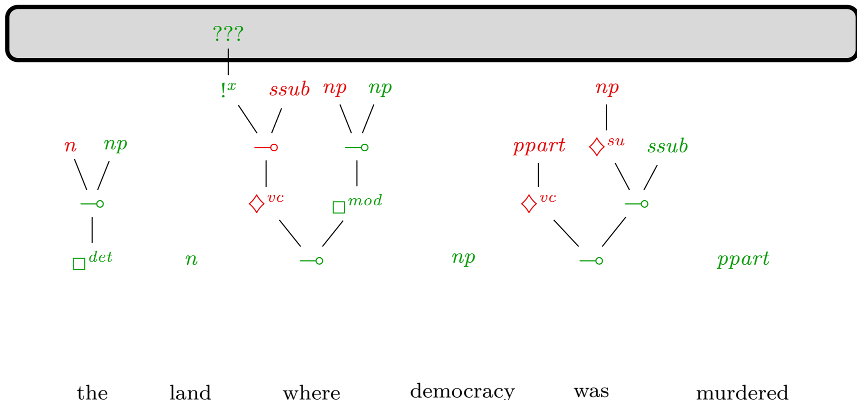

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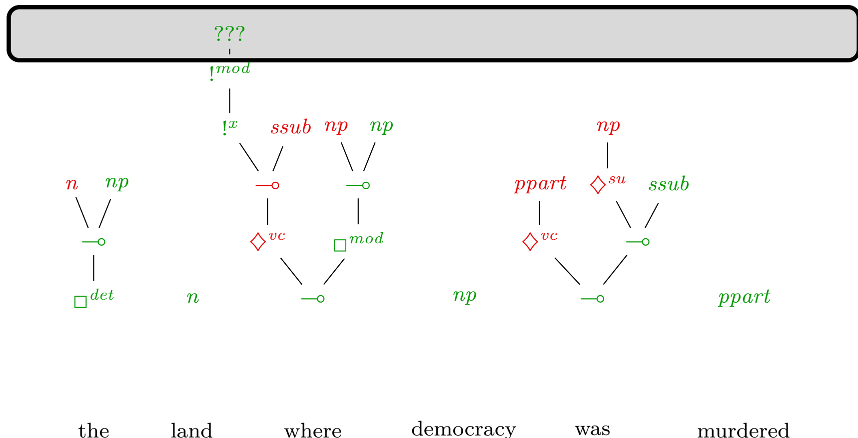

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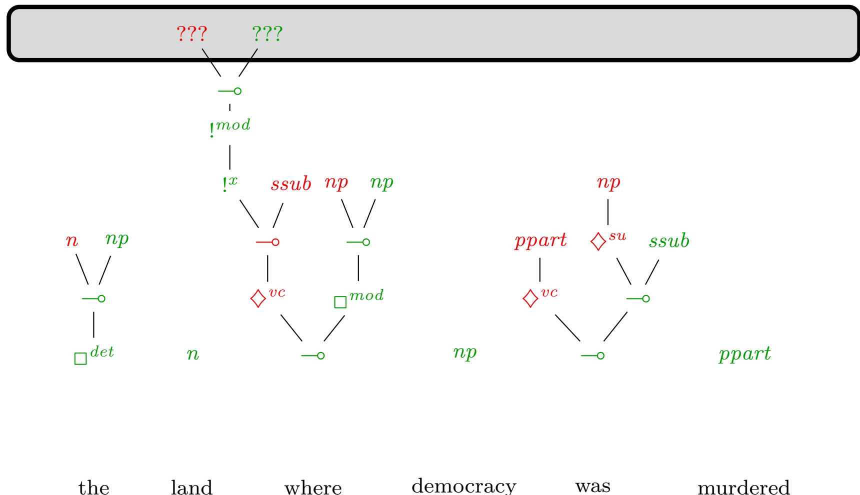

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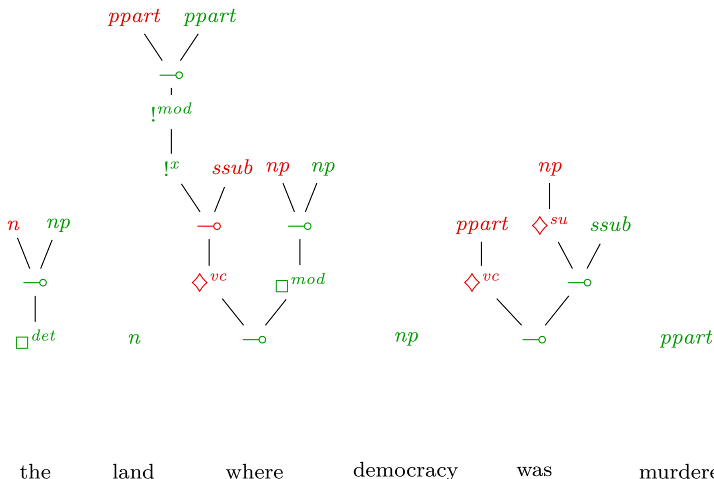


Not just a gray rectangle!

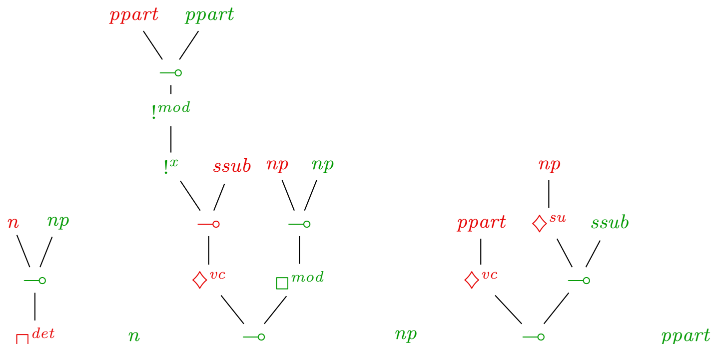
1 decoding step per tree depth; 3 message-passing rounds per step

- *contextualize: states* $\rightarrow$ *states*
  universal transformer encoder w/ relative weights
  (many-to-many, update states with neighborhood context)
- *predict: state* $\rightarrow$ *nodes*
  token classification w/ dynamic tree embeddings
  (one-to-many, predict fringe nodes from current state)
- *feedback: nodes* $\rightarrow$ *state*
  heterogeneous graph attention
  (many-to-one, update state with last predicted nodes)

[Kogkalidis & Moortgat, ???]

Axiom Linking

- ! only consider edges between atoms of the *same* sign and *different* polarity
- ! each atom can only be used *once*



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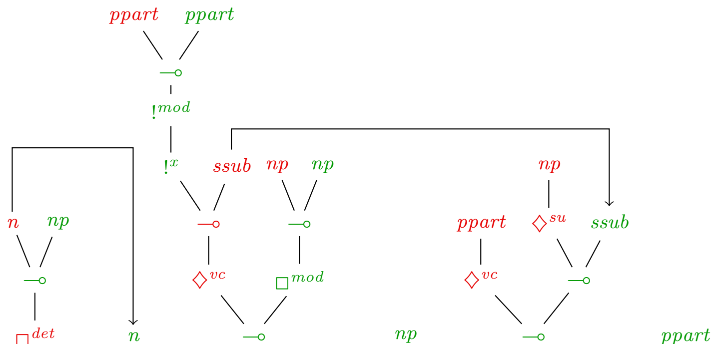

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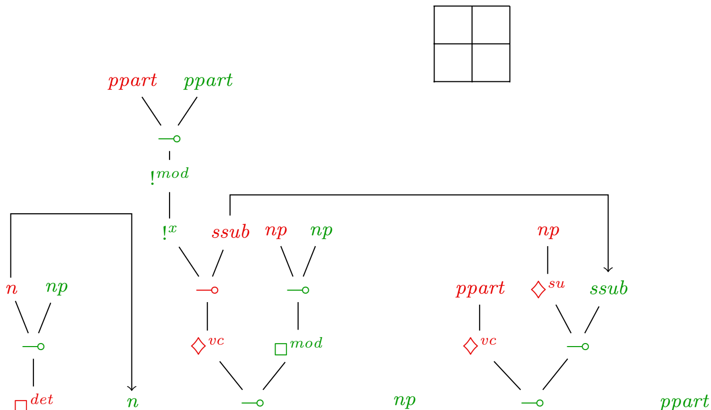

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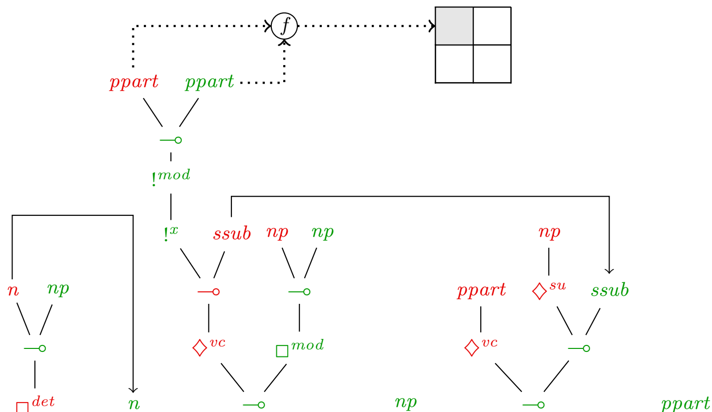

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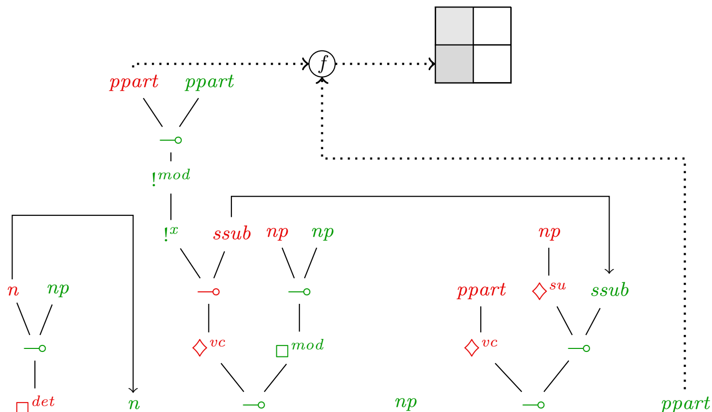

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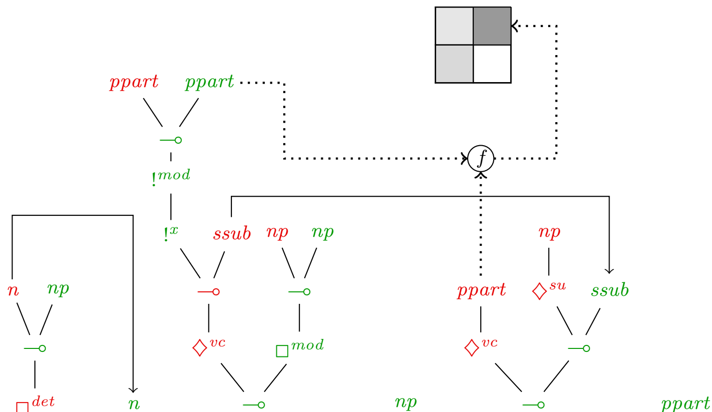

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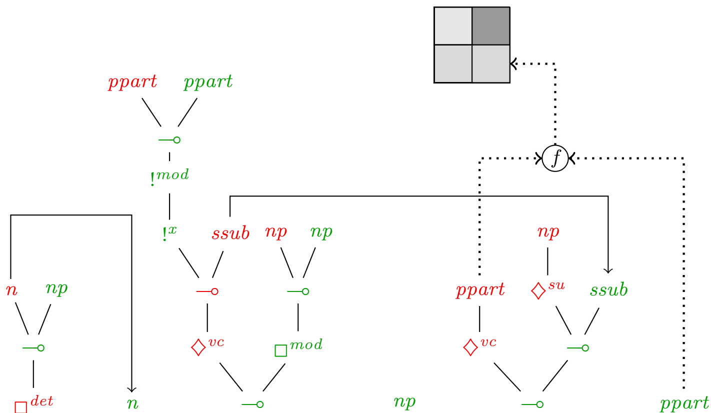

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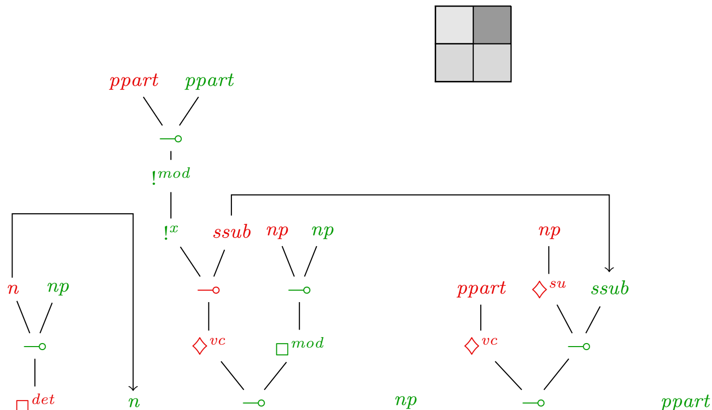

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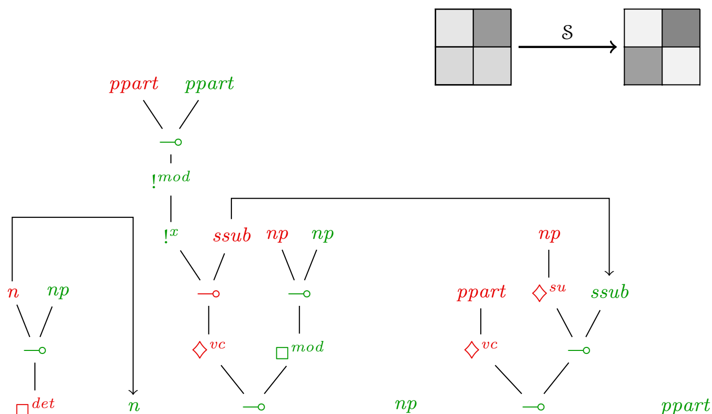

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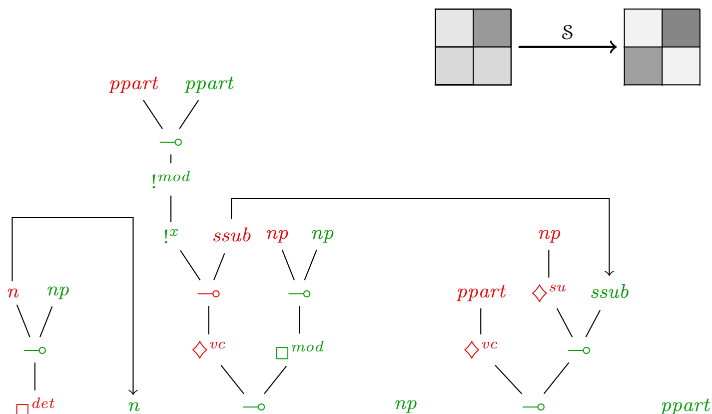

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your turn

break the parser!

Reality check

- tagger: applicable to any CG (applied)
- parser: adaptable to any flavor of linear logic (adapted)
- proofs: plug your own semantics / apply your own morphisms (todo)

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