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Questions and Answers on Dynamic Activities of Agents

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Primary goals

- to *logically* analyse *processes* and *activities*
  - so that the agents in a multiagent and multicultural world can ask on the participants of such activities.
- *Wh-questions* about and plausible *answers* on the participants of *dynamic activities* in different tenses, with time references and specified frequencies
- not only direct answers extracted from natural-language texts or agents' knowledge bases just by keywords; rather, we also want to derive *logical consequences* of such answers.

Tools and methods

- *hyperintensional approach* to natural-language processing
- *Transparent Intensional Logic* (TIL) with its *procedural semantics*
- Genzen's system of *natural deduction* adjusted for TIL and natural-language processing
- *Wh-questions* encode λ-terms with a free variable *x* ranging over entities of type α, which is the type of a possible direct answer
- *answers* by suitable substitutions of the α-entities extracted from input sentences, the constituents of which match a given λ-term; unification known from the general resolution method
- *semantic rules* rooted in the rich semantics of a natural language.
  - In particular, the agents can make use of the relations of *requisites* and pre-requisites between intensions

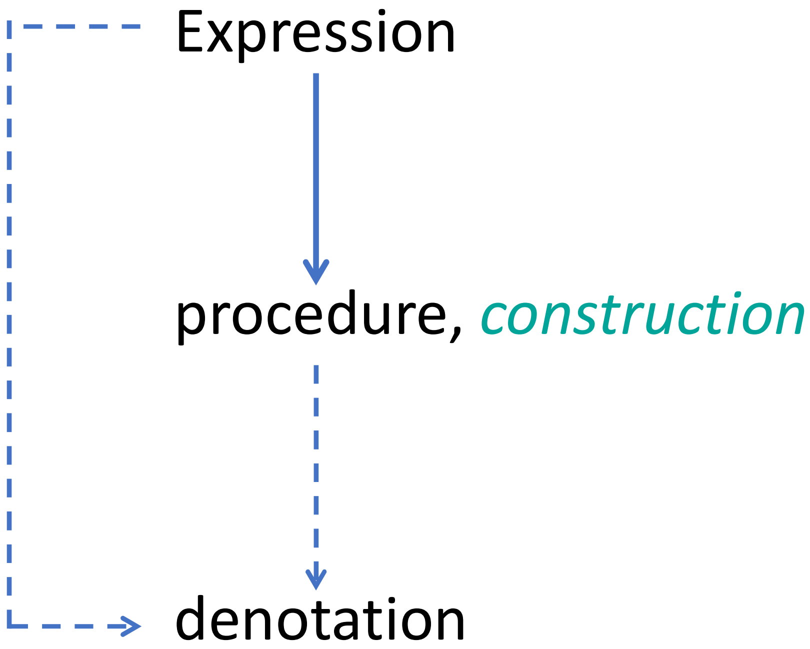
Content

1. Fundamentals of TIL
2. TIL technique of answering Wh-questions
3. The analysis of dynamic activities of agents
4. Wh-questions and answers on the participants of activities

TIL Basic tenets

- *an expression encodes the instruction on how, in any possible world w at any time t, to execute the **procedure encoded by the expression as its meaning**.*
- unlike sets, *procedures are algorithmically structured*;
  they consist of a finite number of steps (constituent sub-procedures) that can be *executed*, operated on, learnt, shared, followed, …
- procedure is not only a sequence of instructions, because a sequence cannot be executed; rather, the ***procedure itself is designed to be executed***
- Not only particular parts matter, but also the ***way of combining these parts into one whole instruction*** that can be followed, understood, executed, learnt, etc., matters.
  - Bernard Bolzano; *Wissenschaftslehre* (1837, §49)

TIL semantic schema



Stratified ontology of TIL: ramified hierarchy of types

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Constructions

- ***Variables*** $x, y, p, w, t, \ldots$ v-construct
- ***Trivialization*** ^0C constructs C (of any type)
  - a *fixed pointer* or *reference* to *C*
  - In order to operate on *C*, *C* needs to be grabbed, or 'called', referred to, first. Trivialization is such a grabbing mechanism.
- ***Closure*** $\underset{\alpha_1}{[\lambda x_1} \ldots \underset{\alpha_n}{x_n} \underset{\beta}{X}] \rightarrow (\beta\ \alpha_1 \ldots \alpha_n)$
- ***Composition*** $[\underset{(\beta\ \alpha_1 \ldots \alpha_n)}{F}\ \underset{\alpha_1}{X_1} \ldots \underset{\alpha_n}{X_n}] \rightarrow \beta$
- *Execution* ^1X, ***Double Execution*** ^2X

TIL Ontology (types of order 1)

(non-procedural objects)

- ***Basic types***

  truth-values {T, F} **(ο)**

  universe of discourse {individuals} **(ι)**

  times or real numbers **(τ)**

  possible worlds **(ω)**

- ***Functional types*** **$(\beta\ \alpha_1 \ldots \alpha_n)$**

  partial functions $(\alpha_1 \times \ldots \times \alpha_n) \rightarrow \beta$

  PWS Intensions – *entities of type* **$((\alpha\tau)\omega)$**; $\alpha_{\tau\omega}$

TIL Ontology (higher-order types)

- *Constructions of order 1* ($*_1$)
  - → construct entities belonging to a type of order 1
  - / belong to $*_1$: *type of order **2***
- *Constructions of order 2* ($*_2$)
  - → construct entities belonging to a type of order 2 or 1
  - / belong to $*_2$: *type of order **3***
- *Constructions of order n* ($*_n$)
  - → construct entities belonging to a type of order $n \geq 1$
  - / belong to $*_n$: *type of order **n + 1***

And so on, *ad infinitum*

- ***Functional entities***: $(\beta\ \alpha_1 \ldots \alpha_n)$ / belong to $*_n$

  (n: the highest of the 'native' types to which β, α_1, …, α_n belong)

Structured meanings

"Tom is wise"

$\lambda w\ \lambda t\ [{}^0Wise_{wt}\ {}^0Tom]$

- in any possible world w (λw) at any time t (λt), do this:
- take the individual Tom (${}^0Tom$);
- take the property of being wise (${}^0Wise$);
- extensionalize the property with respect to the world w and time t of evaluation (${}^0Wise_{wt}$);
- produce a truth-value **T** or **F** according as Tom has the property of being wise in that world w and at that time t of evaluation ($[{}^0Wise_{wt}\ {}^0Tom]$).

Displayed vs. Executed Procedures

- An occurrence of *C is displayed in D* if the execution of *D* does not involve the execution of this occurrence of *C*.

$$\lambda w \lambda t\ [{}^0Computes\ {}^0Tom\ {}^0[{}^0\boldsymbol{Cotg}\ {}^0\pi]]$$

- Otherwise, *C* is *executed in D*, i.e. a *constituent part of D*; *C* occurs extensionally or intensionally
- *Procedures are displayed by Trivialization,* ^0C; yet, the effect of Trivialization can be cancelled by Double Execution
- *C* occurs *displayed* in *D* iff *C* occurs within the scope of Trivialization the effect of which is not cancelled by Double Execution

  $^0[\ldots C \ldots]$ → *C* is a displayed object;

  $^2[\ldots {}^0[\ldots C \ldots]\ldots]$ → *C* can remain displayed, or become an executed constituent

Problem: within the scope of Double Execution it is not possible to determine at the syntactic level whether *C* is displayed or executed; *the decision must be postponed to the evaluation phase*

Example: *If P then C else D* $\quad {}^2[{}^0\iota^*\ \lambda c\ [[P \wedge [c = {}^0C]] \vee [\neg P \wedge [c = {}^0D]]]]$

Hyperintensionality

- was born out of a negative need, to block invalid inferences

  a computes 2+5; 2+5 = $\sqrt{49} \vdash$ *a* computes $\sqrt{49}$

  - *Carnap* (1947, §§13*ff*); there are contexts that are neither extensional nor intensional (attitudes)
  - *Cresswell*; any context in which substitution of necessarilly equivalent terms fails is hyperintensional

- We have defined hyperintensional contexts *positively*; the context of a displayed construction;
  - a context is *hyperintensional* if the very meaning *procedure* is an object of predication

Blocking invalid inferences is one side of the coin;

yet, there is naturally the other side, ***which inferences are valid in hyperintensional contexts?*** To this end, we have developed the *substitution methods*

β-reduction by value

$$[\lambda x\, F(x)\, A] \mid\!- F(A/x)$$

underspecified:

- How to execute the substitution *F*(*A/x*)?

a) ‘by name’: *construction A* is substituted for *x* → non-equivalent, loss of analytic information

b) ‘by value’: execute *A* first, and only if it does not fail, substitute the produced *value* for *x* – *substitution method* → bingo, no problems !!! ☺

$$[\lambda x\, F(x)\, A] = {}^2[{}^0Sub\, [{}^0Tr\, A]\, {}^0x\, {}^0F(x)]$$

Algol’60: “call-by-value” and “call-by-name”

Java: manipulates with objects “by name”, however, procedures are called “by-value”

Huskell: “call-by-name” !

Substitution method; *broadly applied*

- Application of a function to an argument (β-reduction by value)
- Existential quantification into hyperintensional contexts
- *Anaphoric* preprocessing

In addition, hyperintensional approach is needed, for instance, for

- General analytic schema for sentences with *presuppositions*
- Sentences in different *tenses*
- active vs. passive
- …

Wh-questions

- the variety of possible answers to empirical Wh-questions is huge; depends on the *type α* of an α-intension the value of which is asked for.
- "Which Czech ladies are among the first fifty players in WTA ranking singles?" $\rightarrow (o\iota)_{\tau\omega}$
- Possible answer: {Barbora Krejčíková, Karolina Plíšková, Petra Kvitová, Karolína Muchová, Marketa Vondroušová} / $(o\iota)$
- "What is John's salary?" $\rightarrow \tau_{\tau\omega}$

The technique of answering Wh-questions

1. $\lambda w \lambda t\ [[{}^0\mathit{WTA\text{-}ranking}_{wt}\ {}^0\mathit{Barty}] = {}^0 1]$
2. $\lambda w \lambda t\ [[{}^0\mathit{WTA\text{-}ranking}_{wt}\ {}^0\mathit{Sabalenka}] = {}^0 2]$
3. $\lambda w \lambda t\ [[{}^0\mathit{WTA\text{-}ranking}_{wt}\ {}^0\mathit{Krejcikova}] = {}^0 3]$
4. $\lambda w \lambda t\ [[{}^0\mathit{WTA\text{-}ranking}_{wt}\ {}^0\mathit{Pliskova}] = {}^0 4]$
5. $\lambda w \lambda t\ [[{}^0\mathit{WTA\text{-}ranking}_{wt}\ {}^0\mathit{Muguruza}] = {}^0 5]$

and so on …

- The answer to the question "Who are the first three players in WTA tennis singles"?, i.e.

Q. $\lambda w \lambda t\ [\lambda x\ [[{}^0\mathit{WTA\text{-}ranking}_{wt}\ x] \leq {}^0 3]] \rightarrow (o\iota)_{\tau\omega}$

The technique of answering Wh-questions

is derived like this.

(1) $[\lambda x\ [[^0 WTA\text{-}ranking_{wt}\ x] \leq {}^0 3]]$ Question (raised in a given *w* and *t*)

(2) $[[^0 WTA\text{-}Ranking_{wt}\ x] \leq {}^0 3]$ 1, λ-E

- the algorithm searches a given knowledge base for those sentences the constituents of which match with (2).
  - In addition, basic algebraic operations can be applied.
- Thus, the first matching sentence is $[[^0 WTA\text{-}Ranking_{wt}\ {}^0 Barty] = {}^0 1]$, as $1 \leq 3$.
- Substitution $^0 Barty / x$ yields the answer $x = {}^0 Barty$.
- “Who else”? $x = {}^0 Sabalenka$ $(2 \leq 3)$, $x = {}^0 Krejcikova$ $(3 \leq 3)$.

Dynamic activities

- A large number of Wh-questions concerns the *participants of activities*;
- Yet, these participants often belong to just one logical type, mostly ι or τ, which is too coarse-grained.
- We need a more detailed classification of their types. Our specification of *activities* is based on the linguistic theory of *verb valency frames* and on their logical analysis.

"John (the agent) is going (the activity) to Brussel (Dir3) by car (Inst) at an average speed of 50 miles per hour (Man)."

- "What is John doing?"
- "Who is going to Brussel?"
- "How quickly does John go to Brussel?", etc.

Dynamic activities

frequent *kinds of participants*:

- Pat – the object affected by the activity
- Ben – beneficient (somebody (or something) who has a benefit from the activity)
- Manner – the manner of the activity execution (measure, speed etc.)
- Inst – instrument
- Time – when the activity takes place
- Time1 (the time when the activity starts)
- Time2 (the time when the activity ends)
- Loc – the place of activity
- Dir1 – the direction of activity – *from where*
- Dir2 – the direction of activity – *which way*
- Dir3 – the direction of activity – *where to*

Dynamic activities

- Logical specification draws on the ideas of Tichý (1980)
- general pattern for analysing an activity $P \rightarrow \pi$ with the actor $A \rightarrow \iota$ and participants $X_1^{Part\text{-}1}, \ldots, X_n^{Part\text{-}n}$

$$\lambda w \lambda t\ [[{}^0Do_{wt}\ A\ P] \wedge$$
$$[{}^0Ass_{wt}\ P\ {}^0X_1^{Part\text{-}1}] \wedge [{}^0Ass_{wt}\ P\ {}^0X_2^{Part\text{-}2}] \wedge \ldots \wedge [{}^0Ass_{wt}\ P\ {}^0X_n^{Part\text{-}n}]]$$

- *"John builds a house in Bali"*

$$\lambda w \lambda t\ [[{}^0Do_{wt}\ {}^0John\ {}^0Build] \wedge$$
$$[{}^0Ass_{wt}\ {}^0Build\ {}^0House^{Pat}] \wedge [{}^0Ass_{wt}\ {}^0Build\ {}^0Bali^{Loc}]]$$

- *"When and for whom does John build a house in Bali?"*

$$\lambda w \lambda t\ \lambda when\ \lambda whom\ [[{}^0Do_{wt}\ {}^0John\ {}^0Build] \wedge [{}^0Ass_{wt}\ {}^0Build\ {}^0House^{Pat}]$$
$$\wedge [{}^0Ass_{wt}\ {}^0Build\ {}^0Bali^{Loc}] \wedge [{}^0Ass_{wt}\ {}^0Build\ when^{Time}] \wedge [{}^0Ass_{wt}\ {}^0Build\ whom^{Ben}]]$$

Dynamic activities – in past or future

- "*When did John build a house in Bali for Marie*"?

$$\lambda w \lambda t\, \lambda when\, \exists t'\, [[[{}^0Do_{wt'}\, {}^0John\, {}^0Build] \wedge [t' \leq t]] \wedge$$
$$[[{}^0Ass_{wt}\, {}^0Build\, {}^0House^{Pat}] \wedge [{}^0Ass_{wt}\, {}^0Build\, {}^0Bali^{Loc}] \wedge$$
$$[{}^0Ass_{wt}\, {}^0Build\, when^{Time}] \wedge [{}^0Ass_{wt}\, {}^0Build\, {}^0Marie^{Ben}]]]$$

- The situation gets more complicated if a sentence in past or future comes with a *time reference T* when this or that happened or will happen.
    - the sentence is associated with a *presupposition* that the current time *t* is in the proper relation with respect to the reference time *T*.
- Moreover, the sentence can also convey information on the *frequency* of the process to be executed in the reference time *T*

Dynamic activities

- a strict definition of the *If-then-else-fail* function that complies with the compositionality constraint

If ***Presupposition*** *P* then *C* else *Fail*
(to produce a truth-value)

$$^{2}[^{0}\textit{The-only}\ \lambda c\ [P \wedge [c = {}^{0}C]]]$$

- ***The-only*** is *a singulariser function* ($*_n$ ($o*_n$)) that returns the only construction, the member of a singleton; ***otherwise undefined***
- $c \rightarrow *_n$: *a variable ranging over* ***procedures;***
- ^{0}C: ***procedure C*** *is an object to operate on****;***
- ***Hyperintensional logic is needed*** *to deal with* ***procedures****, not only with their* ***products.***

Dynamic activities – time reference

"*John has built a house in Bali in 2020*"

presupposes that the time *t* in which the truth conditions are being evaluated comes after the end of 2020. If it is not so, the sentence has *no truth value.*

$$\lambda w \lambda t\ [If\ [t \geq_{\tau} {}^0 2020]\ \text{then}$$

$$[\exists t'\ [[{}^0Do_{wt'}\ {}^0John\ {}^0Build] \wedge [{}^0 2020\ t']] \wedge$$

$$[[{}^0Ass_{wt}\ {}^0Build\ {}^0House^{Pat}] \wedge [{}^0Ass_{wt}\ {}^0Build\ {}^0Bali^{Loc}] \wedge [{}^0Ass_{wt}\ {}^0Build\ {}^0 2020^{Time}]]$$

$$else\ fail]$$

Dynamic activities – frequency

- The method of analysis also takes account of the *frequency* of the activity to be executed in the reference time interval *In-Time*.
- The general analytic schema for sentences *S* in past tenses is this.

$$\lambda w \lambda t\ [{}^0Past_t\ [{}^0Frequency_w\ S]\ {}^0In\text{-}Time] =$$

$$\lambda w \lambda t\ \mathit{If}\ [{}^0In\text{-}Time \leq_\tau t]\ \mathit{then}\ [[{}^0Frequency_w\ S]\ {}^0In\text{-}Time]\ \mathit{else\ fail}$$

  - $\leq_\tau$ means that the reference interval *In_Time*/($o\tau$) comes before time *t*, or, in general, in a proper relation with respect to time *t*.
  - *Past, Future* / $((o(o(o\tau))(o\tau))\tau)$;
  - *S* is the proposition to be evaluated;
  - *Frequency* / $((o(o\tau))o_{\tau\omega}\omega)$ is the frequency of time intervals in which the proposition *S* takes the truth-value **T** in world *w.*

Dynamic activities – frequency

John often built houses in Bali in 2007

$$\lambda w \lambda t\ [{}^0Past_t\ [{}^0Often_w\ \lambda w \lambda t\ [[{}^0Do_{wt}\ {}^0John\ {}^0Build] \wedge$$
$$[{}^0Ass_{wt}\ {}^0Build\ {}^0House^{Pat}] \wedge [{}^0Ass_{wt}\ {}^0Build\ {}^0Bali^{Loc}]]]\ {}^02007]$$

- The frequency modifier *Often* denotes a world-dependent function that takes a proposition $p \rightarrow o_{\tau\omega}$ to the class of those intervals $d \rightarrow (o\tau)$ which are contained in the chronology of p (i.e. $p_w \rightarrow (o\tau)$).
- Letting aside vagueness of the term 'often', be it three or five times a year, if these intervals are frequent in 2007, the proposition is evaluated to **T**.

Thank you for your attention

If questions

then answers ☺

else fail