Foundations and Challenges of Change in Ontologies and Databases
Bozen-Bolzano, Italy
29-31 January 2014

Temporal Dynamic Description Logic

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About Me

- **2005.09-2008.07**
  - PhD in Computer Science
  - Institute of Computing Technology, Chinese Academy of Sciences
- **2008.08-present**
  - Associate Professor, School of Computer Science, Guilin University of Electronic Technology
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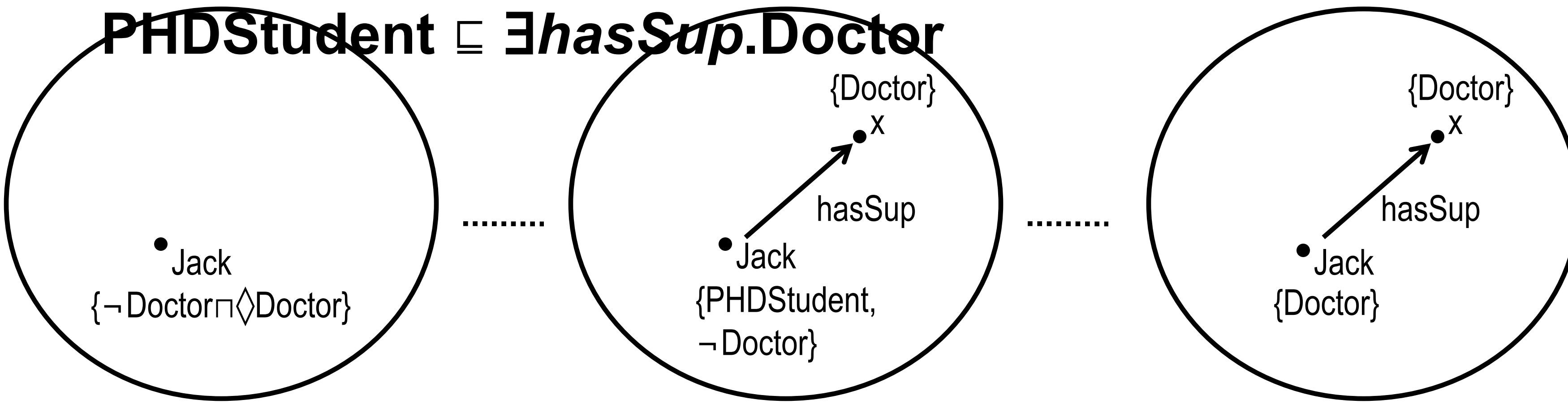
- **2013.08-present**
  - Visiting Academic
  - School of Computer Science, University of Manchester

Temporal description logic (TDL)

- For capturing temporal aspects of concepts in ontologies.

$$\neg \mathbf{Doctor} \sqcap \Diamond \mathbf{Doctor} \sqsubseteq \Diamond(\mathbf{PHDStudent} \sqcap \neg \mathbf{Doctor} \sqcap (\mathbf{PHDStudent} \sqcup \mathbf{Doctor}))$$

$$\mathbf{PHDStudent} \sqsubseteq \exists \mathit{hasSup}.\mathbf{Doctor}$$



- Two-dimensional logics [GKWZ03]
  - Temporal description logic
  - Dynamic description logic

} joint?

Different temporal extensions of DLs

- Explicit notion of time or implicit time

- Interval-based notion of time or point-based time

  – External representation of time or internal representation

- Linear time or branching time

Different temporal extensions

- Varying DL component: DL-Lite, EL, ALC, SHOIQ, …
- Different choice for applying temporal operators:
  concepts, TBox axioms, ABox assertions
  - ¬Doctor ⊓ ◊Doctor ⊑ ◊(PHDStudent [illegible] Doctor)
  - ◊(Citizen ⊑ HASVote)
  - PHDStudent(Jack) ∧ ◊(PHDStudent(Jack) [illegible] Doctor(Jack))
- Additional constraints on concepts and roles:
  rigid concepts, rigid roles
- interpretation domains: expanding, constant
- ……

Different temporal extensions

- Explicit notion of time or implicit time
- Interval-based notion of time or point-based time
  - External representation of time or internal representation
- Linear time or branching time

Dozens of combinations!

- Varying DL component: DL-Lite, EL, ALC, SHOIQ, …
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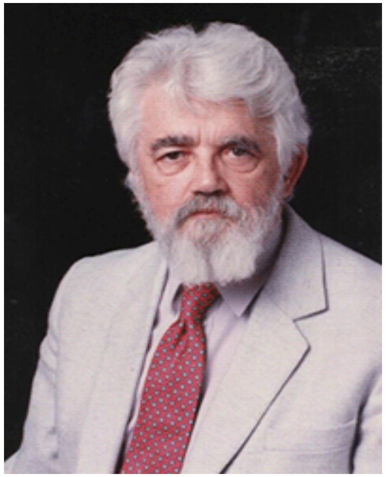
- interpretation domains: expanding, constant
- ……

Reasoning about actions

- Representation and Reasoning about Actions
- Situation Calculus [Mcc63]
- John Mccarthy
  - father of AI, 1956
  - Winner of Turing Award, 1971



- *John Mccarthy (1927-2011)*

Action Formalisms

based on PDL [GL95]

Based on propositional logics

based on LTL [CGV02]

Based on DL ?

Gap ?

Action formalism based on DL. [BLM+05]

Based on first- or higher-order logics

Situation Calculus

Fluent Calculus

....

DL-Based Action Formalisms

- Background knowledge: RBox, TBox
- States: ABoxes
- Action: α = (pre, occ, post)
  - **pre:** ABox assertions
  - **occ:** primitive literals
  - **post:** set of conditional post-conditions, φ/ψ

- Update ABox after the execution of actions.

Extension of the DL-based action formalism

(M,w)⊨$<\pi>\varphi$ iff some state w'∈W exists with (w,w')∈T(π) and (M,w')⊨φ.

(M,w)⊨$[\pi]\varphi$ iff for every state w'∈W: if (w,w')∈T(π) then (M,w')⊨φ.

- Background knowledge: RBox, TBox
- Atomic actions: come from Baader et al.'s formalism

$$\alpha \equiv (pre, occ, post)$$

- Complex actions:

$$\pi, \pi' ::= \alpha \mid \phi? \mid \pi \cup \pi' \mid \pi;\pi' \mid \pi^*$$

- Formulas:

$$\phi, \psi ::= C(p) \mid R(p,q) \mid <\pi>\phi \mid [\pi]\phi \mid \neg\phi \mid \phi \vee \psi \mid \phi \wedge \psi$$

Dynamic description logic DDL($X^@$)

X: DLs ranging from ALCO to ALCHOIQ ,

$X^@$: extension of X with the @ constructor.

Features of DDL($X^{@}$) (1/3)

(1) **Complex actions can be constructed**

- TBox:

$$\text{Customer} \equiv \text{Person} \sqcap \exists \text{holds.CreditCard}$$

$$\text{VIPcustomer} \equiv \text{Customer} \sqcap \geq 10\ \text{boughr.}(\text{Book} \sqcup \text{CD})$$

- Atomic Actions:

$$\text{buybook}(a,b) \equiv (\ \{\text{Customer}(a), \text{Book}(b)\}, \{\ \};$$
$$\{\text{Instore}(b)/\neg\text{Instore}(b), \text{Instore}(b)/\text{bought}(a,b)\}\ )$$

$$\text{order}(b) \equiv (\ \{(\text{Book} \sqcup \text{CD})(b)\}, \{\ \};$$
$$\{\neg\text{Instore}(b)/\text{Instore}(b)\}\ )$$

- Complex Action:

$$\text{VIPbuybook}(a,b) \equiv \text{VIPcustomer}(a)?\ ;$$
$$(\ (\text{Instore}(b)?\ ;\ \text{buybook}(a,b)\ ) \cup$$
$$(\neg\text{Instore}(b)?\ ;\ \text{order}(b);\ \text{buybook}(a,b))\ )$$

Features of DDL($X^{@}$) (2/3)

(2) **Properties on (complex) actions can be described directly**

- necessary conditions for the execution of (complex) actions

<VIPbuybook(a,b)>*true* → (VIPcustomer(a)∧Book(b)) √

<VIPbuybook(a,b)>*true* → Instore(b) ×

- results on the execution of actions

[VIPbuybook(a,b)]bought(a,b) √

[buybook(a,b)]bought(a,b) ×

Features of DDL($X^@$) (3/3)

(3) **Reasoning problems on actions be reduced to the satisfiability problem of formulas**

- Executability of actions
- Projection problem
- Consistency/realizability of actions
  - whether a given action makes sense w.r.t. the knowledge base

    buybook(a1,b); buybook(a2,b) ✗

- Satisfiability problem
  - a Tableau decision algorithm is provided.
  - the complexity upper-bound is
    - EXPSpace if $X \in$ {ALCO, ALCHO, ALCOQ, ALCHOQ},
    - N2EXPTime if $X \in$ {ALCOI, ALCHOI, ALCOIQ, ALCHOIQ}.

Temporal extension of DDL(X@)

To investigate temporal properties of actions.

Approach:

- the ongoing of time is embodied as the execution of atomic actions (time units)
- two temporal assertions are introduced:

$\phi, \psi ::= C(p) \mid R(p,q) \mid <\pi>\phi \mid [\pi]\phi \mid \neg\phi \mid \phi \vee \psi \mid \mathbf{E}(\phi \mathbf{U}^{\pi} \psi) \mid \mathbf{A}(\phi \mathbf{U}^{\pi} \psi)$

$\mathbf{E}(\phi \mathbf{U}^{\pi} \psi)$: there exists some path of π su

$\mathbf{A}(\phi \mathbf{U}^{\pi} \psi)$: "ϕ until ψ" holds in any path of

$$\mathbf{EF}\ \varphi =_{def} \mathbf{E}(true\mathbf{U}\varphi)$$

$$\mathbf{AF}\ \varphi =_{def} \mathbf{A}(true\mathbf{U}\varphi)$$

$$\mathbf{EG}\ \varphi =_{def} \neg\mathbf{AF}(\neg\varphi)$$

$$\mathbf{AG}\ \varphi =_{def} \neg\mathbf{EF}(\neg\varphi)$$

$$\mathbf{AX}\ \varphi =_{def} \neg\mathbf{EX}(\neg\varphi)$$

$$\mathbf{EX}\ \phi =_{def} \vee_{\alpha \in N_A} <\alpha>\phi$$

$$\mathbf{E}(\phi \mathbf{U} \psi) =_{def} \mathbf{E}(\phi \mathbf{U}^{(\alpha 1 \cup \ldots \cup \alpha n)^*} \psi)$$

$$\mathbf{A}(\phi \mathbf{U} \psi) =_{def} \mathbf{A}(\phi \mathbf{U}^{(\alpha 1 \cup \ldots \cup \alpha n)^*} \psi$$

Description example of TDDL($X^{@}$)

- liveness property: good things will eventually happen.

  $\mathbf{EF}((\exists bought^{-}.Customer)(b))$

  $\mathbf{E}(Instore(b)\ \mathbf{U}^{VIPbuybook(a,b)}\ \neg Instore(b)\ )$

- safety property: bad things will never happen.

  $\mathbf{AG}\ \neg(\geq 2\ bought^{-}.Customer)(b)\ )$

  $\mathbf{AG}\ (\ Instore(b) \vee (\exists bought^{-}.Customer)(b)\ )$

- Reduced to satisfiability problem of formulas.
- A **Tableau decision algorithm** is provided.

Limitation of DDL($X^@$)/TDDL($X^@$)

- TBox:
  - only concept definitions, no GCIs
  - acyclic
- RBox:
  - on transitive property
- Atomic action:
  - no defined concept name occurring in the effect set ***post***.

Result of: difficulty of ABox updating.

Difficulty of ABox updating

Example.

- RBox & TBox:

Trans($\boldsymbol{R}$),

$\boldsymbol{A} \sqsubseteq \exists \boldsymbol{R}.\boldsymbol{A}$, $\boldsymbol{A} \sqcap \boldsymbol{B} \sqsubseteq \bot$, $\boldsymbol{B} \sqsubseteq \forall \boldsymbol{R}.\boldsymbol{B}$

- ABox:

$\boldsymbol{A}(a)$

- Update or new information:

$(\exists \boldsymbol{R}.\boldsymbol{B})(a)$

Difficulty of ABox updating

Assumptions	DLs	Approach	References
Acyclic TBox; no def. concept names in U	ALC~AL CQIO	PMA semantics + distance on primitive concept names (NOT defined concept names).	LLMW06, LLMW11
	DL-Lite$_F$	PMA semantics	GLPR06, GLPR07
	DL-Lite$_R$	Both revision and update	KZ11, KZC13
	DL-Lite$_{FR}$	Based on cl$_T$(A) (Coincide with PMA if no role names occurring in GCIs and concept assertions.)	CKNZ10

Thank you!