Rule-Based Design

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Why study this book?

Chapter 1

Why study this book?

To help you decide whether to study this book, you might answer the following questions:

a Do you participate, either now or in the future, in the making of business processes? (yes/no)
b Does your participation have consequences in the organization you work for? (yes/no)
c The business processes you make have various stakeholders. Must agreements among these people be concrete and explicit? (yes/no)
d Are information systems being used that facilitate or enable these business processes? (yes/no)
e Do you want to learn how to specify requirements in a precise way? (yes/no)

If you have answered all of the above questions with yes, then you are a member of the target audience of this book. Let us consider each question separately, to see what your reading effort might bring to you.

Requirements elicitation

First of all, this book is written for people who are involved in the design of business processes. Architects, database administrators, functional designers, requirements engineers and consultants alike can benefit from the conceptual approach taken in this book. They will learn how to specify business processes as a composition of constraints, incrementally adding or changing rules in the course of *requirements elicitation*. All professionals who specify, design, build, or change business processes can enrich their knowledge and skills. Other stakeholders however, such as patrons, users of software applications, business partners, process owners, managers, and tool vendors, might find this book too detailed for their purposes, because this book is about the 'how' rather than the 'why'.

Second, this book is about practice. It is meant to have consequences in the organization you work for. Please take a moment to think about your own role in the innovation process. Are you the one to make requirements explicit and concrete? If you are an auditor, it is your task to note whether or not requirements are fulfilled. If you are a scientist, it is your job to reflect on requirements. If you are an observer of business processes, you will not make requirements explicit and concrete. In all of these roles, you will scrutinize requirements rather than create them and make them explicit. However, if you are an information architect or a requirements engineer, then this is what you are hired to do. The skills described in this book will help you to succeed.

Yet, you may have already browsed through this book, seen a formula, and wondered how practical this book is. The formulas in this book make natural language precise; that is their practical value. This book explains what they mean and how you can benefit. If you learn to express yourself formally, the computer can transform your functional requirements into a full fledged functional specification. System designers can take these functional specs, add other, non-functional requirements (e.g. about cost, user interfaces, maintenance service levels etc) and create the correct information systems from them. You can also reap the benefits of a consistent specification. Once your functional requirements are free of errors, consistency of your requirements is a mathematically guaranteed property. It comes for free by using the tools that accompany this book.

Third, this book aims at making requirements explicit and concrete. For business

processes that matter, explicit and concrete requirements are a necessary thing. In practice however, stakeholders may sometimes agree on vague and imprecise requirements in order to reach agreement. Being involved in the making of some business process, you may well be the person who is responsible for concrete requirements. That may require considerable social skills. This book gives you a fine instrument to formulate requirements precisely. When used wisely, you can achieve great progress in getting stakeholders to commit to concrete requirements.

Ampersand

We call this approach *Ampersand*. The Ampersand approach employs business rules to formulate a sound basis for subsequent information systems design and to actually *define* the processes of the business. It is named after the ampersand symbol &, which means "and". The name hints at the desire to have it all: getting the best from both business and IT, achieving results from theory and practice alike, and realising the desired results effectively and more efficiently than ever before. This book will explain the approach, and the core notions of the accompanying Ampersand tool.

The fourth question addresses information technology. This book is about information systems as well as business processes. Ampersand hardly makes a distinction between the two. From a business perspective, this book is about business processes that make substantial use of information technology. Typical examples are taken from administrative processes in the public and financial sector, without limiting the scope to that particular area. From a technical perspective, this book is about designing information systems by having the functional specifications generated straight from the functional business requirements. Ampersand uses tools to automate this process. Automated design techniques allow you to spend more effort on elicitation of the requirements. Business processes that do not employ any information technology are beyond the scope of this book.

Finally, this book is aimed at an audience that is willing to invest some effort to master the skill of making requirements precise. Ampersand is an approach that lets you define what you mean in a precise way. That takes effort. The more experience you get, the more patterns you will discover and reuse in different situations. For that reason, you must be prepared to make a genuine effort.

If you still answer the previous questions positively, the authors cordially invite you to read further and join us in the quest to make better use of information technology in today's organizations.

That brings us to the next question: What is this book about? If the topic is design of information systems and business processes, why do we need yet another approach? That question addresses the very vision upon which Ampersand is based. The following sections share that vision, each giving a perspective on Ampersand from a different angle.

1 Vision on inspired design

This book is about designing information systems that support (the execution of) business processes. The people who execute business processes, but managers and customers as well, hope for flawless system designs. A well-designed information

Compliance

system helps them to do their job effectively and efficiently, in full *compliance* with applicable rules. Rules are needed to coordinate the work among all those people. Ampersand is based on precisely those rules. It acknowledges that there are rules of different kinds. Some rules may be agreed upon by individuals, others imposed by law, and still others might be prescribed specific regulations that apply to your situation. From this book you will learn how to design based on those rules. We hope that this inspires you to realise information systems in which people dare to share; reassured by the knowledge that they *can* live by the rules.

This book is written in a firm belief that one day, information systems will be designed and built rapidly, at low cost, and 100% compliant. Guaranteed functionality and more predictable innovation projects are part of that professionalism. One day, information systems will be a commodity, abundantly available at a predictable (low) cost, with predefined quality, and delivered almost on-the-spot. Such professionalism will create room for inspired design. It is inspiration, leading to beauty and fun, that is a common denominator of information technology today and in the years to come. Feelings, perceptions and experiences of users will increasingly drive the design of successful information systems.

Inspired design can be demanding. It requires designers to express themselves, very much like an artist, a violinist, painter or writer. Before creating music that touches the hearts of your audience you must have full control over the instrument, the color palette, the language. This truth holds for any creative profession. Room for creativity comes, once your skills no longer require your attention. Designing business processes and information systems is no exception. Craftsmanship precedes art.

Rule-based design was developed as a contribution to the profession of designing information systems and business processes. It offers hope to designers who wish to lift their work to a more creative level, by automating much of the tedious, technical work involved. This book proposes a way to produce correct, consistent and complete designs. It shows how you can be sure that your design fully complies with the requirements of your patrons. It promises you can save time by automating design activities and showing you how to get it right the first time.

This book was written for designers who share this desire and are willing to invest in this vision. Besides inspiration and talent, genuine artistry requires knowledge, hard work, and craftsmanship. This book aims at making you successful, by providing the knowledge. It requires you to practice your techniques until you can do them effortlessly and correctly. Craftsmanship is what you learn by doing.

The next few sections explain why business rules are useful. Each section takes a different perspective: the business, processes, coherence, information technology, formalism, and methods. Together, these perspectives make up the vision, which characterizes our approach to Rule-Based Design.

1.1 VISION ON THE BUSINESS

Business rules are meant for communication with stakeholders in the business [28]. The idea is expressed concisely in the Business Rules Manifesto (that is available at `www.businessrulesgroup.org/brmanifesto.htm`). An example of a business rule is that all citizens over 16 years of age may vote. This particular rule applies to Nicaragua (from 1984 onwards). It does not hold in the United States, however, which allows citizens to vote from the age of 18 (says the 26th amendment of 1971). So business rules *apply* in a particular context, during a particular span of time.

Business rules are as close to the business as one can get. They enlarge the scope of requirements engineering to include business goals [24]. Other examples of business rules are:

- Every application for a new pension plan must be decided upon within three days of receiving that application. (e.g. in the context of a life insurance company)
- An application for a green card must be put aside if the identity of the applicant cannot be established legally. (e.g. in the context of immigration)
- Every payment must be authorized by two different staff members, and any payment may be authorized only by staff that is properly authorized to the full amount to be paid. (e.g. in the context of a medical benefits administrator)

Business rules formalize mutual agreements between stakeholders, commitments of

managers, rights and obligations of employees, etc. into 'laws', intended to serve the purpose(s) of an organization. The creation and withdrawal of rules is an ongoing process, similar to a legislative process in a state.

1.2 ON BUSINESS PROCESSES

Rules have a potential for improving the way business processes are designed. Business processes are characterized by stakeholders and the agreements they make.

For example, a business process that delivers fresh flowers throughout the globe has many different stakeholders, each of which plays his own part. The sales organization accepts orders from across the globe, and forwards every order to an associated florist close to the delivery point. These florists have agreed beforehand to deliver fresh flowers according to predefined quality standards, delivery times, prices, etc. A financial broker deals with the money, and so on.

All stakeholders are committed to well defined agreements, which makes the entire process work. The result is that I can send flowers to my mother-in-law for her birthday, while I am in a location halfway across the globe. That is possible only because many stakeholders work together and fulfill their commitments.

This way of dealing with business processes focuses on agreements among stakeholders. That is precisely the point of view taken by Ampersand. Agreements are made concrete in terms of rules, which are maintained by various actors. Since a business process contains both human actors and automated actors, maintaining a rule can be done either by people or by computers.

For instance, what happens if the law lays down a rule saying that voters must be registered? Suppose voter Abe Gandalf is *not* registered? This is a clear violation of the legal rule. If that rule is maintained by a computer, Abe Gandalf's vote can not be captured as valid data as long as he is not registered. It should give Abe an error message, and perhaps explain the problem by telling about the rule. After Abe Gandalf has been registered, the computer can handle the vote. That is how a computer maintains rules. If clerk Margaret maintains that rule as an election official, she would most likely send Abe Gandalf back home. But in order to do so, she needs information about the possible violation. So when Abe Gandalf reports for voting, Margaret's information system should signal that Abe is not registered.

The example above illustrates how rules can be operated in two different ways. The first way is rules maintained by computers; they must remain satisfied at all times. The second way concerns rules maintained by people. The computer must signal violations to these people, who in turn should take some appropriate action in order to maintain the rule. Thus, the information system that supports a business process is characterized by a set of rules that people maintain.

1.3 ON INFORMATION TECHNOLOGY

An information system contains data to represent facts in a changing world. Along with the world, data in an information system changes over time. Consequently, a rule that is satisfied at one moment may be violated some time later, as the data changes. That data should however always satisfy the business rules, whatever that data might be. In that sense, business rules constrain data. And the challenge for the information system and its users is to keep all of the recorded data compliant to these constraints.

So, business rules must be formalized for two reasons. One reason is that computers must enforce the rules. But equally important: the workers using the systems must also share an unambiguous and undisputed understanding of all the applicable rules.

This book describes a method for formalization that is independent of any computer language. Thus, it can be implemented in any (sufficiently powerful) computer system.

1.4 ON COHESION

Business rules create cohesion among an otherwise unrelated set of stakeholders. Every agreement and commitment they keep is a building block to a more cohesive system. A system (of people and computers) can be highly regulated, with little room for own initiative. It can however also be regulated very sparsely, leaving much room for individual actions. In all cases, the rules serve as the 'glue' to create a coherent system that serves its purpose.

This form of cohesion leaves the maximum amount of space for individuals, which is supported by the following observations. If a rule is considered appropriate, people and computers will refrain from actions that violate the rules. If a rule is considered obsolete, it ought to be removed from the system. In this sense, a rule-based process leaves people as free as possible, while maintaining a cohesive system of rules.

Rule-Based Design promotes a vision in which business processes are governed by business rules. Rules apply across processes and procedures. There should be one cohesive body of rules, enforced consistently across all relevant areas of business activity (article 2.3 of the manifesto).

1.5 ON FORMALISM

Ampersand enhances business rules with a formal representation. This is necessary to ensure that commitments between stakeholders are concrete and unambiguous. A business rule in a formal representation can be checked for consistency with other rules by means of software tools. The design of an information systems follows directly and can be automated to a high extent, as promised by article 5.3 of the manifesto.

This book uses the mathematical formalism of relation algebra to analyse requirements and formulate rules. It applies knowledge representation techniques [6], which are firmly rooted in existing theory from the previous century and earlier [33, 9, 27, 30]. This formalism enables contemporary professionals to describe and manipulate the business concepts and the associations between them effectively, quickly, and without mistakes. Proficiency in this skill to describe and manipulate will allow you to make functional specifications, to conduct conceptual analyses, and to search for and establish new business rules.

This book makes an effort to introduce operators that help to describe the knowledge of the business. The material is introduced slowly, one step at a time, with as little formalism as the authors think possible, to be found in the 'Theory' part of this book. If you are new to this topic, prepare for some effort, but rest assured that it will be worthwhile.

1.6 ON METHODS

This book proposes a method that puts functional requirements at the focal point of the design of business processes and information systems. Design artifacts such as data models, conceptual analysis, function point counts, service design, etc. must follow from these functional requirements. If business rules constrain the design space, they must be incorporated in the functional specification. If the functional specification represents the functional requirements without inconsistencies, the remainder of the design process is largely automatable.

This vision puts requirements engineers in a special position. They must elicit requirements from various audiences, helping these audiences to make their wishes concrete. This requires communicative and advisory skills. Also, a requirements engineer must interpret these requirements to select or write business rules to make requirements explicit and concrete. This requires technical insight in information systems that support business processes. It also requires the skill to ensure that business rules are correct, i.e. they represent precisely what is needed in the business. Finally, the requirements engineer must help stakeholders with solutions rather than endless questions. The stakeholders may give fragments of requirements, and the requirements engineer must make them complete and consistent.

Rule-Based Design helps requirements engineers with tools that automate large parts of the design process. This helps to overcome some of the difficulties involved in designing information systems reliably and repeatably. And that is precisely the problem addressed by this book.
In the following section we introduce the main types of business rule.

2 Types of business rule

Business rule

Theory, leads and inspiration about business rules can be found abundantly by reading the Business Rules Manifesto, consulting the world wide web, or reading the vast amounts of literature. This book uses the word *business rule* for a rule that "reflects a commitment from the business", as intended by the Business Rules Manifesto. That is: we use business rules as requirements (article 1 of the manifesto) from the business (article 9.1), of the business (article 10.1) and for the business (article 8).

Condition-action rule

There are several important categories of business rule. Many business rule engines available in the marketplace use rules of the condition-action or event-condition-action types, both of which are excellently suited for execution by computer. A *condition-action rule* has the structure:

if ⟨some condition is fulfilled⟩ **do** ⟨perform some activity⟩

Event-condition-action rule

An *event-condition-action rule* has the structure:

when ⟨some event has happened⟩ **and if** ⟨some condition is fulfilled⟩
do ⟨perform some activity⟩

Imperative rule
Production rule

They are called "*imperative rules*", because they command actions to be executed by computers. This is also why they are also called *production rule*: they "produce" actions, and the actions produce new information to be processed.

Computation rule
Derivation rule

Another category of rules is called "*computation rules*" or "*derivation rules*". Such rules can be used to assist in complicated computations. Tax returns are a good example to illustrate this. The complication in tax returns is that certain rules are applicable in very specific situations only. Citizens earning an income from several sources are confronted with many more tax rules than elderly people with just a single and stable pension. Business rules engines are popular tools for such situations, because a rule engine helps to guide you through the complicated maze of rules. One of the later chapters in this book will illustrate this idea of navigating the rules.

Invariant rule

In this book we focus on "*invariant rules*". These are the kind of rules that the business wants to be complied with, at all times. The business information systems must help in keeping these rules *true*, that is: violations must be prevented, or be repaired as soon as possible. Invariant rules differ from the rule categories above for two reasons. First, the rule can be checked at any time, even when nothing is happening, and

no violations of the rule should exist. Second, the rule does not necessarily prescribe a particular action how to prevent or repair possible violations. As an example, consider a business rule stating that "only officers may enter the officer's mess". If GI Pete Doe tries to enter the mess, there are different ways to maintain this rule. One way is to promote Pete Doe to officer and allow him in. Another way is to send Pete to the cafeteria across the street. A third way is to bluntly refuse access. A fourth way is to move the mess out of the building and let Pete in. A fifth way is to get rid of this rule. And maybe the reader can come up with still other ways to maintain the rule.... It goes to show the character of invariant rules: the rule should be *true* at any time, but we do not prescribe how to achieve that.

The categories of rules mentioned above are far from exhaustive. Clearly, the notion of *business rule* carries many different meanings for different people in different circumstances. It is as if every new idea of using the rules, justifies a new categorization of rules. Each time you encounter the phrase, you may want to identify the purpose for which they are used.

3 Backgrounds

Rule-based design, as introduced in this book, is deeply rooted in well know theories. Design artifacts such as data models and service specifications ought to be derived from business rules, rather than drawn up by designers. This requires a formal method supplemented with tools, in which designers represent business rules in heterogeneous relation algebra [29].

The Ampersand approach, a successor of CC [11, 21], was developed for that very purpose. In conjunction with this approach, software has been developed that generates functional specifications directly from business rules. Also, there exists software that generates a prototype application to enforce all business rules. For practical reasons, Ampersand has been designed such that any use of the formal language is restricted to the designers only. At no occasion the need arises to confront users with the formalism. Business analysts and software architects must learn how to use it, though.

Rule-based design draws on research on business rules, software engineering, relation algebra, and design methodology. Let us look at each of these topics briefly.

Research on business rules has a long tradition. Much of the research is related to active databases [8], that use the ECA pattern (event-condition-action) to describe rules. In research aimed at automating software design, such as [37], this leads to the assumption that business rules must be executable. From a business perspective, this is not necessarily true. A counterexample: the rule 'every action performed must be authorized by a superior', would become quite unworkable if every action performed would trigger an authorization request to a superior.

Declarative approach

In the Ampersand approach, which is a purely *declarative approach*, actions are not specified, but derived. All ECA-rules required to make computers work are derived from the rules (by a tool), enabling an implementation of requirements that is free of errors.

In a comparison of available methodologies for representing business rules, Herbst et.al. [16] show that common methods are insufficient or at least inconvenient for a complete and systematic modeling of business rules. That study remarks that rules in all methodologies can be interpreted as ECA-rules. However, the authors do not identify the imperative nature of ECA-rules as an explanation for the shortcomings of methodologies. Methodologists generally place business rules on the data side of business models [32].

Ampersand uses the business rules to actually *define* the business process, making

rules the common basis for both the data and the process side of information systems. The fact that this requires a formal method has consequences [38]. It means that system boundaries can be articulated, the functional behaviour of the system is defined, and there is proof that the system meets its specification.

Outside academia, business rules are increasingly acknowledged as important areas of research and development, and market researcher Gartner expects a consistent growth of licence revenue in business rules technology. Some important interest groups can be found at:

Business Rules Forum	`www.businessrulesforum.com/`
Business Rules Group	`www.businessrulesgroup.org/`
European Business Rules Conference	`www.eurobizrules.org/`
Business Rules Community	`www.brcommunity.com/index.shtml`

Most rule engines available in the market place provide decision support by means of separating business rules from process logic. Current research on business rules takes similar directions, e.g. [2, 34, 26]. An advantage of separating business rules from process logic is that the business process (such as a mortgage application procedure) will often remain stable, even if rules and regulations change. By the same count, however, this separation would restrict the use of business rules to applications in which the process is not affected, leaving designers in charge not of one, but two distinct tasks: rule modeling and process modeling. The Ampersand approach lifts this restriction, because the process is derived from business rules.

Our finding that business rules are sufficient to define business processes, corroborates the claim of the Business Rules Group [28] that rules are a first-class citizen of the requirements world (article 1.1 of the manifesto). The phrase 'sufficient to define business processes' implies that designers need not communicate with the business in any other way. If desired, they can avoid to discuss technical artifacts (data models, etc.) with the business. As a consequence, requirements engineering can stay much closer to the business, by using the language of the business proper. This supports the Business Rules Group in her claims that business rules are a vital business asset, that rules are more important to the business than hardware/software platforms, and that business rules, and the ability to change them effectively, are fundamental to improving business adaptability.

Declarative rule

Date [7] has criticized SQL for being unfaithful to relation algebra and advocates *declarative rules* instead as an instrument for application development. This book implements some of Date's ideas, by using relation algebra faithfully to describe business rules and define the applications both at the same time.

4 Prior experience

Various research projects and projects in business have supplied a significant amount of evidence that supports the power of business rules. These projects have been conducted in various locations. Research at the Open University of the Netherlands (OUNL) has focused on two things: developing the method, developing the course, and building a violation detector. Research at Ordina and TNO Informatie- en Communicatie Technologie has been conducted to establish that the rules, captured by our methods, are capable of representing genuine business rules in genuine enterprises. Collaboration with the university of Eindhoven has produced a first design of a rule base. Experiments conducted at TNO, KPN, Bank MeesPierson, ING-Bank, Rabobank and Delta Lloyd have provided experimental corroboration of the method and insight into limitations and practicalities involved. This section discusses some of these projects, pointing out which evidence has been acquired by each.

The CC-method, the predecessor of Ampersand, was conceived in 1996, resulting in

a conceptual model called WorkPAD [20]. The method used relational rules to analyze complex problems in a conceptual way. WorkPAD was used as the foundation of process architecture as conducted in a company called Anaxagoras, which was founded in 1997 and is now part of Ordina. Conceptual analyses, which frequently drew on the WorkPAD heritage, applied in practical situations resulted in the PAM method for business process management [23], which is now frequently used by process architects at Ordina and its customer organizations. Another early result of the CC-method is an interesting study of van Beek [35], who used CC to provide formal evidence for tool integration problems; work that led to a major paradigm shift in IT-projects. The early work on CC has provided evidence that an important architectural tool had been found: using business rules to solve architectural issues in large projects.

The CC-method has long been restricted to be used in conceptual analysis and metamodeling [22, 12], although its potential for violation detection was recognized as early as 1998. Metamodeling in CC was first used in a large scale, user-oriented investigation into the state of the art of BPM tools [13], which was performed for 12 governmental departments. In 2000, a violation detector was written for the ING-Sharing project, which proved the technology to be effective and even efficient on the scale of such a large software development project. After that, the approach started to take off.

In the meantime, TNO Informatie- en Communicatie Technologie (at that time still known as KPN Research) has used CC modeling for various other purposes. For example, CC modeling has been used to create consensus between groups of people with different ideas on various topics related to information security, leading to a security architecture for residential gateways [19]. Another purpose that TNO used CC modeling for was the study of international standardizations efforts such as RBAC (Role Based Access Control) in 2003 and architecture (IEEE 1471-2000) [17] in 2004. Several inconsistencies have been found in the last (draft) RBAC standard [3]. Also, it was noted that for conformance, the draft standard does not require to enforce protection of objects, which one would expect to be the very purpose of any RBAC system.

The analysis of the IEEE 1471-2000 recommendation has uncovered ambiguities in some of the crucial notions defined therein. Fixing these ambiguities and expliciting the rules governing architectural descriptions has resulted in a small and elegant procedure for creating (parts of) such architectural descriptions in an efficient and effective way [18]. Additional research at TNO [14] looks into the possibilities of developing context-dependent 'cookbooks' for creating architectural descriptions in a given context, based on CC-modelling.

The efforts at TNO provided the evidence that the CC-method did achieve its purpose, which is to accelerate discussions about complex subjects and produce concrete results from them in practical situations.

In 2002 research at the OUNL was launched to further this work in the direction of an educative tool. A major deliverable of this work was the Ampersand software tool. This was subsequently used in software development efforts at Bank MeesPierson [5]. The tool provided engineering support in describing and analyzing rules governing the trade in securities. The engineer found that the business rules could very well be used to do continuous audit, solving many problems where control over the business and tolerance in daily operations are in conflict.

At Rabobank, in a large project for designing a credit management service center, debates over terminology were settled on the basis of metamodels built in CC. These metamodels resulted in a noticeable simplification of business processes and showed how system designs built in Rational Rose should be linked to process models [4]. The entire design of the process architecture [25] was validated in CC. At the same

time, CC was used to define the notion of skill based distribution. This study led to the design by Ordina of a skills-based insurance back-office for Interpolis. The same CC-models that founded the design at Interpolis were reused in 2004 to design an insurance back office for Delta Lloyd.

This work provided useful insights about reuse of design knowledge. It also demonstrated that a collection of business rules may be used as a design pattern [15] for the purpose of reusing design knowledge. In 2005 Ordina started a project to make knowledge reuse in the style demonstrated at Delta Lloyd into a repeatable effort. In 2006, the CC-method was refined into the Ampersand approach at the OUNL by adding the capability to generate functional specifications from rules.

5 The power of business rules

Business rules have a high potential for changing the way business processes and information systems are designed. Since business rules can be communicated so much easier, rule-based BPM carries the promise of bringing BPM closer to the business. The process control principle that we introduce in the next chapter, takes business rules one step further: it shows that business rules can be used to control processes without using a process model. This is achieved by exploiting the implicit temporal constraints that can be derived from (static) business rules. This solves the problem of restrictively ordered activities, imposed by workflow technology.

Currently, process modeling techniques force an ordering of activities upon the organization, which can sometimes be too confining. Although case management [36, 10] does improve flexibility, it still requires process modeling and still requires a significant design effort. Rule-based BPM does not have these limitations. It enforces only the rules that an organization is bound to, either by outside sources (e.g. legislation) or by creating rules internally.

To use rule-based process control, designers must learn to represent business rules in relation algebra. Evidence gathered so far suggests this can be done, but more work is required to make it easy. Further research is planned to make tools that help designers formulate business rules in a graphical manner.

Potential benefits are possible in compliance and governance, as required for instance by Sarbanes-Oxley [1] and other legislature. Our findings support a tighter integration of formal methods in software engineering [38]. The increased quality of specifications can make offshoring much easier.

It has also become clear that the power of business rules, when represented in relation algebra, goes well beyond business process management alone. Rules have also been used in architectural studies, reusing knowledge in design patterns. Also, rules can be used to describe the modeling techniques and methods themselves; this is referred to as Metamodeling. The Open University of the Netherlands is currently teaching a metamodeling course and a business rule course, both of which employ the tools described in this book.

Further research is required to bring this work from principle to production. Work on a business rules repository is ongoing. The Ampersand tool will be extended to enhance support for process design. The prototype generator is being made suitable for use by business analysts, to enhance their ability to make good designs.

6 Acknowledgements

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Of course, we would like to thank our reviewers, especially Silvie Spreeuwenberg and others who have meticulously pointed out flaws in earlier versions. Besides, we wish to thank TNO in Groningen (the Netherlands) for being the first user of Ampersand. Thank you also to colleagues at the Open University of the Netherlands, the University of Utrecht, the University of Twente, and the Technological University of Eindhoven, who have inspired and criticized this work. The warmest thanks are for our families, who have sacrificed so much time to get this book where it is today.

7 Reading Guide

This introduction provides an overview of business rules from a specific point of view: Business rules describe requirements, and therefore they can be used to design information systems and business processes. This book serves as an introduction to those who wish to make this happen in their own working environment. The first part, Methodology, elaborates a vision on business processes control. It introduces the idea of Rule-Based Design from a practical perspective, and motivates why this is a good idea. The second part, Theory, introduces a way to write business rules. You are introduced to a formal way of writing language. The third part, Practice, discusses case studies that show how Rule-Based Design is used in practice.

Part I

Methodology

Ampersand

Chapter 2

Ampersand

An Approach to Control Business Processes

1 Introduction

This chapter shows how to use business rules for specifying both business processes and the software that supports them. This approach yields a consistent design, which is derived directly from business rules. This leads to software that complies with the rules of the business.

The approach, called Ampersand, is specifically suited for business processes with strong compliance requirements, such as financial processes or government processes that execute legislature. Features of Ampersand are: rules define a process, no process modeling is required, *compliance* with the rules is guaranteed, and rules are maintained by systematically signalling participants in the process.

Compliance

A case study completes this chapter.

2 Rules

Ampersand lets you design information systems to control business processes. It is based on rules. But what exactly are rules? Merriam-Webster's dictionary contains over a dozen different definitions. Some of those are in agreement with this book:

- A prescribed guide for conduct or action.
- An accepted procedure, custom, or habit.
- A regulation or bylaw governing procedure or controlling conduct.

For practical purposes, however, you will need a definition that you can use when you design information systems and business processes. We need a definition that lets you tell a rule apart from other statements. The following definition provides the means to say whether a statement is a rule or not.

Business rule

A *business rule* is a verifiable statement that some stakeholders intend to obey, within a certain context.

Here is an example of a rule:

In our club, a coat of any guest shall be in the cloakroom, as long as the guest is in the club.

Let us analyse this statement, to better understand what we mean by a business rule.

Scope

a Rules have a *scope*.
The context of the stakeholders is our club in which this rule is valid. We call this the scope of this rule. A rule may or may not hold beyond its scope. People may or may not wear their coats outside of the club.

Stakeholder

b Rules have *stakeholders*.
Anyone involved in a rule is called *stakeholder*. For example, to ensure that guests put their coats in the cloakroom, there may be a bell boy to take the coats in and hand them out again, or there may be a staff member who sees to it that people who try to smuggle their coats inside are intercepted. Or a simple notice may inform the dear guests to leave their coats, or else. Whenever a rule has no stakeholders, then apparently no one is interested if the rule is obeyed or not. Such a

rule has no business merit, and we do not consider it to be a business rule. Stakeholders who "live by the rules" are working to satisfy rules, each in his or her own role.

Verifiable

c Rules are *verifiable*.
If there is a guest inside the club who holds a coat, we have a violation of this rule. We call a rule verifiable if its violations can be spotted unambiguously and objectively. That violation could be a signal to someone to take action. A floor manager might summon the offender to take his or her coat out to the cloakroom. Or, a staff member might take the coat from the guest and put it away in the cloakroom. Or even the guest himself might take some action. He might toss his coat out of the window, ensuring that it is beyond the scope of this rule. Technically, that would be an acceptable thing to do, unless there are rules in place that forbid littering the street... Whatever actions happen, the situation should be restored to where the rule is complied with.

For a better understanding, let us look at some counterexamples. The following statements are *not* rules:

– *Our club is transparent to the outside world.*
Whether this statement is true or not is open for discussion, depending on what you think "transparent" means. For this statement to be a rule, we must be able to determine objectively whether it is true or not. Within the context of this book, this statement is not a rule because it is not verifiable.

Concrete

Rules must have the property of being *concrete*.

– *Club members get up in the morning and go to sleep in the evening.*
This is not a rule if none of the stakeholders really cares. If nobody is willing to maintain the truth, we have no rule.

Relevant

Rules must have the property of being *relevant*.

– $E = mc^2$
This is a law of nature, which is considered true in any scope and without the intervention for any stakeholder whatsoever. No one will check to see if the rule is obeyed or violated, and certainly will no stakeholder put in an effort to undo violations. Even if we would consider this to be a rule, there is no need to maintain what mother Nature maintains for us. Such irrelevant rules and laws of nature are out of our scope, they are not business rules.
Business rules must represent agreements that people care about.
– *Peter Lee Jones has visited the club this morning.*
This statement can be either true or false, so it is a verifiable statement. And once we have established its truth, it will never change. Therefore, we call this a fact rather than rule, even though theoretically, there is no reason why facts should not be rules.

Rules usually assume a number of things tacitly. That is also the case in our example. The rule sounds: "In our club, a coat of any guest shall be in the cloakroom, as long as the guest is in the club." It assumes a number of things, such as:

– There is a club, which we call "our club". To avoid uncertainty, we had better remove the reference to "our" club, and supply the exact name of the club.
– Coats have owners, especially guests can be owner of a coat.
– Coats can be in the cloakroom. This also implies that there is a cloakroom.
– Guests stay in the club for a certain period of time.

If one of these assumptions is not true, the rule is meaningless. Requirements engineers, who write rules on behalf of stakeholders, must be aware of these tacit assumptions.

Also, the exact phrasing of a rule is really important. Rephrasing can cause problems, because there may be implicit assumptions underlying the statements. The following examples show how seemingly innocent rephrasings can unwillingly change the

intended meaning:

- In our club, guests must put their coats in the cloakroom.
  This rule does not prevent a guest from taking his coat into the club. He or she can take the coat out, right after putting it in the cloakroom. To avoid this and similar situations, it is good practice not to prescribe actions, but to describe a state.
- In our club, the coat of each guest must be in the cloakroom, as long as they are in the club.
  This rule assumes that every guest has precisely one coat. If this is not the case, then what?
- In our club, all coats must be kept in the cloakroom at all times.
  In this case, coats of members and staff are also kept in the cloakroom...
- In our club, the bell boy will put your coat in the cloakroom.
  This rule affects anyone entering the club. It does not say what to do with your coat when the bell boy is absent. Besides, it is not specific about "you". In principle, this rule also applies to the mailman who drops by to deliver some mail...

In order to check whether a statement is a rule, please ask yourself the following questions:

a Can I decide objectively at any moment in time, whether the rule is satisfied or not? If so, this statement is verifiable. As a double check, can I think of a situation that violates the rule?
b Where and in which situation(s) does this statement make sense? This gives you the scope.
c Can you identify who are affected by this rule? If so, these people (or groups) are your stakeholders.
d Is there an intention to keep this statement true? If so, which stakeholder(s) take which action(s) to maintain this rule? If none of the stakeholders have such intention, your statement is not a rule.

3 Rules in Business

Define
Business process

Business rules can be used to manage and control business processes. In this sense, business rules actually *define* the *business process*. This yields compliant systems and compliant processes. This chapter explains the principle, which can be summarized as: signal violations (in real time) and act to resolve them. This drives a series of events to comply with all business rules. It lets us conclude that business rules are sufficient as an instrument to design compliant business processes and information systems.

Whenever and wherever people cooperate to work together, they coordinate their work by making agreements and commitments. These agreements and commitments constitute the rules of the business. A logical consequence is that these rules must be known and understood by all who have to comply. From this perspective, business rules are the cement that ties a group of individuals together to form an organization. In practice, many rules are documented, especially in larger organizations. Life of a business analyst can hardly be made easier: rules are known and discussed in the organization's own language, and stakeholders know (or are supposed to know) the rules and abide by them.

Maintain

The role of information technology is to help *maintain* business rules. That is: if any rule is violated, a computer can signal that and prompt people (inside and outside the organization) to resolve the issue. The Ampersand approach uses this as a principle for controlling business processes. For that purpose two kinds of rules are distinguished: rules that are maintained by people and rules that are maintained by computers.

A rule maintained by people may be violated temporarily, for the time required to fix the situation. For example, a rule might say that each benefit application requires a decision. This is violated from the moment an application arrives until a corresponding decision is made. Allowing the temporary violation gives a person time to make a decision. For that purpose, a computer monitors all rules maintained by people and signals them to take appropriate action. Signals generated by the system represent (temporary) violations, which are communicated to people as a trigger for action.

A rule maintained by computers need never be violated. Any violation is either corrected or prevented. If for example a credit approval is checked by someone without the right authorization, this can be signalled as a violation of the rule that such work requires authorization. An appropriate reaction is to prevent the transaction (of checking the credit application) from taking place. In another example the credit approval might violate a rule saying that name, address, zip and city should be filled in. In that case, a computer might correct the violation by filling out the credit approval automatically.

Since all rules (both the ones maintained by people and the ones maintained by computers) are monitored, computers and persons together form a system that lives by the rules. This establishes compliance. Business process management (BPM) is also included, based on the assumption BPM is all about handling cases. Each case (for instance a credit approval) is governed by a set of rules. This set is called the *procedure* by which the case is handled (e.g. the credit approval procedure). Actions on that case are triggered by signals, which inform users that one of these rules is (temporarily) violated. When all rules are satisfied (i.e. no violations with respect to that case remain), the case is *closed*. This yields the controlling principle of BPM.

Procedure

Closed

This principle rests solely on rules. Computer software is used to derive the actions, generating the business processes directly from the rules of the business. To compare: workflow management derives actions from a workflow model, that captures a procedure in terms of actions. Workflow models are specified by modelers, who take the rules of the business, and transform these into actions plus an appropriate but fixed order to achieve the desired result.

The new approach has two advantages: the work to draw up a workflow model can be saved and potential mistakes made by process modelers can be avoided. It sheds a different light on process models, whose role is reduced to documenting and explaining a process to human participants in the process. Process models no longer serve as a 'recipe for action', as is the case in workflow management.

The following section discusses an example, that illustrates this process control principle.

4 An example

Consider the handling of permit applications by a procedure based solely on rules. Each permit application is seen as a case to be handled, using the principle of rule-based process control (section 3). First the business rules are given that define the situation. We subsequently discuss a scenario of the demonstration that is given with the generated software and the data model (also generated from the rules) on which that application is based.

The example consists of the following business rules.

a An application for a permit may be accepted only from one individual whose identity is authenticated.
b Each application for a permit must be treated only by authorized personnel.
c Every application must lead to a decision.

d An application for a particular type of permit may never lead to a decision about another type of permit.
e Every employee must be assigned to one or more particular areas.
f An employee may only handle applications from those areas to which (s)he is assigned.

First, we establish that each statement is indeed a business rule by showing that each rule is falsifiable. For that purpose, one example is given of a violation for each rule:

a An application for a permit from an individual with suspicious identity or credentials.
b An application that is handled by an unauthorized person.
c A permit application without a decision.
d An application for a building permit that leads to a decision about a hunting permit.
e An employee assigned to no area at all (perhaps an apprentice?).
f An employee assigned to Soho who handles an application from the East End.

As for the IT consequences, notice that violation d can be prevented by a computer, by consistently choosing the type of the permit as the type of the corresponding decision. This causes rule d to be free of violations all the time. Rule c may be violated for some time, but in the end a decision must be made. So the work is assigned to an employee who makes that decision. Rule e may also be violated for some time, but the employee cannot handle applications for the time being. Rules a, b, and f may be enforced by preventing all transactions that might violate the rule. Thus, a system emerges that complies with all these rules.

An application to controls this process has been built on a computer. The functional specification was generated by software that translates a set of (formalized) rules into a conceptual model, a data model, and a catalogue of services with their services defined formally. This specification defines a software system that maintains all rules mentioned above. The specification guarantees that many rules can never be violated, and the remaining ones such as c yield a signal as long as a decision on the application is pending. A compliant implementation was obtained by building a prototype generator that produces a database application according to the given specification.

An actual scenario of interleaved user and computer activities, used in demonstrations of information systems generated by business rules, proceeded as follows:

a An employee creates a new application for 'Joosten', who wants to have a 'building permit'.
b The system returns an error message for violating rule a. This means that an application for a permit from an individual whose identity is unknown is not accepted.
c The employee remembers he should have checked the identity of the applicant. He asks for identification and enters the applicant's passport number into the system.
d The employee can now record the new application. As far as this employee is concerned, he is done with the application.
e Next, an employee must be allocated for making the required decision. If an employee is chosen in violation of rules b or f, that transaction is blocked.
f The employee who makes the decision records it in the information system. The fact that this decision is about a building permit is copied (by the computer) from the application, without any interference from the employee.

Notice that this system may be criticized for picking an employee 'by hand'. This behaviour is a logical consequence of *not* having the rules in place for picking employees. One could argue that the system is incomplete, because there are too few rules. Adding appropriate rules will yield a process in which employees are assigned automatically. This illustrates how a limited (even partial) set of rules can be used

already to generate process control. In practice, this means that process control may be implemented incrementally.

Automated data analysis tools can also use the business rules to produce specification artifacts such as an UML class diagram, or formal specifications of the software services required to maintain all rules. These deliverables are not shown here for the sake of brevity.

5 Control Principle

After discussing rule-based design (section 3) and illustrating it with an example (section 4), let us discuss the consequences of rule-based control of business processes in some more detail.

The principle of rule-based BPM is that any violation of a business rule may be used to trigger actions. This principle implements Shewhart's Plan-Do-Check-Act cycle (often attributed to Deming) [31]. Figure 2.1 illustrates the principle. Assume the ex-

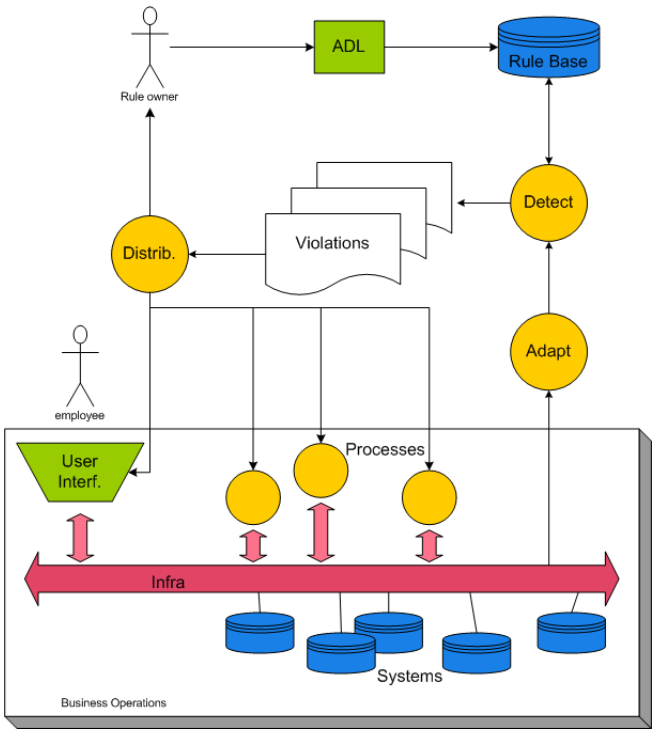


FIGURE 2.1 Principle of rule-based process management

istence of an electronic infrastructure that contains data collections, functional components, user interface components and whatever else is necessary to support the work. An adapter observes the business by drawing information from any available source (e.g. a data warehouse, interaction with users, or interaction with information systems). The observations are fed to a detector, which checks them against business rules in a rule base. If rules are found to be violated, the detector signals a process engine. The process engine distributes work to people and computers, who take appropriate actions. These actions can cause new signals, causing subsequent actions, and so on until the process is completed.

Event

The system as a whole cycles repeatedly through the phases shown in figure 2.2. The detector detects when rules are violated and signals this by analyzing *events* as they occur. The logic to detect violations dynamically is derived from the business rules.

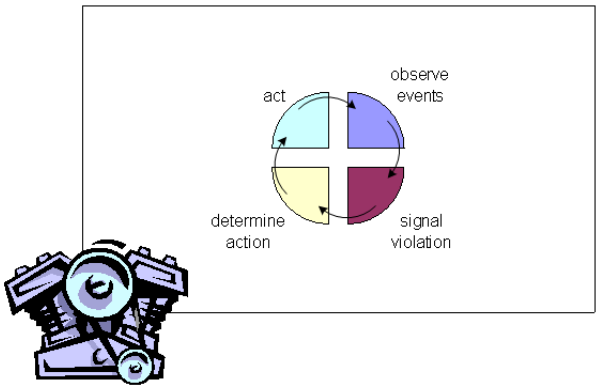


FIGURE 2.2 Engine cycle for a rule-based process engine

Violation
Signal

This results in systematic and perpetual monitoring of business rules. Whenever a *violation* is detected, a *signal* is raised for the attention of some actor or actors Signals sent to specific actors (either automated or human) will trigger actions. These actions can cause other rules to produce signals by which other actors are triggered. So the actual order of events is determined dynamically.

6 Rule Management

Changing the rules is done by altering the contents of the rule base. The behaviour of the organization will change accordingly. A rule that is removed can no longer be violated, so the signals caused by that rule will cease to exist. New rules create new kinds of violations, which cause people to take new kinds of action. In this way, changing the rules has a profound impact on the processes governed by these rules.

For this reason, an organization must obviously manage their rules. Since the rules of the business change all the time, business processes change along with them. Documenting the rules is one thing, but a process needs to be in place to deal with rule changes.

Even rule changes are subject to rules. The process of legislature in a country is a good example; countries have rules that govern how new laws are made. In most organizations, simpler processes than that will be in place. By defining the "rule management process" as "the collection of rules that govern rule changes", you can use our approach to define that process, just like any other process.

7 Case Study: A Service Desk

This section demonstrates the Ampersand approach by means of a case study.

Practicable business rules
Invariant rules

Business rules can and will apply to people, processes, and overall corparate behaviour. If we restrict to rules that we want to capture in some information system (perhaps *practicable business rules* is a suitable name), then this book is primarily concerned with what we call the *invariant rules*, also known as integrity rules or constraints. These rules assert facts that must (need to, ought to, should) hold at all times. Several other categories of practicable business rules can be pointed out, but we will not be examining them in this book, mainly because those rules cannot be easily captured by way of Relation algebra and the Ampersand approach.

The case study is about an IT Service Desk that handles incoming customer calls about software and hardware problems. It illustrates a multi-step process involving components, problem solutions, and responses that may or may not be acceptable.

The process is driven by just a few business rules about the relations between incoming calls, the required responses, and business activities to provide those responses.

Our way of working is as follows.

a We start with the business rules. The customer's point of view first, and we add a few business rules that are indispensable from the point of view of internal processing.
b Based on these few rules, a small but coherent business process engine can be generated. We discuss the abstract structure of this engine. It consists of a conceptual model, and of a set of rules now rephrased as exact formulas.
c Next, we demonstrate how this engine works in practice, by tracing one call from start to finish. We show how the process is driven by alternating between performing some business activities, and signalling rule violations, until no violations remain.

Of course, it is just a small example and we cannot elaborate on the details, exceptions or extensions. However, you are welcome to try and expand the example. This will give you a feel of our Ampersand method, and also about the versatility of the business rules approach in general.

7.1 THE BUSINESS RULES

From the customer's point of view, we can establish one all-important rule:

1 Every call must get an acceptable response.

No more, no less.

This rule ensures that every process instance, once initiated, will get to be concluded. In effect, this one rule governs the entire process, driving it from start to finish. The rule is violated as long as there exists some call with no response at all, in other words: there is work to do. But even if some response is available for a call, the rule may be violated. For instance, the response may be recorded in the system, but nobody thought to tell the customer. Or, the client is informed but the client does not accept it because it does not solve the problem. The wording of the rule is very precise: it requires that the response must be acceptable.

Switching to the point of view of internal processing, we have several more rules:

2 Every call is entered by exactly one client.

3 Every call involves at least one hardware- or software component.

4 Every response describes at least one problem solution that applies to at least one component involved in the call.

Let us briefly explain these rules. The requirement 2, that every call should originate with exactly one customer, is quite natural. And it ensures that the company can send an invoice to each customer, for services rendered; a process however that is beyond the scope of our example.

Rule 3 states that a call must involve some hardware- or software components. This also is rather obvious: if no components are involved, then why put in a call? Later on, we will see that both rule 2 and rule 3 establish a property of one particular relation, a type of business rule that is generally named "multiplicity rules" or "cardinality".

The fourth rule states that every response must describe at least one problem solution. Not just any problem solution: it must apply to some component or other that is involved in the call. The idea is that a problem solution can be useful only if it applies to at least one of the components involved in the call. Notice that this rule is

a simplification of reality. Call analysis, assessing which components are involved, and determining the problems and appropriate solutions can be quite a difficult job. Again, we consider this part of the process beyond our scope. We simply assume that the job gets done somehow, and that all knowledge about components and problem solutions is recorded somehow, somewhere.

7.2 SPECIFICATION OF THE RULE ENGINE

By inspecting the few rules above, we can see there are five concepts involved: Client, Call, Response, Component, and Problem Solution.
These concepts are involved in six relationships, such as:

– Call is *placed_by* a Client, and
– Problem Solution is *described_in* a Response.

Of course, all kinds of refinements and extensions can be conceived. But for this case study, we are satisfied with our five concepts and six relationships. A suitable way to understand and discuss these is by drawing a diagram, such as figure 2.3. This

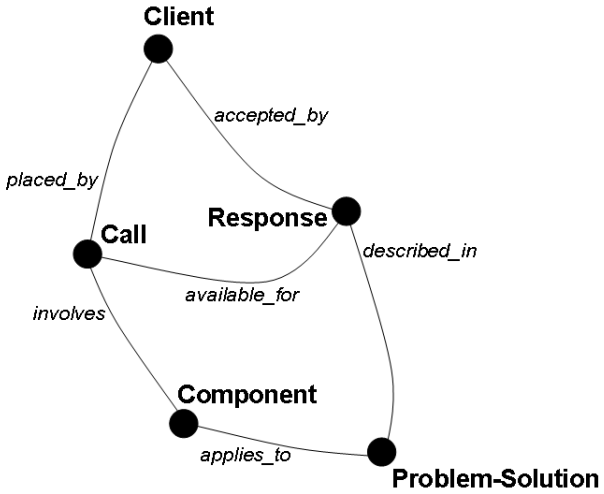


FIGURE 2.3 Diagram of the conceptual model

diagram gives a clear picture of the concepts and relations involved in our rules. But please beware that the picture does *not* show any rules at all. It merely depicts the structure, a conceptual model consisting of concepts and relations.

To get at the actual rules, we need to delve somewhat deeper. In fact, there is some mathematics involved to rephrase the rules in perfect detail. Perfect meaning: precise and unambiguous. So much so that a computer can read the stored data for all the concepts and relations, and calculate each and every violation of the rules. The mathematical rephrasing of rules into exact formulas will be extensively discussed later in the book. For now, we will use the four rules as phrased above.

The conceptual model and the rules together specify exactly what is needed to run the business. In effect, they constitute the functional specifications of a business process engine that will maintain these rules, and signal any violations. Non-functional specifications concern important aspects of information systems design that we do not capture in our business rules. For instance, security demands, scalability properties, response times, user interface requirements etc.

7.3 THE RULES AT WORK

Let's play the part of a helpdesk employee. As you enter the Service Desk workspace on a friday morning, you notice that two calls have already been handled this morning. All relevant facts about these calls have been recorded correctly. Those facts may be inserted in the previous diagram, as shown in figure 2.4. You may check

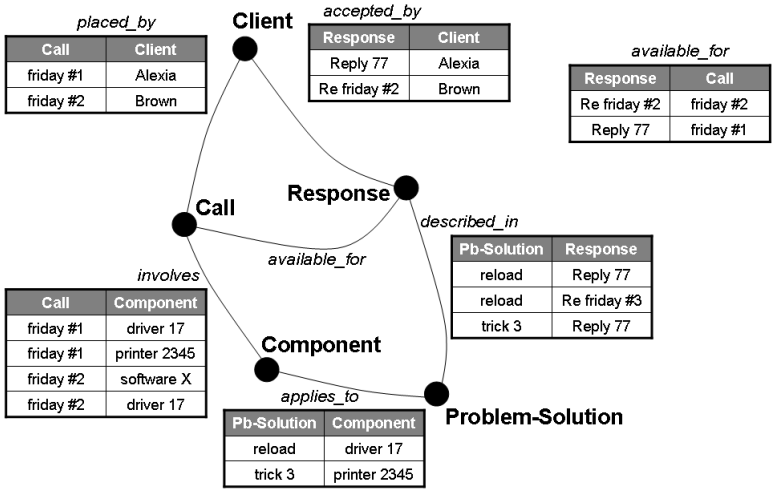


FIGURE 2.4 Initial data on record. No violations

that indeed, all four rules are complied with. There are no violations to be resolved, no work to be done. You may notice a component named "software X" for which at present, no problem solutions are known. This however is no cause for alarm, because a lack of solutions violates none of our rules.

Then, a new call comes in from the client named Capone, and your work begins.

Step1 In the relation *placed_by*, you enter the client name and the call identifier, which is "friday #3". In figure 2.5, the new fact is inserted in the correct place. For your ease of reading, the new fact is placed at the bottom of the table, and highlighted. For the business process engine however, positioning nor highlighting have any significance. As the data is being inserted into the computer, the engine will check the rules, and detect two violations:

– rule 1 says that every call must have an acceptable response, but no response is available for "friday #3".
– rule 3 says that every call is related to at least one hardware- or software component, but "friday #3" is unrelated.

Notice that there is no priority among these violations, there are no rules that tell you what to do first. Rules that dictate the order in which activities must be executed are sometimes called imperative rules. In practical situations, rules about the particular order of work may be convenient, as it keeps track of what can or needs to be done. But even more often, you will find that the particular order is unimportant, the real importance is what can or needs to be done.

In our case example, you need to find out which components are involved in this call. Let us assume that you find that two components are involved: the "software X" and that "driver 17", again. And you should also prepare some response for this particular call. So you enter three new facts into the computer:

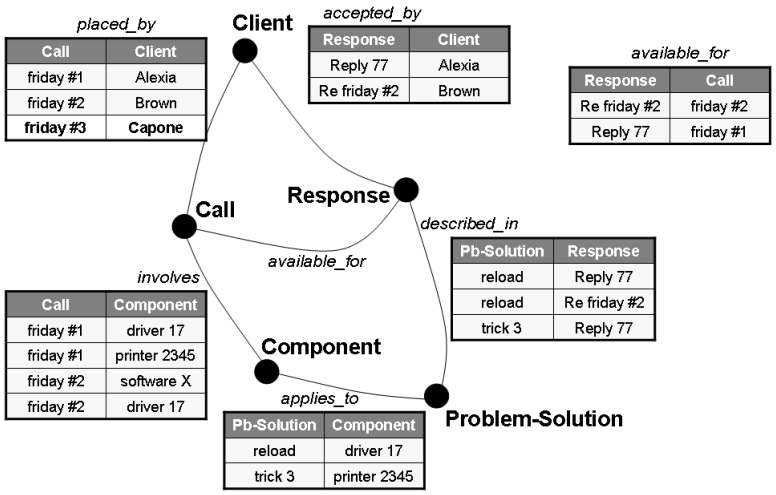


FIGURE 2.5 Step 1: new call placed. Violations

– the call "friday #3" involves the component "software X",
– the call "friday #3" involves the component "driver 17", and
– response "Re friday #3" is available for the call "friday #3".

Step 2 You enter the data into the system, while realizing that it does not matter whether you do it one at a time (in any arbitrary order), or all at once. Once you

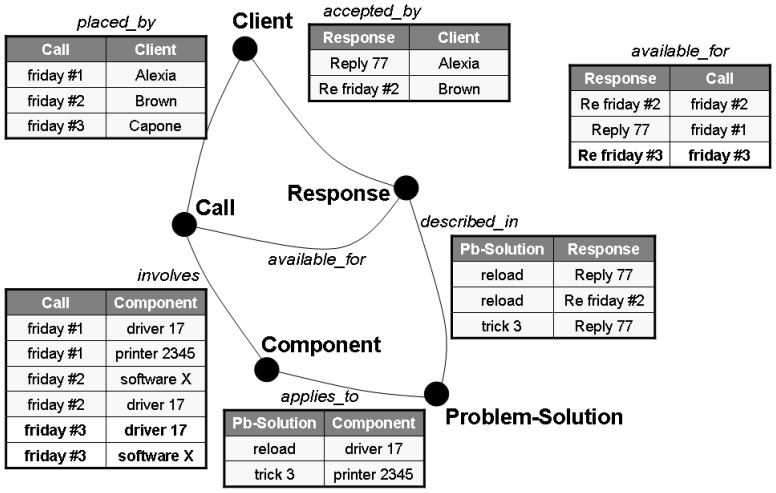


FIGURE 2.6 Step 2: call analysis. Other violations

have entered all three tupels, you find that some of the previous violations have been remedied, but now other violations emerge (figure 2.6).

– rule 1 is still being violated. A response is available for "friday #3", but as yet, the client has not accepted it.
– rule 4 says that every response describes at least one problem solution. Moreover, that problem solution must apply to at least one component involved in the call.

The available response is empty, as it describes no problem solution.

Step 3 The helpdesk employee (you) now notices that component "driver 17" is involved, and a problem solution is already known for that one: "reload" the driver. So you *describe_in* your response that particular problem solution (figure 2.7).

placed_by

Call	Client
friday #1	Alexia
friday #2	Brown
friday #3	Capone

accepted_by

Response	Client
Reply 77	Alexia
Re friday #2	Brown

available_for

Response	Call
Re friday #2	friday #2
Reply 77	friday #1
Re friday #3	friday #3

involves

Call	Component
friday #1	driver 17
friday #1	printer 2345
friday #2	software X
friday #2	driver 17
friday #3	driver 17
friday #3	software X

applies_to

Pb-Solution	Component
reload	driver 17
trick 3	printer 2345

described_in

Pb-Solution	Response
reload	Reply 77
reload	Re friday #2
trick 3	Reply 77
reload	**Re friday #3**

FIGURE 2.7 Step 3: try one solution

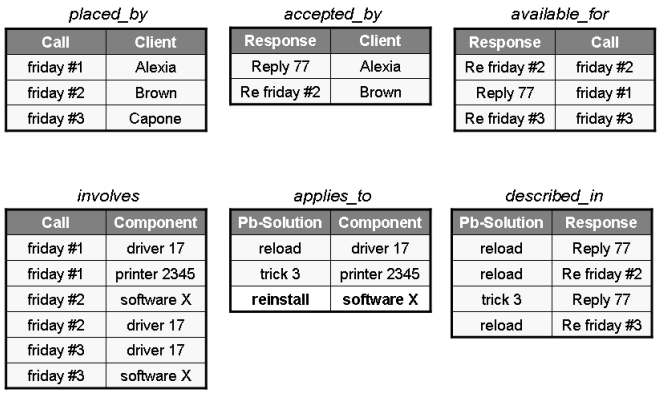
Incidentally: this figure depicts only the tables and the tuples populating them, but no more. This way of representing the information may be harder to understand for people. But of course, it does not affect the workings of the process engine in any way.

When you record this tuple, the engine will calculate that rule 4 is no longer violated. This rule concerns four relations (*available_for*, *involves*, *applies_to* and *described_in*). Notice how new tuples were entered in three, but not all four relations. In this case, the violation is resolved because a suitable tuple already existed in the fourth relation, *applies_to*. Thus, a suitable response is now available.

Step 4 As yet, the client has not accepted a response, and rule 1 is still being violated. You, or the computer, may infer from the data that only one tuple in relation *accepted_by* seems to be missing. Indeed, automatically inserting the fact "Response Re friday #3 is *accepted_by* Client Capone" would eliminate the final violation.

But this is a bad idea. The computer cannot make a real-world decision like deciding whether a response is acceptable or not. And indeed, when asked, the client clearly states that reloading driver 17 does not solve the issue. Hence, this fact may not be entered into the *accepted_by* relation, neither automatically nor manually. Contacting the client has not really changed the situation of step 3. The recorded facts are still as shown in figure 2.7, and the violation of rule 1 is still there.

Step 4 revisited So you need to come up with another response that is better than the one available now. Let us assume that you invite somebody else, a back-office employee, to examine the nature of the call and the components involved. She notices that "Software X" may be the cause of the trouble. A reinstallation of that component may solve the issue, and so she adds a new tuple into the relation *applies_to*. She informs you of the addition, and the situation is now as in figure 2.8.



placed_by

Call	Client
friday #1	Alexia
friday #2	Brown
friday #3	Capone

accepted_by

Response	Client
Reply 77	Alexia
Re friday #2	Brown

available_for

Response	Call
Re friday #2	friday #2
Reply 77	friday #1
Re friday #3	friday #3

involves

Call	Component
friday #1	driver 17
friday #1	printer 2345
friday #2	software X
friday #2	driver 17
friday #3	driver 17
friday #3	software X

applies_to

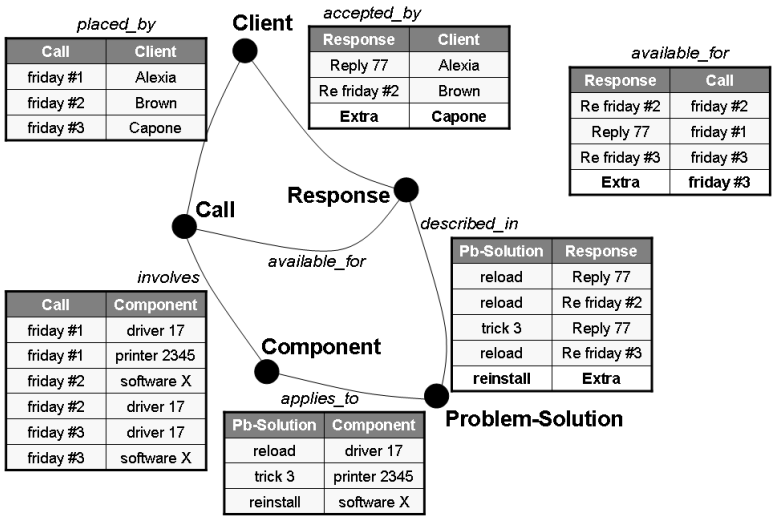
Pb-Solution	Component
reload	driver 17
trick 3	printer 2345
reinstall	**software X**

described_in

Pb-Solution	Response
reload	Reply 77
reload	Re friday #2
trick 3	Reply 77
reload	Re friday #3

FIGURE 2.8 Step 4: other solution

Step 5 This new problem solution alone, does not remedy the violation of rule 1. But now that it is available, you can easily compose a new response for the client. Your new response gets the name "Extra" as its identifier, and you record several facts for it. The new problem solution is *described_in* it, you make it *available_for* the call, and you inform the client of it. And luckily, this time it works: the response "Extra" is *accepted_by* the client "Capone". Moreover, when you insert all this information into the three corresponding relations, the computer detects no more violations. All business rules are complied with, which is to say that the process terminates (figure 2.9).



placed_by

Call	Client
friday #1	Alexia
friday #2	Brown
friday #3	Capone

accepted_by

Response	Client
Reply 77	Alexia
Re friday #2	Brown
Extra	**Capone**

available_for

Response	Call
Re friday #2	friday #2
Reply 77	friday #1
Re friday #3	friday #3
Extra	**friday #3**

involves

Call	Component
friday #1	driver 17
friday #1	printer 2345
friday #2	software X
friday #2	driver 17
friday #3	driver 17
friday #3	software X

applies_to

Pb-Solution	Component
reload	driver 17
trick 3	printer 2345
reinstall	software X

described_in

Pb-Solution	Response
reload	Reply 77
reload	Re friday #2
trick 3	Reply 77
reload	Re friday #3
reinstall	**Extra**

FIGURE 2.9 Step 5: no more violations. Process terminates

Summary From a business perspective, the following scenario has been executed:

– The client placed a new call.

– The system signalled violations of two rules.
– The helpdesk workers then performed various business activities, and recorded the data obtained in these activities.
– Every time, the system used the latest data to check compliance to the rules and generated new signals for each rule violation.

After a number of steps, and having entered all the relevant data, all the rules were complied with, no violations persisted, and no signals for work needed to be raised. This means that this, and in fact all calls have been processed successfully. Our case is complete.

7.4 POINTS OF INTEREST

This case study is rather simple. It describes the essence of a primary process: how a call for service is answered. Several interesting observations can be made even in this simple case:

Declarative versus imperative rules Our rules are declarative in nature. They describe which states are okay: every rule is satisfied, there are no violations. Or not, some rule is violated, and there is work to be done. But the rules do not say how, by whom, or in which work sequence the activities need to be executed. Imperative rules dictate exactly what must be done how, when and by whom. It is well possible to write imperative rules, but we advocate against it because such rules will produce process flows that cannot be easily adapted to new demands. The declarative rules do not enforce any particular sequence of work. It lets the workers free to decide whichever activity can or should be done.

Application supports the workers The information system generated from rule requirements should determine whether the data being entered, combined with the data already present, violate the rules. The system can then either prevent the new data from being entered (the data is rejected for being wrong). Or the system should signal violations to the workers so that corrective actions can be taken. But the system should not enforce a particular order of entering the data about real-world events. Ampersand's concept of business process does not presuppose any event sequence. The only provision on the process is that, in the end, all rules are satisfied and no violations remain.

Processing adds data As the business process is being executed, and violations are being resolved, data is constantly being added. Less common is that data already recorded in the system has to be changed. Changing some data may raise new and often unexpected violations. As a consequence, rework may be required for cases that are currently being processed or even for completed cases. In exceptional cases, you may even have to delete some data. But deletions may have even greater consequences than mere changes. For instance, an all-too-easy way to deal with a call, is to delete the fact that it was placed. Such an act would frustrate the very purpose of the business process engine.

Violations and activities are not the same All violations can and should be remedied. This is achieved by executing activities (and recording the data into the system). However, it is wrong to assume that a single violation corresponds to one bit of data or one particular activity. The case shows examples where a single new fact results in several violations. Also, one violation may require multiple changes or additions of data items for elimination. We even have an activity that resulted in no data at all (the client was informed of the response "Re friday #3" but this response was not acceptable). The implication is that a computer may calculate the violations, but it cannot always determine the appropriate actions to eliminate them. It often

requires some judgment to decide what is wrong, and what must be done to remedy the rule violations that the computer signals. For that, we will always need people with a sound judgment of reality.

Extensions Our specifications contain five concepts, six relations, two multiplicity rules, and two composite rules. Many extensions are conceivable. It is important to realize that whenever you add something new to these specifications, be it a concept, a relation or a rule, you must do so for a sound purpose based on business goals. To illustrate the point, let us consider some extensions.

- A rule like "a Response is *accepted_by* at most one Client" seems appropriate. In fact, every relation should be inspected to determine its multiplicity constraints; as will be explained in the next chapter.
- We stated that the client was informed of the response "Re friday #3" but this response was not acceptable. Apparently, a relation "Client is *informed_of* Response" might be added to model this part of the business. And whenever you add a relation, you should also think about rule(s) that might apply to it. Here, you probably want to control the business process by ensuring that "IF a Response is *accepted_by* a Client, THEN that Client is *informed_of* that Response". This kind of composite rules will be discussed in chapter 4.
- Another extension may be to discern between "Problem" and "Solution", that are now lumped together into one concept. You might want tot replace this by two concepts plus a relation. This kind of improvement, and many others, will be covered in chapter 5.
- Still other options are to record which employees are handling the calls, or to add a rule that calls may be placed only by clients who have negotiated a service contract. In the end, the business must decide which rules serves their purposes best. And it is up to you, as a designer, to capture those rules in the specifications in the best possible way.

This concludes our demonstration how a business process is controlled by way of business rules. And even though our case study included only four rules, the business process being driven is far from trivial.

The computer brings each signal to the attention of some designated actor(s) who must take action to remedy the violation. The actor will then enter new information into the system (or sometimes adjust the data already in the system). The computer will then check all the data, old and new, and signal the latest violations. This process is repeated until no violations remain. As a consequence, when all rules are satisfied, there is no more work to be done, and the case can be closed.

The approach taken by Ampersand is to drive the process by alternating between the business actions (choosing and executing business activities, and recording the data), and system actions (inspecting all the rules and signalling rule violations), until no violations remain. Moreover, the Ampersand approach ensures that in the end, all the rules will be complied with. This concludes our demonstration how compliance to the business rules provides us with a sound way to control the processes of the business.

8 Consequences

Controlling business processes directly by means of business rules has consequences for designers, who will encounter a simplified design process. From a designer's perspective, the design process is depicted in figure 2.10. The effort of design focuses on requirements engineering. The main task of a designer is to collect rules to be maintained. From that point onwards, a generator (G) produces various design artifacts, such as data models, process models etc. These design artifacts can then be fed into an information system development environment (another generator la-

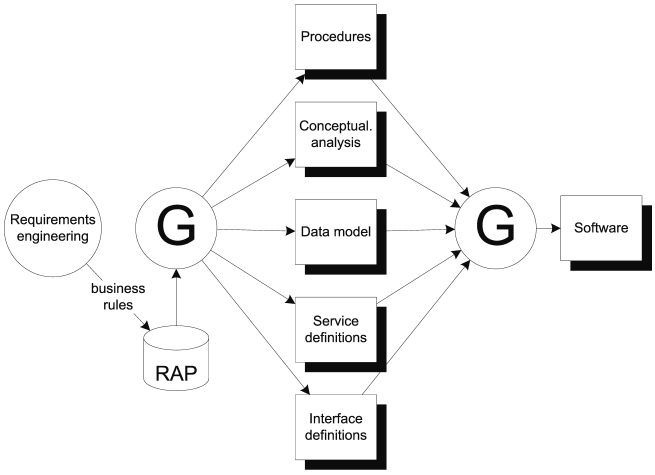


FIGURE 2.10 Design process for rule-based process management

belled G). That produces the actual system. Alternatively, the design can be built in the conventional way as a database application. The rule base (RAP, currently under development) will help the designer by storing, managing and checking rules, to generate specifications, analyze rule violations, and validate the design. For that purpose, the designer must formalize each business rule, using a supportive tool (Ampersand). He must also describe each rule in natural language for the purpose of communication to users, patrons and other stakeholders.

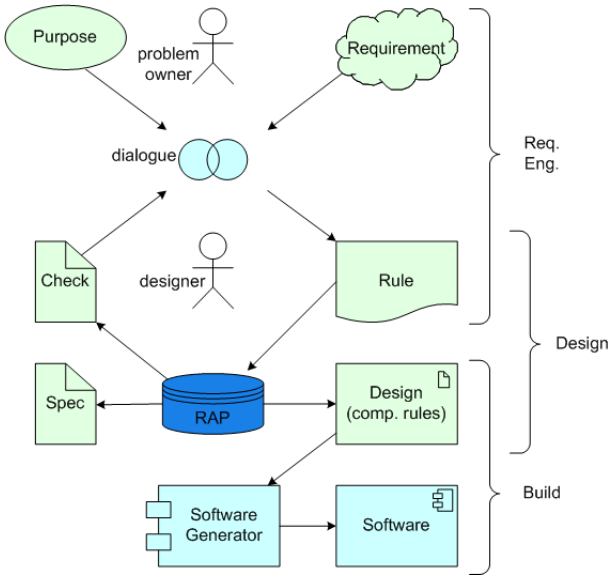


FIGURE 2.11 Design process for rule-based process management

From the perspective of an organization, the design process looks like figure 2.11. The focal point of attention is the dialogue between a problem owner and designer. The former decides which requirements he wants and the latter makes sure they are captured accurately and completely. The designer helps the problem owner to make requirements explicit. Ownership of the requirements remains in the business. The designer can tell with the help of his tools whether the requirements are sufficiently complete and concrete to make a buildable specification. The designer sticks to the principle of one-requirement-one-rule, enabling him to explain the correspondence of the specification to the business.

Part II

Theory

Concepts and Relations

Chapter 3

Concepts and Relations

1 Introduction

The Business Rules Manifesto proclaims as its central thesis or "mantra": Rules are built on facts, and facts are built on terms. But what are they, the terms, facts and rules that the Manifesto talks about? How must you understand them, how are they interconnected, and why can you rely on just these notions to build a rigorous framework for business rules? The answer is found in mathematics: relation algebra is a formal method to define, implement and work with well-formed business rules. Relation algebra provides todays professionals with a way of thinking and a way of working: what to do to describe and manipulate relations effectively, quickly, and without mistakes. Proficiency in these skills will allow you to analyze business requirements, to conduct conceptual analysis, to search for and create new rules, to test the outcome, and finally to produce exact specifications.

This chapter explains almost all about two basic notions that we will be needing as we identify, express, and manipulate the rules in the business environment. These two notions are: concept and relation.

We will introduce them using a language-oriented approach. Which is natural, as business workers express their requirements and ways of working in natural language. But to turn that into very exact rules that can be handled by computers, we cannot escape using a mathematical formalism, called relation algebra. Theory about "Relation Algebras" is a distinct branch in mathematics which came about in the nineteenth century by the efforts of mathematicians such as De Morgan, Peirce, and Schröder [9, 27, 30]. Their results have been studied, expanded and enhanced throughout the twentieth century. This has resulted in a clear and well-understood formalism that meets our needs in describing business rules.

After reading this chapter, you are expected to be familiar with these notions because all business rules approaches are built upon these fundaments. The Ampersand approach is no exception.

This chapter is outlined as follows. We start from fundamentals: basic sentences. Next, we discuss some mathematical notions that the Business Rules Manifesto implicitly uses in its article 3.1 "Rules build on facts, and facts build on concepts expressed by terms". Examples will illustrate the theory, in order to give a better understanding of the ideas and formalisms. And do not worry, we only need a basic and almost intuitive understanding, no advanced mathematics is involved.

2 Sentences

2.1 BASIC SENTENCES

Business workers use natural language to talk about things in the real world. Therefore, we need a clear and unambiguous way to capture the meaning in natural language sentences. Let us consider the following basic sentences to start with:

- ABBA sang the song Waterloo,
- DoeMaar sang Smoorverliefd,
- Joosten receives building-permit number 5678,
- William Kennedy has residence-permit NL44,
- ABBA sang 'Money, money, money',

– Ersin Seyhan has residence-permit NL901,
– the Open University offers the course Business Rules,
– Fatima has passed the exam for Business Rules,
– Caroline has passed the exam for Spanish Medieval Literature.

Term

These sentences follow the scheme: noun - verb - noun, in which the nouns refer to objects in the real world. The Business Rules Manifesto uses the word *term* to refer to the individual real-world objects such as ABBA, the building permit number 5678, the residence permit NL_44, Caroline, and the Business Rules course.

Instead of 'term', many other words are in use: software engineers call them 'instance' and mathematicians call them 'element'. In knowledge engineering and model theory, such things are called 'atom'. Throughout this book we use the word 'atom', though any synonym like 'instance', 'item', 'element', 'member' or 'object', will do in practice.

Atom

An *atom* refers to an individual object in the real world, such as the student called 'Caroline'. But what if there are three different Carolines? What does it mean to say: "Caroline has passed the exam for Spanish Medieval Literature."? This sentence might be true for one Caroline, but false for the others. Clearly, to avoid ambiguous sentences, an atom must identify exactly one real-world object, no more, no less. Or rather, it suffices that the atom identifies one object within the context in which we are working: if the context is a group with only one Caroline, there will be no ambiguity. Similarly, ABBA is unique among all pop groups in the world; there ought to be only one building permit with number 5678; etcetera.

Fact

Each of the basic sentences above represents a *fact*, something that is taken to be true. The example sentences follow the noun-verb-noun scheme, but the notion of basic sentence applies to just about any sentence that has two atoms related by a verb-like expression. For example, if we use the name 'Caroline' and the number '3' as atoms, the following is also a basic sentence: "In Caroline's house there are three rooms". This basic sentence contains two atoms, and if we leave out those atoms, a template remains, as in: "In ... 's house, there are ... rooms". So, a *basic sentence* in natural language relates two atoms.

Basic sentence

Still, a basic sentence does not accommodate arbitrary atoms. For example, switching the atoms produces a sentence "In 3's house, there are Caroline rooms" which makes no sense at all, it is non-sense. In this particular example, the first blanks are clearly meant for a person and the second one should obviously be a number. In other sentences, other concepts may be required. For instance, in the sentence "... has passed the exam for ..." the first blanks are supposedly some student and the second blanks must be some course.

Concept

In Ampersand, an abstraction like 'student', 'number', and 'course', that you need to replace by an actual student, number, or course, is called a *concept*. Concepts should not be confused with atoms: concepts are abstract, and atoms are concrete. Atoms are the terms, the individual things in the real world that you can point out. A concept is an abstraction, it is not the individual thing but the type of thing. We can say for example that Caroline (an atom) is a student (a concept), ABBA is a pop group, and NL_44 is a residence permit.

So basic sentences have a fixed template, and moreover, every term (or atom, as we prefer to call it) that you fill in on the blanks, belongs to a certain concept. The Business Rules Manifesto, in its article 3.1, hints at just this distinction between term and concept. That article can be explained as:

– a *term* expresses a business concept, it corresponds to an individual thing that is relevant in the business context,
– a *concept* is an abstract description or definition that is instantiated (expressed) by the actual realworld thing (term or object),

– a *fact* makes an assertion about the concepts, it is a basic sentence that expresses a relationship between two terms.

2.2 CONCEPT

As we want to describe our business rules with computer precision, we must be rigorous in our definitions.

At the surface level, a *term* refers to one individual thing that exists in the real world. At the deep level, a *concept* stands for terms that are similar: they share the same meaning, have similar properties, similar behavior, and similar connections with other terms or concepts.

Intension

Every abstract concept comes with an *intension*: a definition that lets you determine whether an arbitrary 'thing' in the business environment is an instance of the concept. The reader of the definition is expected to understand which 'individual terms that exist in the real world' meet the definition and should be (represented as) a term in the extension of the concept. Next, a concept also has an *extension*, more often called *population* or *contents*. This is the set of all terms that the concept actually stands for, at present. It is customarily denoted using a *bracket notation*, for instance Age = { 7, 3, 5, 2 }. Occasionally square brackets are used: Age = [5; 3; 2; 7]. In mathematics, the special symbol $\in$ is used to denote that an element is contained in the set, so we have: $3 \in Age$, $7 \in Age$, etc.

Extension
Population
Contents

Inclusion

The *inclusion* symbol $\subset$ is used to denote that one set is a subset of another, it is contained in it. For instance { 3, 7 } $\subset$ Age, or { William Kennedy, Ersin Seyhan, Caroline } $\subset$ Person. Because the inclusion symbol is not easy to type, we will often replace it with the symbol $\vdash$, which means exactly the same.

Subsets usually contain less atoms than the enveloping set, but in general, the two sets are allowed to be equal. If we want to draw attention to the fact that equality is permitted, we sometimes write $A \sqsubseteq B$. But if equality is not permitted, we must write two assertions:

$$A \subset B \text{ and } \neg (A = B)$$

Three important properties to remember about atoms are:

– each instance of the concept is considered to be whole and indivisible, and it is why we use the name 'atom'. The element 'ABBA' is regarded as one indivisible member of the Popgroup concept, even though, from another point of view, it may be composed of four units,
– there is no specific order or sequence among the atoms of a concept,
– an atom can occur only once in the population. That is: each atom must differ from every other element within the set. A term meets the concept definition, or it does not. It is meaningless to say that it meets the definition twice.

Entity integrity

The latter property is sometimes referred to as *entity integrity* by database designers.

A concept is characterized by its intension, a sound definition that exemplifies its business semantics, its meaning, properties, behaviour. Definitions are generally stable, and do not change overnight, regardless whether there are millions, hundreds, tens or even no instances on record for the concept. And although definitions can change over time, such changes are not very frequent.

To contrast: extensions can and will change constantly. The extension is the time-varying part. At any given moment, there is a specific content, and that content can differ from the content one minute before or after. For instance, Student is an important concept at any university, but the student population is constantly changing. A concept may even have an *empty extension* at some time, denoted $\emptyset$. But even if two

Empty extension

concepts are both empty, we consider them to be different: a Student concept differs from the Car concept, even if there are neither students nor cars on record.

In general, concept names are nouns such as 'Student', 'Customer' or 'Car', sometimes qualified to better express its meaning, e.g. 'Old-timer Car', 'Bachelor Student', or 'Priority Customer'. By convention, we write the name of a concept with a capital: 'Popgroup', 'Permit', or 'Course'.

2.3 RELATION

Above, we defined 'fact' as a basic sentence that expresses a relationship between two terms. Having abstracted the individual terms to concepts, we also desire an abstract notion to replace the individual fact templates. The answer provided by mathematics is called: relations.

Let us introduce this by way of an example: some friends organizing a tennis tournament which will include a mixed-double competition. Although the group of friends has 4 women and 5 men, only three pairs want to participate in the mixed double. These are the facts:

- Aisha doubles with Marek.
- Sophie doubles with Raúl.
- Nellie doubles with Toine.

Obviously, the template for these facts is: ... *doubles with* ... with the first concept being Woman, the second concept involved is Man. We now introduce the relation named *doublesWith* which is defined as "the set of all pairs of one woman and one man wanting to participate in the upcoming tennis tournament". We can write the pairs one by one:

- $\langle$ `'Aisha', 'Marek'` $\rangle \in$ *doublesWith*.
- $\langle$ `'Nellie', 'Toine'` $\rangle \in$ *doublesWith*.
- $\langle$ `'Sophie', 'Raúl'` $\rangle \in$ *doublesWith*.

Or we may list the entire population of *doublesWith* in one go:

$$doublesWith = \{ (\text{Nellie}, \text{Toine});\ (\text{Aisha}, \text{Marek});\ (\text{Sophie}, \text{Raúl}) \}.$$

Instance diagram

We can also make a drawing of this relation, a so-called *instance diagram* or Venn diagram. This shows all facts as arcs connecting the woman and man that together

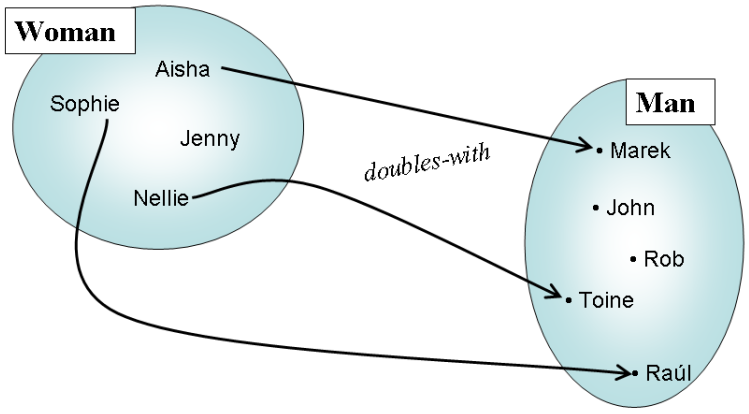


FIGURE 3.1 Instance diagram: which woman *doublesWith* which man

make up a pair, as shown in figure 3.1. An instance diagram provides very detailed

insight into the current state of affairs in the business, which can be very useful sometimes. It works fine for small examples, but this kind of diagram quickly becomes unreadable if many pairs participate.

We may also use a layout with two columns as in table 3.1.

Woman	*Man*
Sophie	Raúl
Aisha	Marek
Nellie	Toine

TABLE 3.1 *doublesWith*: tabular layout of the participating pairs

Facts can be represented in many ways. A telephone directory lists names with telephone numbers in a tabular layout, a dictionary does the same with words and their meanings. But a story about a poker or bridge game may be illustrated with a diagram showing the hands of each player.

The time and effort people take to communicate the contents of relations indicates the importance of suitable representations. In practice, form follows function: depending on circumstances, audience, and the sheer number of facts, the designer chooses a representation that best suits the purpose.

2.4 CARTESIAN PRODUCT

The most comprehensive representation of a relation is a two-dimensional array. It shows all instances of one concept, Woman, along one axis, and all instances of the second concept, Man, along the other axis, like a spreadsheet page as in table 3.2. It allows you to easily mark participation in the tournament.

doublesWith	Marek	John	Rob	Toine	Raúl
Sophie	-	-	-	-	x
Aisha	x	-	-	-	-
Jenny	-	-	-	-	-
Nellie	-	-	-	x	-

TABLE 3.2 Two-dimensional layout of the participating pairs

This representation lets you consider all possible combinations of one woman and one man, a total of $4 \times 5 = 20$ possible pairs. The "set of all possible pairs" is called a *Cartesian product* in mathematics.

Cartesian product

Formally, the *Cartesian product* of two concepts A and B is (the set of) all pairs that combine one atom from the first concept A, with one atom from the second concept, B. Obviously, the number of pairs in the Cartesian product is equal to the number of atoms in A times the number of atoms in B; which explains (in part) why it is called a 'product'.

The Cartesian product of concepts A and B is denoted as: $A \times B$. We sometimes denote it as $\mathbb{V}_{[A,B]}$ or $\mathbb{V}$ for short, with the V's lefthand side rendered as a double line, if the printer can do that. Of course, if there is any chance of ambiguity, $\mathbb{V}_{[A,B]}$ should be written in full to prevent confusion with, say, $\mathbb{V}_{[B,C]}$ or $\mathbb{V}_{[B,A]}$.

Another good example of Cartesian product is a deck of common playing cards. There are 4 suits {spades, diamonds, clubs, hearts}, and 13 ranks. Because every combination is possible, there are 52 playing cards in the Cartesian product of $Suit \times Rank$, as shown in figure 3.2. The cards in the picture are neatly arranged, but remember that in general, there is no special ordering along the axes.

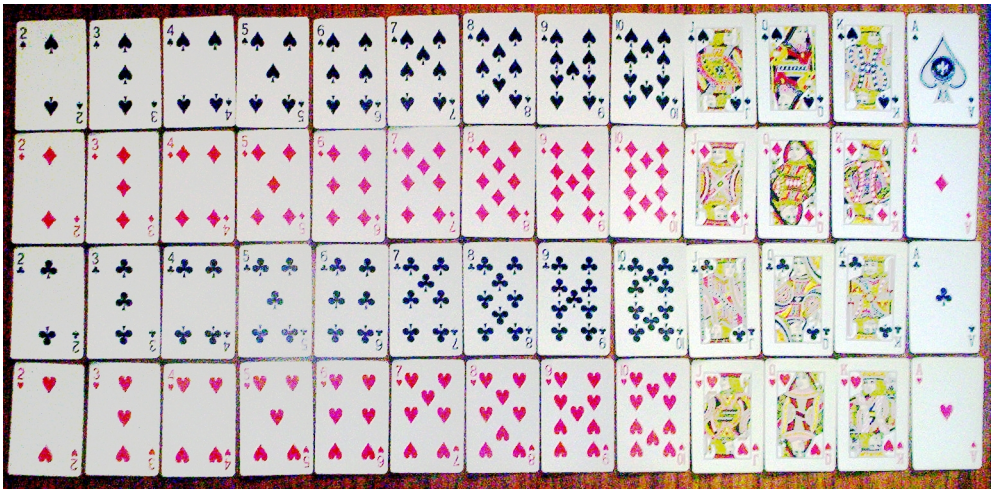


FIGURE 3.2 Set of 52 playing cards

To be exact: this is different from $Rank \times Suit$. While the tuple (diamonds, ace) looks very similar to the tuple (ace, diamonds), there is a big difference as the two atoms are written in inverse order. This finesse will be important later on when we discuss the inverse of a relation.

Some standard terminology when discussing Cartesian products:

Source
Target
Tuple

- the left-hand set of the product is called *source* or *domain*,
- the right-hand set of the product is called *target*, or *co-domain*, or sometimes *range* or *image*,
- each single element of the product is called a *tuple* or *pair*.

2.5 RELATION IN MATHEMATICS

Relation

Having defined the Cartesian product, we can now explain the formal definition of a *relation* which is:

- a named subset of the Cartesian product of two concepts, where all tuples in the subset have a similar meaning, similar properties, and similar behavior.

Relation name

The *relation name* is usually a verb, possibly qualified, like you saw in the templates for basic sentences. We will generally write the relation name in italics and in lowercase. Whatever name you choose for a relation, make it (almost) self-explanatory. When trying to understand a design, the business stakeholders will start to look at names first. So make sure that the names are really close to the intent of the relation, its real-world meaning and pragmatics. Relation names, being verbs, often seem to express some kind of activity. But beware: the intention of relations is never to prescribe action, there is no imperative rule involved. Each tuple in a relation only records a single fact: that a certain woman doubles with a man in a tennis tournament, that the customer buys an item, receives a receipt, and pays the money. The fact may come into being at some moment in time, but its timing is irrelevant. The fact as such becomes and remains true, and will be kept on record indefinitely.

Intension
Pragmatics

Like with concepts, a relation has an *intension*, a precise definition. The definition serves to determine which pairs should be represented in the extension of the relation, and which ones ought to be absent. The definition or *pragmatics* captures the meaning of the relation.

You should check that *doublesWith*, with its three couples entered for the tennis competition, is indeed a relation according to our definition. Another example of a relation is the subset of community cards lying face-up on the table in a poker game,

shown in figure 3.3.

FIGURE 3.3 Community cards on the table are a special selection of playing cards

A tuple in a relation refers to one instance of the source and one instance of the target, and the tuple is fully identified by exactly these two atoms. Therefore, there is no need to have special identifiers to distinguish the tuples of a relation: the identification of its source- and target instance suffices.

To summarize so far:

- an *atom* corresponds to an individual real world thing. Each atom or *term* is captured as an instance, an element in a set, and that set is the extension of a concept,
- a *concept* is an abstract description or definition that is instantiated by the actual realworld things or objects. The intension is the definition of the relevant terms; the extension is the set of all terms in the business context that meet the definition,
- a *fact* is a basic sentence that expresses a truth about two terms,
- a *relation* is an abstract description of facts. Mathematically, it is defined as a subset of the Cartesian product of two concepts, and it captures the deep structure of basic sentences,
- the *intension* of the relation provides the definition or meaning of the relevant facts,
- the *extension* of the relation consists of *pairs*, and each *tuple* represents a single fact that is true in the business context.

EXERCISE 3.1

has_name : *Client*→*Name*

Suppose a legal consultant has two clients, labeled *C_1* and *C_2*. Their names are Martin and Stacey. Write down the basic sentences to express this knowlegde in natural language. Then, state the deep structure of these sentences.

ANSWER

C_1 *has_name* Martin
C_2 *has_name* Stacey

EXERCISE 3.2

sells : *Vendor*×*ProductType*

Invent three basic sentences to represent some content in this relation.

ANSWER

Vendor_1 *sells* Shampoo
Vendor_1 *sells* Toothpaste
Vendor_2 *sells* Chair

2.6 TERMINOLOGY AND NOTATIONS

Some standard terminology when discussing relations:

Declaration
– the relation *declaration* is the combination of its name, its source and its target, together with its definition, i.e. its meaning or intension,

Signature
– the *signature* of a relation is the combination of relation name, (the name of) source concept, and (the name of) target concept,

Type
– the *type* of a relation is defined as (the name of) the source concept, and (the name of) the target concept. In other words: a relation type indicates the full Cartesian product, the relation is its subset.

Type is important when we compare the extensions of relations. If two relations have different types, then they contain tuples with atoms taken from different source or target concepts. Only if two relations are of the same type, i.e. both relations are subsets of the same Cartesian product, can we compare their contents.

To avoid ambiguity in discussions, every relation should have a unique signature, i.e. the name, source and target are a unique combination. Often, if sources and targets are not in doubt, the relation name is enough to know about which relation we are talking. Sometimes one name is used for several relations. Theoretically, this is fine provided that the types are different. For stakeholders, it may be rather confusing.

To denote the signature of a relation with name r, source A and target B, we write

$r : A \times B$, or $r_{[A,B]}$ for short.

The customary notation for writing the contents of a relation is

$r = \{ (a, b) \mid (a, b) \in r \}$

A more concise notation is sometimes used for a single tuple:

$a\ r\ b$ means that tuple $(a, b) \in r$

For a given atom $a \in A$, we can determine all elements $b \in B$ that are related to a. This set, which in general may have 0, 1 or any arbitrary number of elements, is called the target of the element a:

$target(a) = \{ b \in B \mid (a, b) \in r \}$

Likewise, for a given $b \in B$, the subset of instances in A that relate to b is called the source of b:

$source(b) = \{ a \in A \mid (a, b) \in r \}$

Notice in the above formulas that the left-hand sides do not indicate about which relation we are talking. To avoid confusion, a subscript may indicate the relation for which the target and source are being considered:

$target_{relation}(a)$, and $source_{relation}(b)$

Source
Target
So now the words *source* and *target* have double usage. First, every relation r has a

source and a target concept. And second, each atom of the source has its own target set, and each instance of the target has its source set.

Universal relation

Bear in mind that in general, a relation is not the entire set of all possible combinations of elements, but only a subset, a selection of certain pairs. To emphasize this important difference, the Cartesian product $\mathbb{V}_{[A,B]}$ is sometimes called the *universal relation* of A and B, with "universal" meaning that it contains all possible tuples that can be produced from (the current contents of) A and B.

Symbol

Various mathematical *symbols* will be needed further on. You can read the symbols out aloud by pronouncing them as follows:

$\forall$ means 'for all'.
$\exists$ means 'there exists'.
$\wedge$ means 'and'.
$\vee$ means 'or'.
$\rightarrow$ means 'implies'.
$\leftarrow$ means 'is implied by', which is the same but it goes in the other direction.

The symbols are merely a mathematical shorthand notation and pronunciation. Just remember the meanings and pronunciations above, and you will find nothing mysterious about them.

2.7 IDENTITY RELATION

Identity relation

At this point, we want to introduce to you a special relation: the so-called *identity relation*, abbreviated to Id or even to $\mathbb{I}$ (for this particular relation yes, an uppercase i).

This relation can be defined for every concept, taking that concept for its source as well as for its target. The definition states that each atom (of the source) is equal to itself (now as an atom in the target). The contents of this relation contains every possible tuple composed of two identical elements.

identity	Apple	Orange	Pear	Berry	Grape
Apple	x				
Orange		x			
Pear			x		
Berry				x	
Grape					x

TABLE 3.3 Identity relation is special selection of the Cartesian product with identical source and target

In the matrix representation of table 3.3, the identity relation has a marking exactly on the diagonal, and nowhere else. The example tells us five facts: 'fruit w is identical to fruit w', for all five fruits, ranging from apple to grape. Another way to write down this identity relation is as follows:

$$\mathbb{I}_{Fruit} = \{(w, w) \mid w \in Fruit \}$$

The subscript indicates the concept for which the Identity relation is taken. If the concept is not in doubt, the subscript is usually omitted.

2.8 NAMING

We aim to use the notions of atom and fact, concept and relation consistently throughout this book. Other authors coin other names and notions that may look rather similar in meaning and usage, but often there are subtle differences.

For instance, UML programming works with 'classes', a notion that is similar but not equal to our notion of concept. And database modelling uses the name 'entity', or sometimes even 'type', for a notion that is also similar but not equal to our concept.

The SBVR standard (more on that later) defines term as a 'verbal designation of a general concept in a specific subject field'. The 'general concept' that this alludes to, is described as a 'unit of knowledge created by a unique combination of characteristics'.

The many different names and definitions may be a cause of confusion. Illustrative of this is the SBVR statement that "a concept type is an object type that specializes the concept 'concept', whereas a concept is related to a concept type by being an instance of the concept type."

So according to the SBVR naming convention, a person John Doe should be called a concept, which is an instance of the concept type *Customer*. We however prefer to call *Customer* the concept, and refer to the person John Doe as an instance of Customer.

Also, what we call a relation goes under different names. SBVR calls 'fact type' for what we prefer to call a 'relation'. UML coins the word 'association', and 'reference' and 'relationship' are used by still others.

For some readers, words like 'source' and 'target' may bring to mind the hyperlinks of the World Wide Web. However, hyperlinks, strictly speaking, are not relations. Although a hyperlink does provide a link from a source (webpage) to a target (another webpage), the reverse, from target back to source, is missing. For a given webpage, there is no sure way to know all webpages that have a hyperlink to it. Moreover, hyperlinks do not implement the referential integrity demand (see below), resulting in the infamous "error 404" reports.

2.9 INTEGRITY

When you deal with concepts and relations in computers, you must always adhere to two demands.

First, for every concept, it must be so that *every atom is unique within the extension*. Remember that each atom represents a single term in the business environment. That term meets the definition of the concept, or it does not. It is a member in the population, or it is not. But never can it be in the population, twice! If students are identified by their first names, then the computer can only deal with one student named Caroline. This demand was referred to as *entity integrity*.

Entity integrity

Second, we stated that each tuple in (the extension of) a relation refers to one instance of the source and one instance of the target concepts. This requires that those two *atoms referred to must actually exist* in the current extensions of the concepts, they must be on record. This important demand is usually referred to as *referential integrity*.

Referential integrity

At first glance, these two are rather trivial demands. However, one must realize that extensions are constantly changing. Therefore, if an atom is deleted from (the current extension of) some concept, the consequence is that all tuples referring to that very atom ought to be deleted also, in all relations that the concept may be involved in, either as a source or as a target. On the other hand, whenever we want to insert a tuple in a relation, we must assure that the associated source and target atoms are present in their respective extensions.

2.10 VALIDATION

The intension (definition) of a relation tells us how to decide which facts ought to be true in the business environment. The extension is the current content, it captures all of the facts that are currently on record.

You must realize that these two are fundamentally different. For example, the current content of the relation may not be up-to-date: a fact is true, but not yet recorded. Or a tuple is recorded for a relation, but the corresponding fact is no longer true. This kinds of problems may not always be attributed to a computer issue or a business error, e.g. a customer has posted a complaint but the mail has not yet been received.

Validation

The activity to check whether the computer-stored information is a valid representation of the situation in the real business world is called *validation*. Such a check will concern the (current) contents of one or more extensions. Validation may also be used in a broader sense: whether an entire design captures all the relevant features of a business environment. Validation in general requires a human effort, as only humans have a grasp of reality. Only on rare occasions can the computer signal validation problems.

Verification

Do not confuse validation with *verification* which is only an internal check on the stored information, and reporting possible problems, especially problems with integrity. Such checking can be done automatically, by computers, without referring to the real world. Clearly, problems detected by verification may sometimes be caused by invalid data, but there may also be errors in the data store or in the programmed checks.

3 Models and diagrams

3.1 MODELS AND DIAGRAMS

If you are trying to understand a business context, you will need to get a grip on the concepts and relations that are important. You start out with basic sentences, try to extract the deep structure of the sentences, and keep note of the structures you have uncovered so far.

Conceptual model

A *conceptual model* is the exhaustive listing of all concepts and relations that are relevant in a certain (business) setting. Such a listing can be provided in textual form, which will make it dull and incomprehensible, and only a trained engineer or computer programmer will like it. The listing can also be provided in a more attractive way, such as a diagram, a graphical representation of the model, or even by way of a prototype system for users to explore and play with.

For a conceptual model to be correct, we require that the signature of each relation shall be unique: for any given source and target, there is at most one relation with a certain name. The same name may be used elsewhere in the model, for relations defined on other sources or targets. However, it can become quite confusing for people trying to read and understand a model if different relations have identical names.

3.2 CONCEPTUAL DIAGRAM

A good way to get a grip on the concepts and relations in your business environment is by making a diagram such as figure 3.4. A picture is often very useful to oversee the context, and to discuss important aspects with stakeholders.

The example conceptual diagram uses dots to represent concepts, connected by arcs that represent the relations. This diagram employs the arrow notation, with the arrowhead pointing from the source (shaft of the arrow) to the target concept (point of the arrow). Relation names are written next to each arc, so that the unique signature of each relation (name, source and target) is easy to read from the diagram.

Remark that the diagram does not show current students or courses that are presently available. Nor does it show which students are involved in which course. In general,

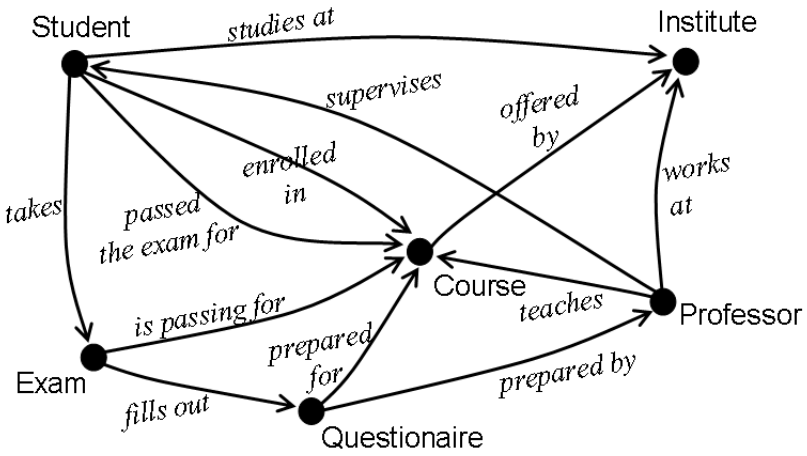


FIGURE 3.4 Example of a conceptual diagram

abstracting away from the contents enables you to oversee the structure of many relations at once.

The diagrams are easy to understand as long as the number of concepts and relations is moderate. When the numbers go up, say more than 20 concepts, then the sheer size of the diagrams makes them incomprehensible for most people, and again, only the trained specialists will like to work with such diagrams.

In this kind of diagrams, the arrowheads are sometimes placed at the base of the arc (as in the 'crow's feet' notation well known from database modelling). Other notations place it halfway, or at the end of the arc, as for instance is common in UML diagrams. Still other notations omit the arrows altogether, so that source or target must be looked up in the documentation of the conceptual model.

3.3 INSTANCE DIAGRAM

You can also use diagrams to show (some of) the contents of the concepts and relations. Such a diagram is called an Instance diagram, as shown in figure 3.5.

The instance diagram provides a level of detail that is lacking in the conceptual diagram. It depicts some instances of the concepts and relations, corresponding to true facts of reality. Already at this small scale, the diagram is rather cluttered. As mentioned before, instance diagrams are generally not very comprehensible due to the sheer amount of detail. They are mostly used only with small subsets, to illustrate a certain finesse of argument or to highlight some intricacy.

4 Operations on relations

We started out with basic sentences, facts that are true within a certain business context. Sentences can be combined in many ways to produce other sentences. By making the right combinations, the new sentences express true assertions about the business that is true as well.

Relation algebra provides numerous operations to produce new relations from existing ones. Learning to use them is vital in order to exploit the expressive power of relations: applying the operators correctly will ensure that the new sentences, your new facts, will be true as well.

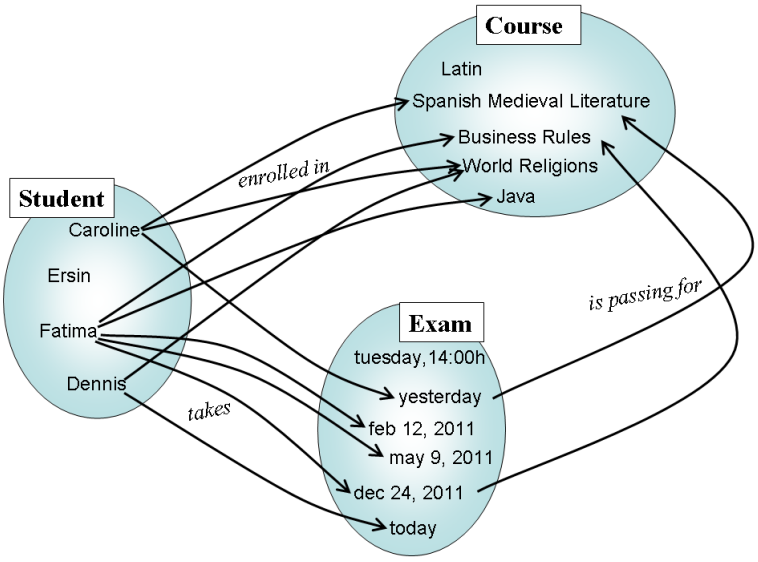


FIGURE 3.5 Example of an instance diagram

We begin with two operators that have only one argument: complement and inverse. Then we discuss operations that are known from set theory: intersection, union, and difference. A genuine relational operator is discussed next: composition. Other relational operators such as 'dagger' and 'implication' are discussed thereafter.

4.1 COMPLEMENT

Complement operator

The *complement operator* is used to indicate the tuples that are *not* in the population of a relation.

Consider the mixed doubles, defined as subset of the Cartesian product of Woman $\times$ Man. The relation signature is $doublesWith_{[Woman,Man]}$. The complement is the relation that has the same type, but its contents is the 'remainder': all pairs in $\mathbb{V}$ that are *not* in the original relation. For this reason, some authors refer to this operation as *negation*.

Negation

Complement is usually denoted by an overstrike, $\bar{r}$, and you pronounce it as 'complement of r'. Because overstrike is not easy to type, it may be denoted by a minus sign in front of the relation: *-r*.

A tabular representation of the complement relation is easy to write down. In the example of teams for the mixed double, it contains a total of $4 \times 5 - 3 = 17$ tuples, representing all potential couples that are not entered for the mixed doubles competition (table 3.4).

complement of *doublesWith*	Marek	John	Rob	Toine	Raúl
Sophie	x	x	x	x	
Aisha		x	x	x	x
Jenny	x	x	x	x	x
Nellie	x	x	x		x

TABLE 3.4 Pairs not entered for a mixed double competition

Set difference

Another way to denote a complement is by way of *set difference*, using the backslash \symbol. The set difference $F \backslash G$ is all instances that are contained in set F, at the left, but not contained in the righthand set, G. So we may denote the complement of relation $r_{[A,B]}$ as the difference $\mathbb{V}_{[A \times B]} \backslash r$.

Obviously, if there is any ambiguity what the enveloping Cartesian product would be, then the complement would also be in doubt. To illustrate the point: the complement of all students attending class is probably those students that are enrolled for the course, but that do not attend todays class. But perhaps the speaker meant the people in the classroom that are not students, such as the teacher and perhaps a visitor?

Involutive

Complement is a so-called *involutive* operator: apply the operator twice, and it will reproduce the original relation. In formula:

$$\overline{\overline{r}} = r$$

4.2 INVERSE

Earlier, we pointed out that the Cartesian product of a set A and a set B is $A \times B$, and this is not the same as $B \times A$ (except of course if $A = B$, more on that later). However, a relation that contains tuples of the form (a, b) can easily be altered into a relation containing tuples of the form (b, a) simply by changing the order of the elements. Mathematically, it is a brand new tuple, as source and target differ from before.

Inverse
Conversion

This operation, producing a new relation from an existing one, is called 'taking the *inverse*', inversion, or sometimes *conversion*. It is denoted by writing a $^\smile$ symbol (pronounced 'flip') after the relation name:

$$sang^\smile{}_{[Hit\ song, Popgroup]}$$

We may pronounce this as 'flip of Popgroup *sang* Hit song'. For most of us, it is more comfortable to change the relation name into something more sensible like 'Hit song *wasSungBy* Popgroup', or 'Hit song *originatedFrom* Popgroup'. Beware however that in general, different relation names mean different relations!

The formal declaration of the inverse relation $r^\smile$ of a relation declared as $r_{[A,B]}$ is as follows:

$$r^\smile{}_{[B,A]} \text{ having contents} \{ (\ b, a\ ) \mid (\ a, b\ ) \in r\ \}$$

As the inverse operator merely swaps the left and right hand sides of each tuple, it is easy to write down the extension of the new relation, if given the extension of the old one. In a tabular form, the inverse operator merely swaps columns, as shown in table 3.5.

Man	*Woman*
Raúl	Sophie
Marek	Aisha
Toine	Nellie

TABLE 3.5 Inverse of the selected couples for a mixed double competition

In the two-dimensional matrix layout (see table 3.2), the inverse operator mirrors the entire content of the matrix along the diagonal. The two axes, source and target, are swapped accordingly.

Involutive

Like complement, the inverse operator is also *involutive*: apply it twice, and you end up with the original relation. This may be no surprise, as the inverse operator does not change the facts, it merely rephrases them. In formula:

$$r^{\smile\smile} = r$$

4.3 SET OPERATIONS

Set theory in mathematics describes several operators that produce new sets from existing ones. Each operation unambiguously defines which elements will belong to the new set, and which ones are excluded.

In particular, we assume that you are familiar with the intersection, union and difference operators on sets. It ought to be an easy exercise to verify for arbitrary sets F and G that:

$$F \cup G = (F \backslash G) \cup (F \cap G) \cup (G \backslash F)$$

and

$$(F \setminus G) \cap (F \cap G) = \emptyset$$

Set operation

Because we defined relations as subsets of a Cartesian product, we can apply any *set operation* to two relations r and s, provided of course that they share the same types. We have:

Intersection
- *Intersection* : $r \cap s$ is the relation that contains the tuples that are contained in relation r as well as in s, or $r \cap s = \{(x,y) | (x,y) \in r \text{ and } (x,y) \in s\}$

Union
- *Union* : $r \cup s$ is the relation that contains all pairs that are present either in relation r or in s, or $r \cup s = \{(x,y) | (x,y) \in r \text{ or } (x,y) \in s\}$

Difference
- *Difference* : $r \backslash s$ is the relation that only takes tuples of relation r not present in s, or $r \backslash s = \{(x,y) | (x,y) \in r \text{ and } \neg(x,y) \in s\}$. You may check that this is equivalent to the intersection $r \cap \bar{s}$.

Remember, if relations are not defined on the same Cartesian product, they will contain tuples that cannot be compared. Such relations are disjoint, and the set operations above produce no meaningful results.

4.4 COMPOSITION

Composition operator

The *Composition* operator produces a new relation from two existing ones. It combines two expressions into a single expression. The formal definition of composition is as follows.

Let $r_{[A,B]}$ and $s_{[B,C]}$ be two relations, with the same concept being the target of r as well as the source of s. Then the composition of r and s, is the relation with type A $\times$ C. Its content is calculated as

$$\{ (a, c) \mid \text{there exists at least one } b \in B \text{ such that } a \; r \; b \text{ and } b \; s \; c\}$$

The composition operator is denoted by a semicolon ; between the two relation names, like this: $r \; ; \; s$. It is pronounced as 'composed with', in this case: r composed with s.

The figure 3.6 illustrates how composition works. An Actor (at the left) *possesses* some Skills (middle), and Skill *required-for* a Role (at the right). The meaning of the composition relation is: the Actor *possesses at least one of the Skills required for* the Role. In natural language, you might say that the actor has some skill for the role, but the formalization is much more precise. It is a combination of two facts: the actor possesses a particular skill. And the skill is required for the role. In fact, the actor may possess several skills, or the role may require many skills, but exact information about skills is absent from the composition. For an actor to be related to a role means only that the actor has at least one required skill for the role.

Another example was seen in figure 3.5 by composing relation *takes* with *isPassingFor*. Student Caroline takes an exam, yesterday, that is passing for Spanish Medieval Literature. Also, student Fatima takes several exams, and one of them is passing for the

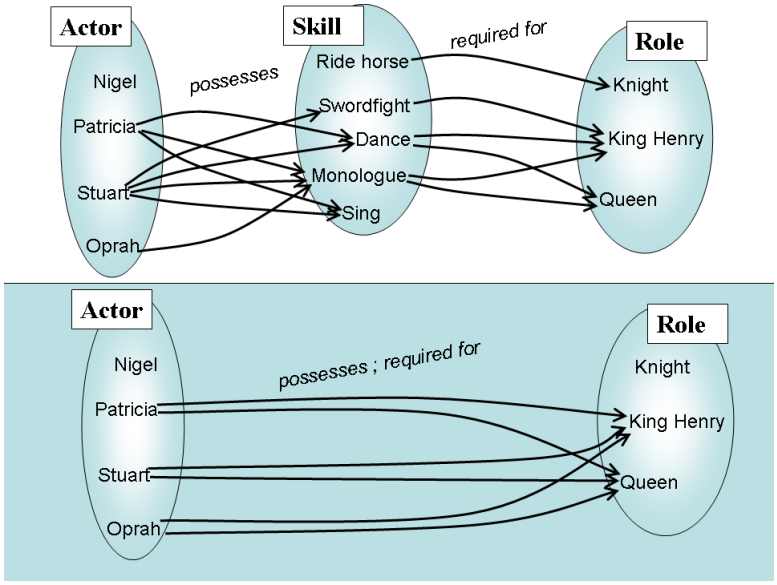


FIGURE 3.6 Instance diagram of a composition

Business Rules course. But according to the diagram, no exam was taken by Dennis that is passing for World Religions.

Obviously, you cannot compose just any two relations. If there is no middle ground, then composition has no meaning. Readers familiar with relational database theory will recognize that composition corresponds to the 'natural join' operator.

4.5 ADVANCED OPERATORS

Apart from composition, several other operations can be defined for two relations. We will briefly discuss them, although we will rarely use them. Moreover, mathematically speaking, it can be shown that all these advanced operations can be reduced to ordinary composition. In the following definitions, let $r_{[A,B]}$ and $s_{[B,C]}$ be two relations, with B being the target of r and the source of s.

Relative addition

The *relative addition* of r and s, is the relation with signature $(r \dagger s) : A \times C$, and its content is defined as

$$\{ (a, c) \mid (\forall\, b \in B) \text{ either } a\ r\ b \text{ or } b\ s\ c \text{ or both} \}$$

The relative addition operator is denoted by the symbol †, pronounced as 'dagger', between the two relation names.

To illustrate how relative addition works, consider a company that receives a lot of customer questions about a number of topics. Frontdesk employees are able to explain some of the topics over the telephone to customers. Or they may connect a customer through to some back office employee who specializes in certain topics. A frontdesk employee can be teamed up with a backoffice employee if together, they cover all possible topics. Figure 3.7 shows an instance diagram that contains three possible teams.

The natural language interpretation of relative addition is just that: a tuple (a, c) is in the relative addition if the two relations, *canExplain* from a and *isSpecializationOf* to c, together cover the entire middle ground of possible topics for questions. More formally: the relative addition equals those tuples (a, c) in $A \times C$, such that the entire set B is contained in the union of their two sets $target_{[r,]}(a)$ plus $source_{[s,]}(c)$.

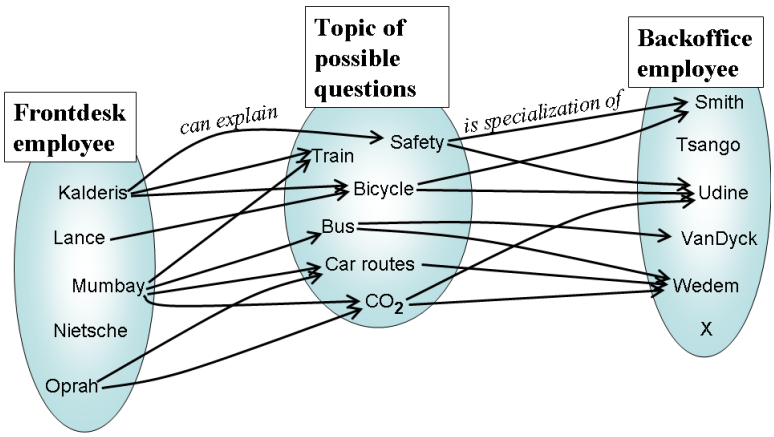


FIGURE 3.7 Instance diagram for Frontoffice-Backoffice teaming

Relative subsumption

The *relative subsumption* of relations r and s, is the relation with signature $(\ r \rceil\ s\ ) : A \times C$. By definition, its content is

$$\{\ (a, c\ ) \mid (\forall\ b \in B\ )\ \text{if}\ \ b\ s\ c\ \ \text{then}\ \ a\ r\ b\ \}$$

The operator is denoted by the] symbol. Let us illustrate the idea of this operator with an example, which will also explain why we use the] symbol as it resembles an inclusion symbol.

Suppose some institute offers tours abroad for students. Whether a student is eligible for a tour destination, depends on whether he or she has passed for the required courses. Two relations are involved:

– Course *requiredFor* Destination
– Student *passedTheExamFor* Course

and these are combined to produce a new relation

– Student *isEligibleFor* Destination

Figure 3.8 shows a sample of the instance diagram. Caroline is eligible to go to Madrid, because she passed for the required course Spanish Medieval Literature. For the trip to Rome, two courses are required, Latin and World Religions. Student Ang has passed for both courses, so he qualifies. Student Brown is less fortunate, as she has not yet passed for Latin which is one of the required subjects. Remark that the destination of Amsterdam requires no courses at all, hence all students are eligible irrespective of their achievements in exams.

For a destination to be open to a student requires that for all courses: if Course *requiredFor* Destination then Student *passedTheExamFor* Course. In other words, for a student a to be eligible for a destination c, it is required for every course b that the set $target_{passedTheExamFor}\ (a)$ is contained in $source_{requiredFor}\ (c)$.

Or, if we use the inclusion symbol in the opposite direction, we may write:

$$target_{passedTheExamFor}\ (a)\ \supset\ source_{requiredFor}\ (c)$$

This inclusion explains why we use the] symbol to denote the relative subsumption of two relations r] s. Some authors call this operator the "left residual", and it may be denoted by the forward slash / instead of the square bracket.

Relative implication

Finally, the *relative implication* of r and s, is the relation with signature $(\ r \lfloor\ s\ ) :\ A \times C$.

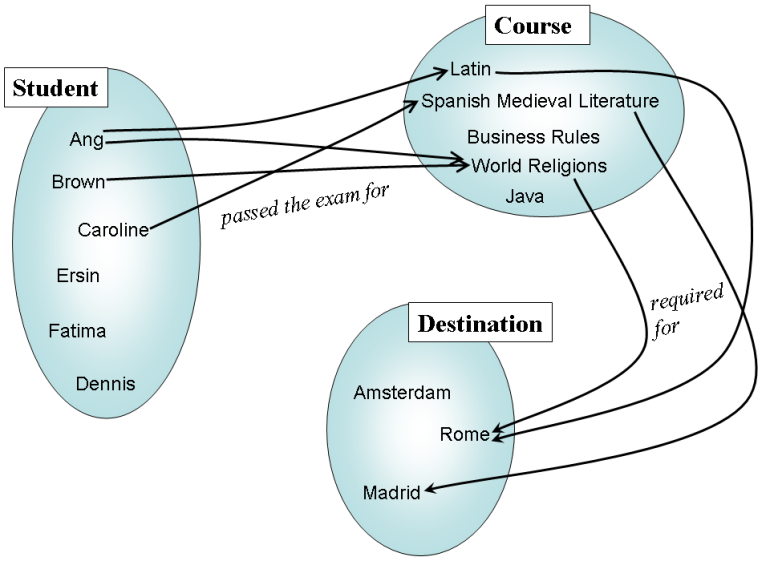


FIGURE 3.8 Instance diagram for *passedTheExamFor* and *requiredFor*

By definition, its content is

$$\{\ (a, c)\ \mid (\forall\ b \in B)\ \text{ if }\ a\ r\ b\ \text{ then } b\ s\ c\ \}$$

We denote this operator by a square bracket [, resembling the inclusion symbol $\subset$. for the similar reason as above. Some authors call this operator the "right residual", and instead of the square bracket they may denote it by the backslash $\backslash$.

5 Laws for operations on relations

Using clauses like 'and', 'or', 'if', 'then', 'for all' and 'exists', you can combine basic sentences into rather complex phrases. Just so, relation operators enable you to write complex formulas. But often, one meaning can be phrased in several equivalent ways, and a mathematical formula can be written in several ways. It can be difficult to decide whether different expressions have the exact same meaning, and if they will be true (or false) in exactly the same circumstances. For example:

– $for^{\smile}; sent \ \vdash\ deliveredTo$, meaning: 'An Invoice *for* a certain Order is *sent* to a particular Customer, only if that certain Order was *delivererdTo* that particular Customer.' In other words, only invoices for delivered orders should be sent to the customer.
– $\overline{deliveredTo}; sent^{\smile} \ \vdash\ \overline{for^{\smile}}$, meaning: 'If an Order was not *delivered to* some Customer and that Customer was *sent* an Invoice, then certainly that particular *Invoice* was not *for* that *Order*.'

Do these formulas express the same business meaning, or not? As a designer, you want to pick an easy way to express a certain text. To do that, you need the ability to rewrite one formula into another without loss of meaning.

This section introduces important laws from relation algebra that allows you to do exactly that. The laws are useful, because they allow you to manipulate with entire extensions at once, instead of having to consider all the tuples one by one. As a rule designer, you must learn to use these laws, and manipulate and reason with formulas and operators, just like you have once learned to manipulate with numbers.

5.1 LAWS FOR SET OPERATORS

Operators on sets obey laws that are well known in set theory. For instance, when determining the intersection of multiple sets, it makes no difference in which order the intersections are calculated. To put it more formally: intersection is

$$\cap \text{ is associative: } (A \cap B) \cap C = A \cap (B \cap C) = A \cap B \cap C \tag{3.1}$$
$$\cap \text{ is commutative: } A \cap B = B \cap A \tag{3.2}$$

Associative
Commutative

Union, like intersection, is also *associative* and *commutative*, i.e. $\cap$ may be replaced by $\cup$ in the two laws above.

$$\cup \text{ is associative: } (A \cup B) \cup C = A \cup (B \cup C) = A \cup B \cup C \tag{3.3}$$
$$\cup \text{ is commutative: } A \cup B = B \cup A \tag{3.4}$$

Distributivity

When a formula combines union and intersection, the laws of *distributivity* apply:

$$\begin{array}{lcl} A \cap (B \cup C) & = & (A \cap B) \cup (A \cap C) \\ A \cup (B \cap C) & = & (A \cup B) \cap (A \cup C) \end{array} \tag{3.5}$$

The first line reads: "intersection with a union equals the union of the intersections", and the second one can be pronounced as "the union with an intersection equals the intersection of the unions".

5.2 LAWS FOR COMPOSITION AND RELATIVE ADDITION

Composition and relative addition are associative operators. Just like in law 3.1, it does not matter how brackets are placed in an expression with two or more of the same operators. As a consequence, brackets may be omitted and the expression looks less cluttered.

$$(p;q);r = p;(q;r) = p;q;r \tag{3.6}$$
$$(p \dagger q) \dagger r = p \dagger (q \dagger r) = p \dagger q \dagger r \tag{3.7}$$

Neutral

The next law is special for composition. It states that the identity relation $\mathbb{I}$ may be removed if used in a composition: the identity relation is *neutral* with respect to composition and can be omitted.

$$r;\mathbb{I} = \mathbb{I};r = r \tag{3.8}$$

Diversity

Similarly, you may remove the complement of identity $\overline{\mathbb{I}}$ (sometimes referred to as *diversity*), if it appears in a relative addition.

$$r \dagger \overline{\mathbb{I}} = \overline{\mathbb{I}} \dagger r = r \tag{3.9}$$

5.3 LAWS FOR THE INVERSE OPERATOR

The following laws show how the conversion operator behaves.

$$\text{involutive: } r^{\smile\smile} = r \tag{3.10}$$
$$\text{distributive: } (r \cup q)^{\smile} = r^{\smile} \cup q^{\smile} \tag{3.11}$$
$$\text{and also: } (r \cap q)^{\smile} = r^{\smile} \cap q^{\smile} \tag{3.12}$$

In the next two laws, the order of the relations r and s is reversed:

$$(r;s)^{\smile} = s^{\smile};r^{\smile} \tag{3.13}$$
$$(r \dagger s)^{\smile} = s^{\smile} \dagger r^{\smile} \tag{3.14}$$

5.4 LAWS FOR DISTRIBUTION IN COMPOSITIONS

When working with compositions of relations, it often happens that a union or intersection appears somewhere in the formula. There is one distributive law that allows to remove the union operator from compositions of relations.

$$p;(q \cup r);s \quad = \quad (p;q;s) \cup (p;r;s) \tag{3.15}$$

As relations p and s are arbitrary, you may replace either one with the identity relation. It would be nice if the same kind of distribution would hold for intersection, $\cap$, but alas not. Distribution does not apply for intersections in general. Only if certain conditions are met, does distribution apply for intersections. This will be demonstrated later on.

5.5 LAWS FOR COMPLEMENT

The best known law concerning complement is that it is an involutive operator: apply it twice and the original relation is reproduced:

$$\text{involutive: } \overline{\overline{r}} = r \tag{3.16}$$

De Morgan

The mathematician *De Morgan* was first to formulate these laws:

$$\overline{r} \cup \overline{s} \quad = \quad \overline{r \cap s} \tag{3.17}$$
$$\overline{r} \cap \overline{s} \quad = \quad \overline{r \cup s} \tag{3.18}$$

The laws above are frequently used because they allow the complement operator to 'move around' in your formulas. There are similar laws involving ; and † operators, also named after De Morgan:

$$\overline{r};\overline{s} \quad = \quad \overline{r \dagger s} \tag{3.19}$$
$$\overline{r} \dagger \overline{s} \quad = \quad \overline{r;s} \tag{3.20}$$

Equations 3.18 and 3.20 are collectively known as De Morgan's laws. Lesser known, but almost as important are equivalences which De Morgan called "Theorem K". These will be discussed in the next chapter.

5.6 LAWS ABOUT INCLUSION

Laws about set inclusion are very important, because inclusion lies at the basis of rule assertions that the next chapter is all about. This section provides some laws about the inclusion operator $\vdash$ or $\subset$. The following assertion is obviously true for relations r and s sharing the same type:

$$(r \cap s) \;\vdash\; r \;\vdash\; (r \cup s) \tag{3.21}$$

Inclusion can be combined with the flip and complement operators, which produces the following equivalences. Beware though that the order of r and s is reversed in the second formula only:

$$r \vdash s \quad \Leftrightarrow \quad r^{\smile} \vdash s^{\smile} \tag{3.22}$$
$$r \vdash s \quad \Leftrightarrow \quad \overline{s} \vdash \overline{r} \tag{3.23}$$

Monotonicity

Inclusion also combines easily with operators other than flip and complement, sometimes referred to as the *monotonicity* of inclusion. But beware that the following laws are not equivalences but work in only one direction:

$$r \vdash s \quad \Rightarrow \quad r \cap t \vdash s \cap t \tag{3.24}$$
$$r \vdash s \quad \Rightarrow \quad r \cup t \vdash s \cup t \tag{3.25}$$
$$r \vdash s \quad \Rightarrow \quad r;t \vdash s;t \tag{3.26}$$
$$r \vdash s \quad \Rightarrow \quad t;r \vdash t;s$$
$$r \vdash s \quad \Rightarrow \quad r \dagger t \vdash s \dagger t \tag{3.27}$$
$$r \vdash s \quad \Rightarrow \quad t \dagger r \vdash t \dagger s$$

5.7 OPERATOR PRECEDENCE

To conclude this section, we give some conventions that govern precedence of operators. Just like in arithmatics, where for instance "take the square of" takes precedence over addition. These conventions save brackets and simplifies the writing of formulas with multiple operators. Table 3.6 contains the precedence rules.

expression	precedence rule	to be read as
unary operators $r^\smile$ and $\bar{r}$ have highest precedence		
$\bar{r};q$	flip and complement always take precedence	$(\bar{r});q$
$\bar{r} \dagger r$	(also if flip or complement appear	$(\bar{r}) \dagger q$
$r^\smile;q$	at the righthand side)	$(r^\smile);q$
$r^\smile \dagger q$		$(r^\smile) \dagger q$
; and †, having equal precedence, take precedence over ∩ and ∪, = and ⊢		
$p \cap q;r$	; and † bind stronger than ∩ and ∪, = and ⊢	$p \cap (q;r)$
$p \cap q \dagger r$	(also if ; or † appears at the lefthand side)	$p \cap (q \dagger r)$
$p \cup q;r$		$p \cup (q;r)$
$p \cup q \dagger r$		$p \cup (q \dagger r)$
∩ precedes over ∪		
$p \cup q \cap r$	∩ binds stronger than ∪	$p \cup (q \cap r)$
= and ⊢ have weakest precedence of all		
$p = q \cup r$	∪ and ∩ bind stronger than = or ⊢	$p = (q \cup r)$
$p = q \cap r$		$p = (q \cap r)$
$p \vdash q \cup r$		$p \vdash (q \cup r)$
$p \vdash q \cap r$		$p \vdash (q \cap r)$

TABLE 3.6 Precedence of operators

6 Homogeneous relations

So far, we discussed relations based on Cartesian products with sources and targets arbitrary. But the same concept may be used for both source and target. This section is devoted to exactly such relations, and the special features that they have.

Endorelation

A relation for which one concept serves both as source and as target is called an *endorelation*.

Heterogeneous relation

All other relations will be called *heterogeneous relations*: their source and target concepts are different.

We already encountered one example of a relation with identical source and target, namely the Identity relation, abbreviated $\mathbb{I}$. Examples of endorelations are easy to think of, once you realize that they correspond to basic sentences that express facts about similar terms.

Some examples are: Person *isRelatedTo* Person, in arithmetics: Number *isGreaterThan* Number, and in chemistry: Compound *mayDecomposeInto* Compound. Or in software maintenance: Software-change *interferesWith* Software-change. In business administration: Department *isSubordinateTo* Department. And in process design: Usecase *isSubvariantOf* Use-case.

In a conceptual diagram, the endorelations are easy to spot because the relation connects a concept with itself, and there will be an arc pointing back to its origin.

Let us consider a relation $r_{[A,A]}$. By our definition, relation r is homogeneous as its source and target are the same. We can point out several characteristics that the relation r may, or may not have.

6.1 REFLEXIVE

Reflexive

A relation $r_{[A,A]}$ is called *reflexive* if for all elements x in the set A, the tuple (x, x) is in r. The relation *isACloseFriendOf* is an example: everybody is a close friend of themselves. The condition can be stated as:

$$\mathbb{I} \vdash r$$

Irreflexive

The complete opposite is a relation with the property that identical pairs (x, x) are forbidden. Relations with this property are called *irreflexive*. Two irreflexive examples are *isSpectatorOfPerformanceByActor* or *isParentOf*.

In a matrix representation, a reflexive relation will show markings in all cells on the diagonal (and probably in other places as well, but that does not concern us). To contrast, an irreflexive relation may have markings anywhere, except on the diagonal.

An endorelation can, but need not be reflexive or irreflexive. In general, no specific conditions apply for tuples (x, x) to be, or not to be in the extension. For instance, when elections are held, then a relation Person *votesFor* Person may, or may not show that some people voted for themselves. Of course, the votes remain secret in general.

6.2 SYMMETRIC

Symmetric

Relation r is called *symmetric* if for any tuple $(x, y) \in r$, the inverse tuple (y, x) is also in r. This can also be written as:

$$r^{\smile} \vdash r$$

We leave it to the reader to verify that a relation is symmetric if and only if equality holds, i.e.

$$r^{\smile} = r$$

Examples of relations that are symmetric (or at least ought to be so) are *isMarriedTo*, *isInAMeetingWith*, and *isInTheSameClassAs*.

Asymmetric

A relation r is *asymmetric* if for any tuple (x, y) in r, the inverse tuple (y, x) is not in r, which of course can be written as:

$$r^{\smile} \cap r = \emptyset$$

An example of a relation that is asymmetric is *awardsBonusPaymentTo*. Of course, violations may occur: two managers that award bonuses to one another. Remark that an asymmetric relation is automatically irreflexive. Indeed, we do not want a manager to award a bonus to him- or herself.

Like with (ir)reflexivity, many endorelations are neither symmetric nor asymmetric. The relation Website *hasHyperlinkTo* Website is an example: some websites may link to one another, but there is no rule or obligation to do so.

Antisymmetric

An endorelation may be 'almost' asymmetric, meaning that it would be asymmetric were it not for some specific tuples (x, x). Such relations are called *antisymmetric*, and they are characterized as

$$r^{\smile} \cap r \subset \mathbb{I}$$

6.3 PROPERTY RELATION

In some situations, an endorelation p may be both symmetric and antisymmetric at the same time. Some careful reasoning shows that such a relation p must satisfy the condition: $p \vdash \mathbb{I}$. We leave it to the reader to verify that both the identity relation and the empty relation $\emptyset$ are symmetric and antisymmetric.

Binary property

However, there is more to it, if we consider the elements of the source (and target!) set A. We can divide A into two subsets: one subset with the atoms x that do satisfy $(x, x) \in p$, and the subset of all other elements in A that are not in $p : (y, y) \notin p$. The relation p divides the source set in two disjoint subsets. In other words, the relation p can be understood as a property of atoms of A. Yes, the atom x is in the subset for which (x, x) is in p. Or no, the tuple (y, y) is not in p. For this reason, an endorelation that is symmetric and antisymmetric is sometimes called a *binary property* for A.

By the way: there are other ways to specify properties for atoms of A, as will be shown in the chapter on design considerations.

6.4 TRANSITIVE AND INTRANSITIVE

Transitive

If a relation is homogeneous, then we may define the composition with itself. In fact, this can be done over and over again, and you can derive many new endorelations in this way. As an example, consider the relation *isCloseTo*. If Utrecht *isCloseTo* Hilversum, and Hilversum *isCloseTo* Almere, then we have Utrecht *isCloseTo* someplace that *isCloseTo* Almere. A relation r is called *transitive* if the composition with itself is contained in the relation itself:

$$r ; r \vdash r$$

Another example of transitivity is the 'subset' relation among sets: if $A \subset B$ and $B \subset C$ then $A \subset C$, or (excuse the complicated notation!)

$$\subset ; \subset \vdash \subset$$

Intransitive

The opposite of transitivity is shown in family-relationships as studied in genealogy. If we have Person *isParentOf* Person, then we can compose the *isParentOf* relation with itself. The composite is in fact the *isGrandparentOf* relation, and a person may not be both parent and grandparent of a child. Hence, *isParentOf* is an example of an *intransitive* relation, meaning:

$$r ; r \cap r = \emptyset$$

Repeat the composition and you arrive at Person *isGreatgrandparentOf* Person, etcetera. Genealogy now jumps to one generalized relation Person *isAncestorOf* Person, which is a transitive relation. The reader should verify that this particular relation does satisfy the inclusion $r ; r \vdash r$, but equality $r ; r = r$ does not hold. Again, like reflexivity and symmetry, many endorelations have neither the transitive nor the intransitive property.

6.5 SUMMARY OF ENDOPROPERTIES

The various properties that endorelations may have, can be written using mathematical symbols.

reflexive	$(\forall a)\ a\ r\ a$	(3.28)
irreflexive	$(\forall a)\ \neg a\ r\ a$. *Or equivalent* : $\neg(\exists a)\ a\ r\ a$	(3.29)
symmetric	$(\forall a,b)\ a\ r\ b\ \rightarrow\ b\ r\ a$	(3.30)
asymmetric	$(\forall a,b)\ a\ r\ b\ \rightarrow\ \neg(b\ r\ a)$	(3.31)
antisymmetric	$(\forall a,b)\ a\ r\ b\ \wedge\ b\ r\ a\ \rightarrow\ a = b$	(3.32)
transitive	$(\forall a,b)\ (\exists x)(a\ r\ x) \wedge (x\ r\ b)\ \rightarrow\ (a\ r\ b)$	(3.33)
intransitive	$(\forall a,b)\ (\exists x)(a\ r\ x) \wedge (x\ r\ b)\ \rightarrow\ \neg(a\ r\ b)$	(3.34)

6.6 STRUCTURE OF A SET

There is a close link between the structure of a set, and the properties of an endorelation. If for a set A an endorelation p exists that is reflexive, symmetric and transitive at the same time, then the set A can be partitioned. That is: we can point out a number of subsets (called partitions) A_1, A_2, A_3 ..., up to A_n, such that each element of A is contained in exactly one of the subsets. The intersection of any two subsets is empty, and the union of all subsets equals the original set A. Such a relation is called an *equivalence relation*.

Equivalence relation

Examples are easy to find: Employee *worksAtTheSameDepartmentAs* Employee, or Student *hasSameGradeAs* Student. An instance diagram of this kind of relation resembles an archipelago of islands: the entire set consists of islands, every element is in one island, and islands do not overlap. This is also called a *partitioning* of the set A.

Partitioning

It is well possible to have more than one equivalence relation (and matching partitioning) for a concept. For example, cars can be partitioned according to color, or age, or mileage, weight, value or any other property.

If for a set A we have an endorelation p that is reflexive, asymmetric and transitive at the same time, this means that the set A has some ordering or hierarchy. The relation is said to be an *ordering relation* or *order*. For example: Employee *isSubordinateTo* Employee, amounting to hierarchy among workers. Or Department *isPartOf* Department, which corresponds to organizational top-down structure. Other examples are set inclusion and ancestor relations.

Ordering relation

An instance diagram of this kind of set resembles a tree with branches, with the elements arranged along the separate branches. Or to be precise: one or more trees. Notice that in general, the ordering is incomplete, as not every possible combination of two employees will participate in the relation: neither is subordinate to the other. In an instance diagram, these employees will appear on separate branches. This is called a *partial order* because there exists tuples (x, y) such that neither $(x, y) \in p$ nor $(y, x) \in p$.

Partial order

It is called a *total order*, or linear order, if any two elements can be compared: either $(x, y) \in p$ or $(y, x) \in p$. In other words, $p \cup p^{\smile} = \mathbb{V}$. For a linear order, the instance diagram will resemble a single line, or a tree with just a single branch. All elements will be neatly arranged on that line. An example is the common *isSmallerThanOrEqualTo* relation on numbers.

Total order

6.7 THE *isA* RELATION

To conclude this section on endorelations, we finish with an ubiquitous relation that is *not* homogeneous. In large sets, one can point out all kinds of subsets. For example, in the set of all customers we can pick out all customers who joined last week, or who haven't paid the last invoice, or who live in New Amsterdam, or who have not ordered a Harry Potter book. The corresponding basic sentences are simple, like 'X, the customer who joined last week *is* customer X', or 'Y, the customer who lives in New York *is* customer Y'. The common template looks like '.... *isA* ....'. In all cases, we have a relation with the subset as source, and the enveloping set as target. An instance of the former *isA* instance of the latter, no exceptions.

The definition (intension) of the first concept, which is the subset, is more limited, more restrictive than the intension of the enveloping concept. And necessarily, the extension of the first concept is contained in the extension of the other concept. Whenever this is the case, we call the source the *specialisation*, the target being the *generalisation*.

Specialisation
Generalisation

Inclusion relation

An *inclusion relation* is a relation for which the source is a proper subset of the target.

This kind of relation is quite common in conceptual models, and they are easy to spot because they are usually named *isA*. Examples of this kind of relation are easy to think of: Student *isA* Person. Or in arithmetics: Prime-Number *isA* Number. Or chemistry: Pure-Substrate *isA* Compound. But please do not make the mistake to think that these are endorelations, as their sources and targets are really different!

As a closing remark: it is quite possible that the extension of one concept is a subset of the extension of another one. All customers in the shop happen to be male, all company cars run on diesel fuel. But this alone, is not enough for generalisation-specialisation. The customers need not be male by definition; company cars may run on any kind of fuel and still be a company car. Here, the subset property is just a coincidence, and the extensions of the concepts, without changing definitions, can be quite different at some other time.

7 Multiplicity constraints

Basic sentences express single facts. By studying the deep structure of sentences, we arrived at the notion of relation, called 'fact-type' by the Business Rules Manifesto. The Manifesto states that rules build on facts. Indeed, even a single relation can be subjected to control: the relation must satisfy some business rule. A business rule that governs a single relation is by its very nature rather simple and easy to understand. Such rules are frequently encountered, and they have their own name: *multiplicity constraints*. They express knowledge about how the tuples in a relation should be organised, and what behaviour is expected or prevented.

Multiplicity constraint

From mathematics we learn that multiplicity constraints come in exactly four flavours. Each one has been given a distinct name: univalent, total, injective and surjective. The rule analyst can establish for every relation which constraints apply. The multiplicity constraints can be applied in any combination, which results in a total of 16 possible combinations. Indeed, relations can be found in practice where no constraints apply and anything goes, up to relations that are under very restrictive multiplicity constraints.

7.1 UNIVALENT AND TOTAL

These two multiplicity constraints must be verified at the source concept. A relation r is said to be *univalent*, if every atom in the source occurs in at most one tuple of the

Univalent

relation. This means that every atom in the source is related to at most one atom in the target.

Total

A relation r is said to be *total*, if every atom in the source occurs in at least one tuple of the relation. This means that every atom in the source is related to at least one atom in the target.

These properties are easily verified in a matrix representation of the relation. If we write the relation with the source at the left, and the target across, then univalent means that there is at most one hit on every row. Total means that there is at least one hit on every row, and more than one hit is also fine.

In an instance diagram (figure 3.9), univalence means that at most one arc emanates from every source element. Total means that at least one outgoing arc is drawn for each element.

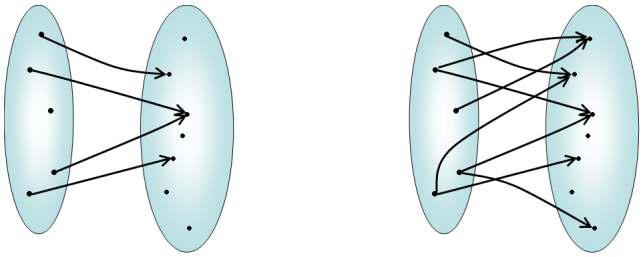


FIGURE 3.9 Left: univalent, not total; right: total, not univalent

7.2 INJECTIVE AND SURJECTIVE

These two multiplicity constraints are to be verified at the target concept.

Injective

A relation r is said to be *injective*, if every atom in the target occurs in at most one tuple of the relation. This means that every atom in the target is related to at most one atom in the source.

Surjective

A relation r is said to be *surjective*, if every atom in the source occurs in at least one tuple of the relation. This means that every atom in the source is related to at least one atom in the source.

Again, these properties are easy to verify in a matrix representation. Source at the left, target across, then an injective relation will show at most one hit in each column, whereas a surjective relation will show one or more hits in every column of the matrix.

In an instance diagram (figure 3.10), injective means that in each target element, at most one arc arrives. Surjective means that at least one incoming arc is drawn to each element.

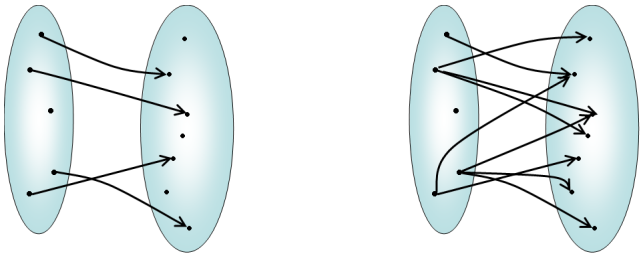


FIGURE 3.10 Left: injective, not surjective; right: surjective, not injective

7.3 FUNCTION

One combination of multiplicity constraints appears frequently in practical applications, and they deserve their own name: function.

Function

A relation r is a *function* if it is both *univalent* and *total*. So every atom in the source is related to exactly one atom in the target concept.

To emphasize the property of being a function, we often use a shorthand notation. We simply write

$r : A \rightarrow B$

the arrow here means that relation r has signature $r_{[A,B]}$ and it is both univalent and total. Alas, the meaning of this arrow in the formula, differs from the meaning of arrows used in conceptual models such as figure 3.4 or instance diagrams such as figure 3.11.

The word 'function' is also used in mathematics, with notation $f(x) = y$. For instance the function 'square': $f(x) = x^2$. It is no coincidence that the same word is used: in a mathematical function, each and every number x is related to exactly one other number y. Thus, the mathematical function 'square' is both univalent and total. This becomes clear if we write (x, x^2) instead of $f(x) = x^2$. This relation contains tuples such as $(1,1)$, $(2,4)$, $(3,9)$ but also $(0,0)$, $(-1,1)$, $(-2,4)$. Indeed, the 'square' function produces correct tuples in this way, exactly one tuple for each number x.

7.4 INJECTION, SURJECTION, BIJECTION

Functions are frequently encountered, and they often even have additional multiplicity constraints, either injectivity or surjectivity. A function r (a relation that is both univalent and total) is called:

Injection
Surjection
Bijection

Injection, if the function is injective
Surjection, if the function is surjective
Bijection, if it is both injective and surjective.

Figure 3.11 depicts these properties. The reader is invited to verify that every *isA* relation is always an injection. And also to think of counterexamples: a relation may well be an injection without being an *isA* relation!

Notice in the rightmost example that the inverse relation is also a function. A closer inspection reveals that a bijection requires that the source and target datasets must have exactly the same number of atoms, for each atom in the source is related to one target element, and reversely.

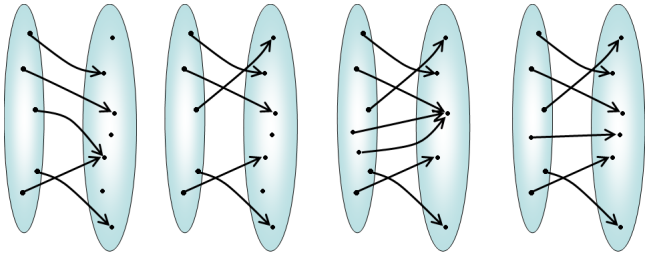


FIGURE 3.11 Common combinations of multiplicities. Left to right: function, injection, surjection, and bijection.

Although most relations are subject to some multiplicity constraints, this does not mean that such rules apply for every concept in every relation. For example, a business may dictate that each invoice is sent to one customer. Or, for every invoice in

the source concept, there is exactly one tuple in the relation *isSentTo* in which that invoice appears. But not the other way around: one customer may be sent no invoice at all, or she may receive hunderds.

Multiplicity constraints are very important in conceptual models, and we will discuss some more features of multiplicities in the next chapter that is all about rules.

Rules

Chapter 4

Rules

1 Introduction

The skill to write rules precisely is a most desirable asset. Whenever you use rules to represent agreements that business stakeholders agree to comply with, accuracy in language is required. Ampersand provides an accuracy that is sufficient to guarantee buildable specifications. The skill to do that will make you special, as opposed to those analysts who specify 'roughly' what the business needs. You will receive your greatest compliment, however. This skill does three things for you. It allows you to think and work precisely on your own. It lets you share requirements with 'systems people' with mathematical precision. And it lets you share business requirements in the (natural) language of the business. The moment you receive compliments for genuinely understanding the situation, that is when you can feel the thrill of grasping the requirements right. Those are the things you can achieve by practicing the techniques in this chapter.

This chapter defines the notion of rules, discusses their properties within relation algebra, and helps you to learn reading and writing rules fluently.

First, we discuss rules in general, and we outline how rules can be formulated in relation algebra. We provide a number of laws that you must learn in order to write the same rule in different ways. Next, we discuss rule violations: what are they, what needs to be done to detect them, and what kinds of business rules cannot be violated at all. The section that follows outlines a procedure to translate a rule assertion to natural language. That will help you to understand rules for yourself, and also to explain them to others. A section is included with examples showing how to use laws and how to manipulate with rules and relations. This illustrates how to transform one rule assertion into another, without a change of intent or meaning. The goal is to find a best way to formulate and explain the rules to business stakeholders.

2 Rule definition

2.1 BUSINESS RULE

A business rule is a prescribed guide for conduct and/or action, and it always removes some degree of freedom in the everyday work practice. In chapter 2 (page 21) we gave our definition of *business rule* as:

a verifiable statement that some stakeholders intend to obey within a given context.

A business rule is some regulation or principle that governs the conduct within a particular area (or "context") of the business. The rule provides guidance, knowledge, descriptions or prescriptions regarding potential, allowed, or prohibited actions, business processes and/or human activities. Keywords are: governance and guidance.

The essence of a business rule is in the guidance it provides for doing business. If we have a rule, and write it down in different ways but always keeping the same semantics and guidance, then we still have the same rule. We can rewrite the same rule in one natural language or another (English, Dutch, Spanish, ...), or write it in a controlled version of natural language (such as RuleSpeak), or in a formal language, such as relation algebra. Nor does it matter if the rule is implemented in an information system, in workflow procedures, or if it remains a spoken instruction for

workers to follow. No matter how or where the rule is implemented, the rule is there and the business should abide by it.

The business, and not the IT support department, is responsible for the business rules. To formulate them, to have them implemented, to enforce them and take appropriate action if violated, to revise or even delete them as the business sees fit.

If a rule cannot be managed in this way by the business, then it should not be considered a business rule. It can still be a rule of course, for instance 1+1=2, or $\overline{p} \cup \overline{q} = \overline{p \cap q}$, or the law of gravity. The point is that these are not *business* rules: nobody in the business is interested in maintaining them. Such rules do not provide any intelligent guidance for the business.

Business jurisdiction

To be a business rule, there must be *business jurisdiction* in formulating and maintaining that particular rule. And at least one stakeholder in the business must have the intent to have the rule obeyed, at all times.

2.2 CATEGORIES OF RULES

Business rules come in a great variety. To list but a few categories described in the literature:

- Abstract guidance: our company respects customer privacy.
- Statistical rules: at least 80% of all flights must leave on time.
- Rules of thumb, based on past experience: our employees are always between the age of 15 and 70.
- Arithmetical rules and calculations: three strikes and you're out, or: delivery will cost 15% of the net value for postage and package with a maximum of $ 20.
- Comparisons of physical values: blood acidity should remain under pH 7, or: date of delivery is between 7 and 15 days after date of order acceptance.

We do not claim that this list is correct and exhaustive. For example, you might say that some of them are not rules, because they do not express obligations or necessities, words like 'must' or 'cannot' are lacking to restrict freedom of actions. And others would extend the list to include 'advice'. An advice confirms or reminds that some degree of freedom does exist or is allowed, and therefore is just the opposite of a rule that removes some degree of freedom.

It may be disappointing for you to learn that in fact, many categories cannot easily be described in relation algebra. Luckily however, many rules that guide everyday business conduct can be well captured in expressions and assertions of relation algebra, although some ingenuity is sometimes called for.

2.3 DEFINITIONS ARE RULES, TOO

Concepts and relations may be referred to as *structural rules*. Intuitively, concepts and relations provide structure, but how can they be perceived as rules?

Each time a relation or concept is introduced, you can interpret that as a rule dictating its existence. The declaration of a new relation, e.g. Student *takes* Exam, can be interpreted as a rule, which says: "In our context, there must be a relation between students and exams, to be referred to by the name *takes*". It also says that, in this context, if anyone at all *takes* an exam, it must be a student. And if a student is involved in this relation *takes*, then it is an exam that is taken, and not another kind of thing. Similarly, the mere introduction of a concept, e.g. *Customer*, means that the stakeholders agree that: "In our context, there exists a concept *Customer*". By implication, they also agree that there can be atoms, such as 'Kim', 'Paul', and 'Marek', that are instances of *Customer*. So in a formal sense, there is nothing wrong in perceiving concepts and relations as 'rules'.

Structure

Nevertheless, business stakeholders might not always recognise them as valuable business rules. They might find it so self evident! So why call anything so utterly obvious a rule? To spare business stakeholders discussions about the obvious, it is useful to distinguish *structure* from *constraints*. Concepts and relations belong to the structure, rules belong to the *constraints*. Structure (i.e. concepts and relations) allows us to distinguish basic sentences (such as "In Caroline's house, there are 3 rooms.") from non-sentences (such as "In 3's house, there are Caroline rooms."). The structure formalizes language. It defines which types of sentences make sense in the business context. Constraints tell us which of those sentences are true. They allow us to distinguish facts (i.e. true sentences) from non-facts.

A final word about true facts, false facts, and non-facts. We are concerned with actual facts of the business, and not with hypothetical ones. The latter kind causes all kinds of philosophical problems, as the example conceived by Russell may illustrate: "the king of France is bald". Clearly, this fact is false. But the opposite sentence, "the king of France is not bald", is equally false. What is the problem here? If we would draw up a list of all bald persons, and another list of people known to be not bald, then the king of France would not turn up in either list. In other words, an atom "the king of France" does not refer to any real person, it is not within our context. So "the king of France" is not really an atom, and sentences about it cannot be dealt with.

2.4 UNCONSTRAINED CONCEPTUAL MODEL

Unconstrained conceptual model

Business vocabulary

Structural business rule

Operational business rule

In theory, we could envision a conceptual model with definitions of concepts and relations only, without any rules or multiplicity requirements. This is sometimes referred to as an *unconstrained conceptual model*. It can be populated with any and all kinds of instances and, provided that entity integrity and referential integrity are complied with, no violations would ever occur. In terms of the SBVR, the unconstrained model constitutes a *business vocabulary*, and it captures the *structural business rules*, but no more.

The idea behind the unconstrained conceptual model is that you can now impose the *operational business rules* one by one. Each time, you must resolve the violations that emerge as the rule is being added. After a number of steps, the model would have all its rules in place with no remaining violations. This approach would provide the designer with an insight of the true impact of each individual rule.

2.5 A RULE AND ITS ENFORCEMENT ARE SEPARATE CONCERNS

Does rule management mean that all rules are enforced by a computer?

The answer to that question is a definite No! There are infinitely many ways how a business may allow its workers to deal with violations, such as:

- Guideline: advocate the rule to workers and teach it in training courses, but do not enforce.
- Comply or explain: always allow rule override, but require that an explanation is provided.
- Post-authorize: if a rule is violated, it may be approved after the fact, but you may be subject to sanctions or other consequences if you break the rules beyond your authorization.
- Pre-authorize: only allow exceptions for workers with prior approval.
- Sanction: if you violate the rule, you will always incur a penalty.
- Deferred enforcement: allow violations only temporarily, in order to wait for workers with the required knowledge and skills to fix the violations.
- Enforce immediately: never allow a violation, and systematically prevent any attempt to break the rule.

The above levels of enforcement apply to the business workers: they must know how to deal with possible violations of the rule, and know the consequences. The level may be made to vary over time (start with mild tutelage but be increasingly severe), among departments (the front office may use deferred-enforcement but immediate enforcement is used at the back office), and among employees (no penalties for novices).

How information systems enforce rules is an entirely different matter. In the Ampersand philosophy, a computer supports workers, but should never patronize them. All rules that are enforced by the business are off limits for the computer. Only if the business deliberately decides to have a rule maintained fully automatic, may a computer do so. This happens for example when the business perceives a rule as almost a “law of nature”. In those cases the computer may bluntly enforce the rule. For example, the rule that a financial transaction should never lose money on the way, can be regarded as a law of nature from a business perspective. Naturally, computers must maintain such rules under all conceivable circumstances at all times.

For rules that are maintained (enforced) by the business, a computer may signal violations, but go no further. So after detecting a violation, a computer may react in one of two fundamentally different ways:

Immediate
- *immediate enforcement*: if a transaction attempts to add, change or delete data in such a way that it would cause a rule to be violated, then the entire transaction will be rejected. The fact to be recorded violates the rule, so it is presumably false. If a user asks why this transaction is rejected, the computer can refer to the rule that was violated as the reason for rejecting the transaction.

Deferred
- *deferred enforcement*: if a transaction attempts to add, change or delete data in such a way that it would cause a rule to be violated, then this rule may permit the transaction, but every violation is immediately signalled to some stakeholder. Since users are involved in the enforcement, the computer must allow the rule to be violated as long as it takes to restore compliance.

2.6 STRUCTURAL RULES ARE RULES TOO

Deontic rule

In practice, many rules are maintained by people, with computers signalling violations and suggesting courses of action. Such rules are called *deontic rules*, and you can generally express them with the phrase "it ought to be the case that". These rules should be complied with eventually, but can be violated temporarily. An example of a deontic rule is: ”Once a rental reservation is confirmed, a car of the requested model should be assigned for the requested period”.

Alethic rule

There is another type of constraint called *alethic rule*, and they can be expressed by phrases such as "it is necessarily always the case that". In theory, such a rule is structural: a violation will never occur in the business environment. An example of an alethic rule is: ‘Every car has a unique licence plate number’. Notice that the concepts ‘car’ and ‘licence plate number’, as well as the relation ‘has’ are assumed to be well-defined: definitions are rules, too. The alethic rule dictates that it is necessarily always the case that a car has exactly one licence plate number (the relation is in fact, a function).

Alethic and deontic are called two ‘logic modalities’ of rules. However, the two modalities are not absolutely rigid. For instance, the rule about unique licence plates is alethic for most organizations, but for the Department of Motor Vehicles it is deontic.

2.7 STATIC VERSUS DYNAMIC RULES

Another classification is concerned with static versus dynamic rules. A familiar example of static rule is that a person must be classified as 'married' if (s)he has a spouse. Next, a dynamic rule says that a classification 'married' may never change to 'unmarried'. Nor may an 'unmarried' person have her status changed directly into 'divorced'.

To enforce such dynamic rules, one must be able to compare things before and after a change. Thus, the conceptual model has to carry some notion of time, or a sequence of statuses. This is very well possible, and in our opinion, the distinction between static and dynamic features is a gradual one, not absolute. Although both static and dynamic rules can be captured in one conceptual model, we do not presume that it is easily done. A lot of ingenuity may be called for to come up with a design that is consistent as well as understandable.

3 Expressions and assertions

3.1 BUSINESS RULES AND RULE ASSERTIONS

Business people often know their rules and talk about them in rather offhand ways. The co-workers understand each other, even if they use ambivalent expressions for the rules. But for rule engineers, analysts and developers, such liberty is unacceptable. Precision in rule formulation is a necessity, and a strict and formal language is called for. Whereas business rules are communicated in natural language, we resort to relation algebra in order to achieve unambiguity in asserting the rules.

But first, we must make a clear distinction between expressions and assertions.

Expression

An *expression* in relation algebra produces a new relation from existing ones. It constitutes a formal definition (description) of the new relation. The previous chapter provided various operators for this: set operators such as union $\cup$, complement $\overline{r}$, and difference $\backslash$. And relational operators like composition, relative addition, and inverse (flip). The good news is that these operations produce exact and unambiguous definitions of the new relation. The bad news is that it is often hard to explain the definition and meaning of the new relation in natural language (we will come to that later).

Assertion

An *assertion* is a formula that compares two sets, or more in particular: two relations. The comparison will produce either a 'true' or 'false' answer. The two common forms of assertion are the inclusion, $r \vdash s$, and the equality $r = s$.

We only need to consider these kinds of assertion because the theory of Proposition Logic tells us that any compound statement can be written in the Horn clause format. That is, every statement can be rewritten as implication, or more generally, as an inclusion. Also, the equality assertion $r = s$, is just a combination of two inclusions, $r \vdash s$ and $s \vdash r$.

The assertions above look simple, but in practice, both r and s may be complicated expressions, involving any number of relations and operators so much so that the assertion becomes hard to explain to the business stakeholders.

An assertion may evaluate to a 'true' at some times, and to 'false' at other times. Which, depends on the current extensions of the relations at the time of the comparison. It has to be determined by inspecting the recorded instances for the relations involved in both sides of the assertion.

Some assertions will always turn out to be true, regardless of the information stored in the relation extensions. For instance, we know that $\overline{r} \cup \overline{s} = \overline{r \cap s}$, regardless of the

extensions of r and s. This assertion is a law of relation algebra, it is not a rule under business jurisdiction.

Rule assertion

A *rule assertion* is an assertion, a formula in relation algebra, that, according to some stakeholder in the business, ought to evaluate to true, always and for any and all content of the relations involved in the assertion. If it turns out that the assertion at some point in time is violated, then the stakeholder has work to do in order to fix the problem. But violations of the rule do not signify that the rule itself is invalid and useless.

3.2 MATCHING AN ASSERTION WITH AN EXPRESSION

Assertions and expressions are not the same. But the two are closely linked. In fact, any assertion can be matched to an expression. The match is easy to explain: we just need to consider violations of the assertion.

An assertion such as $r \vdash s$ states that every tuple in r must belong to s also. No tuple should be present in r that is absent from s. That is to say: the assertion comes down to $r \backslash s = \emptyset$, or $r \cap \overline{s} = \emptyset$, both formulas capturing exactly the same meaning, the same business rule.

Now, if one (or more) tuples exist in $r \backslash s$, then the business rule is violated, and the assertions above are not true. Therefore, we can match the assertion $r \vdash s$ with the expression $r \backslash s$ (which can also be written as: $r \cap \overline{s}$). Important to realize: the expression is a relation, but the assertion is a logical 'true' or 'false'.

The implication of the match is that the latter expressions ought to be empty, always. If any tuple is present in the set $r \backslash s$, then the business rule is violated.

In an instance diagram for these relations, the lefthand expression r, should always end up as a subset of s, the righthand expression. And when we interpret this in controlled natural language, we will have a rule that says: 'if' a tuple is contained in the relation r, 'then' that tuple must be contained in relation s.

Likewise, the assertion $r = s$ can be matched to the union $(r \backslash s) \cup (s \backslash r)$ of set differences, which, by the way, can be rewritten in several ways: as $(r \cap \overline{s}) \cup (s \cap \overline{r})$, as $(r \cup s) \cap (\overline{r} \cup \overline{s})$, as $(r \cup s) \cap \overline{(r \cap s)}$, or as $(r \cup s) \setminus (r \cap s)$.

4 Laws about rule expressions

Relation algebra comes with many laws: rules about expressions that are always true, regardless of the current extensions of the expressions. Such laws let us reason about expressions, they enable us to rewrite expressions in different ways without loss of meaning. The previous chapter already introduced some of those laws of relation algebra. This section lists some more laws for you to know and work with. We cannot be exhaustive though. In practice, if you are faced with a particular rule expression, there may always be some special law that lets you rewrite and simplify it.

4.1 RULE EXPRESSIONS FOR MULTIPLICITY CONSTRAINTS

The multiplicity constraints were introduced in the previous chapter by making statements about individual elements and tuples in the relation, for instance:

– Relation $r : A \times B$ is *univalent* if every element in the source occurs in at most one tuple of the relation r, or: every element a in the source A is related to at most one element b in the target B.

In fact, multiplicity properties are expressable as rule assertions. For this, we look at various compositions of the relation r with its own flip. We claim that:

– $r^\smile; r \vdash \mathbb{I}_B \;\Leftrightarrow\; r$ is univalent,
– $\mathbb{I}_B \vdash r^\smile; r \;\Leftrightarrow\; r$ is surjective,

and

– $\mathbb{I}_A \vdash r; r^\smile \;\Leftrightarrow\; r$ is total,
– $r; r^\smile \vdash \mathbb{I}_A \;\Leftrightarrow\; r$ is injective.

We leave it to the reader to prove these four equivalences. It may help to draw instance diagrams in order to get a good understanding of the equivalences. For clarity, we indicated the source and target of the identity relations on A and B.

For the sake of completeness, we also stipulate:

– $\mathbb{I}_A \vdash r; r^\smile \;\wedge\; r^\smile; r \vdash \mathbb{I}_B \;\Leftrightarrow\; r$ is a function,
– $\mathbb{I}_A = r; r^\smile \;\wedge\; r^\smile; r = \mathbb{I}_B \;\Leftrightarrow\; r$ is a bijection.

Notice how the expressions $r; r^\smile$ and $r^\smile; r$ appear repeatedly in these formulas. In fact, these two compositions constitute endorelations on the source and target of r, respectively. So the relation r provides us with nice partitionings on these two concepts (see the section on structure of a set in the previous chapter). For example, a relation Employee *worksAt* Department can be composed with its inverse *worksAt*$^\smile$ to produce a relation Employee *worksAtTheSameDepartmentAs* Employee. In a similar fashion, a relation Student *has* Grade will give rise to an equivalence relation Student *hasSameGradeAs* Student, and a partitioning of the set of students according to their grades.

4.2 LAWS INVOLVING MULTIPLICITIES

The above equivalences come in handy on many occasions. For instance, multiplicities of the flip of a relation will be immediately obvious, just by inspecting the assertions above:

– r is injective $\;\Leftrightarrow\;$ $r^\smile$ is univalent, and
– r is surjective $\;\Leftrightarrow\;$ $r^\smile$ is total.

Proving these equivalences is not hard. For instance, r is injective is equivalent to $r; r^\smile \vdash \mathbb{I}_A$. Now flip is an involutive operator, therefore $r = r^{\smile\smile}$. Thus we may rewrite the expression as $r^{\smile\smile}; r^\smile \vdash \mathbb{I}_A$. And this formula tells us that $r^\smile$ is univalent. We leave it to the reader to check that the reverse is also valid, i.e. to prove that r is univalent implies that $r^\smile$ is injective. And to prove the above equivalence of surjective and total for r and $r^\smile$.

It is fairly easy to check that if two relations have the same multiplicities, then the composition also has that multiplicity. If r and s are univalent (or total, or ...), then $r; s$ is univalent (or total, or ...) as well.

If two relations r and s are defined on the same Cartesian Product, then we can inspect the multiplicities of their intersection $r \cap s$ or union $r \cup s$ of two relations. For instance, if r is univalent, then $r \cap s$ will also be univalent. The following line of reasoning proves this:

a We know $(r \cap s) \vdash r$ and obviously, $(r \cap s)^\smile \vdash r^\smile$ as well.
b It follows that $(r \cap s)^\smile; (r \cap s) \vdash r^\smile; r$.
c We also know r is univalent, thus $r^\smile; r \vdash \mathbb{I}$.
d Therefore $(r \cap s)^\smile; (r \cap s) \vdash \mathbb{I}$, or in other words: $r \cap s$ is univalent.

As the intersection operator is commutative (you may interchange the order of the two relations), it is clear that univalence of either r or s is sufficient for $r \cap s$ to be univalent. Regrettably, this does not hold the other way around: $r \cap s$ may be univalent without either r or s being univalent.

Similar issues arise for the union of two relations, $r \cup s$. The above line of reasoning shows that if the union is univalent, then r is univalent, as $r = r \cap (r \cup s)$ and the latter relation is univalent. But not the other way around: both r and s may be univalent without $r \cup s$ being so. The laws for multiplicity constraints, and equivalences more in general, are not trivial, and a good rule designer should always check her rule rewritings to avoid mistakes.

4.3 LAWS FOR REWRITING COMPOSITIONS

When working with compositions of relations, it often happens that a set operator such as union, intersection or implication appears somewhere in the expression. The following distribution law shows how the union operator can be moved out of a composition:

$$p;(q \cup r);s \quad = \quad (p;q;s) \cup (p;r;s) \tag{4.1}$$

It would have been nice if distribution would also hold for the intersection operator, $\cap$. Alas, distribution does not apply for intersections in general, it can only be proven that:

$$p;(q \cap r);s \quad \vdash \quad (p;q;s) \cap (p;r;s) \tag{4.2}$$

But equality does hold under special circumstances:

$$\text{if } p \text{ is univalent then} \qquad p;(q \cap r) \;=\; (p;q) \cap (p;r) \tag{4.3}$$

$$\text{if } s \text{ is injective then} \qquad (q \cap r);s \;=\; (q;s) \cap (r;s) \tag{4.4}$$

For functions (i.e. univalent and total relations), the following laws may come in handy, for instance to move a relation across an inclusion $\vdash$. If f is a function, then we have:

$$r \vdash s;f^{\smile} \quad \Leftrightarrow \quad r;f \vdash s \tag{4.5}$$

$$r \vdash f;s \quad \Leftrightarrow \quad f^{\smile};r \vdash s \tag{4.6}$$

Notice the subtle difference in the assertions as to where the function f and its inverse appear.

An example to illustrate the usefulness of these formulas is as follows. Image a shop where salespeople are authorized to sell items of specific types only, such as sportswear, mens wear, childrens clothes, ladies apparel etc. Suppose we have three relations:

- Employee *sells* Item,
- Employee *is_authorized_for* Type,
- Item *belongs_to* Type, and important: this relation is a function.

You may state the rule that an employee is authorized to sell only the items of specific types as: "If employee A sells a certain item X, then employee A must be authorized for the type of clothes that the item X belongs to". The formula for this assertion is:
$sells \vdash is\_authorized\_for \,;\, belongs\_to^{\smile}$

But a collegue of yours may propose a different rule: ”If employee K sells an item belonging to a certain type Z, then the employee K must be authorized for type Z”. And she proposes the assertion:
$sells\ ;\ belongs\_to \vdash is\_authorized\_for$

So, does your collegue disagree with you? No! By virtue of the rewriting laws above, you know that the two assertions express the same rule.

Another useful law for functions f, not hard to prove by yourself, is:

$$f;\overline{r} \quad = \quad \overline{f;r} \tag{4.7}$$

which is to say that you can move the complement across the composition operator. This gives us a handle to come up with laws to replace the relative addition operator † by ordinary composition. Still, beware that the next laws hold for functions f only, not for relations f in general:

$$\overline{f} \dagger r \quad = \quad f;r \tag{4.8}$$
$$r \dagger \overline{f^{\smile}} \quad = \quad r;f^{\smile} \tag{4.9}$$

4.4 THEOREM K

The previous chapter announces a law by De Morgan that was named ”Theorem K”. It is also known as "Schröder Rule" or Modular Law. This theorem concerns an inclusion rule for relations involved in a composition. The assertion may be written in different ways.

$$p;q \vdash \overline{r} \ \Leftrightarrow \ p^{\smile};r \vdash \overline{q} \ \Leftrightarrow \ r;q^{\smile} \vdash \overline{p} \tag{4.10}$$

The three assertions are not identical: you can check this by inspecting the types of the relations involved. We use the left-and-right arrows to indicate that the three assertions are equivalent. De Morgan proved that if one of them is true (or false), then the other ones are true (or false) as well.

The interpretation of this theorem is important. Imagine a closed chain of three atoms x, y and z such that (x, y) is in p, and (y, z) is in q, and (x, z) is in r. Theorem K says that if you look in relation p and then cannot find some x, y and z to make up a closed chain with relations p, q and r, then you will never find closed chains in the Instance Diagram, no matter in which relation (or inverse) you start to look.

Theorem K is very convenient for ”moving around” the complement operator in formulas. Like other laws, theorem K is handy if you want to rewrite an expression, for instance when you need to replace a complement operator in one of your formulas. You should become familiar with theorem K, De Morgan’s laws and others, and we strongly suggest that you go through a number of exercises. Only by doing exercises and understanding corrections and elaborations, will you get the hang of it and become proficient in using the laws governing relations.

4.5 SOUND RULE

Of course, you should try to formulate good rule assertions. But what makes a rule ‘good’? A main advantage of stating rules in relation algebra is that the assertions are precise: they can only mean one thing, in the conceptual model. The rule assertion must be (re)phrased using the words, terms and examples that are meaningful within the business context. If that explanation can be understood by some

stakeholder to mean something else than intended, you should remedy either the explanation, or improve the rule.

But there are other considerations for quality, and here are a few guidelines that you should adhere to when you write down your rule assertions.

Declarative
– *Declarative*: a rule assertion declares what should be kept true. Not, how this should be enforced, when, or by whom.

Atomic
– *Atomic*: a business rule catches one aspect only, not more. The rule assertion ought to be indivisible; if you can break it up by rewriting it as several assertions without loosing information, then do so. The separate rules can be validated and managed (changed) independently.

Business oriented
– *Business oriented*: the rule explanation must be in a language that the business stakeholders can understand and accept.

The last item in this list is particularly important. It says that in the end, it is not up to you to decide whether a rule is good enough. It is the business stakeholders who are responsible for their own rules. You are merely the expert helping them to catch the rules and write them down. The guidelines above are concerned with only one rule at a time. In the next chapter, we will discuss guidelines to assess the quality of entire sets of rules.

5 Violation of a rule

Rules are assertions of the form $r \vdash s$ that ought to evaluate to 'true', always. If you want to use business rules to guide your way of doing business, you must be very precise not only about your rules, but also about how to handle violations. Business rules can and should be well-defined, so that they can be checked for compliance with your business requirements. We claim that the use of relation algebra in designing for business rules will deliver high-quality rule-based designs.

Because we specify an exact formula, the computer can determine whether the rule is violated. This is done by inspecting the expression that we matched with the assertion, i.e. difference $r \backslash s$, and determine its extension. The contents of this difference ought to be the empty set, always.

Violation
A *violation* of a rule is a single tuple in the relation $r \backslash s$.

Beware that one violation of the rule assertion need not automatically be one infraction of the business rule in the real world. You may not make the assumption that a business requirement or business rule is always captured in a rule assertion in a perfect one-on-one correspondence. For instance, a rule "a bridge players' hand is 13 cards" will be violated twice if a fourteenth card is dealt to one player, as another player has got only 12 cards.

Also, there may be no infraction in the real world but an error in the current recording of data, or the violation may even be a problem of the design. It is the stakeholders responsibility to remedy the violation, but in some cases, it is the rule assertion that must be repaired to prevent false violations.

To clearly understand a rule, you must understand its violations: what does each single violation mean in the business environment, how did it come about, what must be done to repair the violation and make the rule 'true' again, in the data store and in the real world. If you do not understand the violations, then you do not truly understand your rule.

5.1 ENFORCEMENT STRATEGIES

The "immediate enforcement" strategy dictates that any transaction that would create a violation, is prohibited. This is similar in appearance to a definitional rule: violation is prevented at all times. But it works quite differently. Violating a structural rule is impossible because you cannot record a fact that is not compliant with the structure of the conceptual model. Violation of a behavioural rule that by the designers' choice has immediate enforcement is made impossible only because there is active checking for violations, presumably fully automatic. And preventive action is taken before the violation materializes, presumably fully automatic as well. In database management systems, this mechanism is known as a transaction-rollback.

A business rule with the "deferred enforcement" strategy is associated with a list of all the tuples that are in violation of the rule. This list constitutes a "to-do" worklist for the stakeholders engaged in keeping this rule true. However, it does not say what must be done: a violation may be remedied in many ways. For instance, the violation may be authorized as an exception by a supervisor. Or some corrective action may be taken by an employee. Or, the information system may wait three days and, if the violation still exists, undo the original transaction that caused it.

6 Rules in natural language

In order to achieve agreement with stakeholders, rule engineers shouls always revert to natural language. For the purpose of validating his rules with these stakeholders, he must be sure that his natural language is a correct reflection of his rules. The skill to express a formally defined rule in natural language must therefore be mastered by every rule engineer. Fortunately, we can outline a procedure to do just that, and it can even be executed by computers.

This section provides an introduction on how to translate a rule into natural language.

6.1 EXAMPLE TRANSLATION TO NATURAL LANGUAGE

Let us start by discussing an example: an insurance company that distributes work on insurance policies among employees in the form of work packages. At this point, you will be familiar with the idea that relations can serve as templates for basic sentences in natural language. The following three relations (in fact, functions) are illustrated with a number of basic sentences:

concerns:*Workpackage*→*Policy*
sentences: WP538 concerns the insurance policy 7683992/Johnson
WP09 concerns the insurance policy 8229001/Brown
WP3042 concerns the insurance policy 0029931/von Humboldt

FollowsProcedureFor:*Workpackage*→*ProductType*
sentences: WP538 follows the procedure for the type fire insurance policy.
WP09 follows the procedure for the type life insurance policy.
WP3042 follows the procedure for the type life insurance policy.

belongsTo:*Policy*→*ProductType*
sentences: Policy 7683992/Johnson belongs to the type fire insurance policy.
Policy 8229001/Brown belongs to the type life insurance policy.
Policy 0029931/von Humboldt belongs to the type life insurance policy.

Suppose you have expressed (as a rule) that there must be a product type for every work package that concerns a policy, and that each work package must follow the procedure that corresponds to the correct product type. Let us assume you came up with the following rule:

$$concerns \vdash FollowsProcedureFor; belongsTo^{\smile}$$

In order to be sure that this rule represents the correct requirement, it must be translated to natural language and validated with stakeholders. This translation starts with the structure of the basic sentences, which serve as templates for each relation:

- The (formal) expression *w concerns p* means that workpackage *w* concerns insurance policy *p*.
- The expression *w FollowsProcedureFor t* means that workpackage *w* follows the procedure for productType *t*.
- The expression *p belongsTo t* means that the policy numbered *p* belongs to the productType *t*.

If we figure out what we have written down, we obtain the following interpretation by using these basic sentence templates.

- For every workpackage that concerns a particular policy, the work package follows the procedure for the productType to which the policy belongs.

This is phrased much more precisely than the original phrase you started with. There is however a fundamental objection to this way of working. Suppose the modeler made a mistake when formulating the rule assertion, and she repeated the same mistake while translating back into natural language. Then it would still be in doubt whether the formula is a correct representation of what is needed. Surely it is better to rely on a standardized procedure.

6.2 A PROCEDURE FOR TRANSLATING TO NATURAL LANGUAGE

The following procedure helps to translate an arbitrary rule *r* to natural language systematically:

- Express the rule as a relation algebra expression, as explained in the section on expressions and assertions. In general, that expression can be rather complex.
- State that the *a expression b* must be true for every *a* and *b*.
- Translate each operator in *a expression b* by using the translation table (table 4.1), work outward-in, and mind the precedences of operators.
- Repeat this until no operators or composite relations remain. In general, you now have a very long text that involves a lot of base relations and atoms of multiple concepts.
- For each base relation, check its multiplicity constraints to see if you can use it to simplify this text.
- Replace each relation by controlled-language, using the template for basic sentences.
- Simplify the controlled-language text if possible, but be careful to keep the meaning correct and unambiguous.
- Rephrase into understandable business language.

Let us redo the example of section 6.1 using this procedure carefully. The first step tells us to use the rule as a relation. That will be a relation that relates work packages to product types. So we begin by stating that the rule must be true for every work package *w* and policy *p*

w $(concerns \vdash FollowsProcedureFor; belongsTo^{\smile})$ p
(apply the translation for implication in table 4.1)
If w *concerns* p is true then w $(FollowsProcedureFor; belongsTo^{\smile})$ p must be true as well.
(apply the translation for composition in table 4.1)
If w *concerns* p is true then (there exists at least one product type t such that w *FollowsProcedureFor* t and t *belongsTo*$^{\smile}$ p) must be true as well.
(we can simplify the language somewhat)
If w *concerns* p then there exists at least one product type t such that w *FollowsProcedureFor* t and t *belongsTo*$^{\smile}$ p.
(apply the translation for inverse in table 4.1)
If w *concerns* p then there exists at least one product type t such that w *FollowsProcedureFor* t and p *belongsTo* t.
(replace each relation by natural language)
If workpackage w concerns insurance policy p then there exists at least one product type t such that workpackage w follows the procedure for productType t and policy p belongs to the productType t.
(we can simplify the language based on the fact that 'FollowsProcedureFor' and 'belongsTo' both are functions. This means: there is precisely one product type, for which a work package must follow the procedure and there is precisely one product type to which each policy belongs.)
If workpackage w concerns insurance policy p then the product type t of which workpackage w follows the procedure, is the productType to which policy p belongs.
(we can simplify the language somewhat more.)
Every workpackage that concerns an insurance policy follows the procedure for the productType to which that policy belongs.

Controlled natural language sentence

This procedure gives more certainty that the natural language corresponds to the rule. The result is called a *controlled natural language sentence* (abbrev: CNL-sentence), because it is made in a controlled way. Even though it sounds like it has been made by a computer, a CNL-sentence is a meaningful and correct sentence in the natural language. There is another reason why this procedure is attractive, because it can partly be executed by a computer. Only in the last steps, you are simplifying language "as humans would". That simplification is necessary to make proper language from your statements, to be scrutinized by business stakeholders.

Table 4.1 contains the necessary translation phrases for the operators on relations introduced in the previous chapter. Also remember that $a \in A$ means that the term 'a' is an atom of concept A, and $a\ r\ b$ means that the tuple (a, b) is in relation $r_{[A,B]}$, that is: it is true that atom 'a' from A is related by relation r to the atom 'b' of B. It is also good practice to avoid using abstract letters, a, b, r, s and to employ the actual names of your concepts and relations.

Exercising through a fair number of translations carefully is the best way to gain experience and become proficient at reading formulas. You will find that it will help you to find and correct errors in formulas. The errors made by others, or even those made by yourself. At first, you will often refer back to the translation table 4.1 but soon, you will get the hang of it and can do without the translation table. And you will learn to translate intuitively, without explicitly taking all the steps of this procedure.

6.3 EXAMPLE

Consider a relation r: $A \times B$ that is univalent. In the section about rule expressions for multiplicity constraints, the relational assertion for univalence was formulated. Let us translate that formula into natural language, quite similar to the translation

		expression	*to natural language*
implication	$\vdash$	$x\ (r \vdash s)\ y$	if $x\ r\ y$ is true then $x\ s\ y$ must be true as well.
equivalence	$=$	$x\ (r = s)\ y$	$x\ r\ y$ is true in precisely the same cases as $x\ s\ y$.
complement	$\overline{\ }$	$x\ \overline{r}\ y$	not $x\ r\ y$.
inverse	$\breve{\ }$	$x\ r\breve{\ }\ y$	$y\ r\ x$
identity	$\mathbb{I}$	$x\ \mathbb{I}\ y$	$x = y$.
union	$\cup$	$x\ (r \cup s)\ y$	either $x\ r\ y$ or $x\ s\ y$ (or both).
intersection	$\cap$	$x\ (r \cap s)\ y$	$x\ r\ y$ as well as $x\ s\ y$.
composition	;	$x\ (r;s)\ z$	there exists at least one atom y such that $x\ r\ y$ as well as $y\ s\ z$. Or: some atom y exists that is both related to x (by r) and z (by relation s).
relative addition	†	$x\ (r \dagger s)\ z$	for all possible atoms y, either $x\ r\ y$ or $y\ s\ z$ (or both). Or: no atom y exists that is unrelated to x as well as z.
relative implication	[	$x\ (r[s)\ z$	for all y, $x\ r\ y$ implies $y\ s\ z$. Or: no atom y exists such that $x\ r\ y$ and not $y\ s\ z$.
relative subsumption	]	$x\ (r]s)\ z$	for all y, $y\ s\ z$ implies $x\ r\ y$.

TABLE 4.1 Translations of operators to controlled_language

in the previous paragraph. The first part is a rather mechanical "fill in the dots" exercise. Because both the source and target of $\mathbb{I}_B$ are B, we begin with stating that for any two atoms of B, b and b':

$b\ (r\breve{\ };r\ \vdash\ \mathbb{I}_B)\ b'$
means *(translate the implication cf. table 4.1)*
If $b\ (r\breve{\ };r)\ b'$ is true then $b\ \mathbb{I}_B\ b'$ must be true as well.
means *(translate the identity relation $\mathbb{I}$)*
If $b\ (r\breve{\ };r)\ b'$ is true then b equals b'.
means *(translate the composition $r\breve{\ };r$)*
If there exists some $a \in A$ such that $b\ r\breve{\ }\ a$ and $a\ r\ b'$, then b equals b'.
means *(translate $r\breve{\ }$)*
If there is $a \in A$ such that $a\ r\ b$ and $a\ r\ b'$, then b equals b'.
means *(simplify)*
If $a\ r\ b$ and $a\ r\ b'$, then b equals b'.
means *(rephrase more simple)*
For every a, there is at most one b such that $a\ r\ b$.

The derivation above is rather a mechanical, a 'fill in the dots' exercise. To understand its business significance, our univalent but rather abstract relation r should be replaced by a concrete one. Suppose that relation r means that persons (instances of set A) can be reached at telephone numbers (instances of the set B).
We know that 'for every a, there is at most one b such that $a\ r\ b'$. Replacing the abstract symbols a, r and b by their business meaning, it reads: "for every person, there is at most one telephone number such that the person *can_be_reached_at* telephone number". That is: every person can be reached at one telephone number at the most.

6.4 EXERCISES

EXERCISE 4.1

sells : *Vendor* × *ProductType*
hasName : *ProductType* → *Name*
issuedTo : *Order* → *Vendor*
contains : *Order* × *ProductType*
orderAccepted : *Order* × *Vendor*

Provide two or three basic sentences to populate each relation.

ANSWER

sells : *Vendor*×*ProductType*
Vendor ⟨*v*1⟩ *sells* ProductType ⟨*p*3⟩.
Vendor ⟨*v*2⟩ *sells* ProductType ⟨*p*5⟩.
Vendor ⟨*v*1⟩ *sells* ProductType ⟨*p*5⟩.
hasName : *ProductType*→*Name*
ProductType ⟨*p*3⟩ *hasName* ⟨*Rubberduck*⟩.
ProductType ⟨*p*5⟩ *hasName* ⟨*PizzaMargharita*(*large*)⟩.
issuedTo : *Order*→*Vendor*
Order ⟨*o*14⟩ has been *issued to* Vendor ⟨*v*1⟩.
Order ⟨*o*2⟩ has been *issued to* Vendor ⟨*v*1⟩.
Order ⟨*o*6⟩ has been *issued to* Vendor ⟨*v*2⟩.
contains : *Order*×*ProductType*
Order ⟨*o*14⟩ *contains* (at least one order line for) ProductType ⟨*p*3⟩.
Order ⟨*o*14⟩ *contains* (at least one order line for) ProductType ⟨*p*8⟩.
acceptedBy : *Order*×*Vendor*
Order ⟨*o*14⟩ has been *accepted by* Vendor ⟨*v*2⟩.
Order ⟨*o*6⟩ has been *accepted by* Vendor ⟨*v*2⟩.

Use your answers to this exercise in exercise 2 through 4.

EXERCISE 4.2

Use the procedure of section 6.2, including table 4.1, to make a controlled_language sentence for the expression

contains;*hasName*

What use does this expression have?

ANSWER

o (*contains* ; *hasName*) *n*
means *(translate the composition)*
There exists $p \in ProductType$ such that *o contains p* and *p hasName n*.
means *(transform to controlled language using the templates of the relations)*
There exists a productType *p* such that order *o* contains an order line for productType *p* and *p* has name *n*.

The expression "*contains* ; *hasName*" links the order to (the names of) all types of product on that order.

EXERCISE 4.3

Use the procedure of section 6.2 to make a controlled_language sentence for the rule

contains ⊢ *issuedTo* ; *sells*

What purpose does this rule serve?

ANSWER

The derivation starts by stating that the rule holds for every order o and productType p:

$o\ (contains \vdash issuedTo;sells)\ p$
means *(translate the implication cf. table 4.1)*
If $o\ (contains)\ p$ is true then $o\ (issuedTo;sells)\ p$ must be true as well.
means *(translate the composition (*issuedTo;sells*))*
If $o\ (contains)\ p$ then there exists $v \in Vendor$ such that o *issuedTo* v and v sells p.
means *(transform to controlled language using the relation templates)*
If order o contains an order line for productType p then there exists a vendor v such that order o has been issued to vendor v and v sells p.

The expression $contains \vdash issuedTo;sells$ means that if the order includes a certain productType, then the order must be issued to some vendor who actually sells that productType.

EXERCISE 4.4

Use the procedure of section 6.2 to make a controlled_language sentence for the rule

$acceptedBy \vdash issuedTo$

What purpose does this rule serve?

ANSWER

The derivation starts by stating that the rule holds for every order o and vendor v:

$o\ (acceptedBy \vdash issuedTo)\ v$
means *(translate the implication cf. table 4.1)*
If $o\ (acceptedBy)\ v$ is true then o *issuedTo* v must be true as well.
means *(turn relations into basic sentences using their templates)*
If the order o has been accepted by the vendor v, then that order o has been issued to that vendor v.

This rule means that a vendor should accept only the orders issued to himself, and not any others.

EXERCISE 4.5

This, and the following exercises are given without answers. Given the following relations:
$product$:$ProductType \rightarrow Price$
$orderedBy$:$Order \rightarrow Client$
$isReceivedBy$:$Order \times Client$

a Provide for each relation an appropriate template for the corresponding basic sentence.
b Provide for each relation two or three examples of basic sentences.

Use your answer to this exercise, together with the answer to exercise 1, to do exercises 6 through 7.

EXERCISE 4.6

Given the following rules:

Rule: $isReceivedBy \vdash orderedBy$
Rule: $\mathbb{I} \vdash acceptedBy\ ;\ acceptedBy^{\smile}$
Rule: $acceptedBy \vdash isReceivedBy\ ;\ \mathbb{V}$

a Use the procedure from section 6.2 to construct a controlled_language sentence for each rule.
b State the meaning of each rule in proper natural language.

EXERCISE 4.7

Given the following expressions:

$$issuedTo \cap \overline{acceptedBy}$$
$$issuedTo^{\smile} \cap \overline{acceptedBy^{\smile}}$$
$$acceptedBy^{\smile} \cap \overline{acceptedBy^{\smile} \,;\, isReceivedBy \,;\, \mathbb{V}}$$

For each expression, provide its meaning in natural language. Then, add some examples to make your answer more concrete.

7 Other approaches

Relation algebra is a powerful tool to use with business rules. It helps you to deliver designs that correspond to stakeholder responsibilities: rules must be kept true at all times.

7.1 LIMITATIONS IN RELATION ALGEBRA

Relation algebra focuses on the existence of things, on concepts and relations having correct extensions. The rule assertions then specify how to combine (extensions of) relations to detect any violations.

However, relation algebra has its drawbacks. For one: you cannot do arithmetics in relation algebra. It does not provide a formalism to add up the cost for various items and calculate the bill total. Nor can we make comparisons: one car is more expensive than another, the number of students in a class must always be between 4 and 140. Similar problems arise when a business requires that a password always contains at least 8 tokens, including at least 1 uppercase letter and 2 non-alphabetic symbols.

Spatial or temporal knowledge is also not part of relation algebra. Although not impossible, it is hard to achieve good reasoning with adjacent geographical areas, distances, or time frames.

These drawbacks are inherent to the theory of relation algebra as it lacks arithmetical, spatial and temporal features. But there is also the problem that many business rules are not exact to the last decimal. And rules are often a bit vague on their consequences for the business. For instance, consider a statistical rule that says “at least 85% of all trains should leave on time”. It leaves open what a ‘train’ (departure) is, it is unclear which departure will be the first to violate the rule, and finally: what to do if the rule is violated?

7.2 CONCEPTUAL MODELLING

As we define it, a conceptual model captures all relevant features within (a part of) an organisation by means of concepts and relations. In many organisations, similar but slightly different models and theories are used to capture and model the relevant data of the corporate enterprise. Depending on the underlying modeling theory, such models go by names like Relational Models, UML-models, ORM-models etc.

Relational model

There are subtle differences however. For one, the *relational model* employs entities

with attributes, our theory only uses concepts. And the Relational Model does include something called relation, but it is markedly different from our notion of relation: relations in Relation Models are based on *foreign keys* composed from attributes of an entity.

Foreign key

7.3 PROPOSITION AND PREDICATE LOGIC

Proposition Logic and Predicate Logic, jointly called First-Order Logic, is particularly suited to learn about correct reasoning with facts. It relies heavily on "if/then" *conditional reasoning*: *if* the lefthand side of a sentence ("hypothesis" or "premisse") is true, *then* the righthand side ("conclusion") is true also. If the lefthand side is false, then you know nothing about the righthand side: it may either be true or false. But if you know that the righthand side is false, then of course the lefthand side must be false too. (Notice how the previous sentence is itself an example of conditional reasoning!)

Conditional reasoning

Predicate logic adds the use of predicates and quantifiers to propositional logic, which allows to reason about combinations of facts. We introduced operators such as composition and relative addition for the purpose, which enables us to reason not only with individual facts, but with the entire contents of relations, i.e. abstractions of facts.

Relations and operations on relations can always be rewritten as expressions in predicate logic. In fact, you do this when you translate a rule assertion or expression into controlled natural language.

7.4 OTHER TYPES OF RULES

Business rules can and will apply to people, processes, and overall corparate behaviour. Restricting to the *practicable business rules*, i.e. to the rules that we want to capture in some information system, then we are concerned only with invariant rules, also known as integrity rules or constraints. These rules assert that certain facts must hold at all times, in all evolving states and state transition histories in the contexts in which the rules apply, and any rule violations should be signalled and remedied.

Practicable business rules

Apart from invariant rules, various other categories of practicable business rules can be pointed out.

- State rules and transition rules
  These rules describe the states that instances of a concept or entire set of concepts may be in, and the transitions to other states (lifetime evolution) that may occur as a result of events in the business environment.
- Derivation or deduction rules
  These consist of one (or more) IF-conditions and one (or more) THEN-conclusions. The conclusions may be characterized as static implication, they are necessarily true (*alethic*). For instance, the total amount on a bill is derived by a rule of calculation. The derivation rule is not violated, even if the customer does not pay the amount on the bill.
- Reaction rules
  These are more commonly known as event-condition-action (ECA) rules. They consist of a mandatory triggering event, an IF-condition, and a triggered action. A precise formula specifies in a declarative way which user action or system-derived operation (a data update) should take place whenever the event occurs and the IF-condition applies. In these rules, the conclusions may be characterized as dynamic implication, they ought to be true at some point in time (deontic). An example is the Microsoft Outlook rule wizard that allows you to specify how incoming (or outgoing) messages should be reacted to.

– Production rules
  Production rules may be written as: *if* condition *produce* conclusion. A production rule system holds a store of available facts, and new facts are constantly being added to the set. The system inspects the internal state of affairs and draws conclusions, and there is no longer a need to refer to external events. This approach was popular to implement so-called expert-systems, but it ran into fundamental problems because the semantic categories of events and conditions in the left-hand-side, and actions and conclusions in the right-hand-side, are all mixed up.

We do not examine these type of rules in this book, not because they are uninteresting, but mainly because they cannot be easily captured by way of relation algebra.

The categories above are not necessarily exhaustive: other kinds of rules may be conceived. Nor do we claim that the categories are mutually exclusive. One business rule statement may be categorized as a transformation rule, another statement as integrity rule, while closer inspection may reveal that the two statements capture the same underlying business rule and they merely are different rephrasing of the same rule.

7.5 SBVR AND RULESPEAK

SBVR

The abbreviation *SBVR* stands for Semantics for Business Vocabulary and Rules. SBVR is a standard accepted by the Object Management Group, and it is available at `http://www.omg.org/spec/SBVR/`.

It comes with its own variant of controlled natural language to capture business rules, called RuleSpeak (see http://www.rulespeak.com). This is also an accepted standard to formulate terms and facts, plus the rules about them. The basic idea of RuleSpeak is to use natural language, but to put in certain restrictions so that only clear, unambiguous statements can be formulated, and no vague, uncertain, or undecideable sentences are allowed. RuleSpeak can be classified as a well-structured, controlled natural language: it does not allow arbitrary utterances, but only sentences that follow strict formatting rules. Ideally, the business user can describe her entire business context and way of working using RuleSpeak sentences, which would provide rule designers with a rich resource to base their designs on.

7.6 AND MORE

The above list of approaches is far from exhaustive. However, this book is not the proper place to go into details of the similarities and differences between relation algebra, set theory, variants of description logic, relational modelling, SQL constraints and embedded database procedures, RuleSpeak, or any other theory or de-facto standards.

In the Ampersand approach, our emphasis is on business rules and their formalization. We employ relation algebra as the theory of choice to focus on the existence of things, on concepts and relations having correct extensions. The rule assertions then specify how to combine (extensions of) relations to detect any violations. Relation algebra is a powerful tool to use with business rules, helping you to deliver designs that correspond to stakeholder responsibilities: Yet it is not a simple tool, nor can it take away the real complexity of the business. You need to learn how to use it to achieve the best results. The next chapter will provide useful insights how to use the theory in order to create expressive model for business rules.

Design Considerations

Chapter 5

Design Considerations

The previous chapter outlined how to specify a single business rule. But that is just the beginning. As a designer, you are expected to specify business processes by means of rules. So what must you pay attention to? How do you create a high-quality design? There are many design considerations, principles and rules of thumb that will help you to achieve useful results. This chapter outlines some of them. Their merits have been established in practice, so you may rest assured that they work.

A cookbook-recipe for good design does not exist. Neither does a standard way of working. Nevertheless, there are many principles, are many ideas that will guide and support your work. A good way to learn designing business processes is by doing: Practice makes perfect. The core idea of Ampersand is that a designer:

a A designer first defines a context with:
  – a purpose (why does this context exist?)
  – named stakeholders (who participates and why?)
  – scope (which topics are relevant and which are not?)
b A designer creates agreement among the stakeholders about language, as little as possible and as much as required to formulate requirements in that context.
c Together with stakeholders, the designer elicits concrete rules that define the process(es) of this particular context.
d Stakeholders "from the business" are addressed by the designer in natural language and their own jargon only.

The designer will formalize the "agreed language" by means of relation declarations, so (s)he will know which statements of stakeholders make sense (in the agreed context) and which do not. Rules are formalized too, so the designer will know that all rules are consistent, concrete and complete. By doing so, (s)he will be able to tell apart the statements that are true (in the agreed context) and those that are not. With this knowledge, a designer can coach the stakeholders through the requirements elicitation process in their own language. That is: without bothering other stakeholders with formulas, design models, or "design speak" of any kind. Thus, Ampersand can be used in a conventional requirements engineering practice.

The remainder of this chapter focusses on the skill to create rules. In Ampersand, the natural language representation of a rule and the formal representation go hand in hand. It is the responsibility of a designer to make sure these match. To do so, designers get help from the notation and from tools.

1 Design example

To get a feel how to go about rule design, let us look at an example. Article 14 sub 2 of the Dutch immigration law (Vreemdelingenwet) states:

– A residence permit for limited duration is issued under conditions that are related to the purpose of stay.

This is a business rule in the context of an Immigration Service. Employees of that service are stakeholders. It is their job to keep this rule satisfied, so this rule is obiously one of the building blocks of the primary process of the Immigration Service. But the rule is formulated as a legal text in natural language. We want to express it in relation algebra, to be sure that it is formulated concretely enough. This necessary

to decide whether this rule is satisfied or not in every conceivable situation. It also makes it possible for computers to work with. For every rule expressed correctly in relation algebra, the designer can decide whether concrete sentences uttered by stakeholders are true or false.

So we want to go about carefully: does our formalization represent the text correctly? We proceed as follows.

1.1 LOOK FOR CONCEPTS AND RELATIONS

We start by looking for concepts. It is easy to spot three concepts in the text, namely:

– Residence permit for limited duration (abbreviated to RPLD)
– Condition
– Purpose-Of-Stay

Concepts are typically used in the singular form, rather than in plural. For example, Condition is used in singular, and not in plural as in the original text. This is because we need to capture and identify each condition separately. Also notice that within this context, Stay is not considered to be a concept. This is because the text of the law does not mention anything about the actual stay.

So which relations can we define among these three concepts? The text of the article states that residence permits are issued under certain conditions. Apparently, this type of sentence in natural language is meaningful to the stakeholders, which justifies a relation declaration. So we conceive a relation *issuedUnder* with source RPLD and target Condition. If, for example, residence permit *nl45* was issued because the requestor of that permit has a contract to work for some employer, then the relation *issuedUnder* contains a tuple such as $\langle$`'nl45','hasLabourContract'`$\rangle$.

The law says that there may be conditions related to the purpose of stay. This too is natural language over which stakeholders will agree. So we conceive a relation *relatedTo* from *Condition* to *PurposeOfStay*. A pair in this relation might be a tuple such as $\langle$`'hasLabourContract','employment'`$\rangle$, or $\langle$`'isOver21','hasLabourContract'`$\rangle$. And finally, residence permits and purposes of stay are related, a relation *with* exists between RPLD and Purpose-Of-Stay.

So apparently we have three relations:

– $issuedUnder : RPLD \times Condition$
– $relatedTo : Condition \times PurposeOfStay$
– $with : RPLD \times PurposeOfStay$

By writing down these three concepts and three relations, we have defined a conceptual model shown in figure 5.1. This model represents a small piece of the common language of the stakeholders in the context of immigration. Agreement among these stakeholders is likely, because this is the language that comes straight from the law.

The following section discusses how business rules are conceived.

1.2 ELICIT BUSINESS RULES

The text of the law shows two interesting business rules. First, we understand that each residence permit is related to exactly one purpose of stay. There is at least one (total) and at most one (univalent) purpose of stay for each residence permit. So the relation *with* must be univalent and total. This is a multiplicity constraint that we can insert into the model.

The wording of the law is not completely clear what is meant by “is issued under conditions that are related”. What does it mean exactly? This is an issue to be clar-

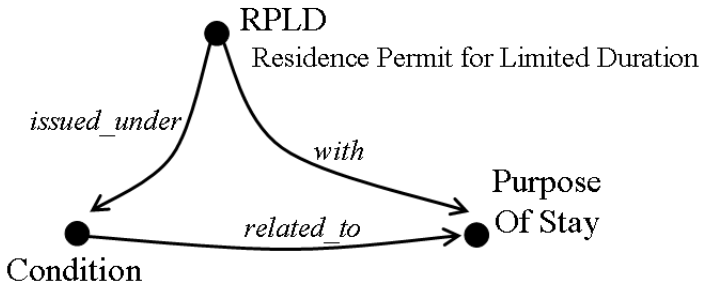


FIGURE 5.1 Conceptual model for the design example

ified in conversation with relevant stakeholders. In the actual case, they came forward with other regulations, saying that each single residence permit must mention all the applicable conditions related to the purpose of stay. This can be rephrased as: if a purpose of stay p is recorded for a permit, and one or more conditions, say $\{cond-1, cond-2, cond-3\}$ are related to that purpose of stay, then the residence permit is issued under all those related conditions.

So if we consider one permit *nl45*, we know that whenever the permit *nl45* came with purpose p, and that purpose p is related to some condition *condN*, then the permit is issued under that condition. Restating this as an assertion in relation algebra:

$$with; relatedTo^{\smile} \vdash issuedUnder$$

which is now the second rule in our model for the Article 14 sub 2.

1.3 VALIDATE THE RESULTS

Having elicited a conceptual model and rules from the text, the question is: did we do it right? Have we captured all the relevant rules? We spotted two rules in the text, but have we captured them correctly? For this, we need to check whether the rules, written in relation algebra, match with what the people at the Immigration Service are trying to do.

Validation

Checking whether our formulas represent the original text, and detecting any possible mistakes in the line of reasoning, is called *validation*. Not the IT designers, but business stakeholders have to certify that all the business rules are captured correctly.

There are several methods for validation, to be discussed later in this chapter. For now, we claim that our small model with its two rules is adequate.

1.4 PRACTICAL IMPLICATIONS

If stakeholders must keep rules satisfied, you must (as a requirements engineer) be aware of the implications your rules have in practice. Not only must a rule be described accurately, but we must establish which events may happen that violate a rule and which reactions restore that rule to satisfaction. It also involves making choices, because some reactions can be performed by a computer and others must be done by a person of flesh an blood. To put your model to work, we can either incorporate the rules in information systems, or we can instruct business workers how to enforce the rules. In most cases however, we will do both: some of the rules can be enforced by automated systems, while other rules need to be maintained by people who can apply discretion and make intelligent decisions about rule violations.

Even though the example described just one or two rules, the stakeholders want to keep them satisfied under various events, e.g.

– when a new residence permit for limited duration is issued, or an existing one prolongued,
– when one particular purpose of stay is altered to become two different purposes, and residence permits for limited duration must refer either to one or the other, but not to both purposes,
– when a new condition is introduced that is related to a purposes of stay, so that some residence permits for limited duration may have been issued that do not yet mention the new condition,
– when an existing condition is dropped from the list of applicable conditions.

1.5 DESIGN STEPS

Now let us revisit what we have done so far. Given the business rule as a natural language text, we have performed three steps in sequence:

a Model design: which concepts and relations are involved?
b Rule design: how to capture the rules from the business, as formal assertions in the model?
c Validation: do people in the business confirm that the model and assertions do capture their requirements correctly?

If done correctly, you have established an implementable model. You will often find that these steps need to be iterated several times before the stakeholders are satisfied with your design. This does not signify that you are a bad designer. Rather, it is a token that the stakeholders come to a better understanding of the actual business requirements. It is their responsibility to formulate requirements.

The essential art of the designer is in understanding the requirements and formalizing the rules. That is: turn business language into exact formulas. You will need to learn how to figure out which concepts and relations are relevant, and how to incorporate them into your conceptual model. Also, you need to determine the right way to connect relations by operators, obtaining the assertions that represent the rules stakeholders care about.

2 Considering the Conceptual Model

First you determine which concepts and relations you need to include in the conceptual model. Remember that concepts and relations represent the kind of things (terms) encountered in the real world and the facts that you want to convey about them. For each concept, its instances must correspond to actual, individual things that exist in the business environment, that can be added, altered, or removed from the context that we consider. For each relation, its tuples must correspond to the facts that are known about the concepts.

2.1 WHAT ARE THE CONCEPTS

In the example, we can visualize a ‘Residence permit for limited duration’ as a real piece of paper. This is clearly a concept. Also, ‘Purpose of stay’ is a concept. This concept however is not something physical or tangible. Luckily, there is an annex to the immigration law ("Vreemdelingenbesluit 2000") which provides an exhaustive list of all purposes of stay. At present, over a hundred different purposes are formally recognized, and you can easily imagine new ones being added to the list, or obsolete ones being removed. Likewise, the concept ‘Condition’ is also intangible, abstract. Again, you can imagine how legislators may introduce new conditions or discard obsolete ones.

These concepts share the property that individual instances can be pointed out, and they can be created, altered, or deleted. Indeed, the core question about a possible concept that a designer needs to answer is: what is the single instance?

This question actually has two parts. The first part is: how to recognize an instance of the concept "in the wild". Here we may see a residence permit, but there, that other thing, that is not a residence permit, but a building permit, or a parking permit, or an application for a residence permit. Try this for more abstract concepts like 'discussion', 'disagreement', 'idea', or even 'joy'. These are concepts, clearly, but without a proper definition, unambiguous and verifiable, you had better not include them in a Conception Model.

The second part is: how to identify and discriminate one individual instance from among its peers. For instance, one condition may be '*hasLabourContract*', and another is '*isUnder21*'. But how about a condition '*is under 14 with labour contract*' , for a child movie star? Is this a separate condition, or is it partially covered by other ones? Where does one condition end, where does the next one start? Again, try this identify-and-discriminate process for more abstract concepts. And if you wonder whether you would introduce 'joy' as a concept in your design, try to answer the question if you want to create new joys or discard obsolete ones.

2.2 SOUND DEFINITION

The definition of a concept is used by the business stakeholders to decide when to insert a new instance or when to delete it if it no longer meets the definition. A sound definition of a concept must clearly address both aspects:

Classification
Discrimination

- *Classification*: how to know that some real world thing is an instance of the concept.
- *Discrimination*: how to distinguish and identify one instance from the other, not only today but also tomorrow.

Look back at the example in chapter 3, where we defined the concept *Customer* as:

- A person who or organisation that, in the past three years, has placed at least one order and has paid for it.

This definition meets the requirements of classification and discrimination. Still, it is not very sound. This is because the definition is not focused on the essence only, but adds extra demands. Those demands specify some business rules about customers, instead of helping us to understand and define the notion of customer! It is often a good idea to look for definitions in a dictionary, for example a Customer is:

- one who uses or buys any of our products or services, or
- any person or organization who views, experiences, or uses the services of another person or organization.

Essential meaning

This is better: a sound definition aims to capture the core meaning of the concept. A definition can mention some further quantification or qualification, but this is rare in practice. The basic, *essential meaning* of a concept (or relation!) often works best. Complicated additions are often a sign that something is not clear yet.

So as a rule of thumb: capture the essence in your definitions, and capture the criteria into rules.

The provisional definition of Customer could well be replaced by either of the dictionary definitions. Plus, we can add a new rule such as 'each customer must place and pay at least one order in the span of three years'. Perhaps you should consult with the stakeholders to ask if they want this new rule, and how they are going to maintain it.

2.3 CONCEPT GRANULARITY

A further design consideration concerns the level of detail, also referred to as granularity, specificity, or (level of) generalisation.

You might argue that 'residence permit for limited duration' is a concept. Yet someone else might argue that 'residence permit' is the real concept, and you are only looking at one special kind of residence permits.

For instance, there may be residence permits for unlimited duration. Others might argue that there are permits of different kinds, and residence permits are just one form of permit. Still others might say: "No, these things are all documents".

For another example: birds and monkeys are both animals, but they are certainly distinct: no bird will ever become a monkey, no monkey will ever be a bird. So apparently, two different concepts may be used, 'bird' and 'monkey'. However, from the point of view of the zoo keeper, both are merely a kind of animal that require feeding, caretaking, veterinary care etc. So in the context of zoo keeping, birds and monkeys have similar relations with other concepts, and it is probably better to employ the general concept of 'animal' and add details later.

All of these arguments are correct, and the rule of thumb is: choose your concepts as detailed, as specific and fine-grained as possible, while keeping the business context in mind.

Frequently you have to deal with both levels, coarse-grained and fine-grained. Animals, and birds and monkeys as well. Documents, but also permits for limited and for unlimited duration. Sometimes you can ignore the general concept altogether, and only model the distinct subconcepts. This solution is probably best if, within your business context, the concepts are essentially different, and any similarities are irrelevant. But more often you will find that you do need the general concept, but how may you include the detailed ones in your model?

There are several ways to do this:

– use a binary-property relation to identify special instances, or
– use a Type concept to hold classifying information for the instances of the general concept, or
– distinguish between the more detailed concepts by means of an *isA* subtype relation.

To discuss these options, consider figure 5.2 showing requests, with only numbers 3, 4 and 5 being accepted:

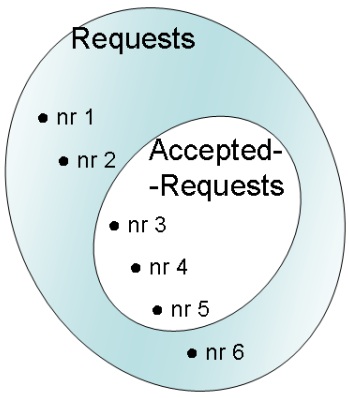


FIGURE 5.2 Instance diagram showing a concept with special instances

2.4 BINARY-PROPERTY RELATION OR TYPE CONCEPT

In chapter 3, we outlined how a binary property of instances may be captured by way of an endorelation that is both symmetric and antisymmetric:

– *isAccepted* : Request × Request

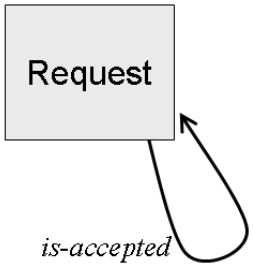


FIGURE 5.3 Binary property captured as endorelation

This way of modelling is perfectly acceptable. And it is easy to understand, as the 'accepted' property is explicitly shown in the conceptual diagram.

Another way to capture the property in the conceptual model is by way of a type concept. For this, we introduce a new concept State with just two instances: State = { 'accepted' , 'rejected' }. And we define a new relation *hasState* : Request × State as follows:

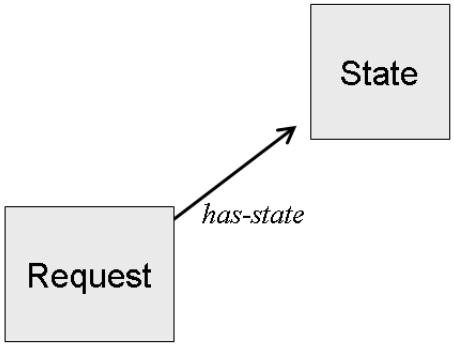


FIGURE 5.4 Binary property captured by a type concept

– for each request q, if $(q, q) \in$ *isAccepted*, then put the tuple (q, 'accepted') in *hasState*
– for all requests q, if not $(q, q) \in$ *isAccepted*, then put the tuple (q, 'rejected') in *hasState*

You should check that *hasState* is a function, and it is easy to see how the relation *isAccepted* can be replaced by *hasState* without loss of meaning. Notice that, *hasState* being univalent, each request is assigned at most one state: a request cannot be accepted and rejected at the same time.

This way of modeling is less explicit, because the reader must know that the *hasState* relation means either 'accepted' or 'rejected'. But the big advantage is that *hasState* is much more flexible than *isAccepted*.

We can easily extend it, for instance to cover a situation where acceptance or rejection hasn't been decided yet. We only need to extend the target set to become State

= {'accepted', 'rejected', 'undecided'}. That is all: from now on, *hasState* can also contain tuples which are undecided. Likewise, we can add a 'partial accept', 'temporary reject' etc. Now try to alter the relation *isAccepted* in such a way that an extra option can be recorded! You will need to add one extra relation for each new instance in State. After several additions, you will have a lot of endorelations, all alike.

This way of modelling, using a State or Type concept, is applicable in many situations. For instance, to model health status of the zoo animals, type of residence permit, eye color of customers, brand of car, etc. It is the customary way to model descriptive information for (the instances of) a concept. As a rule of thumb: whenever you encounter a 'list of things, all alike', you should probably capture them by way of a concept.

But remember, in the end, the business stakeholders decide on what they think is the best way to capture their requirements in the model.

2.5 GENERALISATION/SPECIALISATION

Granularity problems can also be dealt with by modelling the general concept, and the specialisations as well. Because each instance of the specialisation concept will automatically be an instance of the generalisation concept too, an *isA* relation comes quite naturally. It takes the specialisation as its source, the generalisation as its target concept. You should verify that the *isA* relation is always an injection. The disadvan-

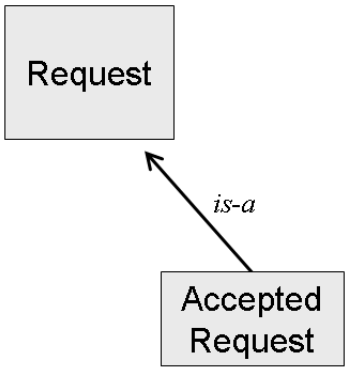


FIGURE 5.5 Binary property captured by way of *isA* subtype

tage of generalisation/specialisation is that the model contains more concepts (and relations), and therefore the conceptual diagram appears, at first glance, to be bigger and more complicated. However, specialisations are easy to explain.

A real advantage is that you can handle specialisations that partially overlap. Many models have concepts such as Employee, Customer, Manager, and the like. You may consider generalizing them to one all-embracing "Person" concept. This generalisation is particularly needed if you have rules about how people might mix their roles. Consider for example a shop where shop assistants serve customers. Normally, we would model two separate concepts, Assistant and Customer. But the two concepts may overlap: some instances of customer may be shop assistants, a shop assistant may act as a customer. To prevent fraud, we don't want assistants to serve themselves. To this end, we first need to introduce the general concept of Person. We add two relations, Assistant *isA* Person, and Customer *isA* Person. The *isA* relations are injective functions by default.

Only then can we formulate the rule that a shop assistant and the customer being served, are not one and the same person. In formula:

$$isA_{[Assistant,Person]}{}^{\smile} \; ; \; serve_{[Assistant,Customer]} \; ; \; isA_{[Customer,Person]} \cap \mathbb{I}_{Person} \; = \; \emptyset$$

The composition of three relations is contained in $\overline{\mathbb{I}_{Person}}$, the diversity relation. As we have two distinct *isA* relations, the complete signatures were written for clarity. In practice, this is rarely necessary, as the signatures can often be inferred from the formula.

Beware, however, that generalizing is something that designers like to do. Business stakeholders do not care for the abstract concepts that result, they prefer the easy names for terms and facts to which they are accustomed.

2.6 THE THING, OR THE TYPE OF THING

A common mistake in model design is to overlook the distinction between things, and the type of things. A few examples may bring this problem home to you:

- A company sells chairs listed in a catalogue, and customers can enter their orders for chairs directly into the company mainframe. But what is 'a chair'? Is it the thing depicted in the catalogue? Or is it the individual items that are delivered to the customer to fulfill an order?
- "If you drive a car, you must possess a driver's licence for that car". As a natural-language expression, this is clear. But it is incorrect as an expression in relation algebra. Just check your driver's licence: there is no mention of a car.
- A client makes a reservation for a hotel room. Upon arrival, a room is allocated for the duration of the stay according to the reservation. Now what is the 'Hotel Room' concept?

As a designer, you should challenge your stakeholders to be clear about their concepts!

2.7 REDUNDANCY

Redundancy

It sometimes happens that some feature of the real world is modelled in more than one place. This is called *redundancy*. Redundancy can be recognized by the problems that it causes in your populations: you find yourself adding the same data into several concepts, or the same tuples into multiple relations. Or, one thing in the real world changes and you have to adjust data in more than one concept and relation. Soon, you will formulate some rule that demands the extensions of two concepts or relations to be equal. But perhaps it is better to simply delete one of them, as there will be no loss of information. With the exception, perhaps, of the *isA* specialisation of a concept.

Beware of derived concepts: a concept that is fully determined by other ones. For instance, a "complaints report" being defined as "the list of all current complaints". The correct concept here is probably "complaint", and not "report". You should capture the derivation as a business rule, and then you may decide either to keep the derived concept, or to eliminate it from your model without loss of information. Be careful, as it may be worthwhile to retain the derived concept anyway. As an example: the total amount of a telephone bill is calculated from the telephone calls. The amount due must be on record, even after all call data have been deleted.

A nasty redundancy problem can arise if you happen to model the type of a thing in two different ways. At one place in your model you use Vehicle, with specialisations such as Lorry, Car or Bicycle. And you use a Type-Of-Vehicle concept somewhere else. This ambiguity can also occur with relations: *isChildOf*, *isSpouseOf* and *isNephewOf* at some places, but *typeOfFamilyRelationship* elsewhere.

The problem is in the abstraction level of the data. At one place, you capture the information at the level of the conceptual model: there is a Lorry concept in your diagram. But you also have a 'lorry' instance in your populations. Obviously, if you

want to write a business rule about lorries, then you are in trouble. The problem should be repaired, but as it involves semantics and definitions, we cannot offer a simple solution that always works.

2.8 WHAT ARE THE RELATIONS

First of all: you must provide a sound definition for each of your relations. Business workers will need to know what tuples should be included in the relations or which ones must be deleted. They will look to the definition for guidance.

Also, use one relation for one definition. Two different meanings require two different relations Be suspicious of any "... or ..." or "... and ..." clauses in your definition, as it may indicate that you are looking at a union or intersection of relations, instead of one single relation.

Although we have discussed concepts first, relations and concepts are conceived in no particular order. A concept without relations is useless, and so is a relation without concepts. Your concepts and relations exist for a purpose: to address stakeholders in their own language and to delimit the language in which stakeholder's concerns are expressed. Therefore, never hesitate to introduce a new relation or concept, but do so only for a good reason, that is: for use in a rule.

2.9 CONCEPT OR RELATION

Sometimes you find yourself wondering whether an aspect of the real world 'is' a relation or a concept. In fact: it is your decision. If you have a lot of information about it, then it is probably best to turn it into a concept and create relations to handle the information. If you need to handle very little information, then probably a relation will do.

Reification

In your model, you can always replace a relation with a concept. This is called *reification* or *objectification*.

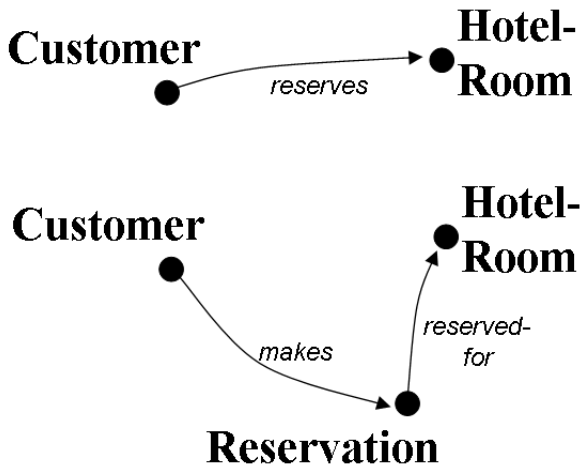


FIGURE 5.6 Reify a relation to become a concept

The idea is that the tuples in the old relation are upgraded to become instances of a new object (see figure 5.6). As every tuple of the relation was linked to exactly one instance in the source concept, we can keep that link intact if we create a new relation from old source concept to our new concept. The univalence and total multiplicities

are inherited by the new relation; and you can check that the new relation is injective and surjective automatically. Furthermore, a relation must be created with the old target concept, and its multiplicities must be determined.

It is possible to demote a concept into a relation, but this is much harder. For one, the candidate concept should be involved in no more than two relations. For another, those two relations must satisfy strict multiplicity demands before you can downgrade the concept and the two relations into a single relation.

Reification is easy, in a model. However, once a model is put into operation, reification is very hard to achieve as the impact on data population is extensive.

2.10 DEALING WITH TIME OR NUMBERS

In everyday speach, people talk about the current state of affairs. Peter might say, for example that he lives at Hopkins House. This fact may be true today, but tomorrow he might have moved elsewhere. When we say that a fact is true or a rule is satisfied, we always mean here (i.e. in the intended context) and now. Tomorrow there may be a different situation, if the underlying facts have changed.

A few examples may illustrate the point.

- A Student receives exactly one Grade for a Course. However, the student may fail to get a passing grade at the first or second attempt. You can model multiple relations (*hasGradeAtFirstTry*, *hasGradeAtSecondTry* etc). A more general solution would be to extend your model with an extra concept Number-of-Attempt and relate it with the concept Grade.
- A Customer has one Address. But the address may vary over time. So instead of one address, the customer may have many addresses, with only one being valid at any particular moment. You may capture this in your model by adding a new concept Valid-Since, and changing the Address concept into Address-Valid-Since. By the way: would you instead have named the new concept Sequential-Number, then the modelling solution looks very similar to the previous one.
- An Employee is allocated to exactly one Manager. This can be modeled by an univalent and total relation *hasManager*. However, the allocation may change over time. This can be modeled by reifying the relation to a new concept *hasManagerSince*. This is linked by three (not two!) relations: to the employee(s), to the managing person, and a relation to the time since when this fact, the particular *hasManagerSince* instance, is true. Instead of referring to a start date by way of a relation *hasManagerSince*, you may prefer to use a Sequential-Number concept. Such a solution can also work fine, except it might become rather confusing from the point of view of managers.

A common feature in the examples above is the rapid increase in the number of concepts. The conceptual model grows in size and complexity in accordance with the amount of time-dependent details that stakeholders require. As an exercise, try to construct a conceptual model that extends the *isMarriedTo* relation to correctly capture the full matrimonial history.

There is much more to say about time in conceptual models, but this book is not the place to go into details of temporal modelling.

A similar problem is in dealing with numbers. Although computers are excellently suited to deal with numbers, relation algebra is not, and at present, the Ampersand tool provides no features to deal with numbers. Of course, you may try to design some workaround, but you will find that it is not that simple. Even a simple sequence such as $0 < 1 < 2 < 3 < 4$ will require that you introduce a concept, Integer, together with an endorelation smallerOrEqual that is an ordering relation, i.e. reflexive, asymmetric, and transitive. And you must populate the concept and the relation

with atoms and tuples, a tedious and uninteresting job.

There is much more to say about dealing with numbers in conceptual models, but again, this is not the place to go into details of modelling numerical data.

3 Considering the business rules

Concepts and relations make up the conceptual model. But rules determine how users will use the model.

Once a conceptual model and its applicable business rules are agreed upon, you will find that the same rules are used in many different locations and business situations.

So, you may expect that in the future, you will need to examine, understand and adjust an existing set of rules much more often than you will need to write a new rule.

Therefore, it is important to understand how rules work. Where in your model do rules come in, what rules should or should not be combined in a model, how can you make sure that you have all the applicable rules for a business context.

3.1 DISTINCT PURPOSES

Earlier, we classified rules according to what they look like in a rule-based design: structural vs behavioural rules, and multiplicity rules as special behavioural rules.

Rules can also be classified according to their use and purpose in the business environment.

Primary rule

A *primary rule* concerns the business services to deliver goods and information to customers. Stakeholders interested in maintaining these rules are the customers, and the workers engaged in delivering the customer services.

Secondary rule

A *secondary rule* governs the way how to perform business activities and procedures correctly and efficiently. Workflow (i.e. the sequencing of business activities), authorizations, read and write permissions, priority rules etc fall into this category. Stakeholders interested in maintaining these rules are managers, auditors, IT support staff etc. To contrast: customers will not care whether these rules are maintained, they just want their demands answered!

Tertiary rule

Some authors also distinguish *tertiary rules* governing the way how IT people should go about their job of designing, implementing and maintaining information systems that support primary and secondary rules. We will not go into details, but there are many interesting issues involved in maintenance in general, and maintenance of rule-based designs in particular. For example, rules may change. Then there may be rules that control the way how to deal with data violations that emerge as the rules are changed. Or rules that govern how incompatibilities between old and new rules should be dealt with.

In our opinion, a designer should aim for a strict separation between rules that serve distinct purposes. Try not to create a conceptual model that mixes primary rules and secondary rules (and tertiary ones). You will find that the respective stakeholders' views of the real world are quite incomparable, or even incompatible.

3.2 RULES DICTATING THE BUSINESS PROCESS

Business processes are commonly described as a series of steps (activities) to produce a desired outcome for some trigger or business event. To coordinate the correct flow of steps, we need sequencing rules: if step 1 is finished, then execute step 2. Or: if steps 61 and 34 and 27 all have finished, then execute step 63.

The process sequence is partly dictated by business requirements ("delivery must take place only after payment is received") and partly by design choices. The process designer may enhance process efficiency by organizing the steps in a particular way, for example, she may follow an efficiency rule like "order picking is done from largest to smallest objects to ease packaging".

Design choices and efficiency rules are genuine business rules too. However, design and implementation choices should not be confused with original business requirements. The rule designer must be aware of such differences, as business requirements are much less volatile than design choices. Or to put it another way: a business process is described by a mix of primary, secondary, and even tertiary rules. Be aware of their different natures.

3.3 EXCEPTIONS TO A RULE ARE EXPRESSED BY NEW RULES

Exceptions to a rule, if you find one, are easy to capture in a model, once you come to realize that 'exception' means 'special situation'. So you just need to add specialisations to some of your concepts, and perhaps relations as well. Next, you need to exclude the special instances from your old rule. And you need to write the new rule to deal with the exceptions.

A brief remark on theory. We expressed the need to classify and discriminate your concepts clearly. The creed about exceptions and new rules highlights the need to be just as meticulous for rules: you need to clearly demarcate each rule, to know where one rule "ends" and another one "begins". From this perspective, you, as a rule designer, should treat rules as the concepts in your own "real world".

3.4 CONFLICTING RULES

Most business contexts are too big to be understood in its entirety. As a result, rules may be formulated by different stakeholders that are conflicting, meaning that you always end up with violations. Beware that you should *not* pick a solution on your own, but the business people should always have the last say.

Contradictory

By definition, two rules are *contradictory* if certain attempts to populate all the concepts and relations used in the rules, will produce violations, even though the data is true and valid in the real world. The only way to avoid violations is to leave out some part of the populations, or even all of it. Thus, the data no longer corresponds to reality. Clearly, such contradictions should be detected by the designer and brought to the attention of the stakeholders. They must adjust their rules, or perhaps keep their rules intact but allow some exceptions.

Consistent

A more general definition looks towards an entire set of rules. The set is called *consistent* if, for all concepts and relations, you can create populations (each counting more than one instance or tuple) in accordance with the definitions, and do so without any rule violation. This is why you must always for your conceptual model provide trial populations that violate none of the rules. Although this is not a conclusive proof of consistency, it does demonstrate that the set of rules is probably consistent.

3.5 ENFORCING THE RULES

Enforcement of rules concerns the way how a business puts the rules into practice: what measures are carried out to keep the rules true. In chapter 4, we argued how a rule and its enforcement are separate concerns. For structural rules, the issue of

enforcement does not arise. Only behavioural rules can be violated, and active enforcement is needed. Basically, three strategies are available: immediate, deferred, or postponed enforcement.

Which enforcement strategy is most appropriate, depends both on business preferences and (in)capabilities of the implemented design. It can vary per rule: some rules require immediate action to prevent any violation at all. Other rules may be violated temporarily, where people treat a violation as a signal to take action. If those signals are ignored, serious consequences may follow. The authors are aware of one example where such signals were ignored for a number of years. Management, confronted with the backlog, decided not to follow up on the many violations, but to just accept them all as one-time exceptions. This resulted in a loss of several millions of euros.

Whenever you think about a rule, you also need to think about how the business people want to have it enforced. This is not a trivial matter: a wrong design choice may require major rework later on. Imagine the rework if you decide to capture a requirement as a structural rule, but stakeholders expected deferred enforcement so that they can look at violations before taking action. Or if you opt for deferred enforcement so that users can remedy violations at their ease, but users want immediate rejection because they do not want to waste time over potential violations.

3.6 ACCUMULATION OF VIOLATIONS

The implication of deferred- or postponed-enforcement is that some violating data is temporarily permitted, so that workers have enough time to understand the violation and resolve it at their ease. There is a risk however, as erroneous data is now present in the data store, and other transactions may take place that build upon the wrong data. If corrective action is postponed for too long, it becomes very difficult to correct the wrong data and undo all the wrong actions.

Some tools provide solutions to this, e.g. by locking all the data involved in a violation for subsequent transactions. However, this solution can quickly bring the entire datastore to a halt. A best possible approach that combines the ease of deferred enforcement with prevention of accumulating violations, is not available yet.

3.7 RULE ENFORCEMENT IN AMPERSAND

Compliance

Enforcement is tool dependent. The actual behaviour that users will experience depends on the particulars of the tool at hand, i.e. how the *Compliance* checking and enforcement is implemented, more than on the algebraic formulas of your rule. This means that when implementing a model, you need to know how your tools will implement the various enforcement options.

The Ampersand tool supports both immediate enforcement and deferred enforcement of rules.

At compile time, deferred enforcement is applied for all rules. Ampersand uses the rule assertion to determine violations, that is: it calculates the contents of the left-hand and right-hand side expressions and then checks the difference between them. It then creates reports of all the initial violations that are detected. The designer should check each reported violation to verify whether the rule formula is wrong, or to determine which data is not compliant to the rule.

At run time, immediate or deferred enforcement can be made to apply, depending on the type of rule. For composite rule assertions, deferred enforcement is the most convenient default.

The immediate-enforcement strategy is applicable as a default for:

– multiplicity constraints of relations, if the constraints are associated with the relation declaration, and
– properties of endorelations, if the properties are associated with the relation declaration, and

Maintain

– rules that are declared with the keyword *maintain*.

The current Ampersand version (2014) does apply this strategy (but be sure to check!)

Sometimes, immediate-enforcement may be too restrictive, and luckily there is a work-around. Every multiplicity constraint can be phrased as an assertion, independent of the declared relation. How to do this was explained in chapter 4. So in fact, the designer does have a choice how to implement multiplicities.

4 Cycle chasing

Suppose your conceptual model is finished: you are satisfied that it contains all the relevant concepts and relations. But how do you check whether you have all the relevant rules? This section outlines a way to use the model for a search of rules.

4.1 CYCLES IN THE DIAGRAM

Cycle

A *cycle* in a conceptual diagram is a closed loop, that connects a concept to itself via a chain of relations and intermediary concepts. Figure 5.7 depicts a cycle made up of five relations. Two different pathways connect the concepts P en T. One passes

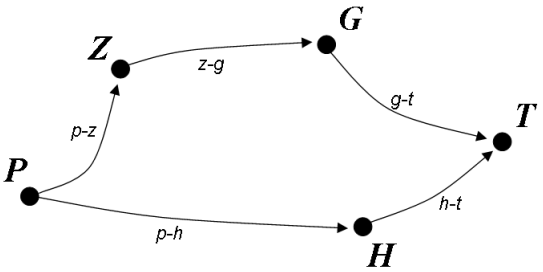


FIGURE 5.7 Cycle in the Conceptual Model

by way of relations *p-h* and *h-t*, the other goes by way of the chain *p-z*, *z-g* and *g-t*. Would we create two relations as follows:

$R = (p - h); (h - t)$

and

$S = (p - z); (z - g); (g - t)$

then the following assertion contains no errors:

$R \vdash S$

The assertion may be free of syntax errors, but is it meaningful? What is its semantics, does it represent an actual business rule or not? We might also have conceived a totally different rule, navigating not from P to T but, for instance from Z to H:

$R = ((z - g) \dagger \overline{(g - t)}\ ); (h - t)^{\smile}$

and

$S = (p - z)^{\smile}; (p - h)$

Or we might use the identity relation on G for one relation, and go the entire circle for the other relation, like this:

$R = Id_{[G,]}$

and

$S = (g - t); (h - t)^{\smile}; ((p - h)^{\smile} \dagger (p - z)); (z - g)$

Evidently, the number of assertions that we can conceive for this, or any cycle, is huge. And the computer will have no problems with the assertion that one relation, R, is contained in another, S. But every time we need to ask: are the assertions meaningful in the business context?

Even the smallest possible cycle, made up of only one endorelation, can be constrained in a lot of ways. The relation may, or may not be, (ir)reflexive, (a)symmetric, and (in)transitive, thus giving rise to at least 8 potential business rules; and you can probably think up some more. Which ones capture an actual business rule, is for the designer to find out.

Summarizing, there are two points worth remembering. The first is that any rule involving composite relations corresponds to a cycle in the conceptual diagram. The second point turns this around: you can use cycles to help you discover rules. In any cycle in a conceptual diagram, you can conceive a number of assertions that might well be a business rule. The latter insight is the basis for the design activity of *cycle chasing*.

Cycle chasing

4.2 CYCLE CHASING

Whenever you see a cycle in the Conceptual Diagram, you should be aware that a rule may be involved. The rule would control consistency of information in the cycle: going down one pathway from source to target, is somehow correlated to going down the other way. It is the designers responsibility to examine each and every cycle, and elicit the potential business rule (or rules). Rules that sometimes the business users never thought of.

It must be emphasized that in cycle chasing, you should examine all cycles. And you may expect to find rules to control all cycles. It is conceivable, but rare in practice, to find a cycle without any corresponding business rule, the implication being that anything goes, there is absolutely no coherence in the relations involved.

The correspondence between rules and cycles is not one-to-one. A multiplicity constraint will control a single relation, without so much as a cycle in the diagram. Really complex rules may control several cycles at once. Or some cycles may be controlled by more than one rule. Although the correspondence between cycles and rules is not exact, you should always check: is every cycle controlled by rules? Is there a difference between the cycle count and the number of rules, and if so, why?

4.3 COUNTING CYCLES

Cyclomatic number

How many cycles are there in a complex conceptual diagram? This is determined by the *cyclomatic number*, and you calculate it as:

$$1 - \textit{number of concepts} + \textit{number of relations} \tag{5.1}$$

The smallest possible conceptual diagram has just one concept: the number of cycles is 0. The extra unit of 1 prevents that we would calculate a negative number for this. Now, if you add one new concept, and use one relation to connect it with

the remainder of the model, then the number of cycles does not increase. But you do create an extra cycle when you add a relation connecting two concepts already present.

In a small conceptual diagram, the cycles are easy to count: they correspond to the "loops" or "eyes" in the diagram. However, for more complex diagrams, with lots of crossing lines, it is much harder to count the loops. The formula makes life easier.

Beware that the rules controlling the loops may be more intricate than what the visible eyes may suggest. Figure 5.8, with 6 concepts and 9 relations illustrates this. The cyclomatic number is $1 - 6 + 9 = 4$, and indeed there are four "eyes", spanned by the relations a-b-c, c-e-f, d-e-h and f-g-i (ignoring inverses, for now).

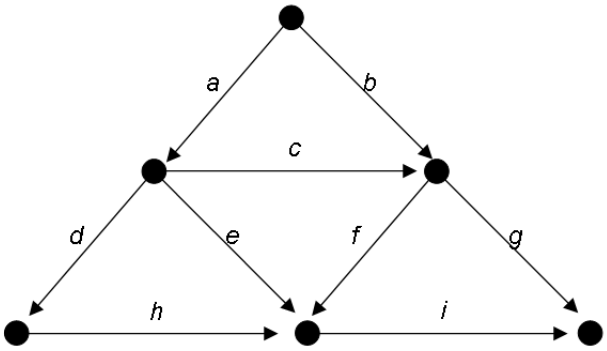


FIGURE 5.8 Relations to be constrained by rules

But controlling rules may for instance traverse the cycles spanned by a-d-h-i-g-b, by a-d-h-f-b, by a-e-i-g-b, and c-d-h-f. And these four rules may even be mashed together into a single rule by using the $\cap$ operator (logical and). Notice however that every relation is included in, and hence controlled by, at least one rule. So there is a correspondence between the business rules and the cyclomatic number. You should use this as a rule of thumb, as a design guideline, when checking your set of rules for completeness.

4.4 CYCLE LENGTH

Try to formulate concise rules that are clear and easy to understand. A rule assertion that is too long and complicated, is probably too hard to understand and may contain errors without your noticing it. And you can almost be sure that you will not be able to explain the rule to your business stakeholders.

Most rules control cycles that involve a small number of relations, usually 3 or 4 or in exceptional cases up to 5 or 6. Anything higher must be regarded with suspicion. A rule involving many relations may be perfectly right, but more likely it is not well understood. You can try to simplify such a rule by looking at its cycle (try to draw it as a loop), and simplify the rule using a shortcut across the loop. Perhaps you need a new relation for this shortcut, but as said before: never hesitate to introduce a new relation. Simplification and clarification of rules is a very good reason to do so.

If you add a new relation, then the cyclomatic number goes up by one. Thus, while trying to simplify one old rule, you may end up with two simpler ones. Together, they should cover the meaning of the old rule.

4.5 REDUNDANT RULES

What if a designer comes up with two rules such as $r \vdash \overline{s}$ and $s \vdash \overline{r}$?

These two assertions clearly express the same business rule. The rule can also be written in yet another form: $r \cap s = \emptyset$. Obviously, there is some redundancy here. In this example we can easily check that the rules are equivalent because we can invoke a law of relation algebra about set negation (see Chapter 3). But it is not always so easy.

Less strict behaviour

Redundant rule

The way out is to look at the behaviour of rules, i.e. at the violations they produce. We say that an assertion R imposes *less strict behaviour* than assertion S if any violation of R always corresponds to a violation of S. In other words: R is more permissive, S causes more violations than R. When one assertion imposes more strict behaviour than the other, then we say that the latter, weaker one is a *redundant rule*. Notice that we do *not* require that sources and targets of the assertions are identical.

The definition above concerns only two rules. If we consider a set of many rules, then a more complex definition of rule redundancy is required, because several rules may together impose the more strict behaviour. However, we cannot explore this extensive subject within the context of this book.

If a rule is redundant, then it is safe to omit it from your conceptual model, because any violations will be caught by the stricter rule (or set of rules). But do consult your stakeholders about it, as they may still desire violations of the weaker rule to be reported separately.

4.6 CHECK FOR REDUNDANT RULES

If two rules traverse and control the same cycle, then this may indicate a redundancy. But not always: rules that traverse and control the same cycle may also augment one another. This is so if neither one is more strict than the other. For instance, think of an endorelation: it may well be transitive and symmetric at the same time. You may consider combining the two into a single rule, which calls for some rewriting of your rule expressions. But always keep in mind that it is the business stakeholders, not you who have the final say on what the rules are.

If two rules traverse different cycles, then you can safely assume they are not redundant. This remains true, even if the two cycles partly overlap (some shared relations and concepts) and even if the rules are written using expressions that have the same sources and targets! In this case, the rules augment one another. Again, you might consider combining them into one rule which will then control more than one cycle.

A final remark on theory. We defined redundancy of two rules as "imposes less strict behaviour than". It is an interesting exercise to check that this constitutes an endorelation among rules. As the relation is reflexive, asymmetric and transitive, it defines a partial order on the set of rules.

4.7 GUIDELINES FOR WORK

Business rules are guidelines for work. Indeed, a sound set of rules may be read by users as if it outlines their workflow. The motivating example in chapter 2 demonstrated this core idea. It showed how business rules may drive a work process. An initial customer action will start off a violation of one rule. The action to repair that violation triggers violations of subsequent rules which must be remedied. After a number of steps, no violations persist and the process is completed.

If you are able to present the rules to your stakeholders in such a natural way that it outlines a business workflow process, then do so. You should be able to demonstrate how the work "flows". Determine which event causes an initial rule violation, and then trace the successive user actions to remedy the violations and make the rules "true" again. In fact, this constitutes a *use case* and it provides you with an excellent

Use case

way to validate your rule design with the users.

Declarative

Business rules in general ought to be *declarative*, that is to say: they should not specify any strict sequencing of behaviour. Nor should they specify how the rule should be enforced. The rules signal violations, but do not dictate what to do to make them true.

For instance, a violation of the rule "a residence permit for limited duration is issued under conditions that are related to the purpose of stay" can be remedied in several ways: by adding a new condition to the permit, or by revoking the permit. Or you can even remove the rule itself, and no longer require the condition and purpose of stay to be related. In general, the more concepts and relations that are involved in a rule, the more options a user can choose from to act and remedy the rule violations.

Indeed, an inclusion rule expressed as a relation algebra assertion can be inspected to see which relations it involves. To remedy a violation, it suffices to manipulate those relations so that one or more tuples disappear from one side in the assertion, or that tuples materialize on the other side. The most desirable or appropriate actions however cannot be decided from the rule alone.

Imperative

A business-rules approach focuses on rules and violations, which differs markedly from the business process approach. Rules that do impose specific sequences of actions are called *imperative*. This kind of rules is abundant in workflow models, where they dictate the how, when, and by whom activities must be undertaken. The imperative rules generally ignore the *why* of action, which is: to ensure compliance with agreements, to remedy the violations of business rules. In a business process, violations are either within the scope of the process and resolving them is part of the process: an Exam paper may only be entered by a Student registrered for the Exam; if not, the Student on-the-spot registration is possible. Or the violations are deemed beyond the scope of the process and it is ignored in the process design: an Exam paper may only be entered by a Student with a valid Student-number. It remains unclear what to do with an exam from a student who does not provide a valid number.

Whereas workflow is a prescriptive way to organize work, declarative business rules merely outline which facts should be kept true and why. The good thing about declarative business rules is that they are guidelines for work, but do not enforce one specific choice of action upon the user. This gives users maximal flexibility to manage their workload, provided that they keep to the rules. It does not constrain the way of work how it should be done, in what sequence, when, or by whom.

5 Validation

What makes a good set of rules? This is a core concern in any design effort, no matter if you are engaged in information systems design, in home decoration, in dance choreography or any other creative effort. A set of rules is good if the stakeholders agree that this is the set they must satisfy (in the given context). So you can do your best, but in the end it is up to the user audience to decide on the quality. For this reason, validation of rules is needed to make sure you get a sign-off by stakeholders.

5.1 BEFORE YOU START

Even before you start validating, as a designer you should perform a number of preliminary checks. Of course, each separate rule should be up to standards; as was explained in the previous chapter. But this is not enough. You should also perform some checking on the combined set of rules. If any of these checks are failed, then the design is not really finished yet and validating it has little value.

- Complete: are all of the user requirements covered?
- Correct: are all of the user requirements expressed correctly in the formulas and definitions? And do all of the formulas and definitions express a requirement correctly?
- Consistent: are the rules not in conflict with one another?
- Syntactically sound: are all formulas and definitions expressed in the correct syntax of relation algebra?

If all of the above is ok, then the design might be finished, and you can start your validation activities.

5.2 BY TRIAL AND ERROR

A first step in validating your design is by examining it by way of populations.

By populating all concepts and relations, you can attempt to produce violations for the various rules. If the violations match exactly with the user expectations, then probably you have a valid model.

In practice, you will often use this method. In fact, populations are key to understanding your models and rules. You only understand a rule if you know what violations it will produce in a population. If you, or your business stakeholders do not understand the violations, you do not understand the rule.

Seeding

A more sophisticated approach to trial-and-error is by having test cases generated and run automatically. At present, software exists that will automatically create populations for all of your relations (this is called *seeding*). It will then proceed to determine whether the rules are violated by the content. Such software gives you a fast, but not 100% reliable way of validating your rules.

Still another approach to trial-and-error is by searching for a counterexample. You invent fictitious but meaningful data, in such a way that your facts are correct, but your rule turns up a violation. Thus, the rule is wrong and should be replaced. Every time you falsify a rule with a counterexample, you have learnt something about it, and therefore increased your understanding of the situation. So, falsification is a valuable, albeit timeconsuming approach to validation.

5.3 BY TRANSLATING BACK

Translation

The rules in your design are expressed in a formal notation, meaning they are unambiguous and can be rigorously applied. However, rule expressions are not always easy to comprehend, not even for experienced designers. Hence, you should provide each rule with a *translation* in natural language. We outlined a translation procedure for that very purpose in chapter 4. Remember that the final step of that procedure requires your own good judgment, both as a speaker of natural language and as expert with extensive knowledge of the business at hand. And do not forget to check that your translation is meaningful and useful in the business context.

5.4 BY CORROBORATION

Corroboration means that others confirm what you are saying. In other words, you want to confer with knowledgeable business representatives, and get them to agree with your rule assertions and explanations. And remember that you want the business intent of your set of rules to be approved as a whole, and not merely the translation that you have provided for a separate rule.

Corroboration may also require that you prepare use cases: demonstrations that show how in a populated conceptual model, an initiating event will produce a se-

quence of violations to be dealt with (automatically or by users) until there are no more violations and the initiating event is dealt with.

5.5 BY COMPARISON

Validation can also be done by comparing with something else. The idea is to prove that (a part of) your rule(s) is equivalent to something else, preferably something that is known to be true and correct. For instance, you can try to populate your design and compare the ensuing violations with the output of an existing information system that covers the same business context.

A more advanced way to do this is by reasoning with the rules and find new implications. Intelligent tools exist that can analyze rules and infer new implications and sentences from them. Then you might discover that some particular implication of your set of rules is unacceptable within the context of your business. Reasoning back, you might discover which rule is at the basis of this faulty implication, and then you can change or discard that rule. However, details of this advanced method are beyond the scope of this book.

5.6 STAKEHOLDERS RESPONSIBILITY

Above, we described how to start design validation. But in the end, validation is the responsibility of the business stakeholders, not yours: they must certify the quality of the design they asked for. Users should validate that the design that is presented to them is

- understandable: they should check that they understand all documentation, explanations and use-cases offered for their benefit,
- complete: they should check that all of their requirements are expressed in the design,
- valid: they should ascertain that the design is a good representation of the business context.

Nevertheless: you can never be 100% sure. Even if stakeholders fully agree, even if you are totally confident, the claims about the validity of a design are based upon only a certain amount of evidence.

6 Rule-Based Design according to Ampersand

Ampersand

The way of working to deliver a Rule-Based Design as described here, is called *Ampersand*. Ampersand guides you to produce a design that meets the business requirements, and that has sound design quality. Quality, of course, depending on expertise and experience of the designer, but perhaps even more so on the capability of business stakeholders to express their requirements, to agree upon the rules that must be kept true within their business context, and to validate their own ways of dealing with rules and violations.

6.1 INGREDIENTS OF THE DELIVERABLE

Ingredients of a Rule-Based Design according to Ampersand are:

Requirements elicitation

- a list of all requirements as put forward by the users. This calls for *requirements elicitation*, an activity that we do not cover in this book. It may take place before, or concurrent with, the initial stages of design,
- a conceptual model that captures all the terms and facts referred to in the requirements, as covered in chapter 3,

– a complete and correct set of rules, asserted in relation algebra, that comprises all business rules listed by the users in natural language, as covered in chapter 4,
– trial populations for all concepts and relations,
– validation evidence to bear witness that the concepts, relations and rules are in full agreement to the requirements,
– technical specifications for use in subsequent IT development activities.

You may have noticed that we did not divulge on the issue of technical specifications. This is because the Ampersand method comes with a tool, also called Ampersand, that takes care of this. After loading the tool with a correct rule-based design script, the tool lets you navigate through the Conceptual Model and all rules. Moreover, it is capable to accept populations of all concepts and relations, and determine each and every rule violation. Once you have scrutinized the model and discussed the business requirements in sufficient detail, you can output from it the functional-specifications document in printable format at your command.

6.2 CHECKING A RULE-BASED DESIGN

A Rule-Based Design is comprised of a conceptual model plus a set of rules. Basic checks on the model include:

– name: each concept or relation has a meaningful and unambiguous name,
– definition: does the definition of each concept and relation cover a single meaning only? Is there no ambiguity, does each concept and relation capture only one real-world feature?
– classification: does the definition enable the users to clearly distinguish an instance (of the concept) or tuple (of the relation) from whatever is not an instance or tuple?
– discrimination: does the definition allow the users to clearly distinguish one instance/tuple from any other instance of the same concept or relation?
– identification: does the definition allow to recognize the same instance/tuple at any future time?

A conceptual model should also be free of duplicate, redundant, and derived concepts. That is, unless the designer has some sound arguments to keep them in the model, and has provided a full set of rules to control their contents.

Basic checks for rules defined on the conceptual model are:

– each relation has its multiplicity constraints stated? Did you consider writing the constraints as distinct business rules, separate from the declaration?
– every relation is controlled by some appropriate rule?
– all concepts and relations can be populated in such a way that no violations emerge?
– each rule assertion is rephrased in natural language, formulated as clearly as possible, so that stakeholders can grasp their meaning and corroborate that the rules are correct?
– every rule violation is understandable and can be remedied by appropriate user actions?

Furthermore, rules in a conceptual model should:

– be consistent, i.e. no contradictions, as evidenced by being populated,
– outline a logical flow of work, evidenced by use cases that show how violations are dealt with by the rules,
– be independent of implementation, i.e. there are no hidden assumptions about rule enforcement, or sequence of execution.

Rule-Based Design is about creating a conceptual model together with a set of associated business rules, in such a way that high quality standards are met. Of course, the final check is with the stakeholders. It is up to the designer to deliver a model and a set of rules to capture their business requirements. It is the responsibility of the business to validate the model and the business rules, and to put the design to work.

Part III

Practice

Examples from practice

Chapter 6

Examples from practice

1 Introduction

This chapter discusses examples of rule design problems that are commonly encountered in real business environments. For each, we outline some ways how you may deal with the problem, so that you understand how to compose a rule-based design, and come up with specifications that exactly capture the business rules. We illustrate the Control Principle from chapter 2 in an extended example and show how business rules can control a business process without using a process model. A good understanding of practical examples will help you to address the problems in your business environment by adjusting solutions or inventing new ones.

2 Sample rules and formalizations

Rules build on facts, but the rules may not always be so easy to find. As a designer, you are expected to assist business stakeholders in formulating their rules. Understandably, users will rarely express their rules as flawless relation algebra statements. It will take some prodding, and experience, to turn the business lingo into clear, *declarative rule* assertions. Let us first consider a small example.

Declarative rule

2.1 CUSTOMERS, ITEMS, AND BILLS

A group of artists (painters, potters) sells their work to customers. Each piece being sold is a unique item, so we don't need to distinguish between the thing or the type-of-thing (item as-delivered to the customer versus item as-advertised in the catalogue).

Figure 6.1 depicts the conceptual model. For now, we ignore the obligation to provide proper definitions for the concepts and relations. An instance diagram (with some improbable tuples) is shown in figure 6.2.

2.2 ONE RELATION

If we consider only one relation, we are looking at multiplicity constraints. The artists may for instance claim that 'every item has its customer, eventually'. This rule of thumb is probably not rigorously enforced, but we can still formulate it as a rule assertion, as follows:

Natural language: every item has its customer.
Controlled language: Every Item is *sentTo* some Customer.
Rule assertion: *sentTo* is total; or: $\mathbb{I}_{Item} \vdash \ sentTo \ ; \ sentTo^{\smile}$.

The lefthand side ($\mathbb{I}_{Item}$) of the assertion is the list of all items, written in the form of a relation. The righthand side $sentTo;sentTo^{\smile}$ is all pairs of items that are related, via *sentTo*, to the same customer. An item not sent to any customer will be present at the lefthand side, but absent from the righthand side relation, which is a violation of this rule. Similar multiplicity constraints are easy to think of, e.g.: an item may be sent to at most one customer. Or: a bill must include at least one item. We leave it as an exercise to decide for all three relations which ones of the four multiplicity constraints should hold.

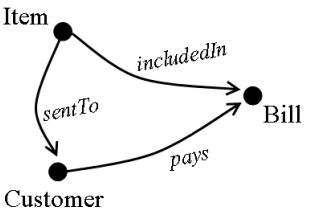


FIGURE 6.1 Diagram of the conceptual model with three relations

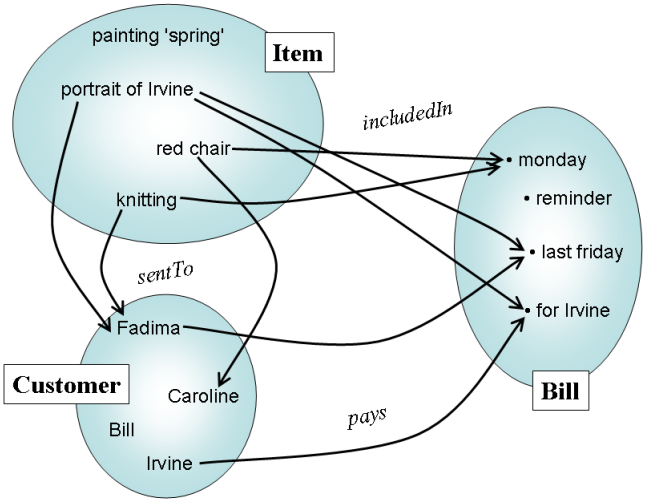


FIGURE 6.2 Instance Diagram for the relations

Referential integrity

Remember that structural rules are rules too. One of the structural rules embedded in this structure is that customers pay their bills at most once. This model does not allow you to record that a particular customer pays the same bill twice. You would need to record the same tuple two times over in relation Customer *pays* Bill, which is impossible by virtue of *referential integrity*. If your stakeholders need the ability to record duplicate payments, then the model has to be adjusted. One solution may be to distinguish two different concepts, Bills and Payments; an example of *reification* discussed elsewhere.

Another structural rule in this model is the concept of customer, defined here as: living person. According to the model, an item is sent to customers only, and therefore it can never be sent to a museum, art gallery or temporary exhibition. That is, unless the notion of "customer" is radically changed to also cover such.

2.3 TWO RELATIONS

Two relations may be combined in a business rule that is still easy to comprehend. For example, we want every sent item to be billed:

Natural language: every sent item must be billed.
Controlled language: *if* an Item is *sentTo* some Customer, *then* that Item must be *includedIn* some Bill.
Rule assertion: $\mathbb{I}_{Item} \cap sentTo; sentTo^{\smile} \vdash \mathbb{I}_{Item} \cap includedIn; includedIn^{\smile}$.

In the rule assertion, the lefthand side lists all items that are related, via *sentTo*, to some customer. Actually, the left-hand side constitutes a property-relation, as explained in the previous chapter. The righthand side is similar, but containing items related to bills, not customers. The inclusion rule now says that each sent item must be included in some bill. A violation occurs if an item is sent that has not been in-

cluded in a bill. Remark that the rule does not ensure that the bill is presented to the correct customer, nor that the bill will be paid by anyone; we will come to that shortly. Or perhaps the business stakeholders prefer the opposite rule:

Natural language: every billed item must be sent.
Controlled language: *if* an Item is *includedIn* some Bill, *then* that Item must be *sentTo* some Customer.
Rule assertion: $\mathbb{I}_{Item} \cap includedIn; includedIn^{\smile} \vdash sentTo; sentTo^{\smile}$.

This rule states that each item that is included in a bill, must have been sent to some customer. Notice that the right-hand side no longer mentions the identity relation. We leave it to the reader to check that, in this case, it may safely be omitted.

Now let us consider a composite relation, e.g. $includedIn; pays^{\smile}$. We can formulate a multiplicity constraint for this relation, just like for any other. Assume, in natural language, that every item shall be paid. The conceptual model imposes the structural rule that whatever is being paid is, by definition, a bill. The model cannot deal with payments for any other type of thing. So we must replace the natural-language "be paid" with something that refers to bills being paid:

Natural language: every item is paid.
Controlled language: every Item is *includedIn* a paid Bill
Rule assertion: $(includedIn; pays^{\smile})$ is total;
or: $\mathbb{I}_{Item} \vdash (\ includedIn;\ pays^{\smile}\ )\ ;\ (\ includedIn; pays^{\smile}\ )^{\smile}$.

A violation of this rule means that either the item has not been included in any bill, or the bill has not been paid.

2.4 THREE RELATIONS

We can write down more business rules variants if we consider all three relations. Of course, some of these assertions may be in conflict with another one, or they may not reflect how business is conducted. The purpose of these examples is to understand how various rule assertions can be formulated. You must learn to translate and explain them to the stakeholders, so that they can decide on the ones that reflect their actual way of doing business.

Business rule variant 1:

Natural language: a customer must pay if some item on the bill was sent to her.
Controlled language: *if* an Item is *sentTo* a Customer, *then* that Item must be *includedIn* some Bill and the Customer must *pay* it.
Rule assertion: $sentTo \vdash includedIn\ ;\ pays^{\smile}$.

Business rule variant 2:

Natural language: a customer will pay if some item on the bill was sent to her.
Controlled language: *if* Customer *pays* Bill, *then* at least one Item must have been *sentTo* the Customer and be *includedIn* the Bill.
Rule assertion: $pays \vdash sentTo^{\smile}\ ;\ includedIn$.

Notice the fine distinction here. Variant 2 may be rephrased as: *if* the customer pays the bill *then* at least one item is sent. But rephrasing variant 1, the if- and then-clauses are switched around: *if* at least one item is sent *then* the customer pays the bill. Which is to say: every sent item must be paid for. This finesse of natural language clearly shows the need for precision and for a structured, controlled-language approach!

Business rule variant 3:

Natural language: paid items were sent.
Controlled language: *if* a Customer *pays* some Bill and that Bill *included* a certain Item, *then* that Item was *sentTo* that Customer.

Rule assertion: $pays\ ;\ includedIn^{\smile} \vdash sentTo^{\smile}$.

This variant has an effect opposite to variant 1. Variant 1 required that sent items must be paid, this variant says that paid items must be sent. A customer paying for an unsent item, causes a violation of this rule. Which can then be remedied in several ways: send the item belatedly and add the fact to the population of relation *sentTo*. Or adjust the bill, and content of relation *includedIn*. Or refund the money, and delete the payment from the *pays* relation.

Business rule variant 4:

Natural language: a customer must pay if all the items on the bill were sent to her.
Controlled language: *if* every Item *includedIn* the Bill is *sentTo* the Customer, *then* the Customer *pays* the Bill, or also: *if* every Item is either *sentTo* the Customer or *not includedIn* the Bill, *then* the Customer *pays* the Bill.
Rule assertion: $sentTo^{\smile} \dagger \overline{includedIn} \vdash pays$.

Variants 5 and 6 are negations of variant 4.

Business rule variant 5:

Natural language: a customer will not pay if some item on the bill was not sent to her.
Controlled language: *if* there is some Item that is *not sentTo* the Customer while it is *includedIn* the Bill, *then* the Customer will *not pay* the Bill.
Rule assertion: $\overline{sentTo}^{\smile}\ ;\ includedIn \vdash \overline{pays}$.

Business rule variant 6:

Natural language: if a customer does not pay then some item on the bill was not sent to her.
Controlled language: *if* the Customer does *not pay* the Bill, *then* there is some Item that is *not sentTo* the Customer while it is *includedIn* the Bill.
Rule assertion: $\overline{pays} \vdash \overline{sentTo}^{\smile}\ ;\ includedIn$.

One of the rules or variants above may exactly cover the business requirements, or perhaps some rules should be combined. For instance, variants 5 and 6 together state that the customer shall not pay if and only if not every item was sent to her. But if we rephrase that, and put in another negation, then we have yet another likely rule variant: the customer shall pay a bill if and only if every item included in the bill was sent to her.

However: certainly not all rules and variants will apply to the business environment simultaneously. It is up to the designer to consult with stakeholders and find out exactly which rules do apply. Those rules may be similar to any one of the examples above, but they may also be very specific for the business situation at hand.

3 Rules may refer to terms

So far, we considered rules that refer to facts only. But as stated in the Business Rules Manifesto: rule statements may also involve terms.

A common reason for this is to capture some exceptions to a rule. For instance, a Conceptual Model may contain some hierarchy, e.g. postal code areas in Denmark, with areas being ordered by the *is-contained-in* relationship. Except "Denmark" itself, being the highest-instance in that particular hierarchy. Likewise, in a company database, the Chief Executive Officer is the only employee without a superior. It is only natural that atoms for which there is a rule exception, are named explicitly in the rules. There are other reasons why an atom needs to be literally quoted in a rule.

For instance, a rule may apply only to certain instances or certain types of instance:

– only an employee with status 'manager' may authorize orders for processing.
– only an order having status 'authorized' may be processed.
– any log-in that results an 'illegal attempt' status is a violation and must be reported immediately.

Relation algebra can deal with explicit terms in rules in two ways. The simple approach is to include the term(s) literally in your rule. Here is an example:

Natural language: a divorce can only involve persons with marital-status 'married'.
Controlled language: *if* a Person is *involvedIn* a Divorce, *then* that Person *hasMaritalStatus* 'married'.
Rule assertion: $\mathbb{I}_{Person} \cap involvedIn \,;\, involvedIn^{\smile} \vdash hasMaritalStatus \,;$ 'married' $;\, hasMaritalStatus^{\smile}$.

The lefthand side of the rule assertion captures the persons involved in divorce. The righthand side contains all persons with marital-status equal to 'married'. The rule is easy to understand, because the special value clearly stands out.
By the way: the rule assertion does *not* imply that a 'married' atom will automatically come into existence in the population of marital statuses. A rule does not create populations, it only inspects them to check for violations.

The disadvantage of this approach is that the particular instance value, 'married', is now frozen into the rules of your Conceptual Model, and you may not change its name any more. So let us imagine that we use this approach for a similar rule, like:

Natural language: only an employee with status 'supervisor of the Order Intake department' may authorize orders for processing.

Suddenly, it does not seem such a good idea to freeze this explicit value into the rule, as any reorganization or renaming of job title will force you to change your rule. So another approach is perhaps better.

One idea is to create a special subset in your Conceptual Model first, making sure that exactly your literal terms will populate your subset. You do this is by introducing a property-relation as discussed in the previous chapter. This homogeneous relation, symmetric and antisymmetric by definition, corresponds to your subset. Then use this homogeneous relation in your rule assertion. The example now goes like this:

Natural language: only an employee with status 'supervisor of the Order Intake department' may authorize orders for processing.
Controlled language: *if* an Employee *authorizes* some Order, *then* that Employee is *authorizedAs* 'supervisor of the Order Intake department'.
Rule assertion: $\mathbb{I}_{Emp} \cap authorizes; authorizes^{\smile} \vdash authorizedAs$.

Do remember to populate the homogeneous *authorizedAs* relation, in this example with just one tuple corresponding to one supervisor status.

In this approach, the atom value is not frozen into the rule, and reorganization or renaming of jobs merely affects the population of the relation. The population of the special subset can be edited without changing the rule. The downside is that the rule looks more complicated, is less easy to understand. And you must define and populate correct subsets, instead of simply naming the atom(s) explicitly in your rule.

4 Extended example of incremental design

Incremental design methods bring a distinctive advantage to IT projects, because it allows engineers to decompose a complex business area into smaller, and more manageable business themes and problems. After having determined a suitable de-

composition into fairly independent parts, the project can proceed in small steps by modeling each theme separately. Next, the separate patterns and solutions are merged in such a way that the separate parts work together and produce a correct and consistent design of the full business context.

4.1 SCOPE: THE FLOWERING-PLANTS BUSINESS

For a small business that cultivates flowering plants, we are going to capture the rules that apply to ordering. If some customer orders a batch of flowering plants, what happens? Which rules should be complied with? What agreements ensure that the flowering-plants business can satisfy customer orders? The aim of this section is to outline and illustrate the Ampersand approach, so we will not presume to come up with a perfect solution for the business at hand. For instance, nothing is said about incomplete deliveries, returns or reclamations. Moreover, we make various assumptions and simplifications along the way that ought to be checked back with stakeholders. One such simplification is that we exclude requirements about due dates, as we do not want to deal with time. Rules about the available size of stock are also excluded because we do not want to deal with numbers or arithmetics. But first, read the short description of the business by one of the company owners:

"We have about a dozen workers, including me and a few of my family members acting as senior employees. Most of the work is guided by implicit agreements, but some of the more important jobs are supported by paper documents and software applications. The most important one, of course, is the ordering workflow. Orders come in from customers by telephone or email, and are received by one of the senior employees, being responsible for stock keeping. Each order is recorded: the species and amount of plants, and the requested date of delivery. Occasionally an order is for an unavailable plant, which is a bit of a problem for us. Because we pride ourselves on delivering fresh plants, each order is prepared as late as possible, usually in the (very) early morning of the delivery. At present, we cultivate plants in two different locations, which is why order acceptance is sometimes delayed if stock availability in both locations must be checked."

Furthermore, this company owner has formulated important rule requirements. These requirements, listed below in no particular order, are stated in the language that business stakeholders understand; we did not convert them to some semi-formally controlled language:

a Only plants in stock may be ordered.
b Each plant is cultivated (and kept in stock) and employees work at a single site only.
c Only senior employees should deal with order requests because they are responsible for each stock.
d A picked order is for the same customer who placed the order.
e The actual order may be for fewer plant species than the order request, but never for more.
f The employee who picks the order must write the receipt for it.
g An actual order is for the same customer who put in the order request.
h An order may only be picked by employees who work at the site where the species is cultivated.
i Upon order delivery, the customer receives the receipt of the picked order.
j An order and the corresponding picked order contain exactly the same kinds of plant.
k An order delivery is for the same customer as the corresponding picked order.

Do not presume that these requirements are consistent (without contradictions), that they are valid in all respects, and fully complete. Also notice that the text is not always clear and unambiguous. For instance, the text that "each plant is cultivated"

probably refers to plant species, not to individual plants. And the "kinds of plants" probably means species, too. The term "order" also appears to have multiple meanings. In the analysis, we will distinguish four meanings: order request, (actual) order, picked order and order delivery. Of course, these and other issues should be checked with the stakeholders prior to system development.

Business vocabulary

The designer should be alert to such details as ambiguities and possible differences in meaning, and she should press the stakeholders for clarification. Ideally, all stakeholders should adopt and use a single *business vocabulary*, although in practice that uniformity in language is rarely achieved. A second-best is that the designer, and the users, learn to understand each other's terminology.

For the designer, setting the right scope and context is very important because it determines the quality of her subsequent analysis. All decisions about what will be in- or excluded in the rule requirements, and the design effort, ought to be discussed with, and accepted by the stakeholders.

4.2 SEPARATION OF CONCERNS: PATTERNS

Once the overall business workings and rule requirements are clear, the smart thing to do is not, to create one grand design to capture all features of the business at once. Instead, one should try to distinguish parts that appear to be self-contained and independent. Each part, or pattern, consists of a number of relations, plus rules about those relations. This way of working is called "incremental design".

At this point, the engineer must rely on professionalism and personal experience, because there is no golden bullet to determine a "best possible" decomposition into parts. The parts to be distinguished are not objectively or rigidly outlined, and other business analysts may well prefer some other partitioning. Moreover, in practice, the demarcation of parts is liable to shift considerably as each part is studied in detail and overlooked features are being discovered. But whatever parts you pick, the integration of all parts should produce the same result: a verified design that validly captures all rule requirements of the business.

For now, we will discern three main parts: static business structure, the primary process involving the order processing, and secondary aspects involving employees and their tasks. The order-processing part will be even be subdivided into still smaller parts.

4.3 STATIC BUSINESS STRUCTURE: THE PRODUCE

The basic produce of this business is: cultivated plants. We analyze the requirement that "each plant is cultivated (and kept in stock), and employees only work at a single site".
The two "and"s in this sentence are red flags that it covers more than just one requirement. As we focus on business structure only, we keep only the "each plant is cultivated and kept in stock at a single site", and worry about employees later. So we have that the flowering-plants business is being conducted at certain sites: Site is a relevant concept. And certain plant species are being cultivated and kept in stock: Species and Stock are relevant concepts.

The requirement combines two simple sentences (relations):

– Species *is_cultivated_at* Site
– Stock *is_of* Species

Moreover, we can infer certain multiplicity constraints for these two relations. According to the requirement, a plant species is cultivated at a single site at most, i.e.

this relation is univalent. And stock *is_of* exactly one plant species, i.e. this relation is a function.

Obviously, the number of plants in stock will vary over time, but we will blatantly ignore that in the example. Hopefully, the system developers will deal with this aspect of time later on. For now, in our model, the concept of Stock becomes almost a synonym for Species: a plant species is not cultivated, or if it is, then a single Stock instance is recorded for it. So, in this example and because we ignore time, the *is_of* relation is an injective function.

Figure 6.3 depicts the Conceptual Diagram of this simple pattern. With just three concepts and two relations, the number of cycles is zero. Later, another part of static business structure will be modeled when we discuss the Employee concept.

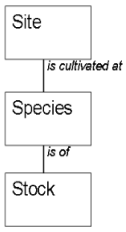


FIGURE 6.3 Conceptual diagram of static business structure

4.4 PRIMARY PROCESS: ORDER PROCESSING

The processing of orders is apparently done in subsequent steps: intake, picking, delivering. This is not evident from the requirements, but it is based upon our interpretation that an order goes through four subsequent stages: order request, actual order, picked order and order delivery. Therefore, we describe the rules and our analysis of the order processing in three parts or "patterns". We analyze the business requirements a few at a time, and work in small steps. This way of working is verifiable and it helps us to produce valid rules. But remember that the choice of patterns does *not* reflect the actual way of working in the business. Although we write that the patterns "start" and "end", no flow of time or workflow is intended. The only thing that "happens" in a pattern, as far as we are concerned, is that violations of its rules are signaled.

Order Intake This pattern starts with an order request being received from a customer, and it ends with an actual order being on record. This pattern is designed to include the following requirements:

- Only plants in stock may be ordered.
- The actual order may be for fewer plant species than the order request, but never for more.
- An actual order is for the same customer who put in the order request.

Notice that a requirement like "only senior employees should deal with order requests" is not included here. The reason is that the primary concern of customers is that their orders be dealt with, but it is irrelevant for them which employee does what. Therefore, we place the business rules about employees and tasks in another, secondary pattern.

This pattern involves three new concepts: Customer, OrderRequest and Order. Officially, the designer should provide precise definitions and check back with the stakeholders, but we skip that for the sake of brevity. And we introduce the following six

relations, again without definitions which would be unacceptable in more realistic business conditions:

- Customer *requests* OrderRequest. This relation is injective and surjective: each OrderRequest *is_requested_by* exactly one Customer (which is to say: relation *is_requested_by* is a function).
- OrderRequest *is_for* Species.
- Customer *places* Order. This relation too is injective and surjective: each Order is placed by exactly one Customer.
- Order *is_for* Species. This relation is total.
- Order *affects* Stock. This relation is total.
- OrderRequest *is_processed_into* Order. This relation is univalent, injective and surjective. It is not total: it is not a violation if an OrderRequest is not processed into an Order.

No multiplicity constraints apply to the OrderRequest *is_for* Species relation. Indeed, a species may be cultivated irrespective whether there are zero, one or many requests for it. And one OrderRequest may be related to no species, to one species, or to any number of species, none of which is a violation. Indeed, a designer needs to pay attention to is how to deal with requests for things that are not being sold, and how to deal with orders requested by people who are not yet a customer.
So, can we allow an OrderRequest from an unknown Customer? No, the business does not permit that, hence we impose a rule to that effect: the *requests* relation is constrained to be surjective. This means that, unless related to some Customer, an instance of OrderRequest is meaningless and should not be recorded. This is an example of a rule that is captured in the Conceptual Model as a structural rule.

A related question is: can an OrderRequest be for a plant species that the company does not cultivate? In this case yes, the business does allow it. Evidently, it is a bit of a problem, as the OrderRequest cannot be processed into a regular Order and the customer probably should be informed to that effect?
One way how the business may deal with this issue is that in response to an OrderRequest, the Customer receive a notification if certain plants cannot be delivered. A business rule should then assure that each species in the OrderRequest is included either in an actual Order (if deliverable), or in the Notification (if not), but never in both. Before proceeding, the designer should of course submit this idea to the stakeholder for approval. As our requirements do not mention the need to inform customers of undeliverable plants, we leave the details to the reader who is invited to provide the appropriate relation(s) and rules.

The relation Order *affects* Stock also needs some explaining. The idea is that later on, in the phase of software development, the relation can be extended to include the exact dates and ordered amounts, and so keep track of the available stock size. As explained, we will not deal with dates and numbers in this example.

Finally, the relation name *is_processed_into* looks a bit suspicious because it suggests processing, a flow of time, sequential workflow. The definition of this relation should clearly explain that it is no more than just a relation linking OrderRequests to Orders, no hidden activities or sequences intended. Surely it does not dictate that you must first record an OrderRequest instance, then execute some action, then record an Order instance, and finally link the two. A relation is not an *imperative rule*, there is no event-condition-action involved. The point here is that relation names should be helpful for understanding, not misleading. If stakeholders have a wrong interpretation of any of your concepts or relations, then you should either explain better, or try to come up with better names.

Imperative rule

The business requirements of the Intake pattern, listed above, can now be rephrased and captured in formulas of relation algebra as follows:

Natural language: only plants in stock may be ordered, or: if an Order is for a

Species, then it affects the Stock for that Species
Controlled language: *if* an Order *is_for* a Species, *then* some Stock exists such that the Order *affects* that Stock *and* that Stock *is_of* that Species
Rule assertion: $is\_for \vdash affects \,;\, is\_of$.

The next requirement is analyzed as follows. Notice how the first part of the statement is perfectly understandable, but does not impose a constraint. The business rule is in the second part that specifies what should not be violated:

Natural language: the actual order may be for fewer plant species than the order request, but never for more.
Controlled language: *if* an Order *is_for* a Species, *then* there is some OrderRequest such that the OrderRequest *is_processed_into* that Order *and* it *is_for* that Species
Rule assertion: $is\_for \vdash is\_processed\_into^{\smile} \,;\, is\_for$.

And finally (as always, be careful of inverses when combining relations!):

Natural language: an actual order is for the same customer who put in the order request.
Controlled language: *if* an Order *is_placed_by* a Customer, *then* there is some OrderRequest that *is_processed_into* that Order *and* it *is_requested_by* that Customer
Rule assertion: $places^{\smile} \vdash is\_processed\_into^{\smile} \,;\, requests^{\smile}$.
Or equivalent: $places \vdash requests \,;\, is\_processed\_into$.

Figure 6.4 is a Conceptual Diagram of the Order Intake pattern. Notice that we include relation Stock *is_of* Species because it figures in one of the rules. With five concepts and seven relations, its cyclomatic number is three. At this point, the reader should verify that each relation participating in a cycle is involved in at least one composite rule, in keeping with the ideas of cycle chasing.

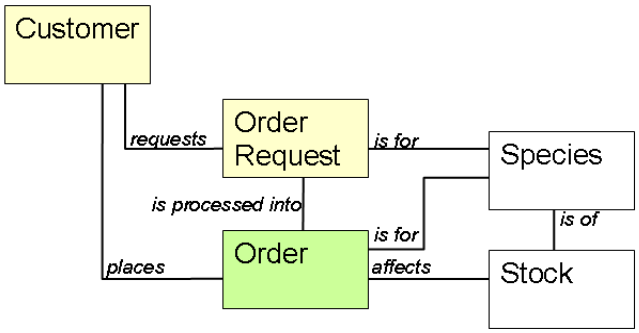


FIGURE 6.4 Conceptual diagram of Order Intake

Order Picking This pattern starts with an order on record, and ends with one or possibly several picked orders, each one ready for delivery. This pattern is designed to include the following requirements:

– A picked order is for the same customer who placed the order.
– An order and the corresponding picked orders contain exactly the same kinds of plant.

We introduce one new concept with three relations:

– PickedOrder *is_destined_for* Customer. This is a function.
– Order *is_processed_into* PickedOrder. This relation is total but not univalent: an Order may be split into several PickedOrders. The reverse relation is a function: each PickedOrder results from exactly one Order.
– PickedOrder *contains* Species. This relation is total but not univalent.

Order picking will obviously affect the amount of plants in stock, and a careful rule analyst will of course bring this point to the attention of the stakeholders. As there are no clear requirements addressing this issue in the example, we will overlook this important aspect here.

The additions will increase the overall cyclomatic number by 2, so we expect two composite rules. One rule will check for violations from the point of view of the customer:

Natural language: the picked order is for the same customer who placed the order.
Controlled language: *if* a Picked Order *is_destined_for* a Customer, *then* there is some Order that *is_processed_into* this Picked Order *and* that *is_placed_by* this Customer
Rule assertion: $is\_destined\_for \vdash is\_processed\_into^{\smile} ; places^{\smile}$.

Another rule should check for violations from the point of view of the plant species. The requirement is that an order and the corresponding picked orders (one or more) contain exactly the same kinds of plant. Actually, this is not one, but two demands packed into a single sentence:

Natural language: A picked order must contain no other kinds of plant than the corresponding order.
Controlled language: *if* a Picked Order *contains* a Species, *then* there is some Order that *is_processed_into* this Picked Order *and* it *is_for* this Species.
Rule assertion: $contains \vdash is\_processed\_into^{\smile} ; is\_for$.
And when we add relation *is_processed_into* at the left sides of both expressions: $is\_processed\_into ; contains \vdash is\_for$.

In the last line, the laws for rewriting compositions were applied.
Recall that $is\_processed\_into^{\smile}$ is a function, so *is_processed_into* is injective and $is\_processed\_into; is\_processed\_into^{\smile} \vdash \mathbb{I}$.

The reverse also holds: the combination of all PickedOrders picked for an Order, must contain at least the same kinds of plant as that order:

Natural language: An order contains no other kinds of plant than the combined picked orders.
Controlled language: *if* an Order *is_for* a Species, *then* this Order *is_processed_into* some PickedOrder (*and*) that *contains* this Species.
Rule assertion: $is\_for \vdash is\_processed\_into ; contains$.

So here we have two rule assertions that apply to the same cycle. In this example, the two assertions can be merged into a single equality. But it is better not to merge two rules, if you think the business prefers to enforce them differently. Picking a species that is not in the order may be signaled immediately as a violation. But forgetting to pick a species on order may perhaps be signaled later, for instance by a Quality Control worker responsible for final checking. The choice of enforcement strategy should be discussed both with the business workers and with the software developers responsible for its implementation. It is a best practice to invite discussions for each separate rule, and rules should not be merged into one assertion too soon. Figure 6.5 is a Conceptual Diagram of this pattern.

Order Delivery This pattern starts with a picked order ready to be delivered, and ends with the customer receiving it. It is a matter of judgment whether to include receipts in this pattern too: you might decide that receipts are not really primary process but serve to initiate another process such as "payments" or "billing". In this example, we will include the receipts, but we stop short of modelling the bills to be paid. The requirements are:

– Upon order delivery, the customer receives the receipt of the picked order.

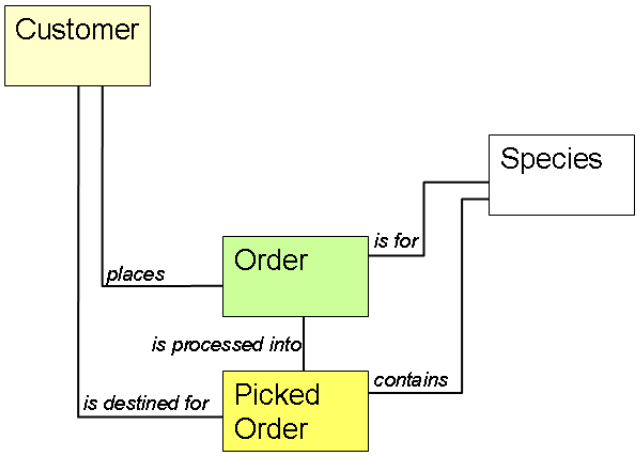


FIGURE 6.5 Conceptual diagram of Order Picking

– An order delivery is for the same customer as the corresponding picked order.

How must we understand the "upon order delivery" phrase in the first requirement? Apparently, it refers to timing, to the event of delivering as it occurs at a certain moment in time. It is not the same as the "OrderDelivery" concept in the second requirement, which can be defined without referring to time. The former requirement may well be rephrased as follows:

– Each customer receives a receipt of the picked order.
– Exactly one receipt is attached to each order delivery.
– The customer receives the receipt of the picked order at exactly the same time as the order delivery to that customer.

The first and second statements are invariant with respect to time, but not the third one which is very much dependent on time. To capture that in relation algebra would require us to include timestamps in the Conceptual Model. We avoid doing that for reasons explained earlier, and so we have to exclude this particular requirement from our analysis. Two concepts and five relations may capture the time-invariant requirements of order delivery:

– Customer *receives* Delivery. The inverse of this relation, *is_received_by*, is a function.
– Customer *receives* Receipt. The inverse of this relation, *is_received_by*, is also a function.
– PickedOrder *is_processed_into* Delivery. This relation ought to be a bijection: each picked order should be delivered, each delivery corresponds to one picked order.
– Receipt *is_of* PickedOrder. This relation is a function.
– Receipt *is_attached_to* Delivery. This relation is a bijection, which will ensure that exactly one receipt is attached to each order delivery.

The Conceptual Diagram depicts the two concepts of Delivery and Receipt in very much the same way, and there is even a bijective relation between them. So why two concepts, if they are so much alike?
Their difference cannot be learned from the diagram, but only from their intensions, the business definitions. A dictionary definition of 'delivery' contains expressions like 'a passing from one to another' and 'that which is delivered'; the focus is on material things that pass into the hands of the customer. The same dictionary describes 'receipt' as 'that which is delivered' also, but adds 'prescription' and 'a signed acknowledgement of money or goods received'. This clearly focuses on information content, not on material goods.
Furthermore, in the day to day business, deliveries may be made by one employee, while receipts may be printed by someone else, at another time and place, being a

matter of business workflow and implementation. So even if the information system will capture both concepts only by data, and the data may be very much alike, their business semantics is certainly different.

The requirements of order delivery can now be captured by two composite rules:

Natural language: An order delivery is for the same customer as the corresponding picked order.
Controlled language: *if* a Customer *receives* a Delivery, *then* there is some PickedOrder that *is_processed_into* this Delivery *and* that PickedOrder *is_destined_for* this Customer.
Rule assertion: $receives^{\smile} \vdash is\_processed\_into^{\smile} ; is\_destined\_for$

The business rule for receipts may be asserted as:

Natural language: Each customer receives a receipt of the picked order.
Controlled language: *if* a PickedOrder *is_destined_for* a Customer, *then* there is some Receipt that *is_of* this PickedOrder *and* this Customer *receives* that Receipt.
Or formulated in reverse: *if* a Customer has a PickedOrder *destined_for* him, *then* this Customer *receives* some Receipt which *is_of* this PickedOrder.
Rule assertion: $is\_destined\_for \vdash is\_of^{\smile} ; receives^{\smile}$.
Or equivalently, its inverse: $is\_destined\_for^{\smile} \vdash receives ; is\_of$.

Figure 6.5 is a Conceptual Diagram of the Order Intake pattern. Remark how this pattern is strongly focused on order delivery, and does not refer to plants any more.

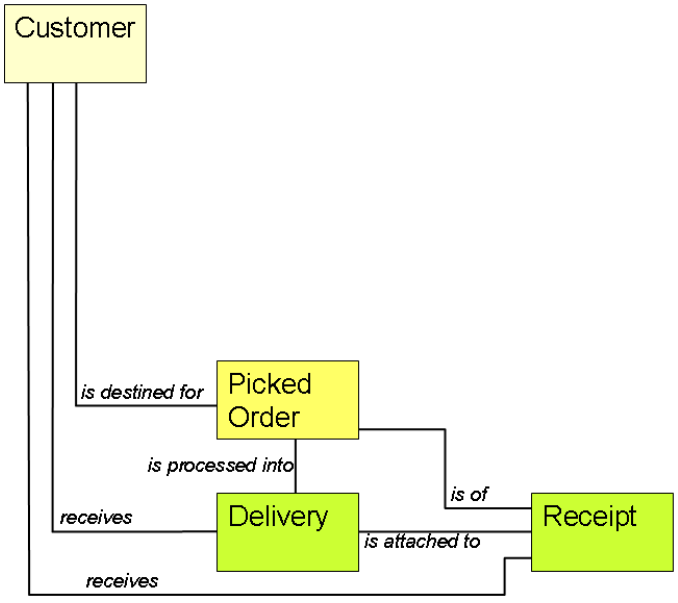


FIGURE 6.6 Conceptual diagram of Order Delivery

Combining patterns: processing orders for customers So far, we analyzed four patterns, accounting for all requirements involving the Customer concept. The combined Conceptual Diagram is depicted in figure 6.7. How well have we done?

Cycle chasing

A first verification of the Conceptual Model and rule assertions to apply the ideas of *cycle chasing* as explained in the previous chapters. For this, calculate the cyclomatic number, and check if there are at least as many rules. In fact, you should look a little closer: is every relation partaking in a cycle, constrained by a rule? If the number of rule assertions is less than the cyclomatic number, there might be a relation that is not involved in any compound rule. Such a relation, perhaps subjected to mul-

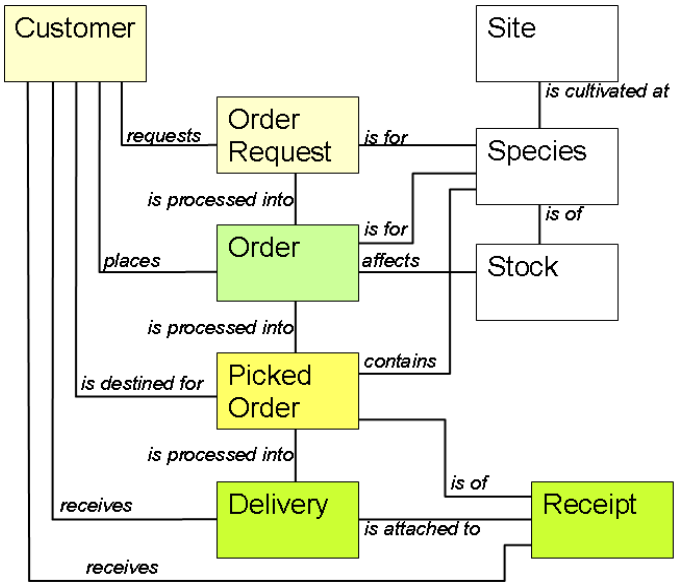


FIGURE 6.7 Conceptual diagram of combined patterns for processing orders for customers

tiplicity constraints, appears to be unconstrained otherwise, meaning: whatever its population, no violations will turn up.

The proper check is to verify that every relation is suitably constrained by some business rule or other. If you perform this check, you will find that relations Species *is_cultivated_at* Site nor Receipt *is_attached_to* Delivery are involved in any rule assertions (other than multiplicity constraints). We leave it up to you to analyze this situation and decide upon rules which may be appropriate.

Control principle

Second, recall the *control principle* of chapter 2. The principle states that the combined set of business rules, should drive the entire flow of work. This is a very important feature of Rule-Based Design, and any designer will want to verify that indeed, the rules do accomplish it. Checking this principle reveals a very important shortcoming in our requirements: the rules in our example do not yet drive the workflow!

A customer will expect that a request for plants will result in a delivery of plants. Indeed, we know that OrderRequest *is_processed_into* Order *is_processed_into* PickedOrder *is_processed_into* Delivery. But nothing will guarantee that a customer will receive at least one Delivery in response to one OrderRequest. In fact, the problem is more fundamental: no rule is violated, no signal is raised if a customer never receives any delivery at all, even if a perfectly acceptable order is recorded. In other words: even if all rules specified by the business are satisfied, use cases triggered by the customers may not get to be *closed* from their point of view. The rule to drive the primary process, the processing of orders for customers, is still lacking. Here is a proposal:

Closed

Natural language: If an order is placed by a customer, then that customer receives at least one delivery for it.
Controlled language: *if* an Order *is_placed_by* a Customer, *then* there is a PickedOrder such that the Order *is_processed_into* that PickedOrder, *and* there is a Delivery such that the PickedOrder *is_processed_into* that Delivery, *and* that Delivery *is_received_by* that Customer.
Rule assertion: $places^{\smile} \vdash is\_processed\_into; is\_processed\_into; receives^{\smile}$.

This rule drives the process of placing the order up to its delivery, leaving out the initial part where a customer puts in a request for any plants whatsoever. In fact, a process designer may split the primary process in two: a preparatory part of re-

questing, which may or may not result in an order being placed (and possibly a notification). And the main process, which makes sure that every placed order is indeed delivered.

Static business structure: the employees Having formalized rules about the primary process, let us now consider rules that were left over. The requirements from section 4.1 not yet dealt with, mainly concern employees and their tasks. For a start, it is clear that we should discuss employees and senior employees. As an illustration, let us propose a definition of these two concepts:

Employee

- An *employee* is: a living person, acting for the business and under business jurisdiction.
- A *Senior_employee* is: an employee designated as a senior.

Employee is based on the broader concept of Person. The definition captures the regular employees, and also contracted workers and temporary help. At the same time, it excludes a person and his actions, if such actions are outside business jurisdiction, e.g. as a football player in the weekend. In practice, many definitions are fashioned like that: relying on some broader concept, one or more special properties are listed that lets a user decide unambiguously whether some thing "in the wild" is, or is not an instance of the concept being defined. Chaining refinements in this way is perfectly acceptable in relation algebra.

Senior_employee is defined as a specialization of Employee which itself is a specialization. To be considered senior, the definition states that the employee needs to be designated as such. It does not explain when, why, by whom or how one may be designated. The definition may tell the user how to determine whether an employee is senior, but it is left up to the user to perform this check, it is beyond our business context. If however Senior_employee would be defined as "employee who is responsible for stock", then it is a rule within our context: the set "Senior_employee" should at all times be exactly equal to the source of the relation *is_responsible_for*. Would this indeed be the correct definition, then we have identified a new rule, one that is not so obvious from the requirements.

Figure 6.8 is a Conceptual Diagram of the extended static business structure pattern. Interestingly, the diagram contains no cycle, and no compound rule. Even more interesting: it is disconnected, consisting of two subdiagrams that appear to be unrelated.

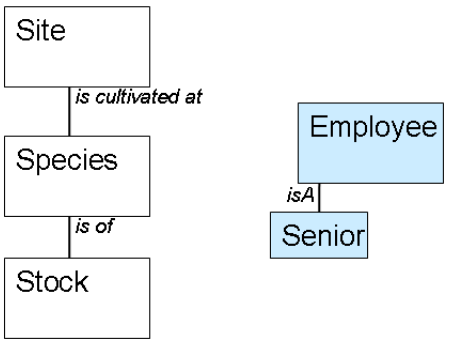


FIGURE 6.8 Conceptual diagram of static business structure, extended

Generalisation

Capturing Senior_employee as a distinct concept is a design choice. In the conceptual diagram, the concept is depicted and labeled "Senior", and there is a *specialization-generalisation* relation: Senior_employee *isA* Employee. As explained previously, a specialization like this can also be captured by an homogeneous property relation *is_senior* on Employee. The Conceptual Diagram would depict that as an arc on one

concept only, the label "senior" now being attached to the relation, not the concept. A third option is to assign each employee a status, with instance values either 'regular' or 'senior'. This removes the label "senior" from the level of the Conceptual Model. Instead, it appears in Instance Diagrams as an instance in the population of Status. Other factors, such as business circumstances or private considerations of the designer will determine which option is preferred.

Secondary process: facts about employees One of the requirements from section 4.1 is:

– Only senior employees should deal with order requests because they are responsible for each stock.

This requirement is captured by way of two relations with unknown multiplicity constraints:

– Senior_employee *is_responsible_for* Stock.
– Employee *deals_with* OrderRequest.

And the requirement is analyzed as follows:

Natural language: Only senior employees should deal with order requests because they are responsible for each stock.
Controlled language: *if* an Employee *deals_with* an OrderRequest, *then* that Employee *isA* Senior_employee (who *deals_with* that OrderRequest)
Rule assertion: $deals\_with \vdash isA^{\smile} ; isA ; deals\_with$

Notice how the "because they are responsible for each stock" part is absent from the controlled language. The phrase uncovers a relation, but it does not lay down any rule. The $isA^{\smile};isA$ composition in the formula constitutes a homogeneous binary-property relation. It contains all instances of the Employee concept who, via *isA*, are related to an instance of the Senior_employee concept. This $isA^{\smile};isA$ composition, representing (the subset of) senior employees among the entire set of employees, has the same practical meaning as an homogeneous property relation *is_senior*.

Structural business rule

Earlier, we outlined how operational business rules can be violated, whereas *structural business rules* cannot be violated within the context of the Conceptual Model. Now consider the rule that only senior employees should deal with order requests. Is this rule a structural one, or is it operational? In this case, it depends.
We defined relation *deals_with* with Employee as its source concept. This expresses the view that in general, any employee might deal with any order request, except there is a restriction, an *operational business rule* in place to forbid it. Alternatively, we could have specified the *deals_with* relation with source Senior_employee. That design choice would have turned the rule into a structural one because the tuples populating such a relation cannot but refer to senior employees.

Operational business rule

A similar design choice concerns relation *is_responsible_for*: do you specify Employee as its source, or do you prefer Senior_employee? The distinction between structural and operational rule is not always absolute, and may depend upon convenience and personal preference.

Another requirement that we have not dealt with is:

– The employee who picks the order must write the receipt for it.

By now, the way of working is familiar.
The first step is to check if any new concepts are mentioned; for these two requirements, not. Next, to check the need for new relations, and to specify their intention (definition) and multiplicity constraints. Here, we need two or even three relations:

– Employee *picks* Order.
– Employee *prepares* PickedOrder.

– Employee *writes* Receipt.

All three relations are injective: Order *is picked by* at most one Employee, etcetera. Moreover, all three are surjective: each Receipt is picked by at least one Employee, etc. That is, the inverses of all three relations are functions.

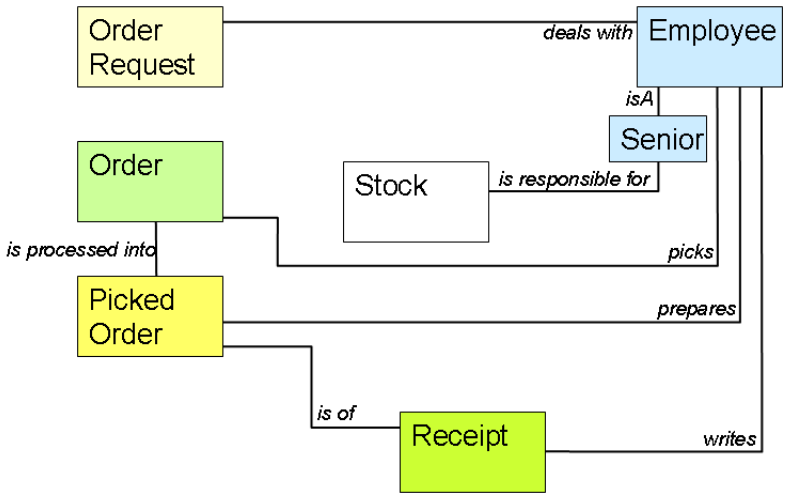


FIGURE 6.9 Conceptual diagram of employee relations

The third step is to go chasing for the precise business rules that lie hidden in the business requirement. As we added three new relations and no concepts, the cyclomatic number went up by 3 and we may expect compound business rules to constrain these relations.

Notice how the phrase that "the employee who picks the order must write the receipt for it" mentions the activity of order picking, but not the outcome, i.e. the PickedOrder. So why did we specify an Employee *prepares* PickedOrder relation? It is because the requirement apparently suggests that the activity of picking for an order is always done entirely by just a single employee, and produces only a single outcome. Always. Even if the order is too large for one person, or if the employee runs out of stock while picking. Put like this, the requirement seems questionable and you should discuss it with the stakeholders.
Meanwhile, we propose to declare the injective relation Employee *prepares* PickedOrder, not evident from the requirements, and turn the single requirement into two distinct rules. The advantage is that the resulting rule assertions are simpler. Moreover, it makes the hidden assumption that each order is to be picked by just one employee explicit, which will ease discussing it with business stakeholders. As said earlier: never hesitate to introduce a new relation or concept if you have a good reason to do so.

Natural language: The employee who picks the order must write the receipt for it.
Controlled language: *if* an Order *is picked by* an Employee, *then* that Order *is_processed_into* one or more PickOrders *and* every one of them *is_prepared_by* that Employee,
plus: *if* an Employee *prepares* a PickedOrder, *then* that Employee *writes* some Receipt which *is_of* that PickedOrder.
Rule assertions: $picks^{\smile} \vdash is\_processed\_into \mathbin{[} prepares^{\smile}$
plus: $prepares \vdash writes \mathbin{;} is\_of$

Relative implication

The *relative implication* operator denoted [was explained in chapter 3.

Figure 6.9 depicts a Conceptual Diagram with employee relations so far. Notice that it does not show the Customer, because as far as the rules are concerned, no direct relation between employees and customers is relevant.

Two final requirements have still not been accounted for:

– Employees only work at a single site.
– An order may only be picked by employees who work at the site where the species is cultivated.

Obviously, we need to add one relation to the model:

– Employee *works_at* Site. This relation is univalent.

The *works_at* relation may perhaps be total, but that is not clear from the requirements. What about new employees who are not yet allocated to a site? Or travelling sales representatives?

An even more serious problem emerges when analyzing the requirement about the site where employees work. What if an order involves several species, and they are cultivated at different sites? As it is, an employee can pick any order, regardless of where he works or where stock is located. It is likely that employees only pick orders for the plant species cultivated at his/her own site, but no such restriction about employees and order picking is in the original list. As with other concerns, you should check back with the stakeholders. Meanwhile, we challenge the reader to propose a working solution for this problem, and extend the design with the relations and rules that are involved in that solution.

4.5 DELIVERING THE RULE-BASED DESIGN

We can merge the concepts, relations and rules discussed above into a single rule-based design accounting for all requirements of the flowering-plants business that we declared to be within our context. Figure 6.10 depicts the integrated Conceptual Diagram of all patterns combined.

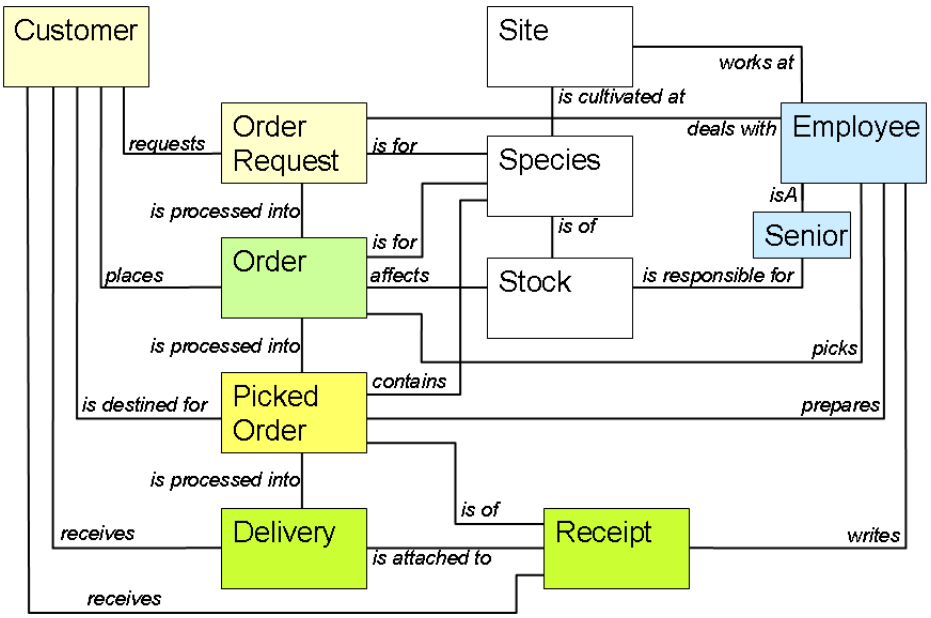


FIGURE 6.10 Conceptual diagram of all patterns combined

In accordance with the Ampersand way of working as explained in 6, ingredients of this rule-based design

– the list of all requirements as put forward by the users,
– a conceptual model capturing all the relevant concepts and relations,
– a complete and correct set of rules, asserted in relation algebra,
– trial populations for all concepts and relations, and

– validation evidence to bear witness that the concepts, relations and rules are in full agreement to the requirements.

An Ampersand script of the design is available on the accompanying website of this book.

Two ingredients of a proper Rule-Based Design are yet to be provided. One is trial data sets for all concepts and relations. The conceptual model with its rule assertions can be populated with test data. Seeding the model with data will bring out the workings of the rules, and possible errors in their precise assertions will become evident. Moreover, it will illustrate the Control Principle: if an order is placed, the customer will receive at least one delivery for it. An extensive set of trial data is excellent evidence to underpin the claim that the model and rules validly capture the business requirements.
The reader is invited to take the Ampersand script provided on the website accompanying this book, and populate it with test data in order to provoke and eliminate rule violations.

The final step before completion is to validate the design with the business. A number of issues as pointed out in the text needs to be clarified, and also our interpretations of the requirements with the business should be checked. A designer should be able to explain the model and all of its formal rule assertions in natural language for the business workers to understand and approve.
While validating, it should be confessed to the stakeholders that several aspects of the business context were noted, but ignored. Some of these issues should be dealt before system development starts, e.g. customers will not receive notifications if they request some non-available plant, or the problems of incomplete deliveries and returns. Or that receipts are written in order to trigger financial processes that we left out of our scope. Other issues may be dealt with in system development, such as the requirements about dates or numeric calculus that we left out because they cannot be easily expressed in relation algebra.

5 Highlights of the example

The example of the flower-cultivation business illustrates how to start from business requirements, how to analyze requirements for each part of the business, to define concepts and relations, and how to capture the rules that control the way of working in the business. The result is a design that captures all the relevant rules, and also gives precise meanings of the concepts and relations used to express these rules in the business vocabulary.

Highlights of the example according to the Ampersand way of working are:

Decomposing the business requirements. Starting from business requirements, we conceived a small number of themes, each with just a few requirements. Which themes to choose, and how to set their scopes, is largely a matter of design experience that is best learned by doing. Per theme, we analyzed the requirements and defined relevant concepts and relations, paying attention to consistency with (concepts, relations and rules in) other themes.

Transform requirements to rules. For each theme, we analyzed the business requirements in imprecise, natural language and transformed them via one or more intermediate steps to precise rule assertions. The analysis brought out various points of ambiguous or inadequate requirements. For the sake of the example, we made several assumptions in order to produce the partial model and rule specifications per theme. Each partial model can and should be presented to, and discussed with those stakeholders having an interest in that theme.

Analyze, capture, clarify, validate. A good designer will analyze each requirement separately, i.e. without reference to other rules. Each rule must be motivated from a business perspective: what is its business purpose? Why should the business workers abide by the rule and not violate it? If you cannot explain a rule to a business stakeholder, then you should ask if it is a rule at all.

Determine constraints of all relations. With very few exceptions, all relations are subject to constraints. Multiplicity constraints, and if a relation partakes in a cycle, then probably some other rule(s) too. Cycle chasing helps to verify a design and capture its rules. You may verify that all relations in the example are properly constrained, either by strict multiplicity constraints or by rules involving cycles, or -most often- by both. Also notice how the majority of cyclic rule assertions involve no more than three relations.

Rules may impact several themes. Requirements can be analyzed, and concepts and relations can be scrutinized and populated per theme. But rules can and often will involve relations specified under other themes. This is no problem at all. Whether or not a rule refers to relations of just one theme or multiple, the rule can and should be asserted in exactly the same way. Also, how to enforce a rule or how to handle its violations depends on business agreements, and not on the particular themes that you have chosen.

Context integration. The integration of partial models and rule assertions produces a Conceptual Model that provides an integral view of the selected business context, and meets all its business requirements. Verification and validation can and should be performed at regular points during design.

Control principle. The Control principle states that a use case is processed, if all violations are eliminated one by one. In the example, the rule to drive the primary process was found to be absent from the requirements, and we had to invent the driving rule ourselves. The extra rule, having little or no impact on the conceptual model, is very significant from a business point of view. In other words: cycle chasing alone, is no guarantee of completeness from a business point of view. It is remarkable how the Control Principle, and the understanding of invariant rules, produced this useful insight in the overall business way of working.

6 Characteristics of good design

The examples in this chapter aim to demonstrate to you the characteristics of good designs. You should always strive for designs that incorporate these characteristics in the best possible way.

However, there is no “perfect design”, no universal truth, nor is there a single best way to come up with a best design. Every business context and environment comes with its own features and requirements, so be sure to validate your design solutions with the stakeholders. Never forget that it is their business problems that you are helping to solve.

Still, no matter what you deliver, always be prepared to discuss and explain your design. Because there is a need to capture more requirements, to improve the ones you did capture, and to have a more sophisticated support for their enforcement. A design is never finished. Therefore, you must pick a moment to stop discussions and freeze the deliverable. That point can be reached for mundane reasons, such as a deadline imposed by management or customer contract.

Important characteristics of a good rule-based design are:

Separating the know from the flow. A rule-based design is declarative and specifies which rules must be abided by. Declarative rules capture what information should be recorded to check compliance to the business requirements, but do not prescribe how to achieve compliance in imperative fashion. Indeed, all rules in the example are declarative by nature.
A good design specifies the rules, but not how to eliminate violations, or the exact actions to be undertaken, or the workflow sequence. This principle is also referred to as "enforcing the rules, not the actions". Declarative rules separate the *knowledge*, i.e. data about the business and violations of rules (the "know"), from *process management*, what actions should be undertaken by which actor (the "flow"). As a consequence, "rule compliance" and "process flow" become distinct issues and can be discussed separately, one with business quality controllers, the other with process managers. Relation algebra maintains a rigorous distinction between the rules, the rule enforcements, and the recorded data as resulting from user actions. This distinction is also a basic characteristic of the Ampersand method.

Match the business requirements and rules. A good designer will analyze the rules and rephrase them for simplicity and clarity. In the end, each requirement corresponds to a single rule ideally. An additional advantage of a close match between rules and business requirements is that it will keep the amount of rules manageable.

Usually, the number of rules is approximately the same as the number of functional requirements. For most information systems and business processes in practice, this number runs typically between 50 and 500. If for a system to be designed you can keep the number of rule assertions manageable, the overall design and the functional specifications will probably be simple and small enough for business users to understand. And the information system will hopefully be of acceptable size and complexity too. The match between business requirements and rule assertions is a feature of the Ampersand method that helps to curb the complexity of designs.

Decompose the problem, compose the solutions. Once the overall business requirements are clearly stated, the smart thing to do is not, to create one grand design to capture all features of the business. A good designer will try to decompose the design challenge into themes that, at first glance, appear to be self-contained and independent, each theme being the domain of just one group of stakeholders with specific business concerns. As there is no sure way to determine a "best possible" decomposition, the engineer must rely on professionalism and personal experience to pick the themes. Each business requirements can be proposed, analyzed, rephrased and rewritten, validated with stakeholders, and finally be captured as a rule that is ready for inclusion in the design. In the end, you as the rule-designer should collect the results for each theme, and merge it into a single, coherent rule-based design. The composability of separate themes (called "patterns") is a useful bottom-up design feature of the Ampersand method.

Incremental design. During design, any and all requirements may change. Because a good design keeps track how the business requirements are matched with the rules, you can quickly determine the impact of a requirement change. New relations can be added to provide more detail, and improved, more refined rules may be formulated. Thanks to the clear and uniform structure of relation algebra, each concept, relation and rule in a rule-based design has a well-defined scope. Therefore, when you need to make a change in your design, it is easy to determine which concepts, rules and relations are impacted by the change. And once the change is made, you can compose the themes and produce a new design that meets the desired changes. Each time a rule is added, the entire specification can be validated. Most of the trial data that was available to validate the previous design can probably

be reused to validate the new one, and you only need to provide new test data to validate the specific changes that you just made.

The ability to handle rules one-by-one, without reference to other rules, is a necessary condition for incremental design, which is an important feature of the Ampersand method.

The Ampersand method and toolset aim to support designers in all of these aspects of good design. The Ampersand toolset for rule-based design support analysis, verification and validation. The toolset provides a designer with an overall view, and it provides views per theme, and views for just one specific rule in the design. Ability to switch between views helps to understand and integrate all local and global aspects, which eases the design effort and improves quality of the design result.

The Ampersand method and toolset also provide flexibility to deal with changes over time. Business requirements, and the models that accommodate them, are not static. Laws and regulations will change, the business environment will evolve in unpredictable ways, new technologies and business services will be introduced. And the business requirements will change accordingly. Because Ampersand has the ability to handle each rule separately, a design can be adjusted by changing just one rule. The separate themes can be integrated again to analyze the overall impact of change.

7 Conclusion

This chapter discussed examples of rule-based design taken from practice. Each example was based on practical problems encountered in the business environment. Once you have a set of business requirements that is properly captured by way of rules, you can reuse the set in other projects having a similar business context and purpose. The rules probably need some adjustment, and variations in rule enforcements or exceptions may be expected, but the overall formalizations will probably not be much different. By studying, understanding and imitating the examples, from this book or others, you will acquire expertise in interpreting the demands from business stakeholders, in phrasing the requirements with rigorous precision, and in designing conceptual models and rule assertions that exactly capture the business requirements. The next chapter discusses how the Ampersand approach was successfully applied in a large systems-development project that centered on rule-based design.

INDiGO

Chapter 7

INDiGO

1 Introduction

This chapter illustrates a way of working that is typical for rule-based design. Each idea that is key to a design is defined as a set of rules. This creates room to discuss different key ideas with different groups of people. The composition of all key ideas yields the solution architecture. The case discussed here is INDiGO, a project where Ampersand proved to be a major asset during the tendering phase. In INDiGO, Ampersand enabled designers to isolate the key concepts and discuss them with stakeholders in a very early stage. As a consequence, a comprehensive system architecture was already available at the start of system design. The contribution of Rule-Based Design was to maintain correctness and consistency of this system architecture under the extreme time pressure that is common to tenders.

In 2007, the Dutch immigration authority, IND, published a tender for its information provisioning. The IND is responsible for executing the laws and regulations related to immigration. This involves residence permits, asylum, naturalisation and appeals in court. The size of this bid and a tight tendering schedule forced contenders to combine forces. Only three consortia qualified for participating in the competition. Competitors were required to define their solutions exhaustively in their offers, forcing the entire design stage to take place within the timeframe of the bid.

One of the consortia, headed by a tandem of the companies Ordina and Accenture, went for a no-risk design approach. They designed an integral solution, named INDiGO[1], consisting of commercial-off-the-shelf (COTS) software components only. Yet the solution had to respect every rule in the Dutch immigration law. In order to meet this quality constraint within the tight schedule of the bid, the consortium decided to compose the solution architecture in a formal manner. The contract was awarded at the end of 2007. When the project started early 2008, the consortium had delivered a start architecture document that contained the integral solution, with detailed descriptions of all key ideas involved in the design. In the summer of 2010, the system went live.

The IND tender marks a first occasion in which Ampersand was used on the critical path in a large IT project. For this reason, INDiGO makes an interesting case study for those who want to use Ampersand. This chapter discusses some of the key ideas of INDiGO and illustrates them with the actual specifications. The first section provides an overview of the guiding principles that govern the design of INDiGO. The second section introduces some of the key ideas, two of which are elaborated in a subsequent section. At the end of this chapter we reflect on the use of formal methods in the design of large information systems and business processes.

2 Guiding principles

This section summarizes the actual requirements of the IND in terms of guiding principles. The IND wanted to become flexible, customer oriented, effective, and efficient. Throughout the design, these four principles have been used to motivate design choices.

[1] This name was chosen by IND after a naming contest among IND personnel

Flexibility in the eyes of IND means that changes in legislation and regulation can be absorbed instantly, without any changes in the software. Coming from a situation in which custom built database applications dominated, this was understandable. IND was used to very long turnaround times indeed, when software changes are needed as a result of new regulations.

Customer orientation means that IND wants to give her clients a red carpet treatment. This involves careful handling of client data, informing clients correctly and in time, complying with the requirements by law, and compliance to all explicit and implicit requirements. Coming from a situation with considerable backlogs and several public incidents, customer focus was a clear driver of many of IND's requirements.

Effectiveness means to IND that every single action taken any day on any location is compliant with then-current regulations, and traceable to the original motivation and legal evidence. IND wanted to eliminate even the possibility to make legal mistakes. But even if a mistake was made, it was required that all actions are recorded in a legal procedure file.

Efficiency means to IND that no unnecessary actions are taken and that processes are well controlled, well organized, and irredundant. The IND came from a situation in which unnecessary manual actions were required, duplicate work existed, and employees sometimes felt like red tape workers. In the minds of these employees, efficiency has a very concrete meaning.

The general principles of flexibility, customer orientation, effectiveness and efficiency are solution independent principles, prescribed by IND. During the tendering process, these principles have been augmented by six others: quality, integration, manageability, consistency, compliance, and security.

Quality means that all properties of interest have been made objectively quantifiable, in ways that enables management control during the transition phase. Since the entire transition is planned in a period of four years, there is a genuine need for making that transition manageable.

Integration means that the user gets the impression of a single application, which results in the perception of simplicity. Integration is achieved by means of a service oriented design.

Manageability means that every singular management incident involves a single adaption in the system, without any software change. This requires that all data is stored in a single place, and all dependencies are implemented in a generative fashion.

Consistency means that all data is consistent with the design rules and remains consistent. Consistency has been built in up front by making all design rules explicit in an Ampersand analysis. The primary instrument for data consistency is the knowledge model.

Compliance means that INDiGO will respect all current legislation and regulations in a durable way. For that reason, the relevant regulations are translated in a knowledge model.

Security means that the design complies with all requirements from VIR-BI, which is the applicable security standard in government. INDiGO can handle all information up to the level "departmentally confidential". Information that is more confidential than that must be kept outside the system.

3 Key ideas

The solution for IND combines a number of ideas into a solution. These key ideas concern permit applications, legal decisions, data validation, traceability, determi-

nation of title, security, identity management, infrastructure, (among others). This section discusses them to provide some insight in the solution and into the overall design choices that were made.

follow the rules An organization in the public sector must follow the rules. These rules originate from many different sources, such as immigration regulations, IND policy, security constraints, applicable laws and legislation, instructions from the department of Justice, etcetera. INDiGO supports this by means of a knowledge model that contains these rules, at least inasmuch they bear consequences for the IT. The main task of INDiGO is to help the IND follow the rules in transparent and traceable ways. The challenge was to design INDiGO such that frequent changes in these rules can be absorbed practically without delay and without any operational disturbance.

standard software The IND insisted on standard software with proven track records. This requirement was fulfilled by an architecture that consists of commercial-off-the-shelf (COTS) software components, with no tailormade components. The experience with two 'playgrounds' in the laboratories of the consortium produced the final selection that was used in the offer to the IND. The solution contains a case management component, a document management engine, a knowledge engine, a (fuzzy) matching engine, a portal environment, a business intelligence component, and a service bus to put these components together.

separation of know and flow One of the most explicit requirements was to separate knowledge about immigration (the "know") from the management of the primary process (the "flow"). This separation was achieved by analyzing the conceptual structure of the IND's process management and the conceptual structure of the knowledge engine, and removing all possible contradictions. After proving this conceptually correct, it posed no problem to create working prototypes of this feature. Oracle-Siebel was selected as case management engine to support the primary process, whereas the knowledge engine was realised by Be Informed.

dynamic changes in the structure of data In a dynamically evolving society, it is impossible to predict all future changes. Still, the IND must follow developments in society closely and without delay. This paradox affects the very data model of the solution, which may change on a day-to-day basis. So the architecture must ensure that any conceivable property can be stored when the need arises. This problem has been solved by putting a knowledge model in place of data model, restricted to immigration knowledge. Since the knowledge model governs the data logic at the solution level (not inside the components), special measures were taken for different components. For example, Oracle-Siebel employs a special table accommodate structural changes without changing its built-in data model.

decision making Each decision made by the IND about a particular alien follows a particular procedure. The architecture has been simplified by choosing the decision as the scope of each procedure. If a number of decisions are made in a single case, this means that as many procedures are conducted. In practice, only simple cases consist of a single procedure.

traceability of decisions A decision structure has been designed to enable the IND to trace every decision to its legal origins, even after many years. The core of this structure is a link between facts that are established by the IND and the documents to prove it. These facts are contained in a decision tree to document the reasoning that supports the decision. References to applicable laws and regulations are automatically inserted in that tree wherever possible. When the decision becomes definitive,

the entire decision structure is secured in records management. The complexity of this structure lies in the collaboration between architectural components. The decision tree is composed by the knowledge engine, facts and data are stored in the case management engine, and documents are maintained in the document manager. So the entire structure requires a closely knit collaboration between these components on a service bus level. The advantage is that IND personnel can reproduce the legal reasoning behind any past decision together with all the evidence at the push of a button.

conceptual model INDiGO employs an enterprise service bus (ESB) to overcome mismatches in the internal data models of the various COTS-components. A comprehensive conceptual model is central in that discussion. The conceptual model produced by Ampersand and the data model that was derived from it, played this role during the tender phase[2]. This model was used to maintain the semantic consistency of all components on the level of the service bus. It maintains business requirements that affect multiple components. In order to maintain this "semantic integrity", the requirements were analyzed using Ampersand.

dynamic action plan INDiGO features a process engine, Oracle-Siebel, and a knowledge engine, Be Informed. Together, these components collaborate to produce flexibility that is hard to achieve in any other way. All cases that are processed by the IND are controlled by a process engine, that monitors the process. The actions to be taken, the order in which they are performed, and the staff involved may vary from case to case. The knowledge engine is used to determine an action plan for each case, using specific knowledge of that case and knowledge about the applicable laws and regulations. This knowledge system computes precisely the right actions for each specific case. It is as though every case gets a process model of its own, rather than the one-size-fits-all process model of earlier systems.

knowledge governs data In order to follow developments, IND introduces new characteristics on a daily basis. Needless to say that these changes can only be followed instantaneously if they can be absorbed without affecting the data model of any component. By representing this knowledge in the knowledge model of Be Informed, these changes can be carried out by changing the knowledge model. This results (almost) instantaneously in the correct changes in the primary process.

Each one of these key ideas has been analyzed, each yielding a set of business rules.

Two of the key ideas will be elaborated. Decision making is shown in section 4, defining the administration of decisions about residence permits. The conceptual model will be briefly discussed in section 5.

When studying these examples, it is worth to notice that our business rules have three important properties:

- Every rule is valid throughout the entire scope (in this example: INDiGO).
- Each rule can be considered independent from other rules.
- The number of rules is small, as compared to the size and complexity of the organization.

4 Decision making

This section elaborates a particular theme from the IND case: the decision making process. After explaining some of the background, we provide the formalization of

[2] at an earlier stage, this model was called Common Message Model, following the conventions of service orientation in the UML

rules that govern the process of deciding about the IND's decision to grant residence permits (green cards).

In 2007, the IND observed that immigration procedures have a generic structure. Only when immigration specific regulations are involved, procedures start to vary. The reason for this can be found in the law.

The generic procedure for dealing with administrative procedures in the Netherlands is laid down in the AWB ("Algemene Wet Bestuursrecht"). The specific issues of immigration regulations are described in the immigration law, called VW ("Vreemdelingenwet"), and related regulations.

Application
Decision

Article 1:3 AWB introduces the ideas of *application* and *decision*, which lay at the heart of the IND's activities. An application is a request by a stakeholder to take a decision. The IND's primary business process includes all the work required to make decisions about particular aliens. Examples are an application for a visa in a consulate or embassy (a procedure called MVVDIP), a prolongation for a residential permit (VVRVRL), or an asylum procedure (ASIEL).

Alien

An *alien* is anyone who does not possess the Dutch nationality and is not entitled by law to treatment as a Dutch national (VW, Art 1.m). In the IND's daily practice, aliens are persons who wish access and the right to stay in the Netherlands, or those who are staying legally in the Netherlands and wish to obtain the Dutch nationality. Hence, aliens are stakeholders to which the IND provides services.

Any given decision is based on one particular article in the law. That article characterizes the decision. For that reason, each type of decision requires its own set of activities to be performed, as outlined by the law. Thus, INDiGO has to act as if each decision is unique, the single instance of a unique procedure. A *procedure* is a set of activities performed to produce a decision on the application of an alien.

Procedure

A decision may be followed by other decisions (an objection or an appeal, etc.) that are related to the same case. So, every case will get a decision in first instance. Other decisions may be added to the case until the decision is accepted or all routes of appeal are exhausted. Every case is about a single residence application, enforcement or other event for which a procedure can be conducted. Every case also has a single purpose for staying, which cannot change during the lifetime of the case. If the purpose for staying changes, applicants have to resubmit a new application and redo the procedure. Figure 7.1 is an example of a married couple, with each spouse going through various procedures for entering the country and staying there. This example shows the procedures in the upper bar. The two lower bars show the situation each of the spouses is in at every moment in time. The example illustrates dependencies that may exist between different cases.

The conceptual analysis that follows focuses on the rules that govern decisions, which are to be maintained by INDiGO. A conceptual model is shown in figure 7.2. A selection of rules has been made to show the essence of the specification and to communicate the flavour of the specification at hand. The formalization is presented one rule at a time, where new relations are introduced when needed.

Rule: decision by INDiGO A rule engine constructs a decision tree for every decision that is being made. The description of the rule engine's decision is looked up from the decision type. In order to formalize this, we introduce the functions:

$$reDescr : Procedure \rightarrow Description \tag{7.1}$$
$$reVal : Procedure \rightarrow DecisionValue \tag{7.2}$$
$$decisionName : DecisionValue \rightarrow Description \tag{7.3}$$

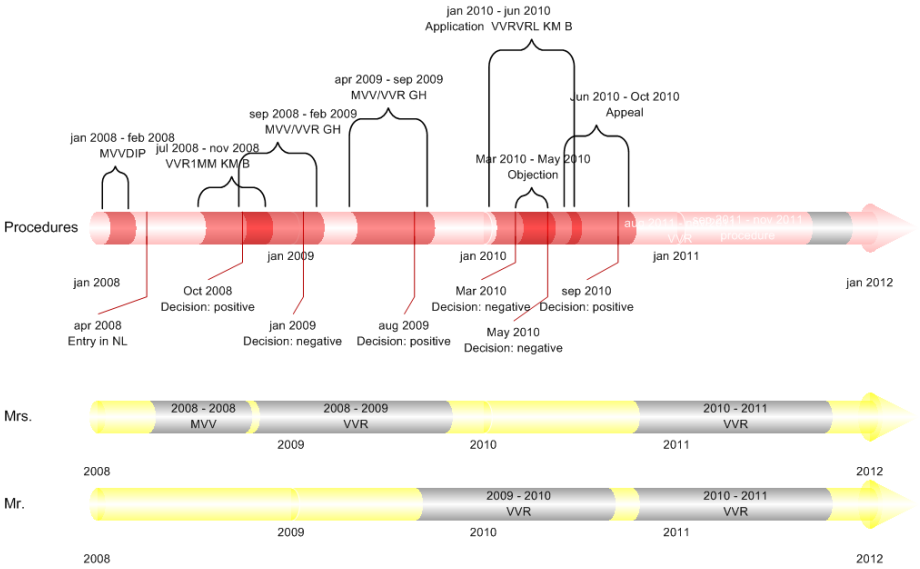


FIGURE 7.1 Example: related cases going through different procedures

The rule is to maintain:

$$reDescr \;=\; reVal; decisionName \tag{7.4}$$

The formalization reduces the process to a mere lookup of standard texts. In many specifications, not only those of the IND, this kind of simplification is a common side effect of the formalization process. It shows how the mental efforts to come up with good specifications will pay off.

Rule: IND's decision Similarly, the description of the IND's decision is looked up from the decision value. In order to formalize this, we introduce function 7.5:

$$decisionDescr \;:\; Procedure \rightarrow Description \tag{7.5}$$

The rule is to maintain:

$$decisionDescr \;=\; decisionVal; decisionName \tag{7.6}$$

Definitions 7.2 and 7.3, introduced in the previous rule, are reused for this purpose. This rule is similar to the previous rule 7.4, illustrating the point that such lookups are common.

Rule: deficiencies The IND starts by checking whether an application for residence is complete. Required documents that the IND is still missing must be signalled, so that an employee can request the additional information and documents. This check can well be automated by formulating a rule about required, but missing documents. Which (types of) documents are required, is determined by the type of application.

Document

A *document* is anything that can be stored in a folder. A document is called *formal* if it represents a right granted on the basis of a decision. The formal document is also a physical product, being issued to someone as a result of a decision. The formaliza-

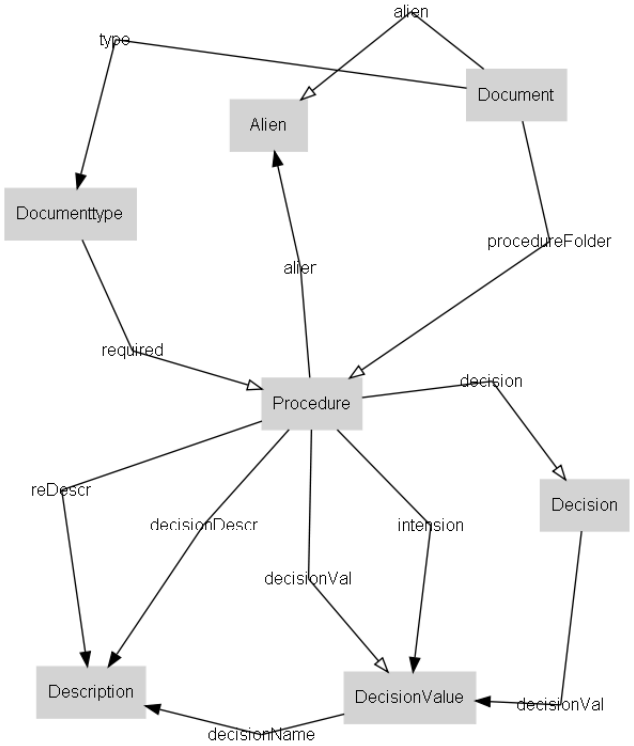


FIGURE 7.2 Conceptual Model of Decision making

tion of the rule (equation 7.12) requires the following five relations.

$$\begin{aligned} \mathit{required} &: \mathit{Documenttype} \times \mathit{Procedure} && (7.7)\\ \mathit{type} &: \mathit{Document} \to \mathit{Documenttype} && (7.8)\\ \mathit{docForProcedure} &: \mathit{Document} \times \mathit{Procedure} && (7.9)\\ \mathit{docAboutAlien} &: \mathit{Document} \times \mathit{Alien} && (7.10)\\ \mathit{alien} &: \mathit{Procedure} \to \mathit{Alien} && (7.11) \end{aligned}$$

The rule that every application shall be complete can be formalized as follows:

$$\mathit{required} \vdash \mathit{type}^{\smile}; (\mathit{docForProcedure} \cap \mathit{docAboutAlien}; \mathit{alien}^{\smile}) \quad (7.12)$$

This rule says that if a document type is required for a particular procedure, then there must actually be a document about the alien in the procedure's set of documents. To signal any missing documents, the system can compute:

$$\overline{\mathit{required} \cap (\mathit{type}^{\smile}; (\mathit{docForProcedure} \cap \mathit{docAboutAlien}; \mathit{alien}^{\smile}))} \quad (7.13)$$

First discrepancy rule Not a computer, but an employee of the IND decides on any given application. So an intended decision may turn out different from the answer given by the rule engine. This is formalized in equation 7.17, which requires the following three relations.

$$\begin{aligned} \mathit{decision} &: \mathit{Procedure} \times \mathit{Decision} && (7.14)\\ \mathit{decisionVal} &: \mathit{Decision} \to \mathit{DecisionValue} && (7.15)\\ \mathit{intension} &: \mathit{Procedure} \to \mathit{DecisionValue} && (7.16) \end{aligned}$$

The rule that says the two must be equal is:

$$decision; decisionVal \;=\; intension \tag{7.17}$$

This rule may be violated, but all discrepancies between the IND's decisions and the rule engine's computations are reported, for accountability purposes. The discrepancies can be computed by:

$$(decision; decisionVal \cup intension) \cap \overline{((decision; decisionVal) \cap intension)} \tag{7.18}$$

Second discrepancy rule Similar to the previous rule, the intended decision may deviate from the final decision. We use definitions 7.14 and 7.16, to state as a rule that the two must be equal:

$$intension \;=\; decisionVal \tag{7.19}$$

This rule reports the following signals:

$$(intension \cup decisionVal) \cap (\overline{intension} \cup \overline{decisionVal}) \tag{7.20}$$

If you do not understand this line of reasoning, check back to the section in chapter 4 that explains how violations of an assertion (like 7.19) can be computed as the extension of an expression (like 7.20). So far, the formalization defines (a selection of) the rules that govern the decision process at IND.

5 Conceptual Model

This section discusses the key principles that govern the conceptual model. It tells how applications for residence permits, documents that are in the alien's file, procedures to handle applications and decisions are interrelated.

Application

Aliens who wish to enter the Netherlands to stay must apply for a residence permit. An application for residence is an application as intended by the administrative law. It is defined in AWB 1.3 sub 3: An *application* is a request of a stakeholder to take a decision.

Figure 7.3 shows a diagram of the conceptual model, as a work in progress: the diagram is neither complete nor correct in its finer details. This analysis contains the concepts discussed in this section.

initiate procedures Every application has been submitted on behalf of just a single alien. It is conceivable to combine applications of different persons, for instance to keep groups and families together. However, the IND processes every application separately, and does not combine them. For each application, a procedure is conducted that leads to a decision. The formalization (equation 7.23) requires the following two relations.

$$behalf \;:\; Application \times Alien \tag{7.21}$$

$$application \;:\; Procedure \to Application \tag{7.22}$$

Besides, we use relation 7.11 linking the procedure to the alien. The rule maintains:

$$behalf \;\vdash\; application^{\smile}; alien \tag{7.23}$$

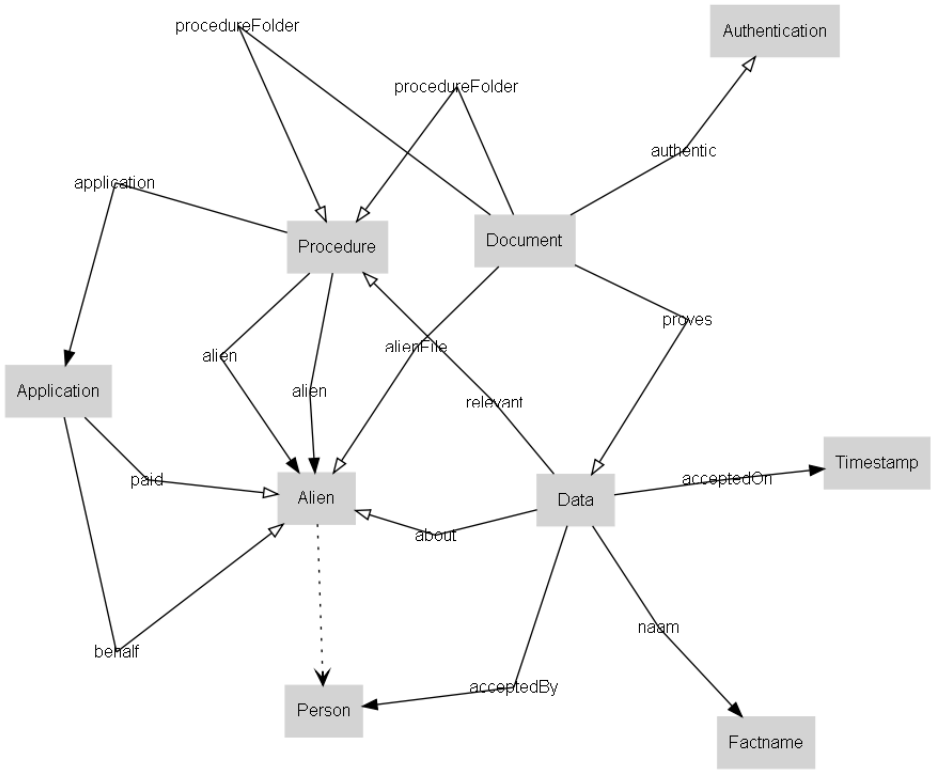


FIGURE 7.3 Conceptual diagram of IND Applications, work in progress

alien file Documents that are in the folder of a particular procedure, reside in the alien's folder by implication. We use definitions 7.9, 7.10, and 7.11, to state the rule to be maintained as:

$$docForProcedure; alien \vdash docForAlien \tag{7.24}$$

relevant facts All data about a person that has been accepted as a fact is relevant for every decision taken about that person. To formalize this in equation 7.27, we need to introduce two relations:

$$about : Data \times Alien \tag{7.25}$$
$$relevant : Data \times Procedure \tag{7.26}$$

Again using relation 7.11, we come up with the rule:

$$about; alien^{\smile} \vdash relevant \tag{7.27}$$

procedure file All evidence corroborating a fact is relevant in the procedure in which that fact is used. In order to formalize this, we introduce:

$$proves : Document \times Data \tag{7.28}$$

Combining this with relations 7.26 and 7.9 we formalize the requirement 3 (page 141): This rule maintains:

$$proves; relevant \vdash docForProcedure \tag{7.29}$$

fees to be paid All applications incur legal fees, which have to be paid by or on behalf of the applicant. This rule signals all applications with fees due. In order to formalize this, we introduce relation 7.30:

$$paid \quad : \quad Application \times Alien \tag{7.30}$$

Using definitions 7.11 and 7.22, we formalize the requirement that fees be paid as a rule:

$$application^{\smile}; alien \vdash paid \tag{7.31}$$

This rule reports the following signals:

$$application^{\smile}; alien \cap \overline{paid} \tag{7.32}$$

authentication All documents in a folder must eventually be attested by some authority as being authentic. Documents that have not yet been authenticated need to be signalled. In order to formalize this, we introduce:

$$authentic \quad : \quad Document \times Authority \tag{7.33}$$

Again using relation 7.9 that gives us all documents involved in a procedure, we may formalize the authentication requirement as:

$$docForProcedure; docForProcedure^{\smile} \vdash authentic; authentic^{\smile} \tag{7.34}$$

This rule reports the following signals:

$$docForProcedure; docForProcedure^{\smile} \cap \overline{(authentic; authentic^{\smile})} \tag{7.35}$$

This concludes our discussion of rules from two themes, decision making and the application procedure. In the actual INDiGO project, slightly over 100 rules were used to get sufficient evidence that all key ideas could be implemented by means of the COTS-components chosen for the IND. For the purpose of this chapter, it is unnecessary to discuss them all. The discussion presented here gives the full flavour of these rules.

The next section presents the data analysis that was generated for this project. It has been generated entirely by the Ampersand compiler. Therefore we can claim with mathematical certainty that this data model can accommodate all data needed to maintain the rules from the previous sections.

6 Data Analysis

The IND requirements, presented in the introduction in an off-hand manner, was translated into an Ampersand script. The script contains over 30 concepts and relations. From this script, a data model can be derived in which all rules from the Ampersand script can be represented. A provisional class diagram based on the script is shown in figure 7.4.

Software analysts and programmers can now proceed to build an information system with the complete and correct set of business rules at its core. In practice, the model will probably be extended with other attributes and classes. However, it is not allowed to remove anything, as that would jeopardize compliance to the rules.

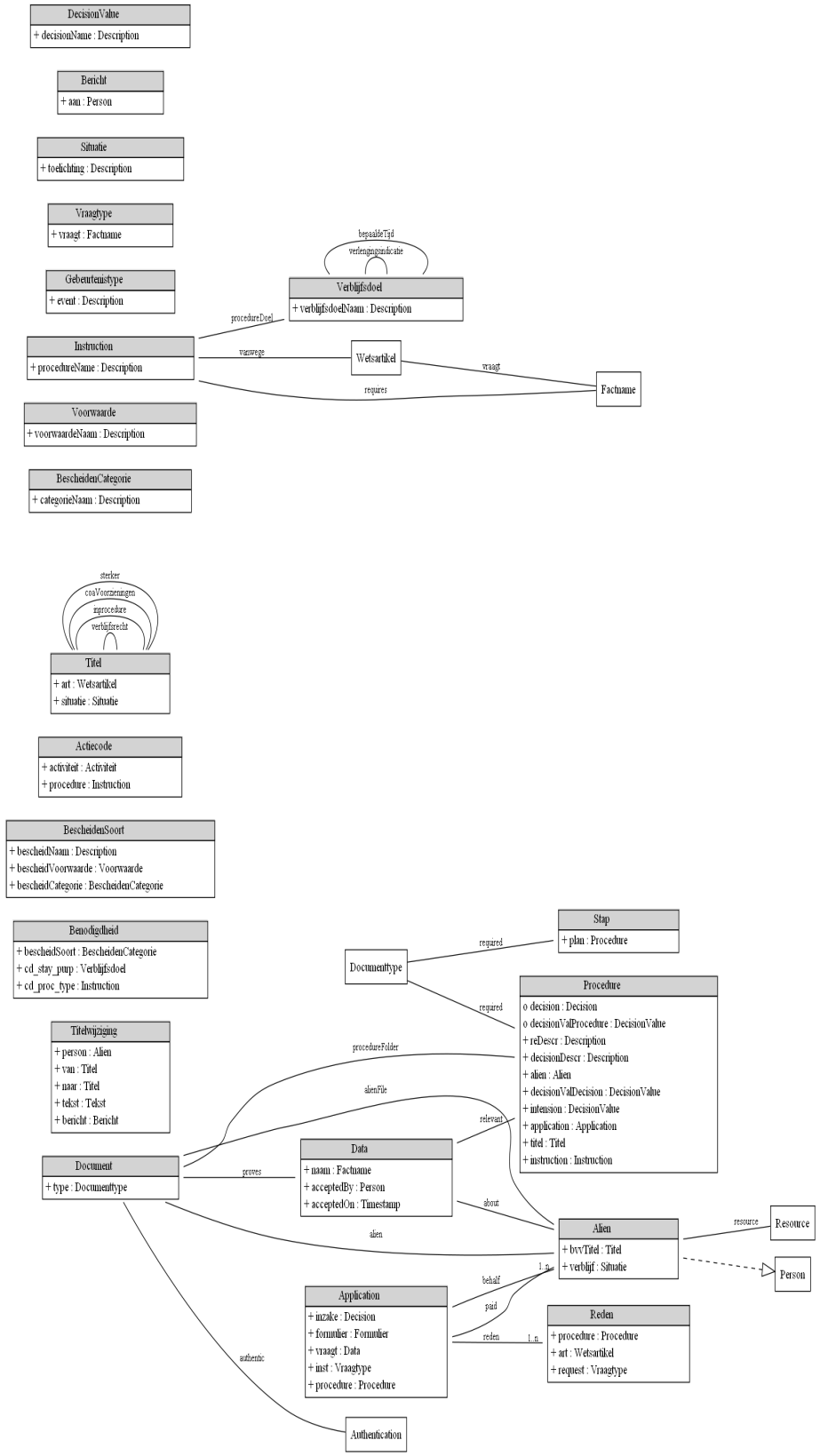


FIGURE 7.4 Provisional Class Diagram of IND

The relevance of conceptual modeling using Ampersand is in its comprehensiveness that enables analysis across the various COTS components in INDiGO. For example, data about aliens is stored in the Oracle-Siebel component, decision trees are built in the Be Informed component, and documents are stored in the document management component. So any rule that involves documents that are related to decisions that are about aliens, affects all three components.

Rules such as we discussed here, will typically affect multiple components of the corporate system architecture. The rules provide the semantic consistence between components, which is most visible on the service bus level. Using the script, the Ampersand tool can take all concepts and relations, multiplicity constraints and rule assertions, and turn it into a complete and formal requirements specification. This comprehensive document is for the convenience of programmers, who use it to configure the data stores; workflow routines, message patterns, user interfaces, and much more.

7 Way of Working

The INDiGO project marked a first occasion in which Ampersand contributed to a large IT project in practice. This experience has not only shown the value of a formal approach, but has also taught some valuable lessons. It came as a surprise that some preconceived opinions about information system design were revised. So we present each lesson as a reaction to the preconceived opinion, that is contested by this experience.

Our people are not trained in formal specifications. The formulas and rules that appear in the functional specifications may look impressive, but they are computer generated. The most desired skill designers must have is to elicit requirements. This skill to write Ampersand is of secondary importance. The functional specifications serve different stakeholders, of whom only the requirements engineer (designer) will ever see or use the formal language. The following specifications are generated by Ampersand:

- a specification intended for business stakeholders, meant to sign-off requirements in natural language only;
- a specification intended for requirements engineers, meant to establish the correct correspondence of natural language requirements and formalized rules;
- a specification intended for builders, containing data models and other artifacts that are useful for realizing an information system that fulfills the requirements.

The lesson is that Ampersand eliminates the need to share any formalism with user communities, officials, and members of the demand organisation. In English: the customer does not have to learn formal specifications at all. That is the task of requirements engineers and designers.

We don't have time to formalize. The lesson is that formalization saves time. The formalization of INDiGO was made as early as the tendering stage, way ahead of the start of the project. The resulting INDiGO architecture has proved robust, and little needed to be changed in the course of time. (Of course, many additional features were added, but the core idea remained stable.) This is a direct result of its consistency, which eliminates the need to change the architecture in hindsight. The large amount of concrete details, that were already captured in the design during the tendering phase, is also a consequence of doing things right the first time.

Why bother about correctness? Correctness of an Ampersand script, and the specifications derived from it, means several things. The type checker ensures absence of

type errors. It means that the specification is representable on a database system, so the system can actually be built.

In the system specification two types of rule are encountered. First, rules that must be maintained rigorously, and the information system must ensure that the rule is adhered to, anywhere and at all times. Second, rules whose violations are signalled. These rules may be violated, but their violations are signalled so that people may intervene. Thus, correctness means that the system of people, supported by computers, maintains all rules throughout time. System correctness is measurable, because the outcome of each rule is either true or false at any given moment. It is achievable, because each requirement can be implemented in software. The requirements are relevant, because they have been discussed and scrutinized by the IND.

But the most important benefit of correctness is what is not there: there is no rework due to mistakes and there are no corrective actions. This saves a lot of frustration. The lesson is that we need to bother about correctness.

Isn't it difficult? Yes, writing good rules is hard. The difficulty lies in analyzing a problem and making it concrete. Writing it in relation algebra helps, because it allows only concrete rules to be written. In the INDiGO project, this feature has contributed considerably in detailing the initial architecture document.

A Repository for Ampersand Projects

Chapter 8

A Repository for Ampersand Projects

1 Introduction

In working with projects within Ampersand, be it for reasons of business specification or for educational reasons, it is useful to keep track of attempts, mistakes and successes. To that end there is an Ampersand repository. Here we discuss the repository RAP (Repository for Ampersand Projects) and in particular we address ATLAS, the part that shows the structured view on Ampersand projects. We write it as an Ampersand script and compiling that script results in a meta-model for Ampersand that is presented as a population of itself.

The Ampersand tool combines two functions. First, the tool has to deal with documents, or more accurately put: with scripts that define business contexts. Managing these documents means that a user should be able to add, store, retrieve, view and edit her scripts. We discuss concepts and relations of this document management system embedded in Ampersand.

The second function is way more important. Ampersand has to "be" a prototype of the information system outlined in a script. That is, Ampersand presents various user interfaces, so that a user may view the overall Conceptual Model, the concepts and relations, the rules, or the violations. Some user interfaces may even allow some data editing. One particular interface even produces a full specification of the prototype system.

The interesting thing about this second function of Ampersand is that Ampersand itself is an information system. Hence, we may write a script with the concepts, relations and rules for "the information system outlined in a script". This is a meta-modelling approach: Ampersand itself is specified by way of an Ampersand script. Full details are rather too technical, and moreover the Ampersand prototype is under continuous development. However, we do present the core notions of a meta-modelling script for Ampersand in this final chapter.

1.1 DOCUMENTS IN THE SESSION

The journey starts by the urgency of expressing a business situation in terms of things, their mutual dependencies and the constraints that hold for the sketched situation. For example our business situation considers scripts that we get from somewhere, that need to be checked before use and that result in several distinguished documents.

In order to record this situation and to construct an information system handling it, we start up a session of the Ampersand tool. The tool shows us a white part of the screen that screams for filling it up with text that we may want to edit to our liking, see figure 8.1.

Next to just using the keyboard or copy-and-pasting useful fragments, we may choose to fill the white screen with a (text)file or a script from the repository and edit it afterwards. Whatever we do to get a script is not really relevant. In fact, the script attempt that is not yet loaded, say the *external script*, is not registered at all, so we only add it to our ontology to indicate that a loaded script did have an origin (but we do not really care what it is).

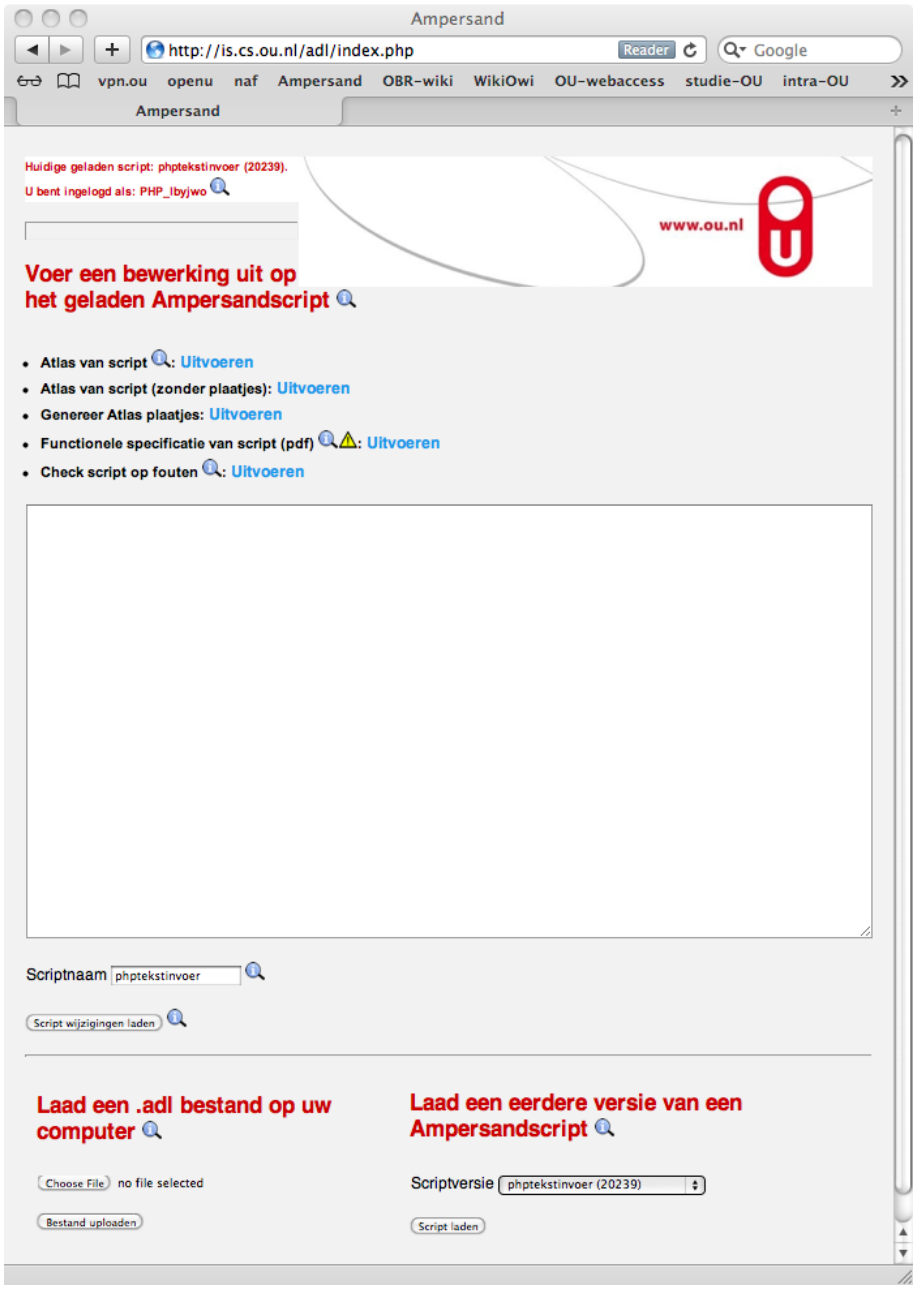


FIGURE 8.1 An unspoiled Ampersand screen

More important is our script once it has been loaded into the repository, that is when we call it an *internal script*. The teletype representation of the script on the screen (with refreshed line numbers) is referred to as the *identity view*. Upon loading the script it is decorated with some details that do not really concern us here (e.g. author, name, number, date, compiler), we just say *info*. What does concern us is the status of the script after the checks on syntax and typecorrectness are executed. If it fails either one, the script is *rejected* and it exhibits an *errorview* on the top of the screen giving hints for repair, see figure 8.2. Although the script is rejected, it remains internal in the repository and it shows its identity view in the white part of the screen. After editing the identity view of a rejected script, we may upload it again and thus enter a new script into the repository.

A script that passes the tests on syntax and typing is called *accepted* and Ampersand contructs with it two special views, in addition to the obligatory identity view: the

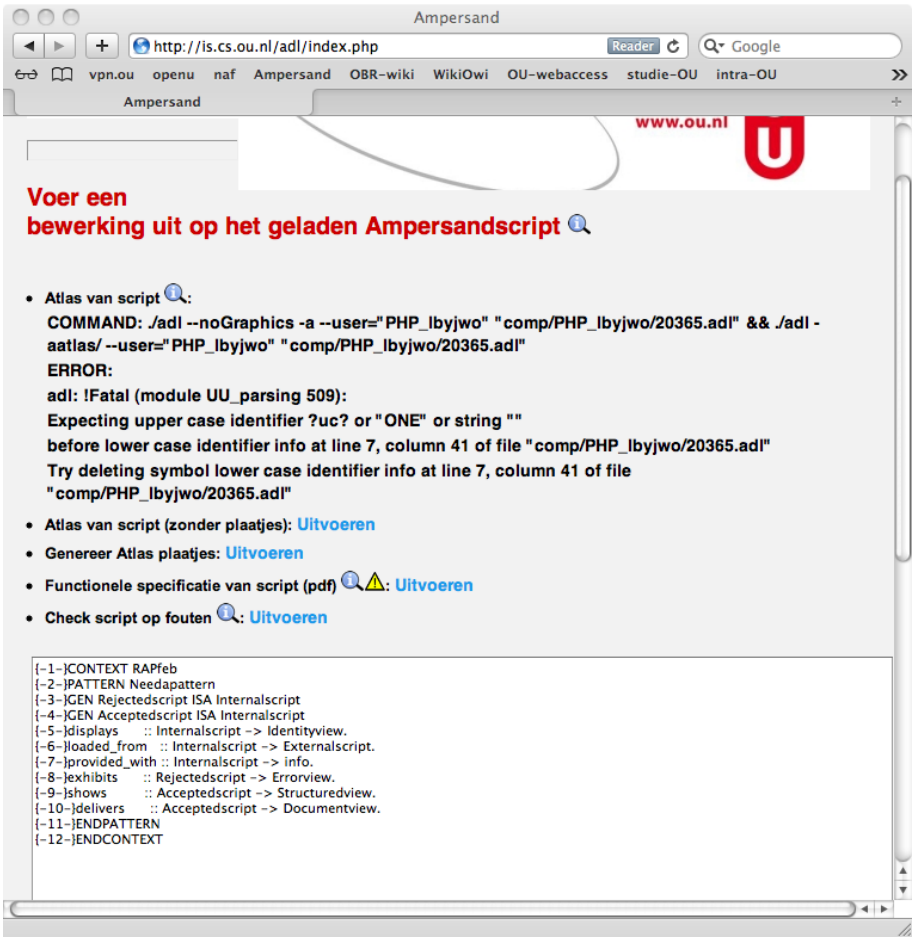


FIGURE 8.2 Error view complaining about the lowercase 'i' in line 7.

structured view and the *document view*.
A structured view is a bunch of webpages with information on the translated script, much of that information is added by the engine under the hood of Ampersand. The structured view is called ATLAS and we shall delve into it below.
The document view consists of a pdf-document with a lot of generated text and definitions of the elements in the script, automatically typeset with LaTeX. The source of that information is partly found in the script, where each construct may be decorated with explanations and templates for wording of the typical sentences that go with these constructs.

The conceptual model of the documents that play a role in this process and that are mentioned in the little journey above is depicted in the figure 8.3 below. That picture is generated by Ampersand as a result from uploading the minimal script in figure 8.2 with a capital 'I' in line 7.

In that script the concepts are declared indirectly by the typing of the relations. No rules are declared in that script and no additional informative stuff is added for the innocent reader or for the document view. The conceptual model now reads:

Note that the rejected and accepted scripts are modeled as ISA's of the internal scripts with a dotted arrow to represent the embedding. If one wants to record constraints of the conceptual model in terms of rules, a good candidate for a rule is the constraint that rejected and accepted scripts form a partition of the internal scripts.

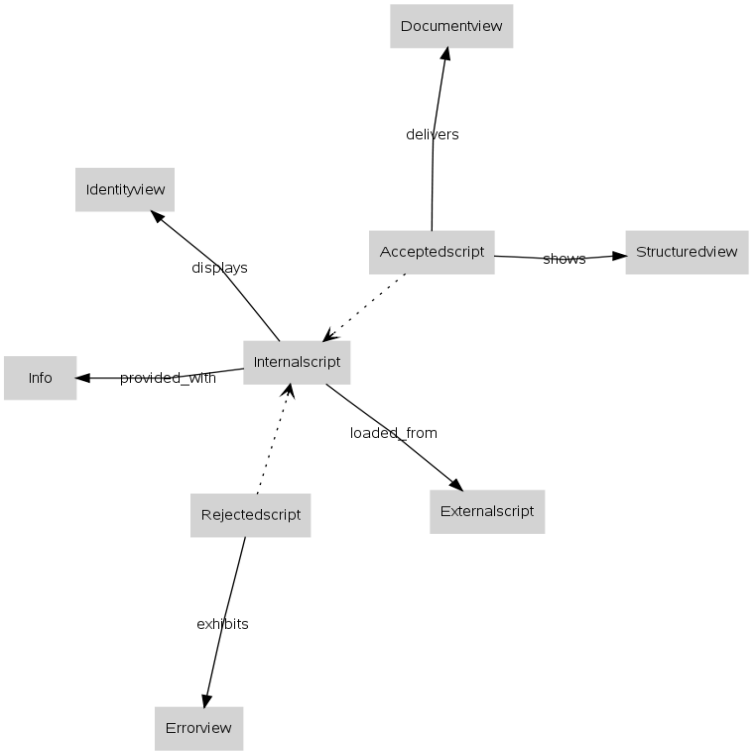


FIGURE 8.3 The conceptual model as drawn by Ampersand

1.2 FUTURE DEVELOPMENTS

The Ampersand system for generating information systems from business rules is under continuous development, and so is RAP. Changes to be expected are technical in the compiler and type checker to allow more freedom in conceptual modeling and in rule expressions. But also farreaching changes in the interaction with the user are to be expected. The editability of the structured view and even on the fly editing of rules and the conceptual model are foreseen. Another upcoming development is the generation of an information system and editing of populations, where satisfaction of rules is guided by the system, currently some prototype for such a system has been constructed.

2 The structured view of a project

After successful uploading and compiling the script we see a check to the right of the first bullet instead of an error view, indicating success and giving entrance to the structured view on the accepted script. The structured view shows the ontology of the system that is portrayed in the Ampersand script. It consists of webpages that list the relevant concepts, the typed binary relations between the concepts and the rules, i.e. the predicates formulating constraints on the relations. Moreover, the population that is declared in the script, may be found on several relevant pages. We sketch the structured view as it can be found in the webpages and we construct the meta-model for it. As an intellectual challenge in abstraction we translate that meta-model in section 2.5 into the script that we use as a running example project illustration in this chapter.

2.1 THE STRUCTURED VIEW OF THE META-MODEL

The home page window of the structured view is called 'Atlas', which is the name for the structured view system, and it shows past and future in the term 'ADL Prototype'. ADL is the old name of Ampersand and the Prototype is the future goal of Ampersand, a generated information system.

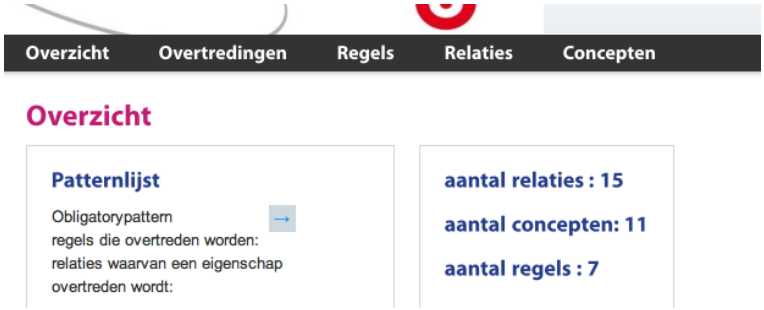


FIGURE 8.4 Overzicht, homepage of the structured view.

The view starts off with an administrative 'home page' in Dutch, called Overzicht. The black bar shows the relevant parts of the structured view, of which the prominent place of the violations (overtredingen) is remarkable. Some hands on experience might explain it, violations do have the habit of popping up even if great care it taken to avoid them. Another important element of this home page is the 'patternlist' that shows the list of components or modules the script consists of. There always is at least one pattern, here we only have one pattern called 'Obligatorypattern'. The arrow to the right of this pattern links to a view of that pattern, see figure 8.5.

In the view of a pattern a generated picture of the conceptual model is shown and the rules and the relations inhabiting the pattern are listed. Each of the rules and relations is clickable for standard information. The rules that come from cardinality and homogeneity properties, however, are not mentioned here, but one level deeper in the properties on the relations they ought to hold for.

In figure 8.6 the information on a rule is depicted, it is the rule about the signature that will be addressed later.

The relations are given in their basic unsugared typing, so even functionality that is part of the typing in the relation declaration is moved to relation properties. By clicking on the relation the details and the population can be shown. The simple properties (cardinality and homogeneity issues) can also be retrieved after applying the appropriate links.

In the structured view the system conforms to the syntax and the typing, but it may fail to satisfy the given constraints or rules. In that case ample information is given on the violation of the rules. In the home page Overzicht some room is reserved for mentioning the violations, but there is also a special page for violations. The page Overtredingen shows the violations for the three different types of rules, declared rules, cardinality and homogeneity constraints. Here we took the liberty to consider two types of constraints: rules and properties.

The page Regels lists the rules, it does so in terms of the relational algebra expressions. As mentioned, only rules that are declared as such will be shown. Since formulae are not fit for human consumption, we introduce below a name in natural language for them. The names are given in the script and will be used in the document view.The presented formulae are linked to several decorative elements, among others a generated picture of the relevant part of the conceptual model.

The page Relaties lists the relations with clickable double arrows for detailed information and population information, as in figure 8.7.

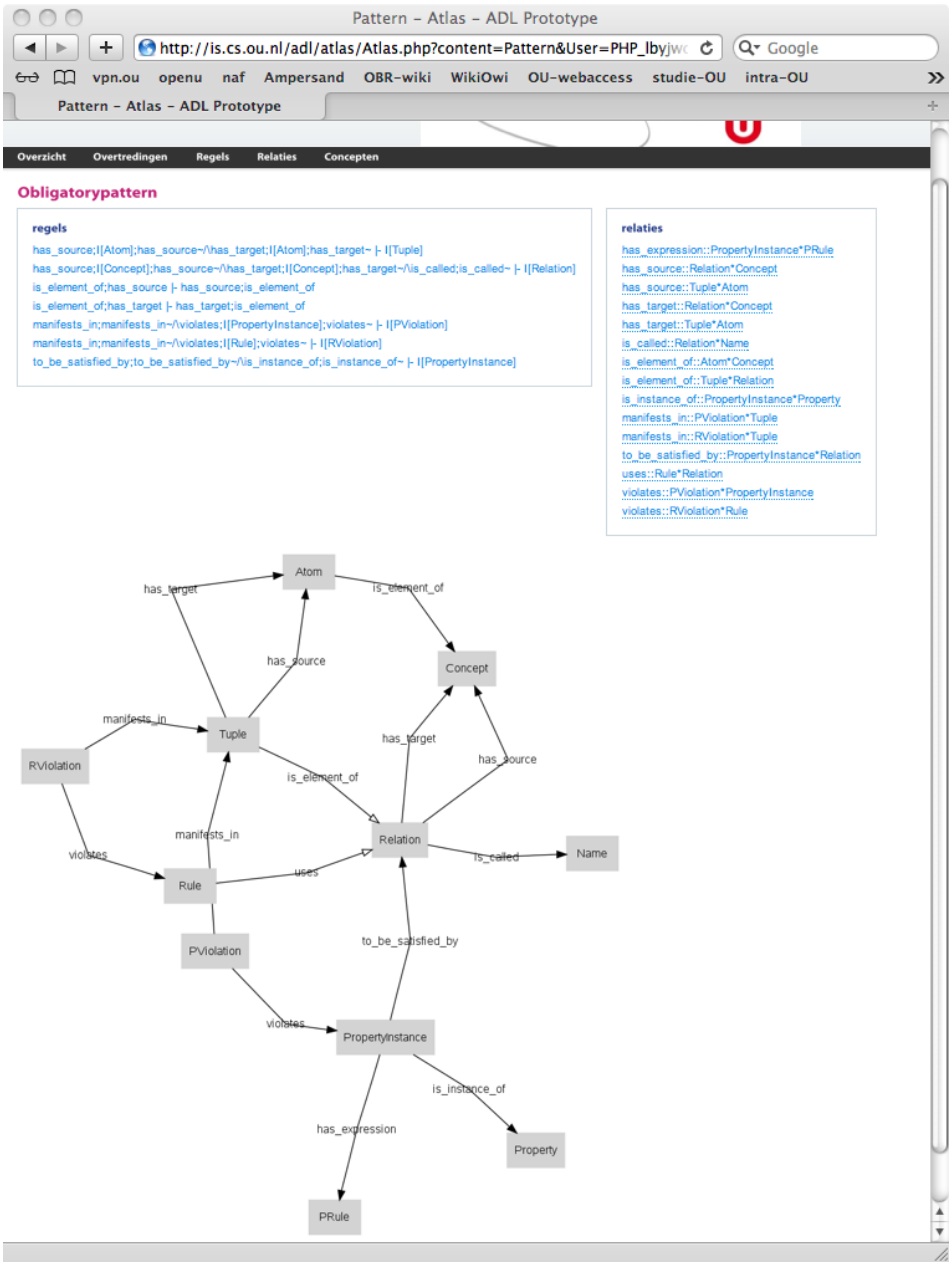


FIGURE 8.5 The pattern contains the conceptual model.

Since the declaration of the relation is not necessarily easy to understand, with each relation some example sentence is given illustrating the use and role of that relation. The simple properties of the relation are covered in the detailed information under the double arrow. There also is a list of the population of the relation, i.e. the tuples (pairs) that are in that relation. For a view on the relation details see figure 8.8.

Finally the page Concepten shows a list of all concepts. A concept name is linked to a description of the concept and the population information thereof.

The journey through the streets and alleys of an Atlas example showing the structured view of some script, should pave the road to a model for Atlas. In the next section we discuss the choice of the notions that make up the meta-model and some of our design decisions.

FIGURE 8.6 Information in a clickable rule.

2.2 MODELLING THE STRUCTURAL VIEW

We use the description in the subsection above to model the structured view, but we do so somewhat sparsely. For reasons of simplicity we abstain from modelling the administative home page and patterns. Some other features that are presented in the links in this complex of webpages that makes up the structured view are considered to be decorative and are left out of the model (e.g. subexpressions, and explanations).

The meta-model of the structured view that we intend to make consists primarily of the basic notions: concepts, relations and rules. Secundarily we add the element level used for populations of concepts, relations and violations. Actually, the meta-model was shown on the example pattern page in figure 8.5, but we repeat it here for your conveniece in figure 8.9.

The basic part consists of

basic concepts, 7 in all, being: 'Concept', simple declared 'Relation', and 'Rule', as we know them from the black bar. We add to them the 'Name' for simple representation of relations. For the properties of relations we add 'Property' and 'PRule' for the rules that are shown as cardinality and homogeneity properties of relations (think of univalence and symmetry). As the derived rules depend on the relation they must hold for we also add 'PropertyInstance'.

basic relations, also 7 in all, being: '*has_source*', '*has_target*' and '*is_called*' to assign a typing and a simple name to a relation. For occurrences of relations in rules we

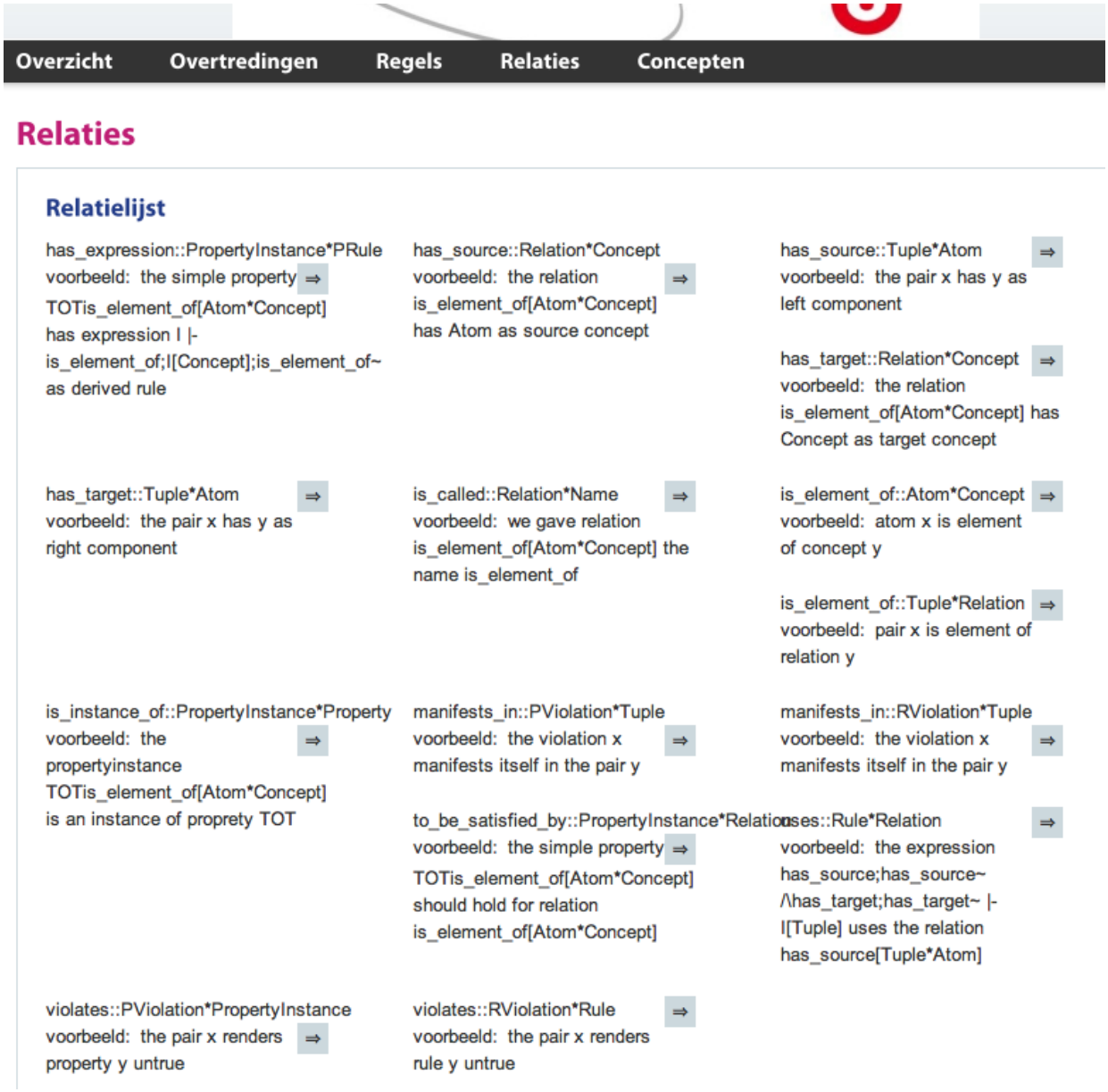


FIGURE 8.7 Relations with examples of paraphrazing sentences that explain them.

have '*uses*' and for the simple properties we have the property via '*is_instance_of*', the relation that ought to satisfy the property is pointed at by '*to_be_satisfied_by*' and the resulting derived rule is given via '*has_expression*'.

basic properties being: every individual relations mentioned is a function, except for *uses*. Two more involved rules are given in the section on rules below.

Some design decisions for the basic part are:

– We consider in the concept 'Relation' in this meta-model only the declared relations, not the host of relations that may be derivable or constructable using catenation, flip and set theoretic operations. The construction nor the properties of relation constructions are relevant in Atlas. The declared relations, however, are.
– In chapter 3 relations are said to have a defining signature consisting of source and target types and a name. To that end we introduce the name of a relation as a separate entity, and we will define a suitable rule to require definedness of a relation by its signature. Relations may have a common name, but in that case

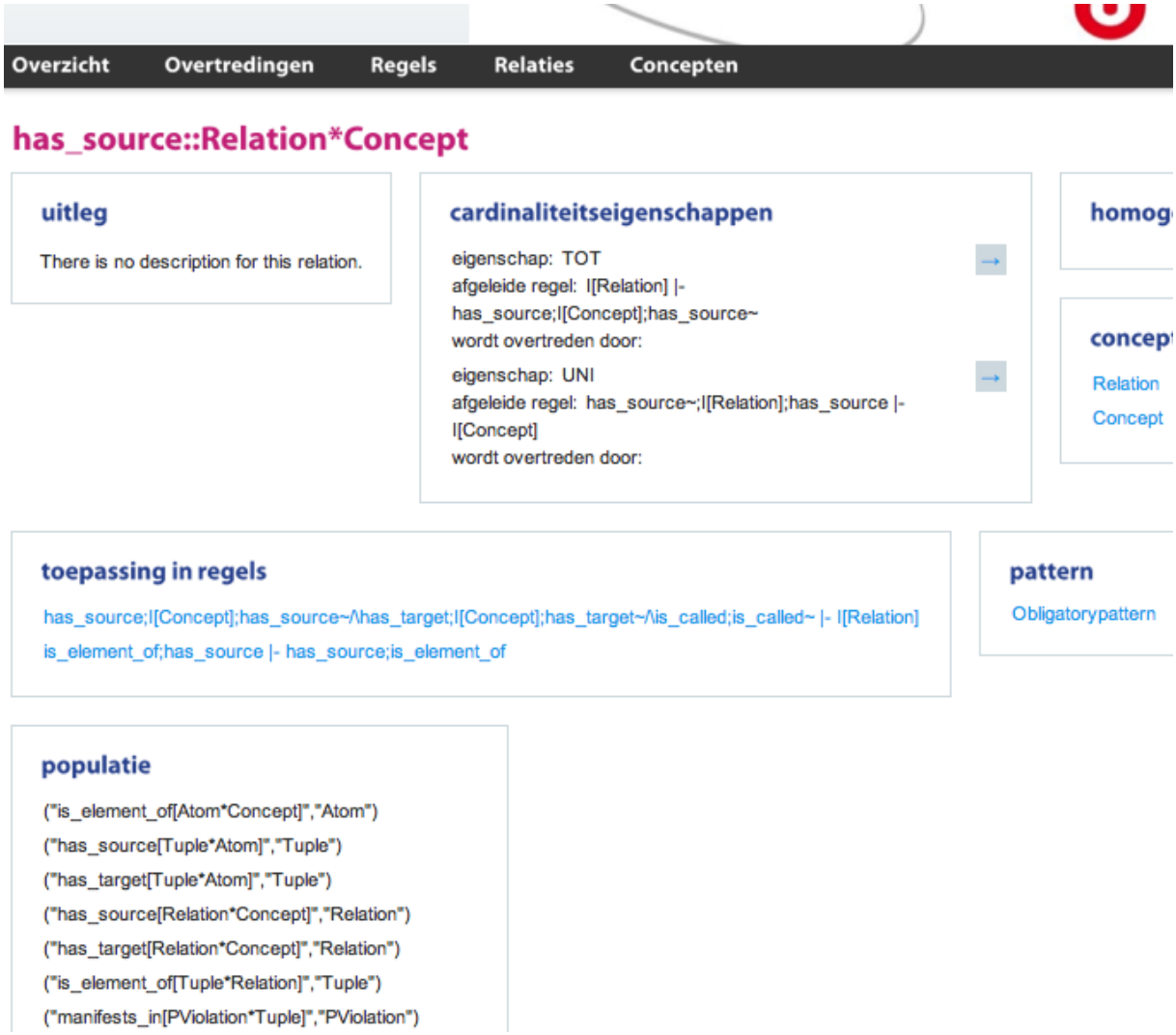


FIGURE 8.8 Relation information including (part of) the population.

they ought to be of different typing. For instance, *is_element_of* may be useful in many sets, but there is only one membership function per set.

– We follow the appearance in the Atlas pages, in which the properties of relations are not mentioned among the rules, though they may be regarded as such. Since there is a very limited collection of prescribed properties for single relations, they can be formulated using a small set of templates (i.e., the concept Property has only a limited number of atoms) and by this limitation they differ from the unrestricted wealth of the other rules.

Next to these basic notions in the structured view, we came across populations consisting of pairs of atoms, tuples, that inhabit the relations. Such a population does satisfy the given typing (otherwise there is no structured view), but it may fail to conform to the rules. In that case violating pairs and the (derived) rules they violate are determined and mentioned.

The (upper) lefthand part of the model is concerned with populations of the model. The concepts as well as the relations are sets and they contain elements. The elements of concepts are called atoms, whereas the elements of the relations are pairs of atoms or tuples. As violations are pairs that violate a rule, they are also part of the population part of the model.

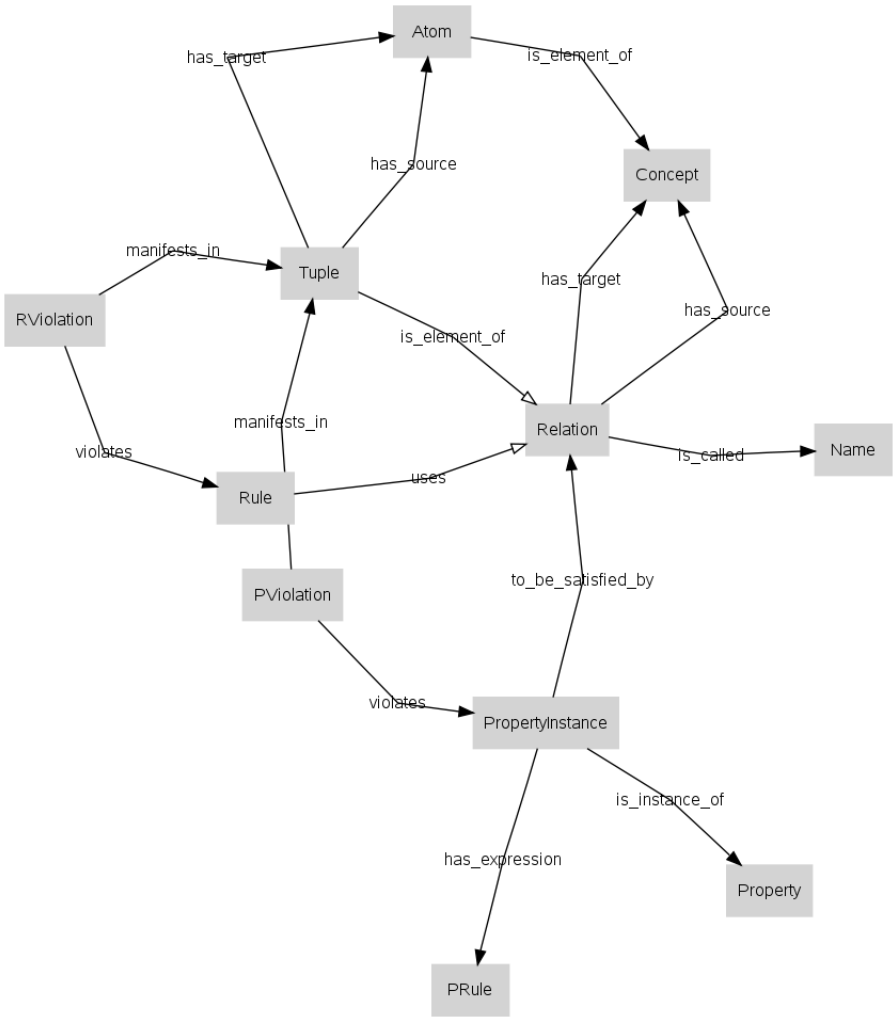


FIGURE 8.9 Conceptual model from pattern page. The basic part figures mainly on the right of the model (7 vertices and 7 edges), the element level is on the north-west side of the model (4 vertices and 8 edges).

The population part consists of:
population concepts, 5 in all, being: 'Atom' for members of the concepts,'Tuple' for members of the binary relations, 'RViolation' for a pair violating a rule and 'PViolation' for a pair violating a property.

population relations, 8 in all, being: '*is_element_of*' for atoms in concepts and also for tuples in relations, for which we also have '*has_source*', '*has_target*' to represent the components of a tuple and, finally, '*manifests_in*' (twice) and '*violates*' (twice) to express what tuple violates what rule or property instance.

population properties being: all of these relations in the population part are functions, the one exception is *is_element_of* : Tuple $\star$ Relation

Design decisions:

– The *has_source* and *has_target* relations between Tuple and Atom are functional. This expresses that we only consider pairs in the cartesian product of concepts and that tuples project onto their components. We do however not require surjectivity of these projections! (for that would mean that we always have to consider the complete cartesian product, even if we only intend to use a scarce part of it).

– Totality of the relation *is_element_of* : Atom ⋆ Concept restricts our attention to elements of concepts. We only consider atoms that are members of some concept, no free elements are lurking around.
  But for the relation *is_element_of* : Tuple ⋆ Relation we do not require totality. This is because a violation may concern a tuple that does not have to belong to any of the relations declared.
– The relation *is_element_of* : Atom ⋆ Concept is required to be univalent, thus forbidding the concepts to have atoms in their intersection. This design decision is one of the first candidates to be reconsidered, because it means that we cannot consider generalisations or subtyping.
  For the relation *is_element_of* : Tuple ⋆ Relation requiring univalence would be silly. Relations do tend have nonempty intersections (e.g. ill and married employees of firms). So the membership relations do have different properties, with reason.

The conceptual model in figure 8.9 may be explained for the visual notions and their properties, the rules have to be defined yet. We do so in the next section.

2.3 RULES

Note that the conceptual model in figure 8.9 above implies a few 'silent' rules because of the set theoretic stage of our meta-model. The concepts in the model are to be sets, so there is a set of concepts, a set of relations and a set of rules and so on. Moreover, the relations that relate the concepts are to be sets too. So there is a set of rule-relation-pairs in *uses* and a set of tuple-relation pairs in *is_element_of*. (Of course the relations that are functions are sets because of their functionality property.) In practice these sets will even be finite sets. In any case, these rules are not mentioned at all in the sequel.

All simple properties of relations may be considered to be rules, but we already decided to represent them as properties of the relation that should obey them. It may be apparent however in the concept name PRule.

Other rules within this meta-model will be described below.

Integrity for tuples.
This rule is also concerned with set theoretic nature, tuples originating from cartesian products of concepts: A tuple is completely determined by its component pair, so for any two components there is at most one tuple with those components, which is an important integrity constraint for the populations of all our relations:

$$\mathit{has\_source};\mathit{has\_source}^{\smile} \wedge \mathit{has\_target};\mathit{has\_target}^{\smile} \vdash \mathbb{I}_{\mathsf{Tuple}}$$

Signature.
Special attention requires the signature. In chapter 3 the reader is urged to consider the signature of a relation, meaning that a relation is determined by the typing and the name only, i.e. two relations with the same typing and the same name are the same. This is the integrity constraint for Relations, which is a concept in our model.

$$\mathit{has\_source};\mathit{has\_source}^{\smile} \wedge \mathit{has\_target};\mathit{has\_target}^{\smile} \wedge \mathit{is\_called};\mathit{is\_called}^{\smile} \vdash \mathbb{I}$$

Typed domain (or: source) and codomain (or: target)
If a tuple is in some relation then the components of that tuple should be typable according to the type of the relation involved. For clarity, write down the correct

concepts in these two formulas:

$$is\_element\_of;has\_source \vdash has\_source;is\_element\_of \quad \text{and}$$
$$is\_element\_of;has\_target \vdash has\_target;is\_element\_of$$

Unique identifier for each property instance.
An instance of a simple property is fully determined by the property and the relation it should hold for. Again this is an integrity constraint, assuring that each distinct property instance is unique.

$$to\_be\_satisfied\_by;to\_be\_satisfied\_by^{\smile} \wedge is\_instance\_of;is\_instance\_of^{\smile} \vdash \mathbb{I}$$

Unique identifier for each violation.
A violation is determined by the tuple that is violating and the rule that is violated. This holds true for violations of rules as well as for violations of properties. Two integrity constraints for violating tuples are therefore:

$$manifests\_in;manifests\_in^{\smile} \wedge violates;\mathbb{I}_{\mathsf{Rule}};violates^{\smile} \vdash \mathbb{I}_{\mathsf{RViolation}} \quad \text{and}$$
$$manifests\_in;manifests\_in^{\smile} \wedge violates;\mathbb{I}_{\mathsf{Propertyinstance}};violates^{\smile} \vdash \mathbb{I}_{\mathsf{PViolation}}$$

These rules cover constraints and several cycles in the conceptual model. However, the cycles with the violations and the tuples are not addressed. The reason is that these cycles show up in the picture but they are not 'conceptual cycles'. There is no reason to expect or demand a connection between a rule-violating tuple and relations that occur in the violated rule other than that very rule.

2.4 THE SCRIPT OF THE PROJECT

Next to the given ontology and population there are some items (or attributes) that are used for the decorations in the structured view and for documentview of the script. We do not add them to the ontology for the structural view. As they tend to be of help in understanding the script in the process of writing as well as reading we do mention them here, before we delve into the script itself.

- The members of three basic concepts Concept, Relation and Rule can be provided with a sentence that explains their meaning. Note that this 'explanation' or 'meaning' differs from comments in the code because it is used in document generation. Moreover, the rule is given a name in the script even before the expression is given, but the name is only used for the documentview.
- A relation can be given a template in order to provide a wording for what it means for a pair to belong to it. This so-called 'pragma' typically has three parts and looks actively like:

  source ⟨left component⟩ relates to target ⟨right component⟩ by default

  and passively it may read:

  source ⟨left component⟩ is related to target ⟨right component⟩ by default

  The standard reformulation for the flipped version is obtained by switching to the passive or active voice respectively.

Now that we embark on the teletype Ampersand script, we need to mention the facts that a project needs a name that identifies the 'context' that we define and that the basic part of the project is a so-called 'pattern' that alludes to the future use of

components in Ampersand projects. They are delimiters and mentioned in the start and at the end. So we first declare the concepts with their interpretations

```
CONTEXT StructuredRAPview
PATTERN Obligatorypattern
CONCEPT Concept "The notion of type, which is an abstract description
that stands for terms in the real world that are similar: they share
the same meaning, have similar properties, similar behaviour,
and similar connections with other terms or concepts."
CONCEPT Atom "The label that uniquely corresponds to an individual
thing (term) in the real world and that can be recorded in a computer."
CONCEPT Relation "The abstract description of binary facts, captured
as a named subset of the Cartesian product of two concepts, where all
tuples in the subset have a similar meaning, similar properties,
and similar behaviour."
CONCEPT Tuple "The fact about (the relation of) two atoms that is true
or important in the business context."
CONCEPT Name "The label that helps to identify a relation and that can
be recorded in a computer."
CONCEPT Rule "The predicate expression on relations or Relation-
Algebra assertion that expresses the verifyable statement that some
stakeholders intend to obey within the business context."
CONCEPT RViolation "A pair is violating a rule."
CONCEPT PViolation "A pair is violating a property."
CONCEPT Property "The simple cardinality or homogeneity property that
may apply to individual relations."
CONCEPT PropertyInstance "The Property that applies to a particular
relation and that some stakeholders intend to obey within the
business context."
CONCEPT PRule "The predicate expression on a single relation that
expresses the PropertyInstance."
```

The relations are declared together with the pragma. They can also be given a meaning. The declaration consist of name, typing and a list of simple properties. In fact the typing has a sugared version in which the function properties (totality and univalence) are replaced by an arrow between the source and target in stead of the star.

```
has_source :: Relation -> Concept
PRAGMA "the relation " " has " " as source concept".
has_target :: Relation -> Concept
PRAGMA "the relation " " has " " as target concept".
is_called :: Relation -> Name
PRAGMA "we gave relation " " the name " "".
uses :: Rule * Relation
PRAGMA "the expression " " uses the relation " "".
to_be_satisfied_by :: PropertyInstance -> Relation
PRAGMA "the simple property " " should hold for relation " "".
is_instance_of :: PropertyInstance -> Property
PRAGMA "the property instance " " is an instance of property " "".
has_expression :: PropertyInstance -> PRule
PRAGMA "the simple property " " has expression " " as derived rule".

has_source  :: Tuple -> Atom
PRAGMA "the pair " " has " " as left component".
has_target :: Tuple -> Atom
PRAGMA "the pair " " has " " as right component".
is_element_of :: Atom -> Concept
PRAGMA "atom " " is element of concept " "".
is_element_of :: Tuple * Relation
PRAGMA "pair " " is element of relation " "".
```

```
manifests_in :: RViolation -> Tuple
PRAGMA "the violation " " manifests itself in the pair " "".
manifests_in :: PViolation -> Tuple
PRAGMA "the violation " " manifests itself in the pair " "".
violates :: RViolation -> Rule
PRAGMA "the pair " " renders rule " " untrue".
violates :: PViolation -> PropertyInstance
PRAGMA "the pair " " renders property " " untrue".
```

The rules are declared with a name for communication about them, but the heart of the rule is the expression that is to be maintained. An explanation serves the documentation need. The second rule has an ambiguous lefthand formula, because there are two sets of sources and targets. By typing the I on the righthand side (`I[Tuple]`), the type checker infers the correct typing.

```
RULE signature MAINTAINS
  has_source;has_source~/\has_target;has_target~/\is_called;is_called~|- I
EXPLANATION "a simple relation is uniquely determined by its signature,
  being its type and name"
RULE integrity_for_tuples MAINTAINS
  has_source;has_source~ /\has_target;has_target~ |- I[Tuple]
EXPLANATION "a tuple is defined by its components"
RULE pviolation_key MAINTAINS
  manifests_in;manifests_in~ /\ violates;violates~ |- I[PViolation]
EXPLANATION "a property violation is completely determined by the tuple
  and the property that it violates"
RULE rviolation_key MAINTAINS
  manifests_in;manifests_in~ /\ violates;violates~ |- I[RViolation]
EXPLANATION "a rule violation is completely determined by the tuple
  and the rule that it violates"
RULE typed_domain MAINTAINS
  is_element_of;has_source |- has_source;is_element_of
EXPLANATION "the source component of a tuple in a relation belongs to
  the source of its signature"
RULE typed_codomain MAINTAINS
  is_element_of;has_target |- has_target;is_element_of
EXPLANATION "the target component of a tuple in a relation belongs to
  the target of its signature"
RULE property_key MAINTAINS
  to_be_satisfied_by;to_be_satisfied_by~/\is_instance_of;is_instance_of~|- I
EXPLANATION "an instance of a simple property is fully determined by
  the relation and the expression"
```

2.5 THE META-MODEL AS A POPULATION OF THE META-MODEL

The basic idea of the Ampersand approach is to take a set of business requirements, and rephrase them to produce a Conceptual Model with rules and populations in such a precise way that a computer can check the business data for violations. In this book, we investigated the underlying notions, and we outlined the requirements and the mathematical constructs (concepts, relations, and rules) needed for this purpose.

Now, if we take one step back, and look at the these ideas from an even more abstract point of view, we may use 'the set of requirements for Ampersand' as just one more example of 'requirements of a business context'! Indeed, we just produced for scripts the Conceptual Model and rules that are fit for a computer. We only need to write down the populations to permit the computer to check for violations in our Ampersand script.

What does such a population look like? To begin, let us write down the population of the relation *is_called* :: Relation $*$ Name.

For example, consider the *has_source* relation which is declared as
`has_source :: Relation -> Concept .`
This declaration identifies this single thing, this relation, by its signature, i.e. its name and typing. It can thus be denoted as `has_source[Relation*Concept]` to identify it in the population of Relation.

So now we have a simple fact (see section 1 of chapter 3), which reads:

The Relation *has_source*[Relation ∗ Concept] is called `has_source`.

This means that the tuple `(has_source[Relation*Concept] , has_source)` is a pair in the population of the relation *is_called*. Another pair in the population of this *is_called* relation is the tuple `(violates[RViolation*Tuple] , violates)`. The population of *is_called* is declared in full by

```
POPULATION is_called CONTAINS
[("is_element_of[Atom*Concept]","is_element_of");
("has_source[Tuple*Atom]","has_source");
("has_target[Tuple*Atom]","has_target");
("has_source[Relation*Concept]","has_source");
("has_target[Relation*Concept]","has_target");
("is_element_of[Tuple*Relation]","is_element_of");
("violates[PViolation*PropertyInstance]","violates");
("violates[RViolation*Rule]","violates");
("manifests_in[PViolation*Tuple]","manifests_in");
("manifests_in[RViolation*Tuple]","manifests_in");
("is_called","is_called"); ("uses","uses");
("to_be_satisfied_by","to_be_satisfied_by");
("is_instance_of","is_instance_of");
("has_expression","has_expression")
]
```

The relation *has_source*[Relation ∗ Concept] is populated too. The population gives for every relation its source concept. There are 15 relations populating Relation and each of them needs to have a source being one of the 11 concepts in Concept. We may picture this situation in an instance diagram as follows:

The population of *has_source*, drawn in figure 8.10, is declared by

```
POPULATION has_source[Relation*Concept] CONTAINS
[("is_element_of[Atom*Concept]","Atom");
("has_source[Tuple*Atom]","Tuple");
("has_target[Tuple*Atom]","Tuple");
("has_source[Relation*Concept]","Relation");
("has_target[Relation*Concept]","Relation");
("is_element_of[Tuple*Relation]","Tuple");
("manifests_in[PViolation*Tuple]","PViolation");
("manifests_in[RViolation*Tuple]","RViolation");
("violates[PViolation*PropertyInstance]","PViolation");
("violates[RViolation*Rule]","RViolation");
("is_called","Relation");("uses","Rule");
("to_be_satisfied_by","PropertyInstance");
("is_instance_of","PropertyInstance");
("has_expression","PropertyInstance")
]
```

Proceeding in this way, all relations in the Conceptual Diagram can be populated. We showed just one Instance diagram, the reader is challenged to produce them all.

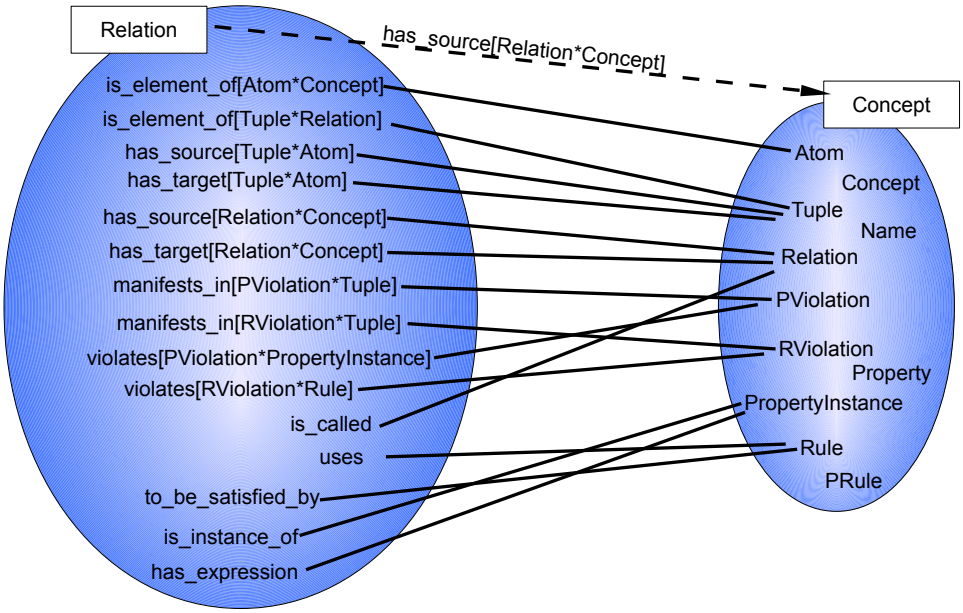


FIGURE 8.10 Instance diagram of the relation *has_source*[Relation ∗ Concept].

The reader is referred to the wiki to see the rest of the rather boring declarations of populations. This also opens up the possibility to browse through the structural view of this script that we have used for the illustrations.

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