Workflow Representations for Human and Artificial Agent Collaborations

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***Abstract*— In this initial research, we are taking a look at process representation and process modelling approaches for collaborative robotics. We take a system-of-systems view and apply work stemming from business process management, workflow systems to enable interoperable workflows. Initial requirements and research needs are identified for planning, executing interoperable process models, which are representing tasks shared among multiple human and artificial systems.**

***Keywords-** Collaborative Robotics; Enterprise Interoperability; Process Modelling; Business Process Management.*

I. Introduction

In the past, production companies have been focusing on optimizing with the goal to increase efficiency and effectiveness. Modern paradigms like the S^3 (Sensing, Smart, Sustainable) Enterprise [1] envision a networked, flexible production system capable of quick adaptation to evolving situations and changing customer demands. This paradigm is suitable for increasing production in Europe, due to the need for late customization of products while still having limited transport times.

The sensing part of the S^3 Enterprise paradigm implies the capability of hardware devices, machines to transmit information about themselves and the surrounding they are aware of. This is needed to be able to react to changes. The smart part implies that intelligent algorithms are in place across the enterprise, being able to either make information available to decision makers, or make decisions on their own rule set. Flexibility often comes at the cost of complexity. Still, decision are to be taken fast. The sustainability part implies evolution and the need of continuous adaptation to heterogeneous factors. Where one important factor here is the customer demand.

Collaborative robotics is one technical approach that conceptually fits into the S^3 Enterprise worldview. Such production systems are highly adaptive, equipped with a number of sensors, and are driven by highly intelligent algorithms. From an interoperability point of view, a unifying model is needed that allows both systems (worker agent, robotic agent) to map their own (mental) models to the unifying one. The unifying level is needed, due to the (obvious) different requirements of the systems, which inhibit integrated approaches. Research in interoperability is concerned with the infrastructure needed that allows lose coupled systems. Here, the systems are the humans and the robots. Both remain independent but need a common understanding.

The remaining parts of this paper are structured as follows. In Section 2, we make research questions explicit. Two exemplary existing business process modelling and execution languages are used to exemplify the modelling of complex human robot interactions. These are presented in Section 3. We conclude this work in Section 4.

II. Models of Collaborative Processes

A unifying model supports loose coupling of independent systems. This increases flexibility as systems might change without influencing others. A unifying level has to provide all features that are needed for the systems' interactions.

To be able to connect independent systems through a unifying level, it must be possible to translate or map system internal models to the common one. The complexity of the overall system increases, and more effort is needed to reach interoperability than to reach integration through a single model.

To understand the requirements for interoperable process models we want to answer the following two questions. What is the overall goal for the model? What are scenarios / functions that need to be covered to reach that goal?

A. Goals of Process Models for Human Robot Collaboration

As the two considered systems (humans, robots) are active, these are referred to as *agents* in the following [2]. The term *agent* signifies that the systems have some sort of intelligence allowing the agents to act autonomous. Agents have control over their actions, allowing the execution of tasks concurrently.

A unifying model has to be useable for the execution phase and for the planning phase of process. It must support interaction and synchronization of human and artificial agents during planning, execution of the common process.

- *Execution Phase*: The execution of process steps may be implemented by humans, or artificial agents, or both. This affects the readability, understandability and usability of the model. Execution of process steps needs to be synchronized across concurrently acting actors.

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- *Planning Phase*: Manual design of process segments as well as automated (re-)planning needs to be possible to support changes and adaptation.

In situations requiring ad hoc adaptation, the phases might be dynamically switched. This implies that re-planning has to respect partially executed plans. At any time the unifying character, allowing the systems to interact, needs to be intact. Workers for example, need to understand the workflow executed by the robot.

B. *Degree of Collaboration*

To understand detailed requirements for situations where systems interact, we analyze human robot interaction with respect to the synchronization of work between human and artificial agents [3]:

- *Binary interaction (Start / Stop)*: Simple interaction (like pressing start / stop) of the worker with the robot. The activities of both agents are synchronized through a simple task where the worker uses control buttons. The robot is passive in the sense of obeying the command without further interaction.
- *Coexistence interaction*: This is a situation, where both agents operate next to each other but have no shared tasks or pieces of work. Hardly any synchronization is required. Both agents must make sure to not interfere with the other agent's work. Some sort of collision detection and avoidance is required.
- *Assistance interaction*: Robot is assisting the human. The robot serves without following individual goals, obeying commands of the user. Synchronization between the two agents takes place through the transmission of commands from the human to the robot, with limited feedback by the robot.
- *Cooperation interaction*: This describes a situation where human and robotic agents, share a work-piece. The synchronization of both agents takes place through the location of the work. Both agents need to be aware where and when the respective other agent works on a part of the work piece. The agents must not perform any steps that interfere with the other's work. This requires some understanding about the other agent's currently executed and immediate next tasks.
- *Collaborative interaction*: Here, human and robotic agents share a task. The synchronization of both agents is not limited to a work-piece, but activities are synchronized. Timing and location, where the tasks are executed, are of importance. Also, the upcoming activities of the collaborator. Both (the human and the robot) need a detailed understanding of the activities including their timing.

III. PROCESS DESIGN APPROACHES

In the following, we take a look at different approaches which fall into two categories. Task centric approaches considered are for example Business Process Management Notation (BPMN), and ARIS [4], communication oriented approaches are for example Subject-oriented Business Process Management (S-BPM) [5], and Agent-oriented Business Process Management (ABPM) [6].

A. *S-BPM*

S-BPM (Subject-oriented Business Process Management) is a process approach, used for manual design of processes, which are executed by humans. Recently extensions have been researched to mix human and artificial agents [7,8].

S-BPM allows to model two aspects, the subject-interaction, and the subject behavior. Subject Interaction Diagrams (SID) show the message flows between subjects. Subject Behavior Diagrams (SBD) show the individual control flow of a single subject. These two diagrams are on two different levels of abstraction. Subjects may be interpreted as roles of agents that prescribe the behavior of that role in a wider process context.

Figure 1 shows a S-BPM process. On top, a subject interaction diagram is presented. The grey boxes are "Collaborator" represent subjects. A subject is similar to a role in a process. It shows the interface where information objects are exchanged, between the subjects. The second part of Figure 1. shows two subjects next to each other, and their internal behavior. Three types of activities are possible: (1) Act (yellow; marked with F), (2) Receive Business Object (green; marked with R), (3) Send Business Object (red; marked with S). One start activity is marked with a "play" triangle; multiple stop activities marked with square.

A formal implementation of S-BPM exists [4, 9] based on Abstract State Machines [10]. Part of that formalization is given in listing 1 below.

Listing 1.: ASM Implementation for verification & automated execution [9]

BEHAVIOR (*subj* , *state*) =
  if SID_*state(subj)* = *state* **then**
    if *Completed*(*subj* , *service*(*state*), *state*) **then**
      let edge = select$_{Edge}$ ({*e* ∈ *OutEdge*(*state*) | *ExitCond*(*e*)(*subj* , *state*)}) in
        PROCEED (*subj* , *service(target(edge)), target(edge)*)
    else PERFORM (*subj* , *service(state), state*)
where
  PROCEED (*subj* , *X* , *node*) =
    SID_*state(subj) := node*
    START (*subj* , *X* , *node*)

The ASM-based Listing 1 is interpreted as follows: Every subject is in a particular state (SID_State). A transition from one state to the next happens when the execution of a service is finished. Service here includes the three activities (send, receive, act). The rule PERFORM is executed until the predicate *Completed* confirms the service has been

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completed. The next edge to be followed for the next state, is selected by the $select_{Edge}$ function.

To conclude, S-BPM has both, a human read-able representation, and a formal representation.

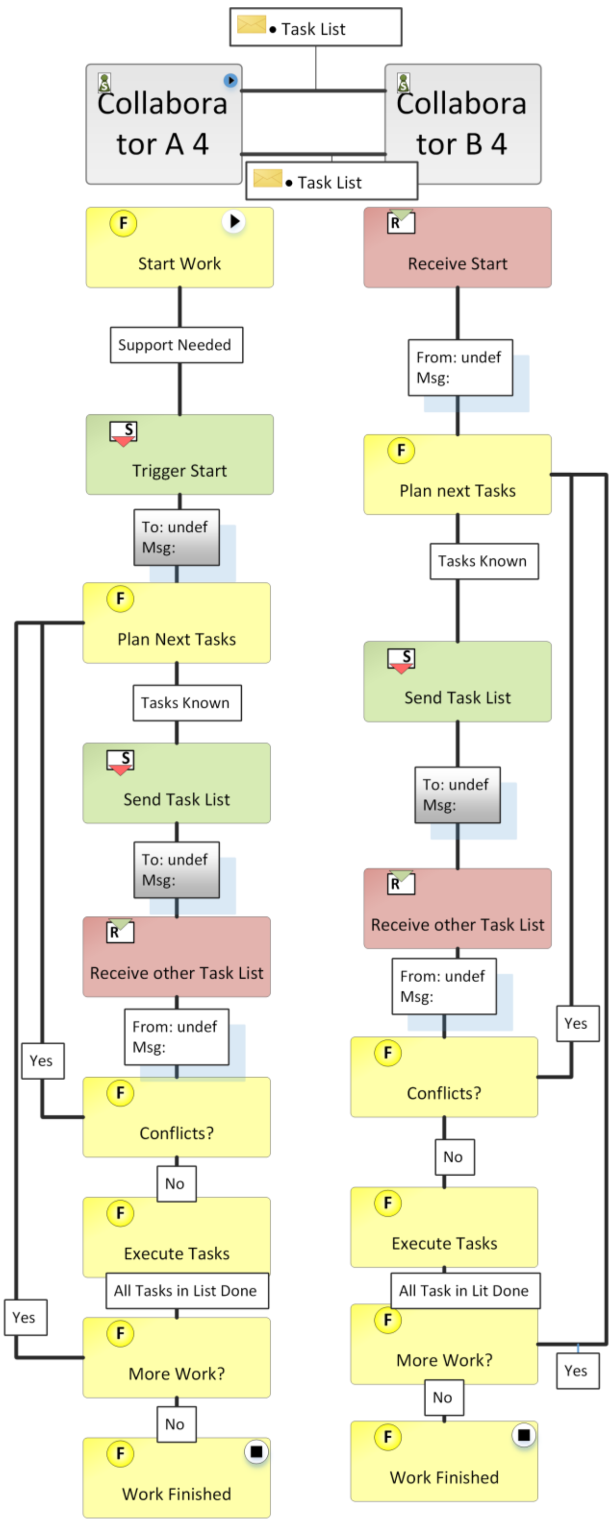

Figure 1. Example of a process model for human robot collaboration [11].

B. BPMN

The Business Process Management Notation (BPMN) is the de-facto standard for representation of processes in the business world [12]. Version 2.0 has been accepted as ISO standard. BPMN 2.0 includes support execution of BPMN process models, and a serialization standard has been added [13]. Some execution engines support the simulation of processes.

Agents' roles may be modelled as pools, and lanes within a pool (see Figure 2). Message flows are used to synchronize tasks in different lanes. This allows the implicit definition and usage of message exchange protocols as standard interfaces between certain "roles". In contrast to S-BPM, this is not explicit in a separate model.

Swimlanes are used to separate different entities working on a process. The yellow diamonds indicate "or" gateways; Green round symbols are start events, where for the robot this is a message based event. Messages sent around are modelled explicitly on the same level. Red circles are stop events.

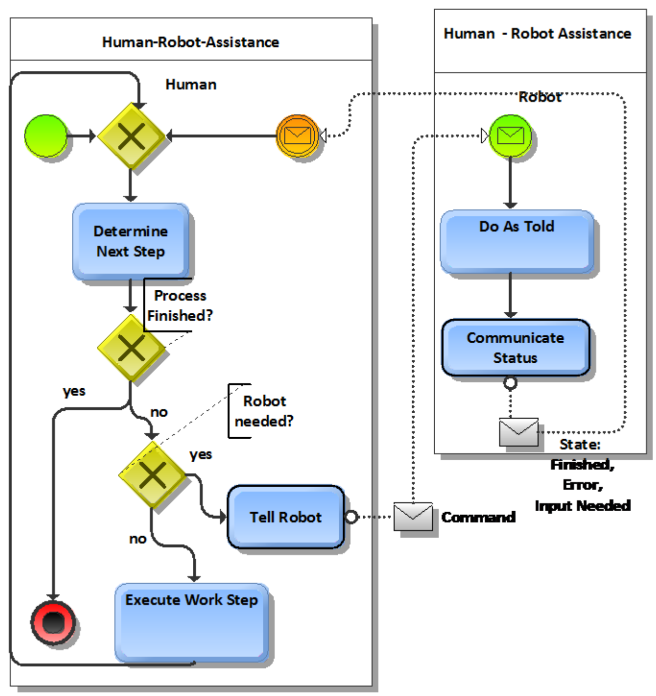

Figure 2. Example of a process model for human robot assistance.

However, BPMN is a large, and feature-rich modeling language. Unfortunately, this feature richness provides problems in practical environments. Most users do not know the exact definition, and usage of all concepts, model constructs [12]. All existing *execution* engines execute only a limited set of concepts. The automated translation from a modelled process to an executable one is at least cumbersome, and dependent on the actual used engine [13].

These problems partially stem from a missing formal semantics, and a missing formal execution environment [14].

For BPMN, we may conclude that while it is well known standard, it is only of limited suitability for communicating the processes to robots. However, an execution environment might take a subset of the BPMN standard, and use that subset to communicate to humans, and robots. Yet, no prior work exists helping in selecting required modelling constructs.

IV. CONCLUSIONS

Given the increase of flexibility required for getting production back to Europe, the number of work environments with human robot collaboration is expected to rise.

Current research focuses on the interaction part of robots with humans in linear, simple processes. However, in the near future, the complexity of processes is expected to rise. This implies the need for communication of these processes to the humans as well as to the robots.

In this initial work, we have analyzed two approaches to business process modelling and execution. For each, we have provided a brief description with respect to its suitability to communicate a complex process to both, the human and the robot.

We will continue this research in the near future, in order to understand the contributions of process models in flexible and interoperable production environments.

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