

An OPM-Based Metamodel of System Development Process

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Abstract. A modeling and development methodology is a combination of a language for expressing the universal or domain ontology and an approach for developing systems using that language. A common way for building, comparing, and evaluating methodologies is metamodeling, i.e., the process of modeling the methodology. Most of the methodology metamodels pertain only to the language part of the methodologies, leaving out the description of the system development processes or describing them informally. A major reason for this is that the methods used for metamodeling are structural- or object-oriented, and, hence, are less expressive in modeling the procedural aspects of a methodology. In this paper we apply Object-Process Methodology (OPM) to specify a generic OPM-based system development process. This metamodel is made possible due to OPM's view of objects and processes as being on equal footing rather than viewing object classes as superiors to and owners of processes. This way, OPM enables specifying both the structural (ontological constructs) and behavioral (system development) aspects of a methodology in a single, unified view.

1 Introduction

A system modeling and development methodology ideally supports the entire system lifecycle, from initiation (conceiving, initiating, and requirement elicitation) through development (analysis, design, and implementation) to deployment (assimilation, usage, and maintenance) [5]. To enable this diversified set of activities, the methodology should be based on sound ontology, which can be either universal or domain-specific; a language for expressing the ontology; and a well-defined system development process. Developers who follow this process use the language to produce the artifacts that are pertinent for each phase of the system's lifecycle. It should therefore come as no surprise that any system modeling and development methodology worthy of its name is itself a highly complex system, and as such, it ought to be carefully analyzed and modeled.

The concept of metadata is quite widespread. In the context of the Internet, for example, metadata is machine understandable information for the Web. Metamodeling, the process of modeling a methodology, extends the notion of metadata and produces metamodels, i.e., models of methodologies. Metamodels have become important means for building, comparing, and evaluating methodologies and

their supporting CASE tools. Hence, it has been the focal point in several efforts to coalesce object-oriented methods and, at the same time, put them on a more rigorous footing [3, 9, 11, 13]. Some of the created metamodels use the methodology being modeled as a tool for describing itself. We refer to this type of metamodeling as **reflective metamodeling** and to the methodology as a **reflective methodology**. A reflective methodology is especially powerful since it is self-contained and does not require auxiliary means or external tools to model itself.

Most of the existing (both reflective and non-reflective) metamodels focus on describing the syntax and semantics of the methodology constructs, leaving out of the metamodel all the procedural and behavioral aspects [4]. These aspects relate to processes that are either part of the language capabilities (such as refinement-abstraction processes) or processes that belong to the development of a system using the methodology. The reason for the lack of procedural modeling is that the techniques used for metamodeling (such as ERD and UML) are structural- or object-oriented. Object-Process Methodology (OPM) overcomes this limitation by supporting the specification of the structural and behavioral aspects of the modeled methodology in a single framework, enabling mutual effects between them.

In this paper, we apply OPM to define a comprehensive lifecycle-supporting system development process. This process follows generic concepts of systems evolution and lifecycle, namely requirement specification, analysis and design, implementation, usage and maintenance, and, as such, it is not specific to OPM-based system development. Nevertheless, applying it in an OPM framework has great benefits as explained latter. In Section 2 we review existing metamodels and criticize their ability to model system development processes. In Section 3 we introduce the foundations of OPM, while the metamodel of an OPM-based development process is presented in Section 4. Finally, in Section 5, we summarize the main benefits of our metamodeling approach and discuss future research directions.

2 Literature Review: Metamodels and Metamodeling

2.1 Metamodel and Metamodeling Definitions

System analysis and design activities can be divided into three types with increasing abstraction levels: real world, model, and metamodel [9, 19]. The real world is what system analysts perceive as reality or what system architects wish to create as reality. A model is an abstraction of this perceived or contemplated reality that enables its expression using some approach, language, or methodology. A metamodel is a model of a model, or more accurately, a model of the modeling methodology [22].

Analogous to modeling, metamodeling is the process that creates metamodels. The level of abstraction at which metamodeling is carried out is higher than the level at which modeling is normally done for the purpose of generating a model of a system [9]. Metamodeling is worth pursuing because of the following reasons:

- With the advent of the Internet, and particularly the Intranet, data integration has become a major concern. Metamodels are the foundation for data integration in software (and even hardware) development. One such major effort is the Resource Description Framework (RDF) [20] which provides a lightweight ontology system to support the exchange of knowledge on the Web.

- Metamodels help abstracting low level integration and interoperability details and facilitate partitioning problems into orthogonal sub-problems. Hence, metamodels can serve as devices for method development (also referred to as method engineering) [1, 2], language modeling, and conceptual definition of repositories and CASE tools [17].
- Defining a methodology is an interactive process, in which a core is defined and then extended to include all the needed concepts. Metamodeling enables checking and verifying the completeness and expressiveness of a methodology through understanding the deep semantics of the methodology as well as relationships among concepts in different languages or methods [10].

The growth of object-oriented methods during the last decade of the 20th century introduced a special type of metamodeling, which we call **reflective metamodeling**. Reflective metamodeling models a methodology by the means and tools that the methodology itself provides. While metamodeling is a formal definition technique of methodologies, reflective metamodeling can serve as a common way to examine and demonstrate the methodology's expressive power.

2.2 Leading Metamodels of Analysis and Design Methods

Metamodels of visual software engineering methods are commonly expressed in ER or class diagrams. These notations model primarily the structural and static aspects of methodologies. ER-based metamodels are also limited in describing constraints, hierarchical structures (i.e., complex objects), explosion, and polymorphism [4] required for specifying complete methodologies or languages.

UML, which is the standard object-oriented modeling language, has several metamodel propositions. The reflective UML metamodel in [13], for example, includes class diagrams, OCL (Object Constraint Language) [21] sentences, and natural language explanations for describing the main elements in UML and the static relations among them. The Meta Object Facility (MOF) [11], which is an OMG standard, extensible four layer metadata architecture, is also applied to metamodel UML. MOF layers are: information (i.e., real world concepts, labeled M0), model (M1), metamodel (M2), and meta-metamodel (M3). The meta-metamodel layer describes the structure and semantics of meta-metadata, i.e., it is an “abstract language” for defining different kinds of metadata (e.g., meta-classes and meta-attributes). The Meta Modeling Facility (MMF) [3] provides a modular and extensible method for defining and using UML. It comprises a static, object-oriented language (MML), used to write language definitions; a tool (MMT) used to interpret those definitions; and a method (MMM), which provides guidelines and patterns encoded as packages that can be specialized to particular language definitions.

These metamodels of UML are incomplete in more than one way. First, UML is only a language, not a methodology, so only the language elements are metamodelled, but not any object-oriented (or other) development process [13]. Second, the consistency and integrity constraints that UML models should follow are not included and formulated in these metamodels. Several “software process models” have been associated with UML to create complete UML-based methods. One such familiar development process is the Rational Unified Process (RUP) [16]. RUP is a configurable software development process pattern that presents the relations between the process lifecycle aspects (inception, elaboration, construction, and transition) and

the process disciplines and activities (business modeling, requirements, etc.). While RUP supplies a general framework of development processes, it does not have a precise underlying metamodel.

The Software Process Engineering Metamodel (SPEM) [12] uses UML to describe a concrete software development process or a family of related software development processes. It uses MOF four-layered architecture, where the performing process (the real-world production process) is at level M0 and the definition of the corresponding process (e.g., RUP) is at level M1.

The Object-oriented Process, Environment, and Notation (OPEN) [8, 14] is a methodology that offers a notation, called OPEN Modeling Language (OML) [7], as well as a set of principles for modeling all aspects of software development across the entire system lifecycle. The development process is described by a contract-driven lifecycle model, which is complemented by a set of techniques and a formal representation using OML. The lifecycle process, including its techniques, tasks, and tools, is described in terms of classes and their structural relations.

The above metamodels, as well as other metamodels that use structural- or object-oriented methodologies, emphasize the objects and their relations within the metamodel, while the procedural aspects are suppressed and revealed only through operations of objects and the messages passed among them [4]. While real-world processes require interaction and state diagrams to describe system dynamics and function, metamodels of methodologies use only packages, classes, and associations. The main reasons for this limited usage of UML include the complexity of its vocabulary [18] and its model multiplicity and integration problems [15]. Object-Process Methodology overcomes this shortcoming by recognizing processes as entities beside, rather than underneath, objects.

3 Object-Process Methodology (OPM)

Object-Process Methodology (OPM) [5] is an integrated modeling approach to the study and development of systems in general and information systems in particular. Enabling the existence of processes as stand-alone entities provides for the ability to model a system in a single unified framework, showing in the same diagram type its structure and behavior. These two major aspects co-exist in the same OPM model without highlighting one at the cost of suppressing the other. Hence, OPM provides a solid basis for modeling complex systems, in which structure and behavior are highly intertwined and hard to separate. Involving the modeling process with the ontology elements, system development methodologies are a prime example of such systems.

The elements of the OPM methodology are entities (things and states) and links. A *thing* is a generalization of an *object* and a *process* – the two basic building blocks of any system expressed in OPM. At any point in time, each object is at some *state*, while object states are changed through occurrences of processes. Respectively, links can be structural or procedural. *Structural links* express static relations between pairs of things, where aggregation, generalization, characterization, and instantiation are the four fundamental structural relations. *Procedural links* connect entities to describe the behavior of a system, i.e., how processes transform and use other entities.

Two semantically equivalent modalities, one graphic and the other textual, jointly express the same OPM model. A set of inter-related Object-Process Diagrams (OPDs)

constitute the graphical, visual OPM formalism. Each OPM element is denoted in an OPD by a symbol, and rules are defined for specifying correct and consistent ways by which entities are linked. The Object-Process Language (OPL), defined by a grammar, is the textual counterpart modality of the graphical OPD-set. OPL is a dual-purpose language, oriented towards humans as well as machines. Catering to human needs, OPL serves domain experts and system architects engaged in analyzing and designing a system. Designed also for machines, OPL provides a firm basis for automatically generating the designed application. Every OPD construct is expressed by a semantically equivalent OPL sentence or part of a sentence and vice versa.

OPM manages system complexity through three refinement/abstraction mechanisms: *Unfolding/folding*, which is used for refining/abstracting the structural hierarchy of a thing; *In-zooming/out-zooming*, which exposes/hides the inner details of a thing within its frame; and *state expressing/suppressing*, which exposes/hides the states of an object. Using these mechanisms, OPM enables specifying a system to any desired level of detail without losing legibility and comprehension of the resulting specification.

Being both object- and process-oriented, OPM enables explicit modeling of the procedural and dynamic aspects of the development process part of a system analysis and design methodology. In the rest of the paper, we present a graphical OPM model of a generic system development process, which includes requirement specifying, analyzing and designing, implementing, and using and maintaining. The legend of this model is provided in [5] and in Appendix A.

4 An OPM-Based System Development Model

The System Diagram, which is labeled **SD** and shown in 0, is the top-level specification of the OPM metamodel. It specifies **Ontology**, **Notation**, and the **System Developing** process as the major OPM features (characterizations). **Ontology** includes the basic elements in OPM, their attributes, and the relations among them. For example, objects, processes, states, and aggregations are all OPM elements. The **Notation** represents the **Ontology** graphically (by OPDs) or textually (by OPL sentences). For example, a process is represented graphically in an OPD by an ellipse, while an object is symbolized by a rectangle.

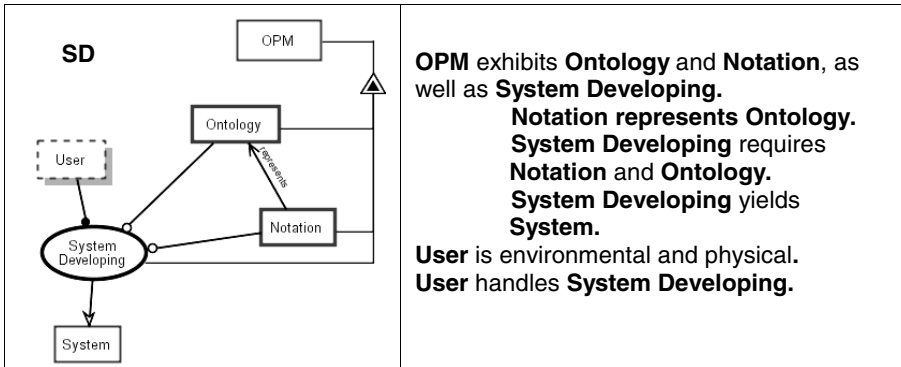


Fig. 1. The top level specification of the OPM metamodel

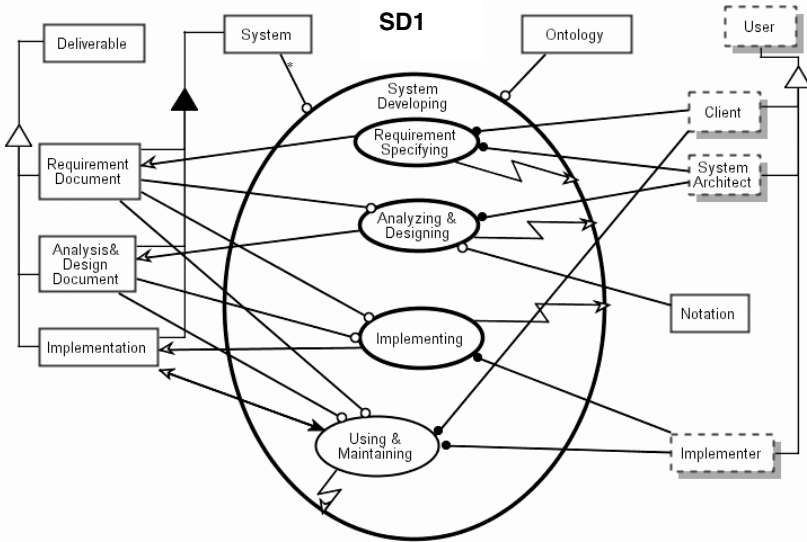


Fig. 2. Zooming into System Developing

The **System Developing** process, also shown in **SD**, is handled by the **User**, who is the physical and external (environmental) object that controls (is the agent of) the process. This process also requires **Ontology** and **Notation** as instruments (inputs) in order to create a **System**.

The OPL paragraph, which is equivalent to **SD**, is also shown in 0. Since OPL is a subset of English, users who are not familiar with the graphic notation of OPM can validate their specifications by inspecting the OPL sentences. These sentences are automatically generated on the fly in response to the user’s draws of OPDs [6]. Due to space limitations and the equivalence of OPM graphical and textual notations, we use only the OPD notation in the rest of the paper.

Zooming into **System Developing**, **SD1** (0) shows the common sequential¹ stages of system developing processes: **Requirement Specifying**, **Analyzing & Designing**, **Implementing**, and **Using & Maintaining**. All of these processes use the same OPM **Ontology**, a fact that helps narrowing the gaps between the different stages of the development process. **SD1** shows that the **Client** and the **System Architect**, who, along with the **Implementer**, specialize **User**, handle the **Requirement Specifying** sub-process. **Requirement Specifying** takes OPM **Ontology** as an input and creates a new **System**, which, at this point, consists only of a **Requirement Document**. The termination of **Requirement Specifying** starts **Analyzing & Designing**, the next sub-process of **System Developing**.

¹ The time line in an OPD flows from the top of the diagram downwards, so the vertical axis within an in-zoomed process defines the execution order. The sub-processes of a sequential process are depicted in the in-zoomed frame of the process stacked on top of each other with the earlier process on top of a later one. Analogously, subprocesses of a parallel process appear in the OPD side by side, at the same height.

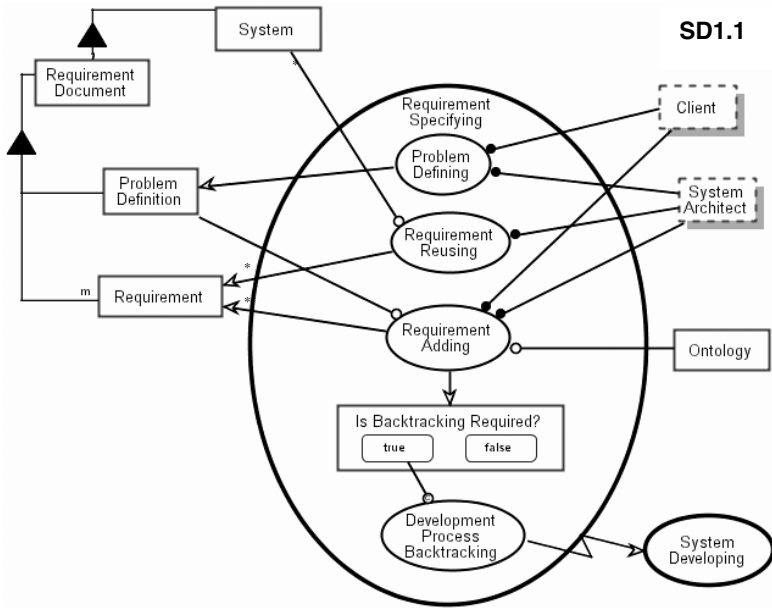


Fig. 3. Zooming into Requirement Specifying

The agent of the **Analyzing & Designing** stage is the **System Architect**, who uses the **Requirement Document** and OPM Notation to create a new part of the system, the **Analysis & Design Document**. When the **Analyzing & Designing** process terminates, the **Implementer** (programmer, DBA, etc.) starts the **Implementing** phase, which uses the **Requirement Document** and the **Analysis & Design Document** in order to create the **Implementation**. Finally, the **Implementer** changes the system **Implementation** during the **Using & Maintaining** stage, while the **Client** uses the **System**.

As the invocation links in **SD1** denote, each **System Developing** sub-process can invoke restarting of the entire development process, which potentially enables the introduction of changes to the requirements, analysis, design, and implementation of the **System**. These invocations give rise to an iterative development process, in which an attempt to carry out a sub-process reveals faults in the deliverable of a previous subprocess, mandating a corrective action.

4.1 The Requirement Specifying Stage

In **SD1.1** (0), **Requirement Specifying** is zoomed into, showing its four subprocesses. First, the **System Architect** and the **Client** define the problem to be solved by the system (or project). This **Problem Defining** step creates the **Problem Definition** part of the current system **Requirement Document**. Next, through the **Requirement Reusing** sub-process, the **System Architect** may reuse requirements that fit the problem at hand and are adapted from any existing **System** (developed by the organization). Reuse helps achieve high quality systems and reduce their

development and debugging time. Hence, when developing large systems, such as Web applications or real-time systems, it is important to try first to reuse existing artifacts adapted from previous generations, analogous systems, or commercial off-the-shelf (COTS) products that fit the current system development project. Existing, well-phrased requirements are often not trivial to obtain, so existing relevant requirements should be treated as a potential resource no less than code. Indeed, as the OPD shows, reusable artifacts include not only components (which traditionally have been the primary target for reuse), but also requirements.

After optional reuse of requirements from existing systems (or projects), the **System Architect** and the **Client**, working as a team, add new **Requirements** or update existing ones. This step uses **OPM Ontology** in order to make the **Requirement Document** amenable to be processed by other potential OPM tools, and in particular to an OPL compiler. The bi-modal property of OPM, and especially the use of OPL, a subset of natural language, enables the **Client** to be actively involved in the critical **Requirement Specifying** stage. Moreover, since the **System Architect** and the **Client** use **OPM Ontology** in defining the new requirements, the resulting **Requirement Document** is indeed expressed, at least partially, in OPL in addition to explanations in free natural English. Such structured OPM-oriented specification enables automatic translation of the **Requirement Document** to an OPM analysis and design skeleton (i.e., a skeleton of an OPD-set and its corresponding OPL script). Naturally, at this stage the use of free natural language beside OPM seems mandatory to document motivation, alternatives, considerations, etc.

Finally, the **Requirement Adding** process results in the Boolean object “**Is Backtracking Required?**”, which determines whether **System Developing** should be restarted. If so, **Development Process Backtracking** invokes the entire **System Developing**. Otherwise, **Requirement Specifying** terminates, enabling the **Analyzing & Designing** process to begin.

4.2 The Analyzing and Designing Stage

During the **Analyzing & Designing** stage, shown in **SD1.2 (0)**, a skeleton of an **OPL Script** is created from the **Requirement Document** for the current system. As noted, in order to make this stage as effective and as automatic as possible, the **Requirement Document** should be written using OPM, such that the resulting OPL script can be compiled. The **System Architect** can then optionally reuse analysis and design artifacts from previous systems (projects), creating a basis for the current system analysis and design. Finally, in an iterative process of **Analysis & Design Improving** (which is in-zoomed in **SD1.2.1 (0)**), the **System Architect** can engage in **OPL Updating**, **OPD Updating**, **System Animating**, **General Information Updating**, or **Analysis & Design Terminating**.

Any change a user makes to one of the modalities representing the model triggers an automatic response of the development environment software to reflect the change in the complementary modality. Thus, as **SD1.2.1** shows, **OPD Updating** (by the **System Architect**) affects the **OPD-set** and immediately invokes **OPL Generating**, which changes **OPL Script** according to the new **OPD-set**. Conversely, **OPL Updating** (also by the **System Architect**) affects the **OPL Script**, which invokes **OPD Generating**, reflecting the OPL changes in the **OPD-set**.

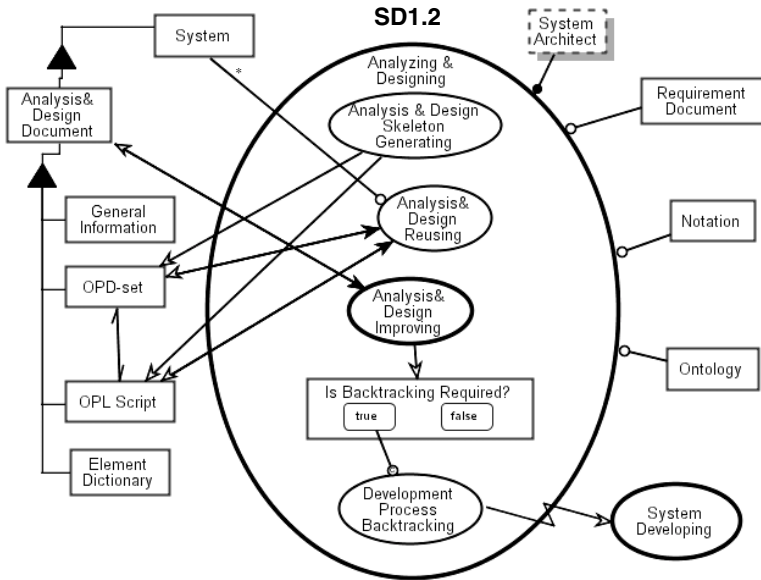


Fig. 4. Zooming into Analyzing & Designing

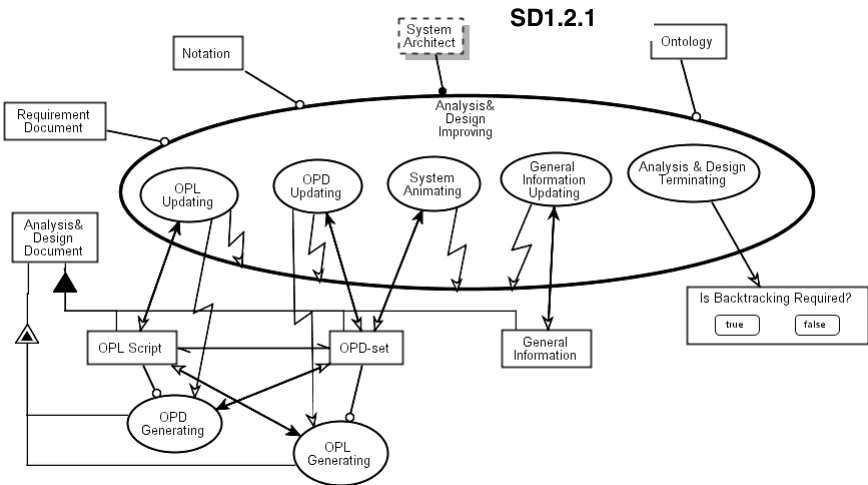


Fig. 5. Zooming into Analysis & Design Improving

Since OPM enables modeling system dynamics and control structures, such as events, conditions, branching, and loops, **System Animating** simulates an **OPD-set**, enabling **System Architects** to dynamically examine the system at any stage of its development. Presenting live animated demonstrations of system behavior reduces the number of design errors percolated to the implementation phase. Both static and dynamic testing help in detecting discrepancies, inconsistencies, and deviations from the intended goal of the system. As part of the dynamic testing, the simulation enables

designers to track each of the system scenarios before writing a single line of code. Any detected mistake or omission is corrected at the model level, saving costly time and efforts required within the implementation level. Avoiding and eliminating design errors as early as possible in the system development process and keeping the documentation up-to-date contribute to shortening the system's delivery time ("time-to-market").

Upon termination of the **Analysis & Design Improving** stage, if needed, the entire **System Developing** process can restart or the **Implementing** stage begins.

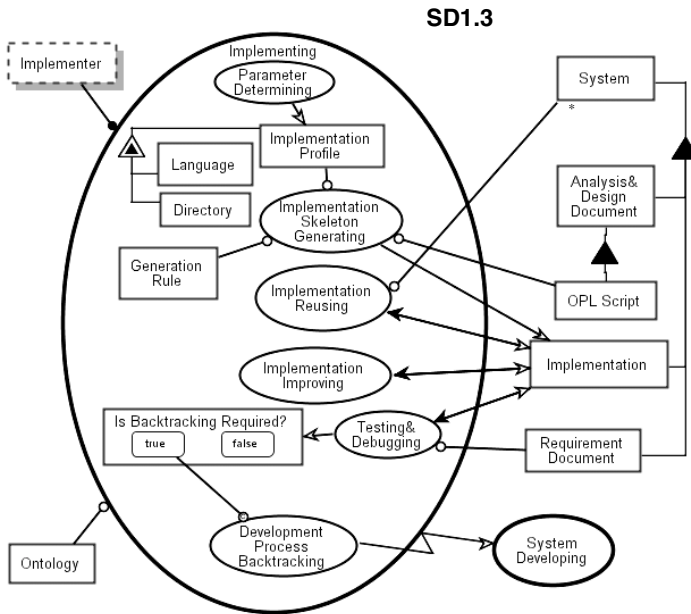


Fig. 6. Zooming into Implementing

4.3 The Implementing Stage

The **Implementing** stage, in-zoomed in **SD1.3** (0), begins by defining the **Implementation Profile**, which includes the target **Language** (e.g., Java, C++, or SQL) and a default **Directory** for the artifacts. Then, the **Implementation Skeleton Generating** process uses the **OPL Script** of the current system and inner **Generation Rules** in order to create a skeleton of the **Implementation**. The **Generation Rules** save pairs of OPL sentence types (templates) and their associated code templates in various target **Languages**.

The initial skeleton of the **Implementation**, which includes both the structural and behavioral aspects of the system, is then modified by the **Implementer** during the **Implementation Reusing** and **Implementation Improving** steps. In the **Testing & Debugging** stage, the resulting **Implementation** is checked against the **Requirement Document** in order to verify that it meets the system requirements defined jointly by the **Client** and the **System Architect**. If any discrepancy or error is detected, the

System Developing process is restarted, else the system is finally delivered, assimilated and used. These sub-processes are embedded in the **Using & Maintaining** process at the bottom of **SD1** (0). While **Using & Maintaining** takes place, the **Client** collects new requirements that are eventually used when the next generation of the system is initiated. A built-in mechanism for recording new requirements in OPM format while using the system would greatly facilitate the evolution of the next system generation [5].

5 Summary and Future Work

We have presented a complete and detailed model of a system for developing systems as part of the OPM reflective metamodel. This system development model follows generic concepts of systems evolution and lifecycle, and as such, it is not specific to OPM-based system development. Nevertheless, applying this process in an OPM framework has great benefits: it narrows the gap between the various development steps and enables semi-automated generations. The elaborate backtracking options of this model, which are built-in at all levels, make it flexible enough to represent a variety of information system development approaches, ranging from the classical waterfall model through incremental development to prototyping.














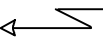
Although object-oriented system development methods have been augmented to include models that enable specification of the system's behavioral aspects (e.g., UML sequence, collaboration, and Statechart diagrams), formal metamodels of these methods relate only to their language aspects. More specifically, the widely accepted object-oriented approach, which combines UML as the language part with RUP as the system development part, provides a formal metamodel only of the static aspects. Conversely, since OPM inherently combines the system's structural and behavioral aspects in a unifying, balanced framework, it can reflectively metamodel both the language and the development process parts of any methodology. This ability to model equally well structural and procedural system aspects is indicative of OPM's expressive power, which is a direct result of its balanced ontology. Recognizing objects and processes as prime ontological constructs of equal status provides for faithful modeling of systems, regardless of their domain, while OPM's abstraction-refinement capabilities enable systems' complexity management.

The system development process specified in this work is designed to accompany the development of any system that involves a combination of complex structure and behavior. The model of this development process provides a theoretical foundation for improving the current version of OPCAT [6], Object Process CASE Tool, that supports OPM-based systems development. **System Animating**, **OPD Updating**, and **OPL Updating** are already implemented as OPCAT services, while **Implementation Skeleton Generating** is in progress. We also plan to implement and incorporate all the other **System Developing** sub-processes into OPCAT in order to make it a fully Integrated System Engineering Environment (I SEE).

References

1. Brinkkemper, S., Lyytinen, K., and Welke, R. *Method Engineering: Principles of Method Construction and Tool Support*, Kluwer Academic Publishers, 1996.
2. Brinkkemper, S., Saeki, M., and Harmsen, F. A Method Engineering Language for the Description of Systems Development Methods. 13th Conference on Advanced Information Systems Engineering (CaiSE'2001), Lecture Notes in Computer Science 2068, pp. 473–476, 2001.
3. Clark, T., Evans, A., and Kent, S. *Engineering Modeling Languages: a Precise Meta-Modeling Approach*. <http://www.cs.york.ac.uk/puml/mmf/langeng.ps>
4. Domínguez, E., Rubio, A.L., Zapata, M.A. Meta-modelling of Dynamic Aspects: The Noesis Approach. International Workshop on Model Engineering, ECOOP'2000, pp. 28–35, 2000.
5. Dori, D. *Object-Process Methodology – A Holistic Systems Paradigm*, Springer Verlag, Berlin, Heidelberg, New York, 2002.
6. Dori, D. Reinhartz-Berger, I. and Sturm A. *OPCAT – A Bimodal Case Tool for Object-Process Based System Development*. 5th International Conference on Enterprise Information Systems (ICEIS 2003), pp. 286–291, 2003. Software download site: <http://www.objectprocess.org>
7. Firesmith, D., Henderson-Sellers, B., and Graham, I. *The OPEN Modeling Language (OML) – Reference Manual*. Cambridge University Press, SIGS books, 1998.
8. Graham, I., Henderson-Sellers, B., and Younessi, H. *The OPEN Process Specification*. Addison-Wesley Inc., 1997.
9. Henderson-Sellers, B. and Bulthuis, A. *Object-Oriented Metamethods*, Springer Inc., 1998.
10. Hillegersberg, J.V., Kumar, K. and Welke, R.J. Using Metamodeling to Analyze the Fit of Object-Oriented Methods to Languages. Proceedings of the 31st Hawaii International Conference on System Sciences (HICSS'98), pp. 323–332, 1998.
11. Object Management Group (OMG). Meta Object Facility (MOF) Specification. OMG document formal/02-04-03, <http://cgi.omg.org/docs/formal/02-04-03.pdf>
12. Object Management Group (OMG). Software Process Engineering Metamodel (SPEM), version 1.0, OMG document formal/02-11-14, <http://www.omg.org/technology/documents/formal/spem.htm>
13. Object Management Group (OMG). UML 1.4 – UML Semantics. OMG document formal/01-09-73, <http://cgi.omg.org/docs/formal/01-09-73.pdf>
14. OPEN web site, <http://www.open.org.au/>
15. Peleg, M. and Dori, D. The Model Multiplicity Problem: Experimenting with Real-Time Specification Methods. *IEEE Transaction on Software Engineering*, 26 (8), pp. 742–759, 2000.
16. Rational Software. Rational Unified Process for Systems Engineering – RUP SE1.1. A Rational Software White Paper, TP 165A, 5/02, 2001, <http://www.rational.com/media/whitepapers/TP165.pdf>
17. Talvanen, J. P. Domain Specific Modelling: Get your Products out 10 Times Faster. Real-Time & Embedded Computing Conference, 2002, http://www.metacase.com/papers/Domain-specific_modelling_10X_faster_than_UML.pdf
18. Siau, K. and Cao, Q. Unified Modeling Language (UML) – A Complexity Analysis. *Journal of Database Management* 12 (1), pp. 26–34, 2001.
19. Van Gigch, J. P. *System Design Modeling and Metamodeling*. Plenum press, 1991.
20. W3C Consortium. Resource Description Framework (RDF). <http://www.w3.org/RDF/>
21. Warmer, J. and Kleppe, A. *The Object Constraint Language – Precise Modeling with UML*. Addison-Wesley, 1999.
22. What is metamodeling, and what is a metamodel good for? <http://www.metamodel.com/>

Appendix A: Main OPM Concepts, Their Symbols, and Their Meaning

Concept Name	Symbol	Concept Meaning
Informational object		A piece of information
Environmental, physical object		An object which consists of matter and/or energy and is external to the system
Process class		A pattern of transformation that objects undergo
State		A situation at which an object can exist for a period of time
Characterization		A fundamental structural relation representing that an element exhibits a thing (object/process)
Aggregation		A fundamental structural relation representing that a thing (object/process) consists of one or more things
General structural link		A bidirectional or unidirectional association between things that holds for a period of time
Condition link		A link denoting a condition required for a process execution
Agent link		A link denoting that a human agent (actor) is required for triggering a process execution
Instrument link		A link denoting that a process uses an entity without changing it. If the entity is not available, the process waits for its availability.
Effect link		A link denoting that a process changes an entity. The black arrowhead points towards the process that affects the entity.
Consumption link		A link denoting that a process consumes an (input) entity
Result link		A link denoting that a process creates an (output) entity
Invocation link		A link denoting that a process triggers (invokes) another process when it ends