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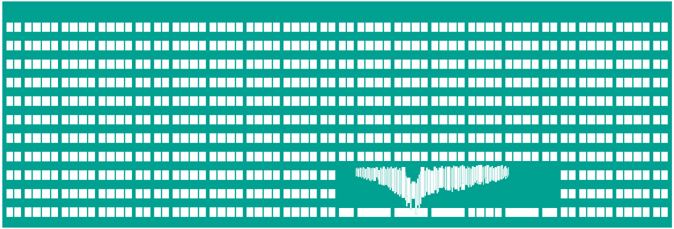

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Adjustment of goal-driven resolution for natural language processing in TIL

Marie Duží, Michal Fait, Marek Menšík

VSB – Technical University of Ostrava

marie.duzi@vsb.cz, michal.fait@vsb.cz, marek.mensik@vsb.cz

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Content

Introduction

- Having a fine-grained analysis of natural language sentences in the form of *TIL* (Transparent Intensional Logic) *constructions*, we apply the *General Resolution Method* (GRM) with its *goal-driven strategy* to answer the question (goal) raised on the natural language data.
- We must deal with *semantic rules* concerning *attitudes*, *property modifiers*, *anaphoric references*, *modalities*, different grammatical *tenses* etc., and also with special *technical rules* of TIL like methods to operate *in* a hyperintensional context, special functions that operate on constructions, namely $Sub/(\ _n\ _n\ _n\ _n)$ and $Tr/(\ _n\ )$ together with Double Execution, properties of propositions like *True*, *False* etc.

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Introduction

- In previous works we assumed that it would be possible to *pre-process* TIL constructions (with respect to the above mentioned special rules) prior to the process of applying the algorithm of transformation into the Skolem clausal form and goal-driven resolution.
- However, as it turns out, this way is under-inferring. It can be the case that we might derive the respective answer entailed by the knowledge base if only we could harmonically *integrate* those special TIL rules with the goal-driven resolution process.

Introduction

- In previous works we assumed that it would be possible to *pre-process* TIL constructions (with respect to the above mentioned special rules) prior to the process of applying the algorithm of transformation into the Skolem clausal form and goal-driven resolution.
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Example

Scenario. John is a married man. John's partner is Eve. Everybody who is married believes, that his/her partner is amazing.
Question. Does John believe that Eve is amazing?

Formalization

Types: *John; Eve*= ; $Married^m$=((*o*) $_!$ (*o*) $_!$) a property modifier; *Married*=(*o*) $_!$ the property of being married; *Amazing; Man*=(*o*) $_!$; *Partner*=( ) $_!$; *Believe*=(*o* $_n$) $_!$; *w* ! !; *t* ! ; *x; y* ! .

Premises:

$w\ \ t\,[[{}^0Married^m\ {}^0Man]_{wt}\ {}^0John]$

$w\ \ t\,[[{}^0Partner_{wt}\ {}^0John] = {}^0Eve]$

$w\ \ t\,8x\,[[{}^0Married_{wt}\,x]\ \ \ [{}^0Believe_{wt}\,x\,[{}^0Sub\,[{}^0Tr\,[{}^0Partner_{wt}\,x]]\ {}^0y\ {}^0[\ w\ \ t\,[{}^0Amazing_{wt}\,y]]]]]$

Conclusion/question:

$w\ \ t\,[{}^0Believe_{wt}\ {}^0John\ {}^0[\ w\ \ t\,[{}^0Amazing_{wt}\ {}^0Eve]]]$

At this point we *cannot* adjust the third premise, i.e. to evaluate the substitution, because this is a general rule. In other words, we do not know as yet which individuals should be substituted for *x*, and thus also for *y*.

Formalization

Types: $John, Eve / ;\ Married^m / ((o\ )_{!}(o\ )_{!})$ a property modifier; $Married / (o\ )_{!}$ the property of being married; $Amazing, Man / (o\ )_{!}$; $Partner / (\ )_{!}$; $Believe / (o\ \ _n)_{!}$; $w\ !\ !$; $t\ !\ $; $x, y\ !$.

Premises:

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$w\ \ t\ 8x\,[[{}^0Married_{wt}\ x]\quad [{}^0Believe_{wt}\ x\,[{}^0Sub\,[{}^0Tr\,[{}^0Partner_{wt}\ x]]\ {}^0y\ {}^0[\ w\ \ t\,[{}^0Amazing_{wt}\ y]]]]]$

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w t [[$^0Partner_{wt}$ ^0John] = ^0Eve]

w t $8x$ [[$^0Married_{wt}$ x] [$^0Believe_{wt}$ x [^0Sub [^0Tr [$^0Partner_{wt}$ x]] ^0y ^{0}[w t [$^0Amazing_{wt}$ y]]]]]

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Premises and negated question in the clausal form

A: $[[^0\text{Married}^m\ ^0\text{Man}]_{wt}\ ^0\text{John}]$
B: $[[^0\text{Partner}_{wt}\ ^0\text{John}] =\ ^0\text{Eve}]$
C: : $[^0\text{Married}_{wt}\ x]$ _ $[^0\text{Believe}_{wt}\ x\ [^0\text{Sub}[^0\text{Tr}\ [^0\text{Partner}_{wt}\ x]]\ ^0y$
$^0[\ w\ t\quad [^0\text{Amazing}_{wt}\ y]]]]$
G: : $[^0\text{Believe}_{wt}\ ^0\text{John}\ ^0[\ w\ t\quad [^0\text{Amazing}_{wt}\ ^0\text{Eve}]]]$

The resolution process should start with the goal G and look for a claus where a positive constituent $[^0\text{Believe}_{wt}\ x\ :::]$ occurs. Obviously, it is the clause C.

In TIL, uni cation consists in substituting constituents for variables. Yet, to unify constructions of the arguments of the function produced by $^0\text{Believe}_{wt}$ as they occur in the clauses G and C, it is not su cient to substitute the constituent ^{0}John for the variable x.

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$\quad {}^0[\ w\ t\ \ [{}^0Amazing_{wt}\ y]]]]$

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Uni cation and Resolution

In addition, we have to exploit the clause B and substitute ^0Eve for $[^0Partner_{wt}\ ^0John]$. As a result, we obtain

$$[^0Believe_{wt}\ ^0John\ [^0Sub[^0Tr\ ^0Eve]\ ^0y\ ^0[\ w\ t\ \ [^0Amazing_{wt}\ y]]]]$$

Next, the application of the functions Sub and Tr must be evaluated. As a result, we obtain the adjusted clause:

C':: $[^0Married_{wt}\ ^0John]$ _ $[^0Believe_{wt}\ ^0John\ ^0[\ w\ t\ \ [^0Amazing_{wt}\ ^0Eve]]]$

Only now can the clauses G and C' be resolved so that the new goal is obtained:

R1: : $[^0Married_{wt}\ ^0John]$ (G+C')

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However, this goal cannot be met, unless the rule of left subsectivity that is universally valid for any kind of a property modi er is applied. In our case the rule results in $[[{}^0Married\ {}^m\ {}^0Man]_{wt}\ x]$ ` $[{}^0Married_{wt}\ x]$. For the purpose of resolution method, we rewrite the rule into the implicative hence clausal form, thus obtaining another clause

M: : $[[{}^0Married\ {}^m\ {}^0Man]_{wt}\ z]$ _ $[{}^0Married_{wt}\ z]$

Now the last goal R1 is easily met:

R2: : $[[{}^0Married\ {}^m\ {}^0Man]_{wt}\ {}^0John]$ (R1+M), ${}^0John/z$
R3: # (R2+A)

By applying an indirect proof we obtained the empty clause that cannot be satis ed, hence the answer to the question Q is YES.

Unification and resolution

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M: $\neg[[{}^0Married\ m\ {}^0Man]_{wt}\ z] \vee [{}^0Married_{wt}\ z]$

Now the last goal R1 is easily met:

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Factive propositional attitudes

The truth of the known sub-proposition is a presupposition of the whole proposition.

$$[{}^0Know_{wt}\ a\ c]\ `\ [{}^0True_{wt}\ {}^2c]$$

$$:\ [{}^0Know_{wt}\ a\ c]\ `\ [{}^0True_{wt}\ {}^2c]$$

Types: $Know/(o\ \ _n)_{!\ }$; $a\ !\ $; $c\ !\ \ _n$; ${}^2c\ !\ \ o_{!\ }$; $True/(oo_{!\ })_{!\ }$.

Additional special rules

In addition to these rules, we often need to apply the rule of True elimination:

$$[{}^0True_{wt}\ p] ` \ p_{wt}$$

In the resolution process we also make technical adjustments, in particu
by applying the rule of ^{20}-conversion:

$${}^{20}C = C$$

for any closed construction C that is typed to v-construct a non-procedural object of a type of order 1.

Example

Scenario: The Mayor of Ostrava knows that the President of TUO does not know (yet) that he (the President) will go to Brussels. The President of TUO is prof. Snasel.
Question: Will prof. Snasel go to Brussels?

Formalization

Types: Snasel, Brussels/ ; Know/(o $_n$) ! ; President(-of TUO), Mayor(-of Ostrava)/ ! ; Go/(o) ! .

Premises:

w t [^{0}Know$_{wt}$ ^{0}Mayor$_{wt}$ ^{0}[w t : [^{0}Know$_{wt}$ ^{0}President$_{wt}$
[^{0}Sub[^{0}Tr ^{0}President$_{wt}$] ^{0}he ^{0}[w t [^{0}Go$_{wt}$ he ^{0}Brussels]]]]]]

w t [^{0}President$_{wt}$ = ^{0}Snasel]

Conclusion/question:

w t [^{0}Go$_{wt}$ ^{0}Snasel ^{0}Brussels]

In addition to these premises and conclusion, we have the above rules their implicative form so that we obtain three additional clauses:

[^{0}Know$_{wt}$ x c] [^{0}True$_{wt}$ ^{2}c]

: [^{0}Know$_{wt}$ x c] [^{0}True$_{wt}$ ^{2}c]

[^{0}True$_{wt}$ p] p$_{wt}$

Formalization

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Premises:

w t [^{0}Know$_{wt}$ ^{0}Mayor$_{wt}$ ^{0}[w t : [^{0}Know$_{wt}$ ^{0}President$_{wt}$
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[^{0}True$_{wt}$ p] p$_{wt}$

Premises and negated question in the clausal form

A: $[{}^0Know_{wt}\ {}^0Mayor_{wt}\ {}^0[\ w\ t\ \ :\ [{}^0Know_{wt}\ {}^0President_{wt}$
$[{}^0Sub\ [{}^0Tr\ {}^0President_{wt}]\ {}^0he\ {}^0[\ w\ t\ \ [{}^0Go_{wt}\ he\ {}^0Brussels]]]]]]$

B: $[{}^0President_{wt} = {}^0Snasel]$

M1: $:\ [{}^0Know_{wt}\ x\ c]\ \_\ [{}^0True_{wt}\ {}^2c]$

M2: $[{}^0Know_{wt}\ y\ d]\ \_\ [{}^0True_{wt}\ {}^2d]$

T: $:\ [{}^0True_{wt}\ p]\ \_\ p_{wt}$

G: $:\ [{}^0Go_{wt}\ {}^0Snasel\ {}^0Brussels]$

Since the strategy is goal-driven, we aim at choosing a clause with a positive constituent $[{}^0Go_{wt}\ :::]$. The only candidate is the clause A. However, there is a problem here. The constituent ${}^0Go$ occurs in the goal G extensionally, while the same constituent occurs in A in the hyperintensional context, i.e. closed by Trivialization and thus not amenable to logical operations.

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$[{}^{0}Sub\ [{}^{0}Tr\ {}^{0}President_{wt}]\ {}^{0}he\ {}^{0}[w\ t\ \ [{}^{0}Go_{wt}\ he\ {}^{0}Brussels]]]]]]$

B: $[{}^{0}President_{wt} = {}^{0}Snasel]$

M1: $:\ [{}^{0}Know_{wt}\ x\ c]\ \_\ [{}^{0}True_{wt}\ {}^{2}c]$

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Since the strategy is goal-driven, we aim at choosing a clause with a positive constituent $[{}^{0}Go_{wt} :::]$. The only candidate is the clause A. However, there is a problem here. The constituent ${}^{0}Go$ occurs in the goal G extensionally, while the same constituent occurs in A in the hyperintensional context, i.e. closed by Trivialization and thus not amenable to logical operations.

Uni cation and resolution

Before resolving the goal G with any other clause, we must resolve A, M M2 and T until the constituent ^{0}Go gets down to the extensional level. Here is how.

R1: $[^0True_{wt}\ ^{20}[\ w\ t\quad :\ [^0Know_{wt}\ ^0President_{wt}$
$[^0Sub[^0Tr\ ^0President_{wt}]\ ^0he\ ^0[\ w\ t\quad [^0Go_{wt}\ he\ ^0Brussels]]]]]]$
(A+M1)
$^0Mayor_{wt}/x,$
$^0[\ w\ t\quad :\ [^0Know_{wt}\ ^0President_{wt}\ [^0Sub[^0Tr\ ^0President_{wt}]\ ^0he$
$^0[\ w\ t\quad [^0Go_{wt}\ he\ ^0Brussels]]]]]/c$

R2: $^{20}[\ w\ t\quad :\ [^0Know_{wt}\ ^0President_{wt}$
$[^0Sub[^0Tr\ ^0President_{wt}]\ ^0he\ ^0[\ w\ t\quad [^0Go_{wt}\ he\ ^0Brussels]]]]]_{wt}$
(R1+T)
$^{20}[\ w\ t\quad :\ [^0Know_{wt}\ ^0President_{wt}$
$[^0Sub[^0Tr\ ^0President_{wt}]\ ^0he\ ^0[\ w\ t\quad [^0Go_{wt}\ he\ ^0Brussels]]]]]/p$

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(A+M1)

$^0Mayor_{wt}/\ x,$

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$[^0Sub[^0Tr\ ^0President_{wt}]\ ^0he\ ^0[\ w\ t\ \ [^0Go_{wt}\ he\ ^0Brussels]]]]]_{wt}$

(R1+T)

$^{20}[\ w\ t\ \ :\ [^0Know_{wt}\ ^0President_{wt}$
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(A+M1)

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$^0[\ w\ t\ \ [^0Go_{wt}\ he\ ^0Brussels]]]]]/c$

R2: $^{20}[\ w\ t\ \ :\ [^0Know_{wt}\ ^0President_{wt}$
$[^0Sub[^0Tr\ ^0President_{wt}]\ ^0he\ ^0[\ w\ t\ \ [^0Go_{wt}\ he\ ^0Brussels]]]]]_{wt}$

(R1+T)

$^{20}[\ w\ t\ \ :\ [^0Know_{wt}\ ^0President_{wt}$
$[^0Sub[^0Tr\ ^0President_{wt}]\ \ ^0he\ ^0[\ w\ t\ \ [^0Go_{wt}\ he\ ^0Brussels]]]]]/p$

Uni cation and resolution

R3: $[^0True_{wt}\ ^2[^0Sub[^0Tr\ ^0President_{wt}]\ ^0he\ ^0[\ w\ t\ \ [^0Go_{wt}\ he\ ^0Brussels]]]]]$

(R2+M2)

^{20}-conversion,

restricted -conversion,

$^0President_{wt}$ / y,

$[^0Sub[^0Tr\ ^0President_{wt}]\ ^0he\ ^0[\ w\ t\ \ [^0Go_{wt}\ he\ ^0Brussels]]]$ / d

In order to resolve R2 a M2 to get R3, we had to apply ^{20} and restricted -conversion in addition to the substitution of constructions for variables

R4: $^2[^0Sub[^0Tr\ ^0President_{wt}]\ ^0he\ ^0[\ w\ t\ \ [^0Go_{wt}\ he\ ^0Brussels]]]_{wt}$

(R3+T)

$^2[^0Sub[^0Tr\ ^0President_{wt}]\ ^0he\ ^0[\ w\ t\ \ [^0Go_{wt}\ he\ ^0Brussels]]]$ / p

Uni cation and resolution

R3: [^{0}True$_{wt}$ ^{2}[^{0}Sub[^{0}Tr ^{0}President$_{wt}$] ^{0}he ^{0}[w t [^{0}Go$_{wt}$ he ^{0}Brussels]]]]]

(R2+M2)

^{20}-conversion,

restricted -conversion,

^{0}President$_{wt}$ / y,

[^{0}Sub[^{0}Tr ^{0}President$_{wt}$] ^{0}he ^{0}[w t [^{0}Go$_{wt}$ he ^{0}Brussels]]]/ d

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To evaluate the substitution, i.e. to obtain the proposition constructed by R4, we make use of the clause B in order to substitute ^{0}Snasel for ^{0}President$_{wt}$. Thus, we have

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^{2}[^{0}Sub[^{0}Tr ^{0}Snasel] ^{0}he ^{0}[w t [^{0}Go$_{wt}$ he ^{0}Brussels]]]$_{wt}$ = Sub, Tr
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As a result, we obtained an adjusted clause
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Hence, the answer to the question Q is YES.

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Hence, the answer to the question Q is YES.

Notes

- We cannot proceed strictly from a goal to meet another goal.
- At the beginning of the resolution process, we rst had to resolve th clause A with other clauses (M1, M2, T), then adjust the result by means of the clause B and the special TIL technical rules, and only then could we resolve the result with our goal G to obtain an empty clause, and thus answer the question Q in positive.
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Concluding remarks

- We introduced reasoning with ne-grained semantics of natural language in the question-answer system based on Transparent Intensional Logic.
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Thank you for your attention

Marie Duží, Michal Fait, Marek Menšík

VSB – Technical University of Ostrava

marie.duzi@vsb.cz, michal.fait@vsb.cz, marek.mensik@vsb.cz

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VSB TECHNICAL UNIVERSITY OF OSTRAVA | FACULTY OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE