On Dispersed and Choice Iteration in Incrementally Learnable Dependency Types

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Main points

- THESIS : surface syntactic dependencies between words are determined by words' valencies
- CONSEQUENCE : dependency grammars cannot be learned from dependency structures they generate
  because of repeatable dependencies

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- CONSEQUENCE : dependency grammars cannot be learned from dependency structures they generate
  because of repeatable dependencies
- MAIN RESULT : grammars treating the repeatable dependencies in a linguistically proper way are

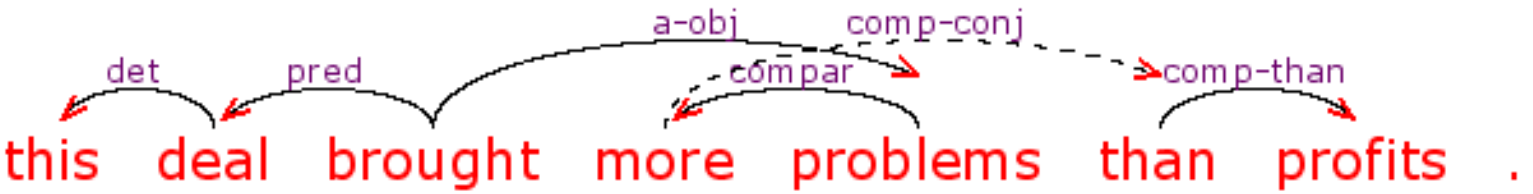
  incrementally learnable from dependency structures

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

brought $\overset{pred}{\longleftarrow}$ *deal* (**Governor :** brought, **Subordinate :** deal)

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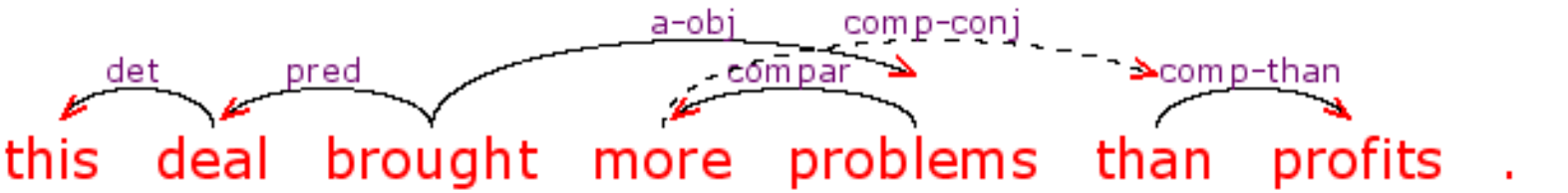


Dependencies are determined by valencies of words

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

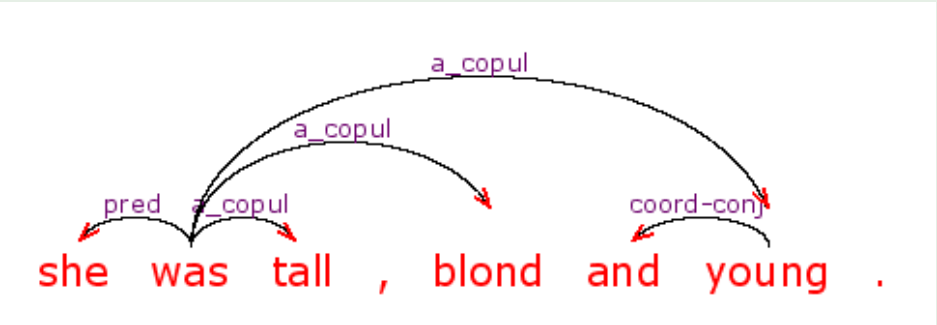
than has −valency comp-conj of a word somewhere on its left

Saturation of comp-conj determines discontinuous dependency

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

Repeatable dependencies

Some dependency valencies are MULTIPLE



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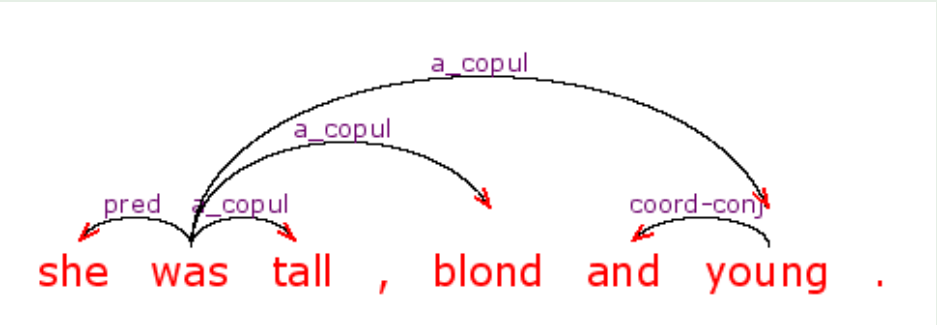

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Principle of Repeatable Dependencies [Mel'čuk'88]

- 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

Categorial Dependency Grammars (CDG)

CDG Types express dependency valencies

PROJECTIVE DEPENDENCIES

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

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

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

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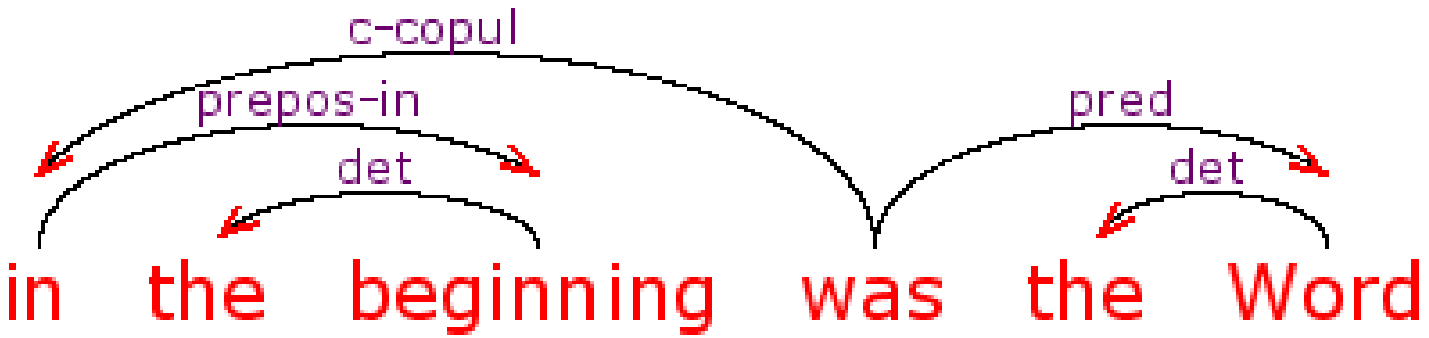

$in \mapsto [c\_copul / prepos - in]$
$the \mapsto [det]$
$beginning \mapsto [det \backslash prepos - in]$
$was \mapsto [c\_copul \backslash S / pred]$
$Word \mapsto [det \backslash pred]$

Categorial Dependency Grammars (CDG)

CDG Types express dependency valencies

NON-PROJECTIVE DEPENDENCIES

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

Dependency : $Gov \overset{d}{-\!\!-\!\!>} Sub$:

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

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

Categorial Dependency Grammars (CDG)

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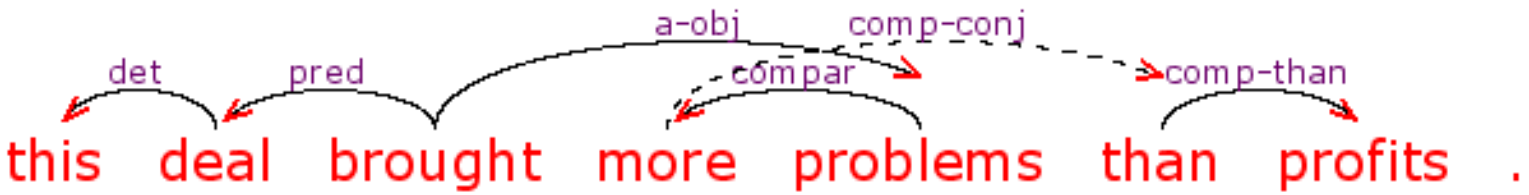

$this \mapsto [det]$
$deal \mapsto [det \backslash pred]$
$brought \mapsto [pred \backslash S / a-obj]$
$problems \mapsto [compar \backslash a-obj]$
$profits \mapsto [comp-than]$
$more \mapsto [compar]^{\nearrow comp-conj}$
$than \mapsto [/comp-than]^{\searrow comp-conj}$

CDG calculus

Left-oriented rules

$\mathbf{L^l}$. $C^{P_1}[C\backslash\beta]^{P_2} \vdash [\beta]^{P_1 P_2}$ $\quad Gov \xrightarrow{C} Sub$

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$\mathbf{\Omega^l}$. $[C^*\backslash\beta]^{P} \vdash [\beta]^{P}$

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D^l. $\alpha^{P_1}(\swarrow C)P(\nwarrow C)^{P_2} \vdash \alpha^{P_1}PP_2$ $\quad Gov \overset{C}{-\!-\!>} Sub$

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 $\swarrow C$, $\nwarrow C$

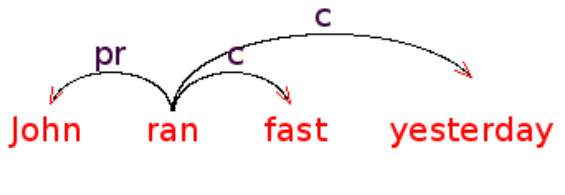
LEXICON :
(empty potentials)

$$John \mapsto [pr]$$
$$ran \mapsto [pr \setminus S / c^*]$$
$$fast \mapsto [c]$$

Derivation

$$\dfrac{\dfrac{\dfrac{\dfrac{\overset{John}{[pr]} \quad \dfrac{\dfrac{\overset{ran}{[pr \setminus S / c^*]} \quad \overset{fast}{[c]}}{[pr \setminus S / c^*]}\, \mathbf{I^r} \quad \overset{yesterday}{[c]}}{[pr \setminus S / c^*]}\, \mathbf{I^r}}{[pr \setminus S]}\, \Omega^r}{S}\, \mathbf{L^l}$$

Dependency structures



$\mathbf{L^l}$	$H^{P_1}[H\backslash\beta]^{P_2} \vdash [\beta]^{P_1 P_2}$	$\mathbf{L^r}$	$[\beta / H]^{P_2} H^{P_1} \vdash [\beta]^{P_2 P_1}$
$\mathbf{I^l}$	$C^{P_1}[C^*\backslash\beta]^{P_2} \vdash [C^*\backslash\beta]^{P_1 P_2}$	$\mathbf{I^r}$	$[\beta / C^*]^{P_2} C^{P_1} \vdash [\beta / C^*]^{P_2 P_1}$
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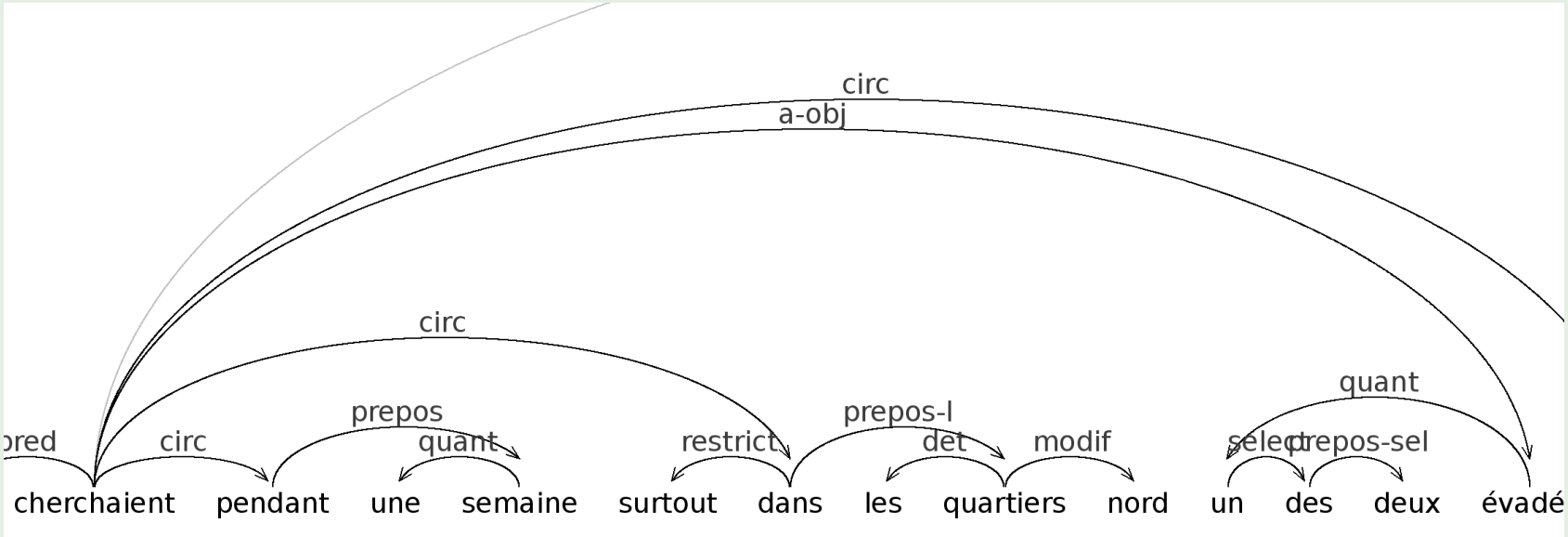
Interpretations of Repeatable Dependencies

Which dependencies are repeatable ?



"They tracked for a week especially in the nord quarters one of the two fugitives systematically blocking entries and exits"

Word Order and Repeatability

Is the dependency circ repeatable for $K = 3$?

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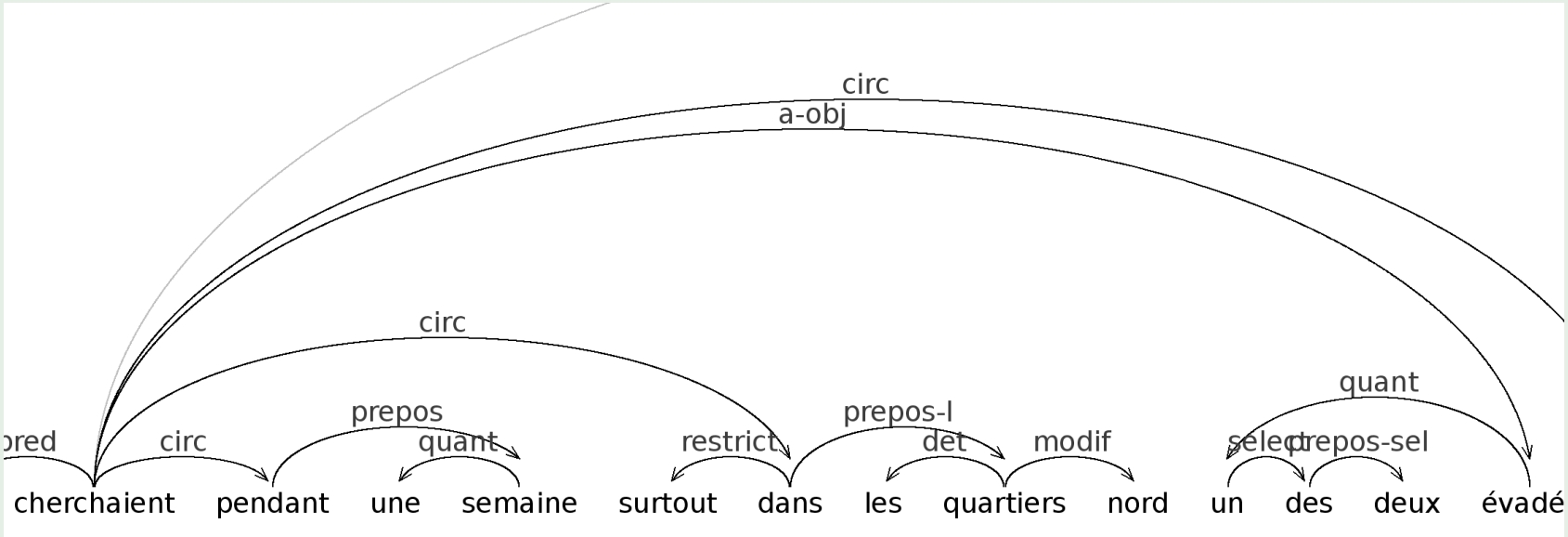

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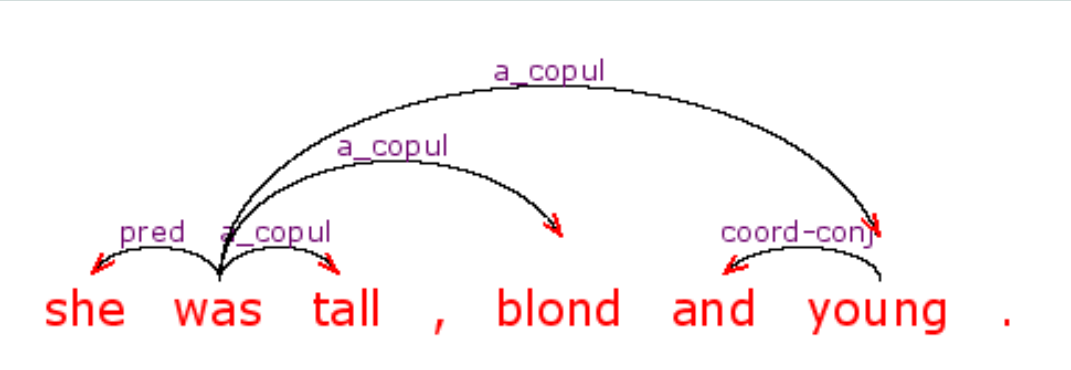
Word Order and Repeatability

PB : Repeatable Dependency Principle is uncertain about the WO

Three Readings of Repeatable Dependencies

Sequentially Repeatable Dependencies and Iterated Types

EX : sequentially repeatable copula dependency



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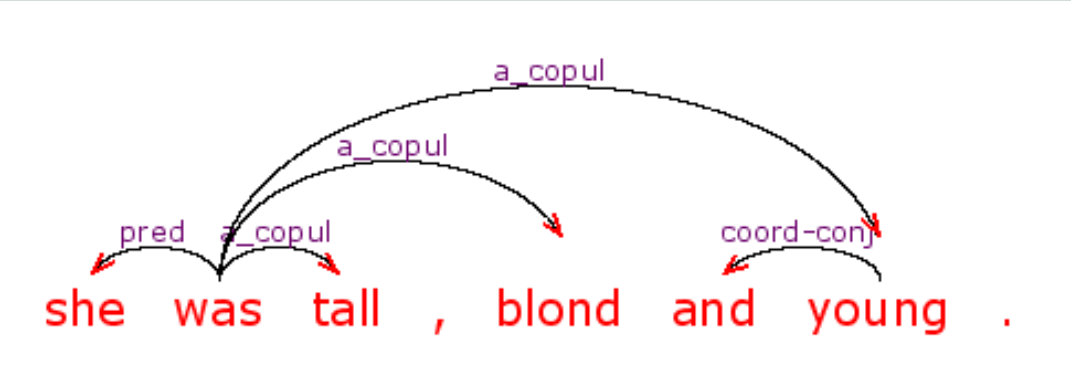

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Iterated Types of CDG

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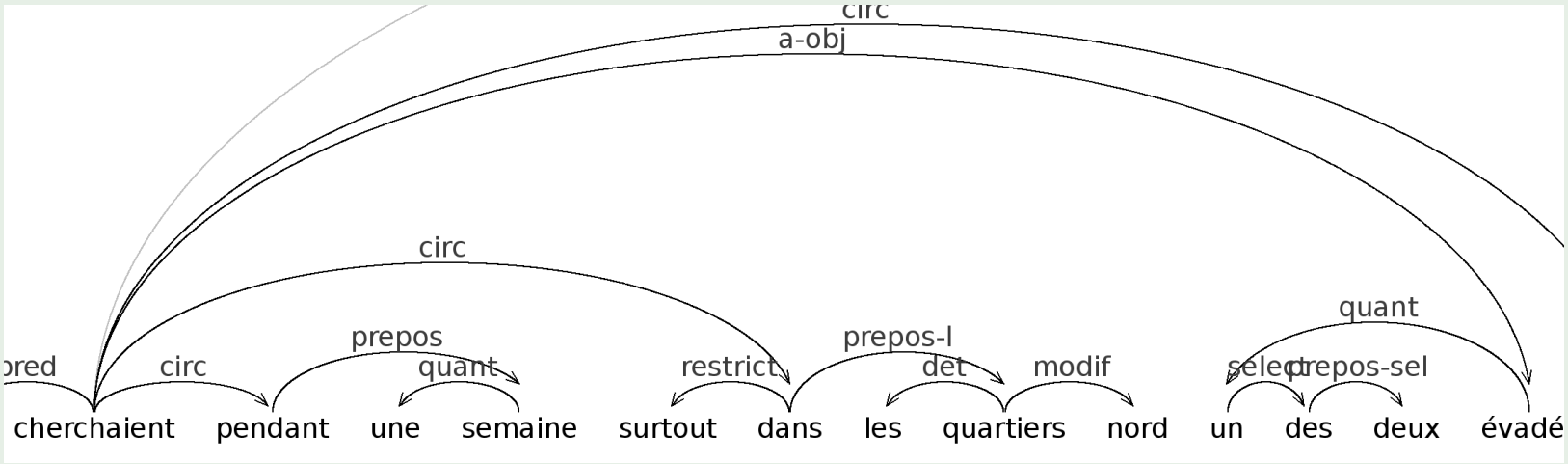
Dispersed Iteration Types

Dispersed Repeatable Dependencies ($K = 3$)



DISPERSED iteration : $cherchaient \mapsto [pred\backslash S/@fs/a-obj/\{circ^*\}]$

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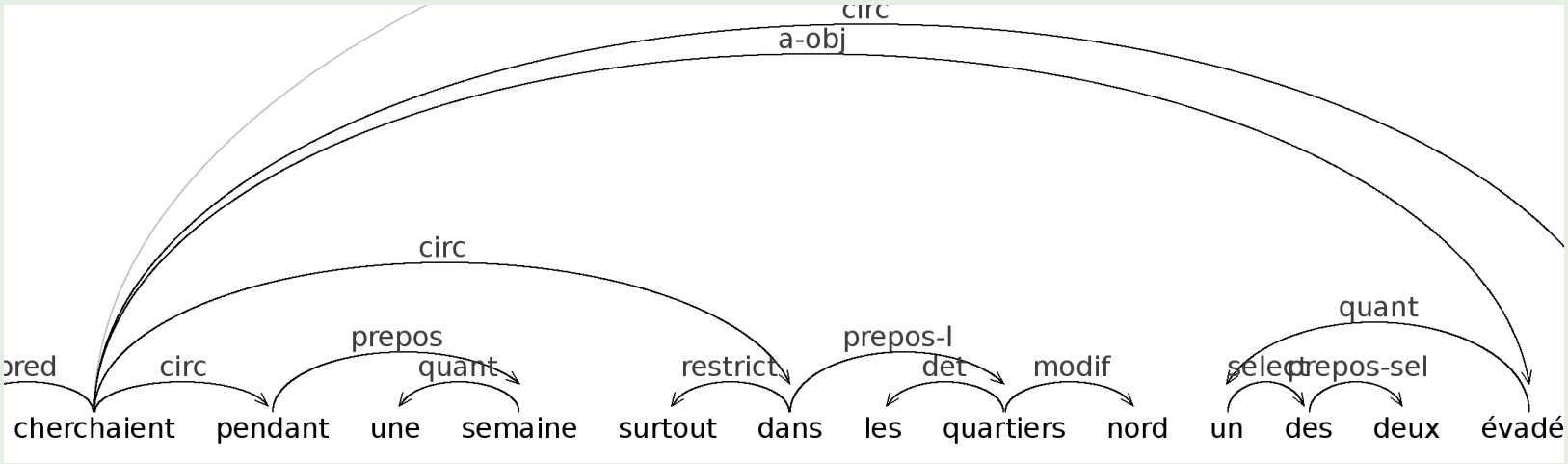

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Extended Type Calculus

DISPERSED iteration

$$\mathbf{LD^I}.\quad C^{P_1}[\{\alpha_1\}\backslash C\backslash\beta/\{\alpha_2\}]^{P_2} \vdash [\{\alpha_1\}\backslash\beta/\{\alpha_2\}]^{P_1P_2}$$

$$\mathbf{ID^I}.\quad C^{P_1}[\{\alpha_1, C^*, \alpha_2\}\backslash\beta/\{\alpha_3\}]^{P_2} \vdash [\{\alpha_1, C^*, \alpha_2\}\backslash\beta/\{\alpha_3\}]^{P_1P_2}$$

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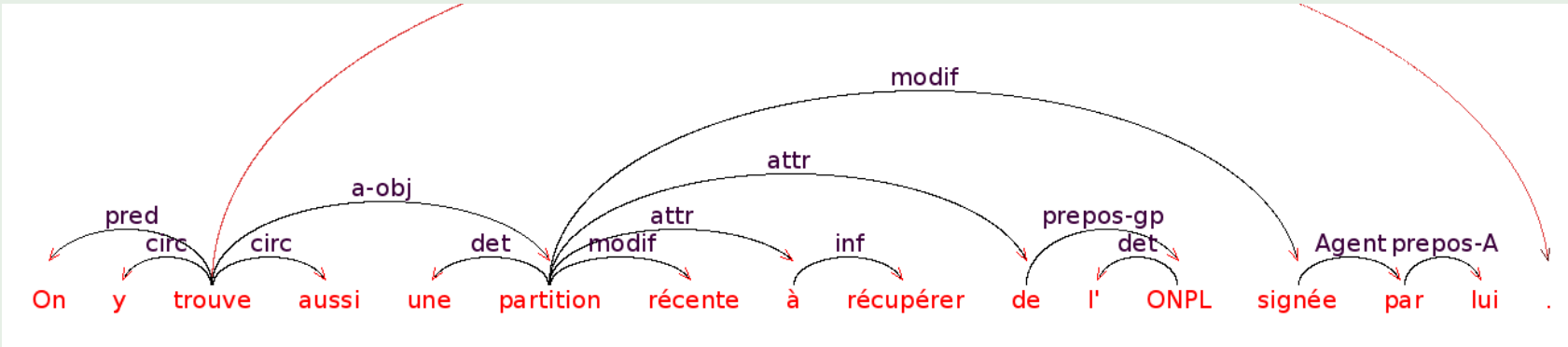
Choice Iteration Types

Choice Repeatable Dependencies ($K = 2$)



*One here finds also a partition recent to obtain of ONPL signed by him

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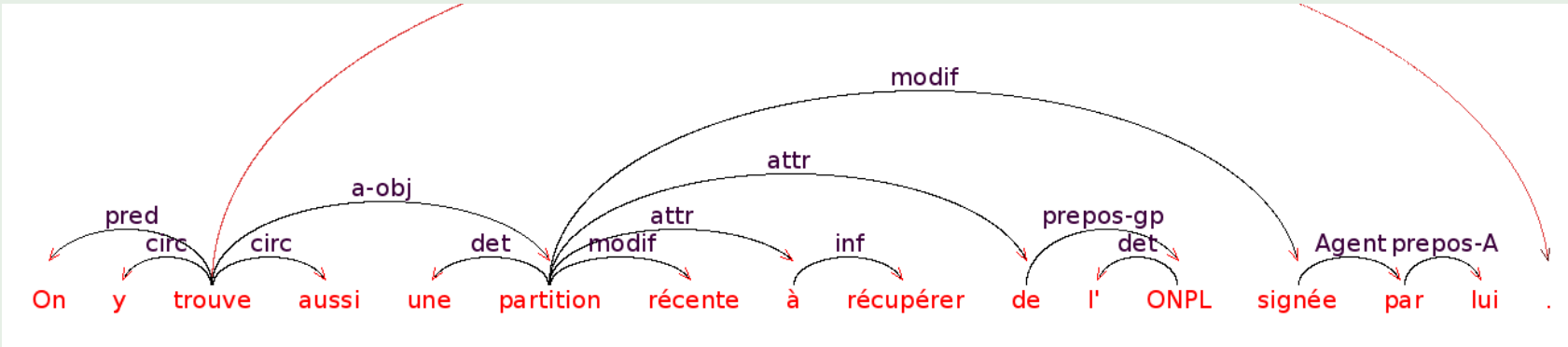

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Extended Type Calculus

CHOICE iteration

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Grammatical inference

symbolic, from positive examples [Gold'67]

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 $L(G_T)$

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Limit points and non-learnability

A limit point in a family $\mathcal{L}$ is a sequence $< L_n >_{n\in\mathbb{N}} \in \mathcal{L}$ such that :

$$\forall i : L_i \subsetneq L_{i+1} \text{ and } \bigcup_{n\in\mathbb{N}} L_n \in \mathcal{L}.$$

Limit Points entail the non-learnability of $\mathcal{L}$.

Unlearnability of Unlimited CDG

Unlearnability of CDG from strings (FG'2004)

TH k-rigid CDG without iterated types are learnable from FA-like structures (and from strings).

TH (1)-rigid CDG are not learnable from strings (a limit point).

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Limit point

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

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

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TH (1)-rigid CDG are not learnable from DS (FG'2010).
So the CDG are not learnable from dependency treebanks !

Incremental Learning (e.g. of Dispersed Iteration CDG)

CDG complying with the Principle of Repeatable Dependencies are incrementally learnable from DS.

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Incremental Learning from DS in $\Delta(G)$

Generalization PO $\preceq$: a PO on CDG compatible with the inclusion of DS-languages : $G \preceq G' \Rightarrow \Delta(G) \subseteq \Delta(G')$

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Inference Algorithm $\mathcal{A}$ for CDG from DS is INCREMENTAL

if for every training sequence (enumeration) σ of $\Delta(G)$ $\mathcal{A}$ is :

1. `monotonic` on σ, i.e. $\mathcal{A}(\sigma[i]) \preceq \mathcal{A}(\sigma[j])$ for all $i \leq j$.
2. `faithful` on σ, i.e. $\Delta(\mathcal{A}(\sigma[i])) \subseteq \Delta(G)$ for all i.
3. `expansive` on σ, i.e. $\sigma[i] \subseteq \Delta(\mathcal{A}(\sigma[i]))$ for all i.

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TH If $\mathcal{A}$ is monotonic, faithful, expansive and stabilizes on σ then $\lim_{i \to \infty} \mathcal{A}(\sigma[i]) \equiv_s G$ $\quad (G \equiv_s G'$ means $\Delta(G) = \Delta(G'))$.

CDG Complying with RD Principle $\sim$ K-Star Revealing

Left (Right) Dispersed K-star Generalization

Of TYPE $t = [\{\alpha\}\backslash\beta_1 d\backslash \ldots \beta_n d\backslash\beta]^P$, $n \geq K$ are TYPES :

$$t_L = [\{\alpha, d^*\}\backslash\beta_1 \ldots \beta_n\beta]^P \text{ and } t_\Omega = [\{\alpha\}\backslash\beta_1 \ldots \beta_n\beta]^P$$

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Of CDG : recursively

$$G = (G' \cup \{w \mapsto t\}) \Rightarrow (G \cup \{w \mapsto t_L, w \mapsto t_\Omega\})$$

till stabilization on $\mathcal{C}^K_{disp}(G)$: K-star Generalization of G

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Dispersed K-star Revealing CDG

CDG G is dispersed K-star revealing for $K > 1$ if $G \equiv_s \mathcal{C}^K_{disp}(G)$

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For $K = 2$ and $G(t) : x \mapsto [a]$, $y \mapsto [b]$, $z \mapsto t$

$G([\{a^*\}\backslash b\backslash S/a/b])$ and $G([a\backslash b\backslash S/\{a, b\}])$ are 2-star revealing
$G([a\backslash a\backslash S])$ and $G([a\backslash S/b/a/b])$ are not.

Learning Algorithm for Dispersed K-star revealing CDG

- is INCREMENTAL wrt the genericity PO $<_{disp}$ induced by :

$[\{\alpha\}\backslash\beta_1 d\backslash\ldots\beta_n d\backslash\beta]^P < [\{\alpha, d^*\}\backslash\beta_1\ldots\beta_n\beta]^P$, $n \geq K$
$[\{\alpha\}\backslash\beta]^P < [\{\alpha, d^*\}\backslash\beta]^P$

Learning Algorithm for Dispersed K-star revealing CDG

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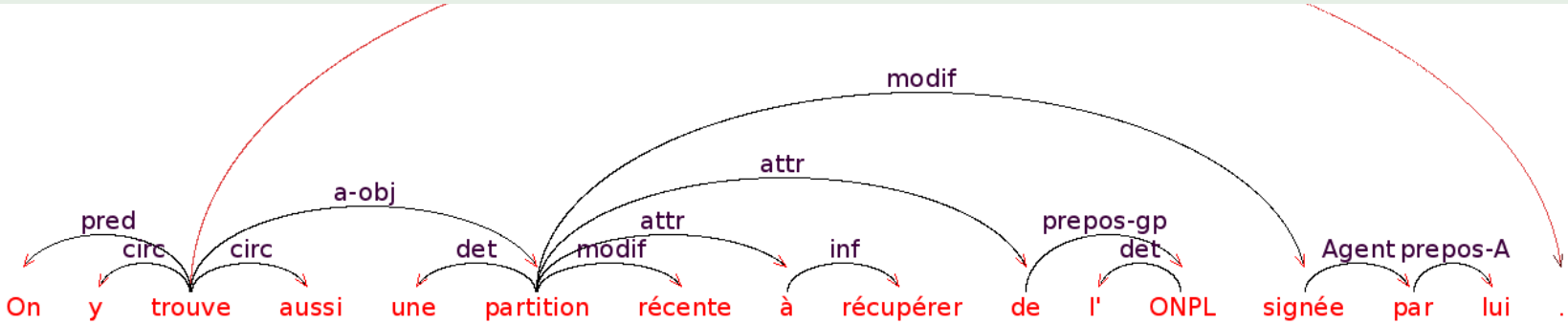
$[\{\alpha\}\backslash\beta]^P < [\{\alpha, d^*\}\backslash\beta]^P$

- computes words' types from their VICINITIES in DS

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



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

Algorithm $\mathbf{TGE}^{(K)}_{disp}$ (type-generalize-expand) :
Input : $\sigma[i]$ (σ being a training sequence).
Output : GCD $\mathbf{TGE}^{(K)}_{disp}(\sigma[i])$.
let G_H be CDG with lexicon λ_H
$\lambda_H := \emptyset$;
(loop) **for** $i \geq 0$ //Infinite loop on σ
let $\sigma[i+1] = \sigma[i] \cdot D$;
let $(x, E) = D$; // D is the next example
(loop) **for every** $w \in x$ // w is a word in D
let $V(w, D) = [l_m \backslash \cdots \backslash l_1 \backslash h / r_1 / \cdots / r_n]^P$ // vicinity of w in D
let $LT := \{l_1\} \cup \cdots \cup \{l_m\}$
let $LF := \{d : d \in LT, card(\{i : 1 \leq i \leq m, l_i = d\}) \geq K\}$ // left K-repeatable
let $RT := \{r_1\} \cup \cdots \cup \{r_n\}$
let $RF := \{d : d \in RT, card(\{i : 1 \leq i \leq n, r_i = d\}) \geq K\}$ // right K-repeatable
let $t_w := [\{lf_1^*, \ldots, lf_p^*\} \backslash l'_{m'} \backslash \cdots \backslash l'_1 \backslash h / r'_1 / \cdots / r'_{n'} / \{rf_1^*, \ldots, rf_q^*\}]^P$ // generalised type
where $\{lf_1, \ldots, lf_p\} = LF$, $\{rf_1, \ldots, rf_q\} = RF$,
where $l'_{m'}, \ldots, l'_1$ is the sublist of $l_m, \ldots, l_1$ without elements in LF
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$\lambda_H(w) := \lambda_H(w) \cup \{t_w\}$; // expansion
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TH $\mathbf{TGE}^{(K)}_{disp}$ incrementally learns dispersed K-star revealing CDG from DS.

Conclusions

- To express the repeatable dependencies in the traditional linguistics' perspective of dependencies as words' valencies one needs iteration
- Unification based inference methods fail when applied to categorial grammars extended by iteration :
  the rigid grammars are not learnable from structures
- K-star revealing CDG, complying with the RD Principle, are incrementally learnable from DS for three kinds of iteration : sequential, dispersed and choice, when used separately

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THANK YOU !

CDG G_{target} is dispersed 2-star revealing and has lexicon :

$John \mapsto [N]$ $\quad$ $to\_the\_station \mapsto [L]$

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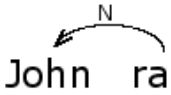
$ran \mapsto [N\backslash S]$ for 

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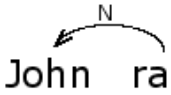
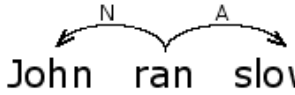
$ran \mapsto [N\backslash S]$ for 

. $ran \mapsto [N\backslash S/A]$ for 

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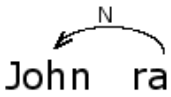
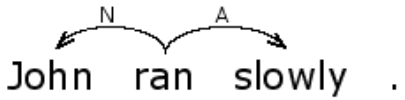
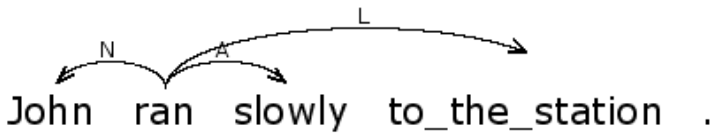
ran $\mapsto [N\backslash S]$ for 

ran $\mapsto [N\backslash S/A]$ for 

ran $\mapsto [N\backslash S/L/A]$ for 

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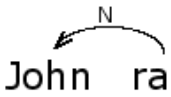
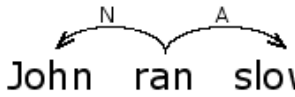
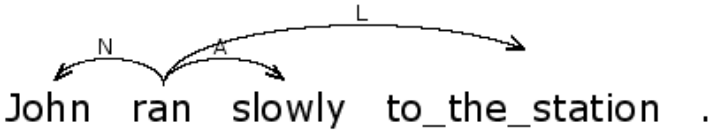
ran $\mapsto [N\backslash S]$ for 

ran $\mapsto [N\backslash S/A]$ for 

ran $\mapsto [N\backslash S/L/A]$ for 

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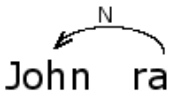
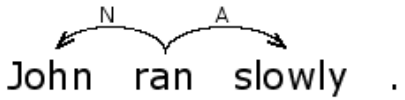
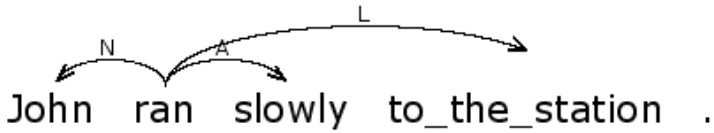
$ran \mapsto [N\backslash S]$ for 

$ran \mapsto [N\backslash S/A]$ for 

$ran \mapsto [N\backslash S/L/A]$ for 

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