Future Enterprise beyond the Concurrent Enterprising Systems

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***Abstract* – The hyper-connected society, to be developed during the next decades, is facing great challenges. New requirements, that should preserve the well-balanced harmony between natural resources and human capital resources, will involve greater responsibility within the global e-democracy framework. Thus the globalization is a strong influence for enterprise development. Enterprise systems are becoming contextual complex adaptive systems. Such systems rely on complex process models to support enterprise operations. The present paper explores various key aspects of Future Enterprise Systems and discusses their practical implications through a case study involving an application of process mining techniques on streams of events collected from a sensor network.**

***Keywords*— discrete event dynamic system, internetable, complexity, adaptability, process recognition**

I. INTRODUCTION

Enterprise architecture as well as interactions between enterprises have become even more complex, in the last decade. Modeling enterprise components and business processes can become a relevant factor in collaborative and interoperability-oriented systems and thus contribute to an increase in performance. Enterprises are more and more associated to complex, adaptive systems.

According to D62 Unit "Future Internet Enterprise System" (FInES), there are 9 basic attributes that should be fulfilled by the "Next Generation of Sustainable Enterprise" (NGSE) in the Digital Era, namely: Humanistic, Inventive, Agile, Cognizant, Sensing, Community-oriented, Cloud computing, Glocal and Green.

Premises have been provided within the Framework Project 6 and 7 programs as well as "Horizon 2020" framework:

- The IST-FP6 project "Roadmap and Vision for Virtual Enterprise (VE) / Virtual Breeding Environment (VBE) / Virtual Organization (VO)" (2004) has concluded that "In 10 years, in response to fast changing market conditions, most enterprises and especially the small and medium enterprises (SME) will be part of sustainable collaborative networks that will act as a breeding environment for the formation of dynamic Virtual Organizations". The FP7-IP project ECOLEAD (2004-2008) has consolidated the above-mentioned vision;
- The infrastructure of the Future Internet community is available as a service (IaaS).
- The successful IP project DBE (Digital Business Ecosystem) FP7(200-2004) and its extension OPAALS (2004-2008) provide a holistic approach for a top-down multi-modelling framework;
- The 4 pillars of the "temple of" "Future Networked Society":
  - IoT – Internet of Things;
  - IoS – Internet of Services;
  - IoP – Internet of People;
  - IoK – Intenet of Knowledge

  received an useful extension:
  - IoE – Internet of Events;
  - IoL – Internet of Locations;
  - IoC – Internet of Content
- "Big Data / Big Project" future experts in the context of a "tsunami" of events and data;

The "IST-RFID Enterprise Interoperability" [16] initiative group is providing an annual "Roadmap & Vision" containing an interesting list of great challenges highlighting new sciences to be developed during coming decades. Among them one could notice: Systems / Complexity Science, Information Science, Web Science, Service science, Decision System Science, among others.

Taking into account these premises, the General System Theory and Application found by Ludwig von Bertalanffy [17] could be a promising approach to identify the complex problem to be solved, such as the systemic methodology that should be derived from a scientific foundation towards different case studies in sectors of economy.

The structure of the paper is further detailed. In the first section, some aspects related to conceptual design principles for future enterprise systems are discussed. In the second section, a model for process discovery component of the enterprise system is proposed and a system architecture is presented. An experimental validation is presented and the results are analyzed in the final section.

II. Conceptual Design Principles for Future Enterprise Systems

Due to the fact that enterprises included many structural entities (componential dimension) and relationships (functional dimension) that are specific to Discrete Event Dynamic Systems, one can conclude that an enterprise can be represented as an Complex, Adaptive System of Systems (CASoS) [3].

This revolutionary systemic approach has an "old root". The founder Ludwig von Bertalanffy has invested huge effort (1924 – 1974) to provide the disk-like modelling framework. [19]

The "System of Systems" is an attractive sintagma that evolved in the last decade of the 20th century. The complex interactions between enterprise systems are creating complex system of systems.

Enterprise Systems can be interpreted as a set of fabricators F represented with regard to M-views set of (perspectives) representations [3] :

VE: {U(.); F(.); M-views, G}

A complex system can have various representations according to the specific scientific research area. The general system theory provides a mathematical highest-level definition [3]:

S: {[E1,n]; R[1,m]}

, where [E1..n] – the set of entities; R the set of relations;

Enterprise Systems can be represented with the aid of interactions, exchanges of information, boundary and composing elements.

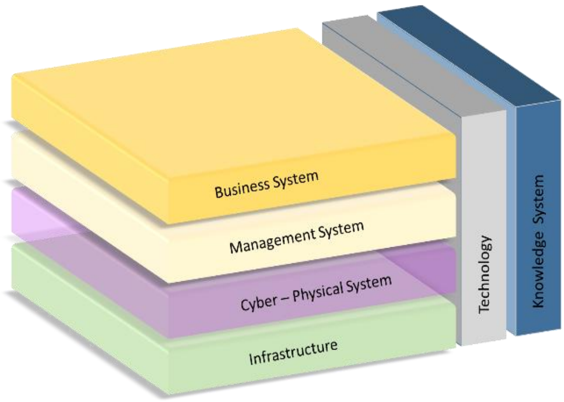

Fig. 1. *Generic Components of Enterprise System*

One way to describe complex systems is "a dissipative structure that imports energy and exports entropy" such as to achieve a level of self-organization.

Taking into account these principles, the authors have proposed a CASoS vertical extension based on 7 levels non-monolithic enterprise systems taxonomy:

- Level 7 – Meta-Metasystem: Digital Business Ecosystem;
- Level 6 – Metasystem- Collaborative Enterprise / Organization;
- Level 5 – Functional systems (SCM, ERP, CRM, FI / CO);
- Level 4 – integrated service-oriented systems (SaaS/ISU; IaaS; PaaS);
- Level 3 – Application-oriented subsystems;
- Level 2 – HUB based granular system;
- Level 1 – Future Internet Infrastructure, FI-Ware Enterprise System Communication;

These Enterprise System principles and paradigms have been discussed by Kapossy [4], Stanescu [3].

Taking into consideration these principles, the present paper's focus is related to the integration of three dimensions for the enterprise systems: Discrete Event Dynamic System / Information System / Knowledge based System, in order to facilitate automated process discovery and recognition.

III. Process Discovery System Conceptual Design

In this section a system capable of discovering a process model from an event stream collected using physical system will be discussed. The proposed system combines ideas from various research fields that have received significant attention in the past few years, namely process discovery and activity recognition.

One of the most important developments in the field of process mining are represented by process discovery techniques [5], capable of extracting the model of process using only repeated observations of its behavior. An important data structure, referred to often in the field of process mining, is the "event log", a tuple formed by a set of sequences of collected events and a function indicating the number of times a certain sequence has been observed.

These techniques had been successfully applied to enterprise informational systems, where the event sources have been the logs of various component applications. However, given the tight integration of virtual and physical resources expected to be present in the future industrial architectures based on the concept of Cyber-Physical Systems (CPS) [6][7][8][9] and the research into applying and extending existing process workflow management techniques, mainly developed in the context of Business Process Management (BPM), in Cyber-Physical environments, especially the aspects related to the modelling and enactment of these processes [10][11][12][13], this paper investigates the application of process discovery techniques methods on streams of events collected from both physical and "virtual" sensors observed by both physical and virtual sensors (the term "virtual sensor" just refers to various logging software components and it is used to highlight the homogenous treatment of various data sources).

For the application of process mining techniques in the case of events derived from (physical) sensor observations (as opposed to the usual application of these techniques involving events collected from the execution of various processes on BPM platforms), the two following problems must be solved:

- Event processing and representation;
- Instance identification; The proposed system will be required to associate each observed event to one or more process instances; In most cases this involves the application of several domain-dependent rules;
- Activity recognition; In order to generate process models at the abstraction level expected by various stakeholder, the system will have to aggregate the events into "higher-level" activities;

As this list of issues reveal, the pre-processing aspects are at the fore-front of this investigation, the proposed system using existing process discovery to extract the process model from the event log that it generates from the raw sensor data.

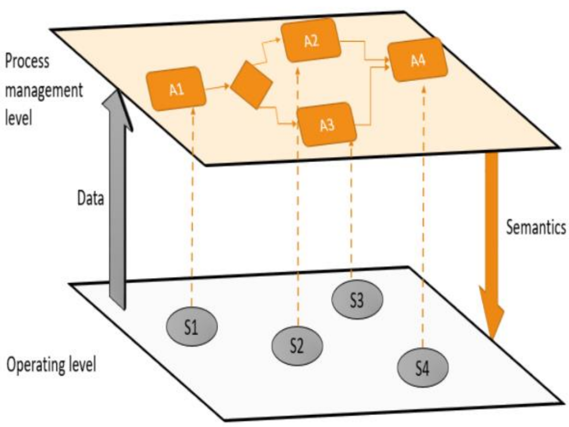

Fig. 2. *Sensors to Process mapping*

A system architecture is presented in this paper built around 4 major components responsible for handling the following tasks: event processing and representation (the domain-dependent component that manages the interface between the system and the existing sensor network), activity recognition, instance identification and process model discovery

The system uses an OWL ontology for its knowledge base, thus enabling an accurate, flexible and consistent way for representing all the collected and processed information (event, discovered activities, etc.)

The activity recognition component uses a method developed in the field of system diagnostics [1][2] is used, that involves recasting the recognition problem into a planning one. The planning domain and problem – represented as PDDL files – are generated from a set of pre-defined templates (domain-specific expert knowledge) and the event information stored in the system's ontology.

The solution used to solve the process instance identification problem is the one proposed by the authors of [15]. Starting from a sequence of collected events, under the guidance of a human operator and a set of heuristic rules (such as the maximum span of a process execution), this technique will generate a set of event correlation rules at the events' attributes level. The correlation relations can be used to partition the event sequence so that the resulting clusters satisfy the specified conditions.

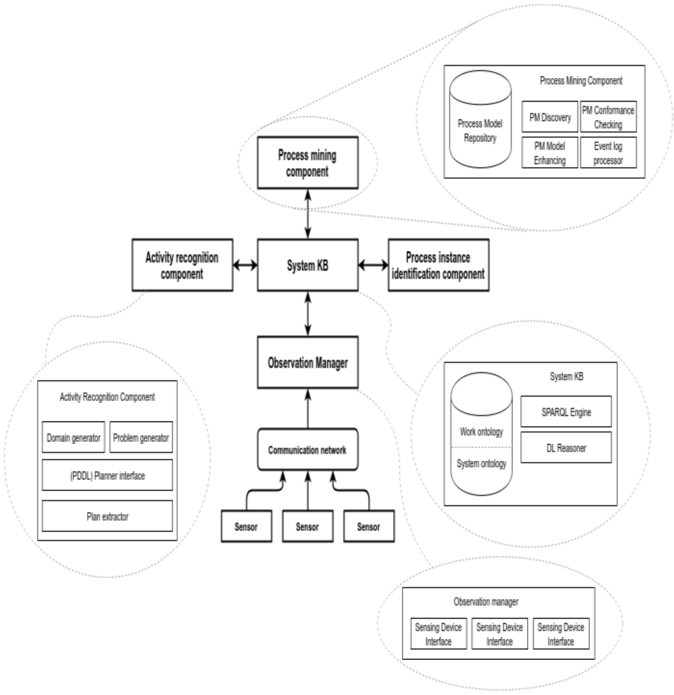

Fig. 3. *The main components of the proposed solution*

IV. Case Study

The initial validation of the proposed solution was performed using a simulated environment composed of a mix of heterogeneous components representative of those found in modern enterprise informational systems. As such, the environment depicted in Fig.2 was used, involving the manufacturing of a product using materials from two suppliers. Additionally, a set of vehicles will be used to transport the raw materials from the suppliers to the manufacturing sites.

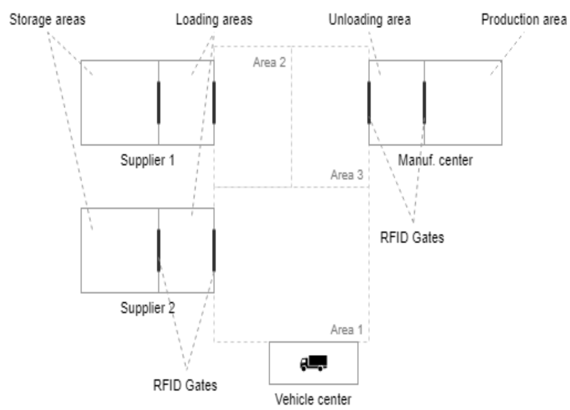

Fig. 4. *Case study representation*

The following event sources were considered for the generation of event stream collected by the system: RFID readers placed on gates in the loading / unloading and packing / unpacking areas of the suppliers' warehouses and the 2 manufacturing sites, GPS sensors placed on the vehicles (signalling the movement between a set of predefined areas). In this scenario, it is assumed that the components are transported in containers – both individual components and the containers are tagged.

After collecting the events and generating their corresponding entries in the KB, the system executes the process instance identification step during which each event will be associated with a set of process executions. Given that the investigated process involves the manufacturing of a single product, the events related to the movement of containers / pallets will be common to multiple process instances and each instance will be uniquely identified by the RFID codes of the two components and final product.

After all the process instances have been discovered, the system must determine the "high-level" activities corresponding to events associated with each process instance. For example, an event whose source if "RFID_Gate_2" might represent a packing operation, whereas two consecutive events referring to the presence of a vehicle in 2 different, adjacent areas represent a transport activity. As mentioned in the previous section, the activity recognition step relies on automatic planning, each sequence of events corresponding to a process instance being transformed into a planning problem, and the resulting partial-ordered sequences of activities being used in the next step to infer the final process model. The planning domain and problem (represented by PDDL files) can be generated from domain-dependent templates and the event related information present in the system's KB.

Usually, planning problems involve generating a plan so that the final state of the system satisfies a set of logical conditions representing the planning goal. However, the approach used in this proposal leverages a set of the "timed initial literals" constructs and special "constraint" action definitions with the goal of generating the exact sequence of transitions in state space of the system under investigation and at the same timestamps as related by the observed events. A snippet from a PDDL domain and problem definition used to generate such a plan is presented in Listing 1. In this example, the "constraint" action "event_12_action" was derived from an event and can be executed in just a short timespan around the event's timestamp. However, the execution of this action is required to in order to satisfy the planning goal, as its effect will set the predicate "constr_12_satisf".

```
 (:init
…
at 1573717429  (event12_cond)
at 1527717529 (not (event12_cond))
)
…
(:action event_12_action
:precondition (and (event12_cond) (at_loc vehicle3
Manuf_Unload_Area))
:effect (and (constr_12_satisf)))
)
…
(:goal and (
…
(constr_12_satisf)
…
))
```

Listing 1

After solving the planning problem for each the event sequence, the results can be used as input for an existing process discovery technique. For the proposed system, the method described in [14] was used. This method, that uses Petri Net "unfoldings" has the advantage of accepting partial ordered sequences of (activity related) events and, relaying on the independence relations between activities provided as input (derived from the action models defined in the planning domain) provides a more realistic process model from fewer process instances (not having to infer concurrent activities from observing all the possible permutations). The resulting process model generated by applying this method for the above mentioned simulated scenario is depicted in Fig. 3

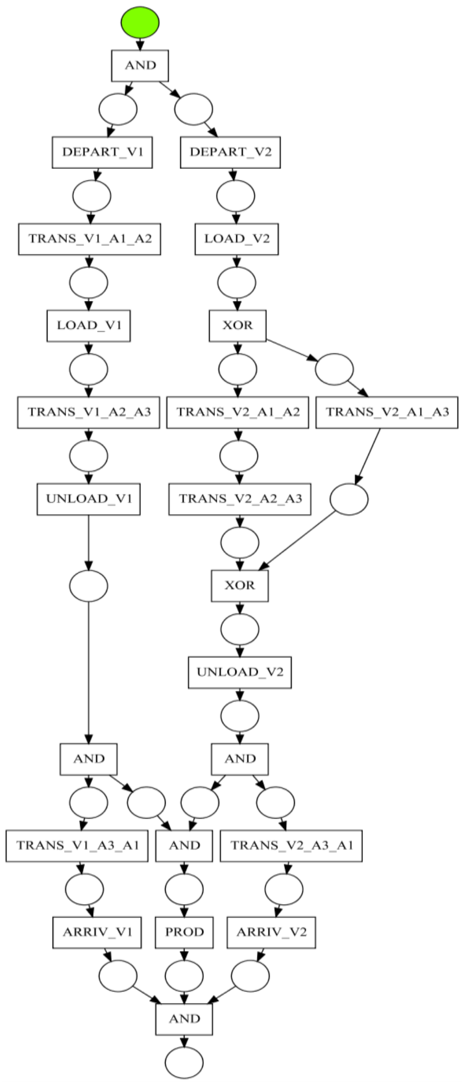

Fig. 3 – Discovered process model

This investigation analyzed the possibility of using observations collected from an existing sensor network in order to retrieve a set of process models. As mentioned in the introduction, this study goes beyond the scope of process discovery techniques, aiming at a practical solution that also covers the pre-processing phase of the collected events, specifically the construction of the event log that enables the application of existing process discovery techniques.

A theoretical limitation of the proposed solution is represented by the fact that automated planners usually return a single solution even though multiple trajectories in the state-space exist. This aspect will be analyzed further in the future using techniques for re-planning.

From a practical standpoint, for solving the planning problem, a non-optimal / satisfying planner was used. A superior solution will involve the usage of an optimal planner. However, due to their lack of support for temporal domains, this approach was not considered at this time. An optimal planner will allow the users some degree of selecting the desired solution by tuning the optimality criterion.[18]

Another problem that was identified is related to the planners' performance in the case of problems with a small number of actions but with a large number of objects. This is an issue that will be treated in the future by analyzing various means of decomposing the planning problem.

V. CONCLUSIONS AND FURTHER WORK

The information system of systems architecture must include, but not be limited to capabilities such as semantic concepts to describe complex system components, support for asynchronous and synchronous communication and a distribution of knowledge processes and a distributed storage to generate business process activities.

The system architecture presented in the latter part of the paper serves to highlight, in the authors opinion, various aspects regarding the development of Future Internet Enterprise Systems such as need to integrate diverse information streams and to expand the application scope of existing techniques and methods. For this, the application of process mining techniques, specifically process discovery, has been explored in the context of event streams collected from both physical and virtual devices. Two major issues regarding this application have been discovered, namely activity recognition and process instance identification, and for each one various possible solutions have been explored. Based on this analysis a system architecture has been proposed and validated in an environment involving a simulated section of a supply chain.

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