Dependency relations, modalities and the syntax-semantics interface

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Abstract

The type logics **(N)L(P)**$_\diamond$ extend Lambek's categorial systems with adjoint pairs of unary modalities $\diamond, \Box$. In previous work, modalities have been used as licensors for controlled forms of restructuring, reordering and copying.

Here, we study a complementary use of the modalities as dependency features coding for grammatical roles. The result is a multidimensional type logic simultaneously inducing dependency and function argument structure on the linguistic material.

Background: NWO project "A composition calculus for vector-based semantic modelling with a localization for Dutch". Thanks to Konstantinos Kogkalidis, Gijs Wijnholds.

Outline

- Recap: modalities for structural control
- A dependency-enhanced type logic: theory and practice
- Challenges: integrating logical and structural reasoning

Legend Core of Lambek CG: residuated families of type-forming operations.

$$A \longrightarrow C/B \quad \text{iff} \quad A \bullet B \longrightarrow C \quad \text{iff} \quad B \longrightarrow A\backslash C$$
$$\diamondsuit A \longrightarrow B \quad \text{iff} \quad A \longrightarrow \Box B$$

Extensions: global, or $\diamondsuit$-controlled, structural options

– **NL**, pure residuation logic — Lambek 1961

– **L**, the former plus global associativity — Lambek 1958

– **LP**, aka MILL, associative+commutative — Lambek-Van Benthem

– subexponentials for restricted copying, McPheat, Valentin, Kuznetsov @MALIN

Note on proof format, compositionality

N.D., sequent-style Judgements $X \vdash A$, formula A, structure X: $X, Y ::= A \mid X \cdot Y$.
Notation $X[Y]$ substructure Y in context X. Axioms $A \vdash A$

Logical rules, e.g. $\backslash$ Elimination, Introduction

$$\frac{X \vdash A \quad Y \vdash A \backslash B}{X \cdot Y \vdash B} \backslash E \qquad \frac{A \cdot X \vdash B}{X \vdash A \backslash B} \backslash I$$

Explicit structural rules, e.g. right / left rotation of structure tree

$$\frac{X[Y \cdot (Z \cdot W)] \vdash D}{X[(Y \cdot Z) \cdot W] \vdash D} \mathsf{A}^r \qquad \frac{X[(Y \cdot Z) \cdot W] \vdash D}{X[Y \cdot (Z \cdot W)] \vdash D} \mathsf{A}^l$$

Steno words instead of their types left of turnstile; Ax: lex type assignment.

$$\cfrac{\cfrac{\cfrac{\text{the}}{np/n} \quad \cfrac{\text{temperature}}{n}}{\text{the} \cdot \text{temperature} \vdash np} /E \quad \cfrac{\text{rises}}{np \backslash s}}{(\text{the} \cdot \text{temperature}) \cdot \text{rises} \vdash s} \backslash E$$

Compositionality

Montague's view Compositional interpretation as a structure-preserving map

$$\lceil\cdot\rceil : \text{Source} \longrightarrow \text{Target}$$

'Universal Grammar', 1970

sending types and proofs of a source logic to their target counterparts.

Concretely Source **(N)L**$+$, Target MILL/**LP**

$$X_{[A_1,\ldots,A_n]} \vdash_{\textbf{(N)L}+} B \quad \xrightarrow{\lceil\cdot\rceil} \quad x_1 : \lceil A_1\rceil, \ldots, x_n : \lceil A_n\rceil \vdash_{\text{MILL}/\textbf{LP}} M : \lceil B\rceil$$

Shortcut **LP**/MILL target terms associated with proofs in source logic **(N)L**$+$.

$$\frac{X \vdash N^{\lceil A\rceil} : A \quad Y \vdash M^{\lceil A\rceil \multimap \lceil B\rceil} : A\backslash B}{X \cdot Y \vdash M^{\lceil A\rceil \multimap \lceil B\rceil}\ N^{\lceil A\rceil} : B}\ E\backslash \qquad \frac{x^{\lceil A\rceil} : A \cdot X \vdash M^{\lceil B\rceil} : B}{X \vdash \lambda x^{\lceil A\rceil}.M^{\lceil B\rceil} : A\backslash B}\ I\backslash$$

Alternative target sCCC, symmetric Compact Closed Category, concretely **FdVect**.
Direct, or via linear λ Coecke et al 2013, Wijnholds & Sadrzadeh 2019

Recall: the need for contol

(N)L$_\diamond$: the argument

- languages exhibit phenomena that seem to require some form of

  reordering, restructuring, copying

- *global* structural options are problematic

  too little (undergeneration), too much (overgeneration)

- extended type language with operations for structural control:
  - *licensing* structural reasoning that is lacking by default
  - *blocking* structural reasoning that would otherwise be available

Associativity: too little

$$\dfrac{\dfrac{\text{what}}{np/(s/np)} \qquad \dfrac{\dfrac{\dfrac{\dfrac{\text{Maisie}}{np} \quad \dfrac{\dfrac{\text{knew}}{(np\backslash s)/np} \quad np \vdash np^1}{\text{knew} \cdot np \vdash np\backslash s}\,/E}{\text{Maisie}\cdot(\text{knew}\cdot np)\vdash s}\,\backslash E}{(\text{Maisie}\cdot\text{knew})\cdot np \vdash s}\,\mathsf{A}^r}{\text{Maisie}\cdot\text{knew}\vdash s/np}\,/I^1}{\text{what}\cdot(\text{Maisie}\cdot\text{knew})\vdash np}\,/E$$

Compare

- what Maisie knew ␣

  position of the hypothesis reachable thanks to A^r (right rotation) ☺

- what Maisie knew ␣ about her parents

  too little: A^r doesn't give access to an internal gap ☹

Associativity: too much

Locality constraint himself :: $((np\backslash s)/np)\backslash(np^{\text{♂}}\backslash s)$, herself :: $((np\backslash s)/np)\backslash(np^{\text{♀}}\backslash s)$

Alice hurt herself / *himself
Alice thinks Bob hurt *herself / himself

No way of distinguishing simple transitive verb $(np\backslash s)/np \neq$ string reducing to $(np\backslash s)/np$

$$\dfrac{\dfrac{\text{hurt}}{(np\backslash s)/np} \qquad np \vdash np^1}{\text{hurt} \cdot np \vdash np\backslash s}\ /E$$

$$\dfrac{\dfrac{\text{Bob}}{np} \qquad \text{hurt} \cdot np \vdash np\backslash s}{\text{Bob} \cdot (\text{hurt} \cdot np) \vdash s}\ \backslash E$$

$$\dfrac{\dfrac{\text{thinks}}{(np\backslash s)/s} \qquad \text{Bob} \cdot (\text{hurt} \cdot np) \vdash s}{\text{thinks} \cdot (\text{Bob} \cdot (\text{hurt} \cdot np)) \vdash np\backslash s}\ /E$$

$$\dfrac{\text{thinks} \cdot (\text{Bob} \cdot (\text{hurt} \cdot np)) \vdash np\backslash s}{\text{thinks} \cdot ((\text{Bob} \cdot \text{hurt}) \cdot np) \vdash np\backslash s}\ \mathsf{A}^r$$

$$\dfrac{\text{thinks} \cdot ((\text{Bob} \cdot \text{hurt}) \cdot np) \vdash np\backslash s}{(\text{thinks} \cdot (\text{Bob} \cdot \text{hurt})) \cdot np \vdash np\backslash s}\ \mathsf{A}^r$$

$$\dfrac{(\text{thinks} \cdot (\text{Bob} \cdot \text{hurt})) \cdot np \vdash np\backslash s}{\text{thinks} \cdot (\text{Bob} \cdot \text{hurt}) \vdash (np\backslash s)/np}\ /I^1$$

$$\dfrac{\text{thinks} \cdot (\text{Bob} \cdot \text{hurt}) \vdash (np\backslash s)/np \qquad \dfrac{\text{herself}}{((np\backslash s)/np)\backslash(np^{\text{♀}}\backslash s)}}{(\text{thinks} \cdot (\text{Bob} \cdot \text{hurt})) \cdot \text{herself} \vdash np^{\text{♀}}\backslash s}\ \backslash E$$

$$\dfrac{\dfrac{\text{Alice}}{np^{\text{♀}}} \qquad (\text{thinks} \cdot (\text{Bob} \cdot \text{hurt})) \cdot \text{herself} \vdash np^{\text{♀}}\backslash s}{\text{Alice} \cdot ((\text{thinks} \cdot (\text{Bob} \cdot \text{hurt})) \cdot \text{herself}) \vdash s}\ \backslash E$$

Modalities for structural control

- The type language is extended with a pair of unary connectives: $\Diamond, \Box$ satisfying

$$\frac{\Diamond A \longrightarrow B}{A \longrightarrow \Box B}$$

- Logic: $\Diamond, \Box$ form a residuated pair. One easily shows

compositions: $\Diamond\Box A \longrightarrow A$ (interior) $\quad A \longrightarrow \Box\Diamond A$ (closure)

monotonicity: from $A \longrightarrow B$ infer $\Diamond A \longrightarrow \Diamond B$, $\Box A \longrightarrow \Box B$

- Structure: *global* rules $\leadsto$ $\Diamond$ controlled *restricted* versions, e.g.

$$A^\diamond : \quad (A \bullet B) \bullet \Diamond C \longrightarrow A \bullet (B \bullet \Diamond C)$$
$$C^\diamond : \quad (A \bullet B) \bullet \Diamond C \longrightarrow (A \bullet \Diamond C) \bullet B$$

Multimodal generalization families $\{\Diamond_i, \Box_i\}_{i \in I}$ for particular structural choices

Control operators: N.D. rules

Structures $X, Y ::= A \mid \langle X \rangle \mid X \cdot Y$

$$\frac{\langle X \rangle \vdash A}{X \vdash \Box A}\ \Box I \qquad \frac{X \vdash \Box A}{\langle X \rangle \vdash A}\ \Box E$$

$$\frac{X \vdash A}{\langle X \rangle \vdash \Diamond A}\ \Diamond I \qquad \frac{Y \vdash \Diamond A \quad X[\langle A \rangle] \vdash B}{X[Y] \vdash B}\ \Diamond E$$

Shorthand $(\Diamond E')$ if left premise of $(\Diamond E)$ is an axiom:

$$\frac{X[\langle A \rangle] \vdash B}{X[\Diamond A] \vdash B}\ \Diamond E'$$

Control operators: terms

Terms: $M, N ::= x \mid \lambda x.M \mid MN \mid {}^{\cup}M \mid {}^{\cap}M \mid {}^{\vee}M \mid {}^{\wedge}M$

$$\frac{\langle X\rangle \vdash M : A}{X \vdash {}^{\wedge}M : \Box A}\ \Box I \qquad \frac{X \vdash M : \Box A}{\langle X\rangle \vdash {}^{\vee}M : A}\ \Box E$$

$$\frac{X \vdash M : A}{\langle X\rangle \vdash {}^{\cap}M : \Diamond A}\ \Diamond I \qquad \frac{Y \vdash M : \Diamond A \quad X[\langle x : A\rangle] \vdash N : B}{X[Y] \vdash N[{}^{\cup}M/x] : B}\ \Diamond E$$

Proof normalization: ${}^{\vee\wedge}M = M$, ${}^{\wedge\vee}M = M$; ${}^{\cup\cap}M = M$, ${}^{\cap\cup}M = M$

Concrete interpretation See Correia et al, 2020, Putting a Spin on Language: A Quantum Interpretation of Unary Connectives for Linguistic Applications.

Controlled extraction: too little $\rightsquigarrow$ just fine

$\Diamond\Box np$: 'moveable' np; key-and-lock: contract $\Diamond\Box np$ to np, once in place.

$$
\dfrac{\dfrac{\text{what}}{np/(s/\Diamond\Box np)} \qquad \dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\text{Alice}}{np} \qquad \dfrac{\dfrac{\dfrac{\text{found}}{(np\backslash s)/np} \quad \dfrac{\Box np \vdash \Box np}{\langle \Box np \rangle \vdash np}\,\Box E}{\text{found}\cdot\langle\Box np\rangle \vdash np\backslash s}\,/E \qquad \dfrac{\text{there}}{(np\backslash s)\backslash(np\backslash s)}}{(\text{found}\cdot\langle\Box np\rangle)\cdot\text{there} \vdash np\backslash s}\,\backslash E}{\text{Alice}\cdot((\text{found}\cdot{\color{red}\langle\Box np\rangle})\cdot\text{there}) \vdash s}\,\backslash E}{\text{Alice}\cdot((\text{found}\cdot\text{there})\cdot{\color{red}\langle\Box np\rangle}) \vdash s}\,\mathsf{C}^r_\Diamond}{(\text{Alice}\cdot(\text{found}\cdot\text{there}))\cdot{\color{red}\langle\Box np\rangle} \vdash s}\,\mathsf{A}^r_\Diamond}{(\text{Alice}\cdot(\text{found}\cdot\text{there}))\cdot\Diamond\Box np \vdash s}\,\Diamond E'}{\text{Alice}\cdot(\text{found}\cdot\text{there}) \vdash s/\Diamond\Box np}\,/I}{\text{what}\cdot(\text{Alice}\cdot(\text{found}\cdot\text{there})) \vdash np}\,/E
$$

$\mathsf{A}^r_\Diamond$: controlled Associativity, $(A \bullet B) \bullet \Diamond C \longrightarrow A \bullet (B \bullet \Diamond C)$

$\mathsf{C}^r_\Diamond$: controlled Commutativity, $(A \bullet B) \bullet \Diamond C \longrightarrow (A \bullet \Diamond C) \bullet B$

Island constraints: too much $\rightsquigarrow$ just fine

Compare the following with in, during :: $(iv\backslash iv)/np$, and which :: $(n\backslash n)/(s/\Diamond\Box np)$

Napoleon slept in this bed
N slept during the speech
the bed which N slept in
*the speech which N slept during

In general, English allows preposition stranding, which is derivable with the controlled asso/commu rules. But some modifiers behave as *islands*, inaccessible for extraction.

$\Diamond$ as an obstacle a modified type assignment imposes the desired island constraint:

$iv := np\backslash s$ during :: $(\Box(iv\backslash iv))/np$ Morrill 1992

- during first has to compose with its np object
- the result type $\Box(iv\backslash iv)$ is *locked* by $\Box$
- $\Diamond$ *unlocks* $\Box(iv\backslash iv)$, thus sealing off during np as an island

We refine the idea of modalities projecting locality domains to take into account dependency info.

Dependency structure

Dependency roles articulate the linguistic material on the basis of two oppositions:

- head - complement relations
  - verbal domain: subj, (in)direct object, ...
  - nominal domain: prepositional object, ...
- adjunct - head relations
  - verbal domain: (time, manner, ...) adverbial
  - nominal domain: adjectival, numeral, determiner, ...

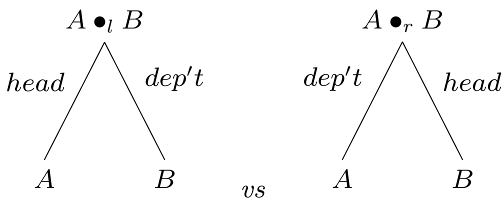
Compare: fa-structure: function vs argument

Orthogonality The fa and the dependency articulation are in general not aligned. This asks for a multidimensional type logic.

E.g. Determiner. Semantically, characteristic function of $(\llbracket N \rrbracket, \llbracket VP \rrbracket)$ relation; morphologically, dependent on head noun.

A first step: bimodal syntactic calculus

Product $\bullet$ is split in a left-headed $\bullet_l$ and a right-headed $\bullet_r$ version:



$$\text{RES} \qquad A \longrightarrow C/_l B \quad \text{iff} \quad A \bullet_l B \longrightarrow C \quad \text{iff} \quad B \longrightarrow A\backslash_l C$$
$$A \longrightarrow C/_r B \quad \text{iff} \quad A \bullet_r B \longrightarrow C \quad \text{iff} \quad B \longrightarrow A\backslash_r C$$

head functor: $C/_l B, \quad A\backslash_r C$

dependent functor: $C/_r B, \quad A\backslash_l C$

Ref MM and Morrill 1991, Heads and phrases. Type calculus for dependency and constituent structure.

Deconstructing the headed product

Define $\bullet_l$, $\bullet_r$ as compositions of regular $\bullet$ and modal marking of the dependent:

$$A \bullet_l B := A \bullet \Diamond B \qquad A \bullet_r B := \Diamond A \bullet B$$

Residuation: translation of the slashes recall: $\Diamond A \longrightarrow B$ iff $A \longrightarrow \Box B$

$$\dfrac{\dfrac{A \longrightarrow C/_l B}{A \bullet_l B \longrightarrow C}}{B \longrightarrow A\backslash_l C} \quad \rightsquigarrow \quad \dfrac{\dfrac{\dfrac{A \longrightarrow C/\Diamond B}{A \bullet \Diamond B \longrightarrow C}}{\Diamond B \longrightarrow A\backslash C}}{B \longrightarrow \Box(A\backslash C)} \qquad \dfrac{\dfrac{A \longrightarrow C/_r B}{A \bullet_r B \longrightarrow C}}{B \longrightarrow A\backslash_r C} \quad \rightsquigarrow \quad \dfrac{\dfrac{\dfrac{A \longrightarrow \Box(C/B)}{\Diamond A \longrightarrow C/B}}{\Diamond A \bullet B \longrightarrow C}}{B \longrightarrow \Diamond A\backslash C}$$

Multimodal generalization families $\{\Diamond_d, \Box_d\}_{d \in DepLabel}$

- $\Diamond_d A\backslash C$, $C/\Diamond_d B$ head functor assigning dependency role d to its complement
- $\Box_d(A\backslash C)$, $\Box_d(C/B)$ dependent functor projecting adjunct role d

Practice

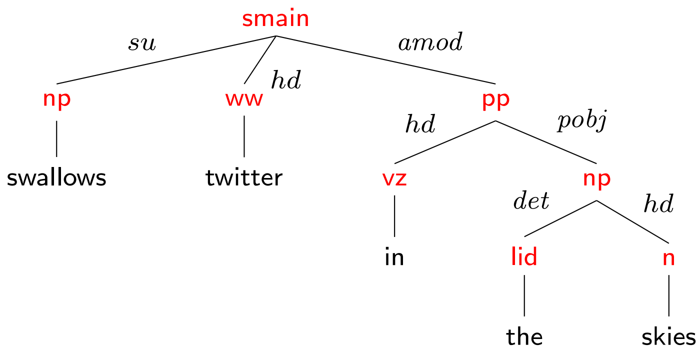
NWO project "A composition calculus for vector-based semantic modelling with a localization for Dutch". Resources and tools for computational study of Dutch.

- Kogkalidis et al 2019, Constructive type-logical supertagging with self-attention networks. RepLNLP.
- Kogkalidis et al 2020a, Æthel: Automatically extracted typelogical derivations for Dutch. LREC.
- Kogkalidis et al 2020b, Neural proof nets. CoNLL

non-directional, dependency-enhanced types, relying on the dependency info to correctly transcribe raw text sentences into proofs and terms of the linear λ-calculus.

Structured data

Dutch treebank LASSY (google translate: zwaluwen kwetteren in 't azuur):

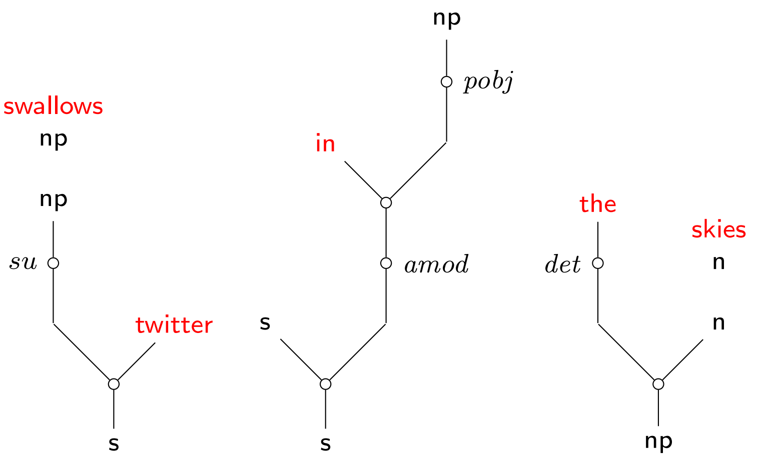


Extracted types:

swallows : np twitter : $\Diamond_{su} np \backslash s$ in : $\Box_{amod}(s \backslash s) / \Diamond_{pobj} np$ the : $\Box_{det}(np/n)$ skies : n

or non-directional: $A \backslash B$, $B/A \rightsquigarrow A \multimap B$

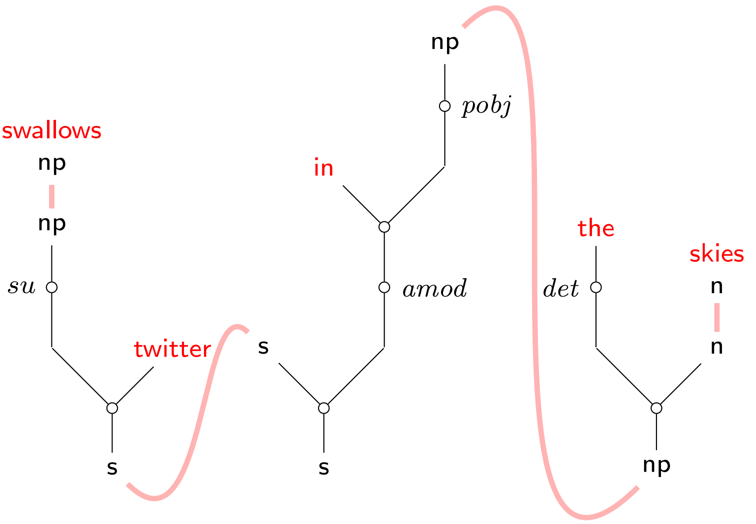
Word modules



$\Diamond_{su} np \backslash s$ $\quad$ $\Box_{amod}(s \backslash s) / \Diamond_{pobj} np$ $\quad$ $\Box_{det}(np/n)$

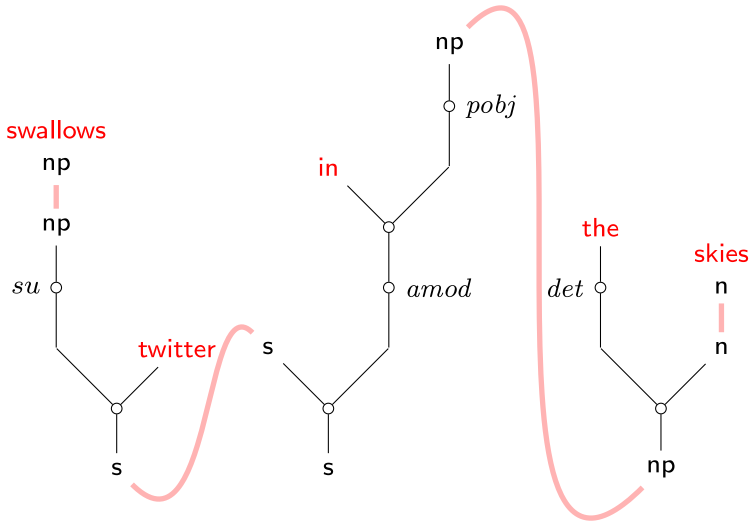
Moot 2002

Word modules, proof structure, proof net



$\Diamond_{su} np \backslash s$ $\quad \Box_{amod}(s \backslash s)/\Diamond_{pobj} np$ $\quad \Box_{det}(np/n)$

Word modules, proof net, λ term

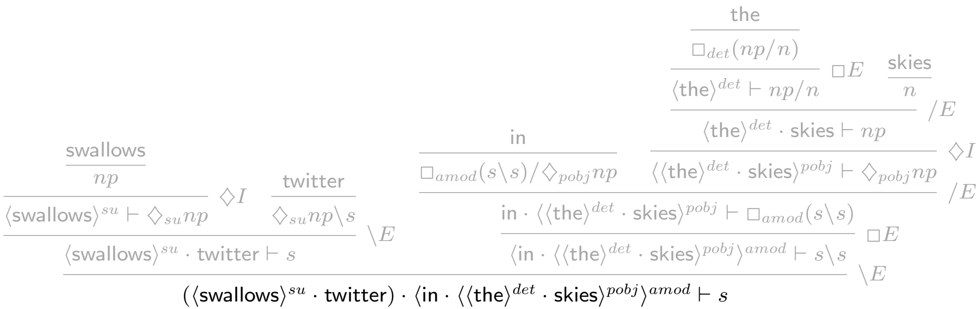


$\Diamond_{su} np \backslash s$ $\quad$ $\Box_{amod}(s \backslash s)/\Diamond_{pobj} np$ $\quad$ $\Box_{det}(np/n)$

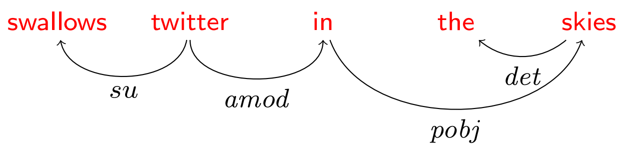
$$({}^{\vee_{amod}}(\text{IN}\ {}^{\cap_{pobj}}({}^{\vee_{det}}\text{THE SKIES}))\ (\text{TWITTER}\ {}^{\cap_{su}}\text{SWALLOWS}))$$

Dependency structure

Derivation, N.D. style:



Induced dependency structure:



$\rightsquigarrow$ within dependency domain, outgoing arcs from head to (head of) dependents

Dependency domains: some consequences

Case study: extraction revisited

Recall Dutch left-branch extraction via controlled associativity, commutativity

$$\Diamond_x A \bullet (B \bullet C) \longrightarrow (\Diamond_x A \bullet B) \bullet C \qquad \Diamond_x A \bullet (B \bullet C) \longrightarrow B \bullet (\Diamond_x A \bullet C)$$

Relative pronoun die :: $(n\backslash n)/(!_x\, np\backslash s)$ $\quad !_x\, A \triangleq \Diamond_x \Box_x A$

ambiguous between subj/obj relativization: $\quad s$ subordinate clause, head-final

mannen die ␣ vrouwen haten $\rightsquigarrow$ men who hate women
mannen die vrouwen ␣ haten $\rightsquigarrow$ men who(m) women hate

Dependency refinement

- distinguish subj/obj relativisation: np hypothesis $\rightsquigarrow \Diamond_{su} np$ vs $\Diamond_{obj} np$

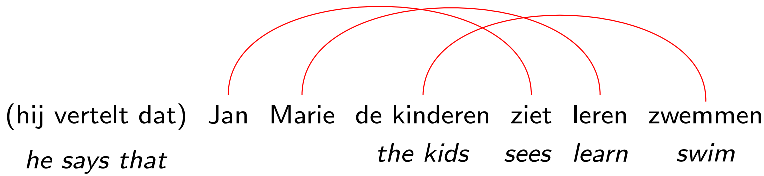
  reduction of derivational ambiguity

- make extraction conditional on $x \succeq d$, for some boundary strength ordering

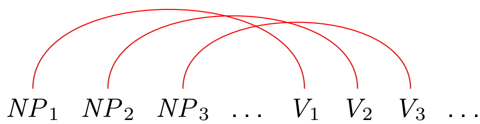
  Morrill's 'island' modalities parameterized for dependency roles

Case study: Dutch verb clusters

Crossing dependencies Huijbregts 1984, Shieber 1985



Pattern copy language w^2, i.e. mildly context-sensitive



Handling verb clusters: two type-logical options

- form-meaning dualism: the Abstract Categorial Grammar method

  abstract syntax, divergent compositional translations:

  $\lceil \cdot \rceil^{string}$ string semantics

  $\lceil \cdot \rceil^{sem}$ meaning assembly

- all-in-one approach

  derivations $\Gamma \vdash A$ with alternating logical and structural phases

  meaning assembly: Elim/Intro logical constants

  surface form: meaning preserving structural transformations

2-MCFG

- infinitival phrases $INFP$: string tuples (*rest*, *verb(cluster)*)
- verb raising triggers IVR_i: head-adjunction — Pollard 1984

$$
\begin{array}{lrcll}
f_0 & INFP(\epsilon, x) & \leftarrow & INF_0(x) & \\
f_1 & INFP(x, y) & \leftarrow & NP(x)\ INF_1(y) & \\
 & & & & \\
g_0 & INFP(y, x \cdot z) & \leftarrow & INFP(y, z)\ IVR_0(x) & \\
g_1 & INFP(y \cdot z, x \cdot w) & \leftarrow & NP(y)\ INFP(z, w)\ IVR_1(x) & \\
 & & & & \\
d_0 & INF_0(\text{vertrekken}) & \leftarrow & & \textit{leave} \\
d_1 & INF_1(\text{zeggen}) & \leftarrow & & \textit{say} \\
d_2 & IVR_0(\text{willen}) & \leftarrow & & \textit{want} \\
d_3 & IVR_1(\text{laten}) & \leftarrow & & \textit{let}
\end{array}
$$

VR triggers: modal/temporal auxiliaries (g_0); verbs of perception, causatives (g_1)

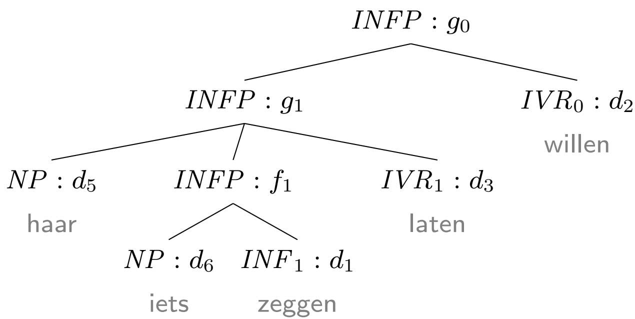
From abstract syntax to string semantics

ACG method typing rule constants, compositional translations $\lceil \cdot \rceil$: Source $\to$ Target

de Groote, Pogodalla c.s.

String semantics: higher-order modelling of tuples: $\lceil INFP \rceil = (\sigma \multimap \sigma \multimap \sigma) \multimap \sigma$

$\triangleq \sigma^{(2)}$



$$
\begin{array}{lclcl}
\lceil f_1 \rceil & = & \lambda x \lambda y \lambda f.(f\ x\ y) & :: & \sigma \multimap \sigma \multimap \sigma^{(2)} \\
\lceil g_0 \rceil & = & \lambda q \lambda x \lambda f.(q\ \lambda y \lambda z.(f\ y\ x \cdot z)) & :: & \sigma^{(2)} \multimap \sigma \multimap \sigma^{(2)} \\
\lceil g_1 \rceil & = & \lambda x \lambda q \lambda y \lambda f.(q\ \lambda z \lambda w.(f\ x \cdot z\ y \cdot w)) & :: & \sigma \multimap \sigma^{(2)} \multimap \sigma \multimap \sigma^{(2)}
\end{array}
$$

$$\lceil g_0\ (g_1\ d_5\ (f_1\ d_6\ d_1)\ d_3)\ d_2 \rceil \quad = \quad \lambda f.(f\ \text{haar}\cdot\text{iets}\ \ \text{willen}\cdot\text{laten}\cdot\text{zeggen})$$

NL

The ACG method is easily adapted to a **NL** source: words as abstract constants.

$$\dfrac{\dfrac{\dfrac{\text{haar}}{NP} \qquad \dfrac{\dfrac{\dfrac{\text{iets}}{NP} \quad \dfrac{\text{zeggen}}{NP\backslash INFP}}{\text{iets}\cdot\text{zeggen} \vdash INFP}\,\backslash E \qquad \dfrac{\text{laten}}{INFP\backslash(NP\backslash INFP)}}{(\text{iets}\cdot\text{zeggen})\cdot\text{laten} \vdash NP\backslash INFP}\,\backslash E}{\text{haar}\cdot((\text{iets}\cdot\text{zeggen})\cdot\text{laten}) \vdash INFP}\,\backslash E \qquad \dfrac{\text{willen}}{INFP\backslash INFP}}{\dagger \qquad (\text{haar}\cdot((\text{iets}\cdot\text{zeggen})\cdot\text{laten}))\cdot\text{willen} \vdash INFP}\,\backslash E$$

$$\begin{array}{rcll}
\lceil\text{zeggen}\rceil & = & \lambda x\lambda f.(f\ x\ zeggen) & ::\ \sigma \multimap \sigma^{(2)} \\
\lceil\text{willen}\rceil & = & \lambda q\lambda f.(q\ \lambda y\lambda z.(f\ y\ willen\cdot z)) & ::\ \sigma^{(2)} \multimap \sigma^{(2)} \\
\lceil\text{laten}\rceil & = & \lambda q\lambda x\lambda f.(q\ \lambda z\lambda w.(f\ x\cdot z\ laten\cdot w)) & ::\ \sigma^{(2)} \multimap \sigma \multimap \sigma^{(2)}
\end{array}$$

$$\begin{array}{lrcl}
 & \lceil\dagger\rceil^{string} & = & \lambda f.(f\ haar\cdot iets\ \ willen\cdot laten\cdot zeggen) \\
\text{compare} & \lceil\dagger\rceil^{sem} & = & \textsc{want}\ (\textsc{let}\ (\textsc{say something})\ \textsc{her})
\end{array}$$

Dependency enhancement

function types $A\backslash B \rightsquigarrow \Diamond_d A\backslash B$

vc: verbal complement

$$\frac{\dfrac{\text{iets}}{np}}{\langle\text{iets}\rangle^{obj} \vdash \Diamond_{obj} np}\ \Diamond I \qquad \frac{\text{zeggen}}{\Diamond_{obj} np\backslash inf}$$

$$\frac{\langle\text{iets}\rangle^{obj} \vdash \Diamond_{obj} np \qquad \Diamond_{obj} np\backslash inf}{\langle\text{iets}\rangle^{obj} \cdot \text{zeggen} \vdash inf}\ \backslash E$$

$$\frac{\langle\text{iets}\rangle^{obj} \cdot \text{zeggen} \vdash inf}{\langle\langle\text{iets}\rangle^{obj} \cdot \text{zeggen}\rangle^{vc} \vdash \Diamond_{vc} inf}\ \Diamond I \qquad \frac{\text{laten}}{\Diamond_{vc} inf\backslash(\Diamond_{obj} np\backslash inf)}$$

$$\frac{\langle\langle\text{iets}\rangle^{obj} \cdot \text{zeggen}\rangle^{vc} \vdash \Diamond_{vc} inf \qquad \Diamond_{vc} inf\backslash(\Diamond_{obj} np\backslash inf)}{\langle\langle\text{iets}\rangle^{obj} \cdot \text{zeggen}\rangle^{vc} \cdot \text{laten} \vdash \Diamond_{obj} np\backslash inf}\ \backslash E$$

$$\frac{\dfrac{\text{haar}}{np}}{\langle\text{haar}\rangle^{obj} \vdash \Diamond_{obj} np}\ \Diamond I$$

$$\frac{\langle\text{haar}\rangle^{obj} \vdash \Diamond_{obj} np \qquad \langle\langle\text{iets}\rangle^{obj} \cdot \text{zeggen}\rangle^{vc} \cdot \text{laten} \vdash \Diamond_{obj} np\backslash inf}{\langle\text{haar}\rangle^{obj} \cdot (\langle\langle\text{iets}\rangle^{obj} \cdot \text{zeggen}\rangle^{vc} \cdot \text{laten}) \vdash inf}\ \backslash E$$

$$\frac{\langle\text{haar}\rangle^{obj} \cdot (\langle\langle\text{iets}\rangle^{obj} \cdot \text{zeggen}\rangle^{vc} \cdot \text{laten}) \vdash inf}{\langle\langle\text{haar}\rangle^{obj} \cdot (\langle\langle\text{iets}\rangle^{obj} \cdot \text{zeggen}\rangle^{vc} \cdot \text{laten})\rangle^{vc} \vdash \Diamond_{vc} inf}\ \Diamond I \qquad \frac{\text{willen}}{\Diamond_{vc} inf\backslash inf}$$

$$\frac{\langle\langle\text{haar}\rangle^{obj} \cdot (\langle\langle\text{iets}\rangle^{obj} \cdot \text{zeggen}\rangle^{vc} \cdot \text{laten})\rangle^{vc} \vdash \Diamond_{vc} inf \qquad \Diamond_{vc} inf\backslash inf}{\langle\langle\text{haar}\rangle^{obj} \cdot (\langle\langle\text{iets}\rangle^{obj} \cdot \text{zeggen}\rangle^{vc} \cdot \text{laten})\rangle^{vc} \cdot \text{willen} \vdash inf}\ \backslash E$$

$$(\textsc{want}\ {}^\cap((\textsc{let}\ {}^\cap(\textsc{say}\ {}^\cap\textsc{something}))\ {}^\cap\textsc{her}))$$

Modelling head adjunction

Logical/structural phases $\mid \Gamma \mid$: antecedent structure term with yield Γ

$$\dfrac{\dfrac{\vdots}{\mid \text{haar iets zeggen laten willen} \mid \vdash INFP}\ \textit{logical phase}}{\dfrac{?}{\mid \text{haar iets willen laten zeggen} \mid \vdash INFP}\ \textit{structural phase}}$$

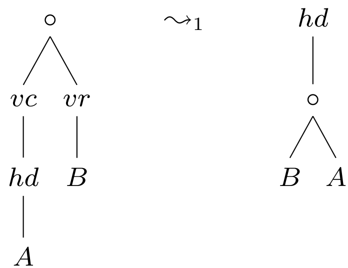
Challenge To reach the end sequent, the VR triggers have to break into the dependency domain of their infinitival complements.

As with Pollard's Head Grammars, we need head marking:

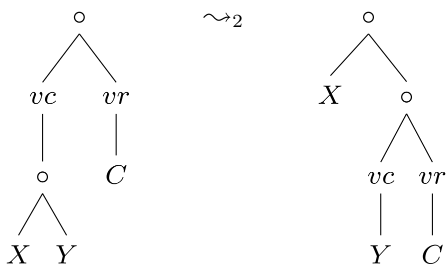
$$\begin{array}{rcl} \text{zeggen} :: \Diamond_{obj} np \backslash inf & \leadsto & \Box_{hd}(\Diamond_{obj} np \backslash inf) \\ \text{willen} :: \Diamond_{vc} inf \backslash inf & \leadsto & \Box_{vr}(\Diamond_{vc} inf \backslash inf) \\ \text{laten} :: \Diamond_{vc} inf \backslash (\Diamond_{obj} np \backslash inf) & \leadsto & \Box_{vr}(\Diamond_{vc} inf \backslash (\Diamond_{obj} np \backslash inf)) \end{array}$$

Structural transformations

- vr trigger in construction with the head hd of its vc merges into complex hd:



- restructuring disassembles complex verbal complements:



iets willen zeggen

$$
\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\text{iets}}{np}}{\langle\text{iets}\rangle^{obj} \vdash \Diamond_{obj} np}\,\Diamond I \qquad \dfrac{\dfrac{\text{zeggen}}{\Box_{hd}(\Diamond_{obj} np\backslash inf)}}{\langle\text{zeggen}\rangle^{hd} \vdash \Diamond_{obj} np\backslash inf}\,\Box E}{\langle\text{iets}\rangle^{obj}\cdot\langle\text{zeggen}\rangle^{hd}\vdash inf}\,\backslash E}{\langle\langle\text{iets}\rangle^{obj}\cdot\langle\text{zeggen}\rangle^{hd}\rangle^{vc}\vdash \Diamond_{vc} inf}\,\Diamond I \qquad \dfrac{\dfrac{\text{willen}}{\Box_{vr}(\Diamond_{vc} inf\backslash inf)}}{\langle\text{willen}\rangle^{vr}\vdash\Diamond_{vc} inf\backslash inf}\,\Box E}{\langle\langle\text{iets}\rangle^{obj}\cdot\langle\text{zeggen}\rangle^{hd}\rangle^{vc}\cdot\langle\text{willen}\rangle^{vr}\vdash inf}\,\backslash E}{\langle\text{iets}\rangle^{obj}\cdot(\langle\langle\text{zeggen}\rangle^{hd}\rangle^{vc}\cdot\langle\text{willen}\rangle^{vr})\vdash inf}\,R2}{\langle\text{iets}\rangle^{obj}\cdot\langle\text{willen}\cdot\text{zeggen}\rangle^{hd}\vdash inf}\,R1
$$

$$({}^{\vee}\textsc{want}\ {}^{\cap}({}^{\vee}\textsc{say}\ {}^{\cap}\textsc{something}))$$

- joint effect: verb raising trigger left-adjoined to the head of its verbal complement
- more complex clusters: $R1 \circ R2^{+}$

Recombinant behaviour

$$
\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\vdots}{\langle\langle \textsf{haar}\rangle^{obj}\cdot(\langle\langle \textsf{iets}\rangle^{obj}\cdot\langle \textsf{zeggen}\rangle^{hd}\rangle^{vc}\cdot\langle \textsf{laten}\rangle^{vr}))\rangle^{vc}\cdot\langle \textsf{willen}\rangle^{vr}\vdash inf}\ \textit{logical rules}}{\langle \textsf{haar}\rangle^{obj}\cdot(\langle\langle\langle \textsf{iets}\rangle^{obj}\cdot\langle \textsf{zeggen}\rangle^{hd}\rangle^{vc}\cdot\langle \textsf{laten}\rangle^{vr}\rangle^{vc}\cdot\langle \textsf{willen}\rangle^{vr})\vdash inf}\ R2}{\langle \textsf{haar}\rangle^{obj}\cdot(\langle\langle \textsf{iets}\rangle^{obj}\cdot(\langle\langle \textsf{zeggen}\rangle^{hd}\rangle^{vc}\cdot\langle \textsf{laten}\rangle^{vr}))\rangle^{vc}\cdot\langle \textsf{willen}\rangle^{vr})\vdash inf}\ R2}{\langle \textsf{haar}\rangle^{obj}\cdot(\langle \textsf{iets}\rangle^{obj}\cdot(\langle\langle\langle \textsf{zeggen}\rangle^{hd}\rangle^{vc}\cdot\langle \textsf{laten}\rangle^{vr}\rangle^{vc}\cdot\langle \textsf{willen}\rangle^{vr}))\vdash inf}\ R2}{\langle \textsf{haar}\rangle^{obj}\cdot(\langle \textsf{iets}\rangle^{obj}\cdot(\langle\langle \textsf{laten}\cdot \textsf{zeggen}\rangle^{hd}\rangle^{vc}\cdot\langle \textsf{willen}\rangle^{vr}))\vdash inf}\ R1}{\langle \textsf{haar}\rangle^{obj}\cdot(\langle \textsf{iets}\rangle^{obj}\cdot\langle \textsf{willen}\cdot(\textsf{laten}\cdot \textsf{zeggen})\rangle^{hd})\vdash inf}\ R1
$$

$$(^{\vee}\textsc{want}\ ^{\cap}((^{\vee}\textsc{let}\ ^{\cap}(^{\vee}\textsc{say}\ ^{\cap}\textsc{something}))\ ^{\cap}\textsc{her}))$$

Conclusion

- modalities as licensors of structural transformations
- dependency-enhanced types: modalities demarcating domains of locality
- options for integrating logical and structural reasoning

□