Asynchronous Multi-Context Systems[1]

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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

Outline

reactive Multi-Context Systems so far ...

Motivation

- **integration** of heterogeneous KR-formalisms
- **awareness** of continuous flow of knowledge

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Realisation

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Realisation

- Contexts with different KR & Reasoning formalisms
- Bridge-Rules for exchange of beliefs
- Notion of Equilibrium as Semantics
- Run represents the change of knowledge and belief over time

... and a slight look to online-applications

- Many different services and sources of knowledge
- Continuous flow of information
- Data collection till sufficient knowledge for their tasks is available
- Communication is often query-based
- Asynchronous communication protocols

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Computer Aided Emergency Team Management

Example Environment - Emergency Team Management

- Emergency Call
- Classification and Prioritisation of each case
- Overview of available rescue units
- Overview on ETAs for each unit and case
- Suggesting optimal assignments
- Communicate Tasks to rescue units

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Requirements

- Fast response to events
- Consider different sources of data
- Modularity for additional components
- Human as last instance for decisions

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→ Need for Output-Rules (OR)

→ Keep track of information provided by OR

→ Input stream for each context

→ Interaction with environment:

- aMCS wide input streams
- aMCS wide output streams

Other Design-Choices

- Each context decide when to compute
  - realised by computation controller cc
- Dynamic adjustments of context-management
  - computation controller (cc)
  - output rules (OR)
  - context-semantics (ACC)
  - context update function (cu)

Asynchronous Multi-Context Systems

Definition

A *data package* is a pair $d = \langle s, I \rangle$, where $s \in \mathcal{N}$ is either a context name or a sensor name, stating the *source* of d, and $I \subseteq \mathcal{IL}$ is a set of pieces of information. An *information buffer* is a sequence of data packages.

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Definition

Let $C = \langle \mathsf{n}, \mathcal{LS} \rangle$ be a context. An *output rule* r for C is an expression of the form

$$\langle \mathsf{n}, \mathsf{i} \rangle \leftarrow b_1, \ldots, b_j, \mathrm{not}\ b_{j+1}, \ldots, \mathrm{not}\ b_m, \tag{1}$$

such that $\mathsf{n} \in \mathcal{N}$ is the name of a context or an output stream, $\mathsf{i} \in \mathcal{IL}$ is a piece of information, and every b_ℓ $(1 \leq \ell \leq m)$ is a belief for C, i.e., $b_\ell \in S$ for some $S \in \mathcal{BS}_{\mathcal{LS}}$.

Definition

Let $C = \langle \mathsf{n}, \mathcal{LS} \rangle$ be a context, OR a set of output rules for C, $S \in \mathcal{BS}_{\mathcal{LS}}$ a belief set, and $\mathsf{n}' \in \mathcal{N}$ a name. Then, the data package

$$d_C(S, \mathrm{OR}, \mathsf{n}') = \langle \mathsf{n}, \{ i \mid r \in \mathrm{OR}, hd(r) = \langle \mathsf{n}', \mathsf{i} \rangle, S \models \mathrm{bd}(r) \} \rangle$$

is the *output* of C with respect to OR under S relevant for n.

Definition

Let $C = \langle \mathsf{n}, \mathcal{LS} \rangle$ be a context. A *configuration* of C is a tuple $cf = \langle \mathrm{KB}, \mathrm{ACC}, \mathrm{ib}, cm \rangle$, where $\mathrm{KB} \in \mathcal{KB}_{\mathcal{LS}}$, $\mathrm{ACC} \in \mathcal{ACC}_{\mathcal{LS}}$, ib is a finite information buffer, and cm is a *context management* for C which is a triple $cm = \langle \mathrm{cc}, \mathrm{cu}, \mathrm{OR} \rangle$, where

- cc is a computation controller for C,
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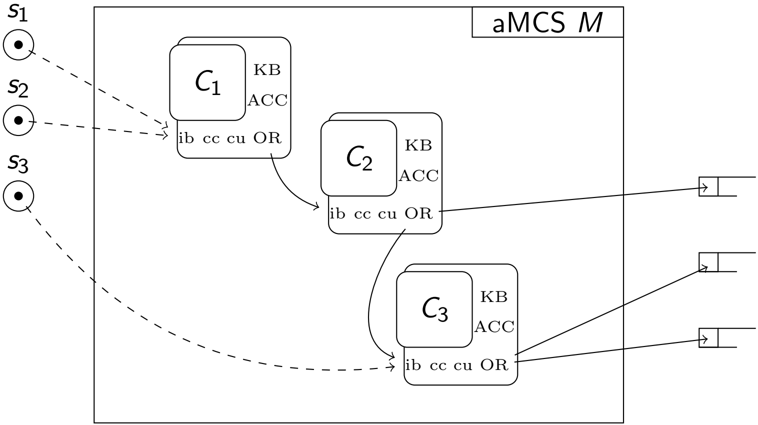
- cu is a *context update function* for C which is a function that maps an information buffer $\mathrm{ib} = d_1, \ldots, d_m$ and an admissible knowledge base of $\mathcal{LS}$ to a configuration $cf' = \langle \mathrm{KB}', \mathrm{ACC}', \mathrm{ib}', cm' \rangle$ of C with $\mathrm{ib}' = d_k, \ldots, d_m$ for some $k \geq 1$.

Asynchronous Multi-Context Systems



Run of an aMCS

Configuration of an aMCS

- Configuration for each Context
- Content of each output stream (output buffer)

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Definition (Run structure)

Let $M = \langle\langle C_1, \ldots, C_n\rangle, \langle \mathrm{o}_1, \ldots, \mathrm{o}_m\rangle\rangle$ be an aMCS. A run structure for M is a sequence

$$R = \ldots, Cf^{t}, Cf^{t+1}, Cf^{t+2}, \ldots \quad ,$$

where $t \in \mathbb{Z}$ is a point in time, and every $Cf^{t'}$ in R ($t' \in \mathbb{Z}$) is a configuration of M.

Run of an aMCS

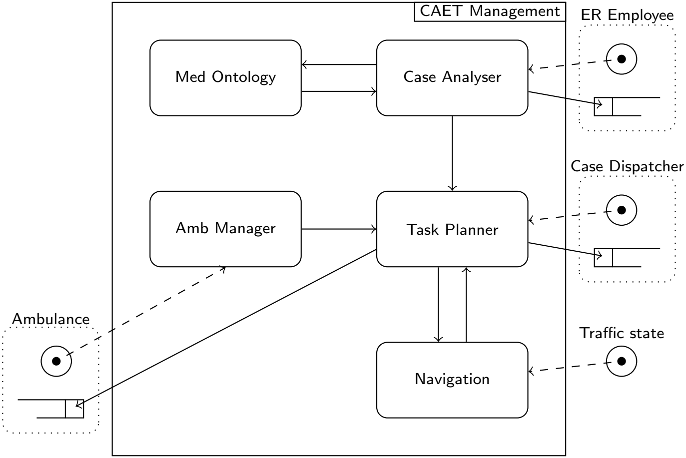
Time-awareness

- Computation of belief sets takes time
- Enumeration of belief sets takes time
- Verification of non-existence of (further) belief sets takes time

Run execution

- If a Context finds a belief set, OR are applied
- Information is distributed to input-buffers of contexts or output streams
- If a Context has finished its computation, EOC is sent to all stakeholders

Example of an aMCS



Differences to rMCS

- rMCSs use equilibria
  - strong semantics
  - tight integration approach where context semantics are interdependent
  - every context need to agree $\rightarrow$ each context needs to wait

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  - strong semantics
  - tight integration approach where context semantics are interdependent
  - every context need to agree $\rightarrow$ synchronous approach
- rMCSs have equilibria as source of non-determinism
- aMCSs have computation time as non-deterministic flavour (concurrency)

Simulation of rMCS

- For each Context C_i of the rMCS, introduce three aMCS Contexts:
  - C_i^{kb} stores its current knowledge base
  - $C_i^{kb'}$ stores update of the knowledge base and compute its semantics
  - C_i^{m} implements the bridge rules and the management function

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  - C_i^{kb} stores its current knowledge base
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  - C_i^{m} implements the bridge rules and the management function
- Three contexts for the rMCS, where
  - C^{obs} receives sensor data and distributes the information,
  - C^{guess} guesses equilibrium candidates and propagates them to C_i^m, and
  - C^{check} compares all results of the contexts and informs other contexts if an equilibrium has been found

Future Work

- Analysis how other approaches (e.g., `clingo` [Gebser et al., 2012]) are capable for prototypical implementations
- implement a prototype for aMCS (work in progress)
- Study modelling patterns and best practices for aMCS
- Analysis how features of other approaches (e.g., online queries, iterative computing, ...) relate to aMCS concepts (e.g., ib, OR,cc, ...)

Related Work

- aMCS are motivated by rMCS [Brewka et al., 2014] and are based on MCS [Brewka et al., 2011a, Brewka et al., 2011b]
- Evolving Mulit-Context Systems [Gonçalves et al., 2014] follow a similar approach to rMCS
- A concept similar for output rules in reactive Multi-Context Systems has been presented as reactive bridge rules [Ellmauthaler, 2013]

Thank you for your interest!

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Definition

A context is a pair $C = \langle \mathsf{n}, \mathcal{LS} \rangle$ where $\mathsf{n} \in \mathcal{N}$ is the name of the context and $\mathcal{LS}$ is a logic suite.

Definition

An aMCS (of length n with m output streams) is a pair $M = \langle \mathsf{C}, \mathsf{O} \rangle$, where $\mathsf{C} = \langle C_1, \ldots, C_n \rangle$ is an n-tuple of contexts and $\mathsf{O} = \langle \mathsf{o}_1, \ldots, \mathsf{o}_m \rangle$ with $\mathsf{o}_j \in \mathcal{N}$ for each $1 \leq j \leq m$ is a tuple containing the names of the output streams of M.

Definition

A *data package* is a pair $d = \langle s, I \rangle$, where $s \in \mathcal{N}$ is either a context name or a sensor name, stating the *source* of d, and $I \subseteq \mathcal{IL}$ is a set of pieces of information. An *information buffer* is a sequence of data packages.

Definition

Let $C = \langle \mathsf{n}, \mathcal{LS} \rangle$ be a context. A *computation controller* for C is a relation cc between a KB $\mathrm{KB} \in \mathcal{KB}_{\mathcal{LS}}$ and a finite information buffer.

Definition

Let $C = \langle \mathsf{n}, \mathcal{LS} \rangle$ be a context. An *output rule* r for C is an expression of the form

$$\langle \mathsf{n}, \mathsf{i} \rangle \leftarrow b_1, \ldots, b_j, \mathrm{not}\ b_{j+1}, \ldots, \mathrm{not}\ b_m, \qquad (2)$$

such that $\mathsf{n} \in \mathcal{N}$ is the name of a context or an output stream, $\mathsf{i} \in \mathcal{IL}$ is a piece of information, and every b_ℓ $(1 \leq \ell \leq m)$ is a belief for C, i.e., $b_\ell \in S$ for some $S \in \mathcal{BS}_{\mathcal{LS}}$.

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Let $M = \langle\langle C_1, \ldots, C_n\rangle, \langle \mathrm{o}_1, \ldots, \mathrm{o}_m\rangle\rangle$ be an aMCS. A *configuration* of M is a pair

$$Cf = \langle\langle cf_1, \ldots, cf_n\rangle, \langle \mathrm{ob}_1, \ldots, \mathrm{ob}_m\rangle\rangle,$$

where

- for all $1 \leq i \leq n$ $cf_i = \langle \mathrm{KB}, \mathrm{ACC}, \mathrm{ib}, cm\rangle$ is a configuration for C_i and for every output rule $r \in \mathrm{OR}_{cm}$ we have $\mathrm{n} \in \mathcal{N}(M)$ for $\langle \mathrm{n}, \mathrm{i}\rangle = hd(r)$, and
- $\mathrm{ob}_j = \ldots, d_{l-1}, d_l$ is an information buffer with a final element d_l that corresponds to the data on the output stream named o_j for each $1 \leq j \leq m$ such that for each $h \leq l$ with $d_h = \langle \mathrm{n}, \mathrm{i}\rangle$ we have $\mathrm{n} = \mathrm{n}_{C_i}$ for some $1 \leq i \leq n$.

Definition

Let $M = \langle\langle C_1, \ldots, C_n\rangle, \langle o_1, \ldots, o_m\rangle\rangle$ be an aMCS. A run structure for M is a sequence

$$R = \ldots, Cf^{t}, Cf^{t+1}, Cf^{t+2}, \ldots \quad ,$$

where $t \in \mathbb{Z}$ is a point in time, and every $Cf^{t'}$ in R ($t' \in \mathbb{Z}$) is a configuration of M.

Definition

Let M be an aMCS of length n with m output streams and R a run structure for M. R is a *run* for M if the following conditions hold for every $1 \leq i \leq n$ and every $1 \leq j \leq m$:

(i) if cf_i^t and cf_i^{t+1} are defined, C_i is neither busy nor waiting at time t, then

- C_i is busy at time $t+1$,
- $cf_i^{t+1} = \mathrm{cu}_{cm_i^t}(\mathrm{ib}_i^t, \mathrm{KB}_i^t)$

We say that C_i *started a computation* for KB_i^{t+1} at time $t+1$.

(ii) if C_i *started a computation* for KB at time t then

- we say that this computation ended at time t', if t' is the earliest time point with $t' \geq t$ such that $\langle \mathsf{n}_{C_i}, \mathrm{EOC} \rangle$ is added to every stakeholder buffer b of C_i at t'; the addition of $d_{C_i}(S, \mathrm{OR}_{cm_i^{t''}}, \mathsf{n})$ to b is called an *end of computation notification*.
- for all $t' > t$ such that $cf_i^{t'}$ is defined, C_i is busy at t' unless the computation ended at some time t'' with $t < t'' < t'$.
- if the computation ended at time t' and $cf_i^{t'+1}$ is defined then C_i is not busy at $t'+1$.

Definition

(iii) if C_i *started a computation* for KB at time t that ended at time t' then for every belief set $S \in \mathrm{ACC}_i^t$ there is some time t'' with $t \leq t'' \leq t'$ such that

- $d_{C_i}(S, \mathrm{OR}_{cm_i^{t''}}, \mathsf{n})$ is added to every stakeholder buffer b of C_i for n at t''.

We say that C_i *computed* S at time t''. The addition of $d_{C_i}(S, \mathrm{OR}_{cm_i^{t''}}, \mathsf{n})$ to b is called a *belief set notification*.

(iv) if ob_j^t and ob_j^{t+1} are defined and $\mathrm{ob}_j^t = \ldots, d_{l-1}, d_l$ then $\mathrm{ob}_j^{t+1} = \ldots, d_{l-1}, d_l, \ldots, d_{l'}$ for some $l' \geq l$. Moreover, every data package $d_{l''}$ with $l < l'' \leq l'$ that was added at time $t+1$ results from an end of computation notification or a belief set notification.

(v) if cf_i^t and cf_i^{t+1} are defined, C_i is busy or waiting at time t, and $\mathrm{ib}_i^t = d_1, \ldots, d_l$ then we have $\mathrm{ib}_i^{t+1} = d_1, \ldots, d_l, \ldots, d_{l'}$ for some $l' \geq l$. Moreover, every data package $d_{l''}$ with $l < l'' \leq l'$ that was added at time $t+1$ either results from an end of computation notification or a belief set notification or $\mathsf{n} \notin \mathcal{N}(M)$ (i.e., n is a sensor name) for $d_{l''} = \langle \mathsf{n}, \mathsf{i} \rangle$.