

OPM vs. UML – Experimenting With Comprehension and Construction of Web Application Models

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Abstract

Object-Process Methodology (OPM), which is a holistic approach to modeling and evolving systems, views objects and processes as two equally important entities that describe the system's structure and behavior in a single model. Unified Modeling Language (UML), which is the standard object-oriented modeling language for software systems, separates the system model into various aspects, each of which is represented in a different view (diagram type).

The exponential growth of the Web and the progress of Internet-based architectures have set the stage for the proliferation of a variety of Web applications, which are classified as hybrids between hypermedia and information systems. Such applications require a modeling approach that is capable of clearly specifying aspects of their architecture, communication, and distributive nature. Since UML and OPM are two candidates for this task, this study has been designed to establish the level of comprehension and the quality of the constructed Web application models using each one of these two approaches.

In the experiment we carried out, third year undergraduate information systems engineering students were asked to respond to comprehension and construction questions about two representative Web application models. The comprehension questions related to the system's structure, dynamics, and distribution aspects. The results suggest that OPM is better than UML in modeling the dynamics aspect of the Web applications. In specifying structure and distribution aspects, there were no significant differences. The results further suggest that the quality of the OPM models students built in the construction part was superior to that of the corresponding UML models.

1. Introduction

Modeling languages and methods for system specification, analysis, and design that have been proposed over the years can be classified into three categories: structure- or object-oriented, behavior- or process-oriented, and hybrids of the two. The object-oriented (OO) approach focuses on the system's objects, while its behavior is encapsulated as operations within these objects. The large number of OO modeling languages that had emerged and proliferated from the mid 1980's to the mid 1990's set the stage for the adoption of the Unified Modeling Language (UML) (OMG, 2002) as the standard object-oriented notation for modeling software systems. Process-oriented approaches, which predate the OO ones, emphasize the system's behavior. Many of them, including Structured System Analysis (SSA) (DeMarco, 1978) and Structured System Design (SSD) (Yourdon and Constantine, 1979), are based on Data Flow Diagrams (DFD), while others, such as Statecharts (Harel, 1987) and Petri nets (Peterson, 1981), are elaborations of state machines.

Proponents of both the object- and the process-oriented approaches have reached the conclusion that focusing on just one aspect of a system while neglecting the other is counterproductive. To remedy this shortcoming, each approach adopted some technique used by its counterpart. DFD-based techniques, for example, rely on Entity-Relationship (ER) or class diagrams for modeling the static data scheme. UML incorporates several process-oriented diagrams, including interaction diagrams, which describe the system dynamics through message passing among objects, and state diagrams (or Statecharts), each of which specifies the behavior of a single object over time in terms of the states it traverses.

The need for adequate representation of both the static and dynamic aspects of a system while keeping the model as simple as possible was a prime motivation for the development of Object-Process Methodology (OPM) (Dori, 2002a). OPM is an integrated modeling and system evolution approach that uses objects, processes, and links to represent the system's structure and behavior in a single model that uses the same diagram type along with equivalent natural language specification. This way, OPM attempts to solve two of the main deficiencies of the object-oriented approach in general and UML in particular: the unbalanced structure-behavior representation and the model multiplicity problem (Peleg and Dori, 2000; Dori 2002b).

The prevalent use of the Internet and the World Wide Web as platforms for distributed information systems has raised questions regarding the ability of OPM to satisfy requirements introduced by the domain of Web application (Reinhartz-Berger et al., 2002a).

In this paper we present our empirical findings about the comprehension of given OPM and UML models and the quality of constructed OPM and UML models in the domain of Web applications. The structure of the rest of the paper is as follows. Section 2 reviews related works that compare modeling languages and methods either theoretically or empirically. Section 3 briefly presents the main principles of OPM and UML. Section 4 describes the experiment hypothesis, setting, and design, while Sections 5 and 6 respectively present and discuss the experiment results. Based on our empirical findings, in Section 7 we summarize the benefits and shortcomings of OPM and suggest ways to improve the methodology and OPCAT, its supporting CASE tool.

2. Related Studies

The emergence of the large number of software and system modeling approaches and notations over the years has underlined the need to evaluate them either theoretically or empirically. Theoretical approaches use metamodeling techniques or define objective criteria for comparing modeling languages in terms of expressiveness, complexity, and accuracy. In one theoretical study, Hillegersberg et al. (1998) applied metamodeling to examine the fitness of the Booch method (Booch, 1991), an object-oriented analysis and design method, to the object-oriented programming languages Smalltalk, Eiffel, and C++. Halpin and Bloesch (1998) studied the relative strengths and weaknesses of Object Role Model (ORM) and UML for data modeling according to criteria of expressiveness, clarity, semantic stability, semantic relevance, validation mechanisms, abstraction mechanisms, and formal foundation. Siau and Cao (2001) compared the complexity metric values of UML with other object-oriented techniques. Their comparison related to seventeen complexity metrics, including independent metrics (such as the number of object types per technique) and aggregate metrics (e.g., the division of work in a specific technique). They found that UML is at least twice as complex as other object-oriented, single view notations.

Modeling languages can also be compared empirically. Empirical studies are based on experiments, in which the results are examined quantitatively according to certain criteria, and the subjects may be untrained people, students, or professional system

analysis and design experts. Kim and March (1995) compared Extended ER (EER) and NIAM (Nijssen Information Analysis Method) (Verheijen and Van Bekkum, 1982) for user comprehension, which was measured by counting the number of correct answers to questions about the various modeling constructs. Shoval and Shiran (1997) compared EER and object-oriented data models from a design quality viewpoint. They measured quality in terms of correctness of the achieved model, time to complete the design task, and designer's model preferences. Otero and Dolado (2002) compared the semantic comprehension of three different notations for representing behavior in UML: sequence diagrams, collaboration diagrams, and state diagrams. The comparison was in terms of the total time to complete the tasks and their scores. They found that the comprehension of dynamic models in object-oriented designs depends on the complexity of the system. Peleg and Dori (2000) compared OPM/T, an extension of OPM to real-time systems, with a variation of Object Modeling Technique (OMT) (Rumbaugh et al., 1991) to the same domain (T/OMT). They examined the specification quality and comprehension of both system's structural and behavioral aspects. The subjects were asked to fill in a questionnaire consisting of statements on a system modeled in one of the techniques and to specify another system using the second technique. The conclusion was that the single view of OPM/T is more effective than the multiple-view of T/OMT in generating a better system specification. Most of the errors in the T/OMT models resulted from (1) lack of integration among the technique's different views and (2) the need to maintain consistency among the three view types (object diagrams, DFD, and Statecharts) and to gather information that is scattered across these views. The comprehension part of the experiment revealed a significant difference in favor of T/OPM in three issues: (1) identifying triggering events of processes, (2) identifying processes that are triggered by a given event, and (3) identifying objects that participate in a process. T/OMT, on the other hand, was found to be better in two other issues: (1) identifying events that affect objects by changing their state, and (2) determining the order of process execution. Following that experiment, the research described in this paper compares the abilities of OPM and UML, the successor of OMT, to model systems in the domain of Web applications.

3. OPM and UML Essentials

Before going into the details of the experiment and its outcomes, we briefly describe the basic principles of the two modeling approaches that were compared in this study.

3.1 Object-Process Methodology (OPM)

Object-Process Methodology (OPM) (Dori, 1995; Peleg and Dori, 1999; Dori 2002a) is an integrated modeling approach to the modeling, study and lifecycle support of systems in general and information systems in particular. Recognizing the existence of processes as stand-alone entities, which is a major departure from the encapsulation principle of the object-oriented approach, OPM enables modeling the system's structure and behavior in a single unified framework. OPM allows processes to complement objects as entities at the same level. This way, structure and behavior, which are the two major aspects that all systems exhibit, co-exist in the same OPM model without highlighting one at the cost of suppressing the other. This unique structure-behavior integration in a single view makes OPM most useful for modeling complex reactive systems, in which these two prime aspects are highly intertwined and hard to separate.

The elements of the OPM ontology are entities (things and states) and links. A *thing* is a generalization of a (stateful) *object* and a *process* – the two basic building blocks of any OPM-based system model. Objects exist, while processes transform them. Transformation can be generation of new objects, consumption of existing objects, or changing objects' states. At any point in time, each object is at some *state*, and object states are changed through occurrences of processes. Links can be structural or procedural. A *structural link* expresses a static relation between two objects. Aggregation, generalization, characterization, and instantiation are the four fundamental structural relations. General tagged relations enable the definition of the semantics of any other structural link. *Procedural links* describe the behavior of a system, i.e., how processes transform (generate, consume, or update) objects, how objects enable processes (without being transformed), and how internal or external events trigger processes. The resulting model is expressed bimodally, both in graphics (through a set of Object-Process Diagrams, abbreviated as OPDs) and in a subset of English (through a corresponding set of Object-Process Language paragraphs).

OPM enables specifying system structure and dynamics to any desired level of detail without losing legibility and comprehension of the resulting specification. This

is done through three refinement/abstraction mechanisms: *unfolding/folding*, which refines/abstracts the structural parts of a thing (mainly an object), *in-zooming/out-zooming*, which exposes/hides the inner details of a thing (mainly a process) within its enclosing frame, and *state expressing/suppressing*, which exposes/hides the states of an object.

Introducing OPM to the Web application domain has required a few extensions (Reinhartz-Berger et al., 2002a). These extensions, which do not add elements to OPM ontology or symbols to its notation, provide for open reuse of component designs through bindings among model modules (Reinhartz-Berger et al., 2002b) and support code mobility and migration specifications (Reinhartz-Berger et al., 2003).

3.2 Unified Modeling Language (UML)

Unified Modeling Language (UML) (OMG, 2002) is an object-oriented language for specifying, visualizing, constructing, and documenting the artifacts of software systems, as well as for business modeling and other non-software systems. UML defines ten types of diagrams, which are divided into three categories. Four diagram types represent structure and include the class, object, component, and deployment diagrams. Five diagram types, which represent different aspects of dynamic behavior, include use case, sequence, activity, collaboration, and state diagrams (Statecharts). Finally, package diagrams represent ways to organize and manage application modules. A system modeled by UML consists of several different, but related, diagrams of various types. UML also provides several extension mechanisms that allow modelers to define domain-specific extensions without having to modify the modeling language. One such mechanism is *stereotype* – a new kind of a model element that extends the semantics of an existing kind of element. User-defined icons can be associated with stereotypes in order to help distinguish them from other model elements.

Several UML extensions have been proposed for the domain of Web applications. One of them, Conallen's extension (Conallen 1999), is based on a set of 18 domain-specific stereotypes, which are commonly used with Web applications. These stereotypes include such implementation-dependent concepts as RMI, IIOP, and Java Script, along with a set of well-formedness rules for using them.

In this study we compared OPM to Conallen's extension to UML because of its adoption by the UML standard user community (UML 0.91 and up). In order to make

the comparison between OPM and UML as fair as possible, the UML models in our experiment used only extensions that were adapted in the core UML, namely, the stereotypes “entity object,” “control object,” “boundary object,” and “server page.”

4. Experiment Goal, Hypotheses, and Design

Following the empirical approach to evaluating modeling languages and techniques, the goal of the experiment was to compare OPM to UML with respect to two aspects: (1) comprehension, namely the level of comprehending a given model expressed in each language, and (2) construction, i.e., the quality and ease of modeling a given system in each language.

4.1 Experiment Hypotheses

Our conjecture (hypothesis) regarding comprehension was that questions which can be answered by inspecting a single UML view would be more correctly answered when UML rather than OPM is used. More specifically, since UML is object-oriented and since a UML system model is comprised of multiple views (diagram types), the UML class diagram would better serve subjects who are looking for answers to questions related to structural parts of a given system. Examples of questions of this type are “What is the database structure of the given application?” and “What are the structure and links of the pages within the application?” Conversely, OPM will be more adequate than UML for understanding the dynamic aspects of a system and the complex relations among various (structural and dynamic) system modules. The reason for this is that answering such questions requires searching multiple UML diagram types, while the OPM model uses the only one diagram type it has, the OPD, albeit at various granularity levels.

With respect to construction, OPM was expected to be more correctly and more easily applied than UML for modeling complex, dynamic applications. The reasons for this conjecture were that OPM uses a single view with three scaling (abstraction-refinement) mechanisms, and that the OPM alphabet consists of a compact set of graphic symbols, as opposed to the large number of view-dependent UML symbols.

4.2 Population Background and Training

The subjects of the experiment were third year students in a four-year engineering B.Sc. program at the Technion, Israel Institute of Technology, who took the course “Specification and Analysis of Information Systems” at the spring semester of the

2002 academic year. Most of them were students of the Information Systems Engineering program, which is managed jointly by the Faculty of Industrial Engineering and Management and the Faculty of Computer Science. They had no previous knowledge or experience in system modeling and specification.

During the 13-week course, the syllabus of which is summarized in Table 1, the students studied three representative modeling notations: DFD for two weeks, UML for five weeks, and OPM for two weeks. They then also studied how to model Web applications in UML and OPM for one additional week each. The students were required to submit four modeling assignments in order to practice the use of DFD, UML (Use Case, Class, and Sequence Diagrams), Statecharts, and OPM.

Table 1. The syllabus of the “Specification and Analysis of Information Systems” course

Week no.	<i>Lecture (3 hours per week)</i>	<i>Recitation (2 hours per week)</i>	<i>Assignment</i>
1	Introduction – system development lifecycle	Relational databases	
2	DFD	Relational databases	
3	DFD and OO approach	DFD	
4	UML Use Case and Class Diagrams	DFD	Modeling in DFD
5	UML structural model	-----	
6	UML structural model	UML Use Case and Class Diagrams	
7	UML Interaction Diagrams	UML structural model	
8	UML Statecharts	UML Interaction Diagrams	Modeling in UML
9	OPM	UML Statecharts	Modeling in Statecharts
10	OPM	OPM	
11	Modeling Web applications with UML (Conallen’s extension)	OPM	Modeling in OPM
12	Modeling Web applications with OPM	Modeling Web applications with UML and OPM	
13	Discussion about analysis approaches	Rehearsal tutorial	

The course staff included one adjunct lecturer and two graduate student teaching assistants, none of whom is an author of this paper. They were all familiar with UML and OPM prior to teaching them, but had no particular preference for, or significantly different knowledge of, any one specific language. The students studied in a single lecture group and four recitation groups, two for each teaching assistant. Knowing that the final exam in the course would serve as a basis for an experiment, the course staff

taught the course uniformly from a common detailed lesson plan. The lecturer also informed the students about their participation in the experiment in the first course session.

4.3 Experiment Design

The experiment took place during the final three-hour examination of the course. The examination contained three tasks. The two main tasks, which related to distributed Web applications and accounted for 80% of the examination's grade, constituted the experiment. The third task, which related to DFD, appeared last in the examination, so its effect on the experiment results, if there was any, was uniform.

The two experimental tasks referred to two case studies: a project management system and a book ordering application. The project management system, presented in Appendix A, is a distributed, data-intensive system that handles projects, their tasks, and their intermediate products. The book ordering application, presented in Appendix B, is a Web-based system that enables searching for books and ordering them electronically. Each appendix presents the models of the respective system in both UML and OPM. Each model consists of five diagrams followed by eight comprehension questions and one modeling problem, which called for extending the system model. The questions on both models for the same case study, which are listed along with their expected answers in appendices A and B (figures 3 and 6, respectively), were identical. The answers to these questions were also identical and independent of the modeling language. The comprehension questions relate to three major aspects of Web applications: structure, dynamics, and distribution.

The two case studies were designed to be identical in their scope, or size. The size was measured in terms of the number of diagrams, objects, features, and relations. The test included two form types, A and B. Since our research question referred to the comprehension and construction quality of OPM in comparison to UML irrespective of the case study, each test form type contained the same case studies in the same order. The only difference was the modeling language in which each case study was expressed. The relatively small number of subjects (81) prevented us from dividing the students into four groups (of about 20 students) in which not only the modeling languages order but also the order of the case studies would be counterbalanced. The test tasks of each group and their weights are summarized in Table 2.

Table 2. Test tasks of the two experiment groups

<i>Test Task</i>	<i>Weight</i>	<i>Group A</i> (40 subjects)	<i>Group B</i> (41 subjects)
Project management system	40%	UML	OPM
Book ordering application	40%	OPM	UML
DFD question (not included in the experiment)	20%	DFD	DFD

The students were divided arbitrarily into two groups of 40 and 41 students, and each group got a different test form type. The students were provided with alternating form types according to their seating positions, so this arbitrary division into the two experimental groups closely approximated random division. Nevertheless, to verify that the populations of these two groups were identical, we carried out a preliminary t-test on the grades the students had received in the “Design and Implementation of Information Systems” course, which is a mandatory course in the Information Systems Engineering program and a prerequisite to the course in which the experiment took place. No significant difference was found between the groups ($t = -0.19$, $p \sim 0.85$). An additional t-test we carried out on the average assignment grades in this particular course yielded similar results ($t = -0.13$, $p \sim 0.90$).

While the time to complete the tasks was not monitored separately for each question, the students did not seem to be under time pressure and did not ask for extra time during the examination.

All the questions about the project management system (in both UML and OPM) were graded by one of the two teaching assistants, while the questions about the book ordering application were graded by the other. This grader assignment scheme was designed to eliminate any potential bias towards one of the modeling languages in grading the examinations. Moreover, the teaching assistants were provided with a detailed grading policy document, examples of which are presented in Table 3.

5. Results

Table 4 summarizes the average score students achieved for each question in the examination. Each comprehension question could score a maximum of 3 points (24 points in total for each system), while each modeling problem could score as much as 16 points, totaling 40 points for each system. Incomplete answers, or answers with

missing elements, scored less according to the detailed grading policy exemplified in Table 3.

Table 3. Examples from the grading policy document of the experiment

Case study	Question no.	Instruction description	Grading policy
Project Management/ Book Ordering	1	Missing element	-0.5
		Additional element	-0.5
Project Management/ Book Ordering	5	Missing class	-0.5
		Additional class	-0.5
		Incorrect classification (e.g., creation instead of effect)	-0.25
Project Management/ Book Ordering	8	Missing node/link	-0.5
		Additional node/link	-0.5
		Incorrect requirement specification	-0.25
		Incorrect link source/destination	-0.25
Project Management/ Book Ordering	1-8	Grade Range	0-3
Project Management/ Book Ordering	9	Grade Range	0-16

Table 4. Average test scores by questions for each case and language

Question No.	Max. Score	Project Management case		Book Ordering case	
		UML	OPM	UML	OPM
1	3	2.03	2.82	2.65	1.99
2	3	1.78	1.88	1.79	2.01
3	3	1.53	2.70	1.55	2.58
4	3	2.78	2.85	1.67	2.03
5	3	1.98	2.49	1.85	2.33
6	3	2.24	2.11	2.20	2.23
7	3	1.90	2.16	1.83	2.14
8	3	1.94	2.40	2.78	2.78
9	16	9.18	10.73	8.32	8.95
Total	40	25.33	30.13	24.63	27.01

As Table 4 shows, in both case studies, almost all the questions (8 out of 9) scored higher when the system was modeled using OPM than when it was modeled using UML. In particular, the construction problems for both systems scored higher when students were required to use OPM.

5.1 Statistical Analysis of the Comprehension, Construction, and Overall Scores

Table 5 presents a summary of all the possible effects between the two experiment factors, namely language (UML vs. OPM) and case (project management vs. book ordering), with respect to (1) the comprehension question score, (2) the construction question score, and (3) the overall grade. The results, normalized to a percentage scale, show significant differences in the main effects (language and case) and insignificant differences in their interaction (language*case). The significance of the two factors was assessed using the Mixed procedure of SAS (Littell et al., 1996), which takes into account the repeated measure structure of the data. Student answers to questions relating to OPM models were significantly better than answers to questions relating to UML models in all three categories. The students comprehended the OPM models 10.5% better than the UML models, while their achievements in the construction category were 7% better when using OPM. Regardless of the modeling language used, on average, students achieved higher scores in the project management system, which was the first case study in each examination.

Table 5. Results of the overall, comprehension, and construction grades – the mixed ANOVA model

<i>Examined modeling aspect</i>	<i>Factor Name</i>	<i>Values of Factor</i>	<i>Mean Grade (%)</i>	<i>F</i>	<i>p-level</i>
Model comprehension Score	Language	UML OPM	67.6 78.1	75.8	<0.0001
	Case	Project management Book ordering	74.2 71.6	4.18	<0.05
	Language*Case			1.66	n.s.
Model construction Score	Language	UML OPM	54.5 61.6	7.41	<0.01
	Case	Project management Book ordering	62.3 54.0	10.8	<0.002
	Language*Case			0.46	n.s.
Overall Score	Language	UML OPM	62.4 71.5	54.2	<0.0001
	Case	Project management Book ordering	69.4 64.5	15.2	<0.0005
	Language*Case			1.17	n.s.

5.2 Statistical Analysis of the Comprehension Questions Subdivision

To gain more insight into the comprehension questions, we divided them into three categories:

1. Structure: questions 1-2 in both case studies, which related to the structure of the system;
2. Dynamics: questions 3-5 in both case studies and question 8 in the book ordering system, which related to the system behavior; and
3. Distribution: questions 6-7 in both case studies and question 8 in the project management system, which related to aspects of the system's distributed nature.

Table 6 presents the analysis of the students' achievements in the comprehension category according to three factors: language, case, and comprehension (structure, dynamics, and distribution). The results, normalized to a percentage scale, show significant differences in the language ($p < 0.0001$) and comprehension ($p < 0.001$) factors. The fact that the 3-way interaction between these factors was significant required further elaboration in which each case study was analyzed for the interaction between the modeling language and the comprehension category.

Table 6. Results of the comprehension grades – the mixed 3-way ANOVA model

<i>Factor Name</i>	<i>Values of Factor</i>	<i>Mean Grade (%)</i>	<i>F</i>	<i>p-level</i>
Language	UML OPM	67.6 78.1	40.7	<0.0001
Case	Project management Book ordering	74.2 71.6	3.26	n.s.
Comprehension Category	Structure Dynamics Distribution	70.6 76.3 70.4	7.47	<0.001
Language*Case			3.41	n.s.
Case*Comprehension Category			1.75	n.s.
Language*Comprehension Category			8.70	<0.001
Language*Case*Comprehension Category			5.30	<0.005

Table 7 shows the average scores of the comprehension categories in each one of the case studies. The average scores of the dynamics comprehension category questions on models done with OPM were significantly higher than the respective questions on models done with UML in both case studies (about 20% higher in the

project management system and more than 15% higher in the book ordering application).

Table 7. Analysis of the significant interaction in the comprehension results:
Language*Comprehension Category for each case

<i>Case</i>	<i>Comprehension Category</i>	<i>Mean Grade (%)</i>	<i>F</i>	<i>p-level</i>
Project Management	Structure	UML: 63.3 OPM: 78.3	13.6	<0.0005
	Dynamics	UML: 69.7 OPM: 89.3	23.6	<0.0001
	Distribution	UML: 67.5 OPM: 74.1	2.67	n.s.
Book Ordering	Structure	UML: 73.98 OPM: 66.67	3.27	n.s.
	Dynamics	UML: 65.45 OPM: 80.83	14.45	<0.001
	Distribution	UML: 67.07 OPM: 72.71	1.94	n.s.

In both case studies, when using OPM the students answered the distribution questions more correctly, but these differences were not statistically significant. For the structure comprehension category questions, the students' results were significantly better when using OPM in the project management system, while in the book ordering application the students' results in this category were insignificantly better when they used UML.

6. Discussion

Examining each question separately, we found out that in the project management system the only question in which UML scored slightly (but not significantly) higher related to representing the navigation order of the project management pages (question 6: 2.24 for UML vs. 2.11 for OPM). However, in the same question about the book ordering system (question 6) the result was reversed in favor of OPM (2.23 for OPM vs. 2.20 for UML).

The largest gap in favor of OPM in the project management system was found in question 3, which was phrased "*What is the trigger of the project order handling process? From which diagram did you conclude it?*" For this question, students who got and consulted the OPM model scored 2.70 (out of 3), almost twice as much as the students who got the UML model, who scored 1.53. The reason for this large

difference is attributed to the fact that "*project order handling*" is a name of an OPM process which explicitly appears in some of the diagrams, while in the UML model the behavior and triggers of this process need to be searched in the sequence diagram.

The next largest gap between the two modeling languages in favor of OPM (2.49 vs. 1.98) was in question 5, which was: "*What database classes are affected by the project order handling process? How? (i.e., are they created, destroyed, or changed?)*" Here, the facts that OPM combines the system's structure and behavior in a single view and that the transformation (creation, destruction, or change) of the process on each object is explicitly shown, helped students who used the OPM model get a more correct answer.

In the book ordering application, the only question in which UML scored higher (2.65 vs. 1.99) was question 1, which related to the types of pages that the user can view and the information presented at each page. This result in favor of UML is probably due to the fact that UML *boundary object* is a special element that represents pages or screens. The symbol and meaning of a boundary object is different than a standard class. OPM, on the other hand, represents Web pages or screens as standard objects, with no special symbol. Assigning a special symbol to Web pages helps to quickly and more accurately identify objects of this type. Although the addition of the boundary object symbol was found to be helpful in answering this particular question, adding special symbols to denote such elements as components, executables, and libraries, as UML indeed does, comes at the price of unjustifiably complicating the language. Indeed, Siau and Cao (2001) found that the UML vocabulary is overall 2-11 times more complex than other object-oriented, single-view techniques.

Regarding the structure comprehension category, the experiment results show that UML was better only in the book ordering system, while OPM was better in the project management case study. One explanation for this difference might be the students fatigue on the three-hour examination. The students captured the structural part of the book ordering system, which was the second case study, more easily from the UML class diagram, a separate view that is exclusively devoted to modeling structure. The reason for which OPM was better in the project management system in structure-related questions is most likely the fact that the OPD called "DB Unfolded" is purely structural, and this enabled the students to find answers to questions 1 and 2 in that OPD even more easily than in the class diagram of UML.

As expected, in the dynamics category, OPM was significantly better in both case studies. We assume that this outcome is due to the fact that finding answers to the behavior questions involved consulting several UML views, while in OPM the answers are found in the single diagram type, and the only thing one has to do is traverse across Object-Process Diagrams at different granularity levels. This type of navigation is easier than moving from one type of diagram to another, with each diagram type using its own set of symbols and distinct semantics. UML diagram traversal involves constantly switching the symbol vocabulary associated with each diagram type. This unnecessary complexity puts extra mental burden on the shoulders of system architects, designers, and the intended audience.

As for the distribution aspect, in both case studies OPM was found to be insignificantly better than UML. This difference can be explained by the fact that the questions in this category involved structural and behavioral aspects of the system distribution that span across different UML views. In other words, to fully answer these questions with the UML model, the students had to integrate information gathered from various diagram types, while in OPM the same information could be achieved by moving from a less detailed diagram to a more detailed (in-zoomed or unfolded) one. Indeed, we have argued that moving across detail levels of the same diagram type, when all the symbols are the same and the only change is the level of detail, is cognitively easier than switching among various diagram types, where each type employs a whole different set of graphic symbols and syntax. The findings in the distribution category reinforce this argument.

The construction results of the experiment were significantly better in OPM than in UML ($p < 0.01$). The main errors in the UML modeling questions occurred when students were required to integrate the different views into a whole, consistent model. The modeling questions required adding a single functionality that affected two UML diagram types—the class diagram and the site map diagram—and called for adding a third diagram of yet another type—an interaction diagram. All these changes were expected to leave the UML model integral and consistent. This task is difficult for trained UML modelers, let alone untrained students. The UML multiplicity of models (views) inevitably often requires numerous corrections in other diagram types so as to maintain overall consistency. Each change potentially triggers changes in the rest of the diagrams, causing a ripple effect that can be intractable. This shortcoming of the object-oriented paradigm in general and UML in particular has been pointed out by

the aspect-oriented approach (AOSD, 2003). Mezini and Lieberherr (1998) claim that object-oriented programs are more difficult to maintain and reuse because their functionality is spread over several methods, making it difficult to get the “big picture.” In OPM, all the changes are done in one diagram type, OPD, the single diagram type of OPM, which combines the structure and behavior that together specify the additional system functionality. The only other update that needs to take place is that of OPDs up the abstraction tree such that consistency is maintained. This is done by inspecting the OPM system map, which is the OPD tree, as described explicitly in the OPM metamodel (Reinhartz-Berger, 2003).

Although the results of our experiment suggest that OPM is significantly better than UML in understanding system dynamics and in modeling Web applications, there are three validity threatening factors that might have influenced the experiment results. First, UML was taught before OPM during the course. Hence, by the time of the final examination students might have forgotten more about how to effectively work with UML than with OPM. On the other hand, UML and its Web application extension were taught for six weeks, twice as much as OPM and its Web application extension (see Table 1). Moreover, since UML was the first modeling language taught, the teaching order could help the students understand and assimilate UML better than OPM.

Second, the project management case always appeared first on the examination, implying that most of the students probably started working on this problem first. Therefore, there are possible fatigue and order factors that are confounded with the comparison results of the two cases and interactions that involve the case factor. Finally, only one scorer assessed each exam question, which might further confound the results. However, all scorers used a well-defined scoring scheme, which mitigates this effect.

7. Summary and Future Work

Comparing OPM to UML in terms of Web applications comprehension and modeling quality, we concluded that the single OPM diagram type, the Object-Process Diagram (OPD), which supports the various structural and dynamic aspects throughout the system lifecycle, is easier to understand and apply by untrained users. The ability to model stand-alone processes in OPM provides for a single mechanism for specifying system behavior. Such behavior modeling is not in line with the object-oriented

encapsulation principle, as it involves more than one object and therefore cannot be faithfully modeled as being owned by a single specific object class. These findings are in agreement with the results described by Peleg and Dori (2000), and are also consistent with findings of another empirical study of ours (Gilat, 2003), which compared OPM adapted to the domain of discrete event simulation to ARENA, a prevalent discrete event simulation software package.

Although we compared OPM to a specific extension of UML for Web applications (Conallen, 1999), we believe that our findings can be generalized. UML's segregation of the system model into multiple views is a major source of difficulty in capturing the system as a whole, understanding its parts, and being able to coherently follow the functionality it performs. This is due to the fact that pieces of a UML system model are scattered across different diagram types, each with its idiosyncratic set of graphic alphabet symbols and syntax. For example, a process can appear as a use-case in a use-case diagram, as an operation in a class diagram, as an action in a state transition diagram, as a message in a sequence diagram, and as an activity in an activity diagram. To be able to model complex systems, the modeling language itself should be as simple as possible, because using a complex language to model a complex system almost guarantees that the resulting model will be intractable. UML is unnecessarily complex in many ways, and this inherent deficiency hinders coherent modeling and comprehension of systems. The outcomes of this empirical study reinforce this assertion.

While model multiplicity of UML is in general a deficiency, there are cases in which the existence of separate views and special symbols can potentially help answering certain questions about a specific aspect of a system, which is expressed in only one type of diagram, such as its desired database schema or execution of its services. These types of questions may be more difficult to answer in an OPM model, if the information resides at separate diagrams with different granularity levels. To overcome this, we have enhanced OPCAT, Object-Process CASE tool (Dori et al., 2003), with animation capability. Using this feature while modeling a system, the designer can run an animated simulation showing the active entities and links at consecutive time points as a visual design debugging aid. This capability enables the system architect to verify that the system behaves and executes as it is supposed to at any point in time. To stay current with the prevailing standard, we have augmented OPCAT with the capability of generating a set of UML views from the single OPM

model, and we plan to also be able to convert a UML model to OPM. These capabilities will enable the system architect to use the most suitable approach for each design portion.

Another experiment which was conducted on 20 graduate and advanced undergraduate students who studied UML and OPM for a year showed similar results. In that experiment, the students had rehearsal tutorials about the core UML and OPM. None of them had studied the extensions of the two modeling languages to the Web application domain. The experiment included two models and nine comprehension questions only. The two models were a Web Sales system, which handles sales through the internet, in UML and a GLAP system, which handles a glossary of terms in a distributed architecture, in OPM. The comprehension questions which refer to system dynamics and distribution were better answered using OPM models. The students noted that the single view and the technology-independent model in OPM helped them understand the system's purpose, functionality, and architecture. Future work should validate our findings with analysis and design experts who are familiar with these languages. This work should use a talk-aloud procedure to validate our interpretation to the causes of the different results between the modeling languages.

Further experiments should also be carried out to compare OPM to other leading modeling languages and methods. More specifically, in our experiment, we compared two diagramming, visual formalisms, Object-Process Diagrams (OPD) and UML. An OPM model is expressed not only graphically but also by a textual modality, Object-Process Language (OPL), which is a subset of English and hence comprehensible to non-IT professionals. The experiment done in this research completely ignored this modality. The contribution of the natural language as a complementary modality to understanding an OPM model should be carefully examined, especially for users who are not familiar with a visual modeling language.

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Appendix A: The Project Management System – Models and Questions

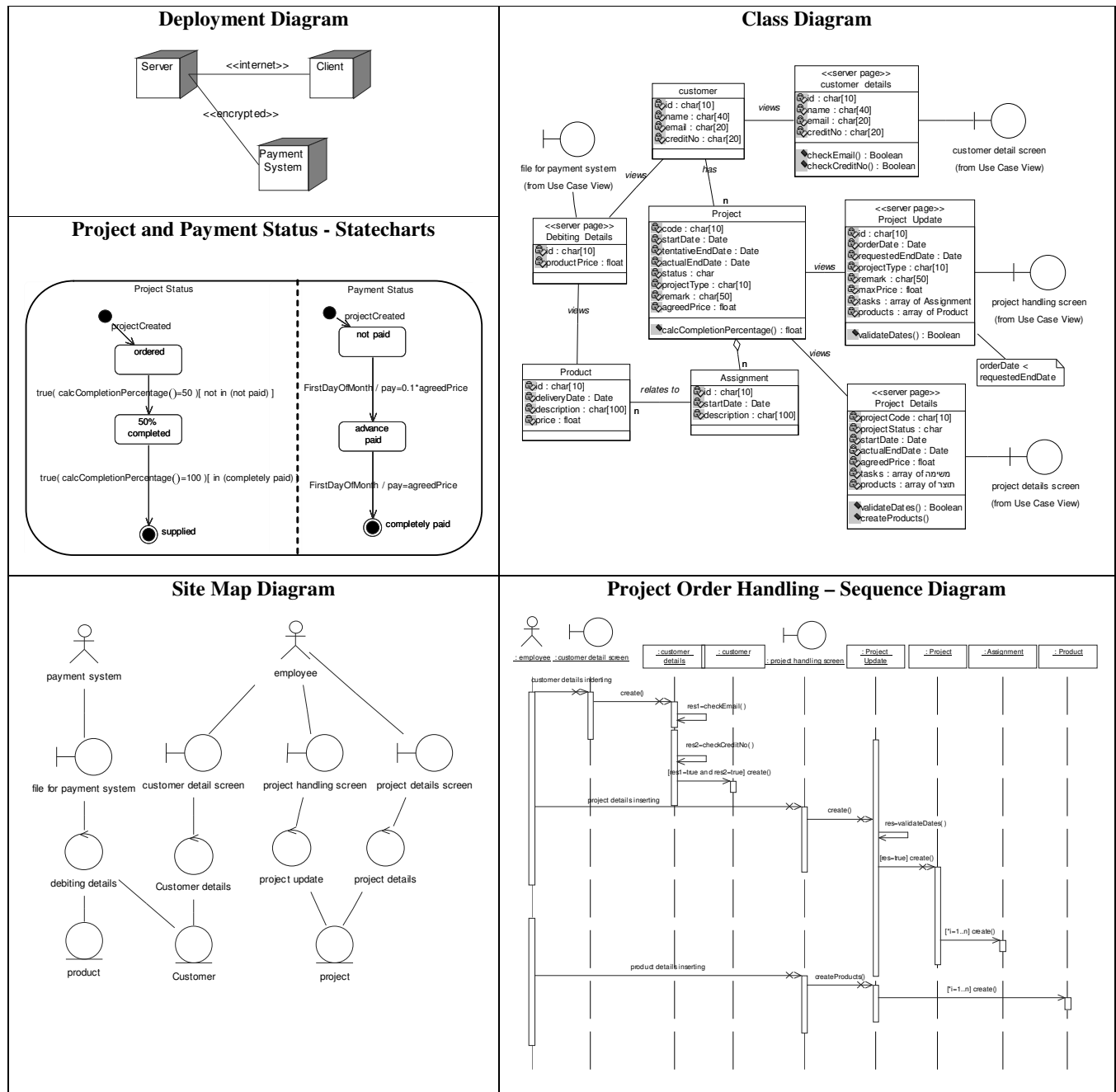


Figure 1. Conallen's UML specification of the project management system

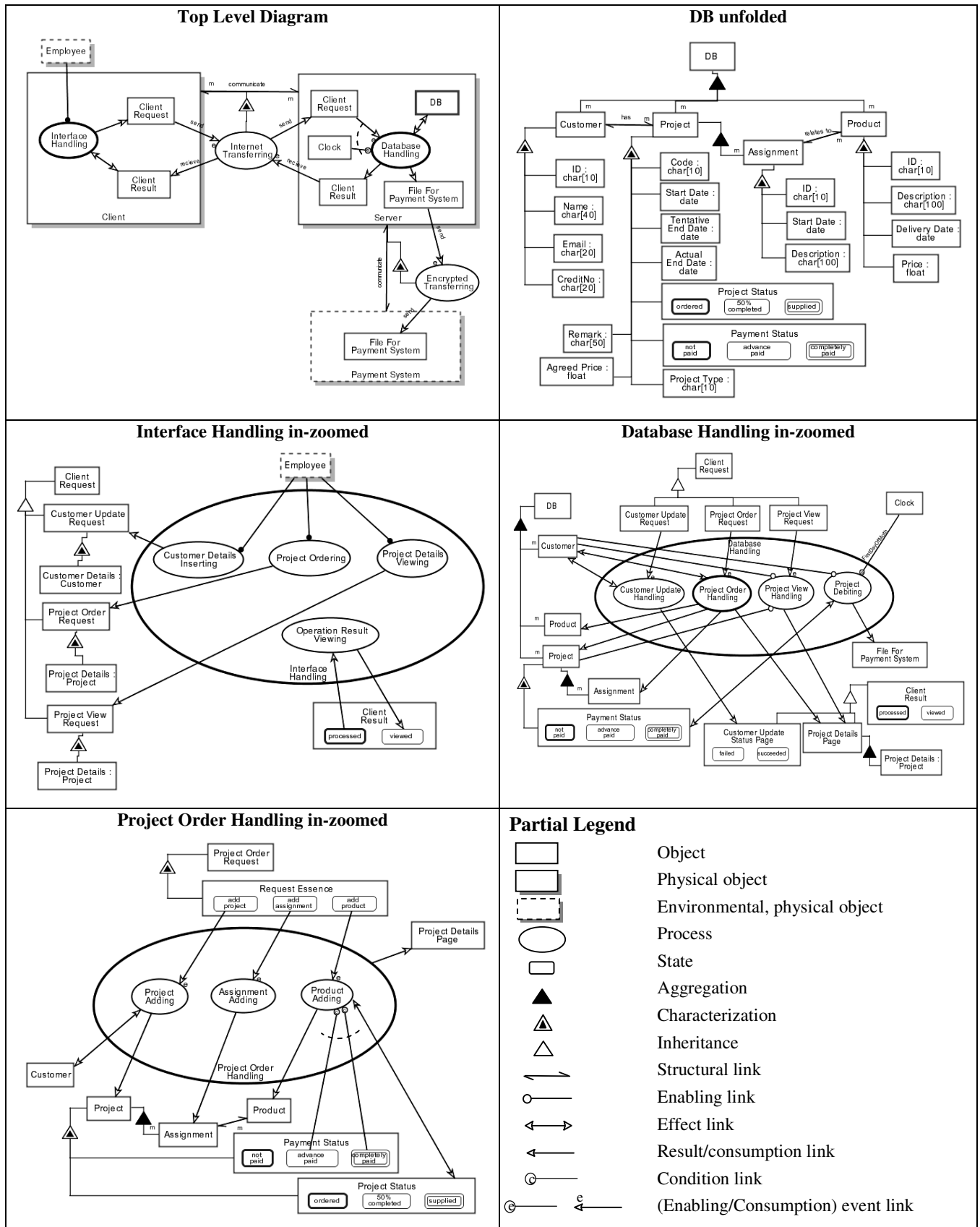


Figure 2. OPM specification of the project management system

Answer all the following questions about the project management system model.

1. What are the classes which form the application's database?

Expected answer: Customer, Project, Assignment, and Product.

2. Does the **structure** of the system support the following query: "who is the customer that ordered a specific product?" Explain.

Expected answer: Yes, there are relations from Product to Customer, through Assignment and Project.

3. What is the trigger of project order handling? From which diagram did you conclude it?

Expected answer: The trigger is the creation of a request for project ordering in the server site.

4. Is it possible that only the advance (10%) of a project of which 50% had been completed was paid? Explain.

Expected answer: Yes, addition of products is possible if (at least) the advance was paid. Hence, it is possible that 50% of the assignments were completed and only the advance (10%) was paid.

5. What database classes are affected by project order handling? How? (i.e., are they created, destroyed, or changed?)

Expected answer: Project is created, Assignment is created, Product is created, and Customer is affected.

6. What is the navigation order in the application? How did you conclude it?

Expected answer: Customer Update Request → Project Order Request → Project View Request.

7. What is the internal architecture (nodes and links) of the system?

Expected answer: The nodes are Client and Server. There is an Internet link between the Client and the Server and an encrypted link between the Server and the Payment System (which is external).

8. What are the system activities from the moment the employee connects to the site and till he gets the project details? From which diagrams did you conclude it?

Expected answer: The employee fills a request for viewing project details. This request is sent to the server. In the server, the project and customer details are fetched and a page with the project details is created and sent to the client. The client displays this page.

9. Add to the model a possibility to view a report of all the projects which 50% of their assignments were completed, but the projects have not supplied yet. The report will be viewed as a result of a manager request after he/she inserts a date range for the report.

Main changes: Adding an environmental, physical object (an actor) called Manager and zooming into the Reporting process (creating a sequence/collaboration diagram).

Figure 3. Questions related to the project management system and their expected answers

Appendix B: The Book Ordering System – Models and Questions

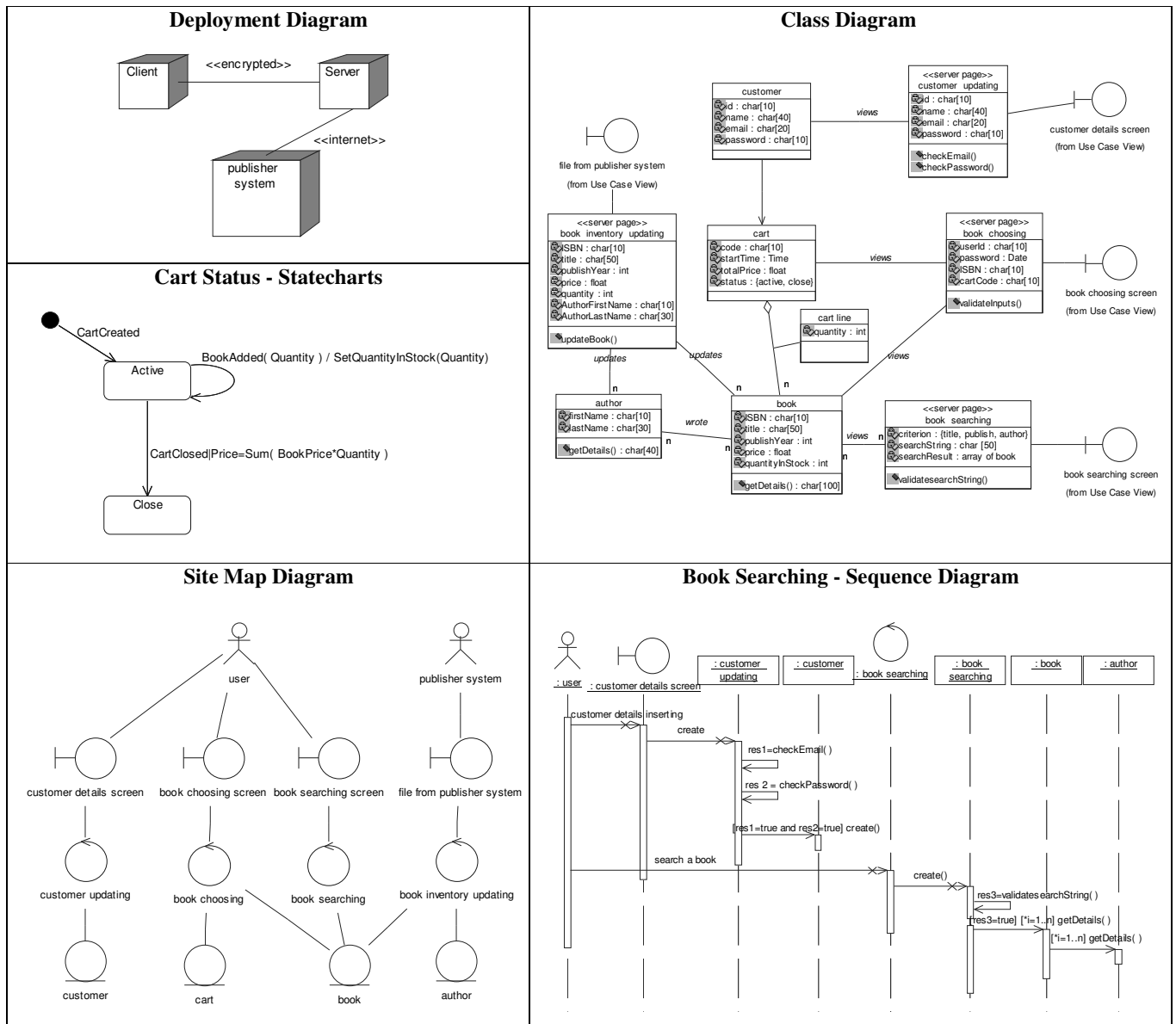


Figure 4. Conallen's UML specification of the book ordering system

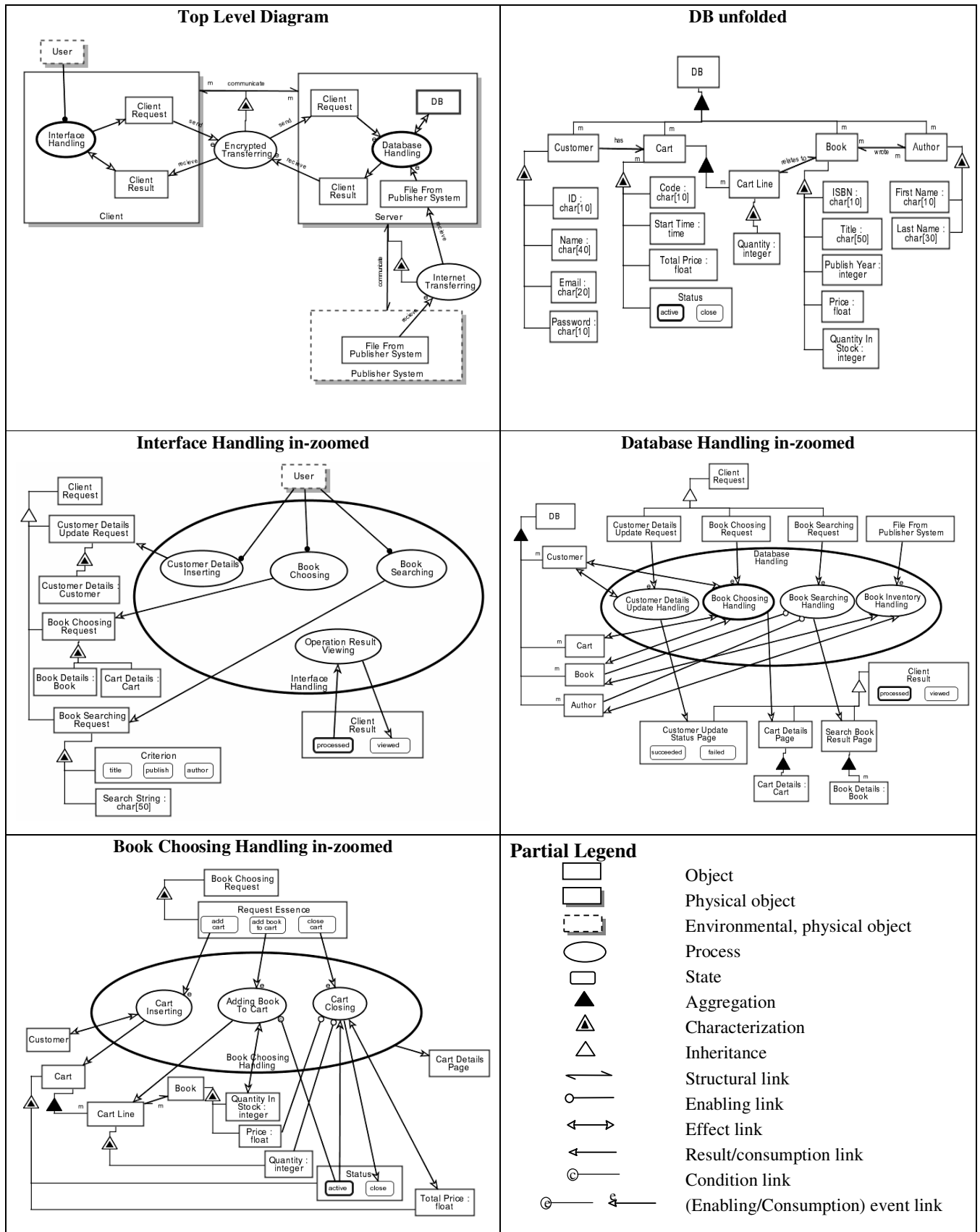


Figure 5. OPM specification of the book ordering system

Answer all the following questions about the book ordering system model.

1. Which types of pages can the user view? What is the information presented at each page?

Expected answer: Customer Details Screen (id, name, email, password), Book Choosing Screen (user id, password, cart code, ISBN), Book Searching Screen (criterion, searched string, search result).

2. Does the **structure** of the system support the following query: "who are the customers that ordered a specific book?" Explain.

Expected answer: Not directly, the relation between Cart and User does not exist.

3. What is the trigger of customer details update handling? From which diagram did you conclude it?

Expected answer: The creation of a request for customer details updating in the server site.

4. What are the inputs and outputs of book searching? What are the database classes used in this process?

Expected answer: The inputs are criterion and searched string. The outputs are the books which satisfy the criterion. The needed DB classes are Book and Author.

5. What database classes are affected by customer details update handling? How? (i.e., are they created, destroyed, or changed?)

Expected answer: User is created or affected.

6. What is the navigation order in the application? How did you conclude it?

Expected answer: In any moment each one of the pages can be displayed according to the user request.

7. What is the internal architecture (nodes and links) of the system?

Expected answer: The nodes are Client and Server. There is an encrypted link between the Client and the Server and an Internet link between the Server and the Publisher System (which is external).

8. What are the states of cart from the moment it is created till it is closed? What are the activities in each state and how does the system transform between the states? From which diagrams did you conclude it?

Expected answer: The cart is created in its active state. As long as it remains active, books can be added. It changes its status to "close" when an explicit request for closing arrives.

9. Add to the model a possibility to print a report of all the active carts. The report will be automatically printed at the beginning of each week.

Main changes: Adding a triggering event of a clock and in-activating the Reporting process (creating a sequence/collaboration diagram).

Figure 6. Questions related to the book ordering system and their expected answers