Software Development as a Workflow Process *

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Abstract

It is a general consensus that automated support for software development is essential to harness the ever increasing complexity of today's software. Many software development models, tools, and environments have been introduced to address such a need; however, they are usually methodology-specific and impose a rather authoritarian policy on the way software is developed. This paper advocates the use of workflow systems to enact the process of software development. Besides being more general and flexible, the workflow paradigm supports useful features lacking in other approaches. Also, it helps to reduce development complexity by allowing both the software development process and the software themselves to be captured using the very same paradigm. This paper introduces a workflow system being developed to support the software development process by presenting a solution to the ISPW-6 Software Process Example expressed in its specification language. This paper therefore serves two purposes: (1) to introduce a new and more general approach to software process enactment, and (2) to identify new requirements for the workflow paradigm, such as event dependency, that are applicable to many other advanced applications.

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† Supported by a Marie Curie Fellowship from the European Commission (ERBFMBICT960653).

1 Introduction

The workflow paradigm is advancing the scope of process modelling by supporting complex control flows, rich process structures, as well as the integration of new and legacy systems that may be heterogeneous. It has enjoyed some success in business process re-engineering [28] and consequently is attracting a lot of attention from other application domains such as scientific and engineering applications [25]. Like many of these application domains, the process of software development [20] is such a complex task that automated tools for the management and the execution of the process are highly desirable. It is precisely because of the fundamental ability of workflows to model, co-ordinate, and monitor complex applications that attempts are being made to extend the paradigm with new features to support more advanced applications.

In the case of software development, existing tools often provide a sequence of phases to be followed and some mechanism for refining a phase into more detailed phases. However, derivations from the pre-defined phases and the top-down refinement approach cannot be easily accommodated without losing a significant amount of control. Such static view of the software development process does not reflect the practice of system developers and hence is inappropriate for the execution of the process. Moreover, support for process management hardly exists.

This paper advocates the use of the workflow paradigm as a basis to support the execution and management of the software development process. Generally speaking, more flexibility is obtained as a result of the use of a general purpose paradigm. In the case of the workflow paradigm, it also provides openness to inter-operate with other systems, distributed execution environment, monitoring facility, and management of human resources. To demonstrate the approach, this paper presents the ISPW-6 Software Process Example [16] using a new workflow specification language called *Valmont*. It is believed that the requirements

extracted from supporting software processes are also applicable to many other application domains. Hence, overcoming the challenges of providing workflow support to the software process will shed light on the problems in other application domains that are possibly less well understood.

The structure of the paper is as follows. Section 2 discusses related work on models and languages for processes and workflows. Section 3 describes the ISPW-6 Software Process Example that is used to demonstrate *Valmont*. Section 4 gives an outline of *Valmont* and the workflow model *Liaison* on which *Valmont* is based. Section 5 gives the assumptions made in the solution. Section 6 to 8 presents a number of *Valmont* specifications for the ISPW-6 Example. Section 9 concludes.

2 Related Work

Traditional techniques such as data flow diagrams are found to be unsuitable for modelling complex processes due to their inability to capture the dynamic aspects of such processes. Petri nets, which are often used to describe and analyse concurrent systems [2], address the inadequacy concerning modelling process dynamics. High-level Petri nets [14] such as predicate/transition nets and colored Petri nets raise the abstraction level closer to that of user applications and hence become more useful for process modelling. An attempt to model workflows using Petri nets is given in [10]. Statecharts [12], which are designed for modelling reactive systems, allow concurrency and process abstraction to be expressed. A far less formal approach to process modelling based on the speech act theory has attracted a lot of attention [22]. A simplified form of it containing four phases: *request*, *commitment*, *performance*, and *evaluation* has been deployed as the modelling framework for Action Workflow [18]. Nevertheless, some features of the workflow paradigm such as the organisation model have not been captured by the above-mentioned proposals.

Recently, the Workflow Management Coalition has issued a proposal for a workflow specification language [26]. The proposal and *Valmont* have close similarities but there are also significant differences. The proposal sketches the components of a specification language that is supposed to be supported by all workflow systems so as to facilitate interoperability of workflow systems and translation between different representations of workflow models. It focuses mainly on the attributes of entities which are only cursorily considered in this paper. However, no concrete syntax is provided and a number of fundamental features are not addressed at all. *Valmont* is more complete in both coverage and syntax. However, it would be more constructive to look at the two languages as complementary to one another.

It is argued in [11] that C&Co, a C-based general purpose programming language, is sufficient to serve as a workflow specification language. Distributed concurrent processes can be created and communication between such processes relies on the use of write-once variables. Transaction primitives supporting compensation and the two-phase commit protocol are provided. The ability of C&Co to express workflow computation and control is beyond dispute but the level of abstraction provided is questionable. Also no organisation model and user interaction are taken into account. Perhaps, C&Co should be seen as an implementation language for the realisation of workflow systems. Like C&Co, WADL [9] captures only the control flows and transaction properties of tasks. Unlike C&Co, it provides a higher-level of abstraction supporting sequential, parallel, alternative, and non-deterministic flows. The last two are not directly supported in *Valmont* but can be modelled easily. The specification language of the METEOR system [17] (consisting of WFSL and TSL) comes much closer to be a "real" workflow specification language with the support of simple control flows, complex dependencies on data flows, process abstraction, transaction support and exception handling; however, several elements, such as the organisation model, are still missing

The specification language of FlowMark from IBM [13] bears a close resemblance to *Valmont* but lacks a number of advanced features that are supported by *Valmont*. These features include richer and more declarative activity assignment constraints, active rules providing a more general framework for handling exceptions, and high-level transactions [1] that are absent in FlowMark.

Among the fundamental elements of the workflow paradigm, the organisation model is probably the least studied element. The only work that the authors are aware of is reported in [3] which advocates an organisation model containing three components: organisation structure, organisation expression, and activity assignment policy. All three components show strong influences from the relational database model. In an organisation structure one "relation" is used for every agent type and every relationship between agent types. An organisation expression is essentially a "view". An activity assignment policy specifies the domain - a conceptual geographical location represented by a domain identifier - of a workflow activity as well as the organisation expression that returns a set of eligible agents for the activity. Unlike *Valmont*, only activities can be given a domain. Furthermore, the relational query language used in organisation expressions may not be computationally powerful enough, for instance it is not clear if recursive search for superior is possible. Generally speaking and evidenced by all examples shown in [3], agent relationships are used only for traversing between agents and there is no need for them to be "first-class" entities in the model.

Besides the above-mentioned models, several models have been used to support process planning, re-planning,

monitoring, and recording [15, 19]; to represent, analyse, and compare development methodologies [23, 24]; as well as to simulate and support process execution [8, 21]. A cursory comparison of the workflow paradigm and the software process can be found in [7]. The similarities between the two are identified; however, their differences are not well addressed. The conclusion is therefore rather simplistic and underestimates the scale and implication of the differences.

3 The ISPW-6 Software Process Example

The ISPW-6 Software Process Example [16] is the first benchmark application example to facilitate objective assessment and comparison between software process models. Several extensions to the example have been introduced since but this paper only discusses the core example in the original description.

The core example concerns the execution and management of a change of requirements for an existing software component. The process is initiated in response to the modification of a requirement unit. It begins with a project leader scheduling and assigning the various engineering tasks in the process. These include modification of the corresponding design unit, modification of the test plan, modification of the unit test, and testing of the modified unit. During the execution of these activities the project leader monitors their progress. The process description specifies constraints on the process including the ordering of some of the tasks, the kinds of personnel responsible for each task, as well as conditions for task initiation and termination. The tasks and the (simplified) control flows between them are depicted in Figure 1. "Monitor Progress" is a task that interacts with all the other tasks in "Develop Change and Test Unit".

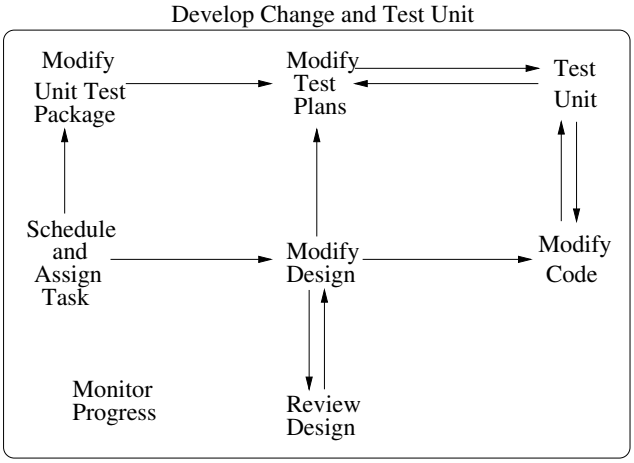

Figure 1. (Simplified) Control Flows in the ISPW-6 Software Change Process

The specifications given in Section 6, 7, and 8 represent only a partial solution to the ISPW-6 Example. The emphasis is on the delicate co-ordination that can be expressed in *Valmont*. Moreover, some features are expressed only once in the specifications as opposed to their multiple uses in the ISPW-6 Example. Further discussion of the individual tasks are given when their corresponding specifications are examined.

4 The *Liaison* Workflow Model

The *Liaison* workflow model used in this paper is based on the WIDE workflow model [4] and is an extension of the reference workflow model proposed by the Workflow Management Coalition [27]. Like the reference workflow model, it captures the fundamental elements of the workflow paradigm: organisation model, information model, process model, and their relationships. Unlike the reference workflow model, it supports a rich organisation model, sophisticated activity assignment constraints, dynamic control flows including the use of active rules, complex process structures, and workflow transactions. *Liaison* extends the WIDE model with more elaborate process event dependencies, dynamic process evolution support, and process integration support. The examples used in this paper are expressed using *Valmont*, which is a specification language for *Liaison*. It is based on a specification language defined earlier by the first author [6].

4.1 Organisation Model

The organisation model registers primarily the organisation structure and resources. It records information about individual employees (*staff*), functional positions held by staff (*position*), groups of staff (*team*) that are put together to serve some transaction, as well as non-human resources (*tool*) such as machines and software. A staff member can hold several positions as well as participate in a number of teams possibly in different capacities according to the positions held. Staff, positions, teams, and tools are collectively referred to as *agents*. All agents are associated with a *domain* which is usually used to model geographical sites or functional units of an organisation.

The organisation model also captures relationships between staff, between positions, and between teams. These relationships are useful for searching agent replacement. The *deputy* relationship allows one staff member to deputise for another that is not available to carry out an activity. The *position hierarchy* captures the *accountability* relationship between positions. When a staff member is not available, a task can be performed instead by his or her senior to whom the staff member is accountable for. The *team hierarchy*

recording the *inclusion* relationship serves a similar purpose. When a team member is not available, the team leader can take over. However, if no one in the team is available, the leader of the *affiliated* team which includes the original team can be brought in.

4.2 Information Model

The information model defines the data used in a workflow process, governs the operations that can be performed on the data, as well as controls the scope and presentation of the data. Data can have one of two possible scopes: *global* and *local*. Global data are shared by all workflow processes. They are persistent and are stored usually in either databases or files. Local data are only accessible from within one workflow process and are shared between activities within the same process. They are managed by the workflow system and are in many ways not unlike global data.

The *entity* data type is introduced to capture external data and their associated operations. Every entity may have a set of associated operations that are often completely different from any other entities. Nevertheless, for the purpose of workflow applications, it is sufficient to treat all entities to be of the same type at the expense of having to perform some type checking dynamically at run-time.

The *form* data type is probably the most distinguishing type in the information model. It resembles the record type in programming languages except that it also contains presentation information. The presentation information is important due to the interactive nature of workflow systems - a lot of information is presented and captured using forms displayed on user terminals. Presentation information include headings, field labels, and formatting information. Each field is typed and can be used to show or update data variables. Default field values can also be defined. A form type can be derived from another form type possibly by removing fields. Moreover a derived form can relax or restrict operations that can be performed on a field. This mechanism encourages and supports re-usability which reduces the maintenance effort.

The information model supports the well-known base types: *integer*, *string*, and so forth. It also supports *list* as a container type whose elements can be of any type including list, entity, and form. Actually types are orthogonal and can be combined freely.

4.3 Process Model

The use of activity abstraction in the process model allows an application to be defined in an incremental fashion and often the resultant design is more comprehensible. In other words, an activity representing a unit of work at one level can be refined into a network of activities in the next level. Activities at the bottom level, so to speak, are the building blocks of the process where actions are actually carried out. The bottom-level activities are referred to as *base tasks* while other activities are called *tasks*.

Every activity definition can contain the following components: (1) a *pre-condition* that has to be satisfied for the activity to start, (2) actions performed by the activity, (3) a *post-condition* that has to hold for the activity to terminate, (4) a *role constraint* about assigning the activity to an agent, (5) a *schedule* for the execution of the activity, and (6) handlers for system-defined as well as user-defined *exceptions*. The action part of an activity varies depending on whether the activity is a task or a base task. For a task it captures the control flows between activities in the next level. For a base task it captures some computation which may be performed over the information model or some external operation performed by the user. Consequently, role constraints may differ between tasks and base tasks. For a task a role constraint may specify dependency between activity assignments of lower-level activities. For a base task a role constraint is always about the base task alone. Base tasks have the option of specifying the forms that can be used for interaction with the user.

A task can be highly dynamic as its execution can be influenced by exceptions raised by the user through the interactive tools provided (e.g. abort a task) or by the workflow system itself (e.g. a *temporal event* that occurs regularly). Therefore, an activity can be at different *states* at different times. Operations are executed only when an activity is in the *running* state. Control flows between activities do not have to be structured in a linear fashion. An activity can be followed by (or *fork*) a number of activities while multiple activities can precede (or *join*) a single activity.

4.4 The *Valmont* Workflow Language

4.4.1 Distribution

Valmont provides a syntactic construct for each of the three models described in the previous subsections. A model defined using such a construct is referred to as a *specification* in this paper. In order to model distribution which can be either a physical or logical notion, each specification can be given a *domain* which qualifies all components defined in the specification. Domains are hierarchical and are used somewhat like Internet domain and host names with inclusion semantics between them. To define a process that is to be executed at different sites, the domain given to the specification can be partially parameterised.

4.4.2 Reusability

Specifications can be reused or combined by importing one specification to another. It should be noted that the domain of an imported specification remains unchanged. The process model plays a central role in a workflow application, it often imports specifications of the other models. On the contrary, the other models only import specifications of their own models.

4.4.3 Modularity

An organisation specification serves two purposes. First, it can be used to define attributes for the various kinds of agents and the relationships between them. Second, it allows instantiation of the various kinds of agents.

An information specification consists of two kinds of definitions. First, data definitions which are similar to type definitions found in programming languages. In particular, a piece of external data is defined as an entity - a very simple form of abstract data type. Second, form definitions provide a mechanism to group and share data. Presentation details can also be captured in the form definitions.

A process specification can contain a number of task specifications which can be further refined or decomposed via other task specifications. Control flows are captured using production-rule-like constructs. Data flows are expressed using parameter passing to forms which is similar to reference passing in procedure calls. Exceptions are dealt with using event-condition-action rules. Activity assignment is specified using a novel syntax.

5 Assumptions of the Solution

The ISPW-6 Example includes both development and management tasks. With the workflow paradigm, the management tasks are best modelled using the build-time system and the monitoring facility of the run-time system. The build-time system is usually used to define the various models before the workflow process is executed even though some control can be defined dynamically or changed during execution. The monitoring facility keeps track of the execution history and runs as long as the process lasts.

It is therefore not surprising that "Schedule and Assign Task" and "Monitor Progress" are not directly modelled in the *Valmont* specifications. The "Assign Task" part is assumed to have been carried out using the build-time system to assign staff to the project team. Alternatively, assignment can be made at run-time by the project leader as required. The "Schedule Task" part is kept as a development task to demonstrate the dynamic scheduling capability. To keep the specifications short, only one task (i.e. "Test Unit") is scheduled and the other tasks are left to run without any scheduling constraints. "Monitor Progress" is not modelled either since the monitoring facility can perform most of the job automatically. The rest of the job can be incorporated as exceptions in the development tasks.

The ISPW-6 Example process is supposed to be initiated by the arrival of the new requirements document and the verbal authorisation from the Configuration Control Board. In the *Valmont* specifications, it is assumed that the initiation of the workflow process (which includes registering the responsible agent and executing agent) is an indication of the receipt of the verbal authorisation. Also the new requirements are assumed to have been stored and accessible to the workflow system.

It should be noticed that both individual tasks and the workflow process can be terminated at any point during the execution by the user or the system itself. In other words, *cancellation* is a pre-defined operation and requires no explicit modelling.

During the execution of the workflow process, a task that is in the ready state will be put into the work-list of the responsible agent (i.e. after assignment resolution) together with the scheduled start time and duration. An email message is also sent to the agent about the arrival of the new task. The agent can then choose when to perform the task. If the task is not started after its scheduled start time, an indication will be made in the work-list. Similarly, an indication will be shown when a task is overdue.

6 Organisation Specification

The organisation model can be used to capture an enterprise with multiple sites. Each site can be considered as a domain. The hierarchy that often exists between sites can be modelled as a hierarchy between domains. In the (partial) organisation specification "Software_Services" given in line 6-30 of Figure 2, the domain qualifier LOCAL (line 6) is actually a domain parameter which is bound to the domain in which the workflow process runs. Parameterised domains allow reuse of organisation models. All components defined in a specification are qualified by the domain of the specification. Domain qualification is however optional as is the case for "Sino_French" defined in line 1-5. *Valmont* allows one specification to import other specifications. The USES clause in line 7 of the "Software_Services" specification allows all components defined in the "Sino_French" specification to be used in the "Software_Services" specification. Often connections to the imported models are to be established, one such connection between "Software_Services" and "Sino_French" is established in line 25 which will be explained later.

Properties of individual employees are captured using the STAFF definition. Attributes appeared after the keyword HAS are user-defined attributes which correspond to the *ex-*

```
1   ORGANISATION_MODEL Sino_French
      ...
2     TEAM Configuration_Control_Board
3     ...
4     END_TEAM;
5   END_MODEL
```

```
6   ORGANISATION_MODEL Software_Services OF LOCAL
7     USES ORGANISATION_MODEL Sino_French;
      ...
8     STAFF HAS
9       ARRAY OF STRING: skills;
10      ARRAY OF STRING: languages;
11      STRING: degree;
12    END_STAFF;

13    POSITION Design_Engineer SUPERIOR Project_Leader
14      ...
15    END_POSITION;

16    POSITION Quality_Assurance_Engineer SUPERIOR Project_Leader
17      ...
18    END_POSITION;

19    POSITION Software_Engineer SUPERIOR Project_Leader
20      ...
21    END_POSITION;

22    POSITION Project_Leader
23      ...
24    END_POSITION;
      ...
25    TEAM Project_Team AFFILIATION Configuration_Control_Board has
26      STAFF: design_engineer;
27      STAFF: quality_assurance_engineer;
28      ARRAY OF STAFF: software_engineers;
29    END_TEAM;
30  END_MODEL
```

```
31  REGISTER TEAM Configuration_Control_Board IN Sino_French
32    (LEADER) (Frank);

33  REGISTER STAFF IN Software_Services OF France
34    (SELF, DEPUTY, languages, skills, degree)
35    [ (Andy, [Billy], ["chinese", "english", "french"],
        ["databases", "software engineering"], "Ph.D."), ... ];

36  REGISTER POSITION Design_Engineer IN Software_Services OF France
37    (SELF, SUPERIOR)
38    [ (Andy, Edward), (Billy, Edward), ... ];
    ...
39  REGISTER TEAM Project_Team IN Software_Services OF France
40    (LEADER,design_engineer, quality_assurance_engineer, software_engineers)
41    (Edward, Andy, Bob, [Chris, David AS Software_Engineer]);
```

Figure 2. A Partial Organisation Model

tended attribute list defined in [26]. Attribute values can be of any type, for instance "skills" is a list-valued attribute and "degree" is a string-valued attribute. Line 31-41 of Figure 2 show how an organisation model can be populated with instances using the REGISTER statements. Line 33-35 register an employee identified as "Andy" with four attribute values. The first attribute "DEPUTY" is pre-defined and provides a list of employees who can stand in for the employee being registered.

Positions are defined using the POSITION definition. Apart from pre-defined attributes, user-defined attributes can be introduced as in the STAFF definition. The optional accountability relationship can also be specified. In line 16-18, the position "Quality_Assurance_Engineer" is defined to be accountable to "Project_Leader" but no such relationship is defined for "Project_Leader" in line 22-24. Line 36-38 show the registration of two "Design_Engineer"'s identified as "Andy" and "Billy". They are both accountable to "Edward". Each employee is assigned to at least one position but can be more as in the case of "David" (see line 41).

Organisations are becoming more team-oriented rather than function-oriented as the former helps to eliminate unnecessary control resulting in better responsiveness and flexibility. Teams can be defined using the TEAM definition, for example in line 2-4 and 25-29. "Project_Team" has been given a user-defined list-valued attribute called "software_engineers" (line 28) and its value is given in line 41. The pre-defined attribute "LEADER" is also registered in line 41. Since a team member can hold more than one position, it is sometime necessary to specify the capacity of a team member. In line 41, "David" serves in the "Project_Team" as a "Software_Engineer" rather than other capacities (e.g. "Quality_Assurance_Engineer") that he may hold. Teams can form a team hierarchy using the inclusion relationship. For instance, the "Project_Team" in "France" is included in the "Configuration_Control_Board" team. This is specified using the AFFILIATION clause in line 25.

7 Information Specification

The information model is actually made up of two models - the *form model* and the *data model*. The form model contains representation details of forms that can be used to interact with the user. The data model can be used to define global and local data. The next two subsections provide partial specifications of the form and data models used in the solution.

7.1 Form Specification

A form specification contains representation details concerning the display of a form and the types of the data that can appear in a form. The "Design_Change_Form" is defined in line 2-10 in Figure 3 and the appearance of the form is given in Figure 4. The heading statement (line 3) prints a string on the screen while NEW_LINE and SPACE correspond to starting a new line and producing some vertical spacing. Each LABEL statement can generate a number of buttons or boxes which may be labelled. For example,

```
1   FORM_MODEL Software_Services OF France
2     FORM Design_Change_Form
3       HEADING "DESIGN CHANGE FORM";
4       SPACE;
5       LABEL "Software Design" LINKS ENTITY: design;
6       NEW_LINE; SPACE;
7       LABEL "New Requirements" LINKS TEXT: requirements_change;
8       NEW_LINE; SPACE;
9       LABEL "Additional Recommendation" LINKS TEXT: fix_design_feedback;
10    END_FORM;

11    DERIVED_FORM First_Design_Change_Form FROM Design_Change_Form
12      WITHOUT fix_design_feedback;
13      ONLY READ FOR requirements_change;
14    END_FORM;

15    DERIVED_FORM More_Design_Change_Form FROM Design_Change_Form
16      ONLY READ FOR requirements_change, fix_design_feedback;
17    END_FORM;
      ...
18  END_MODEL
```

Figure 3. A Partial Form Model

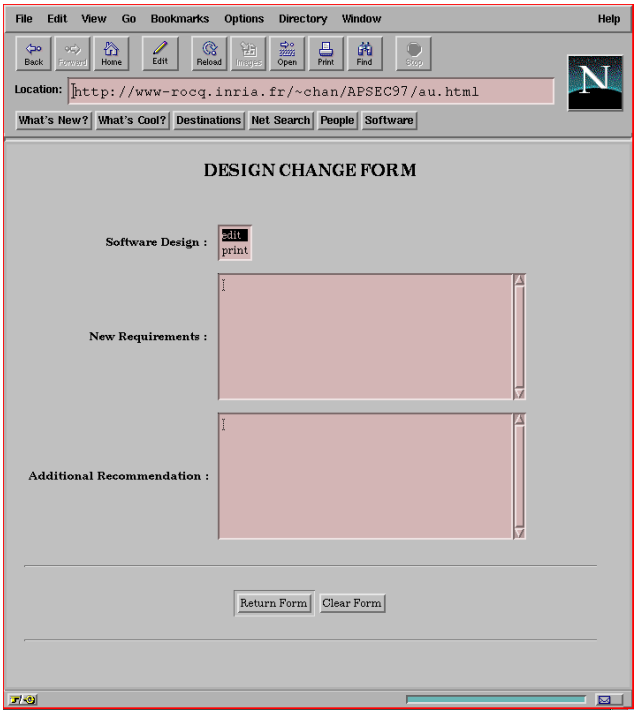

Figure 4. Design Change Form

line 9 generates a box next to the label "Additional Recommendation" to represent a link to a piece of data of type TEXT. It should be noted that fields in a form are references to local data and they are not value holders themselves. The type information of the fields are included to facilitate type checking and efficient formatting.

The "First_Design_Change_Form" is derived from the "Design_Change_Form" and differs from the latter in two ways. First, the field "fix_design_feedback" is removed (line 12). Second, the field "requirements_change" cannot be updated (line 14). Similarly, "More_Design_Change_Form" is derived from the "Design_Change_Form". It restricts access to fields "requirements_change" and "fix_design_feedback" to read-only. Derived forms are used to control the scope and access of local data by means of structural changes, access constraints, and initial values for fields before the form is displayed. Form derivation is simply a syntactic sugaring for defining new forms and does not imply any relationship between forms.

7.2 Data Specification

```
1   DATA_MODEL Software_Services OF France
2     ENTITY design "~ss/ispw6/design.txt"
3       HAS
4       edit "emacs $design";
5       print "lpr $design";
6     END_ENTITY;

7     ENTITY source_code ...
8       ...
9     END_ENTITY;

10    ENTITY object_code ...
11      ...
12    END_ENTITY;

13    ENTITY test_unit_package ...
14      ...
15    END_ENTITY;

16    VARIABLE
17      STRING: fix_design, test_results;
18      BOOLEAN: fix_code, fix_test;
19      TIME: test_unit_start, test_unit_feeback;
20      TEXT: requirements_change, fix_design_feedback, no_of_defects,
21        fix_code_feedback, fix_test_feedback, test_plans;
22  END_MODEL
```

Figure 5. A Partial Data Model

The data model given in Figure 5 contains two categories of data. Line 2-6 captures an external document as an entity and defines two associated operations: "edit" and "print". Operation associated with an entity are usually listed in a pull-down menu in a form. It is also possible to copy an entity from one field to another. Line 17-21 defines variables of various types that can be used with forms as described in the next section.

8 Process Specification

The process model primarily captures various relationships between processes: the refinement relationship, control flows, and data flows.

```
1   WORKFLOW_MODEL ISPW-6 OF France

2   USES ORGANISATION_MODEL Software_Services;
3        FORM_MODEL Software_Services;
4        DATA_MODEL Software_Services;

5   CONTROL
6     START Schedule_Task;
7     Schedule_Task ENABLES Perform_Change;
8     END Perform_Change;

9   EXCEPTION
10    Test_Unit_Delayed
11      WHEN AT(test_unit_start) AND NOT STARTED(Test_Unit)
12      DOES NOTIFY(Project_Team.LEADER, "...");

13    Test_Unit_Overdue
14      WHEN ELAPSED(Test_Unit) > test_unit_length
15      DOES NOTIFY(Project_Team.LEADER, "...");

16    Review_Design_Completed
17      WHEN COMPLETED(Review_Design)
18      DOES NOTIFY(Project_Team.LEADER, "..." + no_of_defects);


19  TASK Perform_Change

20    START Modify_Design, Modify_Test_Plans;

21    Modify_Design ENABLES Review_Design;
22    Review_Design IF (fix_design IN LIST["minor changes", "major changes"])
23      ENABLES Modify_Design;
24    EACH(START_EVENT(Modify_Design),
25         Test_Unit IF (fix_code = TRUE))
26      ENABLES Modify_Code;
27    Modify_Design ENABLES END_EVENT(Modify_Code);

28    EACH((Modify_Test_Plans, Modify_Design),
29         Test_Unit IF (fix_test = TRUE))
30      ENABLES Modify_Test_Unit_Package;
31    Modify_Test_Unit_Package, Modify_Code ENABLES Test_Unit;

32    END Test_Unit;

33  END_TASK;
```

Figure 6. Tasks Modelling the ISPW-6 Software Process Example

The workflow process definition begins with importing an organisation model (line 2), a form model (line 3), and a data model (line 4) relevant to the application.

The control part, line 6-8, specifies the top level activity abstraction of the workflow application. The workflow is supposed to start from the "Schedule_Task" (line 6) and finish with the "Perform_Change" task (line 8). The transition from one task to another is captured using the ENABLE statement (line 7 shows its simplest form). Conditional transitions can be specified by providing a condition as in line 22.

Three exception handlers are defined in line 10-18. "Test_Unit_Delayed" informs the project leader if "Test_Unit" is not started after the scheduled time. AT is a time operator which compares the given time with the current system time while STARTED is a pre-defined predicate indicating if a task has begun. "Test_Unit_Overdue" does the same when "Test_Unit" is not completed by its scheduled time. ELAPSED returns the time interval between the start of a task and the current system time. "Review_Design_Completed" simply informs the project leader of the completion of "Review_Design" together with information about the defects. COMPLETED checks if the given task is finished.

"Perform_Change" is further refined between line 19-33 and is specified to have two starting tasks (line 20). Line 21-27 concern the modification of design and code while line 28-31 deal with the testing of the modified code. A conditional transition is used in line 22 to allow "Modify Design" to be performed repeatedly until the design is considered acceptable by "Review_Design". "Modify_Code" (line 26) can be initiated in two ways: (1) after "Modify_Design" is started (line 24), (2) after "Test_Unit" is finished and suggests more code change (line 25). Line 27 asserts that "Modify_Code" cannot terminate before "Modify_Design" has done so. When a list of events appears on the left hand side of ENABLES without qualification (line 31), they all must hold before the task on the right hand side can start. START_EVENT (line 24) and END_EVENT (line 27) allow delicate control to be specified. In this case, they are used to specify that "Modify_Design" and "Modify_Code" are not ordered sequentially but instead can be overlapped.

In the case of a base task, instead of control statements, computation and message display are specified. Forms are displayed only by base tasks which have the duty of performing computation that may require inputs from the user. The forms to be displayed is specified in the VIEW clause and their contents are filled using local variables (e.g. line 36). The mechanism is similar to pass by reference in procedure calls in programming languages.

Every activity can be given a pre-condition and a post-condition that have to be satisfied for it to begin and end successfully. The pre-condition of "Schedule_Task" given in line 37-39 specifies that the two fields in the form must be blank. The post-condition given in line 43 specifies that all the fields must be filled. The keyword EVERY is a shorthand for all the fields in a form. The role constraint given in line 44-45 states that the task must be carried out by the project leader. It is also possible to use more than one form in a base task. Two forms are specified in "Modify_Design" (line 48-52). One form (line 49-50) is used when it is initiated for the first time and the other form (line 51-52) is used when further change to the design is required. These forms are used only if their associated conditions hold (line 50, 52). A base task can be assigned to multiple agents and is demonstrated in line 60-62. Scheduling constraints can be given like in line 77 which states that "Test_Unit" must start by 9 am on July 1 and should be completed in 7 days.

```
34 BASE_TASK Schedule_Task
35   VIEW
36     Schedule_Form(test_unit_start, test_unit_length);
37   PRE_CONDITION
38     Schedule_Form.start IS NULL;
39     Schedule_Form.length IS NULL;
40   MESSAGE
41     "Please fill in the start time and duration.";
42   POST_CONDITION
43     EVERY Schedule_Form IS NOT NULL;
44   ROLE
45     STAFF Project_Team.LEADER;
46 END_TASK;

47 BASE_TASK Modify_Design
48   VIEW
49     First_Design_Change_Form(requirements_change, design)
50         IF fix_design IS NULL;
51     More_Design_Change_Form(requirements_change, design,
           fix_design_feedback)
52         IF fix_design IN LIST["minor changes", "major changes"];
     ...
53   ROLE
54     STAFF Project_Team.design_engineer;
55 END_TASK;

56 BASE_TASK Review_Design
57   VIEW
58     Review_Form(requirements_change, design,
     fix_design_feedback, fix_design, no_of_defects);
     ...
59   ROLE
60     STAFF Project_Team.design_engineer;
61     STAFF Project_Team.quality_assurance_engineer;
62     STAFF 2 Project_Team.software_engineer;
63 END_TASK;

64 BASE_TASK Modify_Code
65   VIEW
66     First_Code_Change_Form(design, source_code)
67         IF fix_code IS NULL;
68     More_Code_Change_Form(design, source_code, fix_code_feedback)
69         IF fix_code = TRUE;
     ...
70 END_TASK;

71 BASE_TASK Modify_Test_Plans
     ...
72 END_TASK;

73 BASE_TASK Modify_Unit_Test_Package
     ...
74 END_TASK;

75 BASE_TASK Test_Unit
     ...
76   SCHEDULE
77     FOR AT(97/7/1,9:00:00) LASTING INTERVAL(0/0/7);
78 END_TASK;

79 END_MODEL
```

Figure 7. Base Tasks Modelling the ISPW-6 Software Process Example

9 Concluding Remarks

This paper demonstrated the use of a general purpose paradigm and hence a more flexible way to support the software development process. It was shown that the workflow paradigm offered a more comprehensive modelling scope which allows organisation structures, human resources, user interfaces, integration of external services, as well as fine dependency control to be captured. The use of a workflow specification language in this paper is merely for the purpose of illustration and the system is assumed to be operated primarily graphically. Nevertheless, having a workflow language was found to be very helpful in studying the individual features as well as their interaction. The requirements that have been identified so far from the software process [5] also emerge as necessary in other application domains. It is believed that using a well studied application domain such as the software process would help significantly in directing the development of advanced workflow systems which will benefit a whole spectrum of application domains.

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