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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
- *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, *factive verbs,* etc.

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)

Tichy's TIL vs. Montague's IL

Tichý's TIL and Montague style semantics have has some features in common; TIL nevertheless deviates in four relevant respects from the version of λ-calculus made popular by Montague's Intensional Logic.

1. *First*, and most importantly, TIL comes with *procedural semantics;*

meanings are *not identified* with (or modelled as) mappings from world/time pairs.

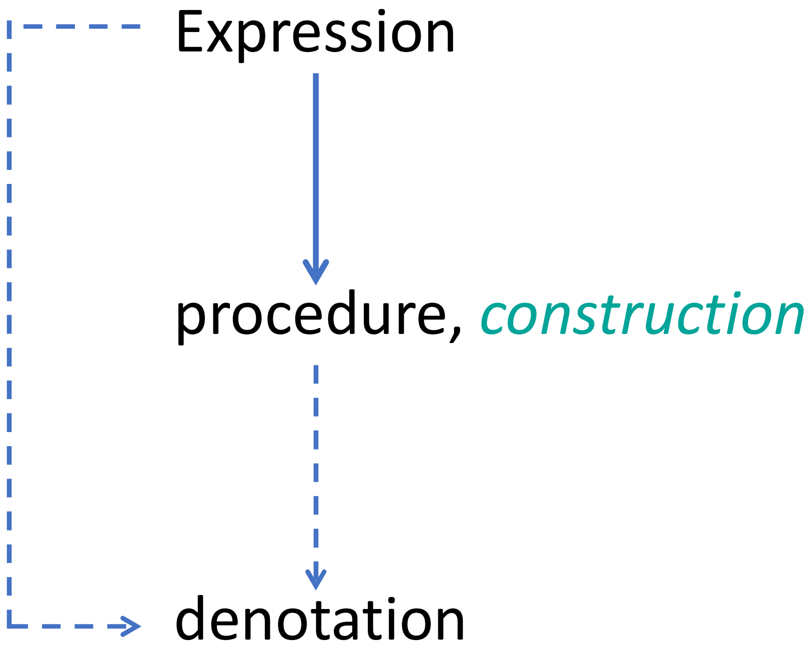
- Montague-like meanings (i.e. mappings) are the products of our meaning *procedures* (TIL constructions).
- We assent to the tenet of *structured meanings*, as procedures are algorithmically structured, unlike set-theoretical mappings; there is no trace of the meaning structure in such a mapping.
- Thus, while Montague's system is an *intensional* logic operating on functions and their values, TIL is a *hyperintensional* logic operating on constructions of functions, functions, and their values.
- As a result, in TIL we deal with *three kinds of context*,
  - hyperintensional level of procedures
  - intensional level of set-theoretic functions
  - extensional level of the functional values.

This distinction is important for a correct typing and valid substitutions. And, hyperintensionality is necessary for a plausible analysis of natural language.

Tichy’s TIL vs. Montague’s IL

2. *explicit intensionalisation* and *temporalisation*. Whereas Montague’s IL combines worlds and times, TIL treats worlds and times as two distinct ground types, which enables separate variables ranging over these two different types.
   - We need this feature because, for instance, we need to differentiate between several degrees of necessity;
3. in TIL, *variables* are not linguistic items. The term ‘*y*’ encodes an atomic procedure as its meaning and picks out the entity that an assignment function has assigned to *y* as its value. Furthermore, our variables can themselves occur as products of procedures placed higher up. It is essential in what follows, in particular for operations into hyperintensional contexts.
4. our λ-calculus is an inherently interpreted formal language, which serves as a device to directly denote (talk about) procedures; TIL λ-terms denote TIL constructions, i.e. meaning *procedures*.
   - Meaning procedures are studied through their structure and constituents as encoded in the λ-calculus of TIL in virtue of the isomorphism between formulae and the procedures.

TIL semantic schema



Stratified ontology of TIL: ramified hierarchy of types

Constructions

- ***Variables*** $x, y, p, w, t, \ldots$ v-construct
- ***Trivialization*** ^{0}C 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*** $[\lambda x_1 \ldots x_n\ X] \rightarrow (\beta\ \alpha_1 \ldots \alpha_n)$, where $x_1 : \alpha_1$, $x_n : \alpha_n$, $X : \beta$
- ***Composition*** $[F\ X_1 \ldots X_n] \rightarrow \beta$, where $F : (\beta\ \alpha_1 \ldots \alpha_n)$, $X_1 : \alpha_1$, $X_n : \alpha_n$
- *Execution* ^{1}X, ***Double Execution*** ^{2}X

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)

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*.

$$\lambda w \lambda t\ [{}^0 Computes_{wt}\ {}^0 Tom\ {}^0[{}^0 Cotg\ {}^0\pi]]$$

- 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: ${}^{20}C = C$
- *C* occurs *displayed* in *D* iff *C* occurs within the scope of Trivialization the effect of which is not cancelled by Double Execution

${}^0[\ldots C \ldots] \rightarrow C$ is a displayed object;

${}^2[\ \ldots {}^0[\ldots C \ldots]\ldots] \rightarrow C$ 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 ⊢ *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?***

Extensional logic of hyperintensions

- The same (extensional) logical rules are valid in all kinds of context;
  - Leibniz's substitution of identicals, existential quantification even *into* hyperintensional contexts, …
- Only the types of objects these rules are applicable at differ according to a context
- *Application of the rules of a calculus is non-problematic when working with constituents, i.e. procedures that occur executed*
- For instance, we can easily quantify even *over a displayed procedure* using as a constituent Trivialization of that procedure

$$\frac{\text{Tom is seeking an abominable snowman (but not Yeti)}}{\text{Tom is seeking something}}$$

$$\frac{\lambda w \lambda t\ [{}^0Seek_{wt}\ {}^0Tom\ {}^0[{}^0Abominable\ {}^0Snowman]]}{\lambda w \lambda t\ [{}^0\exists \lambda c\ [{}^0Seek_{wt}\ {}^0Tom\ c]]}$$

$c \rightarrow *_n$

Abominable/$((o\iota)_{\tau\omega}(o\iota)_{\tau\omega})$: property modifier

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

and so on …

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

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

The technique of answering Wh-questions

is derived like this.

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

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

The technique of answering Wh-questions

"The dean regrets that John doesn't know that *he* (the dean) is sick."

"The dean is Mr Lee"

$$\lambda w \lambda t\ [{}^0Regret_{wt}\ {}^0Dean_{wt}\ {}^0[\lambda w \lambda t\ \neg[{}^0Know_{wt}\ {}^0John\ [{}^0Sub\ [{}^0Tr\ {}^0Dean_{wt}]\ {}^0he\ {}^0[\lambda w \lambda t\ [{}^0Sick_{wt}\ he]]]]]]$$

$$\lambda w \lambda t\ [{}^0{=}\ {}^0Dean_{wt}\ {}^0Lee]$$

- *Regret*, *Know*/$(o\iota *_n)_{\tau\omega}$: hyperintensional factive attitudes; *Dean*/$\iota_{\tau\omega}$: the office; *Tom*/ι; *Sick*/$(o\iota)_{\tau\omega}$; *he* $\rightarrow \iota$: anaphoric variable.
- "Who is sick?", "How is the dean?" or "What doesn't John know?".

(Q1) $\lambda w \lambda t\ [{}^0Sick_{wt}\ who]$

(Q2) $\lambda w \lambda t\ [how_{wt}\ {}^0Dean_{wt}]$

(Q3) $\lambda w \lambda t\ \neg[{}^0Know_{wt}\ {}^0John\ what]$

- Additional types. *who* $\rightarrow \iota$; *how* $\rightarrow (o\iota)_{\tau\omega}$; *what* $\rightarrow *_n$

The technique of answering Wh-questions

- the application of the rules rooted in the rich semantics of natural-language
- dealing with a hyperintensional context.

Factive rules; $a \rightarrow \iota$, $c \rightarrow *_n$, ${}^2c \rightarrow o_{\tau\omega}$.

$$[{}^0K_{wt}\ a\ c] \vdash {}^2c_{wt} \quad \neg[{}^0K_{wt}\ a\ c] \vdash {}^2c_{wt}$$

1. $[{}^0Regret_{wt}\ {}^0Dean_{wt}\ {}^0[\lambda w\lambda t\ \neg[{}^0Know_{wt}\ {}^0John\ [{}^0Sub\ [{}^0Tr\ {}^0Dean_{wt}]\ {}^0he\ {}^0[\lambda w\lambda t\ [{}^0Sick_{wt}\ he]]]]]]$ — $\varnothing$
2. ${}^{20}[\lambda w\lambda t\ \neg[{}^0Know_{wt}\ {}^0John\ [{}^0Sub\ [{}^0Tr\ {}^0Dean_{wt}]\ {}^0he\ {}^0[\lambda w\lambda t\ [{}^0Sick_{wt}\ he]]]]]_{wt}$ — 1, F1
3. $[\lambda w\lambda t\ \neg[{}^0Know_{wt}\ {}^0John\ [{}^0Sub\ [{}^0Tr\ {}^0Dean_{wt}]\ {}^0he\ {}^0[\lambda w\lambda t\ [{}^0Sick_{wt}\ he]]]]]_{wt}$ — 2, ^{20}E
4. $\neg[{}^0Know_{wt}\ {}^0John\ [{}^0Sub\ [{}^0Tr\ {}^0Dean_{wt}]\ {}^0he\ {}^0[\lambda w\lambda t\ [{}^0Sick_{wt}\ he]]]]$ — 3, β-red.
5. ${}^2[{}^0Sub\ [{}^0Tr\ {}^0Dean_{wt}]\ {}^0he\ {}^0[\lambda w\lambda t\ [{}^0Sick_{wt}\ he]]]_{wt}$ — 4, F2
6. $[{}^0{=}\ {}^0Dean_{wt}\ {}^0Lee]$ — $\varnothing$
7. ${}^{20}[\lambda w\lambda t\ [{}^0Sick_{wt}\ {}^0Lee]]]_{wt}$ — 5,6, *Sub, Tr*
8. $[\lambda w\lambda t\ [{}^0Sick_{wt}\ {}^0Lee]]]_{wt}$ — 7, ^{20}E
9. $[{}^0Sick_{wt}\ {}^0Lee]$ — 8, β-red.

The technique of answering Wh-questions

10.	$[{}^{0}Sick_{wt}\ who]$	**Q1**
11.	$who = {}^{0}Dean_{wt}$	9,10 unif.
12.	$[how_{wt}\ {}^{0}Dean_{wt}]$	**Q2**
13.	$how = {}^{0}Sick_{wt}$	6,9 unif.
14.	$\neg[{}^{0}Know_{wt}\ {}^{0}John\ what]$	**Q3**
15.	$what = [{}^{0}Sub\ [{}^{0}Tr\ {}^{0}Dean_{wt}]\ {}^{0}he\ {}^{0}[\lambda w \lambda t\ [{}^{0}Sick_{wt}\ he]]]$	4,14 unif.
16.	$what = {}^{0}[\lambda w \lambda t\ [{}^{0}Sick_{wt}\ {}^{0}Lee]]$	6,15, *Sub*, *Tr*

- We derived the direct answers to the three questions as follows. “Who is sick?”: the dean; “How is the dean?”: sick; “What does John not know?”: that Lee, i.e., the dean is sick.

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 $X_1^{kind\text{-}1}, \ldots, X_n^{kind\text{-}n}$

$$\lambda w \lambda t\ [[{}^0Do_{wt}\, A\ P] \wedge$$

$$[{}^0Asgn_{wt}\ P\ {}^0X_1^{kind\text{-}1}] \wedge [{}^0Asgn_{wt}\ P\ {}^0X_2^{kind\text{-}2}] \wedge \ldots \wedge [{}^0Asgn_{wt}\ P\ {}^0X_n^{kind\text{-}n}]]$$

- *"John builds a house in Bali"*

$$\lambda w \lambda t\ [[{}^0Do_{wt}\ {}^0John\ {}^0Build] \wedge$$

$$[{}^0Asgn_{wt}\ {}^0Build\ {}^0House^{Pat}] \wedge [{}^0Asgn_{wt}\ {}^0Build\ {}^0Bali^{Loc}]]$$

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

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

Dynamic activities – in past or future

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

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

- 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)*

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

- *two-phase instruction* → Double Execution

1. *Checking whether P is true; if so, then the procedure C is selected, otherwise no truth value*
2. *Execution of 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.*

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

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

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

$$\mathit{else\ fail}]$$

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.

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

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

  - $\leq_\tau$ 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

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

- 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**.

references

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Thank you for your attention

If questions

then answers

else fail