# A COMPUTATIONAL SEMANTICS FOR NOMINALIZATIONS

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## 1. Structure of the talk

(1) Formal methods
- Event calculus
- Feferman theories
- Integrity constraints

(2) Applications
- Vendler's data
- Denotationtypes
- Intermezzo: Hierarchical planning
- Lexical meaning

(3) DRT and logic programming

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## References

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## 2. FORMAL METHODS

2.1. **Event calculus.** EC formalises two types of change
• momentanous change
• continous change

• Ontology: eventtypes, fluents (time-dependent properties, such as activities), real numbers, individuals.

• Primitive predicates 1:
- *Initially*$(f)$
- *Happens*$(e, t)$
- *Initiates*$(e, f, t)$
- *Terminates*$(e, f, t)$

• Primitive predicates 2: changing partial objects
- *Releases*$(e, f, t)$
- *Trajectory*$(f_1, t, f_2, d)$

• Primitive predicates 3: no $f$-relevant events between $t_1$ and $t_2$
- *Clipped*$(t_1, f, t_2)$

• Primitive predicates 4: truth predicate
- $HoldsAt(f, t)$

**Axiom 1.** *Initially*$(f) \ \rightarrow \ HoldsAt(f, 0)$

**Axiom 2.** *HoldsAt*$(f, r) \wedge r < t \wedge$
$\neg \exists s < r HoldsAt(f, s) \ \wedge \neg$*Clipped*$(r, f, t) \rightarrow$ *HoldsAt*$(f, t)$

**Axiom 3.** *Happens*$(e, t) \wedge$ *Initiates*$(e, f, t) \wedge$
$t < t' \ \wedge \neg$*Clipped*$(t, f, t') \rightarrow$ *HoldsAt*$(f, t')$

**Axiom 4.** *Happens*$(e, t) \wedge$ *Initiates*$(e, f_1, t) \wedge$
$t < t' \ \wedge \ t' = t + d \ \wedge$ *Trajectory*$(f_1, t, f_2, d) \wedge \neg$*Clipped*$(t, f_1, t') \rightarrow$ *HoldsAt*$(f_2, t')$

**Axiom 5.** *Happens*$(e, s) \ \wedge \ t < s < t' \wedge$
$($*Terminates*$(e, f, s) \ \vee$ *Releases*$(e, f, s)) \ \rightarrow$ *Clipped*$(t, f, t')$

## Scenarios

**Definition 1.** *A* state $S(t)$ *at time* $t$ *is a first order formula built from*

*(1) literals of the form* $(\neg)$*HoldsAt*$(f, t)$*, for* $t$ *fixed and possibly different* $f$*.*
*(2) equalities between fluent terms, and between event terms.*
*(3) formulae in the language of the structure* $(\mathbb{R}, <; +, \times, 0, 1)$

**Definition 2.** *A* scenario *is a conjunction of statements of the form*

*(1) Initially*$(f)$*,*
*(2)* $S(t)$ $\rightarrow$ *Initiates*$(e, f, t)$*,*
*(3)* $S(t)$ $\rightarrow$ *Terminates*$(e, f, t)$*,*
*(4)* $S(t)$ $\rightarrow$ *Happens*$(e, t)$*,*
*(5)* $S(t)$ $\rightarrow$ *Releases*$(e, f, t)$*,*
*(6)* $S(f_1, f_2, t, d)$ $\rightarrow$ $Trajectory(f_1, t, f_2, d)$*.*

*where* $S(t)$ *(more generally* $S(f_1, f_2, t, d)$*) is a state in the sense of definition 3*

(1) Carlos is building a house.

(1) *Initially*(*house*($a$))
(2) *Initiates*(*start*, *build*, $t$)
(3) *Initiates*(*finish*, *house*($c$), $t$)
(4) *Terminates*(*finish*, *build*, $t$)
(5) *HoldsAt*(*build*, $t$) $\wedge$ *HoldsAt*(*house*($c$), $t$) $\rightarrow$ *Happens*(*finish*, $t$)
(6) *Releases*(*start*, *house(x)*, $t$)
(7) *HoldsAt*(*house*($x$), $t$) $\rightarrow$
*Trajectory*(*build*, $t$, *house*($x + g(d)$), $d$)

## 2.2. **Minimal models and non–monotonicity.**

A consequence relation $\models$ is *nonmonotonic* if
$\psi \models \varphi$ does not imply $\psi, \theta \models \varphi$.

In nonmonotonic reasoning, people construct a *minimal model* of the premisses (which is often unique); in monotonic reasoning, they must consider *all* models of the premisses.

(2) 95%

a. If she has an essay to write she will study late i the library.
b. She has an essay to write.
c. She will study late in the library.

(3) MP 38%

a. If she has an essay to write she will study late in the library.
b. If the library stays open then she will study late in the library.
c. She has an essay to write.
d. She will study late in the library.

(4) 90 %

a. If she has an essay to write she will study late in the library.
b. If she has some textbooks to read, she will study late in the library.
c. She has an essay to write.
d. She will study late in the library.

Constraint logic programming: interplay of two languages.

First Language $\mathcal{L}$: Let $\mathcal{L}$ be the language of the structure $(I\!R, 0, 1, +, \cdot, <)$, $\mathcal{T}$ the complete theory of $(I\!R, 0, 1, +, \cdot, <)$ in $\mathcal{L}$

Constraints: first order formulas from $\mathcal{L}$

Let $\mathcal{K}$ be another language, consisting of programmed predicate symbols.

Constraint programming language $CLP(\mathcal{T})$ consists of constraints and formulas from $\mathcal{K}$, whose terms come from $\mathcal{L}$.

**Normal programs**

**Definition 3.** *A complex subgoal is characterised recursively as*

*(1) an atom in* $\mathcal{K}$*, or*

*(2)* $\neg\exists\overline{x}(B_1\wedge\ldots B_m\wedge c)$*, where* $c$ *is a constraint and each* $B_i$ *is a complex subgoal.*

complex body *is a conjunction of complex subgoals.*

*A normal program* is a finite set of formulas of the form $\psi \rightarrow A$ of $CLP(\mathcal{T})$ such that $\psi$ is a complex body and $A$ is a predicate from $\mathcal{K}$.

**The completion of a program**

**Definition 4.** *Let $\mathcal{P}$ be a normal program, consisting of clauses*

$$\overline{B}^1 \wedge c_1 \rightarrow p^1(\bar{t}^1), \ldots, \overline{B}^n \wedge c_n \rightarrow p^n(\bar{t}^n),$$

*where the $p^i$ are atoms. The completion of $\mathcal{P}$, denoted by comp($\mathcal{P}$), is computed by the following recipe:*

*(1) choose a predicate $p$ that occurs in the head of a clause of $\mathcal{P}$*
*(2) choose a sequence of new variables $\overline{x}$ of length the arity of $p$*
*(3) replace in the $i$-th clause of $\mathcal{P}$ all occurrences of a term in $\bar{t}_i$ by a corresponding variable in $\overline{x}$ and add the conjunct $\overline{x} = \bar{t}_i$ to the body; we thus obtain $\overline{B}^i \wedge c_i \wedge \overline{x} = \bar{t}_i \rightarrow p^i(\overline{x})$*
*(4) for each $i$, let $\overline{z}_i$ be the set of free variables in $\overline{B}^i \wedge c_i \wedge \overline{x} = \bar{t}_i$ not in $\overline{x}$*
*(5) given $p$, let $n_1, \ldots, n_k$ enumerate the clauses in which $p$ occurs as head*
*(6) define Def$(p)$ to be the formula*

$$\forall \overline{x}(p(\overline{x}) \leftrightarrow$$

$$\exists \overline{z}_{n_1}(\overline{B}^{n_1} \wedge c_{n_1} \wedge \overline{x} = \bar{t}_{n_1}) \vee \ldots \vee \exists \overline{z}_{n_k}(\overline{B}^{n_k} \wedge c_{n_k} \wedge \overline{x} = \bar{t}_{n_k}).$$

*(7) comp($\mathcal{P}$) is then obtained as the formula $\bigwedge_p Def(p)$, where the conjunction ranges over predicates $p$ occurring in the head of a clause of $\mathcal{P}$.*

**Definition 5.** *A partial interpretation $I$ is a function which maps ground atoms (in $\mathcal{P}$) to $\{\mathbf{t}, \mathbf{f}, \mathbf{u}\}$, and constraints to $\{\mathbf{t}, \mathbf{f}\}$*

**Definition 6.** *Given a normal program $\mathcal{P}$, a real-closed field $\mathcal{A}$, a partial interpretation $I$ and a ground atom $A$, the (immediate)* consequence operator $\Phi_{\mathcal{P}}$ *is defined as*

*(1)* $\Phi_{\mathcal{P}}(I)(A) = \mathbf{t}$ *if there exists a clause $\overline{B} \wedge c \rightarrow p(\overline{s})$ in $\mathcal{P}$ and an assignment $\alpha$ into $\mathcal{A}$ such that $A = p(\overline{s})\alpha$ and $I(c\alpha) = I(B\alpha) = \mathbf{t}$.*

*(2)* $\Phi_{\mathcal{P}}(I)(A) = \mathbf{f}$ *if for each clause in $\mathcal{P}$ of the form $\overline{B} \wedge c \rightarrow p(\overline{s})$ and each assignment $\alpha$ into $\mathcal{A}$ such that $A = p(\overline{s})\alpha$: $I(c\alpha) = \mathbf{f}$ or $I(B\alpha) = \mathbf{f}$.*

## Soundness and completeness

**Theorem 1.** *Let $\mathcal{T}$ be the theory of real-closed fields, $\mathcal{P}$ a normal program, $?c, G$ a query.*

*(1)* $?c, G$ *succeeds iff*

$$\mathcal{T} \wedge comp(\mathcal{P}) \models_3 \overline{\forall}(c \rightarrow G)$$

*(2)* $?c, G$ *fails finitely iff*

$$\mathcal{T} \wedge comp(\mathcal{P}) \models_3 \neg\overline{\exists}(c \wedge G).$$

*Here, $\overline{\forall}$($\overline{\exists}$) denotes universal (existential) closure.*

(1) *Initially*(*height*(0))
(2) *Happens*(*tap–on*,5)
(3) *Initiates*(*tap–on*,*filling*,$t$)
(4) *Terminates*(*overflow*,*filling*,$t$)
(5) $x < 10 \rightarrow$ *Releases*(*tap-on*, *height*($x$), $t$)
(6) *HoldsAt*(*height*(10),$t$)$\wedge$*HoldsAt*(*filling*,$t$) $\rightarrow$
*Happens*(*overflow*,$t$).
(7) *HoldsAt*(*height*($x$),$t$) $\rightarrow$
*Trajectory*(*filling*,$t$,*height*($x+d$),$d$)

(5) $$(x = tap - on \wedge y = 5) \rightarrow Happens(x, y)$$

(6) $$(HoldsAt(height(10), t) \wedge HoldsAt(filling, t) \wedge x = overflow \ \wedge \ y = t) \rightarrow Happens(x, y)$$

(7) $$\forall x \forall y[Happens(x, y) \leftrightarrow (x = tap - on \wedge y = 5) \vee (HoldsAt(height(10), t) \wedge HoldsAt(filling, t) \wedge x = overflow \ \wedge \ y = t)]$$

2.3. **Feferman theories.** $S$ is conservative over $S_0$ iff for all $\phi$ in $L(S_0)$:

$$S \vdash \phi \Leftrightarrow S_0 \vdash \phi$$

**Definition 7.** *Let $L$ be some extension of $L_0$ (e.g. by means of a truth predicate). Then we may code formulas of $L$ as terms in $L_0$. We write $\ulcorner \varphi \urcorner$ for the Gödel number in $L_0$ of $\varphi$ in $L$. This notation will be used interchangeably both for the term in $L_0$ and for the object denoted by that term in a model $M_0$.*

**Definition 8.** $\Delta_n \quad \varphi[\hat{x}_1, \ldots, \hat{x}_n, y_1, \ldots, y_m] = (\ulcorner \varphi \urcorner, y_1, \ldots, y_m)$.

**Axiom 6.** $(T_n A)$ $T_n(x_1, \ldots, x_n, \phi[\hat{u}_1, \ldots, \hat{u}_n, y_1, \ldots, y_m]) \leftrightarrow \phi(x_1, \ldots, x_n, y_1, \ldots, y_m)$

$T_0(\ulcorner \phi \urcorner) \leftrightarrow \phi$

**Theorem 2.** *Let S be a consistent system in the sense that S has a model. Then there exists an extension S' with truth axioms which is conservative over S.*

## Application

- 'Event' is derived notion, via nominalisation in the Feferman calculus
- Hence no event-variables in basic language, but time-variables

**Definition 9.** *If $\varphi(t, \overline{x})$ is a formula, the eventtype generated by $\varphi$ will be $\exists t.\varphi[t, \overline{x}]$.*

**Definition 10.** *If $\varphi(t, \overline{x})$ is a formula, the fluent generated by $\varphi(t, \overline{x})$ is the term $\varphi[\hat{t}, \overline{x}]$.*

Two possibilities to construct terms from predicate $burn(x, y, t)$:

1. Event types: John's burning of the house

$\exists t.burn[j, h, t]$

2. Fluents: John's burning the house

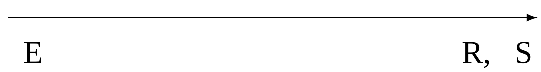
$burn[j, h, \hat{t}]$

$HoldsAt = T_1$

$HoldsAt(burn[j, h, \hat{t}], s) \leftrightarrow burn(j, h, s)$

### 2.4. **Integrity constraints.**

(8) I have caught a flu.

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(9) *Initiates*$(e, f, t)$

(10) *HoldsAt*$(f$,*now*).

$$t < \textit{now}, \textit{Happens}(e, t)$$

$$\text{Happens(e, t)} \wedge \text{Initiates(e, f, t)} \wedge \text{t} < \text{t'} \wedge \neg \text{Clipped(t, f, t')} \leftrightarrow \text{HoldsAt(f, t')}$$

$$[\text{Happens(e, t)} \wedge \text{Initiates(e, f, t)} \wedge \text{t} < \text{t'} \wedge \neg \text{Clipped(t, f, t')}] \vee (\text{now} = \text{t'}) \leftrightarrow \text{HoldsAt(f, t')}$$

• We view a sentence S as a goal ('make S true') to be achieved by updating the discourse model.

(11) I have caught the flu.

$Initiates(\mathrm{e}, \mathrm{f}, \mathrm{t})$

**Axiom 7.** *Happens*$(e, t) \wedge$ *Initiates*$(e, f, t) \ \wedge t < t^{'} \ \wedge \neg$*Clipped*$(t, f, t^{'}) \rightarrow$ *HoldsAt*$(f, t^{'})$

$Happens(\mathrm{e}, \mathrm{t}), \mathrm{t} < now$.

$?HoldsAt(\mathrm{f}, now)$ succeeds.

## 3. APPLICATIONS

### 3.1. **Vendler's data.**

(12)
a. The beautiful singing of the aria surprised us.
b. John's not revealing the secret is unlikely.
c. The singing of the song is fun.
d. John's quickly cooking the dinner surprised us.
e. They were surprised by the sudden coming in of a stranger.
f. They were surprised by a stranger coming in suddenly.
g. (Google) The band's playing of the song is improving and there is some very interesting playing in thirds that we could never quite work out.

(13)
a. *The soprano's singing the aria was slow.
b. The soprano's singing of the aria was slow.
c. John's revealing of the secret occurred at midnight.
d. *John's revealing the secret occurred at midnight.
e. *John's not revealing the secret occurred at midnight.
f. (Google) The video and the band's playing of the school's alma mater [*sic*] capped the evening.
g. (Google) Clearly the Passover slaying of Egypt's firstborn occurred at midnight on the $15^{th}$ of Nisan.
h. (Google) The contract provides that *the* transfer of the assets and *undertaking of the business* is deemed to have occurred at midnight on 31 August.
i. The physician's revealing of the secret took place yesterday.
j. *The physician's revealing the secret took place yesterday.

### 3.2. Coercion.

(14) a. The physician's revealing of the secret is impossible.
b. The physician's revealing of the secret took place yesterday.

(15) a. The president's revealing of a state secret was a surprise.
b. That the president revealed a state secret was a surprise.

### 3.3. Intensionality.

(16) a. The beheading of the most famous spy took place yesterday.
b. The beheading of James Bond took place yesterday.

(17) a. The beheading of the most famous spy surprised us.
b. The beheading of James Bond surprised us.

### 3.4. Negation of containers.

(18) a. The singing of the song didn't occur at noon.
b. (Google) The End of the World didn't occur at midnight, December 31 1999.
c. *John's kicking the cat didn't occur at noon.

## 3.5. **Perfect nominals.**

(19) a. The singing of the song
b. The saving of us (Stevenson)
c. (Google) Deidre Haren begins the play with her beautiful singing of ‘A Poultry Tale’
d. stunningly beautiful singing of Cenerentola.
e. (Google) the Passover slaying of Egypt’s firstborn
f. *the Passover slaying Egypt’s firstborn
g. On account of his deliberate buying up of stocks
h. *quickly cooking of the dinner.
i. *having cooked of the dinner.
j. *being able to cook of the dinner.
k. *not revealing of the secret.
l. (Google) It may be more difficult to imagine the aria’s place in the drama or story of the whole opera when listening to *a recording of just that aria*.

## 3.6. **Imperfect nominals.**

(20) a. *The singing the song.
b. *beautiful singing the song.
c. (Google) He also plays Johnny Seoighe after *singing the song beautifully*.
d. quickly cooking the dinner.
e. On account of deliberately buying up stocks
f. (Google) Mordechai Vannunu has spent the best part of the last fifteen years in solitary confinement in a cell in the desert for *having revealed the ‘secret’* of Israel’s ‘Jericho’ missiles.
g. (Google) Lisa gets Martin tucked into bed. Martin tells her he is sorry for *not being able to cook the dinner* he had planned for her.
h. (Google) ... *not revealing the secret* when you use it in any transform is a rather fundamental and well-known principle [in cryptography].

### 3.7. **Possessives.**

(21) a. John's house
b. The house of John
c. John's singing the song
d. *The singing the song of (by) John

(22) a. He shocked us by (his) telling a dirty joke.
b. He entertained us by *(his) singing of arias. (50)

(23) He insists on no one/*no one's knowing about the experiment.

(24) a. They objected to Tom*('s) getting nothing and John*('s) everything.
b. We speak of good people*('s) going to heaven, and wicked people*('s) to the Devil. (Defoe)

### 3.8. **Negation of nominals.**

(25) a. The arrival of the train surprised us.
b. The non-arrival of the train surprised us.
c. The arrival of the train occurred at noon.
d. *The non-arrival of the train occurred at noon.
e. The unexpected non-arrival of the train
f. *The non-arrival of the train unexpectedly

(26) a. Second, there was no directive to report *the non–arrival of a combatant ship* [from a story about USS *Indianapolis*, torpedoed by a Japanese submarine]
b. The non–departure of a boat or plane.

(27) a. Andrew's not stopping for the traffic light.
b. “Vehicles not stopping for pedestrians in crosswalks is the number one complaint we receive regarding traffic safety" said Lieutenant Mark Gover.

(28) ?Andrew's not stopping for the traffic light took place at noon.

### 3.9. **Nominals and determiners.**

(29) a. *his leaving her that you predicted.
b. his revealing of the secret that you predicted.

### 3.10. **Pluralized nominals.**

(30) a. He ignored the sayings and doings of the ladies of his family.
b. blessings of the children.
c. *blessings the children.

### 3.11. **Ellipsis.**

(31) a. *John's fixing the sink was surprising, and Bill's was more so.
b. John's fixing of the sink was skillful, and Bill's was more so.

(32) a. John's fixing of the sink was skillful, and Bill's was more so.
b. *John's fixing of the sink was surprising, and Bill's was more so.

(33) a. *John's fixing the sink was skillful.
b. John's fixing the sink was surprising.

### 3.12. **Iterated nominalization.**

(34) a. John's supporting his son's not going to church
b. John's improving his singing
c. John's watching the dog's playing
d. My discovering her not leaving
e. his discussion of John's revealing the secret

(35) a. . . . the speeding up of the building of the houses . . .
b. . . . speeding up the building of new ontologies . . .
c. This was the first I knew of *his objecting to my going to Nashville*.

### 3.13. **Denotation types.**

| | |
|---|---|
| Perfect nominal | set of event types |
| Imperfect nominal | fluent |
| Narrow container | set of event tokens; i.e. a subset of $Happens$ |
| Wide container | set of fluents |
| Binary determiner | Relations between eventtypes and eventtokens |

(36) a. Your breaking the record was a surprise.
b. *Your breaking the record took place at ten.

$$Happens(break[x, record, \hat{t}], t)$$

### 3.14. **Determiners.**

(37) (During the morning rehearsals,) every singing of ‘A Poultry Tale’ lasted five minutes.

$\exists x \approx ?(A(x), B(x)$ ’$\forall x \approx ?A(x), \neg B(x)$ fails’

(38) *Every singing ‘A Poultry Tale’

$$u < s \leq v \;\leftrightarrow\; Happens(e, s).$$

**Definition 11.** *Let $u, v$ be terms defining real numbers. The interval $(u, v]$ is an event token of the event type $e$ if*

*(1)* $u < s \leq v \;\rightarrow\; Happens(e, s)$

*(2) for all terms $t$ with $t > v$, the query $?u < s < t,\ \neg Happens(e, s)$ succeeds; and similarly for terms $t$ with $t \leq u$.*

*If $(u, v]$ is an event token of the event type $e$, we also write $Happens(e, (u, v])$.*

Abbreviate $\exists t.sing[x, p, t]$ to $e(x)$.

$$?Happens(e(x), (u, v]),\ v < now,\ v - u \neq 5min \text{ fails.}$$

### 3.15. **Coercion of nominals, and the role of tense.**

(39) The collapse of the Germans is unlikely.

(40) That the Germans will collapse is unlikely.

(41) That the Germans collapsed is unlikely.

**Definition 12.** *Let $e$ be an event type, then there exists a canonical fluent $f$ associated to $e$ defined by $f = Happens[e, \hat{t}]$. We will refer to this fluent as* that*($e$). We also define tensed variants of that($e$) as follows*

*(1)* $\text{that}_{Pa}$*($e$)* = $(Happens(e,t) \wedge t < R)[\hat{R}]$

*(2)* $\text{that}_{Fu}$*($e$)* = $(Happens(e,t) \wedge t > R)[\hat{R}]$

*Observe that*

$$HoldsAt(that_{Pa}(e), now) \text{ iff } ?Happens(e,t), t < now \text{ succeeds},$$

*so that the complementizer translates an integrity constraint into a sentence, as it should.*

$$?HoldsAt(unlikely(e),\ now) \text{ succeeds}.$$

$$?Happens(e,t), t > now \text{ succeeds}.$$

$$?HoldsAt(unlikely(that_{Fu}(e)), now) \text{ succeeds}.$$

$$?HoldsAt(unlikely(that_{Pa}(e)), now) \text{ succeeds}.$$

$$HoldsAt(surprise(g), s) \ \rightarrow \ HoldsAt(g, s).$$

(42) The beheading of the king surprised us.

$$?HoldsAt(surprise(that_{Pa}(e)), t), t < now \text{ succeeds},$$

### 3.16. **Intensionality of nominals.**

(43) The beheading of the tallest spy occurred at noon.

(44) The beheading of the king occurred at noon.

(45) Mary predicted the beheading of the tallest spy.

(46) Mary predicted the beheading of the king.

$$?HoldsAt(predict(that_{Fu}(e(s))), t), t < now \text{ succeeds},$$

$$?HoldsAt(predict(that_{Fu}(e(k))), t), t < now \text{ succeeds}.$$

$$?Happens(e(s),\ t),\ noon(t), t < now \text{ succeeds}$$

$$?Happens(e(k),\ t),\ noon(t), t < now \text{ succeeds}.$$

### 3.17. **Present perfect in imperfect nominals.**

(47) He admits *having revealed the secret*.

(48) He has revealed the secret.

(49) He admits that he has revealed the secret.

$Initiates(e, f, t)$

$$?HoldsAt(f, now) \text{ succeeds.}$$

$that_{PP}(f) \ = \ HoldsAt[f, \hat{R}]$

$$?HoldsAt(admit(that_{PP}(f)), now) \text{ succeeds.}$$

$$HoldsAt(admit(g), s) \ \rightarrow \ HoldsAt(g, s).$$

3.18. **Negation.**

(50) John saw Mary not smoke.

(1) $$\neg Happens(e, s) \; \rightarrow \; Happens(\sim e, s),$$

(2) $$\neg Happens(e, t) \; \leftrightarrow \; Happens(\sim e, t).$$

**Definition 13.** *The* fluent negation $\approx e$ *of an event type* $e$ *is defined by* $\approx e := \neg Happens[e, \hat{t}] = \neg that(e) = that(\approx e)$.

$$\neg HoldsAt(f_2(c), t) \ \wedge \ HoldsAt(time_{f_1}(a), t) \ \rightarrow \ Happens(\sim e, t).$$

(51)
a. The non–arrival of USS *Indianapolis* at Leyte caused consternation.
b. *The non–arrival of USS *Indianapolis* at Leyte unexpectedly ...
c. The unexpected non–arrival of USS *Indianapolis* at Leyte caused consternation.
d. The fact that USS *Indianapolis* did not arrive at Leyte caused consternation.
e. USS *Indianapolis'* not arriving at Leyte caused consternation.
f. USS *Indianapolis'* not arriving at Leyte quickly/?unexpectedly caused consternation.
g. *The non–arrival of USS *Indianapolis* at Leyte occurred at noon, July 31, 1945.
h. Every non-arrival of a ship causes consternation.
i. (Google) Second, there was no directive to report the non–arrival of a combatant ship.

3.19. **Hierarchical planning.**

**Definition 14.** *Suppose a scenario for the fluent* $f$ *is given. In the context of this scenario, the event* $e$ *is interpreted using* $f$ *by* hierarchical planning *if* $Happens(start_f, s) \wedge s < r < t \wedge HoldsAt(f, r) \wedge Happens(finish_f, t) \rightarrow Happens(e, r)$

(52) Carlos built a house.

3.20. **Lexical meaning.**

3.20.1. *Perfect nominals.*

(53) During the morning rehearsals, every singing of 'A Poultry Tale' was interrupted.

(54) *During the morning rehearsals, every singing 'A Poultry Tale' was interrupted.

(55) a. *John's cooking the dinner meticulously was interrupted by a phone call.
b. John's meticulous cooking of the dinner was interrupted by a phone call.

**Definition 15.** *Suppose a scenario for the fluent* $f$ *is given. In the context of this scenario, the event* $e$ *is interpreted using* $f$ *by* hierarchical planning *if* $Happens(start_f, s) \wedge s < r < t \ \wedge \ HoldsAt(f, r) \ \rightarrow \ Happens(e, r)$

$$?Happens(\exists t.sing[x, p, t], \ \ (u, v]), \ Happens(finish_{sing(x)}, v), \ v < now \text{ fails.}$$

3.20.2. *Imperfect nominals.*

(56) Deborah's singing a 'Poultry tale'

$sing[d, p, \hat{t}]$.

$$?HoldsAt(p(y), s),\ HoldsAt(p(y'), t),\ s < t,\ y' < y \text{ fails}.$$

$$HoldsAt(increasing(p), s) \ \rightarrow\ HoldsAt(sing[d, p, \hat{t}], s).$$

## 4. DRT AND LOGIC PROGRAMMING

**Single DRS.**

(57) Max arrived.

(58)

| $m$ | $t$ | $e$ |
|---|---|---|
| $Max(m)$ | $t < n$ | $e \subseteq t$ |
| | $e : arrive(m)$ | |

$$max(\mathrm{x}, \mathrm{t}) \rightsquigarrow max[\mathrm{x}, \hat{\mathrm{s}}]$$
$$arrive(\mathrm{x}, \mathrm{t}) \rightsquigarrow \exists \mathrm{s}.arrive[\mathrm{x}, \mathrm{s}]$$

$?HoldsAt(max[\mathrm{x}, \hat{\mathrm{s}}], \mathrm{t}), Happens(\exists \mathrm{s}.arrive[\mathrm{x}, \mathrm{s}], \mathrm{t}),$ `succeeds`

(59) $?HoldsAt(\mathrm{f}, \mathrm{t}), HoldsAt(max[\mathrm{x}, \hat{\mathrm{s}}], \mathrm{t}), Happens(\exists \mathrm{s}.arrive[\mathrm{x}, \mathrm{s}], \mathrm{t}), \mathrm{t} < now$ `succeeds`
$?HoldsAt(\mathrm{f}, \mathrm{t}), Happens(\exists \mathrm{s}.arrive[\mathrm{x}, \mathrm{s}], \mathrm{t}), \mathrm{t} \geq now$ `fails`

**Merging DRSs.**

(60) A delegate arrived. She registered.

(61)

| $x$ | $t$ | $e$ |
|---|---|---|
| $delegate(x)$ | $t < n$ | $e \subseteq t$ |
| | $e : arrive(x)$ | |

$\mathrm{h}$ context fluent

$\mathrm{f(x)}$ 'delegate($x$)'

$\mathrm{e(x)}$ 'arrive($x$)'

$\mathrm{e'(x)}$ 'register($x$)'

(62) $?HoldsAt(\mathrm{h}, \mathrm{t}), HoldsAt(\mathrm{f(x)}, \mathrm{t}), Happens(\mathrm{e(x)}, \mathrm{t}),$
$\mathrm{t} < now$ succeeds

(63)

| | | |
|---|---|---|
| $y$ | $t$ | $e$ |
| | $t < n$ | $e \subseteq t$ |
| | $e : register(y)$ | |

(64) $?HoldsAt(\mathrm{h}', \mathrm{t}), HoldsAt(\mathrm{s(x)}, \mathrm{t}), Happens(\mathrm{e}'(\mathrm{x}), \mathrm{t}),$
$\mathrm{t} < now$ succeeds

(65) $HoldsAt(\mathrm{h}, \mathrm{t}) \wedge HoldsAt(\mathrm{f(x)}, \mathrm{t}) \wedge Happens(\mathrm{e(x)}, \mathrm{t}) \ \rightarrow \ HoldsAt(\mathrm{h}', \mathrm{t})$

(66) $?HoldsAt(\mathrm{h}, \mathrm{t}), HoldsAt(\mathrm{f(y)}, \mathrm{t}), Happens(\mathrm{e(y)}, \mathrm{t}), HoldsAt(\mathrm{s(x)}, \mathrm{t}),$
$Happens(\mathrm{e}'(\mathrm{x}), \mathrm{t}), t < now$ succeeds

$\mathrm{f} = \mathrm{s},\ \mathrm{x} = \mathrm{y},$

(67) $?HoldsAt(\mathrm{h}, \mathrm{t}), HoldsAt(\mathrm{f(x)}, \mathrm{t}), Happens(\mathrm{e(x)}, \mathrm{t}), Happens(\mathrm{e}'(\mathrm{x}), \mathrm{t}), t <$
$now$ succeeds

(68)

| | | | |
|---|---|---|---|
| $x$ | $t$ | $e$ | $e'$ |
| $delegate(x)$ | $t < n$ | $e \subseteq t$ | $e' \subseteq t$ |
| | $e : arrive(x)$ | $e' : register(x)$ | |

(69) A delegate arrived. His wife arrived somewhat later. She registered (as accompanying person).

**Definition 16.** *Let an argument with premises* $\Gamma$ *and conclusion* $\varphi$ *be given. Suppose* $\Gamma$ *corresponds to the integrity constraint* $?G_0$ `succeeds`*, and* $\varphi$ *corresponds to the integrity constraint* $?G_1$ `succeeds`*. Then* $\varphi$ *follows from* $\Gamma$ *if a substitution satisfying* $?G_0$ *also satisfies* $?G_1$*. Since DRSs can be made to correspond to integrity constraints, the same chracaterization applies to DRSs.*

**Computational incorporation of lexical meaning.**

(70) a. Max rief oft am Montag an.
Max often called on Monday.
b. Am Montag rief Max oft an.
On Monday, Max often called.

(71)

$$\begin{array}{|c|}\hline n \;\; m \;\; t_m \\ t_m < n \\ Montag(t_m) \\ Max(m) \\ \begin{array}{|c|}\hline t^q \\ t^q \subseteq t_m \\ \hline\end{array} \;\; \left\langle \begin{array}{c} oft \\ t^q \end{array} \right\rangle \;\; \begin{array}{|c|}\hline e \\ e : anrufen(m) \\ e \subseteq t_q \\ \hline\end{array} \\ \hline\end{array}$$

(72)

$$\begin{array}{|c|}\hline n \;\; t \;\; m \;\; s^{oft} \\ t < n \\ t \subseteq s^{oft} \\ Max(m) \\ \begin{array}{|c|}\hline t^q \; t^m \\ t^q \subseteq s^{oft} \\ Montag(t^m) \\ t^m \subseteq t^q \\ \hline\end{array} \;\; \left\langle \begin{array}{c} oft \\ t^q \end{array} \right\rangle \;\; \begin{array}{|c|}\hline e \\ e : anrufen(m) \\ e \subseteq t^m \\ \hline\end{array} \\ \hline\end{array}$$

$setof(\mathrm{S}, \mathrm{C}, \mathrm{X})$

$\mathrm{S} = \{\mathrm{X} \mid \mathrm{C}(\mathrm{X})\}$

$length(\mathrm{L}, \mathrm{Y})$

(73) Max rief oft an.
Max often called.

(74) $?HoldsAt(\mathrm{f}, \mathrm{s}), \mathrm{s} < now, length(\mathrm{S}, \mathrm{y}), setof(\mathrm{S}, \{HoldsAt(\mathrm{f}, \mathrm{t}), Happens(\mathrm{a}, \mathrm{t}), \mathrm{t} < now\}, \mathrm{t}), \mathrm{y} \geq \mathrm{N}$ succeeds.

(75) $HoldAt(\mathrm{f_{Mo}}, \mathrm{s}) \wedge\ |now - \mathrm{s}| \leq 7\ days \rightarrow HoldsAt(\mathrm{f_{CMo}}, \mathrm{s})$

$?length(\mathrm{S}, \mathrm{y}), setof(\mathrm{S}, \{HoldsAt(\mathrm{f}, \mathrm{t}), Happens(\mathrm{e}, \mathrm{t})\}, \mathrm{t}), \mathrm{y} \geq \mathrm{N}$ succeeds

$?length(\mathrm{S}, \mathrm{y}), setof(\mathrm{S}, \{HoldsAt(\mathrm{f_{Mo}}, \mathrm{t}), Happens(\mathrm{a}, \mathrm{t})\}, \mathrm{t}), \mathrm{y} \geq \mathrm{N}$ succeeds

$?HoldsAt(\mathrm{f'}, \mathrm{s}), \mathrm{s} < now, length(\mathrm{S}, \mathrm{y}), setof(\mathrm{S}, \{HoldsAt(\mathrm{f_{Mo}}, \mathrm{t}), Happens(\mathrm{a}, \mathrm{t}),$
$\mathrm{t} < now\}, \mathrm{t}), \mathrm{y} \geq \mathrm{N}$ succeeds

$f' = f_{Mo} = f_{CMo}$

(76) $?HoldsAt(\mathrm{f_{CMo}}, \mathrm{s}), \mathrm{s} < now, length(\mathrm{S}, \mathrm{y}), setof(\mathrm{S}, \{HoldsAt(\mathrm{f_{CMo}}, \mathrm{t}),$
$Happens(\mathrm{a}, \mathrm{t}), \mathrm{t} < now\}, \mathrm{t}), \mathrm{y} \geq \mathrm{N}$ succeeds.

(77) $?HoldsAt(\mathrm{f'}, \mathrm{R}), \mathrm{R} < now, length(\mathrm{S}, \mathrm{y}), setof(\mathrm{S}, \{HoldsAt(\mathrm{f_{Mo}}, \mathrm{t}),$
$Happens(\mathrm{a}, \mathrm{t}), \mathrm{t} < now\}, \mathrm{t}), \mathrm{y} \geq \mathrm{n}\ succeeds.$

(78) Als er in München war, rief Max oft am Montag an.
While he was in Munich, Max often called on Monday.

A delegate arrived at the hotel.
She went to her room.
Conclusion:
Her room is in the hotel.

$?HoldsAt(f,t), HoldsAt(delegate(x),t), HoldsAt(hotel(p),t), Happens(arrive(x,p),t),$
$t < now$ succeeds
$?HoldsAt(h,t), HoldsAt(she(x),t), Happens(go(x,y),t), HoldsAt(room(y,x,v),t),$
$t < now$ succeeds

$?HoldsAt(g,t), HoldsAt(room(y,x,u),t), HoldsAt(hotel(w),t),$
$t < now$ succeeds

$?Happens(go(x,y),t), HoldsAt(hotel(x),t)$ fails