

Towards Incorporating Context Awareness into Business Process Management

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Abstract—Context-aware technologies provide system applications with the awareness of environmental conditions, customer behaviours, object movements, etc. Further, with such capability system applications can be smart to intelligently adapt their responses to the changing conditions. In regard to business operations, this promises businesses that their business processes can run more intelligently, adaptively and flexibly, and thereby either improve customer experience, enhance reliability of service delivery, or lower operational cost, to make the business more competitive and sustainable. Aiming at realising such context-aware business process management, this paper firstly explores its potential benefit, and then identifies some gaps between the current business process management support and the expected. In addition, some preliminary solutions are also discussed in regard to context definition, rule-based process execution, run-time process evolution, etc. A framework is also presented to give a conceptual architecture of context-aware business process management system to guide system implementation.

Keywords—Business process adaptation, business process evolution, business process modelling, and context awareness.

I. INTRODUCTION

THE rapid growth of context-aware technology, such as Radio Frequency Identification (RFID) and sensor network, has recently brought us smart appliances, building automation, self-adapting logistics chain, etc., which show significant impacts to our everyday life and business operations [2]. These technologies offer the awareness of environmental conditions (e.g., temperature, humidity, etc.), customer behaviours (e.g., browsing time for specific product, the number of interested users, etc.), object movements (e.g., a pallet of goods go through the entrance of a warehouse, the location of a specific product, etc.), and many more. In regard to business processes, such capability enables business processes to perceive customer-related or item-level dynamics during run time [3]. If such capability is incorporated into business process management (BPM), we can imagine that business operations would be smarter, more intelligent, and interactive.

Current application of context-aware technology is mainly limited to very specific areas, such as self-switching-on/off ATMs, building automation (turning on/off air conditioners according to temperature and residents' work time), product tracing in distribution centres, etc. From a BPM perspective, such application merely focuses on applying context-

awareness to improve a specific operation rather than integrating it into the lifecycle of a business process. Aiming to realise a full incorporation of context-aware technology, this research-in-progress paper conceptually discusses the motivation of and the challenges in incorporating context awareness into business process management. In particular, this paper brings contributions in the following aspects:

- Identify the challenges for this incorporation.
- List key topics to conquer the identified challenges, and discuss these topics with related methods and mechanisms.
- Present a preliminary framework to support context-aware business process management.

As little work has been done in this area, this paper intends to sever as a bridge connecting the big picture and the practical implementation of context-aware business process. The rest of the paper is organised as follows: Section II introduces the background of context-aware technology and business process management, and reviews typical works in related areas. Section III illustrates how context-aware business process applications assist business in improving both efficiency and effectiveness of business operations. Section IV addresses the challenges of realising such context-aware business processes, and discusses potential mechanisms and methods to tackle them. Section V presents a preliminary framework of context-awareness business process management system to guide system implementation; and finally the conclusion is given in Section VI along with a discussion of our future work.

II. BACKGROUND AND RELATED WORK

Business process modelling has been rated as one of top three strategic technologies by [4], while context-aware technology has been widely accepted as a promising driver for next technology evolution. To better understand the background of context-aware business process management, this section is to introduce what context and context awareness are, and also review some typical work in the area of incorporating context awareness into business processes.

A. Context and Context Awareness

In line with the increasing popularity of business process management, changing business requirements need companies to rapidly capture contextual information and adjust process models to adapt to it. Dey, Abowd and Salber defined context as “any information that characterises a situation related to the interaction between humans, applications and the surrounding environment” [5]. However, context is ubiquitous and difficult to handle due to the complexity of information selection,

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distribution, modification, and utilisation.

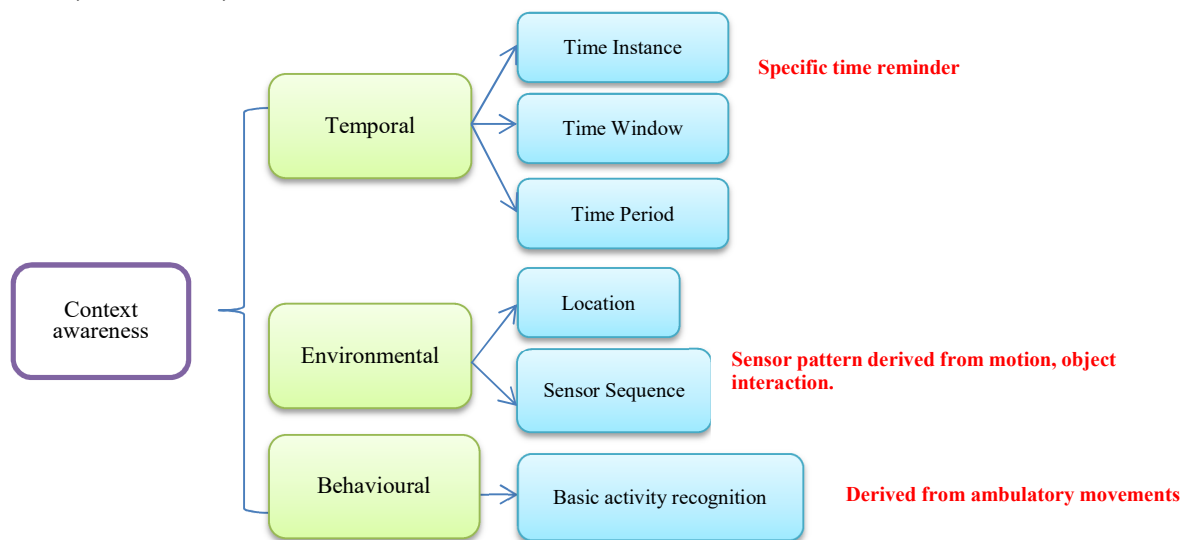


Fig. 1 Context model [1]

The choice of context information used in applications can determine the performance of a whole business process. Context is a silent but pervasive actor in all interplay and communication process which can shape human experience, and conversely can be manipulated through a lens of applications and devices [6].

Context awareness is not a new topic and it can be broadly found in other research models. Around the definition of context-awareness, there are various versions from previous research. Schilit and Theimer defined it as “location awareness” [7]. Dey has defined the same term with an emphasis on its useful information for identifying the entire human-application interaction situation [2]. This shift includes all users and applications and even a wide spectrum of information identification, analysis, modelling, and adoption [1]. In the current context-aware prompting system, both temporal and environmental parameters are used to identify useful and meaningful contextual information. Compared to traditional desktop-bound interaction or human-computer interface, context-aware technology enriches interactions to be more physical, engaging, and tangible [8], [9]. However, few successful products of context-awareness and ambiguity on how to apply this technology for a proper purpose indicated the current poor utilisation of context-aware technology [6, 10]. Das et al. hypothesise a context model based on current work [1], where Fig. 1 illustrates the three main parameters for context awareness to classify different types of contextual information. The temporal context refers to the time-setting reminder during a certain period. It may include all the time instance, time window and time period. The environmental context includes the location or sensor information that is related to complicated activity, also the sensor sequence is vital for prompt situations. Lastly, behavioural context has basic activity recognition functions and numerous context combinations need to be defined.

B. Business Processes and Context

To our best knowledge, the work on incorporating context concept into business processes is still at a relatively early stage. Rosemann and Recker have touched this topic from the management oriented perspective, and at a conceptual level have discussed how different phases of a business process lifecycle integrate with context factors [3]. In the mutual relationship among a business process model, business process design and external context factors as shown in Fig. 2, the scope of a business process model is closely connected with process, and relevant context information can be selected according to the specific business process goals. In order to combine the context information with the goal-oriented business process model, considering the changing economic environment and business situation [11].

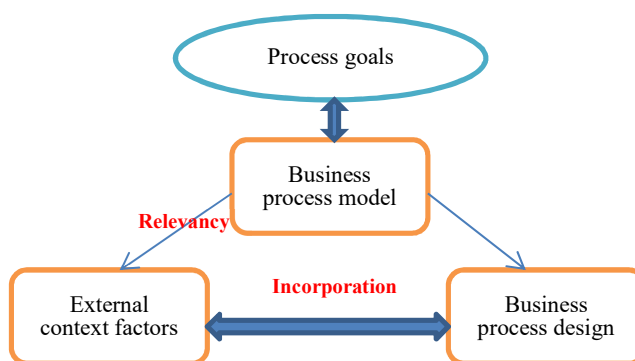


Fig. 2 Incorporating context into business process design

Yet, traditional business processes and business process design methods rarely consider such capability, and therefore can hardly take advantage of it. With increasing attention on internal and external context-related business changes and dynamic workflow patterns, there is a strong demand of adaptive approaches to incorporate context-aware capability

into business process design. The obvious trend for business process management is the shift from activity-oriented modelling perspective to rules-based item/artefact-oriented, which shows enormous potentials in making business process more agile, flexible and adaptive to changes [12]. In this area, Hamadi and Benetallah have proposed a self-adaptive recovery net (SARN) to support workflow adaptability during unexpected failures [13]. In Sadiq et al.'s work on flexible workflows [14], concept "pockets of flexibility" has been proposed to allow ad hoc changes and/or building of workflows. With a focus on organisational factors, BPM group at QUT has extended event-driven process chain (EPC) to represent a range of variations in terms of roles and objects that are associated to tasks [15]. Ly et al. have investigated the semantic correctness issue in process changes, and also set up corresponding criteria [16]. Yet, these works typically focus on process change management without direct consideration of context influences. Before fully embracing context-aware business process management, there are still a lot of challenges beyond adaptive business processes, such as context definition, interactions between business processes and the context, management of process evolution in a changing context, etc. These will be discussed in another section of the paper.

III. MOTIVATION OF INCORPORATING CONTEXT AWARENESS INTO BUSINESS PROCESS MANAGEMENT

The shift to context-aware business process management is expected to bring more intelligence, accuracy, and adaptation towards better personalisation, efficiency and etc. This section first uses a supply chain scenario to illustrate how context-aware business process management works.

In pharmaceutical industry, supply chain is particularly critical for both manufacturer and consumers, as pharmaceutical goods have very high requirements on delivery time and batch control accuracy. Management over pharmaceutical supply chain focuses on monitoring material purchasing process, stock checking process, and distribution process. Traditional supply chain management orders materials according to the estimated sales. To guarantee the production is not influenced by late arrival or lack of materials, a safety stock often has to be reserved all the time. Due to the diversity of stock items and the short preservation period, the cost of maintaining this safety stock is very high.

With context awareness, manufacturers are enabled to fine tuning the supply chain, and thereby reduce the safety stock level. Below are some examples showing how context awareness influences the supply chain management processes.

In regard to stock recording process, by setting up sensors in the warehouse, the manufacturer can automatically record the exact number and type of materials moved into or out of the warehouse, and therefore can maintain very accurate volume, batch information, and storage location of each single type of materials. Further, by monitoring stock levels, this process can also trigger stock replenishment process.

In regard to purchasing and delivery processes, awareness of the location of goods in transit can help the manufacturer

predicate the arrival date, and accordingly re-prioritise stock replenishments, arrange deliveries from alternative couriers, etc. This indicates that according to the perceived dynamics each material purchasing process may have different delivery arrangements, are assigned with different priorities, and even adapt their process structures to better interact with vendor specific sales processes (e.g., varied lead time, special packaging, transportation requirement, etc.). As a return, these make the whole supply chain much more reliable and scalable, and thereby reduce the risk of overstocking or shortage particularly during unpredictable emergencies.

In regard to the distribution of pharmaceuticals, some scarce pharmaceuticals are only delivered on demands, yet such demands are often changing. To ensure the limited pharmaceuticals can serve maximum and most needed patients and get delivered on time, the distribution process needs to modify the destination and quantities of needed pharmaceuticals on the fly, according to the changing demands and buyers. A smart distribution process will keep optimising the delivery map, initiating new deliveries, and rearranging existing deliveries, as well as tracking the movements of pharmaceuticals and updating the demand list. Many decisions have to be made on spot based on perceived changes and analysis on historical transactions, for example whether to redirect a delivery to a new destination depends on the received the demand and the comparison between the likelihood that new demand will stand and estimated opportunity cost.

From the above discussion, we can see the contexts of different business processes include the changes of stock volume, goods location/movement, customer demands, etc. The awareness of these changes makes business process more intelligent and smart to apply finer control of products, create more adaptive and robust supply network, and adjust delivery route at run time to pursue the optimal result. Such flexibility, adaptation, and intelligence provide considerable benefits to the business process management over supply chains, manufacturing, sales, and other areas. This is particularly beneficial to the industries where run-time item-level information and fine process control is desired. Typical targeted industries include pharmaceutical industry, tourism, manufacturing of highly customised products, etc.

Before achieving these benefits, novel management over business processes is required to support the perception to context, run-time resource reallocation, dynamic business process change, etc. Current business process management has no consideration with context awareness at all, a business process has very limited interfaces to receive external inputs, and most of them are for human inputs only. Furthermore, current business process management assumes a business process only sticks to its predefined business logic and process structure using the pre-allocated resources. Table I lists the major differences between traditional and context-aware business process management. Because of these differences, there are a lot of challenges on the way to realising context-aware business process management. To tackle this lack of automatic retrieval of contextual dynamics, specific definition

of context and the mechanisms on interpreting contextual changes to business meaningful event are favoured to incorporate into business process management. Run-time process evolution also calls for dedicated supports on process version management, process change, and migration. Detailed discussions about these challenges and potential solutions are to be given in next Section.

TABLE I
 COMPARISON BETWEEN TRADITIONAL AND CONTEXT-AWARE BPM

Traditional BPM	Context-aware BPM
Limited interfaces to external inputs	Automatic retrieval of context dynamics
Business logic and control are predefined at build time	Adaptable and evolving process definition
Reactive execution under business process engine	Active execution according to perceived changes
Business intelligence stays at strategic decision making level	Application of business intelligence at operational level to assist run-time process changes

IV. CHALLENGES AND POTENTIAL SOLUTIONS OF CONTEXT-AWARE BUSINESS PROCESS MANAGEMENT

According to the identified characteristics of context-aware business process management, this section discusses the challenges and potential solutions in details.

A. Define the Context for Business Processes

In context-aware computing, context has been generally defined as “any information that characterises a situation related to the interaction between humans, applications and the surrounding environment”. When narrowing the scope down to business process management, a meaningful and specific definition of context must be established before realising context-aware business process management.

B. Innovative Business Rule Definition

Business processes are designed as specific interpretation (often graphical) of business rules. In traditional business process management, such rules are often statically defined in an if-then format or something equivalent without considering dynamic contextual changes. In context-aware business process management, such rules should be extended to include the ones navigating the execution of business processes, the ones driving business process evolution, and the ones that can convert basic contextual events into business meaningful events. A comprehensive framework of defining such business rules is in a great demand to build the mechanism for driving context-aware business processes.

C. Definition of Evolving Business Processes and Business Process Evolution

As a distinctive characteristic, business process evolution frequently occurs during the lifecycle of a business process in context-aware business process management. The process structure, allocated resources, and execution related constraints of an evolving business process could be all changing at run time. How to define such a dynamic process

becomes the first challenge to context-aware business process management. In addition, another issue is that the business process evolution should capture what features, and follow what rules. In other words, how can we guarantee the evolved business process is still consistent with previous business semantics, compatible with the supporting IT and organisational infrastructure, collaborating with related business processes, and compliant with business rules and regulations?

D. Management over Evolving Business Processes

The process evolution will easily result in multiple instances of different versions of the same business process running at the same time, as each process instance may evolve differently from others according to its own context. At a process level, how to identify, configure, record, and transit between different versions of the same business process becomes the main issue for process management.

Each of aforementioned challenges opens a directional research topic for business process management development. At a higher level, we introduce a preliminary blueprint for realising context-aware business process management with proposed methods to tackle these challenges.

E. Representation of Context for Business Processes

Representing the context for business process relates to a series of questions, viz., first, how to define the context for business processes; second, what tool is most appropriate for representing the context; and last, how to integrate it into current business process modelling languages.

In regard to the first question, an extensible ontology could be built to represent the general context of business processes, and each specific business process application can concretise this ontology with its own entities or attributes. As shown in Fig. 3, we define a preliminary version of this general ontology for business process context.

The latter two questions can be considered together. There are two main stream business process modelling languages, BPMN and BPEL. BPMN is fully graphical and does not strictly rely on any mathematical foundation, while BPEL follows a canonical structure, which inherently complies with process algebra. As a tool closely related to process algebra, representation theory [17] also serves process description with speciality in formalising the behaviours of and dependencies among process activities. Another advantage of process algebra and representation theory is their easy connection to event-based rules, which are naturally useful for defining the reaction rules to contextual changes. In addition, Petri net and its variety WF-net are also widely used to describe business processes with speciality of representing concurrent controls. Yet, such Petri-net based tools lack the expressiveness of events, and the complexity of process models increases significantly as the size of modelled business process grows. These factors second Petri-net based tools in the competition for process context representation.

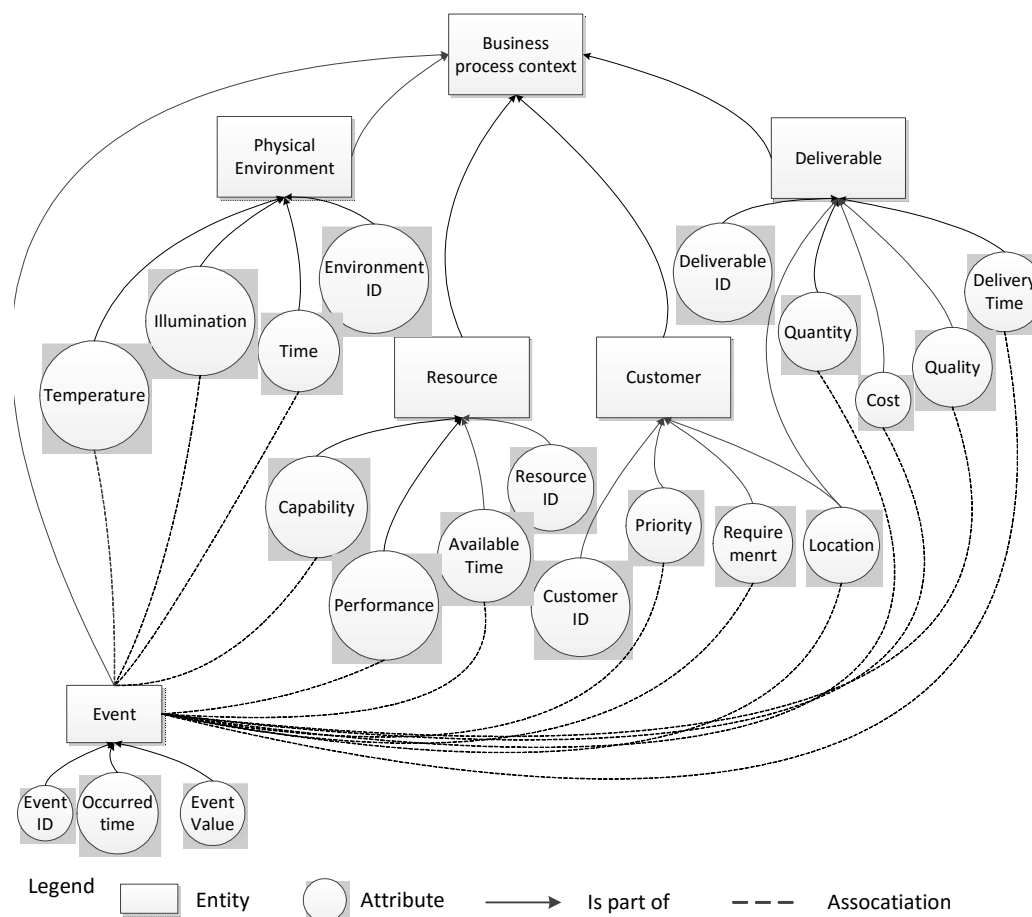


Fig. 3 Hierarchical ontology of general business process context

F. Business Rule Definition

Context awareness relies on sensors' constant/semi-constant monitoring of contextual dynamics. This indicates that new event-oriented rules should be in place to drive business processes to respond or adapt themselves to perceived changes. In the context-aware computing or pervasive computing environment, such sensing is a process of collecting raw events from a group of sensors, filtering the events, and eliciting business meaningful events out of them. Current sensor systems can well handle event collection and filtering, yet event elicitation and responding is mainly left to business process management system.

Event elicitation scans a stream of raw sensor events, and interprets them into business meaning events by matching the events to specific patterns. For example, in a distribution centre the interval of unloading a pallet of products is no less than 30 seconds, and therefore if the last sensed product arrival event is more than 30 seconds old, it indicates the products from a specific pallet have all arrived; otherwise it indicates the arrived products are from another pallet. Our previous work [18], [19] has investigated such event elicitation and identified that event calculus is a very effective tool. Following its six axioms, event calculus can fully characterise the meaning of a stream of raw events and convert the stream into a series of business meaningful events

using certain event-based rules. Such event-based rules describe the dependency among raw events, and use it to work out the business meaning of a series of raw events. Compared to other event modelling methods, such as state transition diagrams and Event Process Chains (EPC), event calculus is superior in modelling actions with indirect or non-deterministic effects, concurrent actions, and continuous changes, in a much concise representation.

Once the business meaningful events are elicited, these events are to be fed to the business process engine to navigate process execution or evolution. At this level, there are two other types of rules relying on these business meaningful events, i.e., process-oriented rules and management-oriented rules. Process-oriented rules focus on evaluating contextual changes, deciding how to adapt the business process, etc. Management-oriented rules are responsible for re-arranging resources to running process instances, prioritising running process instances, etc. Both types of rules belong to event-oriented rules, and therefore Event-Condition-Action (ECA) format naturally fits them.

The process-oriented rules should be able to recognise the predefined business process context, and decide how to adapt the current business process to the perceived changes to the context. Such rules are often extracted from corporate policies and regulations, interviews from process participants, etc. In

practice, such rules are often merged in process definitions, or separately defined in ECA format, or defined from the perspective of artefact lifecycle in artefact-oriented business process modelling [20], [21].

In regard to management-oriented rules, since process changes and contextual changes are hard to predict, such rules are often defined as heuristic rules with non-deterministic estimation. References [22], [23] have discussed how to set up heuristic rule to dynamically allocate resources to running process instances with the emphasis on analysing process structural dependencies. Such techniques can be applied to this scenario as well.

G. Definition of Evolving Business Processes and Business Process Evolution

Different from static business processes, evolving business processes has a changeable structure, a changeable list of needed resources, temporal, and other execution constraints. To represent these dynamics, versions play an essential role. Each version of a business process indicates a specific business process after a certain evolution. This specific business process owns a fixed set of process structure, list of needed resources, and related constraints.

The structure of a traditional business process is often modelled as an extended graph. In set theory, this is represented as graph $g=(T, L)$, where T and L refer to the task set and link set, i.e., $\forall l=(t_1, t_2) \in L, \exists t_1$ and $t_2 \in T$.

Correspondingly, the structure(s) of an evolving business process p will be defined as tuple (G, V, f) , where

- G is the set of all possible business process structures that p could reach, i.e., $\forall g \in G, g=(T, L)$;
- V is the set of versions;
- Function $f:V \rightarrow G$ maps each version to a specific business process structure.

This formula is given to show the extension to the popular business process definition, which is often formalised using set theory.

Once an evolving business process is defined, a process evolution would be a transition from a process version to another version. Instead of through a rigid structural change, such transition should be achieved through a series of process change operations. This series of operations should comply with the 4C constraints for process evolution, viz., the evolved business process keeps the Consistent structure and semantics with the unevolved part of the original process; the evolved business process is Compatible with the IT and organisational infrastructure; the evolved business process is able to continue the Collaboration with its cooperating processes; the evolved business process Complies with the existing rules and policies.

The 4C constraints guarantee the process execution and collaboration will not be violated during process evolutions. Our previous work [24], [25] has touched the process evolution particularly under Consistency restriction by proposing a set of 14 process change operations and related enforcing rules. Any process evolution can be achieved by applying a combination of these 14 fundamental change

operations to the original business process, and the rules ensure the evolution does not break the uninvolved part of the business process, and therefore the evolved business process is still consistent with the original.

H. Management over Evolving Business Processes

This is mainly about identifying, storing, and maintaining the different versions of an evolving business process. Since an evolving business process may yield a massive number of versions, and these versions have complex dependencies on each other. Our previous work [25], [26] on process version management has established a comprehensive supporting framework, where a Version Preserving Graph (VPG) is used to record all process schema information in one large graph in the schema space, and an Multi-level Evolution Diagram (MLED) records all version information (version numbers and dependencies among versions) in the version space. With VPG and MLED as repositories for process models and versions, the business process engine can extract a process model of any existing version, shift a process model from one version to another, record process evolutions and create corresponding new process model using the minimum modelling space.

V. SUPPORTING CONCEPTUAL FRAMEWORK

By considering all above issues, we have proposed a novel framework to support context-aware business process management including context definition and updating, event handling, version management and process evolution, resource management over multiple changing process instances, etc. Though the framework is currently at a preliminary state, it outlines the main components and mechanisms, and how they work together to support context-aware business process management.

Fig. 4 illustrates the architecture of the proposed framework. The block in the top left corner shows that specific business process context information is created by specifying a general context ontology into a domain specific one and instantiating a case of it. The raw events from sensors are elicited into business meaningful events using the eliciting rules, and then the context instance is updated according to the perceived contextual changes in form of elicited business meaningful events. The context instance is also triggering process evolutions and influencing the management over running process instances, following the process-oriented rules and management-oriented rules, respectively. The business process engine maintains changing process versions and related process models in version and model spaces using Multi-Level Evolution Diagram (MLED) and Version Preserving Graph (VPG), respectively. The process execution components extract the process model of a given version and instantiate it for execution. The process evolution component decides whether the process needs to adapt itself to the contextual environment, and update the new process model in the VPG and mark the new version in the MLED.

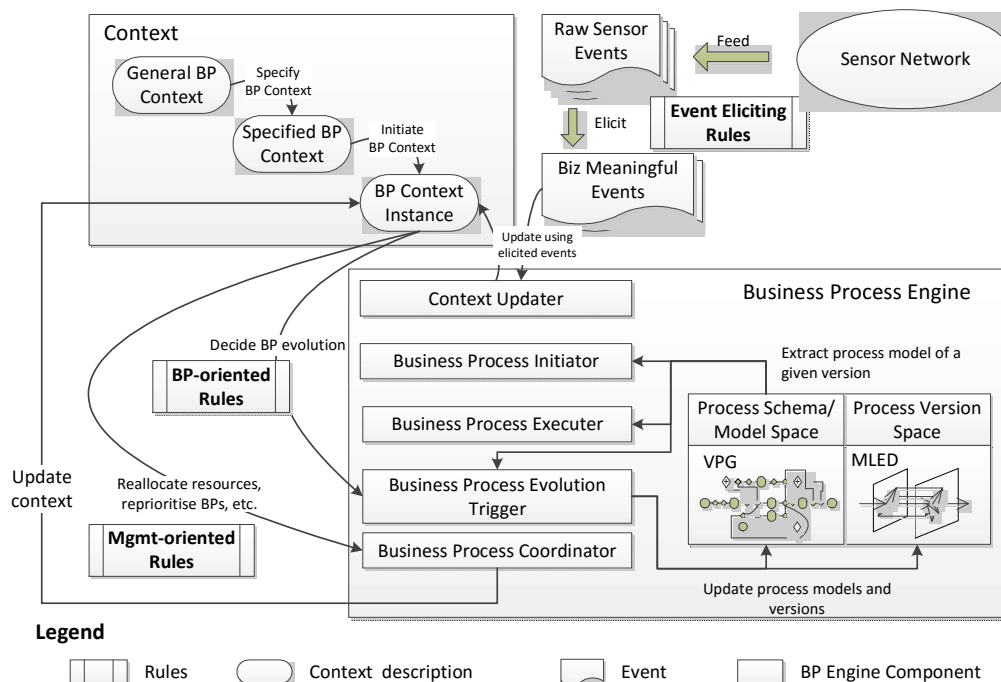


Fig. 4 Architecture of context-aware BPM framework

The proposed framework serves as a reference system architecture for supporting context-aware business process management. This framework conceptually illustrates what components should be included, how they work together, and how the aforementioned rules regulate/guide the functions of specific components. In particular, this framework highlights the following suggestions for future context-aware business process management solutions:

- Efficiently update the business process context by eliciting the massive volume of raw sensor events.
- Use dedicated repositories to store and maintain the changing process models and related versions.
- Rule-based process evolution to adapt business processes to perceived contextual changes.
- Rule-based evolution management to balance the influenced resources, and seek holistic optimism.

As a typical artefact from the perspective of design science research [27], our framework can be evaluated in terms of its validity, utility, quality and efficacy as follows.

- **Validity** – Main mechanisms and methods used in the framework are based on our previous work, which have been published in a series of prestigious venues. This means these work has been peer reviewed and recognised by the experts in related areas.
- **Utility** – The proposed framework gives a general and conceptual architecture for supporting context-aware business processes in different domains. Particularly, the context representation part is designed to be customisable, and thereby can fit any target domain. The event handling part does not restrict event or signal formats, and the eliciting mechanism is applicable to event streams from different sources, such as RFID sensors, satellites, fire/smoke detectors, etc. Thus, as long as the target

domain desires real time perception and response to contextual changes, our framework can help.

- **Quality** – As one of the pioneer work towards context-aware business process management, we have explicitly addressed the challenges of realising context-aware business process management, and provided some preliminary solutions on key topics. A conceptual architecture is also given to guide system implementation. Specific value and merits of the framework are discussed in last paragraph regarding the suggestions.
- **Efficacy** – This is mainly reflected in the efficient space usage of the version preserving graph (VPG). Traditional version management maintains a process model for each version. In comparison, VPG preserves all duplicated process structures in one large graph, and a process model of any version can be directly extracted from the graph. This maximally saves the modelling space.

As the reported research in still in progress, the above evaluation judges this work at its early stage. More systematic evaluation will be conducted once the framework is mature and the related prototype is developed.

VI. CONCLUSION AND FUTURE WORK

This research-in-progress paper has discussed typical challenges in supporting context-aware business process management, and also proposed some primitive methods and mechanisms to the identified challenges. A preliminary framework has been presented to outline how the proposed methods and mechanisms work together to support context-aware business process management. The reported research creates a conceptual foundation for building up systematic supports to incorporating context awareness into business

process management, and our future work is to focus on context representation and the rule-based mechanism to drive process evolution. Next step from now would be incorporating the mentioned mechanisms together and developing a demonstrable prototype.

In addition, the people participating business processes are not given much consideration in the reported research. Context-aware business processes possibly can raise issues like privacy invasion and disclosure, etc., with these people. More investigation on potential ethical issues with context-aware business process management is also an important task of our future work.

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