PENG Light meets the Event Calculus

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Motivation

- Research question:

  How to extend an existing controlled natural language so that we can specify knowledge about events and their effects (= periods during which states hold)?

- Approach:

  We look at a scenario where we can observe and describe a sequence of events as they unfold.

- Basically, "eye-witness" reports.

Motivation

- Research question:

  How to extend an existing controlled natural language so that we can specify knowledge about events and their effects (= periods during which states hold)?

- Approach:

  We look at a scenario where we observe and describe a sequence of events as they unfold.

- Basically, "eye-witness" reports.

- Think about a spy who observes and reports events as they unfold – if that helps.

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PENG Light

- Simple sentences:
  - subject + verb + (complement)* + (modifier)*
- Complex sentences:
  - coordination (and, or)
  - subordination (if ... then, who, that, ...)
  - quantification (every, all, for every, ...)
  - negation (no, is not, does not, ...)
- Questions:
  - wh-questions
  - yes/no-questions
- Anaphoric references

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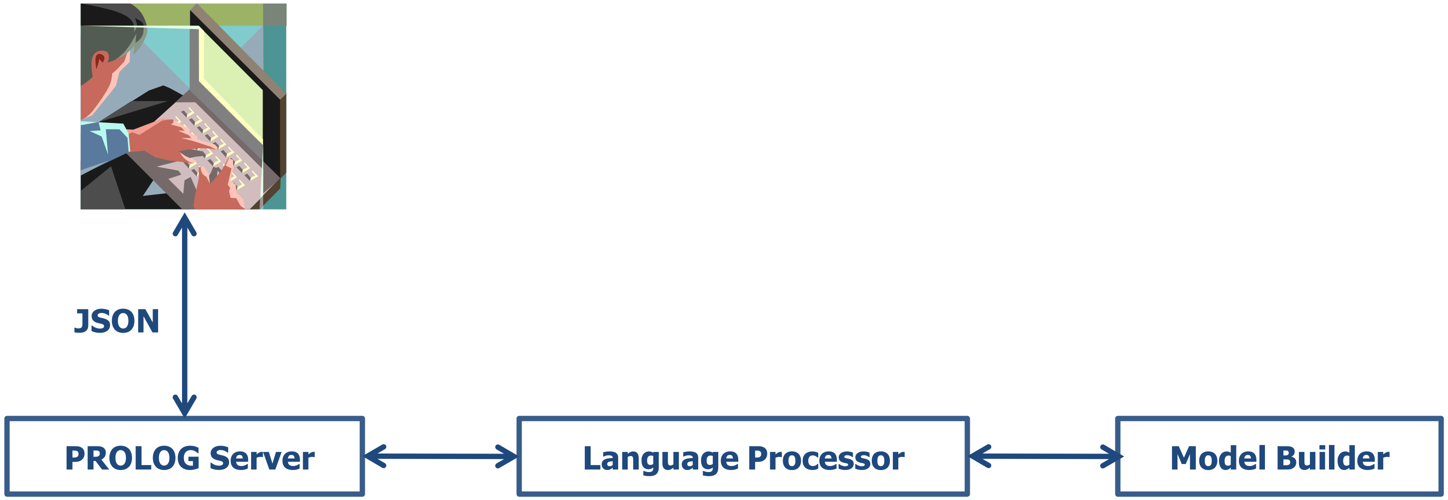
PENG Light

- PENG Light sentences are translated incrementally during the writing process into first-order logic via discourse representation structures.
- During parsing the following activities occur in parallel:
  - anaphoric expressions are resolved
  - a discourse representation structure is generated
  - a paraphrase is produced
  - lookahead information is generated.
- A model builder tries to generate a finite model.

Architecture



A Scenario

- John arrives at 10:10 with Flight AZ1777 in Palermo.
- John gets on a bus at the airport.
- The bus leaves the airport at 11:30 and arrives at the port of Trapani at 13:05.
- John gets off the bus in Trapani.

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- The temporal structure of these sentences is simple.

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- The temporal structure of these sentences is simple.
- Temporal expressions only occur as modifiers of events.

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- John arrives at 10:10 with Flight AZ1777 in Palermo.
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- Temporal structure of these sentences is simple.
- Temporal expressions only occur as modifiers of events.
- These events have a linear temporal ordering.

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A Scenario

- John arrives at 10:10 with Flight AZ1777 in Palermo.
- John gets on a bus at the airport.
- The bus leaves the airport at 11:30 and arrives at the port of Trapani at 13:05.
- John gets off the bus in Trapani.

- For some events, no explicit time point is mentioned.

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A Scenario

- The weather is bad.
- The wind is strong and the sea is rough.

- We can speak about states in PENG Light.

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A Scenario

- If the weather is good then John boards the hydroplane at 14:10 and arrives on Marettimo Island at 15:35.
- If the weather is bad then Johns stays in Trapani and goes to the Albergo Maccotta.

- We can express conditional statements in PENG Light.

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Question Answering

- When does John arrive in Palermo?
- Where does John get on a bus?
- When does the bus leave the airport?
- Who gets off the bus?

- These questions can be answered directly over the resulting knowledge base.
- No additional background knowledge is required.

The Scenario

- John arrives at 10:10 with Flight AZ1777 in Palermo.
- John gets on a bus at the airport.
- The bus leaves the airport at 11:30 and arrives at the port of Trapani at 13:05.
- John gets off the bus in Trapani.

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Question Answering

- Where is John now?
- Where is John at 13:30?
- Why does John stay in Trapani?

- These questions require background knowledge.

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Human Observer

- Given:
  - John arrives at 10:10 with Flight AZ1777 in Palermo.
  - John gets on a bus at the airport.
  - The bus leaves the airport at 11:30 ...

- A human observer can easily infer:
  - John is on the bus at 12:00
    but not anymore in Palermo at that time.

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Human Observer

- Given:
  - John arrives at 10:10 with Flight AZ1777 in Palermo.
  - John gets on a bus at the airport.
  - The bus leaves the airport at 11:30 and arrives at the port of Trapani at 13:05.
  - John gets off the bus in Trapani.

- A human observer can (easily) infer:
  - John is in Trapani at 13:30
    but not anymore on the bus.

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An Event-based Solution

- Thus

    the event of John getting on the bus
    at a given point in time

    initiates that John is on the bus

  and

    the event of John getting off the bus
    at a given point in time

    terminates that John is on the bus.

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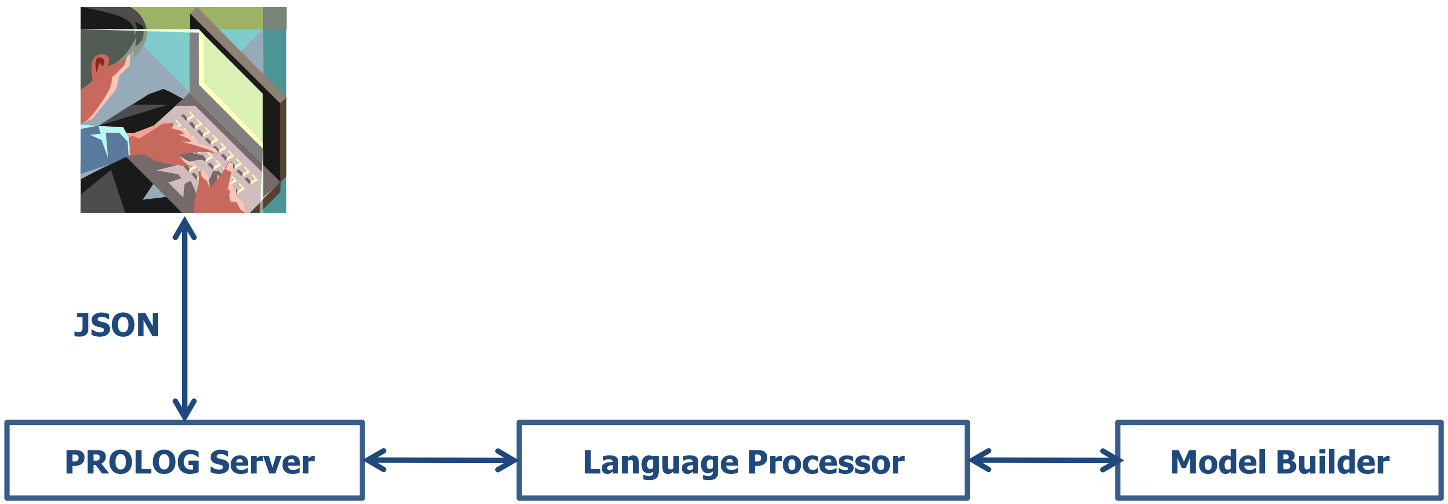
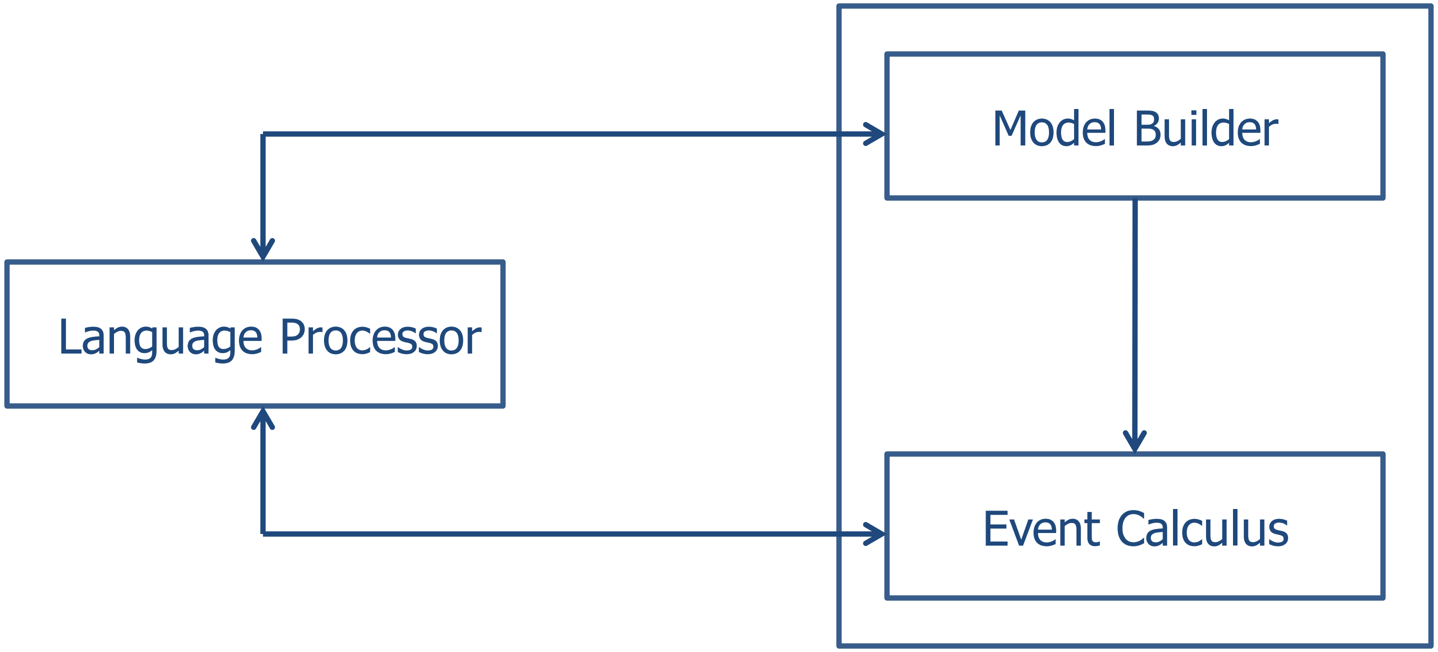
Architecture



Extended Architecture



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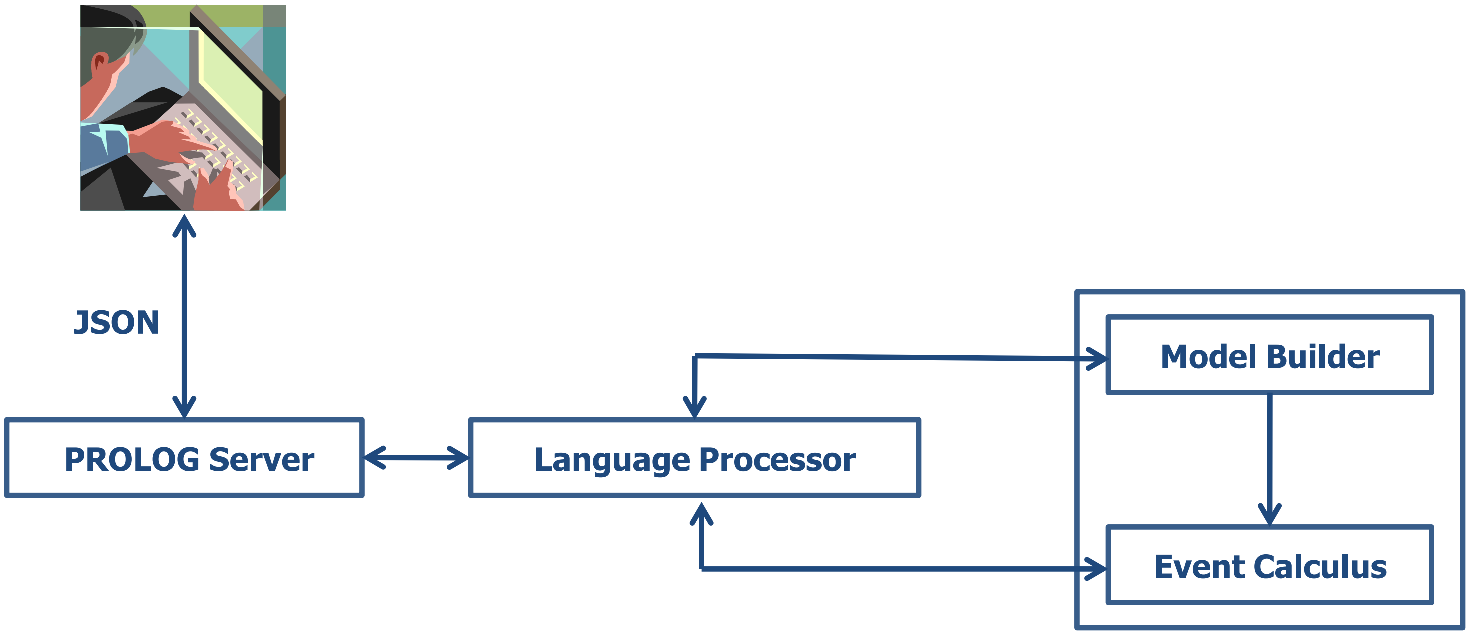
Extended Architecture



The Event Calculus (EC)

- A framework for reasoning about events and time.
- Many versions exist (Kowalski, Shanahan, Mueller, ...).
- EC has been used for database updates, planning, explanation, hypothetical reasoning.
- The basic entities are: events, fluents and time points.
- Events which occur at a given time point

  initiate fluents (= properties, states) that hold

  until they are terminated by other events

  at a later time point.

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Event Calculus (Simplified Version)

- Only two domain independent clauses are necessary:

```
holds_at(F,T2) :-
    happens(E,T1),
    before(T1,T2),
    initiates(E,F),
    \+ clipped(T1,F,T2).

clipped(T1,F,T3) :-
    happens(E,T2),
    terminates(E,F),
    before(T1,T2),
    before(T2,T3).
```

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Event Calculus (Simplified Version)

- Domain specific clauses:

```
initiates(E,located_at(X,Y)) :-
   event(E,arriving(X,Y)).

terminates(E,located_at(X,Y)) :-
   event(E,leaving(X,Y)).
```

Event Calculus (Simplified Version)

- A particular course of events is represented as a set of **`happens/2`** and **`event/2`** clauses:

```
happens(e1,'10:10').
event(e1,arriving(sk1,sk2)).
happens(e2,'11:30').
event(e2,leaving(sk3,sk4)).
before('10:10','11:30').
```

- The **`before/2`** clause keeps track of the temporal ordering.

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Speaking about Events and Effects

- The initial scenario:
  - John arrives at 10:10 with Flight AZ1777 in Palermo.
  - John gets on a bus at the airport.
  - The bus leaves the airport at 11:30 and arrives at the port of Trapani at 13:05.
  - John gets off the bus in Trapani.

needs to be augmented with domain specific axioms.

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Domain-Specific Axioms

- This can be done directly via an extension of PENG Light, for example:
  - If X arrives at Y then this event initiates that X is located at Y.
  - If X gets on Y then this event initiates that X is located in Y.
  - If X is located in Y and Y leaves Z then this event terminates that X is located at Z.

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Domain-Specific Axioms

- We can further restrict the domain and the range:
  - If X gets on Y then
    this event initiates that X is located in Y.
  - If a person gets on a vehicle then
    this event initiates that the person
    is located in the vehicle.
- Additionally, we need to specify that:
  - John is a person.
  - Every bus is a vehicle.

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Model Generation

- PENG Light texts are translated into the input language of a Satchmo-style model builder.
- For example:
  - John arrives with Flight AZ1777 at the airport of Palermo at 10:10.
  - John gets on a bus at the airport.

results in in the following model ...

Model Generation

```
named(sk1,john). theta(e1,theme,sk1).
event(e1,arriving).
theta(e1,instrument,sk2). named(sk2,az1777).
theta(e1,location,sk3).
object(sk3,airport). associated_with(sk3,sk4).
named(sk4,palermo).
theta(e1,time,sk5). timex(sk5,'10:10').
theta(e2,agent,sk1).
event(e2,getting_on). theta(e2,theme,sk6).
object(sk6,bus).
theta(e2,location,sk3). theta(e2,time,sk7).
timex(sk7,'11:15').
before('10:10','11:15').
```

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Model Generation

- Two things to note:
  - terms are wrapped by the predicate `fact/1`:

    ```
    fact(named(sk1,john)).
    ```
- Timestamp for events without temporal modifiers, e.g.:
  - John gets on a bus at the airport.

    ```
    theta(e2,time,sk7).
    timex(sk7,'11:15').
    ```

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Domain-Specific Axioms in PENG Light

- If X arrives at Y then
  this event initiates that X is located at Y.
- If X gets on Y then
  this event initiates that X is located in Y.
- If X is located in Y and Y leaves Z then
  this event terminates that X is located at Z.

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Domain Specific Axioms in Prolog

```
initiates(E,fluent(X,located_at,Y)) :-
   event(E,arriving),
   theta(E,theme,X),
   theta(E,location,Y).

initiates(E,fluent(X,located_in,Y)) :-
   event(E,getting_on),
   theta(E,agent,X),
   theta(E,theme,Y).

terminates(E,fluent(X,located_at,Z)) :-
   event(E,leaving),
   theta(E,agent,Y),
   theta(E,theme,Z),
   holds_at(fluent(X,located_in,Y),now).
```

Interface between the Model and EC

- The following rule:

```
happens(E,T) :- event(E,Type), theta(E,time,X), timex(X,T).
```

sets up the interface between the facts in the model:

```
event(e1,arriving). theta(e1,time,sk5). timex(sk5,'10:10').
```

and the domain-independent axioms of the EC:

```
holds_at(F,T2) :-
  happens(E,T1), before(T1,T2),
  initiates(E,F), \+ clipped(T1,F,T2).

clipped(T1,F,T3) :-
  happens(E,T2), terminates(E,F),
  before(T1,T2), before(T2,T3).
```

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Reasoning

- Domain-independent axioms:

```
holds_at(F,T2) :-
  happens(E,T1),
  before(T1,T2),
  initiates(E,F),
  \+ clipped(T1,F,T2).

clipped(T1,F,T3) :-
  happens(E,T2),
  terminates(E,F),
  before(T1,T2),
  before(T2,T3).
```

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Reasoning

```
initiates(E,fluent(X,located_at,Y)) :-
    event(E,arriving),
    theta(E,theme,X),
    theta(E,location,Y).

terminates(E,fluent(X,located_at,Z)) :-
    event(E,leaving),
    theta(E,agent,Y),
    theta(E,theme,Z),
    holds_at(fluent(X,located_in,Y),now).
```

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Reasoning (Model)

```
named(sk1,john). theta(e1,theme,sk1).
event(e1,arriving).
theta(e1,instrument,sk2). named(sk2,az1777).
theta(e1,location,sk3).
object(sk3,airport). associated_with(sk3,sk4).
named(sk4,palermo).
theta(e1,time,sk5). timex(sk5,'10:10').
theta(e2,agent,sk1).
event(e2,getting_on). theta(e2,theme,sk6).
object(sk6,bus).
theta(e2,location,sk3). theta(e2,time,sk7).
timex(sk7,'11:15').
before('10:10','11:15').
```

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Reasoning

- Given this knowledge, we can now answer the questions:
  - Where is John at 11:20?
  - Where is John now?

  with the help of the Event Calculus and find that John is in the bus at 11:20 and still in Palermo at that time.

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Abductive Reasoning

- The EC can be extended in many interesting ways.
- We can combine the EC with a meta-interpreter for abductive reasoning in order to find explanations for *why*-questions.
- Abductive reasoning is inference to the best explanation.
- It is reasoning backwards from the consequent to the antecedent.
- Abductive reasoning is not a valid form of reasoning, but it can suggest plausible hypotheses.

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Abductive Reasoning

- Let's assume that we want to know
  - Why does John stay in Trapani?

  and we know that
  - If the weather is bad then Johns stays in Trapani and goes to the Albergo Maccotta

  and know also that
  - John stays in Trapani and goes to the Albergo Maccotta.

  then we can infer via abduction that the weather must be bad.

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Future Research: Full Event Calculus

- Use of E-KRHyper as model generator:

$$\mathrm{HoldsAt}(f,t) \leftarrow \mathrm{Initially}_P(f) \wedge \neg\, \mathrm{Clipped}(0,f,t) \qquad \text{(EC1)}$$

$$\begin{aligned}&\mathrm{HoldsAt}(f,t3) \leftarrow \\ &\quad \mathrm{Happens}(a,t1,t2) \wedge \mathrm{Initiates}(a,f,t1) \wedge \\ &\quad\quad t2 < t3 \wedge \neg\, \mathrm{Clipped}(t1,f,t3)\end{aligned} \qquad \text{(EC2)}$$

$$\begin{aligned}&\mathrm{Clipped}(t1,f,t4) \leftrightarrow \\ &\quad \exists\, a,t2,t3\ [\mathrm{Happens}(a,t2,t3) \wedge t1 < t3 \wedge t2 < t4 \wedge \\ &\quad\quad [\mathrm{Terminates}(a,f,t2) \vee \mathrm{Releases}(a,f,t2)]]\end{aligned} \qquad \text{(EC3)}$$

$$\neg\, \mathrm{HoldsAt}(f,t) \leftarrow \mathrm{Initially}_N(f) \wedge \neg\, \mathrm{Declipped}(0,f,t) \qquad \text{(EC4)}$$

$$\begin{aligned}&\neg\, \mathrm{HoldsAt}(f,t3) \leftarrow \\ &\quad \mathrm{Happens}(a,t1,t2) \wedge \mathrm{Terminates}(a,f,t1) \wedge \\ &\quad\quad t2 < t3 \wedge \neg\, \mathrm{Declipped}(t1,f,t3)\end{aligned} \qquad \text{(EC5)}$$

$$\begin{aligned}&\mathrm{Declipped}(t1,f,t4) \leftrightarrow \\ &\quad \exists\, a,t2,t3\ [\mathrm{Happens}(a,t2,t3) \wedge t1 < t3 \wedge t2 < t4 \wedge \\ &\quad\quad [\mathrm{Initiates}(a,f,t2) \vee \mathrm{Releases}(a,f,t2)]]\end{aligned} \qquad \text{(EC6)}$$

$$\mathrm{Happens}(a,t1,t2) \rightarrow t1 \leq t2 \qquad \text{(EC7)}$$

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Conclusions

- PENG Light can be extended in a systematic way to speak about events and their effects.
- PENG Light texts are translated automatically into the input language of a model builder.
- The generated model can be used by the Event Calculus for reasoning about events and time.
- This combinations makes PENG Light an interesting specification language for dynamic domains.

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