Data-driven Logic

or: type theory for the working engineer

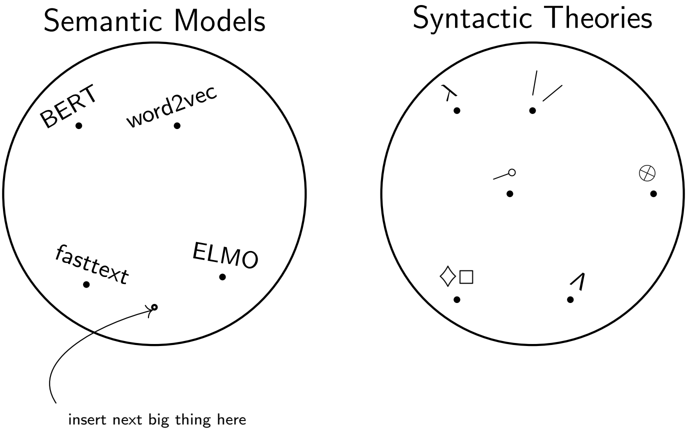
Kokos

Logic & Language ~~2020~~2021[1]

16/12/21

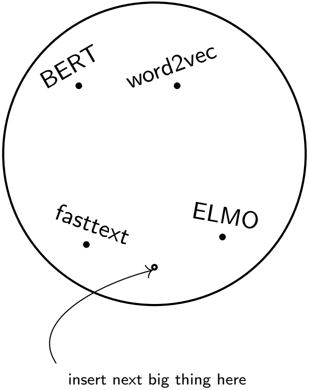
[1] totally not the same slides as last year

The state of NLP affairs



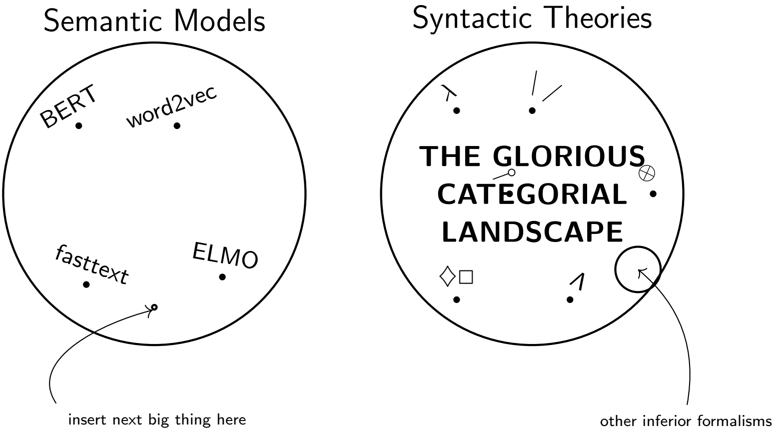
The state of NLP affairs

Semantic Models



Syntactic Theories

The state of NLP affairs



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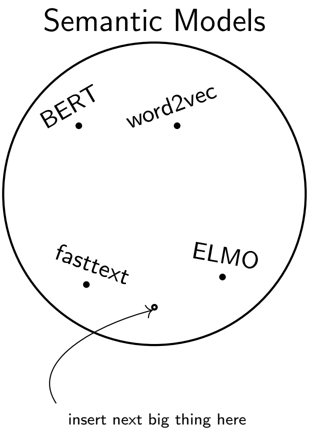
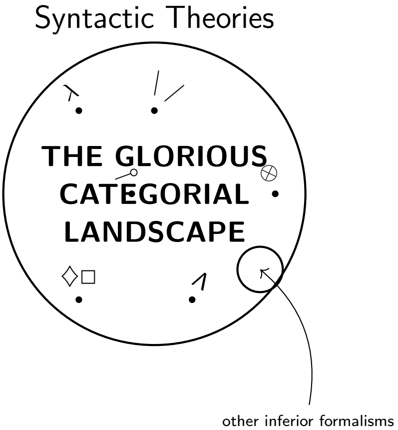
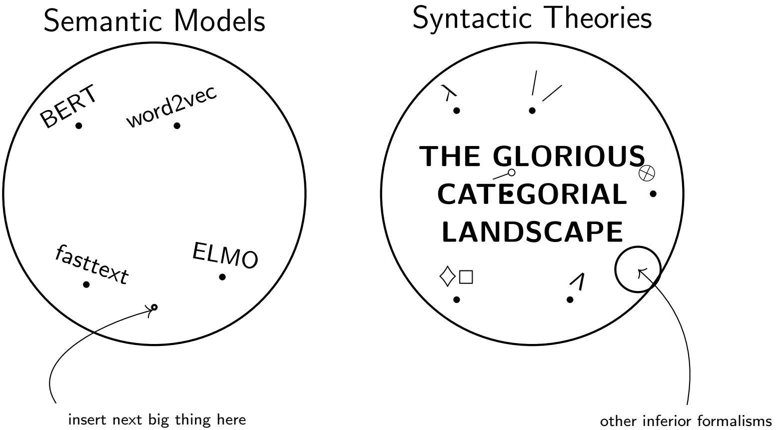




What's missing?

The state of NLP affairs



What's missing?

No (working) unifying theory or application.

Neural Type-Driven Representations

The agenda:

- λ Choosing the logic
- λ Making a dataset: proofs and lexical type assignments
- λ Learning the type assignment process
- λ Navigating the proof space
- λ Syntax-aware & type-correct text representations

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Syntax-Semantics Interface

Type-logical perspective

$$\begin{tikzcd}
\begin{array}{c}\text{Syntax}\\ \mathrm{(N)L}_{(\diamond,\Box)}\end{array} \arrow[d, "h_{der}"] \\
\begin{array}{c}\text{Derivational Semantics}\\ \mathrm{ILL}_{\multimap}\end{array} \arrow[d, "h_{lex}"] \\
\begin{array}{c}\text{Lexical Semantics}\\ \mathrm{IL}_{\rightarrow}\end{array}
\end{tikzcd}$$

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$$

ACG perspective

$$
\begin{tikzcd}
& \begin{array}{c}\text{Tectogrammar}\\ \text{ILL}_{\multimap}\end{array} \arrow[dl, leftrightarrow, "h_{syn}"'] \arrow[dr, leftrightarrow, "h_{sem}"] & \\
\begin{array}{c}\text{Syntax}\\ \text{ILL}_{\multimap}\end{array} & & \begin{array}{c}\text{Semantics}\\ \text{IL}_{\rightarrow}\end{array}
\end{tikzcd}
$$

A twist

Now

Tectogrammar
$\mathrm{ILL}_{\multimap,\Diamond,\Box}$

Syntax
???

CHC

Derivational Semantics
$\mathrm{ILL}_{\multimap,\Diamond,\Box}$

Lexical Semantics
???

Abstract syntax with NLP

Grammar

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

Types inductively defined by:

$$\mathcal{T} := A \mid T \multimap T' \mid \Diamond^d T \mid \Box^d T \qquad A \in \mathcal{A}, T \in \mathcal{T}$$

Rules

$$\frac{\Gamma \vdash \mathtt{s} : A \multimap B \quad \Delta \vdash \mathtt{t} : A}{\Gamma, \Delta \vdash \mathtt{s}\ \mathtt{t} : B} \multimap E \qquad \frac{\Gamma, \mathtt{x} : A \vdash \mathtt{s} : B}{\Gamma \vdash \lambda \mathtt{x}.\mathtt{s} : A \multimap B} \multimap I$$

$$\frac{\Gamma \vdash \mathtt{t} : A}{\langle \Gamma \rangle^d \vdash \triangle^d\ \mathtt{t} : \Diamond^d A} \Diamond^d I \qquad \frac{Y \vdash \mathtt{s} : \Diamond^d A \quad X[\langle \mathtt{x} : A \rangle^d] \vdash \mathtt{t} : B}{X[Y] \vdash \mathtt{t}[\triangledown^d \mathtt{s}/\mathtt{x}] : B} \Diamond^d E$$

$$\frac{\langle X \rangle^d \vdash \mathtt{s} : A}{X \vdash \blacktriangle^d \mathtt{s} : \Box^d A} \Box^d I \qquad \frac{X \vdash \mathtt{s} : \Box^d A}{\langle X \rangle^d \vdash \blacktriangledown^d \mathtt{s} : A} \Box^d E$$

Abstract syntax with NLP

Lexicon $\mathcal{L}$ assigning words types from:

Abstract syntax with NLP

Lexicon $\mathcal{L}$ assigning words types from: A

animals, ducks, I : np

$$\frac{\text{ducks}}{\texttt{ducks} : np}\ \mathcal{L}$$

Abstract syntax with NLP

Lexicon $\mathcal{L}$ assigning words types from: $A \mid \Diamond^{d} T \multimap T'$

$$\begin{array}{rcl} \text{animals, ducks, I} & : & np \\ \text{like} & : & \Diamond^{obj} np \multimap \Diamond^{obj} np \multimap s \end{array} \qquad \begin{array}{rcl} \text{fly, swim} & : & \Diamond^{su} np \multimap s \end{array}$$

$$\dfrac{\dfrac{\text{fly}}{\Diamond^{su} np \multimap s}\ \mathcal{L} \qquad \dfrac{\dfrac{\text{ducks}}{np}\ \mathcal{L}}{\langle\text{ducks}\rangle^{su} \vdash \Diamond^{su} np}\ \Diamond^{su} I}{\langle\text{ducks}\rangle^{su}\ \text{fly} \vdash s}\ \multimap E$$

$\texttt{fly}\ \triangle^{su}\ \texttt{ducks}$

Abstract syntax with NLP

Lexicon $\mathcal{L}$ assigning words types from: $A \mid \Diamond^d T \multimap T' \mid \Box^d (T \multimap T')$

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$$\dfrac{\dfrac{\dfrac{\text{gracefully}}{\Box^{mod}(s \multimap s)}\ \mathcal{L}}{\langle \text{gracefully} \rangle^{mod} \vdash s \multimap s}\ \Box^{mod} E \qquad \dfrac{\vdots}{\langle \text{ducks} \rangle^{su}\ \text{fly} \vdash s}}{\langle \text{ducks} \rangle^{su}\ \text{fly}\ \langle \text{gracefully} \rangle^{mod} \vdash s}\ \multimap E$$

$$\blacktriangledown^{mod}\texttt{gracefully}\ (\texttt{fly}\ \ \triangle^{su}\ \texttt{ducks})$$

Abstract syntax with NLP

Lexicon $\mathcal{L}$ assigning words types from: $A \mid \Diamond^{d}\, T \multimap T' \mid \Box^{d}\,(T \multimap T')$

$$
\begin{array}{rcl}
\text{animals, ducks, I} & : & np \\
\text{like} & : & \Diamond^{obj}\, np \multimap \Diamond^{obj}\, np \multimap s \\
\text{that} & : & \Diamond^{body}\,(\Diamond^{su}\, np \multimap s) \multimap \Box^{mod}\,(np \multimap np)
\end{array}
\qquad
\begin{array}{rcl}
\text{fly, swim} & : & \Diamond^{su}\, np \multimap s \\
\text{gracefully} & : & \Box^{mod}\,(s \multimap s)
\end{array}
$$

$$
\dfrac{\dfrac{\text{animals}}{np}\,\mathcal{L} \qquad \dfrac{\dfrac{\dfrac{\text{that}}{\Diamond^{body}\,(\Diamond^{obj}\, np \multimap s) \multimap \Box^{mod}\,(np \multimap np)}\,\mathcal{L} \qquad \dfrac{\dfrac{\vdots}{\langle \mathrm{I} \rangle^{su}\ \text{like} \vdash \lambda x.(\texttt{like}\ x\ \ \triangle^{su} I) : \Diamond^{obj}\, np \multimap s}}{\langle \langle \mathrm{I} \rangle^{su}\ \text{like} \rangle^{body} \vdash \Diamond^{body}\,(\Diamond^{obj}\, np \multimap s)}\,\Diamond^{body} I}{\text{that}\ \langle \langle \mathrm{I} \rangle^{su}\ \text{like} \rangle^{body} \vdash \Box^{mod}(np \multimap np)}\,\multimap E}{\langle \text{that}\ \langle \langle \mathrm{I} \rangle^{su}\ \text{like} \rangle^{body} \rangle^{mod} \vdash np \multimap np}\,\Box^{mod} E}{\text{animals}\ \langle \text{that}\ \langle \langle \mathrm{I} \rangle^{su}\ \text{like} \rangle^{body} \rangle^{mod} \vdash np}\,\multimap E
$$

$$
\blacktriangledown^{mod} \left(\texttt{that}\ \ \triangle^{body}\ (\lambda x.(\texttt{like x}\ \ \triangle^{su} I))\right)\ \texttt{animals}
$$

Why $ILL_{\multimap,\Diamond,\Box}$?

Why $ILL_{\multimap}$?

- Easier to extract from corpora
- Massive reduction in lexical ambiguity (more later)
- Abstract away from trivial word-order permutations
- Surface syntax matters little to semantics

Why $\mathrm{ILL}_{\multimap,\diamond,\square}$?

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Why $\diamond, \square$?

- More interpretation options
- Subsume dependency parsing
- More informative for semantics
- Modalities can regulate non-logical parsing

Intermezzo: Proof Nets

Proof Nets

A graphical, diagrammatical representation of (intuitionitic) linear logic proofs.

Intermezzo: Proof Nets

Formula decomposition

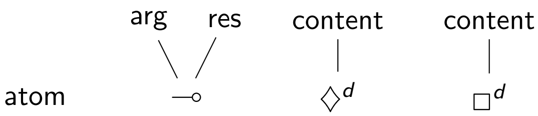
Type formation rules $\equiv$ tree constructors

$$
\begin{array}{lccccccc}
 & & & \text{arg} \quad \text{res} & & \text{content} & & \text{content} \\
 & \text{atom} & & \multimap & & \Diamond^d & & \Box^d \\
\mathcal{T} := & A & \mid & T \multimap T' & \mid & \Diamond^d T & \mid & \Box^d T
\end{array}
$$

Intermezzo: Proof Nets

Formula decomposition

Type formation rules $\equiv$ tree constructors



$$\mathcal{T} := \quad A \quad | \quad T \multimap T' \quad | \quad \Diamond^d T \quad | \quad \Box^d T$$

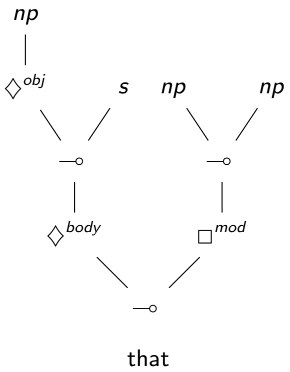
or, overloading $\Diamond$ and $\Box$ as binary operators for brevity

Intermezzo: Proof Nets

Tree Polarization

Let $+$ stand for resources we *have*, $-$ for ones we seek:

$\multimap$ is polarity preserving for the result, reversing for the argument



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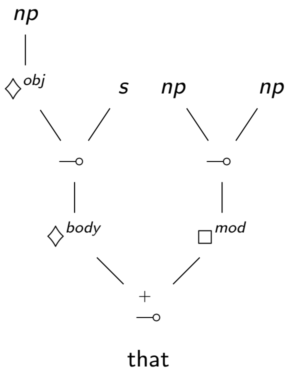

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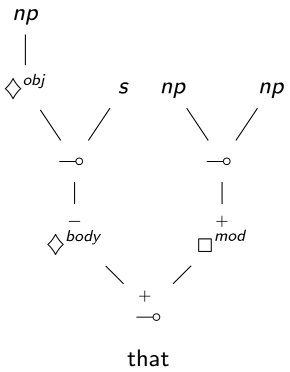

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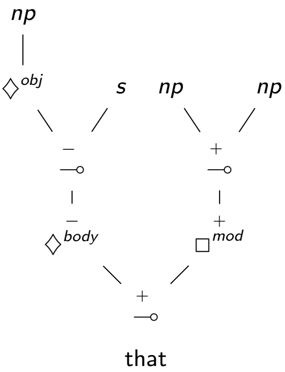

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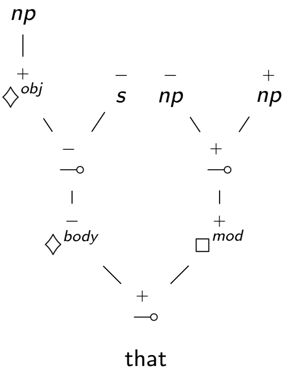

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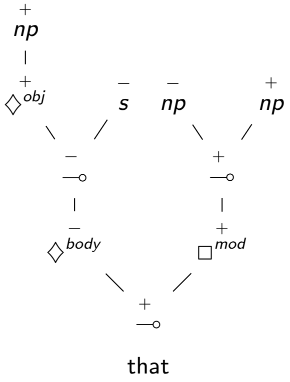
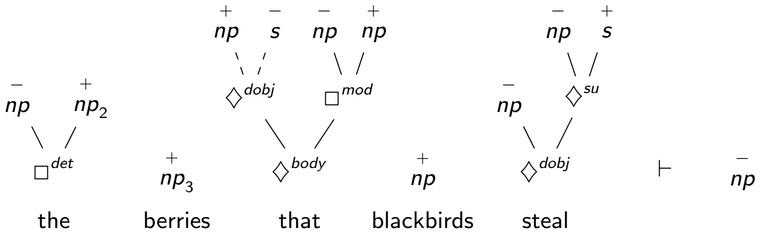


Intermezzo: Proof Nets

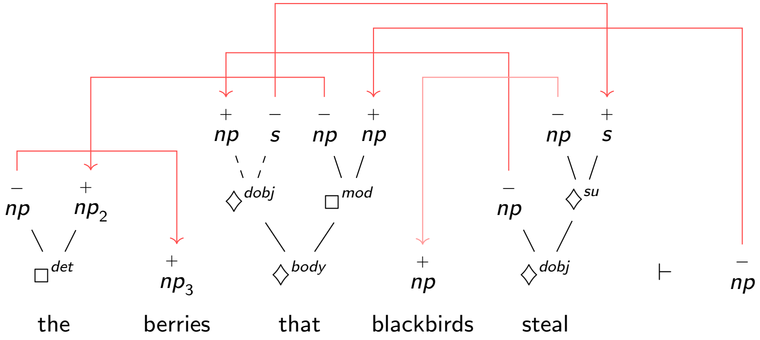
Proof Frame

A sequence of polarized unfolded formulas



Proof Structure

A proof net together with **axiom links**: bijection between pos/neg atoms



Intermezzo: Proof Nets

Traversing a Proof Net

positive (down) mode: start from positive leaf, follow positive nodes to subtree root

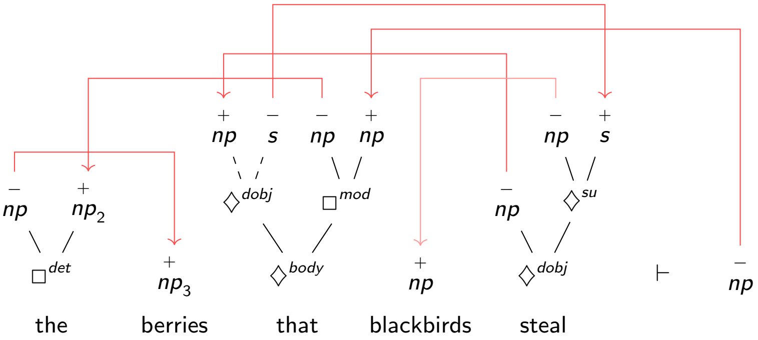
- $\Box$ wrap future with $\blacktriangledown$
- $\Diamond$ wrap variable (context) with $\triangledown$
- $\multimap$ each is an application
  on reaching root, write word or variable name
  and perform negative traversal on negative child of each $\multimap$

negative (up) mode: start from negative root, follow negatives to subtree leaf

- $\Box$ wrap future with $\blacktriangle$
- $\Diamond$ wrap future with $\triangle$
- $\multimap$ each is an abstraction: assign a fresh variable to positive subtree
  on reaching a leaf, cross the axiom link and switch to positive mode

start from conclusion in negative mode

Intermezzo: Proof Nets



From parse graphs to $\text{ILL}_{\multimap,\diamond,\square}$ types

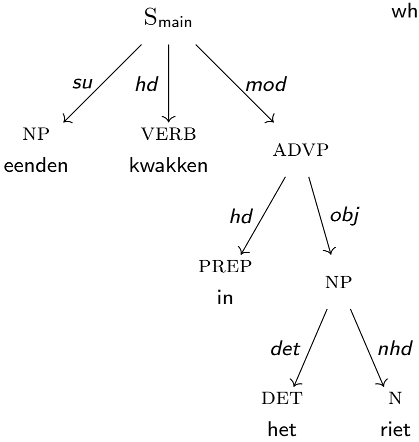
algorithm: graph flooding on dags

init with maps

- from pos & phrasal categories to $\mathcal{A}$
  e.g. $\text{NP} \rightarrow \mathit{np}$, $\text{INF} \rightarrow \mathit{inf}, \ldots$
- from grammatical roles to $\diamond$ (complements) and $\square$ (adjuncts)
  e.g. $\mathit{su} \rightarrow \diamond^{\mathit{su}}, \mathit{obj} \rightarrow \diamond^{\mathit{obj}}, \ldots, \mathit{mod} \rightarrow \square^{\mathit{mod}}, \mathit{det} \rightarrow \square^{\mathit{det}}$

and a strict total order over $\diamond$,
e.g. $\diamond^{\mathit{su}} > \diamond^{\mathit{obj}}$

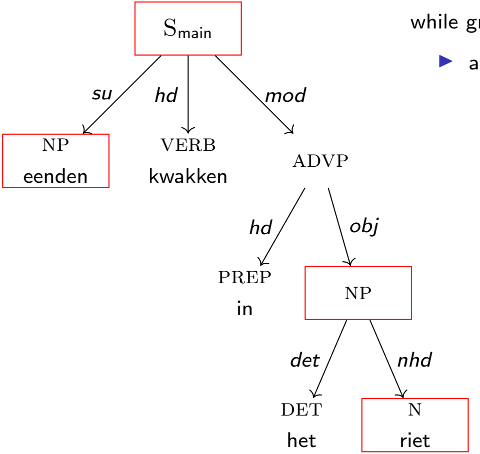
Simple case: trees



"eenden kwakken in het riet"

while graph not fully typed, do:

Simple case: trees



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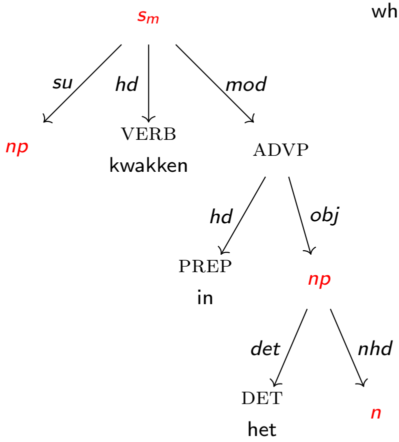

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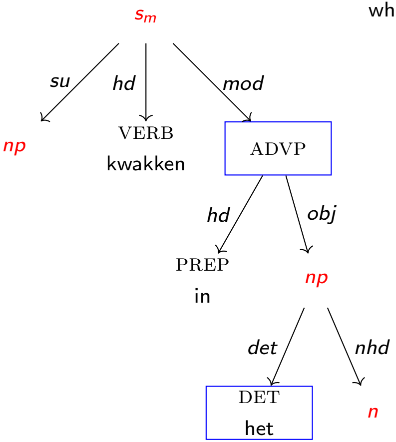

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  parent is typed

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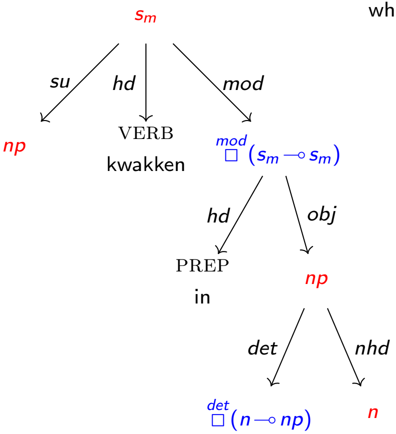

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  if mod: boxed endofunctor of parent
  else:from comp sibs to parent

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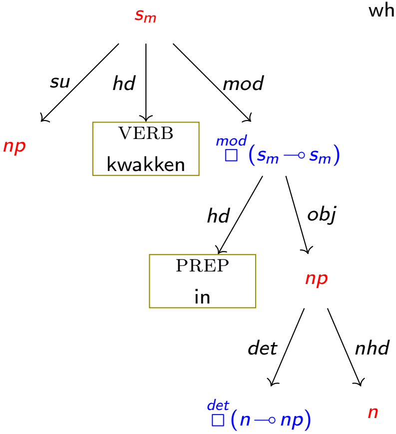

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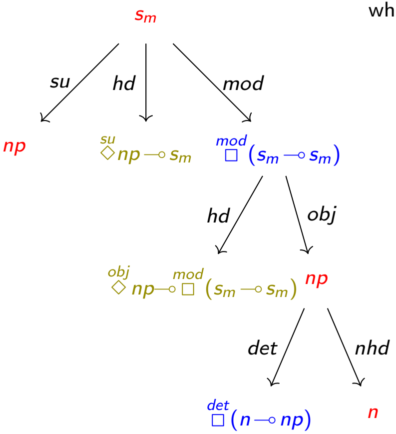

"eenden kwakken in het riet"

while graph not fully typed, do:

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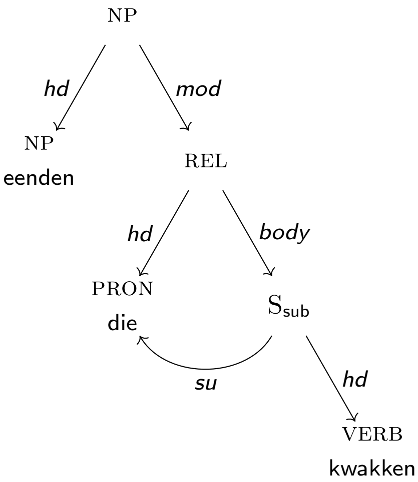
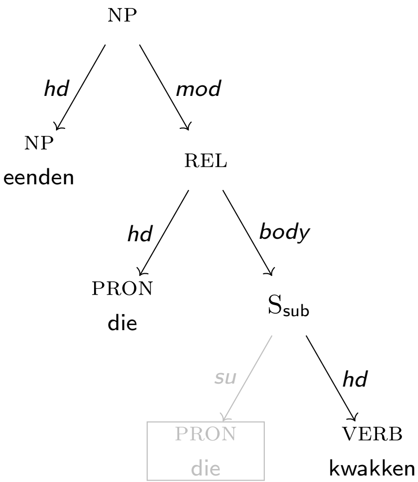
Harder case: unbounded dependencies



"eenden die kwakken"

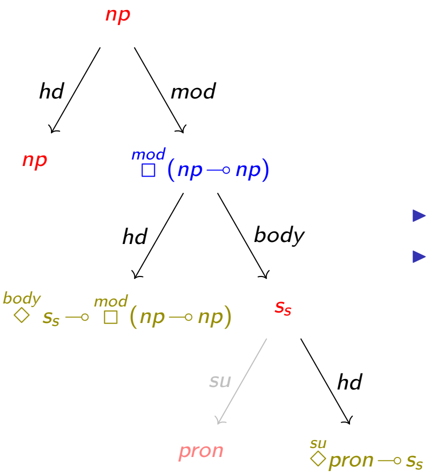
Harder case: unbounded dependencies



"eenden die kwakken"

- detach non-local dependencies

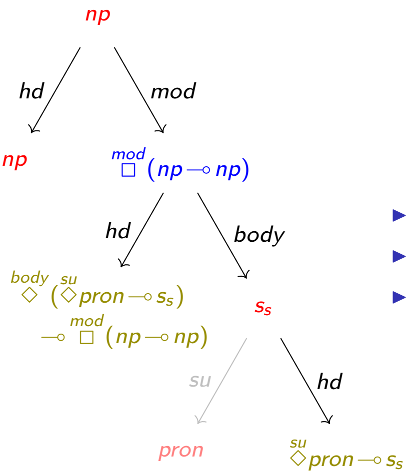
Harder case: unbounded dependencies



- detach non-local dependencies
- type trees as before

"eenden die kwakken"

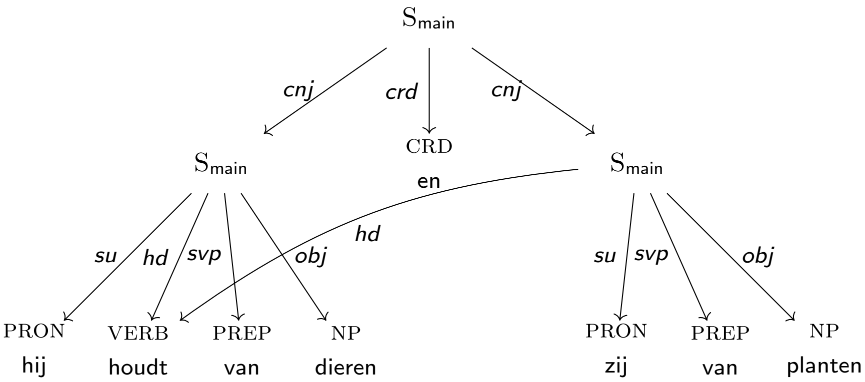
Harder case: unbounded dependencies



"eenden die kwakken"

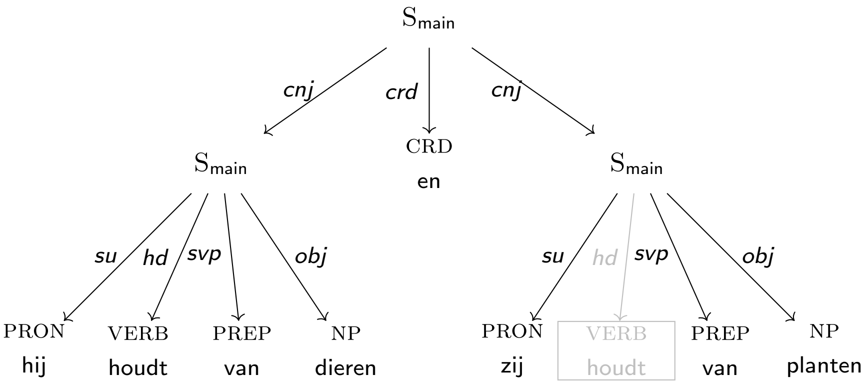
- detach non-local dependencies
- type trees as before
- redact ghosts types from comp sibs

Hardest case: Ellipses



"hij houdt van dieren en zij van planten"

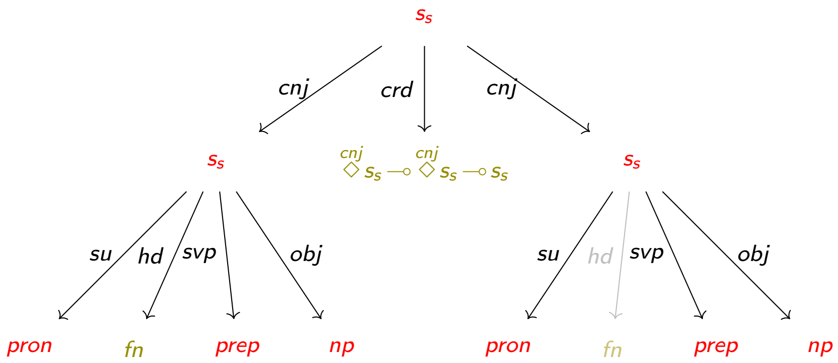
Hardest case: Ellipses



"hij houdt van dieren en zij van planten"

- detach and type trees as usual

Hardest case: Ellipses

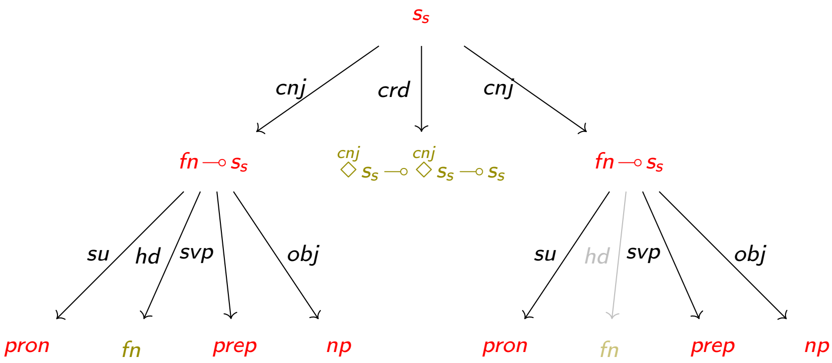


"hij houdt van dieren en zij van planten"

- detach and type trees as usual

$$fn := \overset{svp}{\diamond} prep \multimap \overset{obj}{\diamond} np \multimap \overset{su}{\diamond} pron \multimap s_s$$

Hardest case: Ellipses



"hij houdt van dieren en zij van planten"

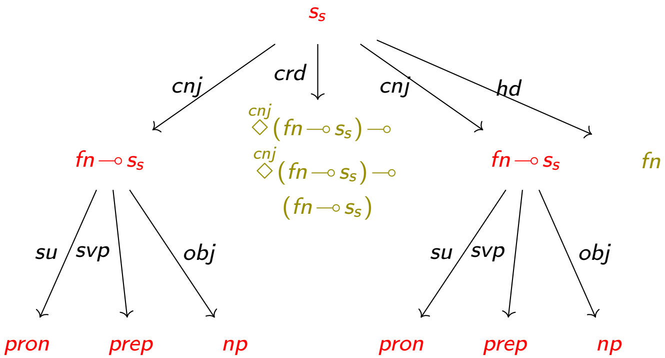
- detach and type trees as usual
- redact missing types from **both** conjuncts

$$fn := \overset{svp}{\diamond} prep \multimap \overset{obj}{\diamond} np \multimap \overset{su}{\diamond} pron \multimap s_s$$

ACG Flashback

- each conjunct represents a tuple of types
  $c = (t_1, t_2, \ldots t_n) \equiv t_1 \otimes t_2 \otimes \ldots \otimes t_n$
- encoded as the higher-order function $(c \multimap r) \multimap r$ and curried into
  $(t_1 \multimap t_2 \multimap \ldots \multimap t_n \multimap r) \multimap r$

Hardest case: Ellipses



"hij houdt van dieren en zij van planten"

- detach and type trees as usual
- redact missing types from **both** conjuncts
- update coord type & attach copies at top level

$$fn := \overset{svp}{\Diamond} prep \multimap \overset{obj}{\Diamond} np \multimap \overset{su}{\Diamond} pron \multimap s_s$$

A glimpse at a higher universe

Second-order IL (system F or polymorphic λ-calculus)

$$\frac{\Gamma \vdash \mathtt{M} : \forall\alpha.\sigma}{\Gamma \vdash \mathtt{M}\tau : \sigma[\tau/\alpha]} \qquad \frac{\Gamma \vdash \mathtt{M} : \sigma}{\Gamma \vdash \Lambda\alpha.\mathtt{M} : \forall\alpha.\sigma}$$

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In that universe, modifiers and coordinators are polymorphic types:

$$\mathsf{mod} := \Lambda\alpha.\mathtt{w} : \forall\alpha.\Box^{mod}(\alpha \multimap \alpha)$$

and

$$\mathsf{crd} := \Lambda\alpha.\mathtt{w} : \forall\alpha.\Diamond^{cnj}\alpha \multimap \Diamond^{cnj}\alpha \multimap \alpha$$

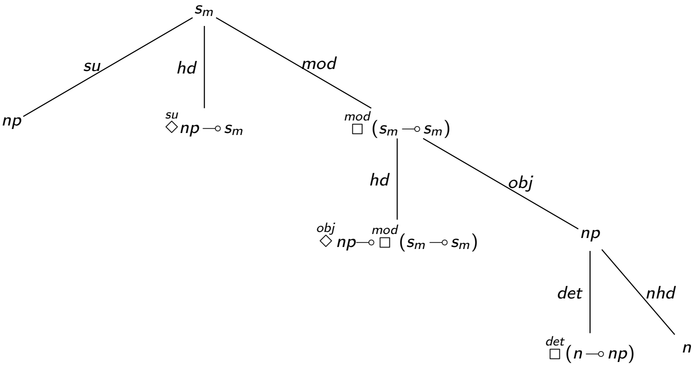
Coordinators as derived types

Elliptical coordinators can also be seen as a transformation of basic types.
If $c = (t_1 \otimes t_2 \otimes \ldots \otimes t_N)$ the conjoined tuples,

$$
\begin{aligned}
crd &= c \multimap c \multimap c \\
&\xrightarrow{vr} c \multimap c \multimap (c \multimap s) \multimap s \\
&\xrightarrow{ar^0} ((c \multimap s) \multimap s) \multimap c \multimap (c \multimap s) \multimap s \\
&\xrightarrow{ar^1} ((c \multimap s) \multimap s) \multimap ((c \multimap s) \multimap s) \multimap (c \multimap s) \multimap s \\
&\equiv ((t_1 \multimap t_2 \multimap \ldots \multimap t_n \multimap s) \multimap s) \multimap \\
&\qquad ((t_1 \multimap t_2 \multimap \ldots \multimap t_n \multimap s) \multimap s) \multimap \\
&\qquad\quad (t_1 \multimap t_2 \multimap \ldots \multimap t_n \multimap s) \multimap s
\end{aligned}
$$

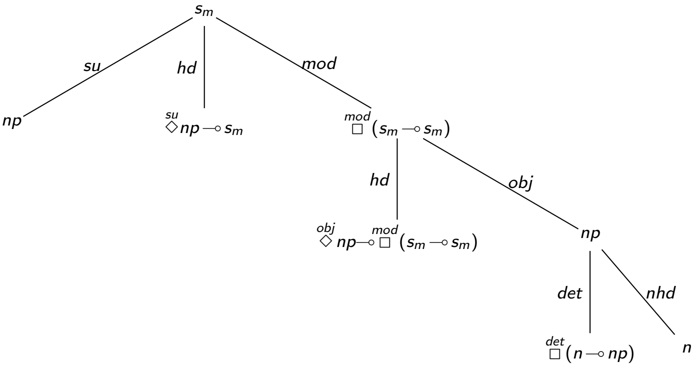
$$
\begin{aligned}
&\Diamond^{cnj} S_{main} \multimap \Diamond^{cnj} S_{main} \multimap S_{main} \\
\xrightarrow{vr^*} &\Diamond^{cnj} S_{main} \multimap \Diamond^{cnj} S_{main} \multimap fn \multimap S_{main} \\
\xrightarrow{ar^1} &\Diamond^{cnj} (fn \multimap S_{main}) \multimap \Diamond^{cnj} S_{main} \multimap fn \multimap S_{main} \\
\xrightarrow{ar^2} &\Diamond^{cnj} (fn \multimap S_{main}) \multimap \Diamond^{cnj} (fn \multimap S_{main}) \multimap fn \multimap S_{main}
\end{aligned}
$$

From graphs to proofs



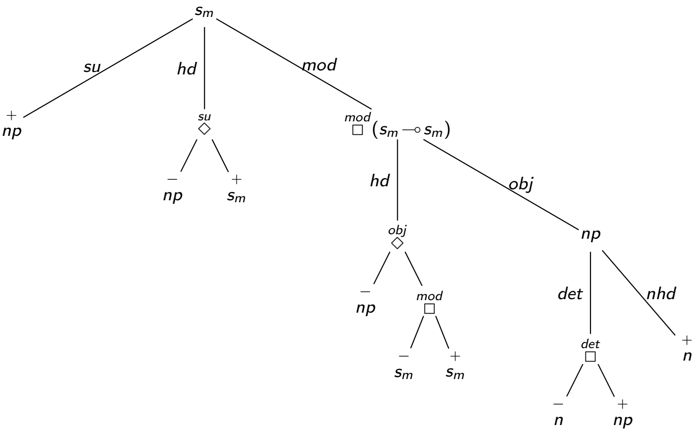
given a typed graph:

From graphs to proofs



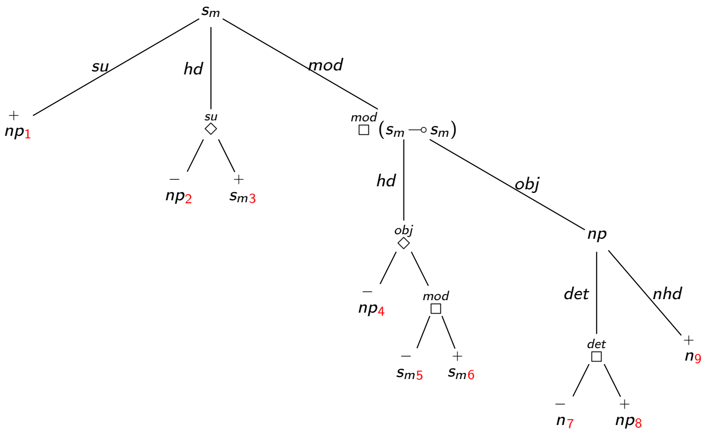
(1) convert types to binary trees and assign polarities

From graphs to proofs



(2) assign identifying indices

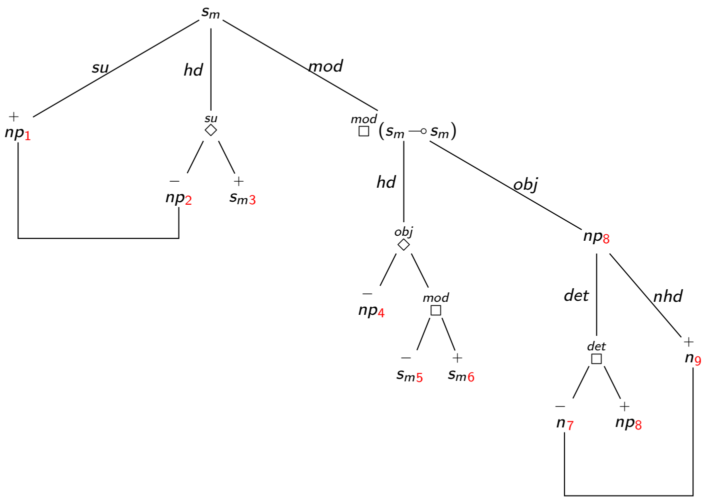
From graphs to proofs



(3) traverse upwards, identifying pos/neg atoms and propagating indices

$$\{2 \mapsto ?, 4 \mapsto ?, 5 \mapsto ?, 7 \mapsto ?\}$$

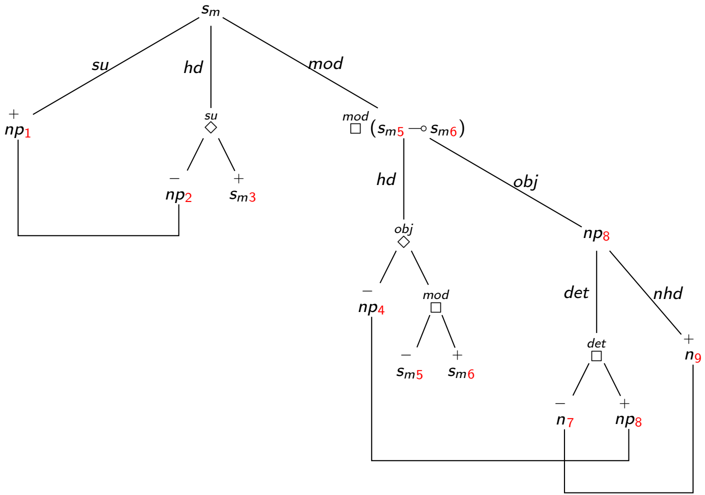
From graphs to proofs



(3) traverse upwards, identifying pos/neg atoms and propagating indices

$$\{2 \mapsto 1, 4 \mapsto ?, 5 \mapsto ?, 7 \mapsto 9\}$$

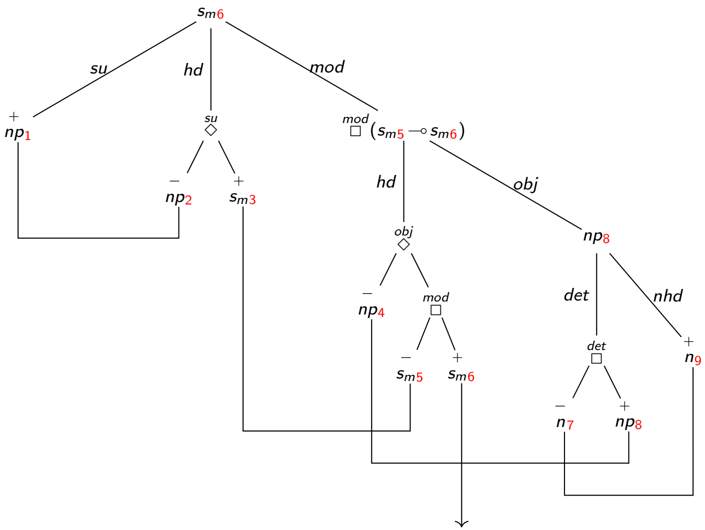
From graphs to proofs



(3) traverse upwards, identifying pos/neg atoms and propagating indices

$$\{2 \mapsto 1, 4 \mapsto 8, 5 \mapsto ?, 7 \mapsto 9\}$$

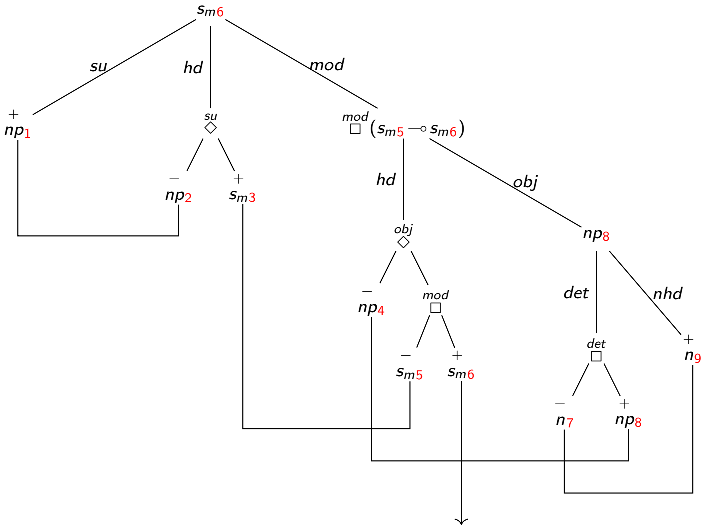
From graphs to proofs



(3) traverse upwards, identifying pos/neg atoms and propagating indices

$$\{2 \mapsto 1, 4 \mapsto 8, 5 \mapsto 3, 7 \mapsto 9\}$$

From graphs to proofs



the resulting structure is a *proof net*

$$\blacktriangledown^{mod}\left(in\ \triangle^{obj}\left(\blacktriangledown^{det} het\ riet\right)\right)\ (kwakken\ \triangle^{su} eenden)$$

..continuing

The agenda:

- λ Choosing the logic
- λ Making a dataset: proofs and lexical type assignments
- λ Learning the type assignment process
- λ Navigating the proof space
- λ Syntax-aware & type-correct text representations

Lexical type ambiguity

Type assignments are often *ambiguous* and context-dependent:

very realistic lexicon		
running ::	$\overset{mod}{\Box}(np \multimap np)$	*running dog*
	inf	*I like running*
like ::	$\overset{obj}{\Diamond} np \multimap \overset{su}{\Diamond} np \multimap s_m$	*ducks like seeds*
	$\overset{obj}{\Diamond} np \multimap \overset{su}{\Diamond} pron \multimap s_m$	*I like ducks*
	$\overset{obj}{\Diamond} inf \multimap \overset{su}{\Diamond} np \multimap s_m$	*ducks like swimming*
	$\overset{obj}{\Diamond} inf \multimap \overset{su}{\Diamond} pron \multimap s_m$	*I like swimming*
	$\overset{obj}{\Diamond} np \multimap \overset{mod}{\Box}(s_m \multimap s_m)$	*I swim like a duck*
	$\ldots$	

Lexical type ambiguity

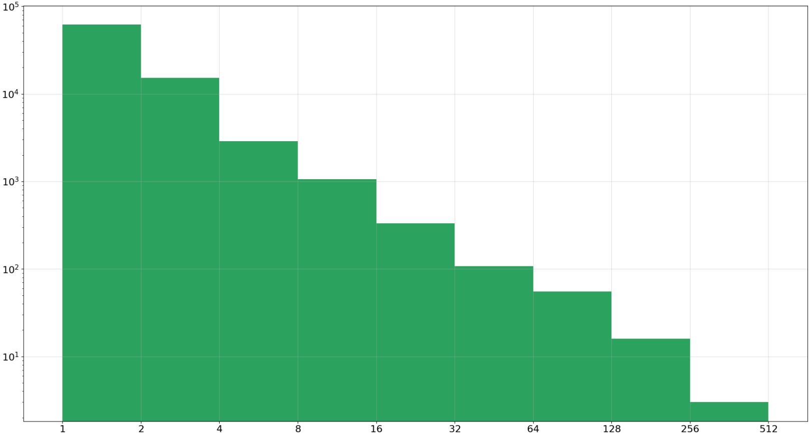
generally:

$$w :: t_1 \& t_2 \& t_3 \& \ldots \& t_n$$

more refined grammar $\Longrightarrow$

- ☹ harder lexical disambiguation (more n per word)
- ☺ easier parsing (*if* one starts from correct type)

Lexical type ambiguity



\# types (*log2-transformed*) per word

Supertagging

General idea

Given a sentence $w_1, w_2, \ldots, w_n$
find the type sequence $t_1, t_2, \ldots t_n$ that maximimizes

$$p(t_1, t_2, \ldots t_n | w_1, w_2, \ldots w_n, \theta)$$

where θ the trainable parameter space

Paleolithic ages

Indipendence Assumption

$$max(p(t_1, t_2, \dots t_n | w_1, w_2, \dots w_n, \theta)) \approx \prod_{i=1}^{n} max(p(t_i, w_i, \theta))$$

Implemented as naive bayes/maximum entropy models, later using feed-forward networks on distributional vectors

- ☺ Beats hand-writing a lexicon
- ☹ Small (if any) context/receptive field
- ☹ No domain generalization
- ☹ Severe sample sparsity when using windows

Discriminative approach

Markov assumption

$$p(t_1, t_2, \ldots t_n | w_1, w_2, \ldots w_n, \theta) \approx \prod_{i=1}^{n} p(t_i | w_1, w_2, \ldots w_n, \theta)$$

Implemented as contextualized token classification using RNNs

- ☺ global context (lossy)
- ☺ domain generalization
- ☹ single answer
- ☹ sample sparsity
- ☹ no codomain generalization (closed world assumption)

Generative approach

~~Markov assumption~~

$$p(t_1, t_2, \dots t_n | w_1, w_2, \dots w_n, \theta)$$
$$\approx \prod_{i=1}^{n} p(t_i | t_1, t_2, \dots, t_{i-1}, w_1, w_2, \dots w_n, \theta)$$

(could be) implemented as a transducer/seq2seq model

- ☺ global context (lossless)
- ☺ many answers
- ☹ sample sparsity
- ☹ no codomain generalization

Generative approach: one more step

The type syntax:

$$cod(\mathcal{L}) := A \mid \overset{d}{\Diamond} T \multimap T' \mid \overset{d}{\Box}(T \multimap T')$$

corresponds to a simple cfg (in prefix notation) with meta-rules:

$$\begin{aligned} S &\rightarrow A & \forall A \in \mathcal{A} \\ S &\rightarrow \overset{d}{\Diamond} S\ S & \forall d \in \mathrm{comps} \\ S &\rightarrow \overset{d}{\Box} S\ S & \forall d \in \mathrm{adjns} \end{aligned}$$

i.e. each type t_i can be written as a sequence of primitive symbols $\vec{\sigma}$

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i.e. each type t_i can be written as a sequence of primitive symbols $\vec{\sigma}$

$$\begin{aligned} & p(t_1, t_2, \ldots t_n | w_1, w_2, \ldots w_n, \theta) \\ \approx & \prod_{i=1}^{n} p(\sigma_i | \sigma_1, \sigma_2, \ldots, \sigma_{i-1}, w_1, w_2, \ldots w_n, \theta) \end{aligned}$$

- ☺ each type contains many subtypes (less sparsity)
- ☺ any valid types can be inductively constructed (open codomain)

Supertagging today

? types are **trees** – but tree transduction requires trees decoded in isolation

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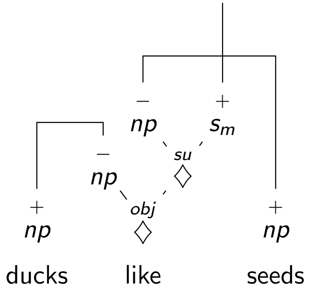
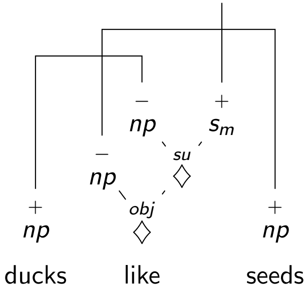
- ? harder to train: the system has to learn a grammar within the grammar
- ? left-right decoding does not make use of *easy* types first
- ? logical constraints are not easy to integrate with neural decoding
- ! new possibilities for parsing and meaning representation

Proof Ambiguity

The type system (being non-directional) permits too many parses:



$\texttt{like (ducks)}^{\texttt{obj}}\ \texttt{(seeds)}^{\texttt{su}}$



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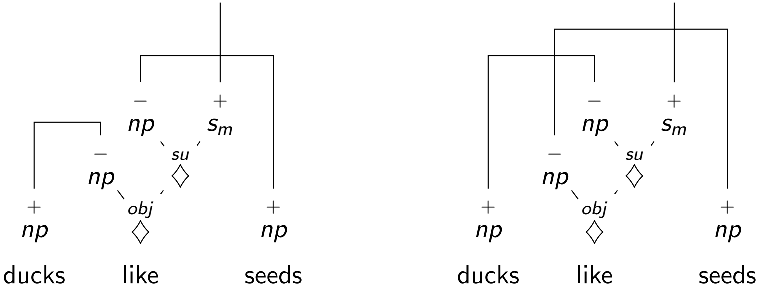


`like (ducks)`^{obj} `(seeds)`^{su} `like (seeds)`^{obj} `(ducks)`^{su}

How can we select the correct one?

Neural Proof Nets

the berries that blackbirds steal

1. pass the sentence through the supertagger

Neural Proof Nets

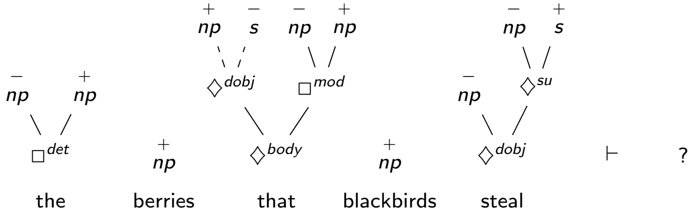
$$\Box^{det}, np, np, \#, np, \#, \Diamond^{body}, \Diamond^{dobj}, np, s, \Box^{mod}, np, np, \#, \Diamond^{dobj}, np, \Diamond^{su}, np, s$$

$\uparrow$

the berries that blackbirds steal

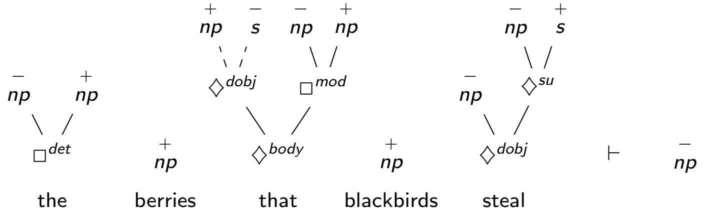
2. parse types to trees and assign polarity information

Neural Proof Nets



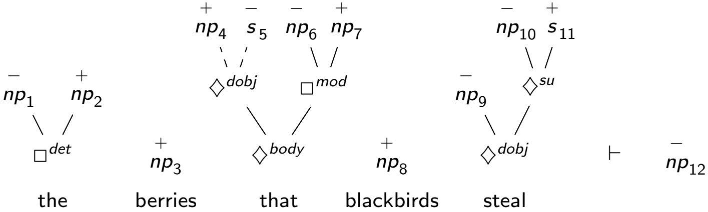
3. find conclusion as the singleton $\mathcal{A}^+ - \mathcal{A}^-$

Neural Proof Nets



4. index pos/neg occurrences and arrange in a table

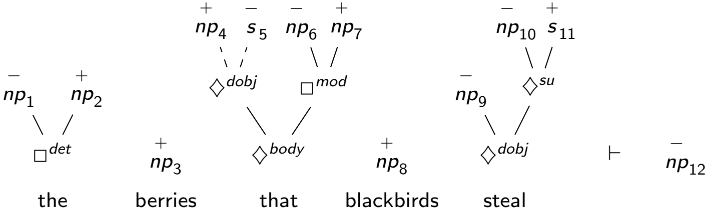
Neural Proof Nets



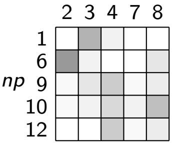
5. fill table with pair-wise agreement scores

		2	3	4	7	8
	1					
	6					
np	9					
	10					
	12					

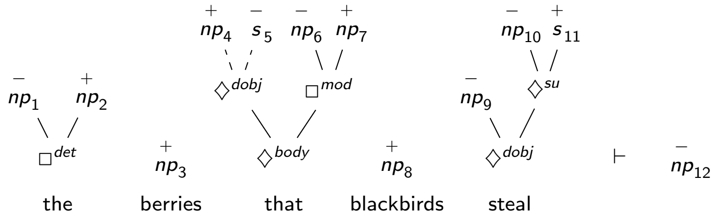
Neural Proof Nets



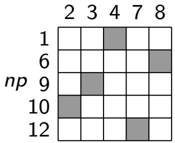
6. discretize result with Sinkhorn



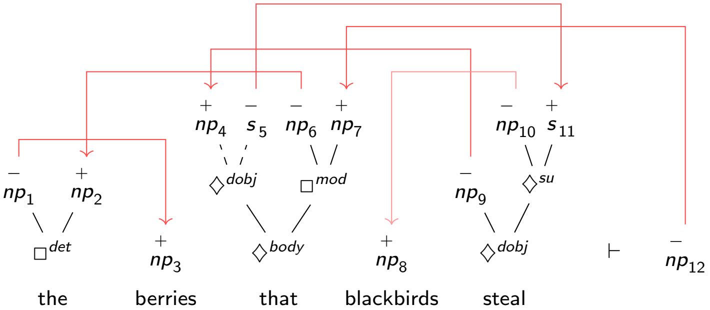
Neural Proof Nets



7. train against ground-truth axiom links



Neural Proof Nets



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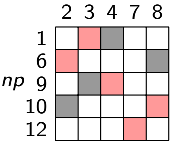

The future

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- λ Making a dataset: proofs and lexical type assignments
- λ Learning the type assignment process
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- λ Choosing the logic
- λ Making a dataset: proofs and lexical type assignments
- λ Learning the type assignment process
- λ Navigating the proof space
- λ Syntax-aware & type-correct text representations
  - meaning representation from proofs: graph traversal/encoding
  - types as recipes/functions on word embeddings, pure interpretations of the system
  - ...
  - [your project/internship/thesis idea here]

diy: github.com/konstantinosKokos/neural-proof-nets