

Inconsistency Management in Reactive Multi-Context Systems¹

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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

Reactive MCS

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

Evolving MCS

- presented at ECAI 2014
- developed in Lisbon
- utilise a “next” operator

“new” reactive Multi-Context Systems

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

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

- **integration** of heterogenous KR-formalisms
- **awareness** of continuous 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

Inconsistency Management

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

Multi-Context Systems

- **Contexts:** knowledge base represented in some logic
Logic: defines the possible knowledge bases and their semantics
Example: Logic programs with answer-set semantics
- **Operations:** each context has a set of operations applicable to the knowledge bases of the context
Examples: addition, revision, updating, forgetting
- **Bridge rules:** declarative non-monotonic rules that model the flow of information between contexts
Apply the operation in the head of the rule, provided the queries (to other contexts) in the body are successful
- **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 $M = \langle C, IL, BR \rangle$, where

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

$$\text{op} \leftarrow a_1, \dots, a_j, \text{not } a_{j+1}, \dots, \text{not } a_m$$

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

Given

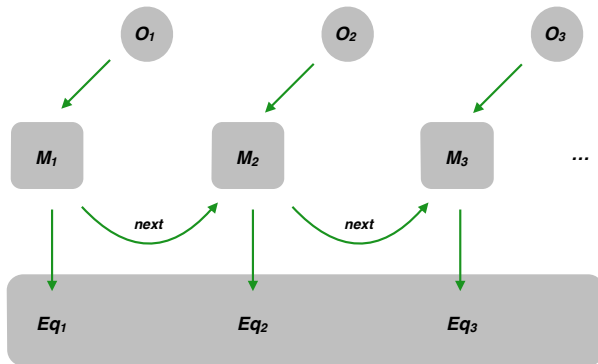
a rMCS $M = \langle \langle C_1, \dots, C_n \rangle, \langle IL_1, \dots, IL_k \rangle, BR \rangle$, with

- an initial configuration of knowledge bases $KB = \langle kb_1, \dots, kb_n \rangle$, such that $kb_i \in KB_i$, for each $i \in \{1, \dots, n\}$, and
- an input stream (until τ) $\mathcal{I} : [1.. \tau] \rightarrow In_M$

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 ($next(op)$) in applicable bridge rules

Semantics - Equilibria Stream



Definition (Equilibrium)

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

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

Definition (Equilibria Stream)

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

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

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?

Definition

A context C_i is **totally coherent** if $\text{acc}_i(kb) \neq \emptyset$, for every $kb \in KB_i$.

Definition

An rMCS M is **acyclic** if the transitive closure of the dependency relation between contexts induced by the bridge rules is irreflexive.

Proposition

Let $M = \langle \langle C_1, \dots, C_n \rangle, \text{IL}, \text{BR} \rangle$ 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?

Definition (Repair)

Let $M = \langle C, IL, BR \rangle$ 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 $\mathcal{B} : [1.. \tau] \rightarrow \text{Bel}_M$ 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
 - ▶ $\mathcal{KB}^1 = \text{KB}$
 - ▶ $\mathcal{KB}^{t+1} = \text{upd}_{M[\mathcal{R}^t]}(\mathcal{KB}^t, \mathcal{I}^t, \mathcal{B}^t)$,

On repairs of rMCS composed of totally coherent contexts

Proposition

Let $M = \langle \langle C_1, \dots, C_n \rangle, \text{IL}, \text{BR} \rangle$ 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 $\mathcal{R} : [1.. \tau] \rightarrow 2^{br_M}$ and $\mathcal{B} : [1.. \tau] \rightarrow \text{Bel}_M$ 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?

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 $i \leq \tau$.

Types of Repairs

Definition (Types of Repairs)

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

- **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 $i, j \leq \tau$.
- **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

Question

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

Definition (Partial Equilibria Stream)

Let $M = \langle C, IL, BR \rangle$ 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 $\mathcal{B} : [1..\tau] \rightarrow \text{Bel}_M$ 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

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

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}

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 $\mathcal{B} : [1.. \tau] \rightarrow \text{Bel}_M$ 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!

And see you on June 12th/13th in Leipzig...

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