Updates of Hybrid Knowledge Bases

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Part I: What's the Problem?

Hybrid Knowledge Bases

Description Logics

- ✓ standard first-order semantics
- ✓ open world assumption
- ✓ expressivity vs. computational complexity
- ✓ implementations
- ✗ poor set of primitives regarding binary predicates (roles)
- ✗ no closed world reasoning
- ✗ hard to express integrity constraints

Logic Programs

- ✓ help resolve the above mentioned problems
- ✓ well-understood declarative semantics
- ✓ good computational properties

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Integration difficulties

- ✗ semantic issues (OWA vs. CWA)
- ✗ pragmatic problems (decidability)

A number of approaches proposed

- CARIN [Levy and Rousset, 1998]
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- ✓ theoretically neat
- ✓ tight integration between the two distinct formalisms
- ✓ generalise most previous approaches
- ✓ known how to achieve decidability and tractability

Example (Cargo Imports Knowledge Base)

$\text{Admissible}(I) \leftarrow \sim\text{SuspectedBadGuy}(I).$

$\text{Approved}(C) \leftarrow \text{Admissible}(I), \text{RegisteredImporterOf}(I, C).$

$\text{LowRisk} \equiv \text{Approved} \sqcap (\exists\text{From.EUCountry})$

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Evolution of Hybrid Knowledge Bases

Knowledge evolves with time.

Example (Cargo Import Knowledge Base Updates)

$c : (\neg \text{LowRiskCommodity})$

$\sim\text{ApprovedImporterOf}(i, C) \leftarrow \text{Tomato}(C).$

Overall Goal

Deal with updates of Hybrid Knowledge Bases.

What is out there?

- Belief Update
- Rule Update

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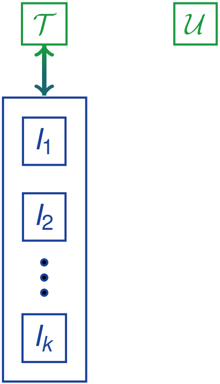

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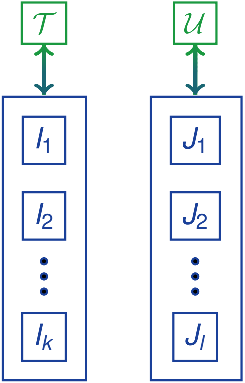

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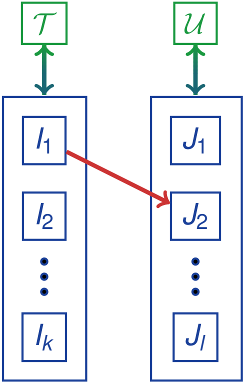

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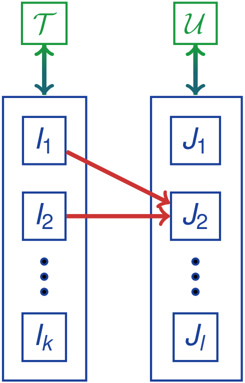

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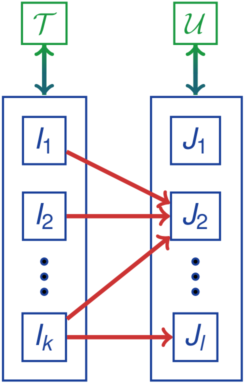

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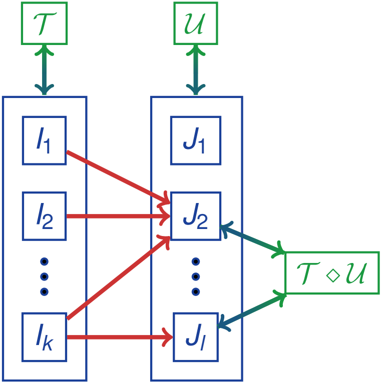

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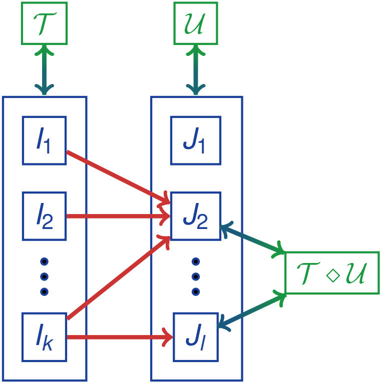

- Winslett's operator $\diamond^W$ – minimizes set difference

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Theorem (Representation Theorem Template)

Let $\mathcal{C}$ be a (constructively defined) class of operators, $\mathcal{P}$ a set of properties and $\diamond$ an update operator.
Then $\diamond$ belongs to $\mathcal{C}$ if and only if $\diamond$ satisfies properties from $\mathcal{P}$.

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  - ✗ representability
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- existing work on ABox updates with a no or a static TBox addresses these issues

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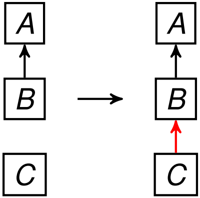

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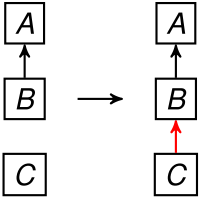

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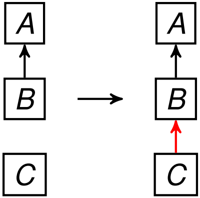

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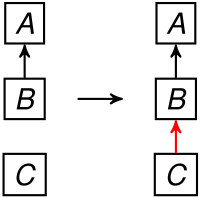

Theorem (Unsuitability of Belief Update for TBoxes)

It is impossible for an update operator to satisfy (KM 3), (KM 4), (KM 8) and the two properties above.

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Belief Update is very far from a solution to ontology updates

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- belief update approach is problematic
  - (KM 4): equivalent updates of equivalent programs lead to equivalent results
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- inertia applied to atoms
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Combining them is difficult!

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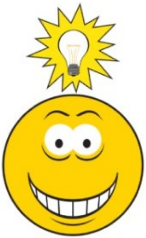
Part II: Addressing the Problem

1. Static Rules and Dynamic ABox



- rules: static queries, policies, business rules, strategies, preferences…
- TBox: static relations between roles and concepts
- a sequence of ABoxes: dynamically changing assertions about individuals in concepts and roles
- we proposed a solution for this scenario and investigated its basic properties

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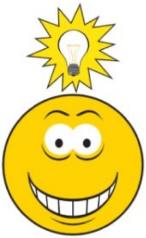

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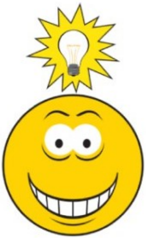

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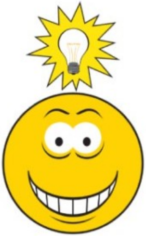

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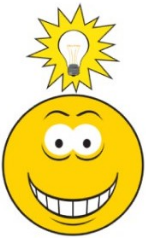

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1. Static Rules and Dynamic ABox (Technicalities)

- we defined semantics for a normal logic program $\mathcal{P}$ updated by an ABox sequence $\mathcal{A} = (\mathcal{A}_1, \ldots, \mathcal{A}_n)$ in the presence of a TBox $\mathcal{T}$
- M is a stable model of a normal logic program $\mathcal{P}$ iff M is the least fixed point of $T_{\mathcal{P}^M}$ where $\mathcal{P}^M$ is the Gelfond-Lifschitz reduct of $\mathcal{P}$ w.r.t. M and

$$T_{\mathcal{P}}(M) = \{ H(r) \mid r \in \mathcal{P} \wedge M \models B(r) \}$$

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M is a minimal change dynamic stable model of $\mathcal{P} \oplus^{\mathcal{T}} \mathcal{A}$ iff M is the least fixed point of $T_{\mathcal{P}^M \oplus^{\mathcal{T}} \mathcal{A}}$ where

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1. Static Rules and Dynamic ABox (Properties)

- ✓ Primacy of new information
- ✓ Syntax-independence w.r.t. to $\mathcal{T}$ and $\mathcal{A}$
- ✓ Generalisation of stable model semantics
- ✓ Generalisation of Winslett's update semantics
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Proposition

Let $\mathcal{P}$ be a finite ground program, $\mathcal{T}$ a TBox, $\mathcal{A}$ an ABox and M a minimal change dynamic stable model of $\mathcal{P} \oplus^{\mathcal{T}} \mathcal{A}$. Then $M \models \mathcal{A}$.

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Proposition

Let $\mathcal{P}$ be a finite ground program, $\mathcal{T}, \mathcal{T}'$ be TBoxes such that $\text{mod}(\mathcal{T}) = \text{mod}(\mathcal{T}')$, *$\mathcal{A}, \mathcal{A}'$ be ABoxes such that* $\text{mod}(\mathcal{A}) = \text{mod}(\mathcal{A}')$ *and M be an MKNF interpretation. Then M is a minimal change dynamic stable model of $\mathcal{P} \oplus^{\mathcal{T}} \mathcal{A}$ if and only if M is a minimal change dynamic stable model of $\mathcal{P} \oplus^{\mathcal{T}'} \mathcal{A}'$.*

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Let $\mathcal{P}$ be a finite ground program. Then M is a stable model of $\mathcal{P}$ if and only if M is a minimal change dynamic stable model of $\mathcal{P} \oplus^{\emptyset} \emptyset$.

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Proposition

Let $\mathcal{P}$ be a finite ground program, $\mathcal{T}$ be a TBox and $\mathcal{A} = (\mathcal{A}_1, \mathcal{A}_2, \ldots, \mathcal{A}_n)$ a sequence of ABoxes (where $n \geq 1$). Let $\mathcal{A}' = (\mathcal{A}_1, \mathcal{A}_2, \ldots, \mathcal{A}_{i-1}, \mathcal{A}_i, \emptyset, \mathcal{A}_{i+1}, \ldots, \mathcal{A}_n)$ for some $i \in \{0, 1, 2, \ldots, n\}$. Then an MKNF interpretation M is a minimal change dynamic stable model of $\mathcal{P} \oplus^{\mathcal{T}} \mathcal{A}$ if and only if M is a minimal change dynamic stable model of $\mathcal{P} \oplus^{\mathcal{T}} \mathcal{A}'$.

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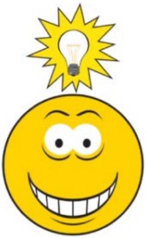
Proposition

Let $\mathcal{T}$ be a TBox, $\mathcal{A}$ an ABox and M an MKNF interpretation. Then M is a minimal change dynamic stable model of $\emptyset \oplus^{\mathcal{T}} \mathcal{A}$ if and only if $M = \mathrm{mod}(\mathcal{T} \cup \mathcal{A})$.

2. Modular Update Semantics



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- define a modular update semantics for these cases
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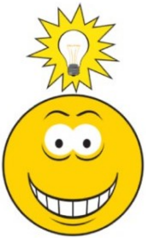

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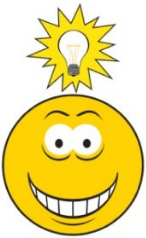

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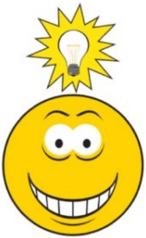

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$$q(Z) \leftarrow B(Z), \sim D(Z).$$

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Model of $\mathcal{K}$

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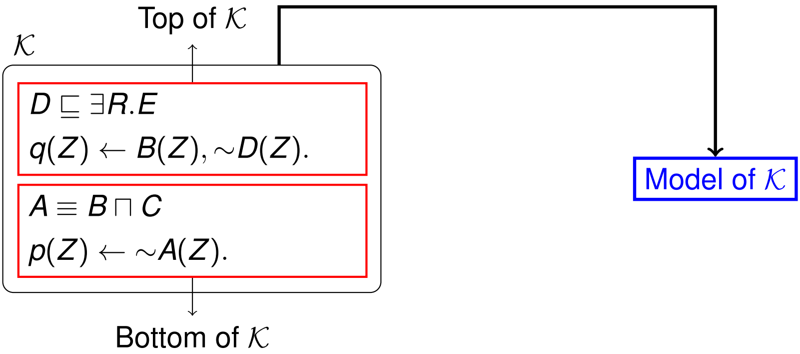

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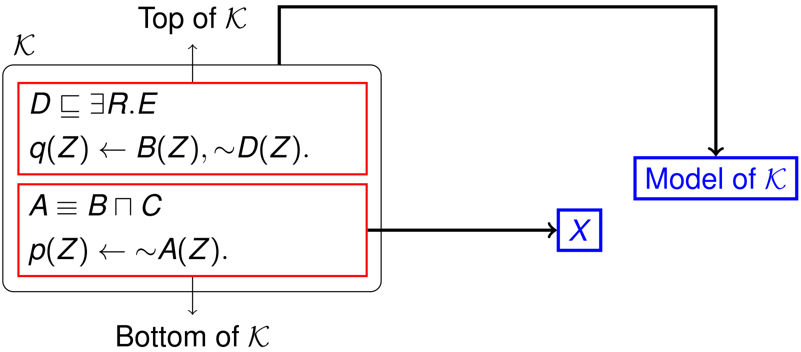

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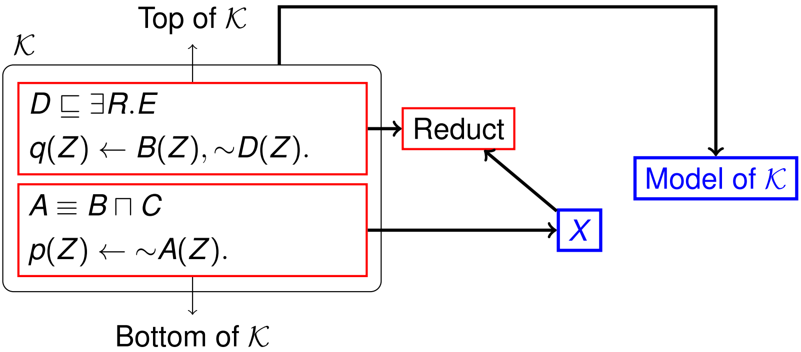

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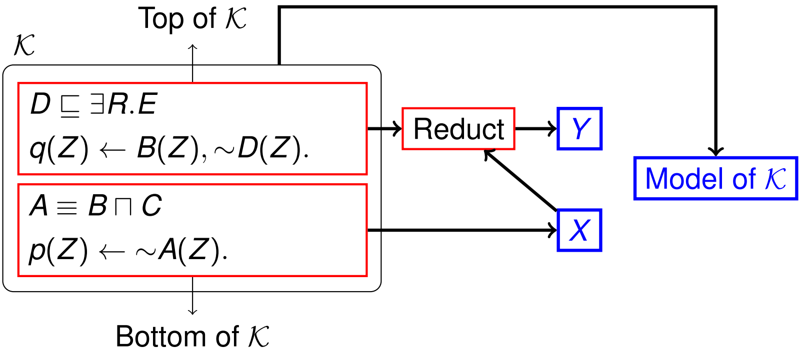

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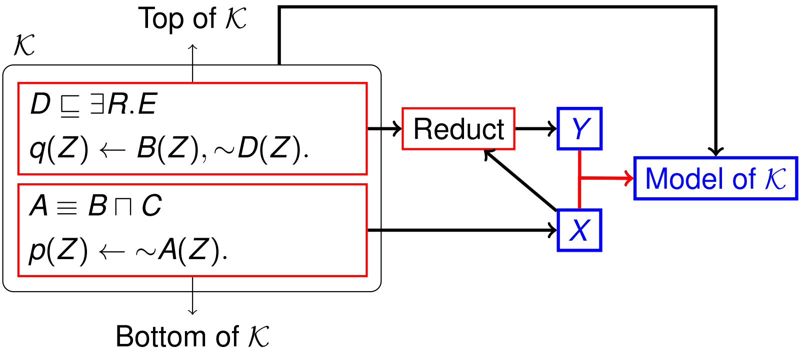

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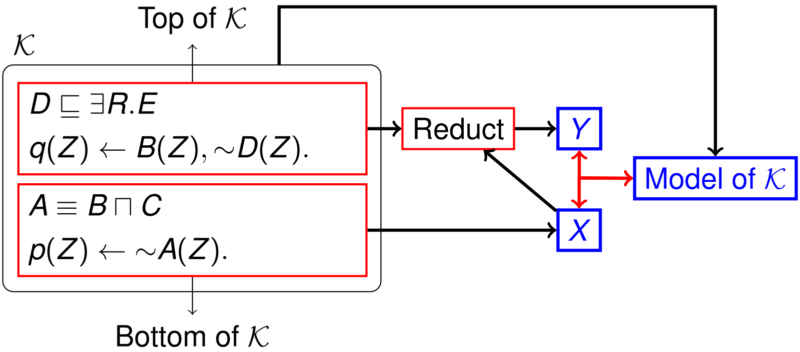

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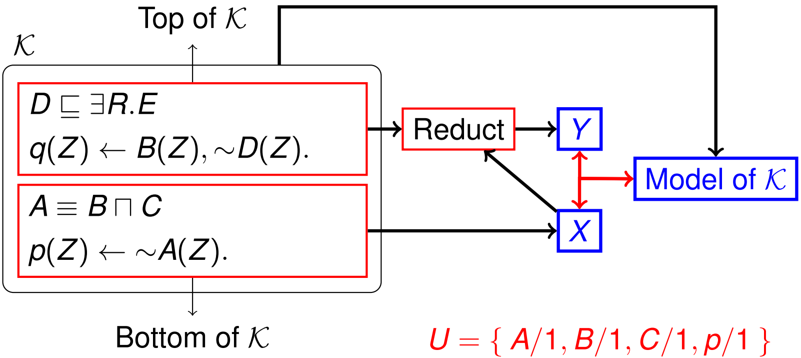

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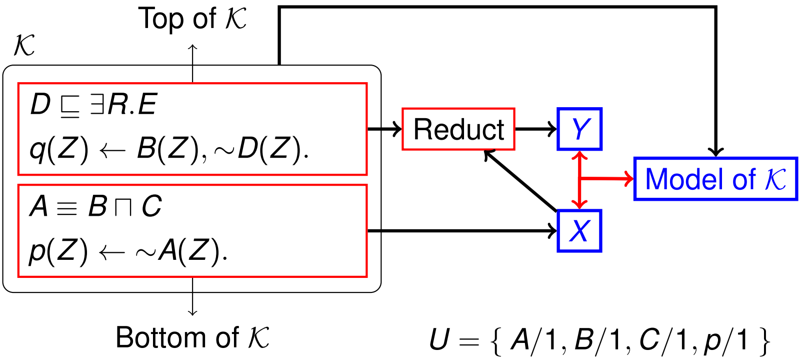

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Theorem (Splitting Theorem)

Let U be a splitting set for a hybrid knowledge base $\mathcal{K}$. Then M is an MKNF model of $\mathcal{K}$ if and only if $M = X \cap Y$ for some solution $\langle X, Y \rangle$ to $\mathcal{K}$ w.r.t. U.

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Definition (Splitting Sequence)

A splitting sequence for a hybrid knowledge base $\mathcal{K}$ is a monotone, continuous sequence $U = \langle U_\alpha \rangle_{\alpha<\mu}$ of splitting sets for $\mathcal{K}$ such that $\bigcup_{\alpha<\mu} U_\alpha = \mathbf{P}$.

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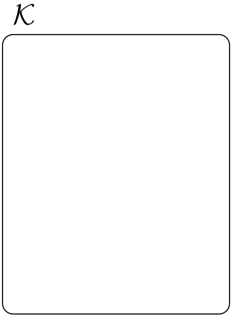

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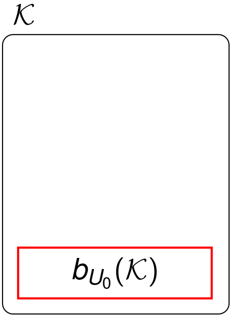

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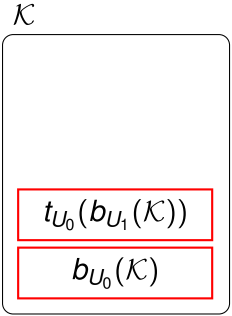

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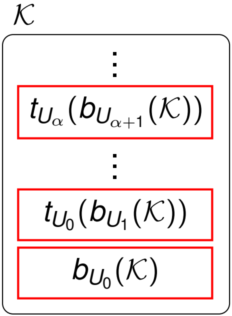

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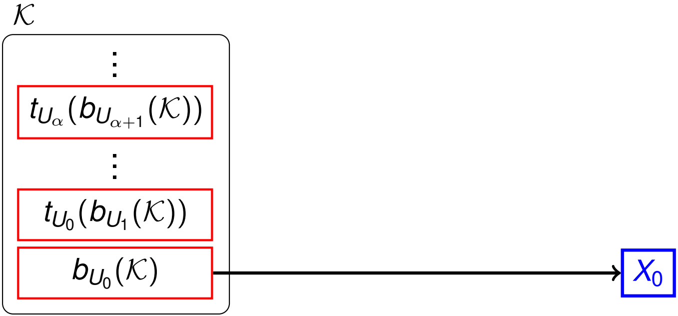

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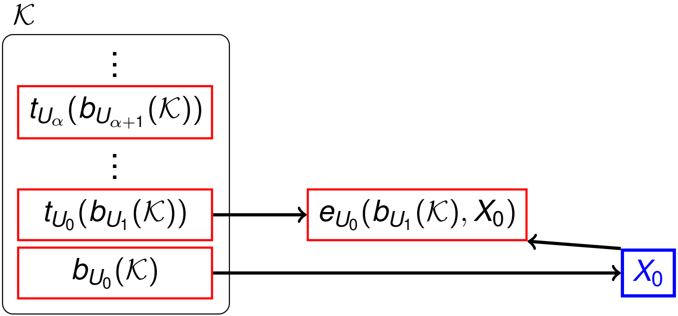

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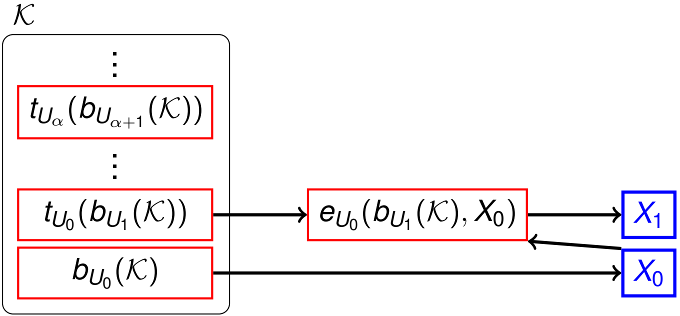

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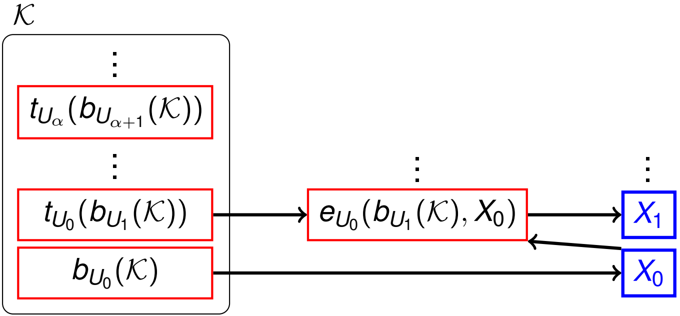

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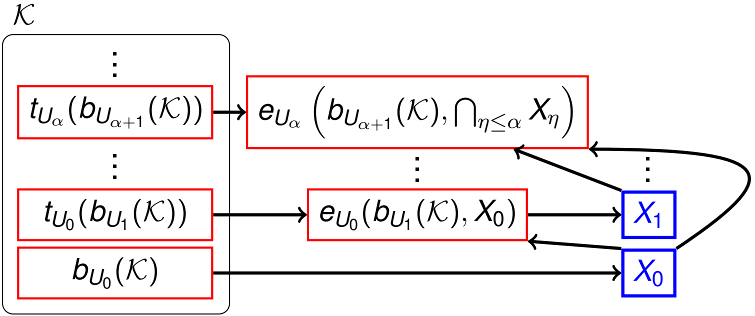

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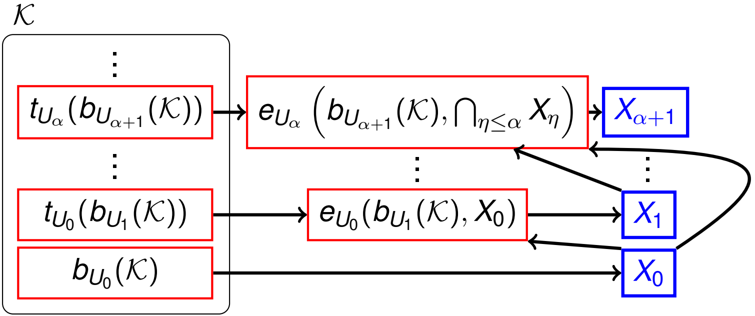

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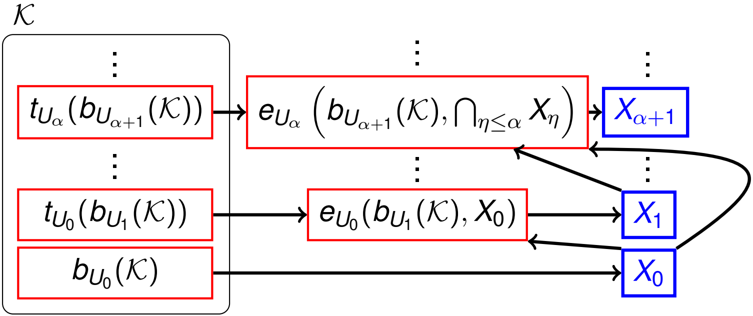

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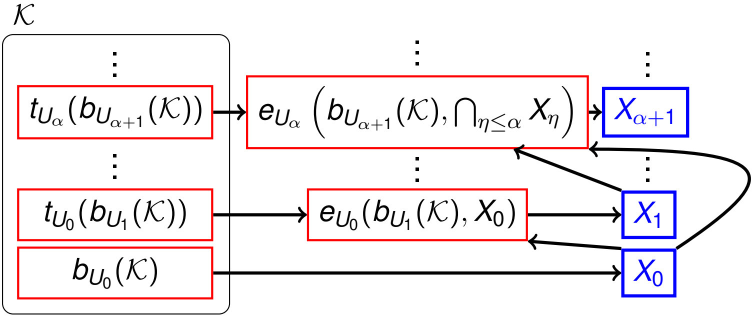

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2. Modular Update Semantics (Operator)

Question

Given

- an update semantics for $\langle \mathcal{O}_i \rangle_{i<n}$ and
- an update semantics for $\langle \mathcal{P}_i \rangle_{i<n}$,

to what type of $\mathcal{K} = \langle \mathcal{K}_i \rangle_{i<n}$ can we easily assign an update semantics?

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- $U = \langle U_\alpha \rangle_{\alpha<\mu}$ is called update-enabling if for all X and all α,

$$\left\langle e_{U_\alpha}(b_{U_{\alpha+1}}(\mathcal{K}_i), X) \right\rangle_{i<n} \tag{1}$$

  contains either only rules or only ontology axioms

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Definition

Let $U = \langle U_\alpha \rangle_{\alpha<\mu}$ be an update-enabling splitting sequence for a dynamic hybrid knowledge base $\mathcal{K}$. We say that an MKNF interpretation M is a dynamic MKNF model of $\mathcal{K}$ w.r.t. U if $M = \bigcap_{\alpha<\mu} X_\alpha$ for some solution $\langle X_\alpha \rangle_{\alpha<\mu}$ to $\mathcal{K}$ w.r.t. U.

2. Modular Update Semantics (Properties)

Using particular update operators:

1. Winslett's minimal change update operator [Winslett, 1990]
2. Refined dynamic stable models [Alferes et al., 2005]

- Independence of Splitting Sequence
- Generalisation of MKNF
- Generalisation of Winslett's Update Semantics
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Theorem (Independence of Splitting Sequence)

Let U, V be update-enabling splitting sequences for a dynamic hybrid knowledge base $\mathcal{K}$. Then M is a dynamic MKNF model of $\mathcal{K}$ w.r.t. U if and only if M is a dynamic MKNF model of $\mathcal{K}$ w.r.t. V.

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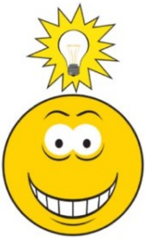

- (KM 4) + stable or strong equivalence = catastrophe

$\mathcal{P}_1: \quad a. \quad b. \qquad \mathcal{P}_2: \quad a \leftarrow b. \quad b. \qquad \mathcal{P}: \quad \sim b.$

- SE-Models: monotonic semantics more expressive than stable models
- view a program as the set of sets of SE-models of its rules
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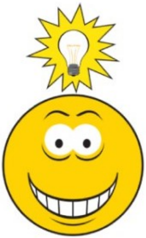

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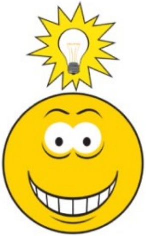

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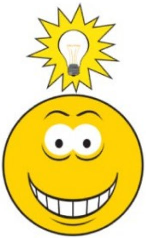

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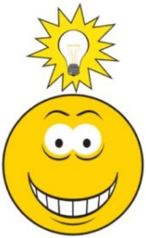

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Addressing Hybrid Updates

1. by restricting the dynamic part of the knowledge base
2. by restricting interaction between DL axioms and rules
3. by aiming to create semantic counterparts of the rule update semantics

Open Questions

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  - principles in line with intuitions
  - operators
  - representability
- rule update
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