A Natural Proof System for Natural Language

Lecture 3: Natural language inference with a natural theorem prover

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Previous lecture

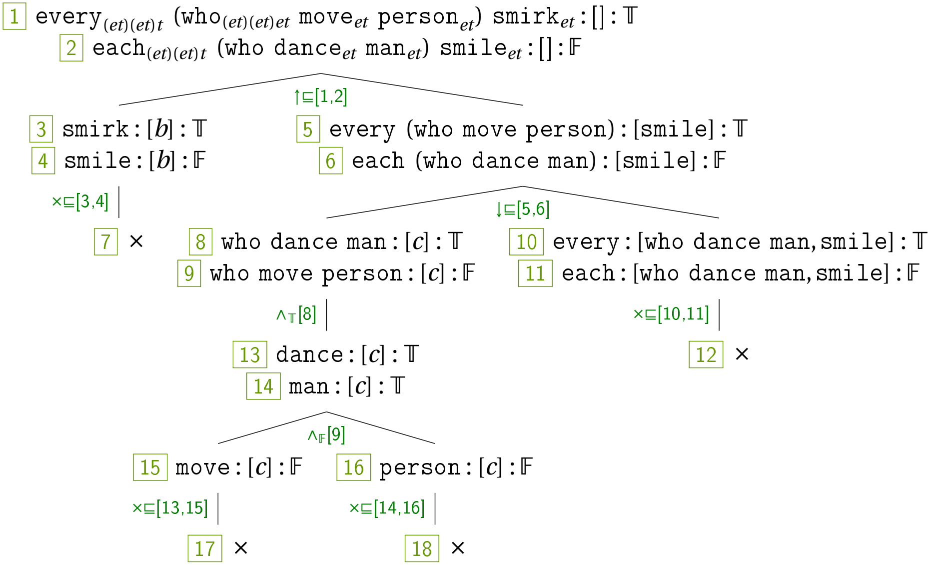
Lambda Logical Forms (LLFs):

- Simply typed λ-terms with e and t basic types;
- No logical constants, only lexical terms and λ-abstraction;
- Similar to syntactic trees of natural language expressions.

Natural tableau system:

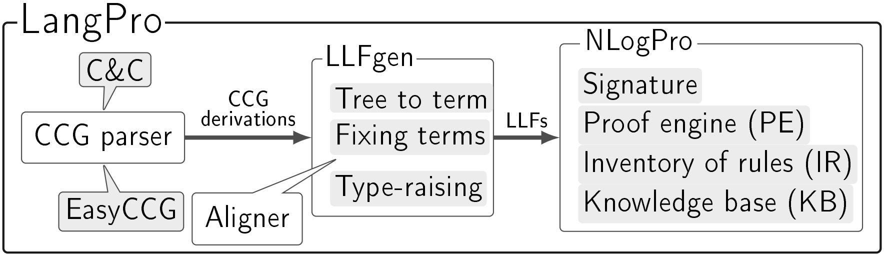
- Tableau entries: $\underbrace{\texttt{LLF:argumentList}}_{\text{Binary format of a term}}\texttt{:truthSign}$
- Monotonicity reasoning achieved with special monotonicity rules

Closed natural tableau



Today's lecture

A natural tableau theorem prover:



Solving natural language inference problems with the prover

LLFs and Categorial Grammar

LLFs are similar to formal derivations studied in Categorial Grammars (CGs) [Ajdukiewicz, 1935, Hillel, 1953].

- CGs treat each lexical item as a function;
- Categorial Type-Transparency principle links syntactic types to semantic ones.

Combinatory Categorial Grammar (CCG) [Steedman, 2000] is the only CG that is scaled up for wide-coverage text processing:

- CCG is well-studied from linguistic perspectives;
- There exists robust and accurate wide-coverage parsers for CCG, e.g., C&C parser [Clark and Curran, 2007] and EasyCCG

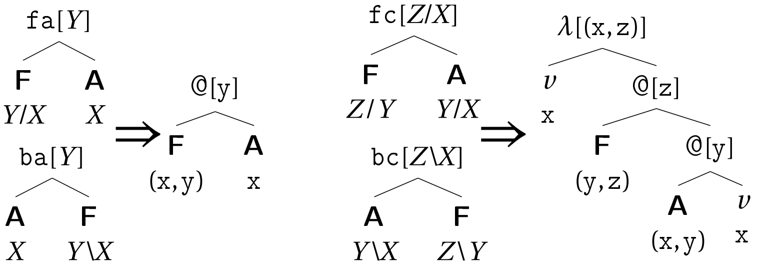
From CCG Trees to LLFs

Producing an LLF from a CCG derivation consists of several steps:

CCG Tree → **CCG Term** → **Fixed CCG Term** → **LLFs** ⇢ **FOL** / **DRT**

CCG Tree → CCG term

CCG Tree → **CCG Term** → **Fixed CCG Term** → **LLFs** ⇢ **FOL** / **DRT**



CCG term → fixed CCG term

CCG Tree → **CCG Term** → **Fixed CCG Term** → **LLFs** ⇢ FOL / DRT

$$[\mathtt{Dow}^{\mathrm{PER}}_{\mathrm{n,n}}\ \mathtt{Jones}^{\mathrm{PER}}_{\mathrm{n}}]_{\mathrm{np}} \rightsquigarrow \mathtt{Dow\_Jones}_{\mathrm{np}}$$

$$\mathtt{nobody}_{\mathrm{np}} \rightsquigarrow \mathtt{no}_{\mathrm{n,np}}\ \mathtt{person}_{\mathrm{n}}$$

$$[\mathtt{ice}_{\mathrm{n}}]_{\mathrm{np}} \rightsquigarrow \mathtt{a}_{\mathrm{n,np}}\ \mathtt{ice}_{\mathrm{n}}$$

$$[\mathtt{two}_{\mathrm{n,n}}\ \mathtt{dogs}_{\mathrm{n}}]_{\mathrm{np}} \rightsquigarrow \mathtt{two}_{\mathrm{n,np}}\ \mathtt{dogs}_{\mathrm{n}}$$

$$[\mathtt{working}_{\mathrm{np,s}}]_{\mathrm{n,n}} \rightsquigarrow \mathtt{who}_{\mathrm{(np,s),n,n}}\ \mathtt{working}$$

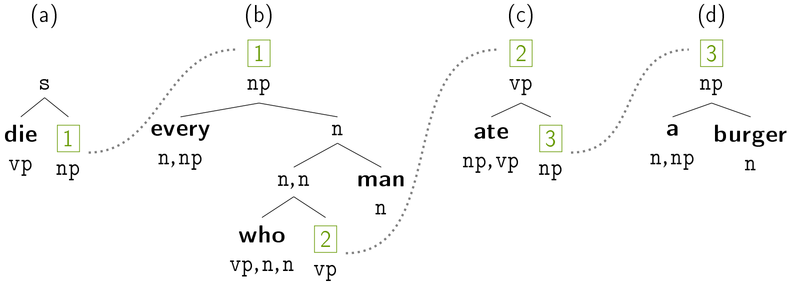
fixed CCG term → LLFs

Every man who ate a burger died

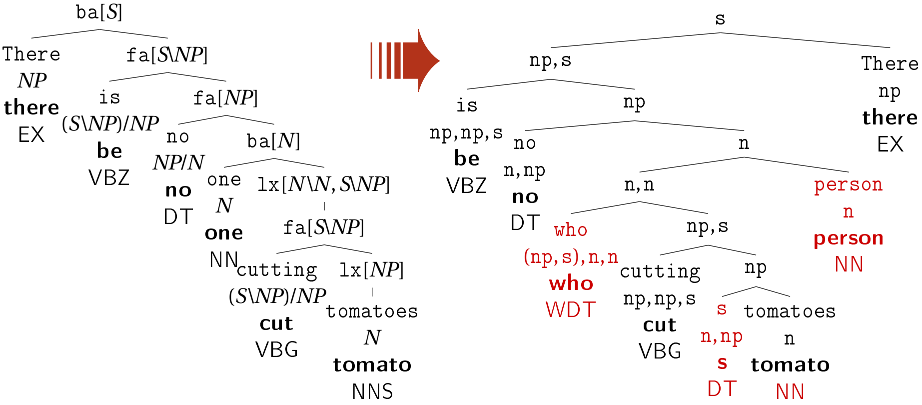
$\mathbf{die}_{\mathrm{vp}}\ (\mathbf{every}_{\mathrm{n,np}}(\mathbf{who}_{\mathrm{vp,n,n}}\ (\mathbf{eat}_{\mathrm{np,vp}}\ (\mathbf{a}_{\mathrm{n,np}}\ \mathbf{burger}_{\mathrm{n}}))\ \mathbf{man}_{\mathrm{n}}))\ \rightsquigarrow$

$\mathbf{EVERY}_{\mathrm{n,vp,s}}(\mathbf{who}\ (\lambda x.\mathbf{A}_{\mathrm{n,vp,s}}\ \mathbf{burger}\ (\lambda y.\mathbf{eat}\ y_{\mathrm{np}}\ x_{\mathrm{np}}))\mathbf{man})\mathbf{die}$

$\mathbf{A}_{\mathrm{n,vp,s}}\ \mathbf{burger}(\lambda y.\mathbf{EVERY}_{\mathrm{n,vp,s}}(\mathbf{who}\ (\lambda x.\mathbf{eat}\ y_{\mathrm{np}}\ x_{\mathrm{np}})\mathbf{man})\mathbf{die})$



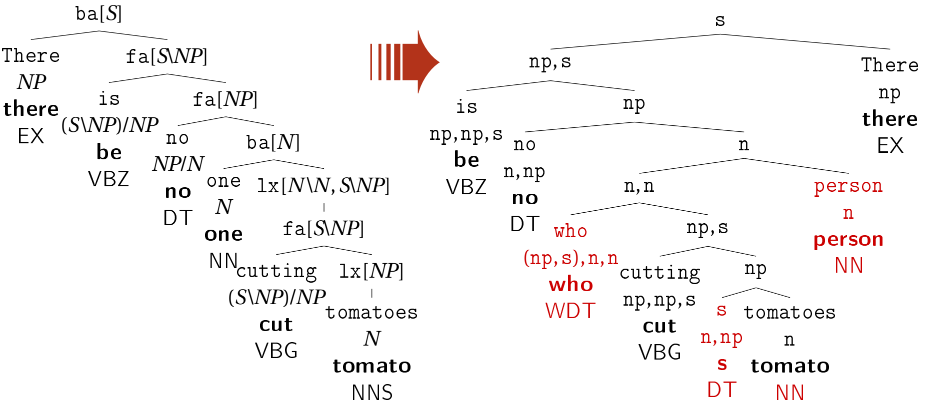
LLFgen (example)



There is no one cutting tomatoes ⇝

be(no(who(cut(s tomato))person))there

LLFgen (example)



be(**no**(**who**(**cut**(**s tomato**))**person**))**there** $\rightsquigarrow$

no (**who** ($\lambda x.$ **s tomato** ($\lambda y.$ **cut** $y\,x$)) **person**) ($\lambda z.$**be** z **there**)

s tomato ($\lambda y.$**no** (**who** (**cut** y) **person**) ($\lambda z.$**be** z **there**))

Uninformative *et*-based types

Semantic types based on e and t are uninformative from a syntactic point of view:

$h_{et} : [c_e]$ — $\texttt{cat}_{et} : [c_e]$ or $\texttt{sleep}_{et} : [c_e]$

$A_{(et)et}\ B_{et} : [c_e]$ — $\texttt{little}_{(et)et}\ \texttt{bird}_{et} : [c_e]$ or $\texttt{high}_{(et)et}\ \texttt{fly}_{et} : [c_e]$

$a_{(et)et}(b_{eet} c_e) : [c_e]$ — $\texttt{quietly}_{(et)et}\ (\texttt{follow}_{eet}\ \texttt{john}_e) : [c_e]$ or $\texttt{wife}_{(et)et}\ (\texttt{of}_{eet}\ \texttt{john}_e) : [c_e]$

Extending the type system

Add syntactic types to semantic ones:

$$\{e, t\} + \{\mathtt{np}, \mathtt{s}, \mathtt{n}, \mathtt{pp}\}$$

A partial order subtyping relation (<:) serves as an interface between syntactic and semantic types:

- $\mathtt{s} <: t$
- $e <: \mathtt{np}$
- $\mathtt{n} <: et$
- $\mathtt{pp} <: et$
- $(\alpha_1, \alpha_2) <: (\beta_1, \beta_2)$ iff $\beta_1 <: \alpha_1$ and $\alpha_2 <: \beta_2$

Syntactic terms

An additional typing rule:

if $A : \alpha$ and $\alpha <: \beta$, then $A : \beta$ too.

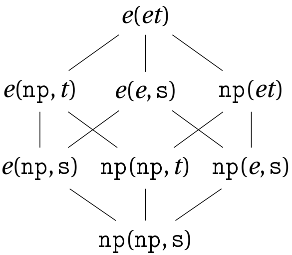
Terms of multiple types:

- $\mathbf{cat}_{\mathrm{n}}$ is of type et
- $\mathbf{red}_{\mathrm{n,n}}$ is of type (n, et) ~~and (et, et)~~
- $\mathbf{see}_{\mathrm{np,np,s}}$ is of type $\mathrm{np}(\mathrm{np}, t)$, eet, ...

Syntactic and semantic terms together:

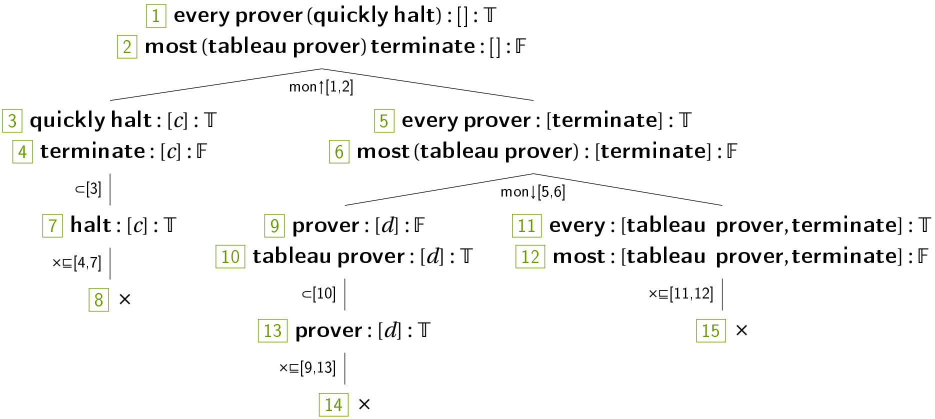
$\mathbf{cat}_{\mathrm{n}}\, c_e$, $\mathbf{love}_{\mathrm{np,np,s}} \mathbf{john}_{\mathrm{np}}\, c_e$, $\mathbf{on}_{\mathrm{pp}}\, d_e$

Types of $\mathbf{see}_{\mathrm{np,np,s}}$



No much changes in tableau proofs

Only the **style** of the terms is changed

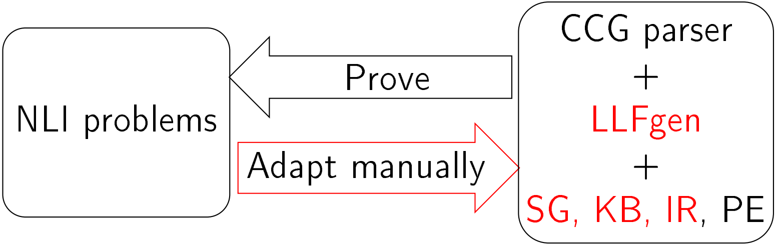


Linguistic Rules

Linguistic rules, in contrast to the algebraic rules, account for a certain syntactic constructions.

We will also include the rules that *remedy* errors introduced in the syntactic derivation trees.

Most of the linguistic rules are collected in a data-driven fashion:



Rules for prepositions

PP@N$_{\mathbb{T}}$

$$p^{\mathtt{IN}}_{\mathrm{np,n,n}}\, d\, N : [c] : \mathbb{T}$$

$$N : [c] : \mathbb{T}$$
$$p_{\mathrm{np,pp}} : [d, c] : \mathbb{T}$$

$\textbf{with}_{\mathrm{np,n,n}}\ g_e\ \textbf{bicycle}_{\mathrm{n}} : [c_e] : \mathbb{T}$

$\textbf{bicycle} : [c] : \mathbb{T}$

$\textbf{with}_{\mathrm{np,pp}} : [g, c] : \mathbb{T}$

PP@N$_{\mathbb{F}}$

$$p^{\mathtt{IN}}_{\mathrm{np,n,n}}\, d\, N : [c] : \mathbb{F}$$

$N : [c] : \mathbb{F}$ | $p_{\mathrm{np,pp}} : [g, c] : \mathbb{F}$

$\textbf{with}_{\mathrm{np,n,n}}\ g_e\ \textbf{bicycle}_{\mathrm{n}} : [c_e] : \mathbb{F}$

$\textbf{bicycle} : [c] : \mathbb{F}$ | $\textbf{with}_{\mathrm{np,pp}} : [g, c] : \mathbb{F}$

Treating PP attachment

SICK-9069 GOLD: entailment BY: C&C

Two boys are [[laying$_{VP}$ [in the ocean]$_{VP\backslash VP}$] [close to the beach]$_{VP\backslash VP}$]

Two boys are [[laying$_{VP/PP}$ [in the water]$_{PP}$] [close to the beach]$_{VP\backslash VP}$]

V@PP

$$V_{\mathrm{pp},\alpha}\,(p^{\mathrm{IN}}_{\mathrm{np,pp}}\,D) : [\vec{C}] : \mathbb{X}$$

$$p^{\mathrm{IN}}_{\mathrm{np},\alpha,\alpha}\,D\,V_\alpha : [\vec{C}] : \mathbb{X}$$

$$\alpha = (\mathrm{np}^*, \mathrm{vp})$$

$$\mathbf{lie}_{\mathrm{pp,vp}}\ (\mathbf{in}_{\mathrm{np,pp}}\ o_e) : [c] : \mathbb{F}$$

$$\mathbf{in}_{\mathrm{np,vp,vp}}\ o_e\ \mathbf{lie}_{\mathrm{vp}} : [c] : \mathbb{F}$$

Treating PP attachment (II)

SICK-340 GOLD: entailment BY: C&C

[schoolgirl$_{N/PP}$ [with a black bag]$_{PP}$] is on a crowded train

[girl$_N$ [with a black bag]$_{N\backslash N}$] is on a crowded train

N@PP$_{\mathbb{T}}$

$N_{\text{pp,n}}\ P_{\text{pp}} : [c_e] : \mathbb{T}$

$N_{\text{n}} : [c] : \mathbb{T}$

$P : [c] : \mathbb{T}$

N@PP$_{\mathbb{F}}$

$N_{\text{pp,n}}\ P_{\text{pp}} : [c_e] : \mathbb{F}$

$N_{\text{n}} : [c] : \mathbb{F}$ | $P : [c] : \mathbb{F}$

1 **schoolgirl**$_{\text{pp,n}}$ (**with**$_{\text{np,pp}}$ b_e) : $[g_e]$: $\mathbb{T}$

2 **with**$_{\text{np,n,n}}$ b **girl**$_{\text{n}}$: $[g]$: $\mathbb{F}$

N@PP$_{\mathbb{T}}$[1]

3 **schoolgirl**$_{\text{n}}$: $[g]$: $\mathbb{T}$

4 **with**$_{\text{np,pp}}$: $[b, g]$: $\mathbb{T}$

N@PP$_{\mathbb{F}}$[2]

5 **girl** : $[g]$: $\mathbb{F}$ | 6 **with**$_{\text{np,pp}}$: $[b, g]$: $\mathbb{F}$

$\times\sqsubseteq$[3,5] | $\times\sqsubseteq$[4,6]

7 $\times$ | 8 $\times$

Expletive *there*

[1] $\textbf{some}_{\mathrm{n,vp,s}}\ \textbf{dog}_{\mathrm{n}}\ (\textbf{be}_{\mathrm{vp,vp}}\ \textbf{run}_{\mathrm{vp}}) : [\,] : \mathbb{T}$

[2] $\textbf{some}_{\mathrm{n,vp,s}}\ (\textbf{that}_{\mathrm{vp,n,n}}\ \textbf{move}_{\mathrm{vp}}\ \textbf{animal}_{\mathrm{n}})(\lambda x.\,\textbf{be}_{\mathrm{np,vp}}\ x\ \textbf{there}_{\mathrm{np}_{thr}}) : [\,] : \mathbb{F}$

$\exists_{\mathbb{T}}[1]$

[3] $\textbf{dog} : [c_e] : \mathbb{T}$

[4] $\textbf{berun} : [c_e] : \mathbb{T}$

aux[4]

[5] $\textbf{run} : [c] : \mathbb{T}$

$\lambda{<}, \exists_{\mathbb{F}}[2]$

[6] $\textbf{that move animal} : [c] : \mathbb{F}$ | [7] $\textbf{be}\ c\ \textbf{there} : [\,] : \mathbb{F}$

$\wedge_{\mathbb{F}}[6]$ | A>, A>[7]

[11] $\textbf{move} : [c] : \mathbb{F}$ | [12] $\textbf{animal} : [c] : \mathbb{F}$ | [9] $\textbf{be} : [c, \textbf{there}] : \mathbb{F}$

$\times\sqsubseteq[5,11]$ | $\times\sqsubseteq[3,12]$ | ×THR[9]

[13] × | [14] × | [10] ×

×THR

$\textbf{be}_{\mathrm{np,vp}} : [C, D] : \mathbb{F}$

×

$\textbf{there}_{\mathrm{np}_{thr}} \in \{C, D\}$

Other closure rules

Open compound nouns:

$$\frac{N_{\mathrm{n}} : [d] : \mathbb{T} \quad H_{\mathrm{pp,n}}(prp\ d) : [c] : \overline{\mathbb{X}} \quad A_{\mathrm{n,n}}\ H_{\mathrm{n}} : [c] : \mathbb{X}}{\times}\ (\times\mathrm{CPN})$$

$N \approx A$ or $N \approx_d A$

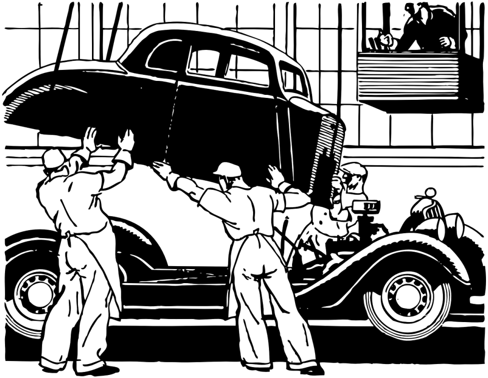
$$\frac{\textbf{protection}_{\mathrm{n}} : [d_e] : \mathbb{T} \quad \textbf{gear}_{\mathrm{pp,n}}(\textbf{for}_{\mathrm{np,pp}}\ d_e) : [c_e] : \mathbb{F} \quad \textbf{protective}_{\mathrm{n,n}}\ \textbf{gear}_{\mathrm{n}} : [c_e] : \mathbb{T}}{\times}\ (\times\mathrm{CPN}^*)$$

Light verb constructions:

$$\frac{l_{\vec{\alpha},\mathrm{vp}} : [c, \vec{D}] : \mathbb{X} \quad u_{\mathrm{n}} : [c] : \mathbb{T} \quad v_{\vec{\alpha},\mathrm{s}} : [D] : \overline{\mathbb{X}}}{\times}\ (\times\mathrm{LVC})$$

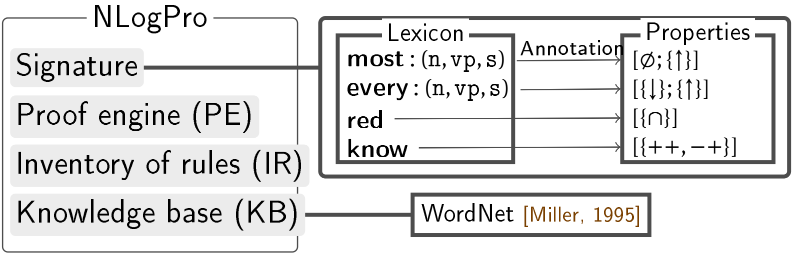
$l \in \{$**do**, **get**, **give**, **have**, **make**, **take**$\}$, $\vec{\alpha}$ is formed by np and pp, and $u \approx_d v$

$$\frac{\textbf{do}_{\mathrm{np,vp}} : [d_e, h_e] : \mathbb{T} \quad \textbf{dance}_{\mathrm{n}} : [d_e] : \mathbb{T} \quad \textbf{dance}_{\mathrm{vp}} : [h_e] : \mathbb{F}}{\times}\ (\times\mathrm{LVC}^*)$$



Building a natural theorem prover

Natural logic theorem prover (NLogPro)



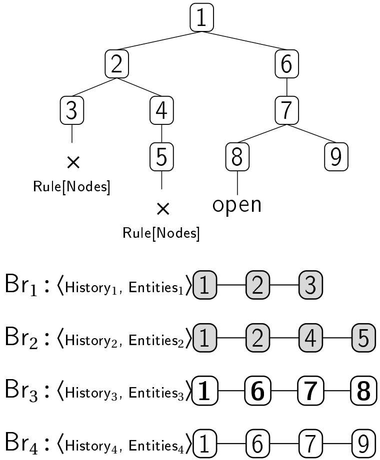
KB uses 4 relations from WordNet 3.0:

- derivation
- similarity
- hyponymy/hypernymy
- antonymy

⚠ No word sense disambiguation system is used.

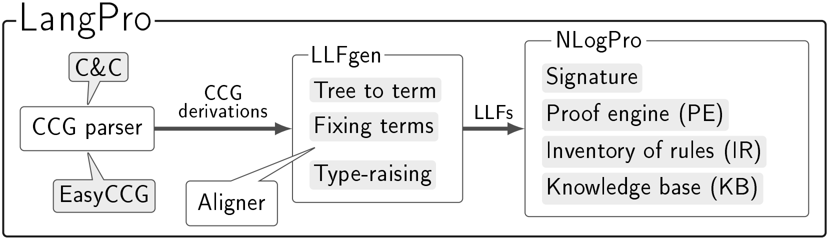
Two data structures

The proof engine builds both a tree and a list structures:



Natural language theorem prover

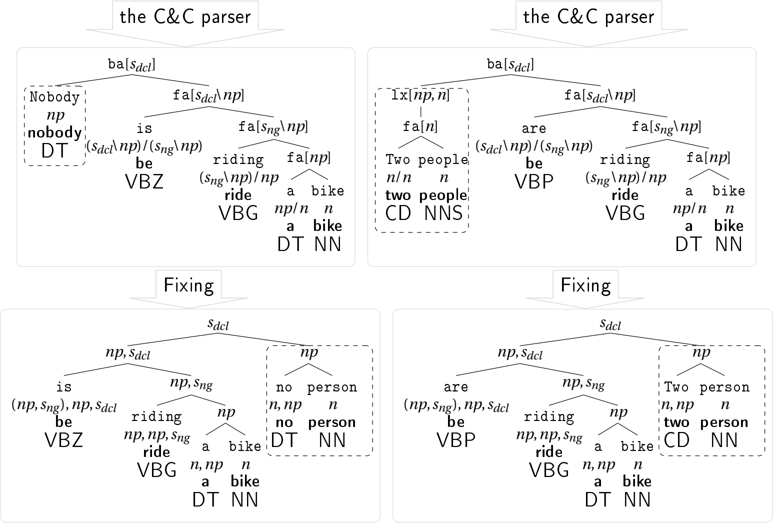
Chaining a CCG parser, the LLF generator and NLogPro results in a theorem prover for natural language.



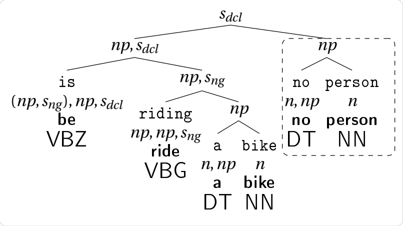
Online demo at: http://naturallogic.pro
git clone: https://github.com/kovvalsky/LangPro

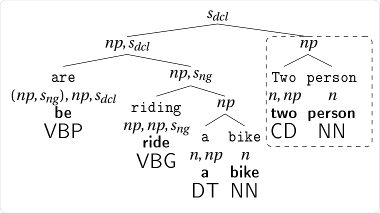
LangPro in action

SICK-2865: `Nobody is riding a bike` $\overset{?}{\Rightarrow}$ `Two people are riding a bike`



LangPro in action (2)





Type-raising | Type-raising

no person (**be** ($\lambda x.$ (**a bike**) ($\lambda y.$ **ride** y x)))
a bike ($\lambda x.$ no person (be (ride x)))

two person (**be** ($\lambda x.$ (**a bike**) ($\lambda y.$ **ride** y x)))
a bike ($\lambda x.$ two person (be (ride x)))

Proving by PE using IR & KB

`intial nodes for entailment checking:`
no person (**be** ($\lambda x.$ (**a bike**) ($\lambda y.$ **ride** y x))): [] : $\mathbb{T}$
two person (**be** ($\lambda x.$ (**a bike**) ($\lambda y.$ **ride** y x))): [] : $\mathbb{F}$

`intial nodes for contradiction checking:`
no person (**be** ($\lambda x.$ (**a bike**) ($\lambda y.$ **ride** y x))): [] : $\mathbb{T}$
two person (**be** ($\lambda x.$ (**a bike**) ($\lambda y.$ **ride** y x))): [] : $\mathbb{T}$

LangPro in action (3)

1 no person (be($\lambda x.$ (a bike) ($\lambda y.$ ride y x))): [] : $\mathbb{T}$

2 two person (be ($\lambda x.$ (a bike) ($\lambda y.$ ride y x))): [] : $\mathbb{T}$

$\exists_{\mathbb{T}}$[2]

3 person: $[c] : \mathbb{T}$

4 be($\lambda x.$ (a bike) ($\lambda y.$ ride y x)): $[c] : \mathbb{T}$

$\text{no}^{n}_{\mathbb{T}}$[1,4]

5 person: $[c] : \mathbb{F}$

6 ×

$$\frac{\textbf{no}\ A\ B : [\,] : \mathbb{T} \qquad A : [c] : \mathbb{T}}{B : [c] : \mathbb{F}}\ \text{no}^{n}_{\mathbb{T}}$$

$$\frac{N^{\text{CD}}\ A\ B : [\,] : \mathbb{T}}{A : [c] : \mathbb{T} \qquad B : [c] : \mathbb{T}}\ \exists_{\mathbb{T}}$$

The SICK dataset

SICK [Marelli et al., 2014b] contains Sentences Involving Compositional Knowledge:

- 10K Text-Hypothesis pairs annotated by humans with three labels: E, C, & N.
- Contains no encyclopedic knowledge, no named entities, relatively small vocabulary, less multiword expressions and no lengthy sentences ($\tilde{9}$ words per sentence).
- SemEval-14 RTE benchmark [Marelli et al., 2014a]
- 84% of crowd workers' labels match the majority, i.e, gold labels.

SICK construction

Original pair	
S0a: *A sea turtle is hunting for fish*	**S0b:** *The turtle followed the fish*
Normalized pair	
S1a: *A sea turtle is hunting for fish*	**S1b:** *The turtle is following the fish*
Expanded pair	
Similar meaning	
S2a: *A sea turtle is hunting for food*	**S2b:** *The turtle is following the red fish*
Logically contradictory or at least highly contrasting meaning	
S3a: *A sea turtle is not hunting for fish*	**S3b:** *The turtle isn't following the fish*
Lexically similar but different meaning	
S4a: *A fish is hunting for a turtle in the sea*	**S4b:** *The fish is following the turtle*

Normalized sentence pairs		Score	Label
S1a: *A sea turtle is hunting for fish*	**S2a:** *A sea turtle is hunting for food*	4.5	E
S3a: *A sea turtle is not hunting for fish*	**S1a:** *A sea turtle is hunting for fish*	3.4	C
S4a: *A fish is hunting for a turtle in the sea*	**S1a:** *A sea turtle is hunting for fish*	3.9	N
S2b: *The turtle is following the red fish*	**S1b:** *The turtle is following the fish*	4.6	E
S1b: *The turtle is following the fish*	**S3b:** *The turtle isn't following the fish*	4	C
S1b: *The turtle is following the fish*	**S4b:** *The fish is following the turtle*	3.8	C
S1a: *A sea turtle is hunting for fish*	**S2b:** *The turtle is following the red fish*	4	N
S1a: *A sea turtle is hunting for fish*	**S3b:** *The turtle isn't following the fish*	3.2	N
S4b: *The fish is following the turtle*	**S1a:** *A sea turtle is hunting for fish*	3.2	N
S1b: *The turtle is following the fish*	**S2a:** *A sea turtle is hunting for food*	3.9	N
S1b: *The turtle is following the fish*	**S3a:** *A sea turtle is not hunting for fish*	3.4	N
S4a: *A fish is hunting for a turtle in the sea*	**S1b:** *The turtle is following the fish*	3.5	N
S1a: *A sea turtle is hunting for fish*	**S1b:** *The turtle is following the fish*	3.8	N

SICK examples and stats

SICK-1241 GOLD: `neutral`

A woman is dancing and singing with other women

A woman is dancing and singing in the rain

SICK-341 GOLD: `contradiction`

There is no girl with a black bag on a crowded train

A girl with a black bag is on a crowded train

SICK-8381 GOLD: `entailment`

The young girl in blue is having fun on a slide

The young girl in blue is enjoying a slide

The FraCaS dataset

The FraCaS test suite [Cooper et al., 1996]:

- Contains 346 problems (45% multi-premised)
- Covers GQs, plurals, anaphora, ellipsis, adjectives, comparatives, temporal reference, verbs and attitudes.
- Three-way annotated by the authors of the dataset.
- Requires almost no lexical or world knowledge

The NLI dataset derived from FraCaS [MacCartney and Manning, 2007].

FraCaS NLI problems

FraCaS-26 GOLD: `entailment`

Most Europeans are resident in Europe
All Europeans are people
All people who are resident in Europe can travel freely within Europe

---

Most Europeans can travel freely within Europe

FraCaS-61 GOLD: `undefined`

Both female commissioners used to be in business.

Both commissioners used to be in business.

FraCaS-171 GOLD: `entailment`

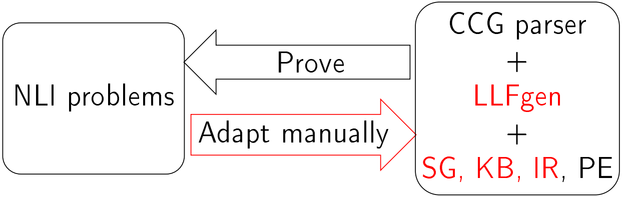
John wants to know how many men work part time.
And women.

John wants to know how many women work part time.

Learning phase

The prover LangPro is (semi-automatically) trained on the NLI datasets [Abzianidze, 2016a].

- **Adaptation**:



  Used datasets: SICK-trial and FraCaS

- **Development**:
  Finding optimal values for certain parameters of the prover based on its performance on SICK-train

Adaptation

The problems that were solved by upgrading one of the components of the prover:

- Treat **few** as ↓ in its 1st arg (*absolute* reading):

  FraCaS-76 GOLD: entailment

  Few committee members are from southern Europe

  Few female committee members are from southern Europe

- Introduce **fit** ⊑ **apply** and **food** ⊑ **meal**:

  SICK-4734 GOLD: entailment

  A man is fitting a silencer to a pistol

  A man is applying a silencer to a gun

  SICK-5110 GOLD: entailment

  A chef is preparing some food

  A chef is preparing a meal

Development phase

Optimal values are searched for:

- The number of word senses to consider;
- The max number of rule application limit (RAL);
- Whether to use a term aligner:
  - Weak aligner aligns everything but terms of type `np`:

    SICK-727   GOLD: `contradiction`

    The man in a grey t-shirt is sitting on a rock in front of the waterfall

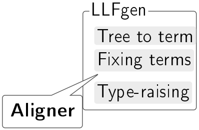
    There is no man in a grey t-shirt sitting on a rock in front of the waterfall

  - Strong aligner aligns everything but terms of type terms of type `np` with ↓arg.

    SICK-423   GOLD: `contradiction`

    Two men are not holding fishing poles

    Two men are holding fishing poles

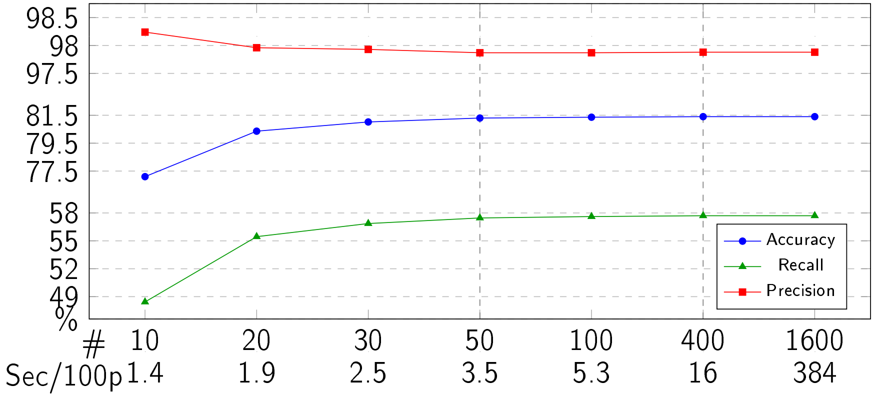


Greedy search for optimal parameters

Acc%	Prec%	Rec%	Sense	Efficiency criterion	Aligner	RAL	Parser
75.09	98.5	43.6	1	[nonP,nonB,equi,nonC]	No	200	C&C
76.42	98.3	46.8	1-5	-	-	-	-
76.89	97.8	48.1	All	-	-	-	-
78.44	97.9	51.7	-	[equi,nonB,nonP,nonC]	-	-	-
79.33	97.9	53.8	-	-	Weak	-	-
81.5	97.7	59.0	-	-	Strong	-	-
81.53	97.7	59.1	-	-	Strong	400	-
81.38	98.0	58.5	-	-	Strong	400	EasyCCG
82.6	97.7	61.6	-	-	Strong	400	Both

The results are given on the SICK-train problems.

Efficient and optimal RAL



The results are given on the SICK-train problems.

Solving FraCaS [Abzianidze, 2016b]

LangPro with C&C

Gold**ccLP**	yes	no	unk
yes	**51**	0	19 + 4
no	1	**14**	2
unk	1	0	**44 + 6**

P = .97, R = .71, Acc = .81

+

LangPro with EasyCCG

Gold**easyLP**	yes	no	unk
yes	**52**	0	22
no	1	**12**	4
unk	2	0	**49**

P = .96, R = .70, Acc = .80

=

LangPro

Gold**LP**	yes	no	unk
yes	**60**	0	14
no	1	**14**	2
unk	2	0	**49**

P = **.96**, R = **.81**, Acc = **.87**

FraCaS-109 GOLD: `contradiction` LP: `entailment`

Just one accountant attended the meeting

Some accountants attended the meeting

Related work (FraCaS)

[MacCartney and Manning, 2008] and [Angeli and Manning, 2014] employ a natural logic that is driven by sentence edits.

[Lewis and Steedman, 2013] employ Boxer-style [Bos et al., 2004] translation into FOL, Prover9 and distributional relation clustering.

[Mineshima et al., 2015] also uses the Boxer-style translation but some HOGQs are treated as higher-order terms. Their inference system is implemented in the proof assistant Coq.

[Tian et al., 2014] and [Dong et al., 2014] uses abstract denotations obtained from DCS trees [Liang et al., 2011]:

$$\mathbf{man} \subset \pi_{\mathsf{subj}}\big(\mathbf{read} \cap (W_{\mathsf{subj}} \times \mathbf{book}_{\mathsf{obj}})\big)$$

[Bernardy and Chatzikyriakidis, 2017] uses Grammatical Framework and Coq. They use gold standard GF trees.

Comparison on FraCaS

Sec (Sing/All)	Single-premised (Acc %)							Overall (Acc %)				
	BL	NL07,08	LS P/G	NLI	T14a,b	M15	**LP**	BL	LS P/G	T14a,b	M15	**LP**
1 GQs (44/74)	45	84 **98**	70 89	95	80 93	82	93	50	62 85	80 **95**	78	**95**
2 Plur (24/33)	58	~~42~~ **75**	-	~~38~~	-	67	**75**	61	-	-	67	**73**
5 Adj (15/22)	40	60 80	-	**87**	-	**87**	**87**	41	-	-	68	**77**
9 Att (9/13)	67	~~56~~ 89	-	~~22~~	-	78	**100**	62	-	-	77	**92**
1,2,5,9 (92/142)	50	- **88**	-	-	-	78	**88**	52	-	-	74	**87**

NL07 [MacCartney and Manning, 2007], **NL08** [MacCartney and Manning, 2008], **NLI** [Angeli and Manning, 2014], **LS** [Lewis and Steedman, 2013],
M15 [Mineshima et al., 2015], **T14a** [Tian et al., 2014] and **T14b** [Dong et al., 2014]

Advantages of our approach over the related ones include:

- Reasoning (with the semantic tableau) over multiple-premises;
- Logical forms close to surface forms;
- Underlying expressive high-order logic.

Curing SICK [Abzianidze, 2015]

Gold SICK-test \ LangPro	Ent	Cont	Neut
Entailment	**805**	0	609
Contradiction	2	**482**	236
Neutral	26	7	**2760**

P=**97.4%**, R=**60.3%**, Acc=**82.14%**

Mainly the usage of WordNet and noisy gold labels are blamed for false proofs.

ID	G/LP	Premise	Conclusion
1405	N/E	A **prawn** is being cut by a woman	A woman is cutting **shrimps**
4443	N/E	A man is singing to a **girl**	A man is singing to a **woman**
2870	N/C	Two people are riding a **motorcycle**	Nobody is riding a **bike**
8913	N/C	A couple is not looking at a map	A couple is looking at a map
363	C/C	P: A soccer ball is not rolling into a goal net C: A soccer ball is rolling into a goal net	

False neutrals

Reason for false neutrals are knowledge sparsity (ca 50%), a lack of rules (ca 25%), wrong labels and parsing mistakes.

ID	G/LP	Premise	Conclusion
4974	E/N	Someone is holding a hedgehog	Someone is holding a small animal
6258	E/N	P: A policeman is sitting on a **motorcycle** C: The cop is sitting on a police **bike**	
4553	E/N	P: A man is emptying a container made of plastic C: A man is emptying a plastic container	
4720	E/N	A monkey is practicing martial arts	A chimp is practicing martial arts
6447	C/N	P: [A small boy [in a yellow shirt]] is laughing on the beach C: There is no small boy [in a yellow shirt [laughing on the beach]]	

Comparison on SICK

SemEval-14 systems	Prec%	Rec%	Acc%	(+LP)	NWS%
Baseline (majority)	-	-	56.69		39.7
Illinois-LH	81.56	**81.87**	**84.57**	(+0.65)	72.8
ECNU	84.37	74.37	83.64	(+1.77)	72.7
UNAL-NLP	81.99	76.80	83.05	(+1.48)	71.2
SemantiKLUE	85.40	69.63	82.32	(+2.84)	71.5
The Meaning Factory	93.63	60.64	81.59	(+2.78)	73.0
UTexas (Prob-FOL)	**97.87**	38.71	73.23	(+9.44)	62.5
LangPro	**97.35**	60.31	82.14		**74.8**

"Hard" problems

The problems from SICK-test that were proved correctly by both ccLangPro and easyLangPro but failed by all the top five systems at the SemEval-14 task.

ID	G	Text	Hypothesis
247	C	T: The woman is not wearing glasses or a headdress	H: A woman is wearing an Egyptian headdress
406	E	T: A group of scouts are hiking through the grass	H: People are walking
2895	C	The man isn't lifting weights	The man is lifting barbells
3527	E	T: A person is jotting something with a pencil	H: A person is writing
3570	C	The piece of paper is not being cut	Paper is being cut with scissors
3608	N	T: A monkey is riding a bike	H: A bike is being ridden over a monkey
3806	E	A man in a hat is playing a harp	A man is playing an instrument
4479	E	The boy is playing the piano	The boy is playing a musical instrument

Conclusion

Natural Tableau is a wide-coverage but still logic-based reasoning system inspired by Natural Logic.

It represents a proof-theoretic approach to NLI.

Natural tableau was successfully scaled up for the NLI task:
CCG parser + LLFgen + theorem prover

Pros and cons of Natural Tableau:

- ✔ Employs higher-order logic to model linguistic semantics;
- ✔ Allows deep logical and shallow (e.g. monotonicity) reasoning;
- ✔ Getting logical form is similar to syntactic parsing;
- ✘ Heavily hinges on CCG parsing;
- ✔ Proofs are highly reliable ($\leq 3\%$ false proofs);
- ✘ Suffers from multi-sense words;
- ✘ No fully automated learning from data yet;
- ✔ Its decision procedure is transparent and explanatory;

Future work

There are really many directions for future work:

- Explore different types of RTE data, e.g., the newswire or human generated data [Bowman et al., 2015];
- Incorporate more knowledge in KB, e.g., paraphrase database [Ganitkevitch et al., 2013].
- Model different phenomena: comparatives, anaphora, cardinals, etc.
- Pairing with distributional semantics: $R(w_1, w_2, r)$ and weighted closure branches;
- Acquisition of lexical knowledge: abductive reasoning;
- Generate LLFs from Universal Dependency trees

  + the Universal Semantic Tagging [Abzianidze and Bos, 2017]

  $\rightarrow^?$ Multilingual Natural Tableau

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