A Survey of Temporal Extensions of DLs

Research school: Foundations and Challenges of Change in Ontologies and Databases 2014
Free University of Bozen-Bolzano, Italy

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  - **Birkbeck College**

What we will see

The paper:

- ***Alessandro Artale and Enrico Franconi. A survey of temporal extensions of description logics. Annals of Mathematics and Artificial Intelligence, 30(1-4):171-210, 2000.***

Outline:

- **Overview**
- **Running Example**
- **A Survey on Existing Solutions**
- **Current Hot Topics, Future Directions**

Outline

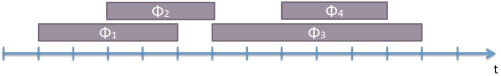
Temporal extensions of DLs

- **How can time be modelled?**

Temporal extensions of DLs

- **How can time be modelled?**
  - **Point-based notion of time**

  - **Interval-based notion of time**



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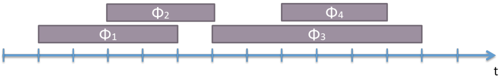

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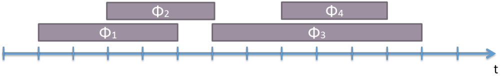

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  - **Implicit notion of time: sequences of events through state-change representations**
  - **Explicit notion of time: definition of temporal operators and new formulae**

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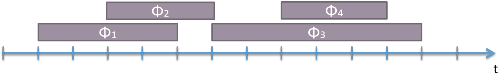

- **How can the temporal dimension be handled?**
  - **Implicit notion of time: sequences of events through state-change representations**
  - **Explicit notion of time: definition of temporal operators and new formulae**
    - **Internal point of view: different states of an individual are modelled as different individual components**
    - **External point of view: an individual has different states in different moments**

Classification of the DL temporal extensions

		Point-based time	Interval-based time
Implicit time			
Explicit time Internal approach			
Explicit time External approach			

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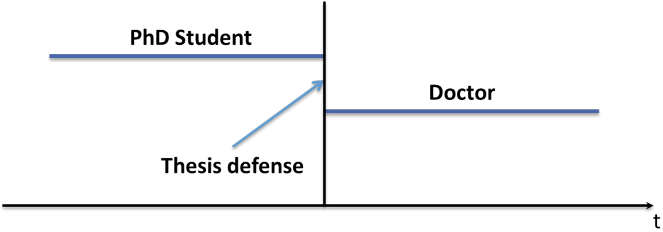
Running example

- **How to become a doctor:**
  - **Be a PhD student for some years (3-4)**
  - **Defend a thesis**
  - **Become a doctor**



- **Let's try to model it with different temporal logics!**

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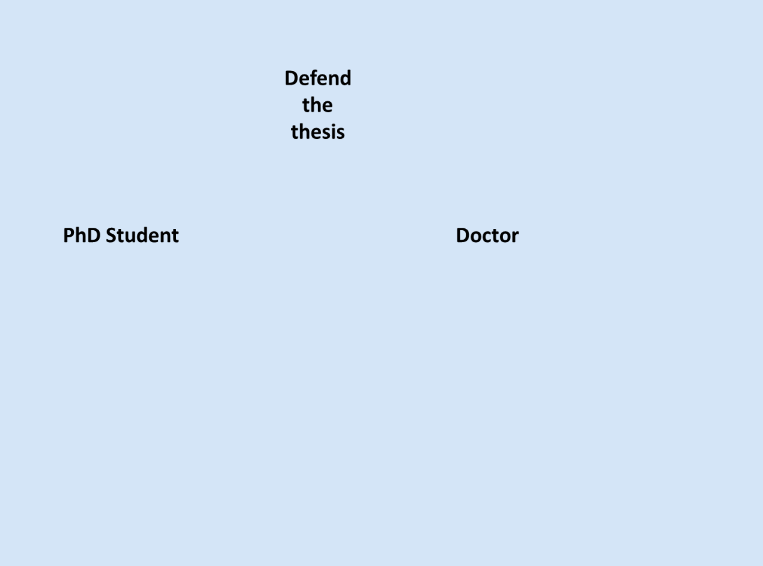
CLASP [DL96]



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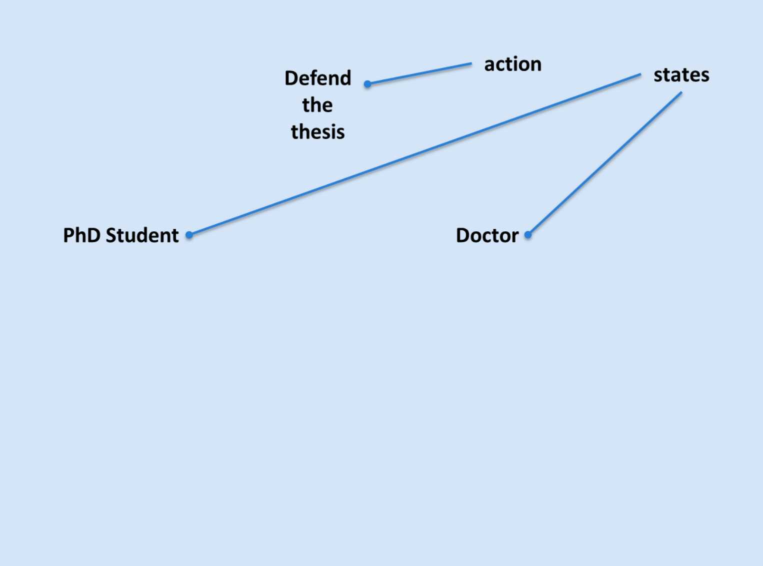

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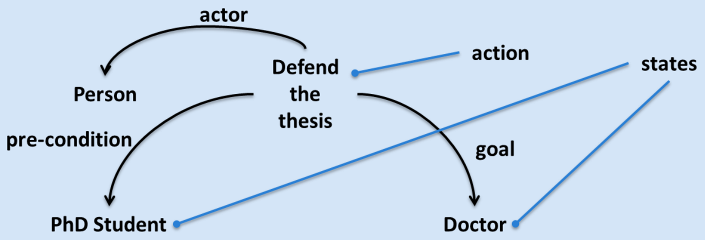
actor
Defend the thesis
action
states
Person
pre-condition
goal
PhD Student
Doctor

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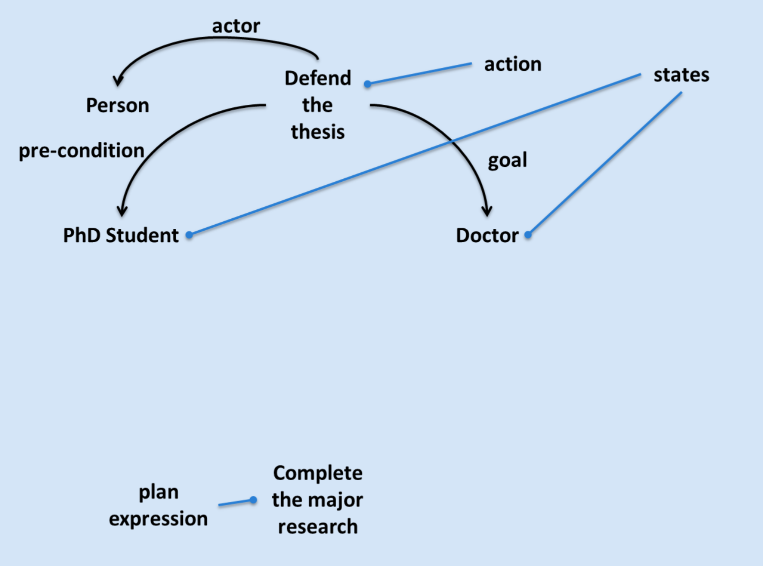
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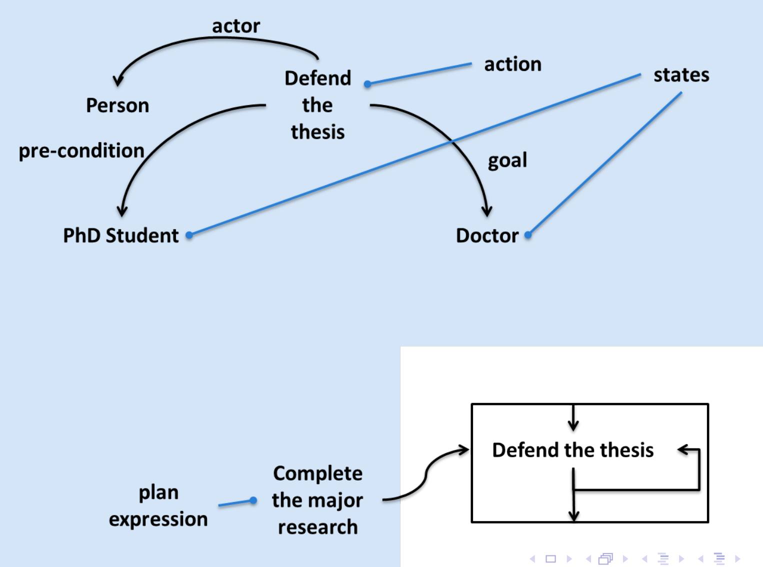
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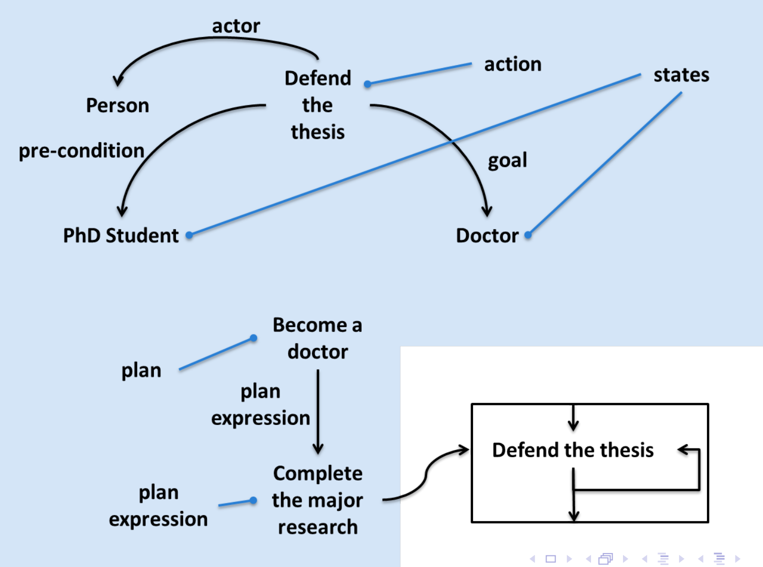
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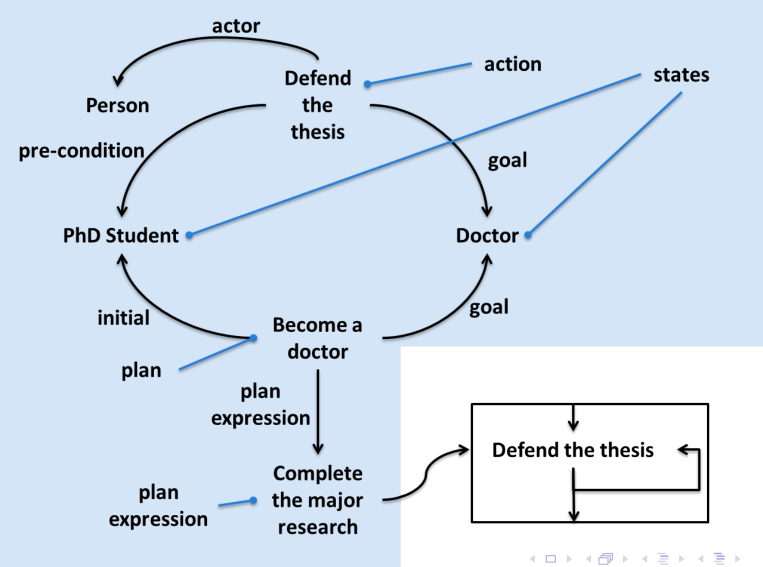

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CLASP

- **A system to reason about plans, proposed by Devambu and Litman (first half of 90s)**

CLASP

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- Two formalisms
  - The CLASSIC DL to define states, actions, plans and relation among them
  - A set of operators to specify the plan expressions
    - SEQUENCE, LOOP, TEST, OR, ...
    - The plan expression is converted in a finite automata

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    - `SEQUENCE`, `LOOP`, `TEST`, `OR`, ...
    - The plan expression is converted in a finite automata
- CLASP performs
  - Plan subsumption
  - Plan recognition: determines if a scenario belong to a given plan

CLASP considerations

- **Actions are instantaneous**
- **The temporal expressivity of Clasp is implicit in the language**
- **Alternatives can be expressed through disjunctions (`OR`)**

CLASP considerations

- Actions are instantaneous
- The temporal expressivity of Clasp is implicit in the language
- Alternatives can be expressed through disjunctions (`OR`)
- Explicit temporal constraints are not expressible
- The terminological representation of states:
  - is not as expressive as the predicate calculus representation used in STRIPS
  - avoids doing general theorem proving when computing state subsumption

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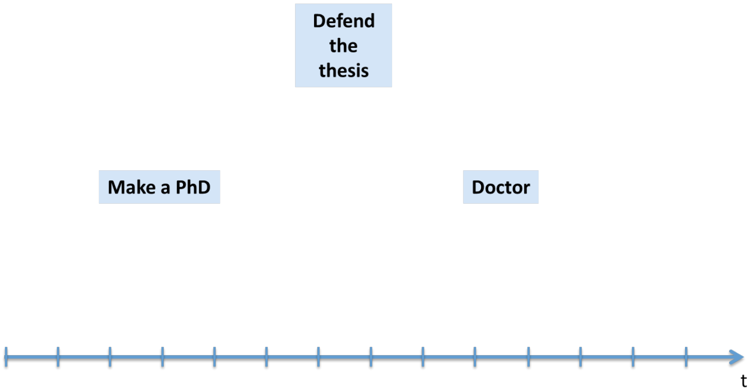
T-REX [WL92]



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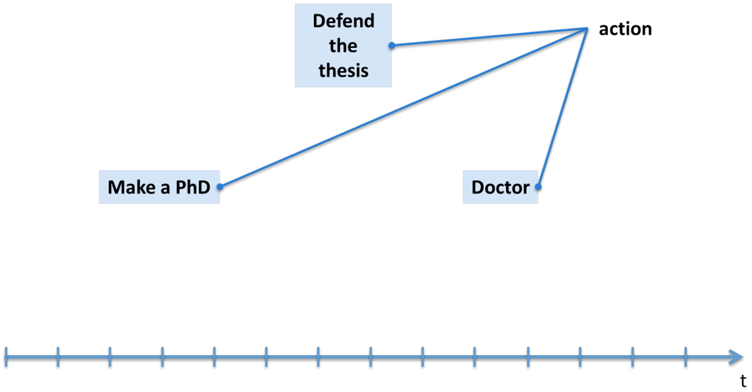

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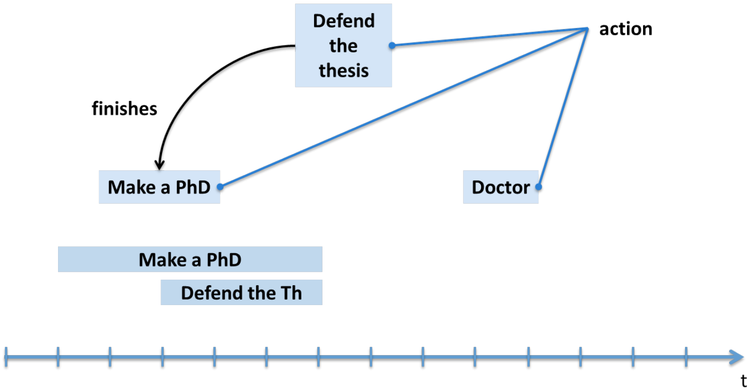
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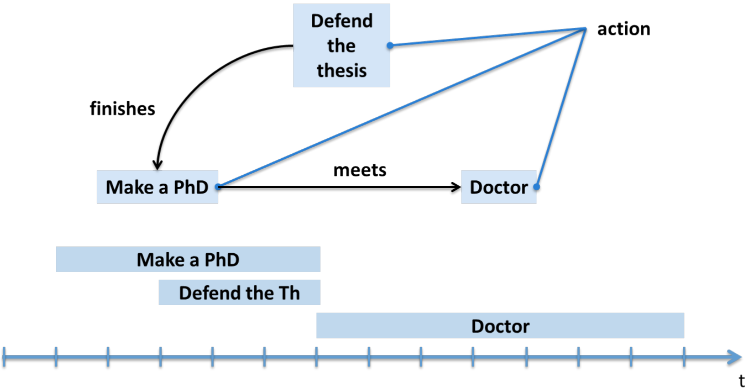
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- Like CLASP, two different formalisms are used
  - The K-REP or the CLASSIC DLs to describe the actions
  - A temporal constraint network to represent the plans
    - Constraints defined through the Allen's relationships
    - before, meets, after, finishes, ...

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    - before, meets, after, finishes, . . .
- T-REX performs the following reasoning tasks:
  - subsumption
  - plan recognition: the system determines if a set of observations are compatible with (i.e., could instantiate) the plan set
    - plans are classified in possible, necessary and impossible

T-REX considerations

- T-Rex conceptual model captures the actions
  - States are not represented

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- **T-Rex conceptual model captures the actions**
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- **T-Rex is an example of external notion of time with an internal approach**
  - **It uses the Allen's relationships to specify the constraints (explicit notion of time)**
  - **Plans capture the time notion (internal approach)**

T-REX considerations

- T-Rex conceptual model captures the actions
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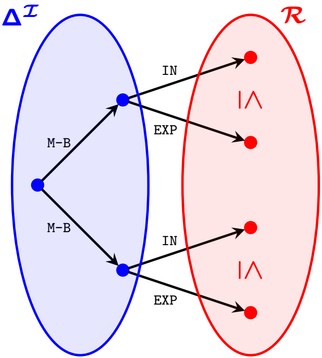
- T-Rex is an example of external notion of time with an internal approach
  - It uses the Allen's relationships to specify the constraints (explicit notion of time)
  - Plans capture the time notion (internal approach)
- The plan subsumption is NP-Complete
  - The crux is to determine the mappings between plans

Time as Concrete Domain [BH91]

- **Idea:**
  - **Abstract individuals are related to values in a *concrete domain***
    - **.. via features**
  - **Tuples of concrete values identified by features can be constrained to belong to a predicate over the concrete domain**

Example [AF00]

- Poor-Manager $\doteq$ Manager $\sqcap$ $\forall$MONTHLY-BALANCE.$\exists$(INCOME, EXPENSES). $\leq$
  - INCOME and EXPENSES are features from $\Delta^{\mathcal{I}}$ to the concrete domain $\mathcal{R}$
  - $\leq$ is a predicate defined over the concrete domain



$\mathcal{ALC}(\mathcal{D})$ [BH91]

- $\mathcal{ALC}$ extended with concrete predicates

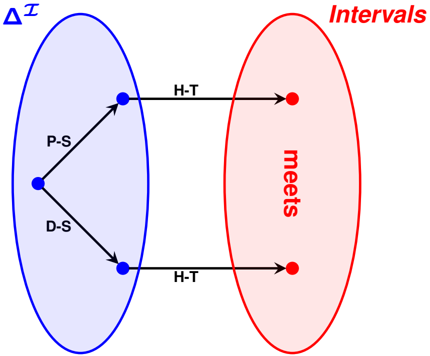
$$(\exists(u_1, \ldots, u_n).P)^{\mathcal{I}} := \{a \in \Delta^{\mathcal{I}} \mid \langle u_1^{\mathcal{I}}(a), \ldots, u_n^{\mathcal{I}}(a)\rangle \in P^{\mathcal{D}}\}$$

- $u_1, \ldots, u_n$ are compositions of features
- $\mathcal{D}$ is called concrete domain

Running Example

Postdoc $\sqsubseteq$ PHD-STATE : PhD-Student $\sqcap$ DOC-STATE : (Doctor $\sqcap$ $\neg$PhD-Student)$\sqcap$

$\exists$(PHD-STATE $\circ$ HAS-TIME, DOC-STATE $\circ$ HAS-TIME).meets



- **Recall: "different states of an individual are modelled as different individuals"**

Considerations

- $\mathcal{ALC}(\mathcal{D})$, $\mathcal{ALCF}(\mathcal{D})$
  - **concept satisfiability, subsumption, and ABox consistency**
    - PSPACE**-complete**
  - **.. under the assumption that satisfiability in the concrete domain is in** PSPACE
- $\mathcal{ALCRP}(\mathcal{D})$
  - **Undecidable**
    - **Decidability if avoiding the interaction of complex roles with existential and universal restrictions**

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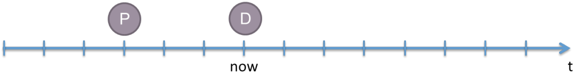
Combining Description Logics and Tense Operators: $\mathcal{ALCT}$ [Sch93]

- Combination of $\mathcal{ALC}$ with point-based modal temporal connectives
  - $\Diamond_P, \Box_P, \bigcirc_P, \mathcal{U}_P, \mathrm{U}_P$
- Time part of the semantic structure
  - $A^{\mathcal{I}} \subseteq \mathcal{T} \times \Delta^{\mathcal{I}}$
  - $R^{\mathcal{I}} \subseteq \mathcal{T} \times \Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$
    - Recall: "an individual has different states at different moments"
- Temporal connectives can be applied only to concepts
  - $\Diamond C_t^{\mathcal{I}} := \{a \in \Delta^{\mathcal{I}} \mid \exists t'.\ t' \leq t \wedge a \in C_{t'}^{\mathcal{I}}\}$

Running Example

- Every doctor has been a PhD student in the past

$$\text{Doctor} \sqsubseteq \Diamond_P \text{PhD-Student}$$



- Every thesis defender is a PhD student that has been a PhD student in the past

$$\text{Thesis-Defender} \sqsubseteq \text{PhD-Student} \sqcap \Diamond_P \text{PhD-Student}$$

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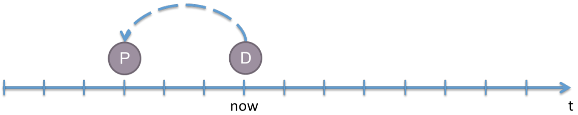

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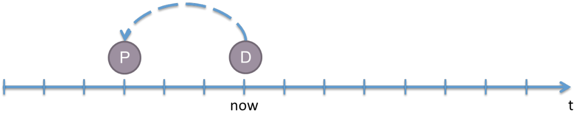

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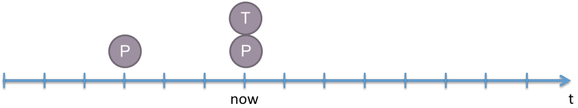

Considerations

- $\mathcal{ALCT}$
  - Empty Abox
  - Linear, unbounded and discrete time structure
    - PSPACE-complete for statisfiability checking
  - Branching, unbounded and discrete time structure
    - EXPTIME-hard
  - Interval-based time structure
    - Undecidable
- Open questions (still open?)
  - Extending $\mathcal{ALCT}(\mathcal{N})$ with past tense?
  - Real numbers?

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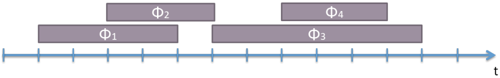
Interval-based Temporal DLs

- **Schmiedel's Formalism**
  - **Idea**
  - **Examples**
- **The Undecidable Realm**
  - **Idea**
  - **Examples**
- **Towards Decidable Logic**
  - **Idea**
  - **Examples**

Interval-based Temporal DLs: Characteristics

- **Interval-based**



- **Explicit, eg:** ***alltime***, $\Diamond TE$
- **Follows the external approach, eg:** $C\langle i, a\rangle$ **for temporal concept assertions and** $R\langle i, a, b\rangle$ **for temporal role assertions**

Schmiedel's Formalism: Idea

- **The first of such an interval-based temporal DL (made in 1990)**
- **Underlying DL = $\mathcal{FLENR}^-$ (no $\top$, $\bot$, $\neg$, $\sqcup$ but with cardinality restrictions on roles, and role conjunction)**
- **Temporal operators = *at*, *alltime*, *sometime***
- **Subsumption is argued to be undecidable**

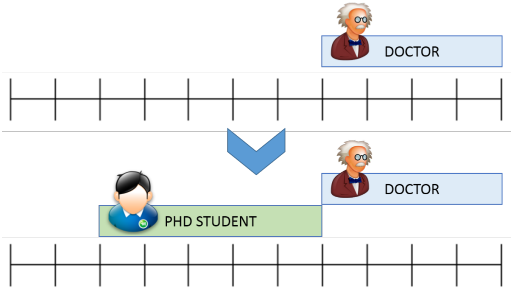
Schmiedel's Formalism: Examples

Concept: PhD students during 1993

$(at\ 1993\ PhDStudent)$

Terminological Axiom: Doctors were PhD students

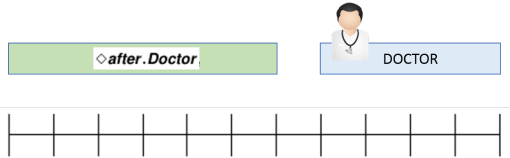
$Doctor \sqsubseteq (sometime(x)(metBy\ now\ x).(at\ x\ (PhDStudent)))$



The Undecidable Realm: Idea

- Developed by Bettini
- Variable-free extension with existential and universal temporal quantification
  - Arbitrary relationships between more than two intervals can't be represented
- Satisfiability and subsumption are undecidable
- Starting from the DL $\mathcal{ALCN}$
- Two concept constructors: $\Diamond \boldsymbol{TE.C}$ and $\Box \boldsymbol{TE.C}$

The Undecidable Realm: Examples



Concept: Persons who become a doctor sometime

$\Diamond \textit{after}.\textit{Doctor}$,
eg: $\langle 1990, \textit{michael} \rangle$ belongs to this, if $\langle 1992, \textit{michael} \rangle$ belongs to *Doctor*

Terminological Axiom: Doctors were PhD students

$\textit{Doctor} \sqsubseteq \Diamond(\textit{metBy}).\textit{PhDStudent}$

Towards Decidable Logics: Idea

- **Developed by Artale and Franconi**
- **Decidable: Expressivity is reduced, universal quantification on temporal variables has been eliminated**
- **Underlying DL (most expressive):** $\mathcal{TL}$-$\mathcal{ALCF}$
- **Temporal variables are introduced by the temporal existential quantifier** $\diamond$**, excluding the predefined temporal var** $\#$

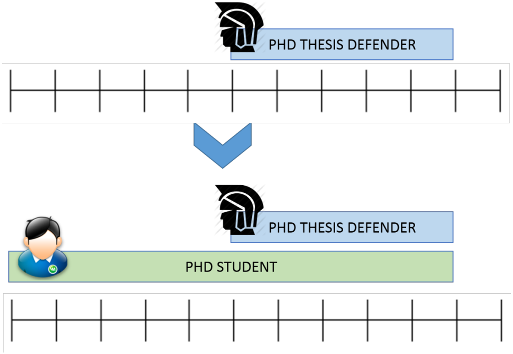
Towards Decidable Logics: Examples

Terminological Axiom: Doctors were PhD students

$\mathit{Doctor} \sqsubseteq \Diamond(x)(\#\ \mathit{metBy}\ x).\mathit{PhDStudent}@x$

Terminological Axiom: PhD thesis defenders finish their PhDs

$\mathit{PhDThesisDefender} \sqsubseteq \Diamond(x)(\#\ \mathit{finishes}\ x).\mathit{PhDStudent}@x$



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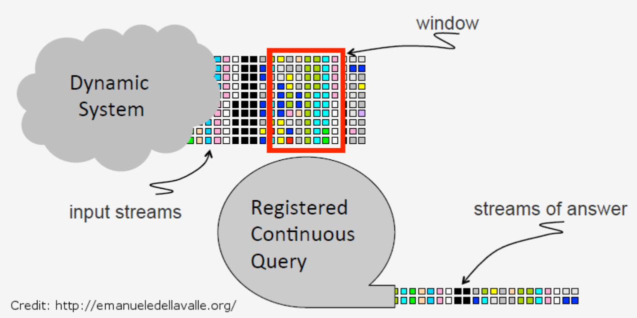
Hot Topics: Temporal DLs for OBDA

- **OBDA over temporal data with validity time**
- **Ontologies capable of temporal conceptual modeling**
- **Developed TQL extending OWL 2 QL, still preserving FO rewritability**
- **Example:**
  - **A fact with its validity time: $\mathit{givesBirth}(\mathit{diana}, \mathit{michael}, 1970)$**
  - **A temporal axiom: $\Diamond_p \mathit{givesBirth} \sqsubseteq \mathit{motherOf}$**

Hot Topics: Stream Query Processing

Query language for RDF streams




```
REGISTER STREAM SWhoIsWhereOnFb AS
PREFIX : <http://…/sr4ld2013-onto#>
CONSTRUCT { ?person :isIn ?room }
FROM STREAM <http://…/fb> [RANGE 1m STEP 10s]
WHERE {
  ?person1 :posts [ :who ?person ; :where ?room ] .
}
```

A Survey of Temporal Extensions of DLs

Research school: Foundations and Challenges of Change in Ontologies and Databases 2014
Free University of Bozen-Bolzano, Italy

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