Foundations and Challenges of Change in Ontologies and Databases
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# Temporal Dynamic Description Logic

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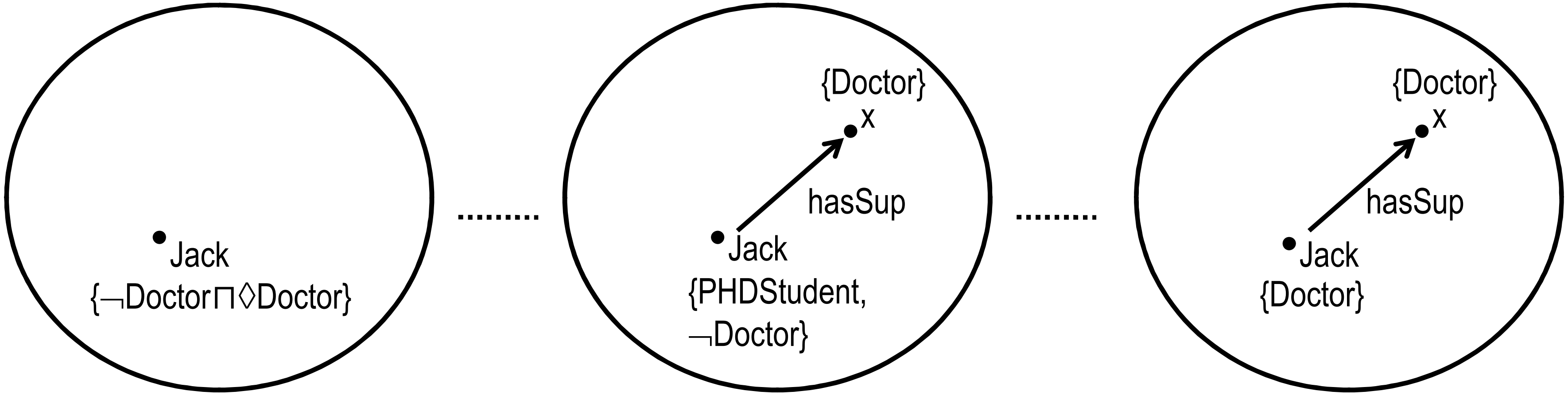
# Temporal description logic (TDL)

- For capturing temporal aspects of concepts in ontologies.

$\neg$**Doctor $\sqcap$ ◊Doctor $\sqsubseteq$**

**◊(PHDStudent$\sqcap\neg$Doctor$\sqcap$(PHDStudent $\mathcal{U}$ Doctor))**

**PHDStudent $\sqsubseteq$ $\exists$*hasSup*.Doctor**



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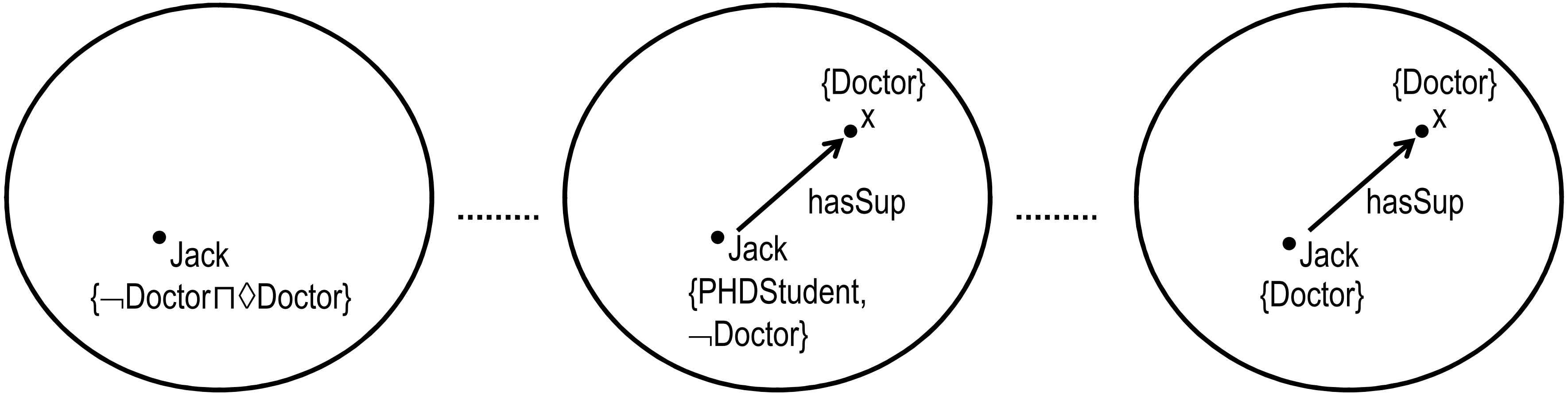


- Two-dimensional logics [GKWZ03]
  - Temporal description logic
  - Dynamic description logic
  - ……

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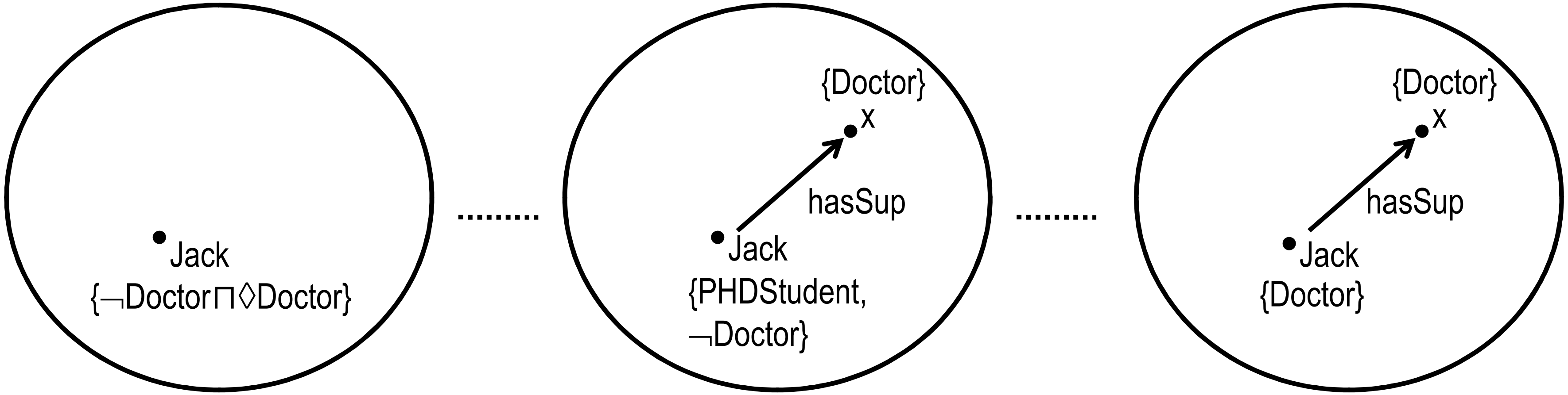


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**joint?**

# 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
  - $\neg$Doctor $\sqcap$ ◊Doctor $\sqsubseteq$ ◊(PHDStudent $\mathcal{U}$ Doctor)
  - ◊□(Citizen $\sqsubseteq$ HASVote)
  - PHDStudent(Jack) $\wedge$ ◊(PHDStudent(Jack) $\mathcal{U}$ 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
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**Dozens of combinations!**

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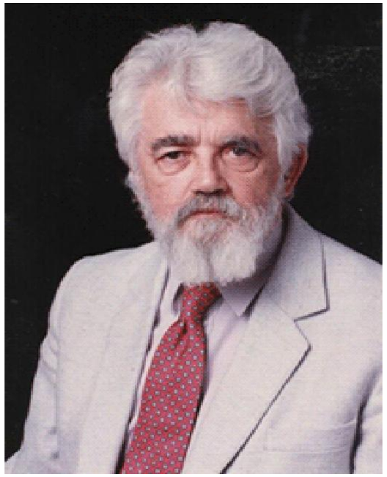
# Reasoning about actions

- 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 propositional logics**

- based on PDL [GL95]
- based on LTL [CGV02]

**Based on DL ?** ← **Gap ?**

**Based on first- or higher-order logics**

- Situation Calculus
- Fluent Calculus
- .........

# Action Formalisms

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**Action formalism based on DL.** [BLM+05]

**Based on first- or higher-order logics**

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# DL-Based Action Formalisms

- Background knowledge: RBox, TBox
- States: ABoxes
- Action: $\alpha$ = (pre, occ, post)
  - **pre:** ABox assertions
  - **occ:** primitive literals
  - **post:** set of conditional post-conditions, $\varphi/\psi$

- Update ABox after the execution of actions.

# Extension of the DL-based action formalism

Basic idea: construct more powerful formalism,

action theory + description logic + dynamic logic

- 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:

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

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

- Atomic Actions:

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

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

- Complex Action:

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

# 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* $\rightarrow$ (VIPcustomer(a)$\wedge$Book(b))

  <VIPbuybook(a,b)>*true* $\rightarrow$ 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:

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

**E**$(\phi$**U**$^{\pi}\psi)$ : there exists some path of $\pi$ such that "$\phi$ until $\psi$" holds.

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

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

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

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

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

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

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

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

# 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***.

Why?

- difficulty of ABox updating.

# Difficulty of ABox updating

Example.

- 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)

# Some results on ABox update

| Assumptions | DLs | Approach | References |
|---|---|---|---|
| Acyclic TBox; no defined concept names occurring in U | ALC~ALCQIO | PMA semantics & only primitive concept names are counted when measuring distance. | LLMW06, LLMW11 |
| | DL-Lite$_F$ | PMA semantics. | GLPR06, GLPR07 |
| | DL-Lite$_R^{pr}$ | Both revision and update. Based on $fcl_T(A)$ . | KZ11, KZC13 |
| | DL-Lite$_{FR}$ | Based on $cl_T(A)$. | CKNZ10 |

# Thank you!