Self-aware architecture to support partial control of emergent behavior

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We strive to improve the control of man-made system of systems by developing capabilities for:

- detecting the emergent behavior in due time by supporting situation awareness of components, and
- keeping the behaviour within a security envelope

Examples of considered system of systems are:

- networked autonomous pervasive computing systems
- mixed human-machine systems, e.g.
  - network enabled capability in military applications
  - advanced flexible manufacturing and logistics systems
  - crisis avoidance and management in complex systems
System of systems are formally described

as self-organizing multi-agent systems that are
– composed of autonomous, interacting components
– exhibiting cognitive, and proactive behavior which is
– susceptible to situational constraints
  • e.g. temporal, spatial, cultural, social, etc.

Research issues in systems of systems (how to?):
• Enable (or improve) observability, predictability, and dependability of system’s behavior
• Keep system’s behavior within security envelope
• Verify system’s behavior during its operation, whenever system has been readjusted (due to self-X properties of the system)
Classical and non-classical computation

- **Classical computational paradigms**
  - e.g. Turing machine paradigm – characterised by "ballistic calculations" that do not accept input or feedback from the environment while performing calculations

- **Non-classical computational paradigms**
  - e.g. interaction-centred computation -- accept supplementary input or environmental feedback while computing, and remember history of computations

- **Computationally**, only non-classical paradigm based computations are capable of describing and analysing cognitive and proactive behaviour of a system of systems.
System architecture and Interactions

SYSTEM (P, Σ)

Actor agents $P = \{p_1, p_2, \ldots, p_i, \ldots, p_n\}$

Communication agents $\Sigma \subseteq P \times P$
Self-awareness and mediated interactions

• Architecture of a conventional system does not change during system’s operation, the functionality may change.
• System of systems usually exhibits self-X behaviour, and may dynamically modify its architecture, as well as functionality
  – that may lead to necessity of on-line verification of its behaviour.
• Dynamic, on-line verification of behaviour is fostered by self-aware architecture, and is essentially based on:
  – shared situation awareness of components, supported by
  – well-defined direct interactions, indirect interactions, and mediated interactions
Situation-aware components

- Awareness of time constraints only

\[ p: T(p) \times \text{dom } p \rightarrow \text{val } p, \quad T(p) \text{ is a well-ordered set of time instants} \]

- Awareness of time and position in space

\[ p: L(p, t) \times \text{dom } p \rightarrow \text{val } p, \]

where \( L(p, t) = \{(l(p, t), t); t \in T(p)\} \),

and \( l(p, t) \) is a function that computes location of agent \( p \) at instant \( t \)
Mediated interactions

Mediated interaction is smart and proactive, its operation depends on situational information and system’s goals.

Time-aware mediated interaction

\[ \sigma_{ij} : T(p_i) \times T(p_j) \times \text{val } p_i \rightarrow \text{proj } \text{val } p_i \text{ dom } p_j \]

\[ K(\sigma_{ij}, t) \subset T(p_i), \text{ and } t \in T(p_j) \]

Time- and location-aware mediated interaction

\[ \sigma_{ij} : L(p_i, t_i) \times L(p_j, t_j) \times \text{val } p_i \rightarrow \text{proj } \text{val } p_i \text{ dom } p_j \]

\[ K(\sigma_{ij}, s(t_j)) \subset L(p_i, t_i), \text{ and } s(t_j) \in L(p_j, t_j), \text{ with } \]

\[ L(p_j, t_j) = \{(l(p_j, t_j), t_j); t_j \in T(p_j)\} \]
Proactive middleware

Forms a backbone of self-aware architecture

Actor agents

Communication agents

Actor agents
Examples of work in progress

• Laboratory experiments and local industrial contracts
• Industry and logistics:
  – „Self-organising Intelligent Middleware Platform for Manufacturing and Logistics Enterprises“, ARTEMIS project
• Crisis management
  – „Modelling crisis management for improved action and preparedness“, FP7 SEC project CRISMA
  – „Information Interoperability and Intelligence Interoperability by Statistics, Agents, Reasoning and Semantics“, EDA project IN-4-STARS2.0
  – Asymmetric Threat Environment Analysis, EDA, ATHENA
Conclusion

Self-aware architecture supported analysis of system of systems behaviour is more adequate since:

– it is based on persistent feedback from the environment
– it is harmonised with the system’s current state
– in many cases it enables to respond to emergent behaviour in due time
– it provides wider choice of effectors, e.g.
  • for adapting the functionality by adjusting parameter values
  • for radical (architectural) changes in interactions and components
Questions, please