Inconsistency Management in Reactive Mulit-Context Systems[1]

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Hybris Workshop
Dresden
November 29th, 2016

[1] Research has been supported by DFG and FWF (projects BR 1817/7-1 and FOR 1513)

Talks so far

Dresden (2013)

- Generalizing Multi-Context Systems for Reactive Stream Reasoning Applications [Ellmauthaler, 2013]
- by Stefan Ellmauthaler

Leipzig (2014)

- Multi-Context Systems for reactive reasoning in dynamic environments [Brewka et al., 2014]
- by Jörg Pührer

Potsdam (2015)

- Asynchronous Multi-Context Systems [Ellmauthaler and Pührer, 2015]
- by Stefan Ellmauthaler

Recent Development

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Reactive MCS

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Evolving MCS

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Reactive MCS

- presented at ECAI 2014
- developed in Leipzig
- equilibrium of one “step” is base kb in next “step”

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“new” reactive Multi-Context Systems

- combined ideas of rMCS and eMCS
- “bilateral” ongoing research on that topic

Outline

1. Motivation
2. Reactive Multi-Context Systems
3. Inconsistency Management

Motivation

- **integration** of heterogenous KR-formalisms
- **awareness** of continous flow of knowledge
  - information is constantly produced and shared
  - shift from static one-shot computation to stream processing
- distinguish between **persistent** and **non-persistent** effects of input streams
- **represent** state transitions over time

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- How to ensure consistency?
- How to repair inconsistent cases?
- How to work with inconsistent cases?

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- **Semantics**: Notion of Equilibrium
  Takes into account the semantics of each context and the operational formulas in the head of the applicable bridge rules

Reactive Multi-Context Systems

Definition (Reactive Multi-Context System)

A *reactive Multi-Context System (rMCS)* is a tuple $M = \langle \mathsf{C}, \mathsf{IL}, \mathsf{BR} \rangle$, where

- $\mathsf{C} = \langle C_1, \ldots, C_n \rangle$ is a tuple of contexts $C_i = \langle L_i, OP_i, \mathbf{mng}_i \rangle$
  - $L_i = \langle KB_i, BS_i, \mathbf{acc}_i \rangle$ is a logic,
  - OP_i is a *set of operations*,
  - $\mathbf{mng}_i : 2^{OP} \times KB \rightarrow KB$ is a *management function*.
- $\mathsf{IL} = \langle IL_1, \ldots, IL_k \rangle$ is a tuple of input languages;
- $\mathsf{BR} = \langle BR_1, \ldots, BR_n \rangle$ is a tuple such that each BR_i is a set of bridge rules for C_i over C and IL of the form

$$\mathbf{op} \leftarrow a_1, \ldots, a_j, \mathbf{not}\ a_{j+1}, \ldots, \mathbf{not}\ a_m$$

  - $\mathbf{op} = op$ or $\mathbf{op} = \mathbf{next}(op)$ for $op \in OP_i$.
  - and every *atom* a_ℓ, is a *context atom* $c{:}b$ or an *input atom* $s{::}b$.

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Semantics

Given

a rMCS $M = \langle\langle C_1, \dots, C_n\rangle, \langle IL_1, \dots, IL_k\rangle, \mathsf{BR}\rangle$, with

- an initial configuration of knowledge bases $\mathsf{KB} = \langle kb_i, \dots, kb_n\rangle$, such that $kb_i \in KB_i$, for each $i \in \{1, \dots, n\}$, and
- an input stream (until τ) $\mathcal{I} : [1..\tau] \to \mathsf{In}_M$

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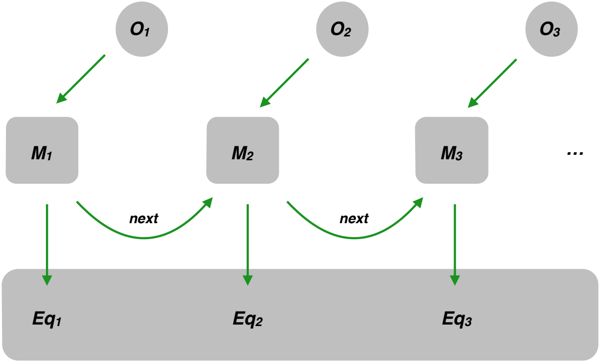
Equilibria Stream

- Static equilibrium at each time instant, with respect to management operations (op) in applicable bridge rules
- Knowledge bases are updated from one time instant to the next one by applying management operations ($\mathbf{next}(op)$) in applicable bridge rules

Semantics - Equilibria Stream



Semantics - Equilibria Stream

Definition (Equilibrium)

Let $M = \langle\langle C_1, \ldots, C_n\rangle, \mathsf{IL}, \mathsf{BR}\rangle$ be an rMCS, $\mathsf{KB} = \langle kb_1, \ldots, kb_n\rangle$ a configuration of knowledge bases for M, and I an input for M. Then, a belief state $\mathsf{B} = \langle B_1, \ldots, B_n\rangle$ for M is an equilibrium of M given KB and I if, for each $i \in \{1, \ldots, n\}$, we have that

$$B_i \in \mathbf{acc}_i(kb'), \text{ where } kb' = \mathbf{mng}_i(\mathbf{app}_i^{now}(\mathsf{I}, \mathsf{B}), kb_i).$$

Semantics - Equilibria Stream

Definition (Equilibria Stream)

Let $M = \langle\langle C_1, \ldots, C_n\rangle, \mathsf{IL}, \mathsf{BR}\rangle$ be an rMCS, $\mathsf{KB} = \langle kb_1, \ldots, kb_n\rangle$ a configuration of knowledge bases for M, and $\mathcal{I} : [1..\tau] \to \mathsf{In}_M$ an input stream for M until τ. Then, an equilibria stream of M given KB and $\mathcal{I}$ is a function $\mathcal{B} : [1..\tau] \to \mathsf{Bel}_M$ such that

- $\mathcal{B}^t$ is an equilibrium of M given $\mathcal{KB}^t$ and $\mathcal{I}^t$, where $\mathcal{KB}^t$ is
  - $\mathcal{KB}^1 = \mathsf{KB}$
  - $\mathcal{KB}^{t+1} = \mathbf{upd}_M(\mathcal{KB}^t, \mathcal{I}^t, \mathcal{B}^t)$, where
    $\mathbf{upd}_M(\mathsf{KB}, \mathsf{I}, \mathsf{B}) = \langle kb'_1, \ldots, kb'_n\rangle$, such that $kb'_i = \mathbf{mng}_i(\mathbf{app}_i^{next}(\mathsf{I}, \mathsf{B}), kb_i)$

Consistent rMCS

Definition

Let M be an rMCS, KB a configuration of knowledge bases for M, and $\mathcal{I}$ an input stream for M. Then:

- M is consistent with respect to KB and $\mathcal{I}$ if there exists an equilibria stream of M given KB and $\mathcal{I}$.
- M is strongly consistent with respect to KB if, for every input stream $\mathcal{I}$ for M, M is consistent with respect to KB and $\mathcal{I}$.

Strong Consistency of rMCS

Question

Can we ensure strong consistency of a rMCS?

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Definition

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Proposition

Let $M = \langle\langle C_1, \ldots, C_n\rangle, \mathsf{IL}, \mathsf{BR}\rangle$ *be an acyclic rMCS such that every* C_i*,* $1 \leq i \leq n$*, is totally coherent, and* KB *a configuration of knowledge bases for* M*. Then,* M *is strongly consistent with respect to* KB*.*

Recovering Equilibria Streams

Question

What if there are no equilibria streams?

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Definition (Repair)

Let $M = \langle \mathsf{C}, \mathsf{IL}, \mathsf{BR} \rangle$ be an rMCS, KB a configuration of knowledge bases for M, and $\mathcal{I}$ an input stream for M until τ. Let

- br_M denote the set of all bridge rules of M
- $M[R]$ denote the rMCS obtained from M by restricting the bridge rules to those not in R

A repair for M given KB and $\mathcal{I}$ is a function $\mathcal{R} : [1..\tau] \rightarrow 2^{br_M}$ such that there exists a function $\mathcal{B} : [1..\tau] \rightarrow \mathsf{Bel}_M$ such that

- $\mathcal{B}^t$ is an equilibrium of $M[\mathcal{R}^t]$ given $\mathcal{KB}^t$ and $\mathcal{I}^t$, with $\mathcal{KB}^t$ inductively defined as
  - $\mathcal{KB}^1 = \mathsf{KB}$
  - $\mathcal{KB}^{t+1} = \mathbf{upd}_{M[\mathcal{R}^t]}(\mathcal{KB}^t, \mathcal{I}^t, \mathcal{B}^t)$,

On repairs of rMCS composed of totally coherent contexts

Proposition

Let $M = \langle\langle C_1, \ldots, C_n\rangle, \mathsf{IL}, \mathsf{BR}\rangle$ *be an rMCS such that each* C_i *is totally coherent,* KB *a configuration of knowledge bases for* M*, and* $\mathcal{I}$ *an input stream for* M *until* τ*. Then, there exists* $\mathcal{R} : [1..\tau] \to 2^{br_M}$ *and* $\mathcal{B} : [1..\tau] \to \mathsf{Bel}_M$ *such that* $\mathcal{B}$ *is a repaired equilibria stream given* KB*,* $\mathcal{I}$ *and* $\mathcal{R}$*.*

Types of Repairs

Question

Are all the repairs equally good?

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Definition

For two repairs $\mathcal{R}_a$ and $\mathcal{R}_b$, we say that $\mathcal{R}_a \leq \mathcal{R}_b$ if $\mathcal{R}_a^i \subseteq \mathcal{R}_b^i$ for every $i \leq \tau$, and that $\mathcal{R}_a < \mathcal{R}_b$ if $\mathcal{R}_a \leq \mathcal{R}_b$ and $\mathcal{R}_a^i \subset \mathcal{R}_b^i$ for some $i \leq \tau$.

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- Minimal Repair if there is no repair $\mathcal{R}_a$ for M given KB and $\mathcal{I}$ such that $\mathcal{R}_a < \mathcal{R}$.
- Global Repair if $\mathcal{R}^i = \mathcal{R}^j$ for every $i, j \leq \tau$.

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- Global Repair if $\mathcal{R}^i = \mathcal{R}^j$ for every $i, j \leq \tau$.
- Minimal Global Repair if $\mathcal{R}$ is global and there is no global repair $\mathcal{R}_a$ for M given KB and $\mathcal{I}$ such that $\mathcal{R}_a < \mathcal{R}$.

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Let $\mathcal{R}$ be a repair for a rMCS M given KB and $\mathcal{I}$. We say that $\mathcal{R}$ is a:

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- Global Repair if $\mathcal{R}^i = \mathcal{R}^j$ for every $i, j \leq \tau$.
- Minimal Global Repair if $\mathcal{R}$ is global and there is no global repair $\mathcal{R}_a$ for M given KB and $\mathcal{I}$ such that $\mathcal{R}_a < \mathcal{R}$.
- Incremental Repair if $\mathcal{R}^i \subseteq \mathcal{R}^j$ for every $i \leq j \leq \tau$.
- Minimally Incremental Repair if $\mathcal{R}$ is incremental and there is no incremental repair $\mathcal{R}_a$ and $j \leq \tau$ such that $\mathcal{R}_a^i \subset \mathcal{R}^i$ for every $i \leq j$.

Partial Equilibria Stream

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What if there are no repairs?

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What if there are no repairs? ... Or we don't want to compute them?

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Definition (Partial Equilibria Stream)

Let $M = \langle \mathsf{C}, \mathsf{IL}, \mathsf{BR} \rangle$ be an rMCS, KB a configuration of knowledge bases for M, and $\mathcal{I}$ an input stream for M until τ. A partial equilibria stream of M given KB and $\mathcal{I}$ is a partial function $\mathcal{B} : [1..\tau] \nrightarrow \mathsf{Bel}_M$ such that

- $\mathcal{B}^t$ is an equilibrium of M given $\mathcal{KB}^t$ and $\mathcal{I}^t$,
- or $\mathcal{B}^t$ is undefined otherwise.

$\mathcal{KB}^t$ inductively defined as

- $\mathcal{KB}^1 = \mathsf{KB}$
- $\mathcal{KB}^{t+1} = \begin{cases} \mathbf{upd}_M(\mathcal{KB}^t, \mathcal{I}^t, \mathcal{B}^t), & \text{if } \mathcal{B}^t \text{ is not undefined.} \\ \mathcal{KB}^t, & \text{otherwise.} \end{cases}$

On Partial Equilibria Stream

Proposition

Every equilibria stream of M given KB *and* $\mathcal{I}$ *is a partial equilibria stream of* M *given* KB *and* $\mathcal{I}$

On Partial Equilibria Stream

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Every equilibria stream of M *given* KB *and* $\mathcal{I}$ *is a partial equilibria stream of* M *given* KB *and* $\mathcal{I}$

Proposition (Partial equilibria streams always exist)

Let M *be an rMCS,* KB *a configuration of knowledge bases for* M*, and* $\mathcal{I}$ *an input stream for* M *until* τ*. Then, there exists* $\mathcal{B} : [1..\tau] \nrightarrow \mathsf{Bel}_M$ *such that* $\mathcal{B}$ *is a partial equilibria stream given* KB *and* $\mathcal{I}$*.*

Conclusion

- We have introduced the “new” rMCS
- acyclic rMCS whose contexts are totally coherent are strongly consistent
- for each rMCS with only totally coherent contexts there exist repairs
- partial equilibria streams are a way to work with cases without repairs

Thank you for your interest!

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And see you on June $12^{th}/13^{th}$ in Leipzig...

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