Categorial Dependency Grammars: Analysis and Learning (Invited Talk)

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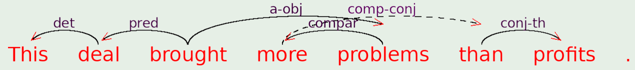
Plan

Basics of Dependency Syntax

Surface Dependency Structures (DS) are graphs of surface syntactic relations between the *words* in a sentence.

A Dependency Structure



Dependencies are determined by valencies of words

brought has +valency pred of a left adjacent word

deal has −valency pred of a right adjacent word

Saturation of valency pred determines projective dependency

deal $\xleftarrow{\text{pred}}$ *brought* (**Governor:** *brought*, **Subordinate:** *deal*)

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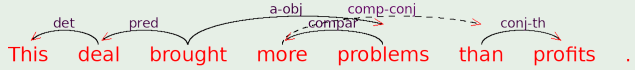


Dependencies are determined by valencies of words

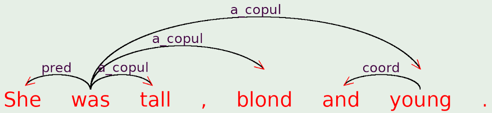
more has +valency comp-conj of a word somewhere on its right

than has −valency comp-conj of a word somewhere on its left

Saturation of comp-conj determines non-projective dependency

more $\overset{\text{comp-conj}}{\dashrightarrow}$ *than* (**Governor:** *more*, **Subordinate:** *than*)

Some dependency valencies are MULTIPLE



pred is non-repeatable

a_copul is repeatable

Principle of Repeatable Dependencies [Mel'čuk'88]

- Every dependency d is either repeatable or non-repeatable
- d is repeatable if SOME governor uses d in SOME DS at least $(K =)$ 2 times
- Any word governing through a repeatable dependency d in SOME DS may have any number of subordinates through d

CDG Types express dependency valencies

PROJECTIVE DEPENDENCIES (AND ANCHORS)

Dependency: $Gov \xrightarrow{d} Sub$:

Governor Type: $Gov \mapsto [..\backslash../../d/..]^P$

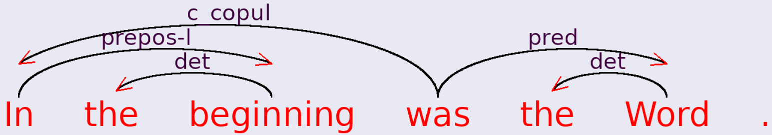
Subordinate Type: $Sub \mapsto [..\backslash d/..]^P$

Anchors are non-important projective dependencies. Used for:

- Anchoring punctuation
- Anchoring the subordinate of non-projective dependencies

Categorial Dependency Grammars (CDG)

CDG Types express dependency valencies



$in \mapsto [c\_copul/prepos-l]$
$the \mapsto [det]$
$beginning \mapsto [det\backslash prepos-l]$
$was \mapsto [c\_copul\backslash S/pred]$
$Word \mapsto [det\backslash pred]$

CDG Types express dependency valencies

NON-PROJECTIVE DEPENDENCIES

Polarized valencies: $\nearrow d$, $\searrow d$, $\nwarrow d$, $\swarrow d$

Dependency: $Gov \overset{d}{\dashrightarrow} Sub$:

Governor Type Potential: $Gov \mapsto [..]^{..\nearrow d..}$

Subordinate Type Potential: $Sub \mapsto [..]^{..\searrow d..}$

CDG Types express dependency valencies

$this \mapsto [det]$
$deal \mapsto [det\backslash pred]$
$brought \mapsto [pred\backslash S/a-obj]$
$problems \mapsto [compar\backslash a-obj]$
$profits \mapsto [conj-th]$
$more \mapsto [compar]^{\nearrow comp-conj}$
$than \mapsto [\ \ /conj-th]^{\searrow comp-conj}$

CDG Types express dependency valencies

NON-PROJECTIVE DEPENDENCIES WITH ANCHORS

Polarized valencies: $\nearrow d$, $\searrow d$, $\nwarrow d$, $\swarrow d$

Anchor valencies: $\#\searrow d$, $\#\swarrow d$

Dependency and anchor: $Gov \overset{d}{\dashrightarrow} Sub \overset{\#\searrow d}{\longleftarrow} Host$:

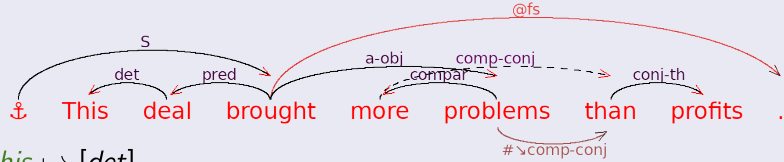
Governor Type: $Gov \mapsto [..]^{..\nearrow d..}$

Subordinate Type: $Sub \mapsto [..\backslash\#\searrow d/..]^{..\searrow d..}$

Host Type: $Host \mapsto [..\backslash\#\searrow d\backslash../..]^{P}$

Categorial Dependency Grammars (CDG)

CDG Types express dependency valencies



$this \mapsto [det]$

$deal \mapsto [det\backslash pred]$

$brought \mapsto [pred\backslash S/@fs/a-obj]$

$problems \mapsto [compar\backslash a-obj/\#\searrow comp-conj]$

$profits \mapsto [conj-th]$

$more \mapsto [compar]^{\nearrow comp-conj}$

$than \mapsto [\#\searrow comp-conj/conj-th]^{\searrow comp-conj}$

$. \mapsto [@fs]$

Left-oriented rules

L^{l}. $[C]^P[C\backslash\beta]^Q \vdash [\beta]^{PQ}$ $\quad Gov \xrightarrow{C} Sub$

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I^{l}. $[C]^P[C^*\backslash\beta]^Q \vdash [C^*\backslash\beta]^{PQ}$ $\qquad Gov \xrightarrow{C} Sub$

Ω^{l}. $[C^*\backslash\beta]^P \vdash [\beta]^P$ $\qquad$ (no new dependency)

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D^{l}. $\alpha^{P_1(\swarrow C)P(\nwarrow C)P_2} \vdash \alpha^{P_1PP_2}$ $\qquad Gov \overset{C}{\dashrightarrow} Sub$

First-Available Rule

FA: in $(\swarrow C)P(\nwarrow C)$, the valency $\swarrow C$ is the **first available** for the dual valency $\nwarrow C$, i.e. P has no occurrences of $\swarrow C, \nwarrow C$

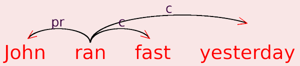
LEXICON:

$John \mapsto [pr]$
$ran \mapsto [pr \backslash S / c^*]$
$fast, yesterday \mapsto [c]$

Derivation

$$\dfrac{\overset{John}{[pr]} \qquad \dfrac{\dfrac{\dfrac{\overset{ran}{[pr \backslash S / c^*]} \; \overset{fast}{[c]}}{[pr \backslash S / c^*]}\,\mathrm{I}^r \qquad \overset{yesterday}{[c]}}{[pr \backslash S / c^*]}\,\mathrm{I}^r}{[pr \backslash S]}\,\Omega^r}{S}\,\mathrm{L}^l$$

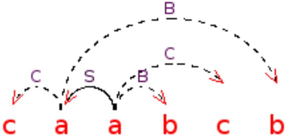
Dependency structures



L^l	$[C]^P[C\backslash\beta]^Q \vdash [\beta]^{PQ}$	L^r	$[\beta/C]^P[C]^Q \vdash [\beta]^{PQ}$
I^l	$[C]^P[C*\backslash\beta]^Q \vdash [C*\backslash\beta]^{PQ}$	I^r	$[\beta/C*]^P[C]^Q \vdash [\beta/C*]^{PQ}$
Ω^l	$[C*\backslash\beta]^P \vdash [\beta]^P$	Ω^r	$[\beta/C*]^P \vdash [\beta]^P$
D^l	$\alpha^{P_1(\swarrow V)P(\nwarrow V)P_2} \vdash \alpha^{P_1 P P_2}$, if FA	D^r	$\alpha^{P_1(\nearrow V)P(\searrow V)P_2} \vdash \alpha^{P_1 P P_2}$, if FA

CDG example: mix [LACL2005]

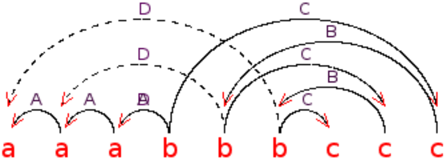
```
a  [S]<↖B,↖C>
   [S\S]<↖B,↖C>
   [S]<↗C,↗B>T
   [S\S]<↗C,↗B>
   [S]<↖B,↗C>
   [S\S]<↖B,↗C>
   [S]<↖C,↗B>
   [S\S]<↖C,↗B>
b  [ ]<↙B>
   [ ]<↘B>
c  [ ]<↙C>
   [ ]<↘C>
```



A CDG for mix with a parse example

In the above grammar, some types have empty heads ; other grammars avoiding empty heads can be provided, but the above one is simpler.

a	[A]<↙D>
	[A\A]<↙D>
b	[B/C]<↖D>
	[A\S/C]<↖D>
c	[C]
	[B\C]



A CDG for $a^n b^n c^n$ with a parse example

Parsing Algorithms

CdgAnalyst (Dekhtyar-Dikovsky-Karlov, TCS 2015)

- Dynamic programming parsing algorithm
- Based on CYK parsing algorithm

  $+$ polarized valency calculus information

Filtering parsers (Alfared-Béchet-Dikovsky, Depling 2011)

- Reduction of the search space
- Based on sentence "complexity" of natural languages

  $\Longrightarrow$ Limit the complexity of potentials

Greedy parsers (Lacroix-Béchet, Coling 2014)

- Transition-Based Dependency Parser
- 3 steps (local / left non-projective / right non-projective)

Theorem 8

Algorithm **CdgAnalyst** *has time complexity*

$$\mathbf{O}\left(l_G \cdot a_G^2 \cdot (\Delta_G \cdot n)^{2p_G} \cdot n^3\right).$$

Complexity of CdgAnalyst (Dekhtyar-Dikovsky-Karlov, TCS 2015)

n : The length of the input string
l_G : The number of assignments in G
a_G : The maximal number of left or right subtypes in G
Δ_G : The maximal valency deficit in G
p_G : The number of polarized valency names in G

Plan

Grammatical class $\mathcal{G}$ is learnable if there is an algorithm A which

- for every target grammar $G_T \in \mathcal{G}$
- every enumeration $\sigma = L(G_T)$ and every prefix $\sigma[n]$,

returns a hypothetical grammar $A(\sigma[n]) \in \mathcal{G}$ **and** :

(*i*) the sequence of languages $\{L(A(\sigma[n])) \mid n \in \mathbb{N}\}$ converges to the target language $L(G_T)$

(*ii*) this holds for all enumerations σ of $L(G_T)$

Learning from **strings**: $\sigma(\mathbb{N}) = L(G_T)$

from **structures**: $\sigma(\mathbb{N}) = \Delta(G_T)$

from strings (FG'2004)

- k-valued CDG **without** $*$ iterated types are learnable from structures and from strings
- rigid CDG **with** $*$ are not learnable from strings (a limit point).

Limit point

$$\begin{aligned} G'_0 &= \{a \mapsto [A], b \mapsto [B], c \mapsto [C'_0]\} \\ G'_n &= \{a \mapsto [A], b \mapsto [B], c \mapsto [C'_n]\} \\ G'_* &= \{a \mapsto [D], b \mapsto [D], c \mapsto [S\ /\ \mathrm{D}^*]\} \end{aligned} \qquad \begin{aligned} C'_0 &= S \\ C'_{n+1} &= C'_n\ /\ \mathrm{A}^*\ /\ \mathrm{B}^* \end{aligned}$$

$L(G'_n) = \{c(b^*a^*)^k \mid k \leq n\}$ and $L(G'_*) = c\{b,a\}^*$.

from structures (FG'2010, ...)

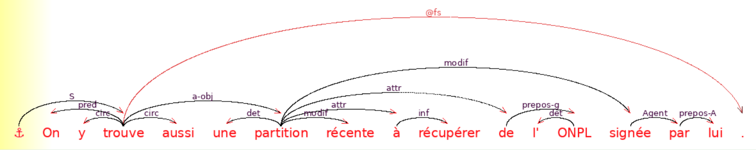
- rigid CDG **with** $*$ are not learnable from DS

So the CDG are not learnable from dependency treebanks !

Type-Generalize-Expand (TGE)

Computes words' types from their VICINITIES in DS

Vicinity $V(w, D)$ of word w in DS D:



$V(partition, D) = [det\backslash a-obj/modif/attr/attr/modif]$,
$V(de, D) = [attr/prepos-g]$

Type-Generalize-Expand (TGE) : types with d^*, repeating principle

Type-Generalize-Expand (TGE) : lexicon level, CV for a subclass

Algorithm TGE$^{(K)}$ (type-generalize-expand):
Input: σ, a training sequence of length N.
Output: CDG TGE$^{(K)}(\sigma)$.

let $G_H = (W_H, \mathrm{C}_H, S, \lambda_H)$ where $W_H := \emptyset$; $\mathrm{C}_H := \{S\}$; $\lambda_H := \emptyset$;
(loop) **for** $i = 1$ **to** N // loop on σ
  let D such that $\sigma[i] = \sigma[i-1] \cdot D$; // the i-th DS of σ
  let $(X, E) = D$;
  (loop) **for every** $w \in X$ // the order of the loop is not important
    $W_H := W_H \cup \{w\}$;
    let $t_w = V(w, D)$ // the vicinity of w in D
    (loop) **while** $t_w = [\alpha\backslash l\backslash \mathrm{d}\backslash \cdots \backslash \mathrm{d}\backslash r\backslash\beta]$
      with at least K consecutive occurrences of d, $l \neq d$ (or not present) and $r \neq d$ (or not present)
        $t_w := [\alpha\backslash l\backslash \mathrm{d}^*\backslash r\backslash\beta]$
    (loop) **while** $t_w = [\alpha/l/\mathrm{d}/\cdots/\mathrm{d}/r/\beta]$
      with at least K consecutive occurrences of d, $l \neq d$ (or not present) and $r \neq d$ (or not present)
        $t_w := [\alpha/l/\mathrm{d}^*/r/\beta]$
    $\lambda_H(w) := \lambda_H(w) \cup \{t_w\}$; // lexicon expansion
    end end
return G_H

TH TGE$^{(K)}$ learns *K-star revealing* CDG from DS (FG 2010)

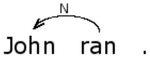
Importantly, no bound on the number of types is assumed

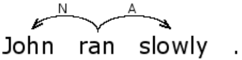
Exemple

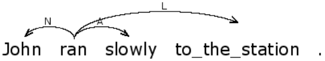
$John \mapsto [N]$ $to\_the\_station \mapsto [L]$
$ran \mapsto [N\backslash A^*\backslash S/A^*/L/A^*],\ [N\backslash A^*\backslash S/A^*]$
$seemingly,\ slowly,\ alone,\ every\_morning \mapsto [A]$

(Global Simple K-star)

Algorithm $\mathrm{TGE}^{(2)}$:

$ran \mapsto [N\backslash S]$ for $(i = 1)$: 

$ran \mapsto [N\backslash S/A]$ for $(i = 2)$: 

$ran \mapsto [N\backslash S/L/A]$ for $(i = 3)$: 

$ran \mapsto [N\backslash A\backslash S/\boxed{A^*}]$ for $(i = 4)$: 

...

Learning approaches with iterated types

Structured Example	Annotation	Number (k) of Types per word	Repetition number (K) for Indiscernibility
functor-argument (FA, proof-tree)	unlabelled (no dep. name)	bound	no bound
dependency structure (DS)	labelled (dep. names)	no bound	bound

from [Béchet-Foret, Machine Learning, 2021]

Criteria and readings of the "repetition principle"

consecutive or dispersed in a type ; left-right ; global

- K-star revealing (complex equivalence property)
- $\supseteq$ Simple K-star (syntactic) : (1) at most $K-1$ occurrences of d and (2) no occurrence of d if there exists at least one occurrence of d^* in each $l_1 \backslash l_2 \backslash ... l_p \backslash$ where each l_i is either d or some x^*
- $\supseteq$ Global Simple K-star : (1) (2) in each $l_1 \backslash l_2 \backslash ... l_p \backslash$ (both sides)

UD Corpora
also available for under-resourced languages (breton)

- producing a CDG grammar
- properties of some dependencies, repeating patterns, measures

Star Scope	Star Pattern	Class constraint
local count dispersed (global count) sided or both	CDG d^* (FG 2010) $+$ choices $(d_1 \vert d_2)^*$ (LACL 2011) $+$ sequences $(d_1 \bullet d_2)^*$ (LACL 2016)	(synt — sem) Simple K-star ICFI 2016, MLJ 2021 K-star revealing (on $\Delta(G)$ semantic)

- beyond d^* : repeating $\ / d_2 \ / d_1 \ / d_2 \ / d_1$, etc. as $\ / (d_1 \bullet d_2)^*$
  a proposal for extended CDG, with iterated sequences of dep.

and TGE-like algorithm for sequences of length 2 [LACL 2016]

Some open questions

from [Dekhtyar-Dikovsky-Karlov, TCS 2015]

(CDG-languages as a class of push-down automata with independent counters)

- An effective tool for showing L is not a CDG-language ?

  status of the copy language $\{ww|w \in \{a,b\}^*\}$?
- Relationships between CDG and other classes of languages ?
- Does the number of non-proj. dep. define a strict hierarchy ?
- Closure under iteration ?

  [Kanazawa Wollic (2016) "Abstract Families of Abstract Categorial Languages"

  Abstract Family of Languages (*full* AFL) if closed under
  - union ✓, concatenation ✓, Kleene plus / *Kleene star*,
  - ϵ-free homomorphism ✓/ *homomorphism*,
    inverse homomorphism ✓
  - and intersection with regular sets ✓

Control over non-projective dependencies ?

THANK YOU !