CYBER PHYSICAL SYSTEMS BASED MODEL-DRIVEN DEVELOPMENT FOR PRECISION AGRICULTURE

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ABSTRACT

In the last few years, a paradigm shift has been identified, from Complex Adaptive Systems towards Internet of Things and Cyber-Physical Systems of Systems. Systems that can integrate physical with virtual environments are creating complex systems. By connecting sensor data, actuator systems within a virtual environment information analysis is enhanced. The focus of the present paper is to discuss the role of Cyber-Physical Systems of Systems, in extending design principles, models and architecture guidelines for the development complex precision agriculture systems. The authors propose an architecture for the future agricultural enterprise as a complex system, addressing sensor networks and automated process modeling.

Keywords: Cyber-Physical Systems, Internet of Things, Generic Architecture.

1 INTRODUCTION

In the very dynamic and competitive market Information and Communication Technology, Control and Modelling tools offer important opportunities, but also generate new challenges. The Digital market space, where the enterprise will reside in the future, provides a unique opportunity to overcome the competitiveness deficit related to technology and services, the market fragmentation and deficit of critical mass in relation with the use of resources.

In the digitalization context, systems that can tightly integrate physical with virtual components represent a priority for research. Research efforts have been concentrated in domains such as: Internet of Things, Internet of Services and Cyber Physical Systems. Moreover, availability and heterogeneity of components as well as constraints structure are subject to a high dynamics which results in such a complex structure of the overall business process that makes the strategic decisions extremely difficult.

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On the other hand, there is a clear need of integration of such heterogeneous elements, which should work together under the requirements of a globally designed, dynamic, specific business, which will result in complex integrated information systems, designed and managed by IT specialists to be used by business people without IT competencies. Devices and service interoperability may prove to be another important issue, which has to be taken into account when using integrating elements from different sources and model them as a complex system.

Cyber Physical Systems of Systems approach is setting a new goal of integrating all the promising results from different areas of research including but not limiting to: intelligent sensor technologies, sensor networks, intelligent objects integrated in the Internet of Things, intelligent decision support systems, robotic systems, big data and cloud computing, context awareness, collaborative systems, human-machine interface and human in the loop, mixed reality systems, semantic web and internet of services.

2 MODELLING OF REAL AND CYBER ENVIRONMENT INTERACTIONS

2.1 Cyber Physical Systems

Cyber-Physical Systems represent an integration of computation and physical systems. The focus of such systems is to bring together the actual physical object and the omnipresent computing and networking systems. CPS is concerned with the actual interaction between the physical and computer systems, thus completing the up to date research for understanding of the systems separately. (Dumitrache 2014)

A generic CPS encompasses physical objects, sensors, actuators, computing devices, controllers and communication network as depicted in Figure 1. (Dumitrache 2013) Developing CPS based system architectures must take into consideration: control theory, networked control systems and networks of devices, real-time, adaptive systems, dynamic reconfiguration, cyber security, embedded systems, interoperability as well as human in the loop.

In this context, embedded systems that control physical processes can be viewed as a sub-set of the wider CPS definition. Together with the technological development, as well as the enterprise evolution and rapid changing environments, enterprises have to adapt in order to implement such changes and align with the emerging enterprise paradigms: Inventive Enterprise, Humanistic Enterprise, Cognitive Enterprise, Community-oriented Enterprise, Agile Enterprise, Glocal Enterprise, and Sensing Enterprise. (Moisescu 2016)

Intelligent Cyber-Physical Systems (ICPS) represent the next generation of advanced networked systems presenting distributed intelligence. Internet of Things and Internet of Services, integrated by multiple feedback loops, allow to develop complex cyber-physical systems. (Dumitrache 2014)

Figure 1: CPS as a multidisciplinary view.

Cyber-Physical Systems can also be interpreted as open socio-technical systems based on the interconnection of the physical, social and virtual worlds thus allowing “smart” human-machine cooperation (H2M and M2M) communication integrating heterogeneous and widely distributed physical devices, supporting high system flexibility and re-configurability as depicted in Figure 2. (Dumitrache 2014)

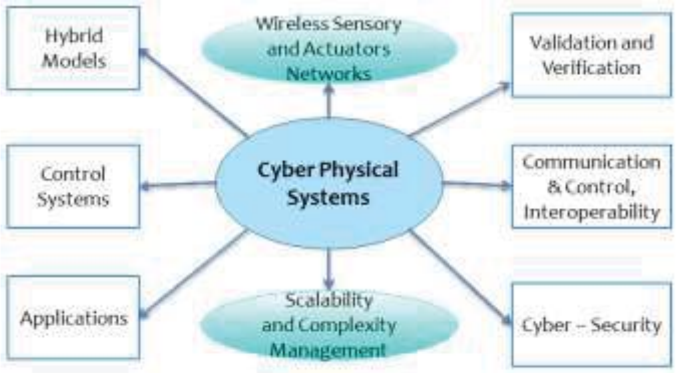


Figure 2: Main components of a Cyber-Physical System.

Elements for CPS Systems Modeling include models of computation: Boolean (logical) circuits, the finite-state machine, the random-access machine, the pushdown automaton, cellular automaton, Turing machine, language recognition.

Challenges related to Cyber – Physical Systems integration with society and industry include: the self-organization and self-management of systems, smart factory, including smart processes and smart products, ambient intelligence, complex heterogenous systems, embedded systems, integration of business and production / manufacturing systems, communication networks and network control systems; Quality of Service.

Another important emerging paradigm closely related to CPS is Industrie 4.0. The underlining principles include (Blanchet et all, 2014): intelligent manufacturing systems including Intelligent Robots and Machines, human-robot interaction, Energy Efficiency And Decentralization; Virtual Industrialization in regard to the concept of “virtual plants and products”; Value Networks aiming at achieving digital integration along the supply chain.

2.2 Internet of Things

An important paradigm in close relation to CPS is the Internet of Things (IoT) which emphasizes the use of existing technologies and architectures for large-scale systems in order to identify and virtualize physical devices. Internet of Things components include: IoT Device Management, IoT Analytics, IoT Security, Event Stream Processing, IoT Platforms, IoT Standards and Ecosystem to create a real intelligent integrated system. (Moisescu 2016)

Communication Network technology can be used in connection with four distinct types of communication: Human-to-human communication; Human-to-machine communication; Machine-to-human communication; Machine-to-machine communication.

Internet of Things allows things to connect to the Internet to add or retrieve information and to enhance its intrinsic value. This includes devices and Machine-to-Machine (M2M) communication, but aims to go beyond the M2M by enabling any object to connect and use the Internet directly of by using an intermediary device. Internet of Things is the environment where things communicate with things, so they can interoperate both locally and globally. Decisions can be based on predetermined rules and events, without requiring human intervention.

Communication between devices is done via protocols. In turn, wireless devices interact with each other through another set of protocols and to communicate with the Internet, they need another set of protocols. Therefore, the Internet of things is actually a sum of several heterogenous networks, which require customers to choose one vendor or work with multiple systems simultaneously.

Wireless Communication technology can be used for four distinct types of communication: Human-to-human communication; Human-to-machine communication; Machine-to-human communication; Machine-to-machine communication

2.3 Precision agriculture

Precision agriculture refers to an evolution of agriculture systems enabled by the use of sensing, control and actuating systems. Data acquired from farming process is routed to processing systems that analyses data and aid farmers in the decision process. A set of processes is the main focus of precision agriculture: planting, fertilizing, harvesting and storing crops. (Melo, 2016)

Key components of precision agriculture include: Sensors that measure soil, environment and crop parameters; satellite imagery or drone acquired images that assist in decision making and aid in measuring relevant parameters; intelligent machinery that uses advanced planning and guidance systems in order to perform tasks. These components allow for prescription, position and agricultural resource inputs. (Zhang et al 2008)

Other relevant concepts related to precision agriculture include: Site-Specific Crop Management, Climate Smart Agriculture and Sustainable Agriculture & Food Security.

2.4 Related technologic enablers

2.4.1 Sensor monitoring and context awareness

More and more objects can be monitored in real time, as the sensors are becoming smaller and cheaper. Due to the increasing number of sensors used, a much larger amount of data is acquired and needs to be processed. Production equipment can be equipped with internal or external sensors, thus providing real-time data about status, and functioning parameters warning of potential problems before they occur, allowing for repairs to be carried out with minimal impact. Also in the transportation industry, sensors can used to monitor cargo, especially perishable.

Context can be defined with the aid of synonyms, such as environment and situation. Context awareness system architectures include the following layers: data acquisition, data modeling and representation, network management, and decision. The following context aware systems architectures have been identified (Indulska et al, 2006) (Li et al, 2015):

- No application-level context model: data acquisition, analysis, and decision is performed by the context awareness system.
- Implicit context model: context awareness system incorporate “off the shelf” components such as libraries or toolkits for data acquisition, analysis, or decision.
- Explicit context model: context awareness system use a predefine and specific model and implement data acquisition, analysis, or decision with the aid of shared or dedicated infrastructure or middleware.

2.4.2 Data storage and analytics

IoT will enable acquisition of huge amounts of “raw” data that need to be processed. Some important issues need to be addressed in order to ensure the evolution of IoT: data storage, data ownership, data security, data traceability, expiry of the data, use of data, data analytics, decision making. Algorithms developed to analyze of the data collected: artificial intelligence algorithms which could be centralized or distributed and fusion algorithms. Automated decision making algorithms include: non-linear, temporal machine learning methods, evolutionary algorithms, genetic algorithms, neural networks, artificial intelligence techniques.

2.4.3 Interoperability

Interoperability plays and is expected to continue to play an important role in the Internet of Things.

In this context, a IoT system has the ability to generate data, process data and use information but also to transfer data to another system capable of using that data and generating information and added value. The 4 layers of interoperability need to be addressed in IoT systems: Technical, Syntactic, Semantic and Business process.

2.4.4 REpresentational State Transfer (REST)

REST's architecture underlying idea is the definition of a resource, where each component of an application must be used or addressed. Resources may be physical objects such as humidity or temperature sensors, abstract concepts such as a collection of objects or dynamic concepts. REST consists of the following components: Resources: The Web is based on URIs to identify resources, as links to resources can be derived using identification schemes; Uniform Interfaces: Resources must be available through a well-defined interface and semantic interaction like Hypertext Transfer Protocol (HTTP). Most Web applications provide REST interfaces while back-end is implemented using different interaction models, the same model can be used in IoT; Descriptive messages: predefined resource overlays provide easy interaction for decentralized systems and servers. Using HTTP and HTML on the Web, users are able to work with individual agreements. For machine-oriented services, data types such as Extensible Markup Language (XML) and JavaScript Object Notation (JSON) have acquired support or services and platforms; Stateless Communication: The server doesn't store information about the client, it must be submitted in each request.

Based on the above observations, REST can be the most effective architecture in creating services inside Internet of Things.

2.4.5 Semantics

Semantic annotations in correlation to IoT technologies allows for machine-interpretable metadata to describe the IoT resources and data. The main Semantic Web technologies that are used in the IoT domain include the Resource Description Framework (RDF), RDF Schema and the Web Ontology Language OWL). There are also query languages such as SPARQL and also repository, processing and reasoning engines and mechanisms that allow accessing and inferring the semantic descriptions.

Linked data are linked to a series of principles, in order to achieve its purpose:

- Things or objects should be accessed and identified with the help of associated URIs Use
- URIs should be accessible from the internet including Domain Name System reference
- Information about the thing should be accessible via its URI using standard representation such as SPARQL, RDF or XML.
- objects should be linked using their specific URI's

3 MODEL-DRIVEN DEVELOPMENT FOR PRECISION AGRICULTURE

3.1 Generic Agricultural Enterprise System Architecture

An Agricultural Enterprise System Architecture base on CPS principles is proposed in the following section. The architecture (Figure 3) is composed of a generic representation and a set of views associated to the representation.

The following principles, depicted form the analysis of state of the art, detailed in the previous sections, have been considered:

Principle 1: Modelling of agricultural production systems as CPS

Principle 2: Designing Agriculture machines sensors and actuators as CPS Networked Systems

Principle 3: Defining organization resources that acting as both service provider and service consumer.

Principle 4: Designing Agriculture machines in accordance with Human in the loop principles

Principle 5: Integrating Sensors, Actuators, machines using CPS models

In this context, when modeling a Cyber-Physical System, a middleware framework is required to provide mechanisms which support the behavior on the control system, tolerate faults and control all the systems which involve the features of both heterogeneity and distributed operation.

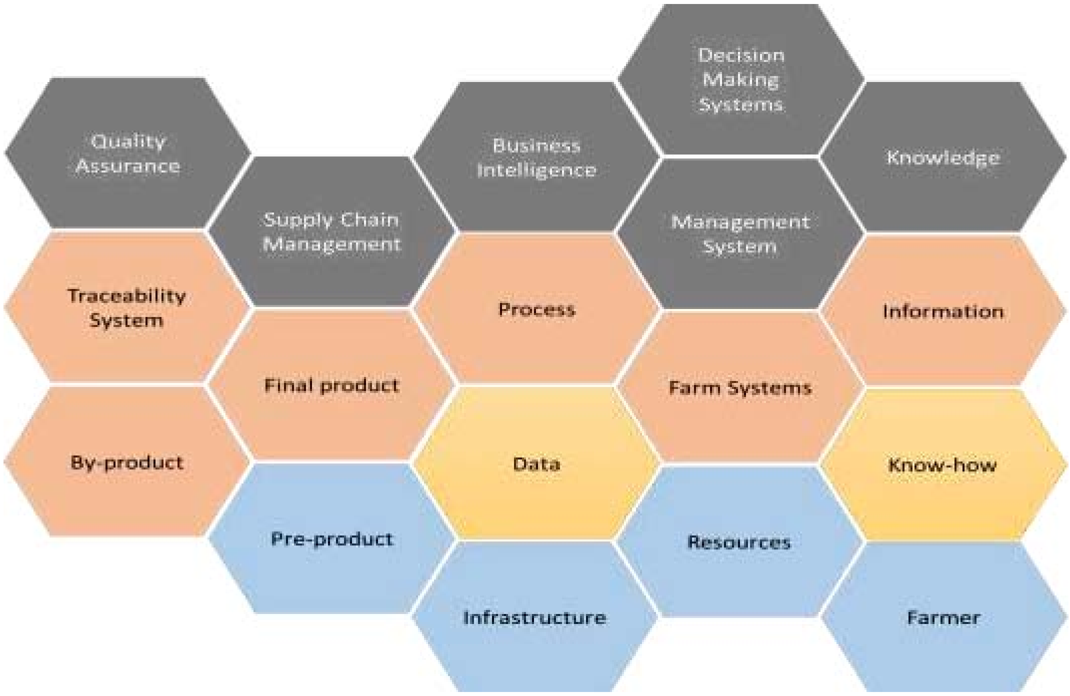


Figure 3: Agricultural Enterprise System Architecture.

The generic Farm Architecture is comprised of building blocks encompassing relevant concepts for the farm organization. The building blocks are organized in tiers and detailed with the aid of architectural views.

- The first layer encompasses the farm existing continuum and is represented by the following: pre-product, infrastructure, resources and farm human resources.
- The second layer includes data models and primary information processing

- The third layer includes processes models, product models by-products, and farm information systems.
- The forth layer includes management systems, business intelligence and decision making, knowledge management and supply chain management.

The following perspectives can be associated with the presented architecture: Organization view, Process Management view, Socio – economic view, Technology view

The following table (Table 1) addresses a short description of each layer of the proposed architecture.

Table 1: Generic description of architecture layers.

Layer	Components	Description
Farm continuum layer	Resources, Pre-product, Infrastructure, Farmer	The layer refers to the existing components of the agricultural enterprise. The farmer is nominated as the central enabler.
Data layer	Data, Know- how	The layer refers to the data acquired from sensors as well as independent measurements. The layer includes an important aspect of existing farms: know-how of the farmer.
Process and capability layer	processes, product, by-products, and farm information systems.	The layer refers to the monitoring, management and control of the agricultural enterprise. Process models and management are a central aspect. A control loop is addressed as a central point of precision agriculture.
Management system	management systems, business intelligence and decision making, knowledge management and supply chain management.	The layer addresses decision support, performance measurement and interoperability with other agriculture enterprises

Elements form each layer can be encapsulated in specific generic components. In order to analyses the impact of CPS principles, the Process component is further detailed.

The process component addresses process modelling including automated process discovery and process execution. Process modelling is closely related to the following technologies discussed in previous section: semantics, sensors and interoperability. Process execution is related to data acquisition from sensors, interoperability and REST technologies. A Process Discovery Component, based on CPS principles, will be detailed in the following section.

3.2 Automatic Process Discovery Component

In the following section the Process Discovery Component of the Agricultural Enterprise System Architecture is detailed. In order to use process discovery methods on observations collected from existing sensor networks, two issues have been identified:

- Identifying the process instance associated to each event
- Activity recognition

For the process instance identification problem, a semi-automatic iterative technique is implemented, takes as input data the un-partitioned sequences of collected events and their attributes and outputs a set of correlation relations between them.

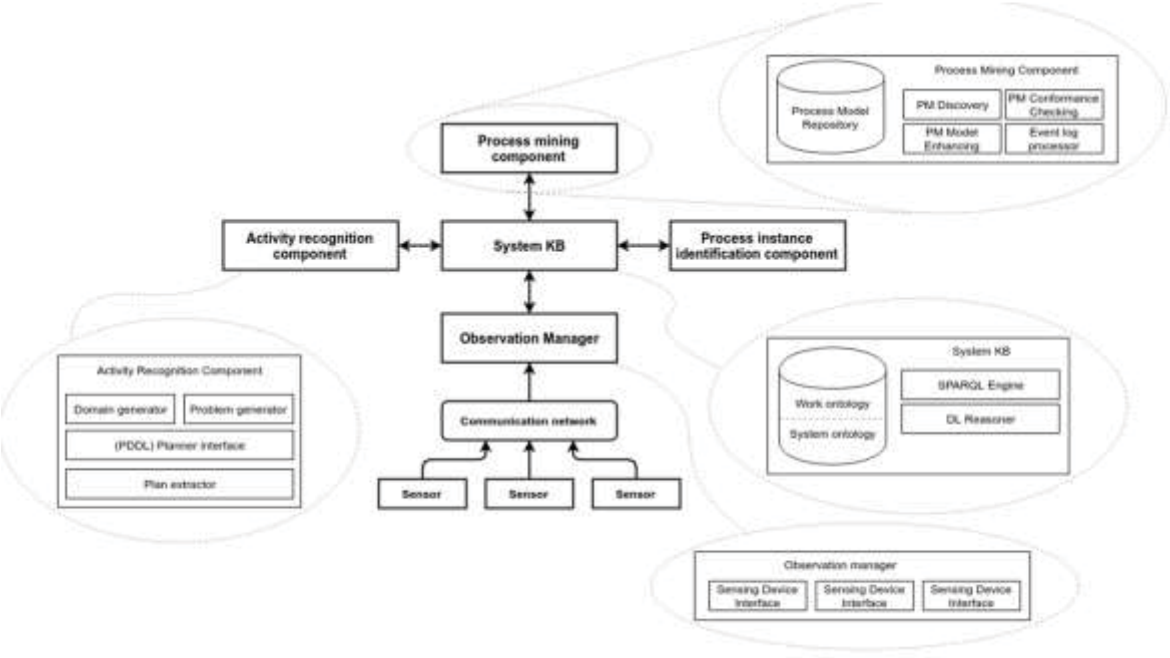


Figure 4: System Components.

The functional diagram of the instance identification component is depicted in Figure 4. The information flow depicted in this figure corresponds to the following set of operations:

- The extraction of information related to the collected events
- The generation of correlation relations based on the semi-automatic iterative method;
- The application of the resulting relations on the system's work ontology by generating OWL individuals corresponding the process instances

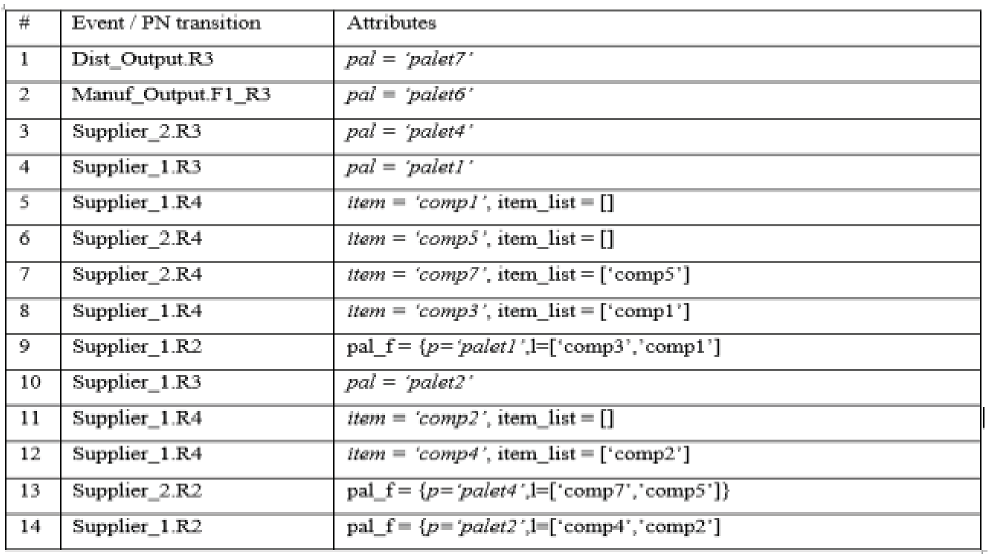
For each sensing device, in the "Sensing Interface Manager" component, a "Sensing Interface Component" will be created. This interface is responsible with the transformation of the primary collected data into a set of uniform assertions that will be added to the system's work ontology. To initialize this interface, information regarding the sensing network's topology, stored in the system's work ontology can be used (depicted in the diagram as the secondary information flow).

4 CASE STUDY

A test environment has been developed that simulates the interactions between 7 actors in a supply chain: 2 suppliers, one producer, a distribution center, 2 retailers and a transporter.

For this system, several RFID readers, placed in various areas of this environment and GPS receivers placed on vehicles provide the input event stream. In order to simulate the behavior of this system, a colored Petri Net was developed in CPN tools and the event sequence was extracted from its simulation (Tabel 2 - example)

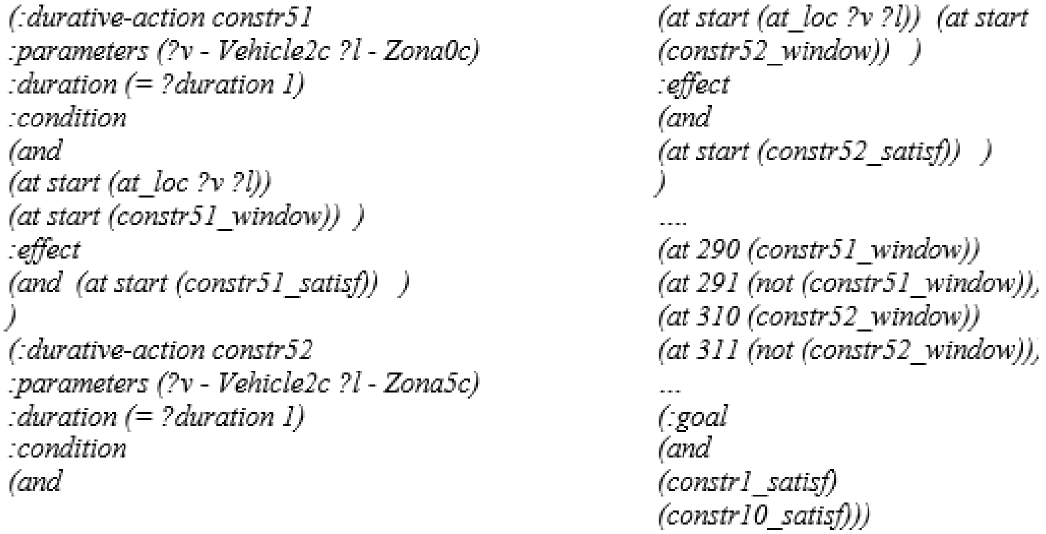
Table 2. Event sequence.



#	Event / PN transition	Attributes
1	Dist_Output.R3	*pal* = *'palet7'*
2	Manuf_Output.F1_R3	*pal* = *'palet6'*
3	Supplier_2.R3	*pal* = *'palet4'*
4	Supplier_1.R3	*pal* = *'palet1'*
5	Supplier_1.R4	*item* = *'comp1'*, item_list = []
6	Supplier_2.R4	*item* = *'comp5'*, item_list = []
7	Supplier_2.R4	*item* = *'comp7'*, item_list = ['comp5']
8	Supplier_1.R4	*item* = *'comp3'*, item_list = ['comp1']
9	Supplier_1.R2	pal_f = {*p*=*'palet1'*,l=['comp3','comp1']
10	Supplier_1.R3	*pal* = *'palet2'*
11	Supplier_1.R4	*item* = *'comp2'*, item_list = []
12	Supplier_1.R4	*item* = *'comp4'*, item_list = ['comp2']
13	Supplier_2.R2	pal_f = {*p*=*'palet4'*,l=['comp7','comp5']}
14	Supplier_1.R2	pal_f = {*p*=*'palet2'*,l=['comp4','comp2']

For each observation, using a set of domain-dependent syntactic rules, several OWL Individuals are created. It is assumed that during the system's deployment, based on expert provided knowledge, the ontology has been populated with entities pertaining to the static aspects of the modeled environment. During the next phase, the sequence of semantically lifted observations is transformed into high-level actions using the planning-based action recognition method. In the case of this supply chain, due to the presence of packing and unpacking actions, no correlation rule can be created in order to correctly partition the events into process instances. Consequently, the instance identification phase is executed based on the results obtained during the action recognition step.

The observations are added to an existing set of action definitions as special, "constraint" actions that force the planner to generate a solution capable to explaining the collected events (Listing 1).



```
(:durative-action constr51
:parameters (?v - Vehicle2c ?l - Zona0c)
:duration (= ?duration 1)
:condition
(and
(at start (at_loc ?v ?l))
(at start (constr51_window)) )
:effect
(and (at start (constr51_satisf)) )
)
(:durative-action constr52
:parameters (?v - Vehicle2c ?l - Zona5c)
:duration (= ?duration 1)
:condition
(and
(at start (at_loc ?v ?l)) (at start
(constr52_window)) )
:effect
(and
(at start (constr52_satisf)) )
)
....
(at 290 (constr51_window))
(at 291 (not (constr51_window)),
(at 310 (constr52_window))
(at 311 (not (constr52_window)),
...
(:goal
(and
(constr1_satisf)
(constr10_satisf)))
```

Listing 1: Special, "constraint" actions.

After registering the resulting action instances in the system's work ontology, the instance identification phase can be performed. Using an implementation of the algorithm mentioned in the previous section, a set of candidate correlation rules have been identified. A human operator is required to specify the parameters of the heuristic rules.

The application of the user selected event correlation rule leads to the creation of new OWL Individuals corresponding to the identified process instances that can be used to build the "event log" data structure, required for the final processing phase – process discovery.

5 CONCLUSIONS

As agriculture systems evolved from mechanized systems to precision agriculture a systemic perspective has emerged. A systemic approach integrating systems and subsystems as well as subsystems and their components is becoming a necessity. Principles of integration of components such as sensors, intelligent machines, actuators, processes and works has been discussed in the previous sections.

Cyber Physical Systems paradigm offers principles, methodologies, methods, modelling tools and control tools in order to develop a precision agriculture architecture. A preliminary Agricultural Enterprise System Architecture has been proposed. The architecture is based on a series of CPS inspired principles. The process building block of the architecture has been further detailed in terms of an Automatic Process Discovery Component. The case study proves the utility of such a component.

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