Chapter 1
On the Fundamentals of Intelligent Process-Aware Information Systems

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Abstract Process-aware information systems (PAIS) are utilized in business and industry world-wide, and processes constitute a valuable knowledge asset for companies. While the enterprise landscape is subjected to a high rate of change, with developments such as globalization demanding new approaches and technologies like cloud computing, big data, mobile applications, or event processing, PAIS have not kept pace with these trends to adequately manage processes. This article gives an overview of the challenges and novel developments of various systems that have focused on addressing this area, specifically approaches that relate to the most recent category of PAIS we call Intelligent Process-Aware Information Systems (IPAIS).

Keywords Intelligent process-aware information systems · IPAIS · Intelligent business process management systems · IBPMS · Smart processes

1.1 Introduction

Competition is fierce for companies in many sectors today, and a significant challenge they face is the increasingly complex environments in which they must operate. Companies collaborate in complex supply chains, and customers and regulators have numerous requirements the companies must conform to. They may need to handle large amounts of data, coordinate collaborations with a number of partner compa-

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nies, incorporate contextual data, manage human-centric and knowledge-intensive processes, integrate or incorporate social media aspects, etc.

This in turn affects company processes, often with a corresponding increase in complexity. To be able to adequately support these complex processes, the information technology (IT) solutions applied in these companies must keep pace with these developments, lest they hinder and confine the companies' capabilities and competitiveness. Especially Process-Aware Information Systems (PAIS) must continually adjust and evolve their processes to be able to handle these new influences and to ensure their capability to model, enact, and support the real-world processes.

These PAIS developments have not gone unnoticed, and leading market research institutes predict a quickly growing need and market for these new process applications. For example, Gartner Research calls these intelligent business process management suites. To account for these developments, they have exchanged their magic quadrant for business process management (BPM) suites [1] with a magic quadrant for intelligent business process suites (IBPM) from 2012 on. In their 2012 version [2] of the magic quadrant they explicitly mention features of IBPM suites that distinguish them from BPM suites. Examples of these are social capabilities, complex event processing (CEP), various types of analyses, or support for business rules. In both the 2012 and the 2014 [3] versions they also name key capabilities of IBPM system (IBPMS) suites, like a graphical modeling environment, content handling, human interactions, business rules, or process repositories.

Like Gartner, Forrester Research also published a study on this topic. They call the new generation of tools smart process applications [4]. They highlight the special properties intelligent processes need nowadays: dynamicity, collaboration, human-centricity, structured and unstructured processes, reporting, transparency, or reporting. They also set up a Forrester Wave for Smart Business Applications [5] and stress the importance of the human as well as capabilities for data and context management. In addition to that, the Forrester Wave for BPM suites [6] states that human-centric, document-centric, and integration-centric BPMs merge into one these days. The key capabilities of these systems involve social processes, cross-organizational processes, collaboration, guidance, and cloud-based services and processes.

Keep in mind that various solutions, tools, and concepts are already in the market and represent the state-of-the-art in applied BPM. The focus of this book goes beyond the current BPM horizon, and considers potential approaches and solutions that could provide insights into and support the future of intelligent processes. Therefore, this book describes fundamentals related to Intelligent Process-Aware Information Systems (IPAIS), their lifecycle, and various advanced approaches and solutions for supporting automated intelligent processes in the complex environments of today and tomorrow.

1.1.1 Evolution of Process Management Systems

In the field of process management systems there has been a substantial amount of scientific work during the last decades. Many terms have been used, including Workflow Management System (WfMS), Business Process Management System (BPMS), or PAIS. In this section, we will give a brief overview about the evolution of these systems.

In the 1990s the term workflow management was popular. Process thinking was already established in companies and WfMS were the systems that brought process-orientation to business information systems. In [7], the evolution of business information systems is discussed: in the 1960s, business information systems were mostly stand-alone systems that were implemented on-top of an operating system. Each of these systems had their own custom-implemented data and user handling. In the 1970s, data management was optimized by introducing dedicated systems for it, the database management systems (DBMS). The same happened in the 1980s to the user interfaces with dedicated user interface management systems (UIMS). Finally, in the 1990s, WfMS enabled the dedicated management of parts of company processes as workflows that were automatically governed by these systems. According to the Workflow Management Coalition (WfMC), a workflow is defined as follows [8]:

> The automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules.

Accordingly, a WfMS is defined as [8]:

> A system that defines, creates, and manages the execution of workflows through the use of software, running on one or more workflow engines, which is able to interpret the process definition, interact with workflow participants and, where required, invoke the use of IT tools and applications.

WfMS were a first step towards implementing, automating, and supporting processes. However, their primary focus was the structural governance of the sequencing of different activities, with the core functionalities being the implementation and enactment of the workflows that were part of a process. They also provided modeling facilities, but this considered only a part of an overall process design. The same applies for diagnosis and analysis of processes. Monitoring capabilities, when included, had only limited functionality. Thus, WfMS did not manage to implement the entire BPM lifecycle as illustrated in Fig. 1.1. This lifecycle consists of the design, the implementation, the enactment, and the diagnosis or analysis of the process.

In the 2000s, two other terms came into the focus: BPMS and PAIS. They are both mostly used for systems that are an extension of WfMS. [9] defines BPM as follows:

> Supporting business processes using methods, techniques, and software to design, enact, control, and analyze operational processes involving humans, organizations, applications, documents and other sources of information.

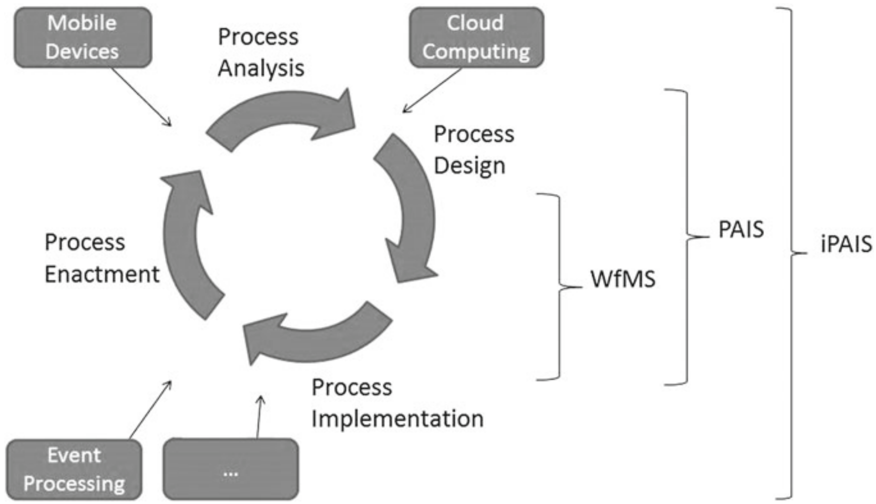

Fig. 1.1 Evolution of process management systems

[10] provides a definition for PAIS that is in line with the preceding definition. A PAIS is

> a software system that manages and executes operational processes involving people, applications, and/or information sources on the basis of process models.

The focus of PAIS was broader than that of WfMS, extending those functionalities with process analysis [9] and enabling better integration and user support. For example, they mostly incorporated more advanced facilities for processing modeling and design, including different features such as organizational models for the processes.

However, in more recent times, new challenges emerged for such systems due to various developments, such as increased organizational and business communication and interaction, new technologies, or the amount of data integration and processing. In Fig. 1.1, a selection of these challenges is presented. One example are the various mobile devices like smartphones or tablets. Many users possess such devices and have an affinity to the mobility and specific user interfaces they have. Thus, a partly mobile implementation of processes comes into play. Another topic gaining momentum is event processing. The myriad of different events important for a company and its processes are recorded and used by information systems (IS). A third example is the trend towards cloud computing: the dynamic provisioning of services using this technology becomes more relevant for integration with processes.

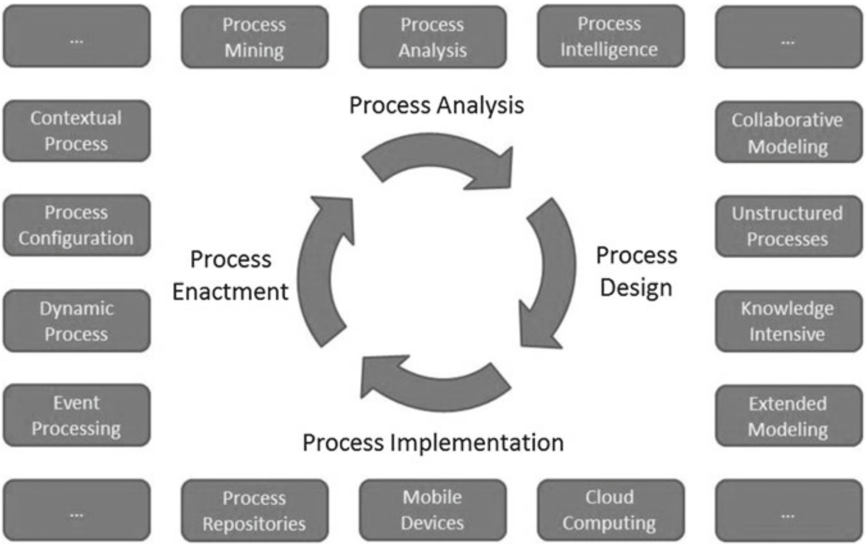

Fig. 1.2 The IPAIS lifecycle

1.2 The IPAIS Lifecycle

In alignment with the BPM lifecycle mentioned in various publications, this section introduces the IPAIS lifecycle as an extension of the BPM lifecycle. An IPAIS extends the capabilities of a PAIS and at least partially incorporates various technologies that can play an important role in the future technical environment. Figure 1.2 shows the different phases of the IPAIS lifecycle with a selection of such technologies. Each phase will be described in a separate subsection and provide examples for approaches and technologies that IPAIS can provide.

1.2.1 Intelligent Process Design

Supply chains, companies, products, and projects grow, while the technologies involved become increasingly complex. This results in process modeling and design becoming complex, while companies strive to cover and automate significantly more real-world processes. Many processes are dynamic at runtime or even completely unstructured, and can no longer be modeled as linearly and statically as, for example, production processes once were. For such processes, the prescriptive way of modeling provided by WfMS or PAIS is not suitable. However, there exist approaches to support users in modeling these processes. One example is DECLARE [11], which is targeted at dynamic, unstructured processes. The approach is based on constraints,and thus the models do not prescribe the exact flow of the process. They rather describe situations in which certain activities can or cannot be executed. At runtime, each activity that does not violate the constraints can be executed. To model processes that are somewhat more structured but still must adapt to different situations, process configuration approaches like C-EPC [12] can be suitable. They enable integration of configurable elements into the process models so that specific fragments of the process can be selected according to parameters that represent the current situation.

Although they are an important asset of organizations, processes were often viewed in isolation. Their connection to and impact on goals, strategies, and other organization assets was often neglected. Today, advanced modeling approaches like [13] based on semantic web technologies exist, which enable the modeled processes to incorporate various types of additional data into the models, better integrating the processes into their organization.

Another feature IPAIS can provide is better support for the complicated modeling of contemporary processes. Examples are advanced correctness checks or a correctness-by-construction approach as provided by [14]. Such approaches prevent the creation of erroneous models. However, process modeling mostly involves significant knowledge and is time consuming. To support reuse of such knowledge, approaches like ProCycle [15] assist the modeler with integrated process lifecycle support. As processes today often involve multiple parties, these are also involved in creating the complex models. Thus, collaborative modeling can substantially reduce modeling efforts. Approaches for dealing with this issue exist, for an overview see [16].

1.2.2 Intelligent Process Implementation

Process implementation refers to the technical realization of the modeled processes to enable their automated enactment. In this areas, various new challenges emerged. With the increasing use of IT systems in organizations, the number of processes enacted by PAIS are also steadily increasing. To manage large numbers of processes effectively, process repositories have been developed. For example, Apromore [17] is a complete process model repository with functionalities for analysis, management, and usage of large sets of process models. However, more specific approaches dealing with specific aspects of such repositories exist. Examples include the querying and retrieval of the models. To support this, [18] provides an approach for visually querying graph-based process models. However, the process models contained in a repository have to be maintained and adapted according to real-world events from time to time, whereby redundancies might be introduced and the maintainability of the models endangered. To counteract this, [19] provides a catalog of 'process model smells' and behavior-preserving refactorings.

As companies collaborate globally, availability of the processes is also a key implementation issue. In this area, cloud computing is on the rise and there are IPAIS approaches combining BPM and cloud techniques. In [20], a novel approach is proposed that supports the distribution of end-user activities via the cloud. Furthermore, the transfer of sensitive data is also addressed. The approach shown in [21], in turn, combines BPM, service-oriented architecture (SOA), and cloud technology to improve the availability of services, in this case for the educational sector.

Another important trend in many domains is the integration of mobile devices in processes. To support this with technology, portions of these processes may be implemented and enacted on these devices. For this purpose IPAIS approaches have been developed that enable partly mobile implementations, such as DEMAC [22], ROME4U [23], or MARPLE [24]. They include features like the transfer of parts of a process to a mobile device even at run-time.

1.2.3 Intelligent Process Enactment

The PAIS area probably affected the most by current challenges and technologies is process enactment. Real-world processes involving humans are mostly dynamic and IPAIS offer ways to align such processes to changing situations. One option for this is the configuration of enactable processes as done in Provop [25]. Some approaches even allow for automatic, correct, and context-sensitive configuration without human involvement [26]. A related area of research seeks to avoid overburdening users with large process models during execution by not configuring the process model but only the part of it that the user is shown. An example is ProView [27, 28], which enables the creation of user-based process views in which changes can be applied that are propagated back to the base process instance.

For even more dynamic scenarios, adaptive process approaches can be utilized, which have been utilized within the scientific community for some time [29–31]. Beyond scientific processes, a prominent approach for run-time adaptation is the ADEPT project [14] that includes correctness guarantees. On this basis, other approaches have been developed that even automate the run-time adaptations of the processes for exception handling [32] or for dynamically inserting software development quality assurance measures [33].

Another aspect gaining importance these days is the context of processes. This incorporates various influences like humans, artifacts, or events occurring while processes are enacted. For most approaches, events and context correspond. However, despite the availability of context management frameworks like [34] or [35], few approaches combine these directly with process enactment. One is presented in [36] that combines a CEP system and a PAIS. Another approach in this area deals with context building and sharing in the context of mobile web services [37]. Artifacts that are tied to the processes are, however, treated explicitly by artifact-centric PAIS approaches. Examples here include [38] and [39]. Both manage the lifecycle of important artifacts and relate it to the processes.

1.2.4 Intelligent Process Diagnosis

PAIS has extended WfMS primarily in the area of process diagnosis and analysis. However, these functionalities were mostly limited to monitoring and simple analyses. In the early 2000s, process mining [40] focused on the discovery of processes utilizing event logs. In particular, the control flow of these processes was the focus. However, mining techniques yield the potential for many types of analyses. One example is social network mining [41] that focuses on the connections of the different participating actors. Similar to this, organizational mining [42] targets the mining of the organizational structures behind the actors in a process.

IPAIS, in turn, goes a step further with more advanced capabilities. In [43] mining is applied for conformance checking of processes. In particular, security audits in the financial sector are applied with mining techniques. Another advanced application [44] enables the prediction of the completion time of future processes based on past instances. As processes are subject to ongoing changes, [45] provides an approach for mining the different executed variants of a process model. Furthermore, the most suitable changes to the process model can be derived. Mining techniques can still be further extended and improved. [46] proposes an approach for comprehensive process diagnostics based on process mining. This includes the control flow perspective, the performance perspective, as well as the organizational perspective. Another interesting extension is semantic process mining [47]. This technique uses semantic annotations in the processes to enable more advanced and comprehensive analyses.

1.2.5 IPAIS Approaches Discussed in This Book

This section provides a brief overview of the specific IPAIS approaches covered in this book. The focus of these approaches covers different IPAIS areas like the presentation of entire IPAIS tools, the delivery of process-relevant information to the users during enactment, and different kinds of analyses conducted on processes.

1.2.5.1 Adaptive Process Management

In today's world, processes are enacted in many domains. Most of them are not as predictable as standardized industrial production processes. They rather map a real world process that is subjected to many often unforeseen influences. Systems that operate in this context are often called cyber-physical systems, as they apply computational elements to control real-world physical entities. Such systems struggle with a vast set of exceptional situations. To achieve better support for the latter, Chap. 2 proposes a system that is capable of automated process adaptations. Furthermore, it can detect exceptional situations and failures and thus apply matching adaptations.

To achieve this, a declarative task specification and AI management techniques are applied to avoid the need for specifying exception handlers at build-time.

1.2.5.2 Case Management Processes

Case management is an approach often used in the context of PAIS and IPAIS. It suits human-centric and dynamic processes well, as it does not focus on the imperative control-flow of a process, but rather focuses on the activities to complete for a specific case and the actors that required to perform these. The approach presented in Chap. 3 is positioned in this area. Its contribution is twofold. First, case management processes are concertized by a formalism that is based on hierarchical state machines and state charts. The latter are also extended to better suit the case management topic. Based on this, an architecture of a case management support system is discussed. This system shall facilitate case management by context-driven recommendations for activity planning.

1.2.5.3 Autonomically-Capable Processes

PAIS are becoming more important as processes gain in their standing as valuable assets of companies. However, both are coupled with substantial costs for the companies due to high efforts for design, evaluation, optimization, or adaptation of the processes. In recent years, there has been a trend towards autonomic computing, making applications more independent and automated and reducing human intervention to a minimum. Chap. 4 presents the vision and challenges of autonomically-capable processes, applying the properties of autonomic computing to IPAIS, including self-configuration, self-optimization, and other self-X properties. Additionally, the state-of-the-art in this area is presented and reviewed. Finally, an example of a concrete system example that realizes many of the discussed properties is presented.

1.2.5.4 Process-Oriented Information Logistics

In today's companies, knowledge-workers are confronted with a steadily rising amount of data, information, and artifacts. These knowledge-workers are taking part in various processes considered valuable to the companies. However, the workers are struggling with different impediments concerning their work. The information and data overload makes it difficult to effectively and efficiently manage and use the different artifacts. This problem is amplified by the fact that the process and the relevant information are mostly managed in different information systems. The approach presented in Chap. 5 addresses this problem. It automates delivery of information to the user, selecting information in a process-oriented and context-aware manner to fit the situation of the knowledge-worker. In addition to presenting the concept, this chapter also discusses concrete use cases and a proof-of-concept prototype.

1.2.5.5 Process Recommendations

Process-related data plays an important role in various enterprises. Such data must be retrieved periodically or in real-time from various data sources and systems. Further, it must be aggregated to KPIs (Key Performance Indicators). That way decision makers are enabled to continuously monitor the business processes in order to maintain high process, product, and service quality. In general, a retrospective analysis of process data is conducted to highlight violated KPIs. However, this cannot ensure prevention of future KPI violations. To counteract this problem, PAIS should also enable prospective analysis of processes to identify processes not performing as intended. Therefore, Chap. 6 presents both a methodology and architecture for predictive process analysis. This is enabled by comparing running process instances with historic data via machine learning algorithms.

1.2.5.6 Reasoning over Process Models

Visual modeling languages like BPMN (Business Process Modeling Notation) have established themselves as a standard for process modeling. However, besides their many advantages, their semi formal nature together with the use of natural language for parts of the processes can introduce problems. Natural languages leave room for interpretation and ambiguities, like homonyms or synonyms. In particular, in the context of collaborative modeling or process model sharing, this can lead to misunderstandings that might even endanger the success of the process. Furthermore, process modeling languages lack machine readable semantics describing the content of the models. Thus, tool-aided support for process modeling and execution is inevitably limited. The contribution of Chap. 7 is situated in the area of semantic processes and addresses these problems. In particular, semantic web technology such as ontologies and reasoners are applied to achieve an extension of process descriptions containing machine readable semantics. In addition to the abstract concept, the chapter presents a proof-of-concept tool for annotating and converting process descriptions that also allows for querying the ontology-based process description.

1.2.5.7 Improving Process Portability

Today's enterprise landscape is subjected to ongoing change including process technologies. Recent trends include various implementation aspects of processes, such as cloud- or service-based PAIS. Such constantly changing technologies, however, promote frequent changes in the applied tooling of companies. In light of this, it becomes important that process specification be done in a way that facilitates their portability to another PAIS without necessitating a complete reimplementation. Adherence to standards like BPMN is one option to support this. However, BPM vendors interpret and implement such standards differently. Thus, portability is hampered and in many cases processes cannot be transferred from one PAIS to another. To tackle this problem, Chap. 8 provides an approach based on metrics for process portability. The contribution of the chapter is two-fold: first, the approach can be used to aid the decision whether to port or to rewrite a process-based application. Second, it can be integrated into the development process to support the creation of more portable processes.

1.2.5.8 Business Process Intelligence

Business processes are an important asset of today enterprises. To maximize the value derived from this asset, one emerging trend in the business intelligence world is BPI (Business Process Intelligence). In particular, BPI is a vast area consisting of various approaches. This comprises methods and best practices from real-time process analysis as well as concrete software tools applying them. Chapter 9 analyzes contemporary software tools enabling BPI. Therefore, the chapter presents an analysis of the features as well as the strengths and weaknesses of each tool. Finally, the chapter discusses two application strategies for BPI software tools in modern enterprises.

1.3 Outlook

PAIS will evolve to include IPAIS technology that is dynamically flexible and can adapt to changing contexts and issues while reducing human intervention and costly administrative and management overhead.

We thus foresee IPAIS as gaining in significance and providing key automation capabilities for addressing the efficiency and effectiveness of business and industry processes improving our society. Before that vision can happen, current PAIS technology needs to fulfill important autonomic capabilities and enhance the process lifecycle, and integrating various technologies and approaches as described in this book can bring us incrementally closer to turning this vision into reality.

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