Modeling Code Mobility and Migration: An OPM/Web Approach

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Abstract

Web applications exhibit dynamic behavior through such features as animation, rapidly changi presentations, and interactive forms. The growing complexity of Web applications require: rigorous modeling approach that would be capable of clearly and explicitly addressing cc mobility issues. While mobile agent systems and programming languages support implementation of code mobility with features such as applets or mobile agents, existing syst analysis and design methods lack the facilities to model code mobility at a satisfactory lev OPM/Web is an extension of Object-Process Methodology (OPM) for modeling distribu systems and Web applications that enables intuitive modeling of code mobility concepts ir single framework. In this paper, we propose generic OPM/Web models for common cc mobility design paradigms, including Remote Evaluation, Code-on-Demand, PUSH, and Mob Agents. An OPM/Web model of a mobile application that handles requests for Quality of Serv over the Internet exemplifies the use and advantages of modeling such systems in OPM/Web.

Keywords: mobile code, code migration, code mobility design paradigms, Web application modeling, Object-Process Methodology.

1. Introduction

Although Web applications seem to exhibit a relatively simple distributed architecture, th underlying architecture is dynamic and complex. The complexity arises from the requirements

Web applications to respond to an unlimited number of heterogeneously skilled users, addr security and privacy concerns, access heterogeneous, up-to-date information sources, and exhi dynamic behavior. The growing complexity of Web applications requires a rigorous modeli approach. Such approach should be capable, among other things, of addressing code mobil issues to enable dynamic reconfiguration of the binding between software components and th physical locations. **Code mobility** is the capability of software systems to dynamica reconfigure the binding between the software components of an application and their physi locations (nodes) within a computer network (Fugetta et. al., 1998). **Mobile Code** is a piece code that exhibits the mobility property, i.e., code that can be transmitted across a network a executed on another node. **Code migration** is the function which controls how code mobility achieved (Dale and DeRoure, 1997). Although most applications do not require mobile co adding this capability to applications supports disconnected operations and can enhance syst flexibility, reduce bandwidth consumption and total completion time, and improve fault tolerar (Fugetta et. al., 1998).

The code migration process involves determining the operation targets, transferring the co and integrating it into the target system. In static system architectures, the targets can determined at compilation time. If the system architecture is dynamic, the operation targ should be computed immediately prior to transferring the code. Following the tar determination, the code can be transferred by applying one of the design paradigms for cc mobility, which extend the traditional client-server paradigm from data to code. Once transferr the code can be integrated with the local target system by activating an instance of it, connecti it to existing data or code, or continuing its transfer over the network to yet another targ

Modeling the code migration process also includes defining process triggers, preconditions a postconditions, and handling security issues and possible transfer errors.

Current techniques for modeling code mobility and migration require determining the operati targets separately from the transferring stage (e.g., by class services) and do not specify how code is to migrate. In the object-oriented approach, the description of code migration is scatter For example, in UML (Object Management Group, 1999), which is the standard object-orien modeling language, code migration specifications are decomposed into at least five views: u case, class, interaction, state, and deployment diagrams. This decomposition is hard to integr to a whole, consistent system and is also complicate to maintain (Mezini and Lieberherr, 1998).

OPM/Web, which is the extension of Object-Process Methodology (OPM) to distribu systems and Web applications, constitutes a complete approach to modeling the structure a behavior of a system within a single view by considering objects and processes as two equa important classes of entities. The purpose of this paper is to show how OPM/Web can clea model all the important aspects of code migration. In Section 2, we review the literatu concerning the main concepts and design paradigms of code mobility, and discuss shortcomings of existing modeling techniques in specifying code migration. In Section 3, connect and map OPM/Web concepts to the terminology of mobility, while in Section 4 the m code mobility design paradigms are modeled in OPM/Web. Section 5 explains and demonstra how to use these models in a complete mobile application, which handles requests for Quality Service. Section 6 summarizes and discusses OPM/Web advantages and shortcomings modeling code migration.

2. Modeling Code Mobility: Literature Review

Applications that involve code mobility are defined in terms of components, interactions, a sites (Carzaniga et. al., 1997). *Components* are the building blocks of system architecture. They further divided into *resource components*, which are objects (architectural elements represent data, or physical devices), and *computational components*, which are programs that embo flows of control. A resource component is represented in object-oriented terms as an object w attributes and operations (services) that contain knowledge about how to execute a particu task, while a computational component, which contains code, may also be characterized private data, an execution state, and bindings to other (resource or computational) componen *Interactions* are events that involve two or more components communicating with each oth *Sites* are nodes or execution environments – they host components and provide support for execution of computational components.

2.1 The Client-Server Paradigm and Related Approaches

The **Client-Server (CS)** paradigm (Renaud, 1993) is the traditional design approach distributed communication among sites, in which messages are transferred from one site another, but actual code is not. In a typical client-server interaction, site S_B, which acts as interaction server, offers a set of services. It also hosts the resources and the knowledge neec for executing these services. Site S_A, which is the operation client, requests the execution of so service offered by S_B by sending it a message. As a response, S_B performs the requested serv and delivers the result back to S_A in a subsequent interaction. If the server does not have all data and knowledge required, it can act as a client in another client-server interaction.

The CS paradigm has been criticized as being too low-level, requiring developers to determ network addresses and synchronization points. CS interaction is also too specific, since the cli must “know” the exact services that the server can provide (Dale and DeRoure, 1997). The Rem Procedure Call (RPC) (Bloomer, 1992) tries to overcome these shortcomings by permitting client to request a service to be executed on a server in the same way a local function call made; The location of the server, the initiation of the service, and the transportation of the resu are handled transparently to the client. The object-oriented approach attempts to make the paradigm more accessible and uniform by adopting reuse, inheritance, and encapsulati principles. OMG’s Common Object Request Broker Architecture (CORBA) (Object Managem Group, 1995) is a CS technology that is based on the object-oriented approach.

2.2 Design Paradigms for Code Mobility

Design paradigms for code mobility extend the CS paradigm by transporting computatio components across a network. Four common design paradigms for code mobility are Rem Evaluation (REV), Code-on-Demand (COD), PUSH, and Mobile Agents (MA). These paradig differ in their preconditions, postconditions, and triggers.

In the **Remote Evaluation** (REV) paradigm (Stamos and Gifford, 1990), a computatio component, C, located at S_A, has the knowledge (represented by code) necessary to perforn service, but it lacks the required resource components, which are located at a remote site Therefore, C is transferred from S_A to S_B and is executed there. The results of this execution delivered back to S_A in an additional interaction.

In the **Code-on-Demand** (COD) paradigm (Carzaniga et. al., 1997), site S_A can access resource components needed for a service, but it does not have the knowledge required to proc them. Therefore, S_A requests the service execution knowledge, i.e., the computation compon C, from its hosting site, S_B. S_B delivers the knowledge to S_A, which subsequently processes C site S_A on the resource components residing there. Contrary to REV, in COD the code is execu at the client.

In the **PUSH** paradigm (Franklin and Zdonik, 1998), site S_B sends a (computational or resour component to site S_A in advance of any specific request. This push-based operation is of preceded by a profiling operation, in which S_A specifies a profile that reflects its users' intere The profile is sent to site S_B, saved there, and used by S_B to decide which components S_A sho receive and when to send them. The advantage of this paradigm over COD is that the users do have to know when to pull new components and where to pull them from. Rather, the syst automatically sends necessary new components when they become available, and they are of used later by the receiving node.

In the **Mobile Agent** (MA) paradigm (Gray et. al., 2000), site S_B owns the service executi knowledge, C, but some of the required resource components are located at site S_A. Hence, migrates to S_A and completes the service using the resource components available there. T migration is usually initiated by the agent (C), but it might be requested by S_A or S_B. Contrary the REV, COD, and PUSH paradigms, which focus on the transfer of just code between sites, mobile agent migrates to the remote site as a whole computational component, along with state, the code it needs, and some of the resource components required to perform the task.

Discussing these design paradigms for code mobility, Carzaniga et al. (Carzaniga et. al., 19 claim that none of them is absolutely better than the others and suggest choosing the m appropriate paradigm for a system under development on a case-by-case basis according to application type and needs.

2.3 Modeling Code Mobility and Migration

Code mobility is supported by such programming environments as Java, Telescript (White, 199 and D'Agents (Gray et. al., 2001). However, current modeling techniques that are used in analysis and design phases of Web applications do not address code mobility concepts a satisfactory level.

Web applications can be classified as hybrids between hypermedia and information syste (Fraternali, 1999). Most commonly, such systems are modeled using hypermedia author techniques or visual software engineering methods, especially object-oriented ones. Hyperme authoring techniques, including Hypertext Design Model (HDM) (Garzotto et. al., 199 Relationship Management Methodology (RMM) (Isakowitz et. al., 1995), Object-Orien Hypertext Design Model (OOHDM) (Schwabe and Rossi, 1998), and WebML (Ceri et. al., 200 model the content and navigational aspects of an application, but not its functionality, physi architecture, or security requirements. Therefore, they do not explicitly address code-rela issues, such as code migration.

Object-oriented development languages, notably UML (Object Management Group, 1999), ena modeling of the application functionality through class services and message passing amc objects. Concepts involving code mobility, such as Java applets, are modeled in separate vie using pre-declared UML stereotypes. Conallen's extension of UML for Web applicati (Conallen, 1999), for example, is based on a set of 18 domain-specific stereotypes, which commonly used with Web applications. These stereotypes include such implementati dependent concepts as RMI, IIOP, and Java Script, along with a set of well-formedness rules using them. In general, UML does not handle the code migration process as a whole patte including its preconditions (e.g., the existence of a request in the client site and source code at server site), postconditions (e.g., the existence of executable code at the client site), and trigg (e.g., a change in a server component). To overcome these shortcomings, UML has be extended by various research teams, including the mobile agent extension (Klein et. al., 200 Agent UML (AUML) (Odell et. al., 2000), and MASIF-DESIGN (Muscutariu and Gervais, 200 Even though the proliferation of such extensions undermine and weaken UML standardizati efforts, they still do not separate the execution knowledge (services) from the resou components (classes). It should come as no surprise that such separation is not possible, si doing so would work against the encapsulation of operations within object classes, which i major principle in the object-oriented approach.

Behavior-oriented techniques, including Aspect-Oriented Design (AOSD site, 2003) a superimposition (Katz, 1993), model parts of the system functionality separately from application structure. They enable static binding of processes to sites, but do not support modeling of dynamic configurations and the actual migration process.

Object-Process Methodology (OPM) (Dori, 2002) combines ideas from the object-orien development methods and behavior-oriented techniques in order to specify the system struct and dynamics within a single framework. OPM enables the existence of processes as stand-alo entities. This way, structure and behavior, the two major aspects that each system exhibits, exist in the same OPM model without highlighting one at the cost of suppressing the other. integrating structure and behavior, OPM provides a solid basis for modeling complex systems, which these two most prominent system aspects are highly intertwined and hard to separa Mobile applications are prime examples of such systems. Since OPM lacks the ability to spec the code migration process and dynamic reconfiguration at run time, it has been extended OPM/Web, as discussed in the next section.

3. OPM/Web and Mobile Components

OPM/Web extends Object-Process Methodology to distributed systems and especially to W applications, enabling the modeling of such systems within a single view. As in OPM, OPM/Web universe of discourse is specified in terms of "things": object classes and proc classes. An *object class* (abbreviated as an object) is a set of object instances which exist, or least have the potential of stable, unconditional physical or logical existence. A *process cl* (abbreviated as a process) is a pattern of transformation of one or more object classes. program, an operation, a procedure, and an algorithm are examples of process classes. An act execution of a process (such as the carrying out of an executable version of a program or algorithm) is a *process instance*. The relations between things (objects and processes) modeled by structural links (e.g., generalization and aggregation) and procedural links (wh specify transformations, enablers, and triggers). Contrary to object-oriented methods, an OI process can stand alone and involve several object classes.

OPM enables managing the complexity of a model applying three refining/abstracti mechanisms: *unfolding/folding*, in which the thing being refined is shown as the root o structural graph; *in-zooming/out-zooming*, in which the thing being refined is blown up to encl its constituents; and *state expression/suppression*, which allows showing or hiding the possi states of an object. Using flexible combinations of these three scaling mechanisms, OPM enab specifying a system to any desired level of detail without losing legibility and comprehension the resulting specification.

Two semantically equivalent modalities, one graphic and the other textual, jointly express same OPM model. A set of inter-related Object-Process Diagrams (OPDs) constitute graphical, visual OPM formalism. Each OPM element is denoted in an OPD by a symbol, and

OPD syntax specifies correct and consistent ways in which entities can be linked. The Obje Process Language (OPL), defined by a grammar, is the textual counterpart of the graphical OP set. OPL is a dual-purpose language, oriented towards humans as well as machines. Catering human needs, OPL is designed as a constrained subset of English, which serves domain expe and system architects engaged in analyzing and designing a system. Every OPD construct expressed by a semantically equivalent OPL sentence or phrase. While the OPD set and the O script are equivalent in their semantic content, they are complementary from a human cogniti viewpoint. Designed also for machine interpretation through a well-defined set of producti rules, OPL provides a solid basis for automatically generating the designed application. integrated software engineering environment, called OPCAT (Object-Process CASE Tool) (D et. al., 2003), automatically translates from one modality to the other in either direction.

OPM/Web enhances the ability of OPM to model distributed systems in general and W applications in particular in two ways. The first extension is the ability to reuse compon designs in an open manner through bindings among model components, thereby improvi model scalability (Reinhartz-Berger et. al., 2002). The second extension is the support for cc mobility and migration specifications. In this paper we focus on defining and modeling cc mobility concepts and design paradigms using OPM/Web.

3.1 ***Mapping Mobility Terms onto OPM/Web Concepts***

The terms used in the various design paradigms for code mobility are mapped to OPM/W concepts as follows.

- A *resource component* is an informatical or physical object. An informatical object is a pi of information, such as the data required for a process execution. A physical object is tangi in the broad sense, for example a device.

- A *computational component* is a process. It can own private data (objects) and include s processes. The migration process can transfer the computational component source code (i a process class), which can be compiled at the target site and run there any number of tim or an executable version of the code (i.e., a process instance), which can run at the target s only a specified number of times.
- A *site*, which is analogous to a node in the UML implementation model, is a physical obj in OPM/Web. This physical object can be in-zoomed to expose its resource a computational components.
- An *interaction* has both structural and dynamic aspects. The structural aspect of an interact specifies how two sites can communicate with each other, irrespective of a specific point time. This aspect is modeled in OPM/Web by a (unidirectional or bi-directional) structu link between the communicating sites, which, as noted, are physical objects. The dynar aspect of an interaction is the ability to transfer data (objects) or code (processes) betw two sites and is specified in OPM/Web by an event-driven process. Since interact conceptually characterizes the communication between the sites, the interaction process associated in the model to the structural link that connects the two interacting sites. T implementation of this interaction may still be carried out as two inter-related processes, o at each interacting site.

A summary of the main OPM/Web symbols and their meanings is provided in Appendix The basic code transferring operations are represented by the generic OPDs in Figure 1. T computational **Component** on the left of Figure 1(a) and Figure 1(b), which is a process cla denoted by an ellipse, is the (unchangeable) input for the **Component Transferring** process, as instrument link between them indicates. In Figure 1(a) the **Component Transferring** proc transfers **Component**'s source code, while in Figure 1(b) **Component Transferring** transfer process instance, i.e., only an executable version of **Component**. Following the UML notation classes and objects, a process instance is denoted in OPM by an ellipse within which the proc class name is written as **:ProcessClassName**, where the identifier of the instance can optiona precede the colon.

The semantics of the arrow with the white (blank) arrowhead from **Component Transferring** the right appearance of **Component** is a *result link*[1], which means that **Component Transferri** creates (a copy of) the process class **Component**, as in Figure 1(a), or an instance of it, as Figure 1(b). The identical path labels[2] on the instrument and result links and the identi component names indicate that **Component Transferring** transfers **Component** as is rather th computing it from an input.

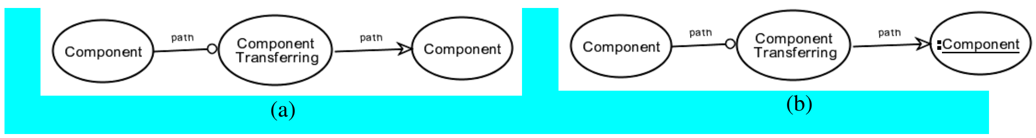

Figure 1. A generic OPM/Web model of a **Component Transferring** process.

(a) **Component Transferring** transfers **Component**'s code, leaving the original **Component** intact.

(b) **Component Transferring** transfers an instance of **Component**, leaving the original **Component** intact.

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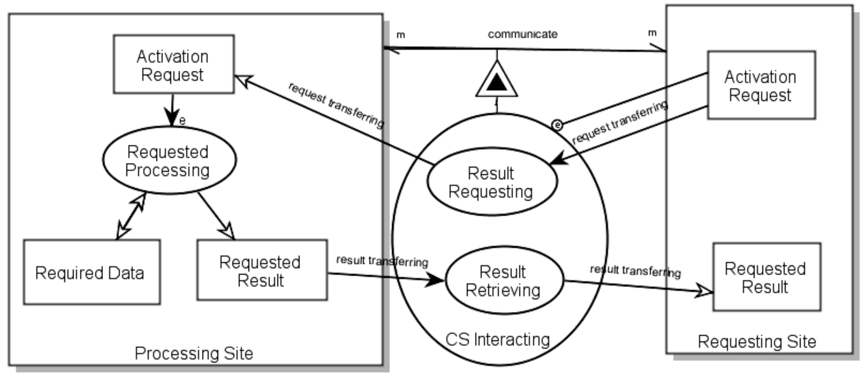
[1] In the original OPM, processes are not connected, and, hence, there is no difficulty to determine which is processing entity. To remove the ambiguity arising from connecting two processes in OPM/Web via consumptio result links, a consumption link is denoted as a black-headed arrow from the consumed entity to the process, wl the semantics of a white-headed arrow from a process to an entity remains a result link.

[2] A *path label* in OPM is a label on a procedural link that removes the ambiguity arising from multi incoming/outgoing procedural links. Here we use identical path labels on the incoming link to and outgoing l from the **Component Transferring** process to denote the transfer flow.

3.2 *Modeling the Client-Server Paradigm using OPM/Web*

Based on the mapping of code mobility terms onto OPM/Web concepts, an OPM/Web model the traditional client-server paradigm, presented in Figure 2, consists of two equival modalities: graphical – the OPD in Figure 2(a), and textual – the OPL paragraph in Figure 2(The objective of this unique dual representation is to enhance the readability of the model humans: engineering-oriented readers, who are familiar with OPM and its diagrammatic notati can relate to the OPD, while domain experts, or those who are new to the OPM graphic notati can refer to the OPL paragraph and learn the correspondence between each OPL sentence phrase and its OPD construct counterpart. The OPL paragraphs also improve syst documentation.

Examining Figure 2, one can see that **Requesting Site** (the client) and **Processing Site** (server) are both physical objects (as denoted by shadowed rectangles). The computatio component, **Requested Processing**, resides in the **Processing Site**, which also hosts the resou components required for that computation, **Required Data** and (later on) **Requested Result**. T two sites are connected via a bi-directional structural link, tagged **communicate**, which exhib (i.e., is characterized by) the **CS Interacting** process. A change in (an instance of) **Activati Request** at the **Requesting Site** initiates the **CS Interacting** process, as the event link (the circ headed arrow with the letter 'e' inside it) between the two things shows. Following the **requ transferring** path, the first subprocess of the **CS Interacting** process, which is **Result Requesti** transfers a copy of **Activation Request** to the **Processing Site**. As soon as this copy is placed at **Processing Site**, it activates the **Requested Processing**, as the consumption event link (the bla headed arrow with the letter 'e' next to it) denotes. This **Requested Processing** potentially affe the **Required Data** object and yields (produces) the **Requested Result** object.



(b) **Requesting Site** physical.

Requesting Site zooms into **Activation Request** and **Requested Result.**

Activation Request triggers **CS Interacting.**

Processing Site is physical.

Processing Site zooms into **Activation Request**, **Required Data** and **Requested Result,** as well as **Requested Processing.**

Activation Request triggers **Requested Processing** when its state changes.

Requested Processing consumes **Activation Request** of **Processing Site.**

Requested Processing affects **Required Data.**

Requested Processing yields **Requested Result** of **Processing Site.**

Many **Requesting Sites** and many **Processing Sites communicate,** and this relation exhibits **CS Interacting.**

CS Interacting zooms into **Result Requesting** and **Result Retrieving.**

Following path **request transferring**, **Result Requesting** consumes **Activation Request** of **Requesting Site.**

Following path **request transferring**, **Result Requesting** yields **Activation Request** of **Processing Site.**

Following path **result transferring**, **Result Retrieving** consumes **Requested Result** of **Processing Site.**

Following path **result transferring**, **Result Retrieving** yields **Requested Result** of **Requesting Site.**

Figure 2. An OPM/Web model of the Client-Server (CS) paradigm:

(a) The OPD (b) The corresponding OPL paragraph

The creation of **Requested Result** enables the second stage of the interaction, executed **Result Retrieving**. Following the **result transferring** path, this process moves the local copy of generated **Requested Result** from the **Processing Site** to the **Requesting Site**.

Table 1 summarizes the structure of **Requesting Site** and **Processing Site** before and after activation of a **CS Interacting** process. The dynamic aspect of the **CS Interacting** process can vividly simulated using OPM Case Tool (OPCAT), as explained in Appendix B.

Table 1. The resource and computational components in **Requesting Site** (the client) and **Processing Site** (the server) before and after an activation of **CS Interacting**

Design Paradigm (**Process Name**)	***Time***	***Requesting Site***	***Processing Site***
Client Server (**CS Interacting**)	Before	**Activation Request**	**Requested Processing** (code) **Required Data**
	After	**Requested Result**	**Requested Processing** (code) **Required Data**

4. OPM/Web Models of Code Mobility Design Paradigms

OPM/Web enables precise modeling of the REV, COD, PUSH, and MA paradigms, which w explained informally in Section 2.2. In this section, we present generic OPM/Web models these design paradigms. In all of these models, **Requesting Site** is the transaction client, and such, it obtains a copy of the **Requested Result** and keeps it at the end of the process. **Activati Request** is the trigger for the code transferring process. The **Resource Site** is the transacti server, i.e., it hosts the **Requested Processing** (as in COD, PUSH, and MA) or the **Required D** (as in REV). The COD, PUSH, and MA models describe transferring a one-time executa version of code (i.e., a process instance) from the **Resource Site** to the **Requesting Site**, a executing it in the remote site. The REV model specifies a process that transfers an executa version of code from **Requesting Site** to **Resource Site** and executes it there. Replacing process instance with a process class supports transfer of source code that can later instantiated, i.e., compiled and executed. The various code mobility models can become gene components in specifications of mobile applications, as explained and demonstrated in Section

Table 2. The resource and computational components in **Requesting Site** (the "client") and **Resource Site** (the "server") before and after an activation of the transfer processes in each one of the four code mobility design paradigms.

Code Mobility Design Paradigm (**Process Name**)	***Time***	***Requesting Site***	***Resource Site***
Remote Evaluation (**REV Interacting**)	Before	**Activation Request** **Requested Processing** code	**Required Data**
	After	**Requested Processing** code	**Required Data** **Requested Processing** instance
Code-on-Demand (**COD Interacting**)	Before	**Activation Request** **Required Data**	**Requested Processing** code
	After	**Required Data** **Requested Processing** instance	**Requested Processing** code
PUSH (**PUSH Interacting**)	Before	**Required Data**	**Requested Processing** code **Profile** **Activation Request**
	After	**Required Data** **Requested Processing** instance	**Requested Processing** code **Profile**
Mobile Agent (**MA Interacting**)	Before	**Required Data**	**Requested Processing** instance **(+ Execution Status + Private Data)**
	After	**Required Data** **Requested Processing** instance **(+ Execution Status + Private Data)**	If clones: **Requested Processing** instance **(+ Execution Status + Private Data)**

Table 2 summarizes the components that reside at the **Requesting Site** and the **Resource S** before and after the transfer of a process instance in each of the four mobile code desi paradigms. Note that the table reflects the situation before **Requested Processing** took place, **Requested Result** does not yet exist. After this transfer, the executable code may be activat creating **Requested Result**.

4.1 Remote Evaluation

The OPD in Figure 3 is an OPM/Web model of the Remote Evaluation (REV) paradigm. **Co Sending** transfers an instance of **Requested Processing** from the **Requesting Site** to the **Resou Site**, while **Code Activating** invokes (triggers the execution of) this instance in the **Resource Si** Finally, **Requested Processing** transfers the **Requested Result** from the **Resource Site** to **Requesting Site**.

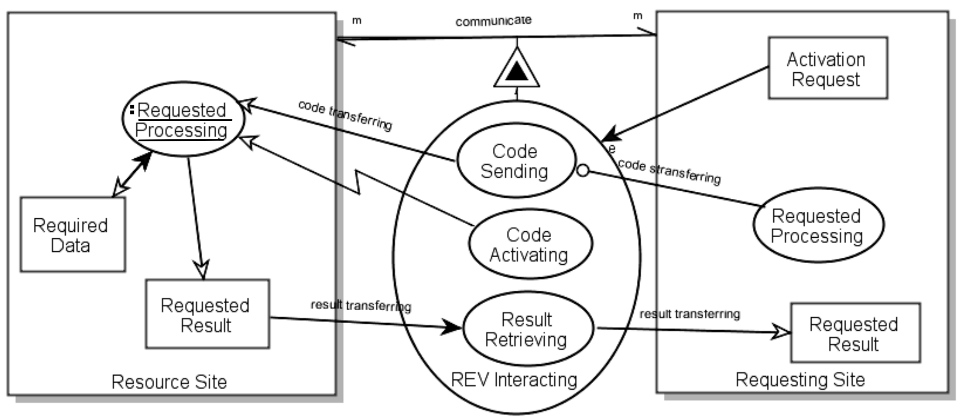


Figure 3. A generic OPD of the REV paradigm

The following OPL paragraph describes the same REV model textually.

Requesting Site is physical.

Requesting Site zooms into **Activation Request** and **Requested Result**, as well as **Requested Processing.**

Activation Request triggers **REV Interacting.**

Resource Site is physical.

Resource Site zooms into **Required Data** and **Requested Result,** as well as **Requested Processing** instance.

Requested Processing instance affects **Required Data.**

Requested Processing instance yields **Requested Result** of **Resource Site.**

Many **Requesting Sites** and many **Resource Sites communicate**, and this relation exhibits **REV Interacting.**

REV Interacting consumes **Activation Request.**

REV Interacting zooms into **Code Sending, Code Activating** and **Result Retrieving.**

Following path **code transferring, Code Sending** requires **Requested Processing** of **Requesting Site.**

Following path **code transferring, Code Sending** yields **Requested Processing** instance of **Resource Site.**

Code Activating invokes **Requested Processing** instance of **Resource Site.**

Following path **result transferring, Result Retrieving** consumes **Requested Result** of **Resource Site.**

Following path **result transferring, Result Retrieving** yields **Requested Result** of **Requesting Site.**

4.2 Code-on-Demand

The OPD in Figure 4 is a generic model of the Code-on-Demand (COD) paradigm. It clea shows that processing (i.e., the activation of a **Requested Processing** instance) in the COD mo occurs at the **Requesting Site**, whereas in the REV model, shown in Figure 3, the processing tal place in the **Resource Site**. The fact that **Requested Processing** is not initially at the **Requesti Site** is denoted in Figure 4 by the result link (the white arrowhead) whose destination is **Requested Processing** instance at the **Requesting Site**, indicating that the **Requested Processi** instance was created there only after the first stage of **COD Interacting**, **Code Retrieving**, occurr As described in Appendix B, OPCAT enables simulation of the behavior of this system, showi more vividly the sequence of occurrences. When the animated simulation is run, the **Request Processing** instance appears only in the postcondition set of **Code Retrieving**.

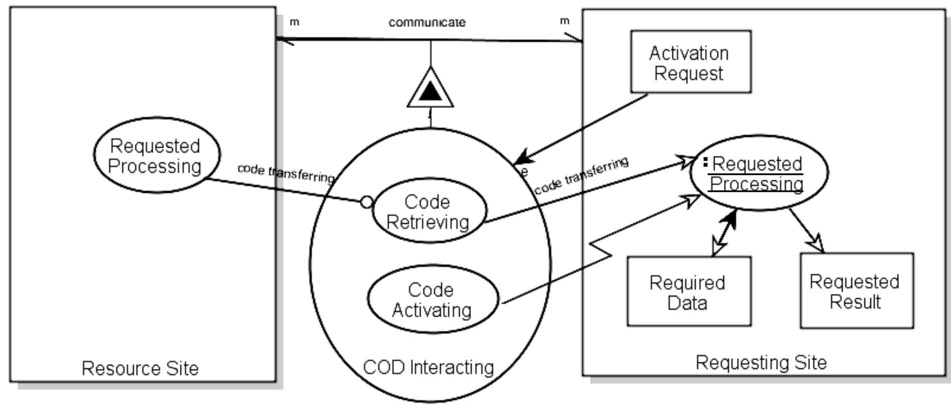


Figure 4. A generic OPD of the COD paradigm

The OPL paragraph below is the textual counterpart of the OPD in Figure 4 of the C(

paradigm.

Requesting Site is physical.
Requesting Site zooms into **Activation Request**, **Required Data**, and **Requested Result,** as well as **Requested Processing** instance.
 Activation Request triggers **COD Interacting.**
 Requested Processing instance affects **Required Data.**
 Requested Processing instance yields **Requested Result.**
Resource Site is physical.
Resource Site zooms into **Requested Processing.**
Many **Requesting Sites** and many **Resource Sites communicate,** and this relation exhibits **COD Interacting.**
 COD Interacting consumes **Activation Request.**
 COD Interacting zooms into **Code Retrieving** and **Code Activating.**
  Following path **code transferring, Code Retrieving** requires **Requested Processing** of **Resource Site.**
  Following path **code transferring, Code Retrieving** yields **Requested Processing** instance of **Requesting Site.**
  Code Activating invokes **Requested Processing** instance of **Requesting Site.**

4.3 ***PUSH***

Figure 5 is a generic model of the PUSH paradigm. The following OPL sentences describe

model.

Requesting Site is physical**.**

Requesting Site zooms into **Required Data** and **Requested Result,** as well as **Requested Processing** instance**.**

Requested Processing instance affects **Required Data.**

Requested Processing instance yields **Requested Result.**

Resource Site is physical**.**

Resource Site zooms into **Activation Request** and **Profile,** as well as **Requested Processing.**

Many **Activation Requests relates to** many **Profiles.**

Activation Request triggers **PUSH Interacting.**

Many **Requesting Sites** and many **Resource Sites communicate,** and this relation exhibits **PUSH Interacting.**

PUSH Interacting occurs if **Profile** of **Resource Site** is **requesting site.**

PUSH Interacting consumes **Activation Request.**

PUSH Interacting zooms into **Code Retrieving** and **Code Activating.**

Following path **code transferring, Code Retrieving** requires **Requested Processing** of **Resource Site.**

Following path **code transferring, Code Retrieving** yields **Requested Processing** instance of **Requesting Site.**

Code Activating invokes **Requested Processing** instance of **Requesting Site.**

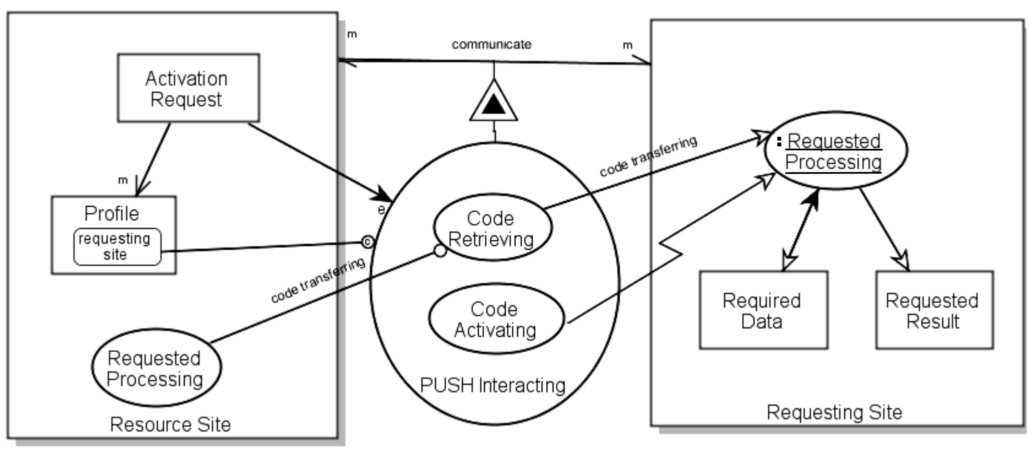


Figure 5. A generic OPD of the PUSH paradigm

The condition link from **requesting site Profile** to **PUSH Interacting** specifies that when trigge

(by **Activation Request**), **Requested Processing** is transferred only to sites that were registered

the **Profile**. The **Activation Request** and the **Profile** are not transferred to the **Requesting Site**, l

only enable the transfer of **Requested Processing** from the **Resource Site** to the relev

Requesting Sites. As noted, the creation of the **Activation Request** and the **Profile** at the **Resou** **Site** is done in a separate process whose execution precedes the execution of **PUSH Interacting**.

4.4 Mobile Agents

Various definitions of an agent (Franklin and Graesser, 1996) agree that all software agents computer programs, but not all programs are agents. Each agent definition indicates so properties that differentiate an agent from a "conventional" program. Various definitions exp an agent to be reactive, autonomous, goal-oriented, temporally continuous, communicati learning, mobile, and flexible. Agents of the same class or of different classes can communic with each other using objects. These definitions of an agent as a computer program w additional characteristics call for modeling an OPM/Web agent as a process instance, wh belongs to a process class. These process instances (agents) initiate their own migration specific points of their execution.

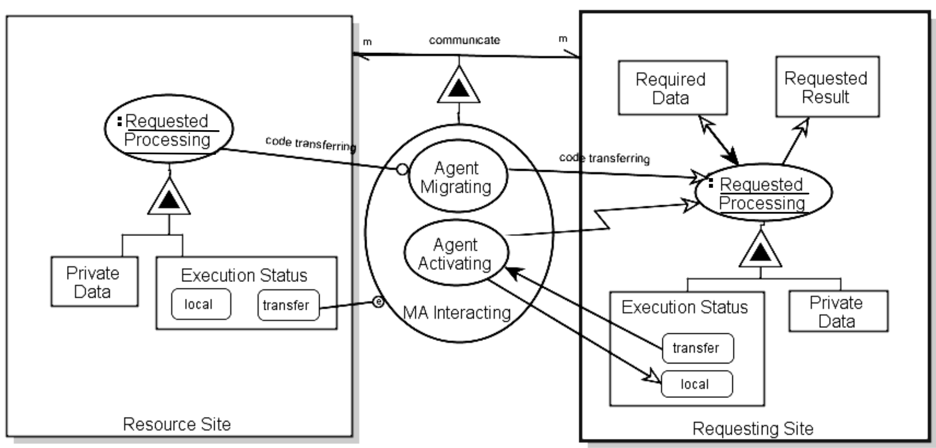


Figure 6. A generic OPD of the MA paradigm

Requesting Site is physical.

Requesting Site zooms into **Required Data** and **Requested Result**, as well as **Requested Processing** instance.

Requested Processing instance exhibits **Execution Status** and **Private Data**.

Execution Status can be **transfer** or **local**.

Requested Processing instance affects **Required Data**.

Requested Processing instance yields **Requested Result**.

Resource Site is physical.

Resource Site zooms into **Requested Processing** instance.

Requested Processing instance exhibits **Execution Status** and **Private Data**.

Execution Status can be **transfer** or **local**.

Execution Status triggers **MA Interacting** when it enters **transfer**.

Many **Requesting Sites** and many **Resource Sites communicate**, and this relation exhibits **MA Interacting**

MA Interacting zooms into **Agent Migrating** and **Agent Activating**.

Following path **code transferring**, **Agent Migrating** requires **Requested Processing** instance of **Resource Site.**

Following path **code transferring**, **Agent Migrating** yields **Requested Processing** instance of **Requesting Site**.

Agent Activating changes **Execution Status** of **Requested Processing** instance of **Requesting Site** from **transfer** to **local**.

Agent Activating invokes **Requested Processing** instance of **Requesting Site**.

Figure 6 and the corresponding OPL paragraph describe a mobile agent model for the case which the agent is cloned from the **Resource Site** to the **Requesting Site**. The agent, which characterized by **Private Data** and an **Execution Status**, initiates (triggers) its own transfer wh its **Executing Status** enters the **transfer** state. After completing the agent transfer, its **Executi Status** returns to the **local** state.

The instrument link from the agent (the **Requested Processing** instance at the **Resource Site**) **Agent Migrating** (within **MA Interacting**) in Figure 6 denotes that this migration clones (i.e., mak a copy of) the **Resource Site**'s agent at the **Requesting Site**. Alternatively, **MA Interacting** mi move the agent, in which case a consumption link from **Requested Processing** of **Resource S** to **Agent Migrating** replaces the instrument link, implying that the agent at the **Resource S** disappears.

5. Reusing OPM/Web Code Mobility Models: The QoS System Example

In this section we demonstrate the expressive power of OPM/Web as a means to explicitly mo what pieces of code are migrated along with their sources and destinations, and the effects of migration on the effectiveness of the application. Transferring a (resource or computation component between sites involves determining the source and target sites, integrating transferred component within the target sites, addressing network security issues, and handli errors that may occur in the process. These aspects can be incorporated in the single, bimo graphic-textual OPM/Web model, in which one or more of the code migration models, presen in the previous section, are reused. To demonstrate our approach, we present an OPM/Web mo of a Quality of Service (QoS) system, a mobile application that is based on (Klein et. al., 200 This system has been chosen in order to be able to demonstrate most of the code mobil concepts and design paradigms explained in this paper and their integration into a compl application. In this QoS system, software components from multiple parties collaborate provide a particular service to end users. The service users access service provider hosts vi Web interface. They select the specific value-added services for their applications. A serv provider communicates with several routers to achieve the QoS goals. The service users c control their requests remotely at any time.

As the System Diagram (SD), i.e., the top-level diagram, in Figure 7 shows, our QoS syst consists of three types of sites: **Client**, **ISP** (Internet Service Provider) **Agency**, and **Rou** **Agency**, each of which may have multiple instances. Each site type is modeled as a physi object that inherits from **Site**, a network node.

At this level of abstraction, the **Client** is shown to include only the **QoS Interface Handli** process, with which the **Service User** interacts. The **Service User** is an actor using the system a

is therefore modeled as an external (dashed) and physical (shadowed) object. Not knowing wh
routers provide the requested service, the **Service User** interacts via the **QoS Interface Handli** process, which the **Client** site hosts. This interaction is indicated in Figure 7 by the agent li (which ends with a black circle) from **Service User** to **QoS Interface Handling**. Each **Client** connected to **ISP Agencies**, and each **ISP Agency** is connected to several sites of type **Rou Agency**.

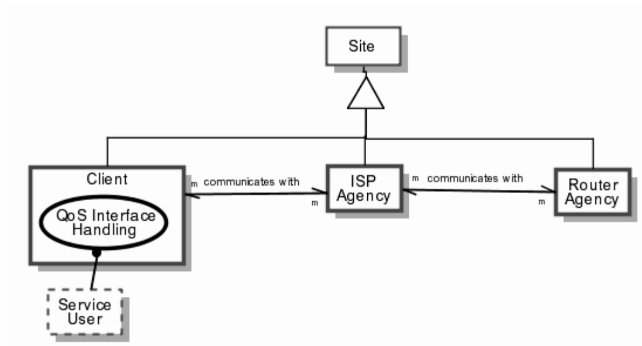


Figure 7. The top level System Diagram of the **QoS System**

If we were to model this system with UML, we would need three different types of UM diagrams: deployment diagrams to describe the system physical architecture, use case diagra to describe the user-system interactions, and sequence diagrams to describe scenarios of communication processes. However, even these three diagram types combined do not descr the details of the interaction processes, as do the next two OPDs in Figure 8 and Figure 9.

Refining the interaction between **Client** and the **ISP Agency**, Figure 8 shows that th communication structural relation exhibits two operations: **CS Interacting** and **COD Interacti** The details of the models of the Client-Server (CS) and Code-on-Demand (COD) paradigms ha been presented earlier. **COD Interacting**, for example, is the same as the process modeled Figure 4, where **ISP Agency** is the server (**Resource Site**), **Parameter Check Request** is

Activation Request, and **Parameter Checking** is **Requested Processing**. Therefore, **CS Interacti**

and **COD Interacting** are not in-zoomed further here.

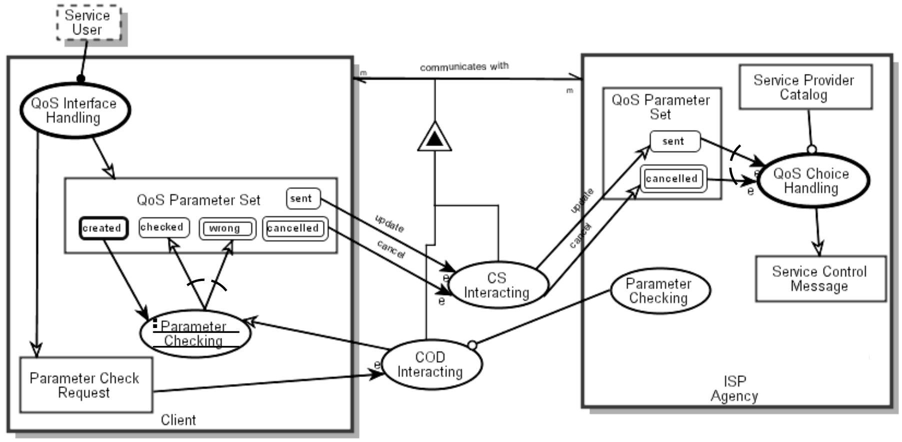


Figure 8. Detailing the **Client** – **ISP Agency** interaction

When weaving these models into a complete application, the combined model can enhanced to handle security issues and possible transfer errors. Since the security and priva algorithms are often pre-defined computational components, they can be modeled as OPM/W processes, from which the transfer processes can inherit both the functionality and the interfa This open reuse mode of OPM/Web, which is beyond the scope of this paper, is described Reinhartz-Berger, Dori and Katz (2002). The different kinds of transfer errors, such communication failures, unknown addresses, and timeout exceptions, can be traced using OI event links. These links model a variety of events, including process timeout, proc termination, state change, state entrance, state timeout, and external events. These types of eve trigger stand-alone processes, which handle the exceptions or errors as explained by Peleg a Dori (1999).

In addition to showing the details of the interaction between the **Client** and the **ISP Ager** components, Figure 8 also zooms into the **Client** and the **ISP Agency** components, exposin more refined view of their internal objects and processes. **QoS Interface Handling**, which is computational component of the **Client**, handles requests that the **Service User** submits. Wh activated by the **Service User**, **QoS Interface Handling** creates the objects **QoS Parameter Set** a **Parameter Check Request**. Upon its creation, **Parameter Check Request** activates **COD Interacti** The occurrence of **COD Interacting** transfers an instance (one-time executable version) **Parameter Checking** from the **ISP Agency** to the **Client**, enabling its local execution at the **Cli** site. This **Parameter Checking** execution changes the state of **QoS Parameter Set** from **created** either **checked** or **wrong**, indicating whether the **QoS Parameter Set** supplied by the **Service U** is correct or wrong. Through the **QoS Interface Handling** process, the **Service User** can contir affecting **QoS Parameter Set**, in order to request services (via the **update** path) or to cancel th (via the **cancel** path). These requests are transferred to the **ISP Agency** by the **CS Interacti** process, which does not need to wait for a response from the **ISP Agency**.

Unlike UML and its extension mechanisms, OPM/Web specifies the communication proces generically, regardless of their implementation technology. For example, the **COD Interacti** process specifies a common design paradigm for code mobility without limiting it to speci implementation language constructs (such as Java applets). As this example shows, OPM/W also supports modeling the events which trigger the communication processes, as well as conditions that enable their activations.

Figure 9 shows a refinement of the interaction between the **ISP Agency** and the **Router Agen** Since not all the **Router Agencies** provide all the services, the **QoS Choice Handling** uses **Service Provider Catalog** as an instrument for creating a **Service Control Message** and the **Serv** **Address** object, which defines a **router agency** address for the required service. If the **Serv** **Control Message** requests a new service (which is the case when its state is **create**), then the **R**

Interacting process is activated, transferring an executable version of **QoS Agent Processing** the **Router Agency** according to the **Service Address**. If the **Service Control Message** is created its **update** or **cancel** states, it is transferred as is to the **Router Agency** by the **CS Interacti** process, enabling the continuous running of **QoS Agent Processing** in the **Router Agency**, wh it can use the **Service Control Message** and any required **Local Data**.

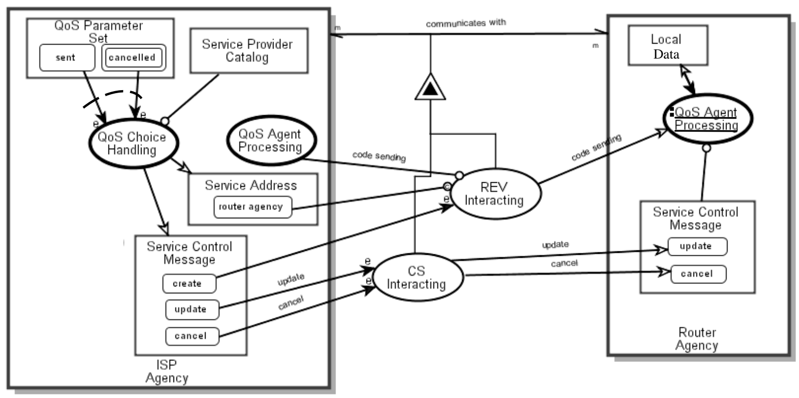


Figure 9. Detailing the **ISP Agency** – **Router Agency** interaction

Other OPM/Web code mobility models could be plugged and linked into our QoS applicati for specific purposes. For example, if we want **QoS Agent Processing** to be able to move or clo itself among various **Router Agencies** according to the Mobile Agent (MA) paradigm, explair in Section 4.4, we can add a structural relation between **Router Agency** and itself and specify t this relation exhibits the **MA Interacting** process as its operation.

6. Summary and Future Work

Existing Web and distributed system development methods are not up to the task of complete a accurate modeling of code mobility and migration. While some of them can specify sta bindings of software components to their physical locations, the specification of dynamic syst reconfiguration and code migration is not satisfactorily supported by any of the existi approaches. Mentally integrating the structure and behavior aspects of these systems in order comprehend them in their entirety can be achieved with current methods only with gr difficulties due to the multiplicity of models that need to be consulted.

Using a small set of concepts and symbols, OPM/Web combines the physical, sta behavioral, and functional views of a system within a single framework. OPM/Web augme OPM to enable modeling code mobility concepts and design paradigms by specifying proces as residents of some node (site) and moving or cloning them to other nodes, where they can activated or transferred further. This approach provides for a technology-independent moc where triggers, preconditions, and postconditions for the migration process are specif generically. Once the mobile application is modeled, a solid skeleton of the technolo dependent implementation can be automatically generated and simulated by the Object-Proc CASE Tool (OPCAT). This skeleton includes not only the structure of the application, but a its behavior, enabling design verification and leaving to the implementer only the coding at bottom level.

The single OPM view with its combined graphic-textual modalities and abstraction-refinem mechanisms benefits from consistency, relative simplicity, and ease of learning. The structu and behavior of the different components are explicitly modeled in the same view, making th understandable and communicable. In order to model distributed applications in UML, a set stereotypes (denoted by different graphical symbols), tagged values, and constraints must defined. Such extension mechanisms undermine UML standardization efforts, since ea researcher or company working in the domain of distributed systems is free to develop a differ set of extensions. Lack of a universal set of such extension entities inhibits the efforts to devel reusable components. The segregation of a UML model into multiple views, which span acr different diagram types, is yet another source of difficulty in capturing and understanding system as a whole (Peleg and Dori, 2000). Indeed, comparing the complexity metric values UML with other object-oriented techniques, Siao and Cao (2001) found that each diagram UML is not distinctly more complex than techniques in other object-oriented methods, but a whole, UML is 2-11 times more complex than other object-oriented methods.

In a separate work (Reinhartz-Berger and Dori, 2003), we have established the level comprehension of a given OPM/Web model and the quality of the models constructed using it comparing OPM/Web experimentally to an extension of UML to Web applications (Conall 1999). Third year undergraduate information systems engineering students had to respond comprehension and construction questions about two representative Web application models. T questions related to the system's structure, dynamics, and distribution aspects. We found t OPM/Web is significantly better in modeling the dynamics of Web applications, while specifying their structure and distribution aspects, there were no significant differences. In b case studies, the quality of the resulting OPM/Web models was superior. The main errors in UML modeling questions occurred when students were required to integrate the different vie into a whole, consistent model. The modeling questions required adding a single functional that affected several UML diagram types. All these changes were expected to leave the UI model integral and consistent. This task is difficult for trained UML modelers, let alone untrair students.

On the other hand, as our experiment indicated to some extent, UML's use of multiple vie may help system architects focus on a specific aspect of a system, and answer questions abou when the needed information is fully contained in a single diagram type, such as a class or interaction diagram. These types of questions may be more difficult to answer by examining

OPM/Web model, since the information might reside in several OPDs at different levels of det

To benefit from this potential advantage of UML and to stay current with the prevailing standa we have augmented OPCAT with the ability to automatically generate a set of UML views fr the single OPM/Web model. Since UML does not have a single mechanism to express sta alone processes, the resulting UML views may not necessarily be unique or complet equivalent to the OPM/Web model. Nevertheless, when we complete developing an UML OPM/Web generator, the system architect will be able to use the most suitable approach for e design portion by using OPM/Web, UML, or a combination of these two approaches. In paral we are working on developing the ability to generate the application (code and database schen from the system's OPL script.

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Appendix A: Main OPM/Web Concepts, their symbols, and their meaning

Concept Name	Symbol	Concept Meaning
Informatical object		A piece of information
Physical object		An object which consists of matter and/or energy
Process class	P	A pattern of transformation that objects undergo
Process instance	:P	An executable version of code
Initial/Regular/Final state		An initial/regular/final 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, possibly with a tag denoting the association semantics
Enabling event link		A link denoting an event (such as data change or an external event) which triggers (tries to activate) a process. Even if activated, the process does not change the triggering entity.
Consumption event link	e	A link denoting an event which triggers (tries to activate) a process. If activated, the process consumes the triggering entity.
Condition link		A link denoting a condition required for a process execution, which is checked when the process is triggered. If the condition does not hold, the next process (if any) tries to execute.
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 (possibly in a specific state), 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. The black arrowhead points towards the process that consumes the entity.
Result link		A link denoting that a process creates an (output) entity. The white arrowhead points towards the created entity.
Invocation link		A link denoting that a process triggers (invokes) another process when it ends
XOR connection		A connection between procedural links denoting that exactly one of the process incoming/outgoing links is applicable (active) in a single execution of the process

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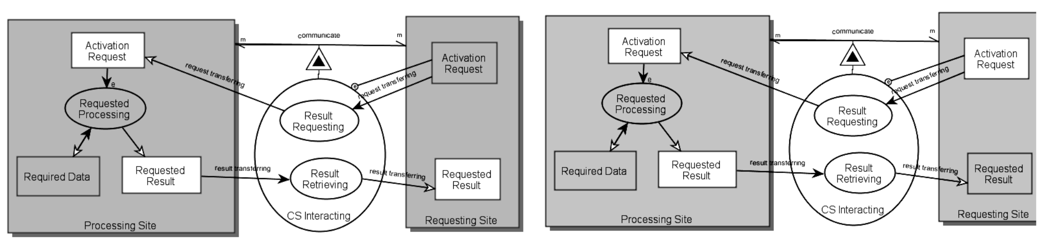
Appendix B: Simulating Mobile Specifications with OPCAT

Using Object-Process CASE Tool (OPCAT)[3] (Dori et. al., 2003), with which the OPM models this paper were generated, a system design model can also be simulated. In the CS paradigm, example, the simulation starts by making the precondition set of the **CS Interacting** process tr This is done by enabling (through highlighting) all the components (objects and processes) wh are not created by processes in the given model, i.e., the objects **Activation Request** **Requesting Site**) and **Required Data** and the process **Requested Processing**, as shown in Figu 10(a). While executing **CS Interacting**, the **Activation Request** at the **Processing Site** becon highlighted, then the **Requested Result** at the **Processing Site**, and finally the **Requested Result** the **Requesting Site**. After the transfer process has been completed, its postcondition set becon true, i.e., **Requesting Site**'s **Requested Result, Processing Site**'s **Required Data**, and **Request** **Processing** are highlighted, as shown in Figure 10(b). Using this simulation capability OPCAT, design errors that were not detected in the static model can be spotted and correc before starting the implementation.



(a) (b)

Figure 10. OPCAT 2 simulation snapshots before (a) and after (b) executing **CS Interacting**. Existing things in a snapshot appear in grey.

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[3] OPCAT 2 can be freely downloaded from http://www.objectprocess.org/