

Introducing Entity-based Concepts to Business Process Modeling

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Abstract. The so-called Internet of Things (IoT) that comprises interconnected physical devices such as sensor networks and its technologies like Radio Frequency Identification (RFID) is increasingly adopted in many industries and thus becomes highly relevant for process modeling and execution. As BPMN 2.0 does not yet consider the idiosyncrasies of real-world entities we suggest new modeling concepts for a physical entity as well as a sensing task and an actuation task to make BPMN IoT-aware.

Key words: Internet of Things, IoT, Business Process Modeling, BPMN

1 Introduction

Today, the gap between the sensors and actuators in the Internet of Things and the business systems at the higher layers of the enterprise world is still a reality. A unified reference architecture is therefore a key prerequisite for realizing interoperability within the IoT world and especially for integration with business processes, so that applications can be realized that are both IoT-aware and meet the requirements of enterprise systems. Currently, the IoT domain is being standardized based on a unified IoT domain model [4] that is discussed in the next section. We apply core concepts from the IoT domain model to the Business Process Model and Notation (BPMN) 2.0 [2]. As BPMN focuses on activities and the implicated flow of process steps while the IoT domain model stresses the relationship between entities and other constructs for which well defined processes might or might not exist, a mapping and integration problem between both domains becomes apparent.

In the remainder of this paper we will use the following typographical conventions: Concepts from the IoT domain model are typeset in `sans serif`, and concepts from the BPMN metamodel are typeset in `constant width`.

2 A Domain Model for the Internet of Things

Based on [1] and [3] a first version of the domain model for the Internet of Things has been developed in [4]. As this model is an extensive conceptual representation

of the IoT domain, it serves as a basic fundament for the presented research work. In this section we shortly explain its core concepts, please confer Fig. 6 in [4].

As the term Internet of Things suggests, the *thing* is the most important concept in the domain model; it is called **Physical Entity**. The main purpose of the domain model is to show, in which way any kind of **User** can interact with a **Physical Entity**, so the association interacts with between the **User** and the **Physical Entity** is the key concept of the model.

To represent a **Physical Entity** in the digital world, a **Virtual Entity** is associated to it. While a **Physical Entity** exists only once, there can be multiple **Virtual Entities** representing it. Every combination of a **Virtual Entity** and its **Physical Entity** forms one **Augmented Entity**.

In order to make the **Physical Entity** accessible from the digital world some hardware, a so-called **Device**, is attached to the **Physical Entity**. To distinguish between **Devices** which observe a **Physical Entity** and **Devices** which control a **Physical Entity**, three subclasses of **Device** are introduced in the domain model: A **Sensor** can be attached to a **Physical Entity** to monitor it, an **Actuator** can be attached to a **Physical Entity** to act on it, and a **Tag** can be attached to a **Physical Entity** to identify it.

To close the gap between the **Device** and the digital world, it hosts several software components in its memory, which are called **Resources**. Depending on the type of the **Device**, such a **Resource** has information about the **Physical Entity**, or it can act on the **Physical Entity**. **Virtual Entities** can be associated with **Resources** via the **Device** and the **Physical Entity**.

As the **Resources** hosted on the **Devices** are expected to have different interfaces, **Services** are introduced as an abstraction concept; they access the **Resources**. These **Services** provide well-defined interfaces to the **Users** for invoking them. Since the **Virtual Entities** are associated with the **Resources**, they can be associated with the **Services**, which access these **Resources**, as well.

Summing up, the interaction of the **User** with the **Physical Entity** can be detailed as follows: The **User** invokes a **Service**, which accesses a **Resource**, which is hosted on a **Device**, which either monitors the **Physical Entity** or acts on the **Physical Entity**.

3 Mapping between IoT Concepts and BPMN Concepts

To bring the IoT domain and business process modeling together, we analyse, how the concepts from the domain model can be modeled in BPMN, and if the chosen BPMN concepts are adequate to reflect the specificities of the Internet of Things. Table 1 summarizes the proposed mapping of IoT and BPMN concepts.

A **Physical Entity** can be modeled as a **TextAnnotation** to an **Activity**. Since the concept of a **Physical Entity** is not defined in BPMN, we use the **TextAnnotation** as the general BPMN concept for attaching further details to a modeling element. The usage of a **TextAnnotation** for the modeling of a **Physical Entity** is not sufficient, and leads to multiple problems: As specified in [2] a **TextAnnotation** only provides additional information for the reader of a

Table 1. Mapping of IoT concepts to current BPMN concepts and their sufficiency for modeling of IoT aware processes

IoT concept	BPMN concept	Sufficiency for Modeling
Physical Entity	<code>TextAnnotation</code>	not sufficient
Virtual Entity	<code>DataObject</code>	sufficient
Augmented Entity	—	not needed in BPMN
Sensor	<code>Participant</code>	sufficient
monitoring	<code>ServiceTask</code>	not sufficient
Actuator	<code>Participant</code>	sufficient
acting	<code>ServiceTask</code>	not sufficient
Tag	—	not needed in BPMN
Resource	—	not needed in BPMN
Service	<code>ServiceTask</code>	not sufficient
User	<code>Participant, Event</code>	sufficient

diagram, but does not affect the flow of the process. Accordingly, the specification of a dedicated **Physical Entity** in the model would not be obeyed during the execution of the process. Second, a `TextAnnotation` can be attached to only one object in the collaboration diagram, but one **Physical Entity** could for instance be monitored by multiple **Sensors**. Third, there is no definition of a lifecycle for a `TextAnnotation`, but a **Physical Entity** naturally persists between several process executions.

The **Virtual Entities** relating to the **Physical Entities** can be modeled as collection `DataObjects` in a BPMN collaboration diagram, because this is the concept for modeling data, which BPMN provides. As the concept of a **Virtual Entity** is not only specific to the IoT domain, but a general concept in informatics, this approach of modeling is considered to be sufficient, and fully serves our purposes.

As the **Augmented Entity** in the IoT domain model is only an abstract concept to combine a **Virtual Entity** and a **Physical Entity**, there is no corresponding concept in BPMN. Since such an abstract concept would not add any benefit for the practical modeling of business processes, the **Augmented Entity** is not needed in BPMN.

Sensors and **Actuators** can sufficiently be modeled as **Participants** in a collaboration diagram, because this concept is defined in BPMN to represent a `PartnerEntity`, which executes a process. If multiple instances of **Sensors** or **Actuators** are involved, the corresponding pools can be decorated with multi-instance markers.

As a **Sensor** is described in the domain model to monitor a **Physical Entity** and an **Actuator** is said to act on a **Physical Entity**, these monitoring and actuation associations can be expressed with `ServiceTasks` in a BPMN diagram. In BPMN `Tasks` are the central concept of execution during the process flow, so this modeling is appropriate. The particular `Task` can implicitly be identified as a `Task` for monitoring or actuation through the `Participant` executing it, the **Physical Entity**, which is represented in the attached `TextAnnotation`, and the

name of the **Task**, which states the means of **monitoring** or **actuation**. So far it can not be explicitly marked as a specific **Task** for **monitoring** or **actuation**.

Even though the concept of **attaching Tags** to **Physical Entities** to make them **identifiable** is one of the most widely adopted applications of Internet of Things technologies, it is a low-level technology, and an introduction to BPMN is not needed. If the process of this identification is of particular interest, the **Tag** can be considered as a **Physical Entity**, which is **monitored** by a **Sensor**.

The **Resources** introduced in the domain model are the software components running on the **Devices**. Since BPMN collaboration diagrams focus on **Participants** executing **Tasks**, introducing the **Resource** to BPMN is not reasonable.

In the domain model the **Services** provide a consistent interface for the **Resources**, which are hosted by **Sensors** and **Actuators**. In BPMN these **Services** can be modeled as **ServiceTasks**, which are executed by the **Participants**, which represent **Sensors** and **Actuators**. As described above, the **Physical Entities**, on which these **ServiceTasks** operate, are referenced in the attached **TextAnnotations**. Although the modeling of the **Services** via **ServiceTasks** seems appropriate, it is not sufficient: In a collaboration diagram it is impossible to distinguish, if the **Service** performs a **sensing** or an **actuating** interaction with the **Physical Entity**.

For the **User** in the domain model, who invokes the **Service**, the different BPMN concepts for the invocation of **Tasks** can be considered. This could be a **Message** from another **Participant** or an **Event**. As there are many concepts for the invocation of **Tasks** in BPMN, no new concept for the **User** needs to be introduced.

The result of our analysis is summarized in Table 1: The **Physical Entity** and the **monitoring** and **actuating Services** can not be represented sufficiently in BPMN.

4 New Modeling Concepts

4.1 Modeling of Physical Entities

To facilitate the modeling of **Physical Entities** we propose a new BPMN element **PhysicalObject**, which is subclassed from **FlowElement** in the BPMN meta-model. In contrast to the **DataObject** the **PhysicalObject** is not subclassed from **ItemAwareElement**, because these are designed to store items, but a **Physical Entity** is an item itself. Accordingly, the BPMN elements **DataState** and **ItemDefinition** are not needed for the **PhysicalObject**. To enable the modeler to refer to the same **Physical Entity** in multiple places of a diagram, we introduce a **PhysicalObjectReference** analogous to the **DataObjectReference**.

We propose the illustration of a brick shown in Fig. 1 as stencil for the **PhysicalObject** to make this new concept usable in a BPMN collaboration diagram. As it is possible that not only one instance of a **PhysicalObject** is used in a process, the stencil can be decorated with a multiple instance marker,

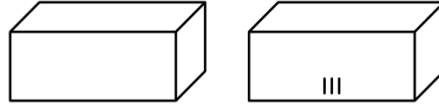


Fig. 1. Stencils for a single `PhysicalObject` (left) and a collection of `PhysicalObjects` (right)

like it is defined in [2] for `DataObjects`. The name of the `PhysicalObject` will be placed above the base line of the stencil.

As `PhysicalObjects` are obviously physical, their lifecycle is not limited to the lifecycle of the modeled process; they persist between process instantiations. This differentiates them from `DataObjects`, which are defined in [2] to not persist between process instantiations, but is similar to `DataStores`, which are also persistent according to [2].

4.2 Modeling of monitors and acts on Associations

To empower the modeler to express that a `Task` reflects a monitors or an acts on relationship between the `Participant` and the Physical Entity represented in the `TextAnnotation`, we introduce dedicated `SensingTasks` and `ActuatingTasks` as new subclasses of the `Task` class.

Since a `Sensor` produces data about a Physical Entity by monitoring it, the `SensingTask` must output this data and provide it for the remainder of the process. Hence, we can derive the following constraint for the `SensingTask`: The `InputOutputSpecification`, which is associated with the `Activity` superclass of the `SensingTask`, must reference at least one `DataOutput`, which must also be referenced by at least one `OutputSet` of the `InputOutputSpecification`. Because an `Actuator` needs an actuating value, an analogous constraint applies to the `ActuationTask`: The `InputOutputSpecification` associated to the `ActuationTask` must reference at least one `DataInput`, which must also be referenced by at least one `InputSet`.

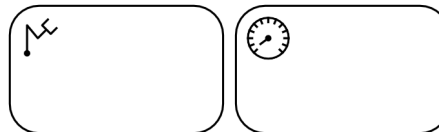


Fig. 2. Stencils for an `ActuationTask` (left) and a `SensingTask` (right)

For the new `Tasks` we propose the icons shown in Fig. 2 to decorate the stencil for the `Task` with: The `ActuationTask` is decorated with an illustration of a robot arm and the `SensingTask` is depicted with a gauge.

4.3 Connecting PhysicalObjects with ActuationTasks and SensingTasks

Analogous to the `DataAssociation` defined in [2], we define a new abstract class `PhysicalAssociation`, derived from `BaseElement`, and two concrete subclasses `ActuationAssociation` and `SensingAssociation`. The former is a directed connection from an `ActuationTask` to the `PhysicalObject`, on which the represented `Actuator` acts on; it can be considered as a *flow of physical interaction*. The latter is directed from a `PhysicalObject` to a `SensingTask`; this can be considered as a *flow of physical information* from a `Physical Entity` to a `Sensor`.

To depict such associations in a BPMN diagram, we propose to reuse the same stencil as it is defined for a `DataAssociation` (cf. Fig. 10.65 in [2]).

5 Conclusions & Outlook

With this paper we have demonstrated first concrete steps towards bringing together the Internet of Things and Business Process Management. We have come up with first suggestions for augmentations to the BPMN 2.0 standard to reflect the most important aspects of the IoT domain model.

Our future work will deal with the further elaboration of the concepts presented in this paper including serializations of the new modeling concepts in the BPMN CMOF and the BPMN XML Schema and the serializations of the diagram elements in the BPMNDI XML Schema.

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