Towards an Integrated Conceptual Modelling Kernel for Business Transaction Workflows[*]

A.P. Barros[1], A.H.M. ter Hofstede[2], H.A. Proper[2]

[1]School of Information Technology
The University of Queensland
Brisbane, Qld 4072
Australia

[2]Faculty of Information Technology
Queensland University of Technology
GPO Box 2434, Brisbane 4001
Australia
e-mail: E.Proper@acm.org

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Abstract

1 Introduction

The workflow concept, proliferated through the recently emergent computer supported cooperative work (CSCW) systems and workflow systems (see surveys in [FYW94, WW93, Rod91] and [GHS95] respectively), advances information systems (IS) implementation models by incorporating aspects of collaboration and coordination in business processes. Under traditional implementation models, applications are partitioned into discrete units of functionality, with (typically) operational procedures used to describe how human and computerised actions of business processes combine to deliver business services. Through an endowment of business process execution semantics, workflows permit a greater organisational fit of ISs. Moreover workflows are specified at a level above traditional applications,

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enabling program binding and access to a loosely-coupled set of databases and files. Therefore, newer applications may be developed out of existing applications to reflect reengineered business processes.

Crucial to the specification of any IS implementation is the *conceptual* level. This, of course, orients the analysis of a given domain towards its essence (deep-structure) rather than to aspects of implementation (physical-structure) or representation (surface-structure). It is a well-known fact the later problems and inadequacies are detected in specifications, the greater the expense of correction [Dav90]. For workflows, the standardisation of concepts is progressing through the Workflow Management Coalition[1]. While the set of terms and references defined so far characterise sufficiently the notion of workflow, e.g. event, process (including pre-conditions, post-conditions and state transitions) and organisational (or actor) role, much of the focus is geared towards workflow management systems and their specification languages. The emphasis is on part of business processing, namely process execution semantics: sequence, repetition, choice, parallelism and synchronisation. A sound conceptualisation requires not only this but also that process semantics, e.g. the messaging, database updates and retrievals involved, to be explicitly captured.

In general, for the conceptual level, *techniques* are available under different paradigms, for the modelling of different aspects of a business domain (see e.g. [OHM$^+$88]). When integrated into well-formed methods, integrated IS specifications - result. A number of paradigms may be discerned for workflow modelling: process-centric, e.g. [DB91]; state-centric, e.g. [DP95]; and actor-centric, e.g. [Die94] (based on the speech-act theory synthesis of [FL80]). Moreover the use of business (or enterprise) models, e.g. as deployed in requirements engineering methods [BB95, LK95, AMP94], in design methods [Ram94] and in CAiSE tools e.g. AD/CYCLE [MMNR90], provides an *organisational embedding* whereby a workflow model's components may be backtracked to its real-world counterparts.

Although, the field of conceptual modelling has become fairly mature, the application of techniques, has, by and large, followed the intuition of the developers of models. This, of course, involves an informal to formal transition. With workflow specifications, this transition is reduced, however a greater alignment is required between the workflow modelling cognition and business processing cognition. Beyond the qualification of fundamental modelling concepts (e.g. process) with organisational attributes (e.g. business service), the business processing semantics need to be infused into the semantics of a technique such that a workflow may be expressed and communicated adequately using that technique. In absence of a universal organisational theory, much uncertainty exists as to how effective conceptual modelling techniques are for business workflows; whether, given the diversity of business processing, any generable prescription of a business processing cognition is in fact possible or desirable.

In general, in one form or another, the requirements which lead to effective conceptual modelling are that: technique should adhere strictly to the conceptual level; should provide a high degree of expressive power; should at the same time facilitate comprehensibility; and should be backed up by a solid formal foundation whereby both the syntax and semantics are clearly defined. Equally importantly, a technique should be suitable for its problem domain, meaning that its concepts and features reflect closely those of the problem domain.

The focus of the paper is on the extension of conceptual workflow modelling techniques for business suitability. Of course, to speak of a general business suitability is vague since there are many types of organisations and many types of business processing [DO85]. Therefore, particular attention is drawn

[1] Refer to http://www.aiai.ed.ac.uk/WfMC/index.html for more details.

to a specific type of (operational) business processing which exhibits precise execution paths. As examples, the processing of insurance claims, bank loans and land conveyancing, are mission-critical in nature and are rarely undertaken without strict operational procedure. Also, multiple interactions with clients and external organisations are typically needed to fulfill service requests.

In [BHPC96], some ground work for developing a more precise notion of business suitability has already been established. In particular, business suitability principles were elicited from an assessment of both classical and business-oriented techniques. The *Organisational Embedding Principle* describes how a model should be backtracked to organisational elements. The *Scenario Validation Principle* identifies the need for scenarios, and in particular, a business transaction, as distinct from business process and business service, for workflow cognition. The *Service Information Hiding Principle* requires that business processing undertaken for business service requests should be insulated from the requests, and in so doing, motivates the need for an explicit treatment of business services within conceptual modelling. The *Cognitive Sufficiency Principle* requires that all concepts involved in workflow model enactment be simultaneously present in the model. Simultaneously absent in the assessed techniques were the combination of structural *and* behavioural aspects of workflows, human to computer interaction and temporal aspects. Finally, the *Execution Resilience Principle* identifies the need for operational error handling to be catered for at the conceptual level, thereby incorporating the recovery management focus of *transactional* workflows into a general exception handling. In this paper, a number of essential modelling concepts and features for business transaction workflows are developed. The approach taken is to develop a a *kernel* technique so that ...

The paper is organised as follows. In section **??**, the problems and suitability principles are defined. In section 3, useful concepts and features are combined, extended along the lines of the principles and applied to a real-world case study. In section 4, the kernel is described formally. Finally in section 5, the paper is concluded and further research issues are identified.

2 A business suitability synthesis

In this section, the main ideas behind Aquino are sketched using the business suitability principles: the Organisational Embedding (section 2.1); Scenario Validation (section 2.2); Service Information Hiding (section 2.3); Cognitive Sufficiency (section 2.4); Execution Resilience (section 2.5).

2.1 Organisational embedding

The *Organisational Embedding Principle* requires that a technique “embed all concepts in a conceptual model, directly or indirectly, but without redundancy, into organisational concepts”. This not only addresses the arbitrary relationship that can exist between conceptual models and their problem domains, but also the situation where specific business world views adopted in techniques, typically enterrpise models, prescribe the essential structure of the conceptual model. The latter is, of course, a violation of the Conceptualisation Principle. Moreover, it precludes the design of an IS process from a network of business processes without first composing an “artificial” business process. This restriction is evident in specification frameworks of integrated modelling techniques, e.g. [Ram94], and CAiSE tools, e.g. AD/CYCLE [MMNR90]. Such a composition at the IS level and not the business level relates to the comprehensibility of a process model, or reflects IS design requirements (of a multi-organisational domain say).

To facilitate organisational embedding, a business processing universe is defined which consists of a set of organisational concepts. (Although not described here) these include: organisational unit, actor and actor roles, service, event, message, process and object type. For a particular area of interest (for IS development), three delineations are imposed over this universe. This is a business scope, a business domain and a business environment. The business scope, is the broadest perspective possible for the area of interest, encompassing both the business domain and the business environment. The business domain is the primary area of interest requiring all the necessary concepts for a detailed description of business processing. A business environment only requires those concepts which describe the business processing interaction with the business domain. For example, the events and their messages, are sufficient for understanding interactions to and from a business domain. Through a consistent perception of a business processing universe, its detailed projection through a business domain and its partial projection through a business environment, a "way of thinking" is also apparent. That is, for an area of interest, the separation of the clients (environment), the server (domain) and the ancillary servers (environment) at the outset, clarifies the modelling detail required.

2.2 Scenario validation

The *Scenario Validation Principle* requires that "a technique should provide an explicit notion of scenario for model validation". Validation is concerned with the interpretation of a conceptual model's domain semantics as distinct from verification which is concerned with formal syntax and semantics. In a general sense, a scenario represents an *effect* in a business domain for some well defined reason, which is expressible using the concepts (of typically more than one partial model). In business processing terms, it is clear that a reason may be associated with an event, and the effect is the resultant triggering of a set processes through which information may be accessed. Furthermore events, possibly invoking processing in the business environment may also result. Ultimately, the occurrence of some final event signifies the (logical) termination of processing; i.e. representing the organisation's recognition that no further processing should proceed.

While scenarios appear synonymous with workflows, there is a subtle distinction. A scenario is a concept which serves interpretation, while a workflow is a concept which serves implementation. Depending on the degree of complexity of a workflow, a scenario may address part, or all of a workflow, and possibly several workflows. In accordance with the *Organisational Embedding Principle*, the notion of a *business transaction*, drawn from a Macroeconomics perspective of organisations [BM91], is proposed as a scenario. Business transactions are accountable units by which an organisation measures its exchange of (goods and) services. Ultimately, this measure is aggregated for a nation's economic metrics [2]. As a subunit of business processing, indeed one which represents a cost closure, a business transaction provides a well-recognised mechanism for workflow model interpretation. The term business transaction will hereafter be preferred over business processing, and the notion *business transaction workflow* will qualify that class of business processing being considered for workflow implementation.

[2] Gross National Product (GNP) and Gross Domestic Product (GDP).

2.3 Service information hiding

A key distinction in business transactions is that between business services and business processes. This is, in fact, a generalisation of the distinction between events and processes. An event, afterall, is associated with some intention, and more than one event may share the same intention. In a business sense, intentions are denoted by business services.

As such, business services are a described (external) organisation of functionality which do not do anything as such, other than being associated with process interactions. This may involve external access such as client requests and responses from outside organisations, or internal access to services in different parts of an organisation. Inherently, they have a set of *states*, e.g. initiated, processing, rejected, and each state is associated with, and dependent on, a particular course of action resulting from a particular event. Business processes on the other hand, are a prescribed (internal) organisation of functionality reflecting the mechanisms by which business services are delivered. Unlike services, they perform concrete actions, (e.g. data transformations, updates and retrievals) and their states are (relatively speaking) dependent on the success of their processing.

The *Service Information Hiding Principle* requires that "a technique should allow the formulation of service requests to be independent of their actual processing". This is to avoid the problem of the *direct* triggering of processes given the context of triggering. From the point of view of the environment or from different parts of an organisation, the actual business processes triggered for some business service request are inconsequential for the formulation of the request. That is, the request is issued for a business service and as a result some internal mechanism is used to determine what action to take. An implication is that when processes are reengineered, the actual request is not affected. This, of course, is an application of the well-known *Information Hiding Principle* in software design.

2.4 Cognitive sufficiency

The *Cognitive Sufficiency Principle* relates the inclusion of all the concepts which "provide a sufficient cognition of a model such that no assumptions about fundamental aspects of business processing *execution* semantics are required". Notable areas of variance in process and workflow modelling techniques are addressed below.

Object and control flows

Although techniques allow either structural or behavioural aspects of processes to be modelled (given their distinctive purposes of analysis), both are required for capturing a business transaction's execution semantics. Structured process models, e.g. a data flow diagram (DFD) [You89], describe object (data) flows, i.e. identifiable *containers* of objects, object stores, i.e. persistent repositories of objects, and object transforming processes. Behavioural process models, e.g. Task Structures [HN93], describe process sequences, repetition, choice, parallelism and synchronisation.

Clearly, behavioural aspects are crucial for the specification of execution semantics. Structural concepts are also important for two reasons. Firstly, object flows are transmitted by triggers related process interactions, i.e. processes and processes, and events and processes. As containers of objects, they should be differentiated from the set of attributes they transmit. For example, a process precondition should make reference to a particular object flow type, when other object flow types have the same set of attribute types as it. Secondly, process specifications would be incomplete without the incorporation of the object transformations and objects stores involved.

HCI

Another area of cognitive insufficiency is the conceptualisation of human to computer interaction (HCI) by techniques. Although traditionally determined at a detailed design stage, HCI *points* and their *dialogues* may be defined in a process model to reduce the *waterfall* between conceptual, design and implementation levels [DMHB90]. Moreover, it is possible to derive them from a business transaction's semantics; e.g. in [Ram94], if a human and computerised actor types involved in an action, that action is refined a method of an external object type (a form). (How do our business transaction semantics extend this idea?).

Temporal aspects

Despite the varying support in techniques, business transactions require temporal specifications for process dependencies, and therefore process pre- and post-conditions. Direct analogues may be found with normal process execution: a process may be required to execute within a time duration of another process (sequence); a process may execute repeatedly within a time duration (repetition); a process may be required to execute either at one time or another (choice); a number of processes may be required to execute simultaneously, at some time (parallelism); or messages from a number of processes may be required within a given time (synchronisation).

2.5 Execution resilience

A more specialised aspect of execution semantics relates to *execution resilience*. That is, errors can occur which affect the normal execution of a business transaction. Of course, error prevention may be defined through database constraints and process pre- and post-conditions while model verification eliminates erroneous specifications. However, *operational* errors can still occur beyond the control of an IS. For example, clients may not abide by business processing rules (borrowers not returning items by their due-dates to a library), or system crashes, may occur.

The *Execution Resilience Principle* requires that "a technique should support the handling of operational errors, so that business processing execution may be verified as being resilient". Although traditional process modelling techniques do not deal with this aspect, a recently proposed workflow modelling technique, e.g. [CCPP95], provides basic mechanisms for exception handling. A more detailed treatment of non-deterministic failures has recently become the subject of workflow implementation specifications. In particular, the database transaction model (more recently described in [GR93]) with its ACID properties (atomicity, consistency, isolation and consistency) has been extended for workflow execution semantics; see survey of transactional workflows issues in [Kim94] (pp. 596-598). Under it, a transaction binds a set of database operations into an atomic unit of execution. Following the requirement of *failure atomicity*, a transaction's changes to a database(s) are *committed* if the execution is successful or *rolled-back* if not. Following the requirement of *execution-atomicity*, the concurrent execution of transactions should have the same effect as if they were executed in a *serialisable* order. Workflows are more complex structures than database transactions, and it is unacceptable that the failure of any one of its processes results in the rollback of the entire workflow.

Like traditional transactions, the notion of *commit* points can be used to define the atomic unit of workflow execution and recovery. The normal place for the occurrence of a commit would be expected to be at the end of a process's execution. However, the atomic unit can be extended to include more than one process. Of course, process objects can be composite in which case the entire superprocess can be regarded as an atomic unit or atomic units can be formed out its decomposed processes.

The broader question of the appropriateness of database transaction rollback for workflow recovery then emerges. For one, workflow processes are more sophisticated than database transactions, e.g. they may involve messaging or they may be human-oriented tasks. Certainly, for a conceptual level specification, it seems to make more sense to describe what the desired action should be rather than having to include its implementation strategy. Clearly, during a crash type of scenario, the desired action is a *redo* of the crashed process. A redos only strategy, as applied in database management system (DBMS) implementations, is associated with a *rollforward* (i.e. a forwards) recovery, aimed at database transaction durability. We therefore propose a rollforward recovery strategy for failures situations. A special type of abort message is dedicated for this, i.e. a failure abort. Additionally, like for distributed transaction management, we recognise the need for *contingencies*. Contengencies are run when transactions fail to start, for whatever reason. Similarly, we adopt contingent processes in workflows with a basic extension which allows a range of contingencies for given numbers of failure. This enhances the robustness of contingency, and allows for the *forcibility* of a process (i.e. having an. As in distributed transaction management, this means that the process should succeed eventually.

We contend that a *rollforward* recovery strategy be adopted when workflows are aborted as a result of application-generated errors. We have introduced another type of abort message to convey this, i.e. a non-failure abort. Following advanced transactions models [AA90] which allow *nested* transactions, we adopt *compensations*. Compensations are an "undo" mechanism since subtransactions commit and release their resources prior to the parent transaction reaching a commit state. If the parent transaction is aborted, unwanted committed data will exist in a database. We appropriate such a strategy for workflow rollback recovery since the rollback can be applied over committed processes. Examples of compensations in a workflow could include: the logical-reverse of an update, i.e. an idempotent update; sending abort messages to remote services for notification; triggering transitions to erroroneous service states.

3 Business transaction modelling: a practical perspective

Having described its main ideas, the detailed modelling concepts and features of Aquino are illustrated through examples of a real-world business transaction example. This is based on *road closures* undertaken by the Queensland State Government's Department of Natural Resources. The full case study is described in [BH96]. This case study provides the complementary empirical insight into An overview of road closures is described in section **??** while the business scope is described in section **??**. The application of Aquino's three fundamental models, the *object*, *process* and *service* models, are described in section 3.2. section 3.3 and section 3.4 respectively.

3.1 Background

As a consequence of the Westminster System used in Australia, the government administration of land falls under a number of statutes (or legislative acts) which involve a number of statutory authorities. In Queensland, the State Government's Department of Natural Resources under the Lands Act[3] is commissioned to grant *tenure* for unallocated state land and reserved land. In a broad sense, this includes: the granting of ownership through freehold titles; the granting of custodianship for some purpose through leasehold titles - leases; the establishment of reserves for national parks and wildlife etc.; and the dedication of roads (which by definition in the Land Act implies public use). These apply to *parcels* of land which are composed of one or more elementary allotments, or *lots*.

In order to grant tenure, the Department of Natural Resources obtains the views of the relevant stakeholders - statutory authorities, affected landholders and affected associations in the community - in order to determine whether proposed and potential use of the parcel affects the surrounding area's current and future land use and the current legislation. The statutory authorities include local governments, electricity power suppliers, telecommunications carriers and environment and heritage regulation authorities.

The process of determining whether tenure should be granted is complex taking from days up to months. During this period, repeated checks are required to ensure that the appropriate requirements are satisfied. These are needed since different actions constantly occur on related aspects of land. For example, during the process of investigating whether a mining lease should be granted, an overlapping part of the land may become heritage-protected while another overlapping part may be needed for a railway corridor. Clearly, the three tenures may result in incompatible land use. Furthermore, repeated interaction with the different stakeholders may be necessary to resolve unsatisfied requirements. During this period also, business processes may change due to changes in legislation as well as in organisational restructures. In short, an effective coordination of processing requires: the integrity of tenure grants to be preserved; insulation from business process change; a minimisation of customer interaction.

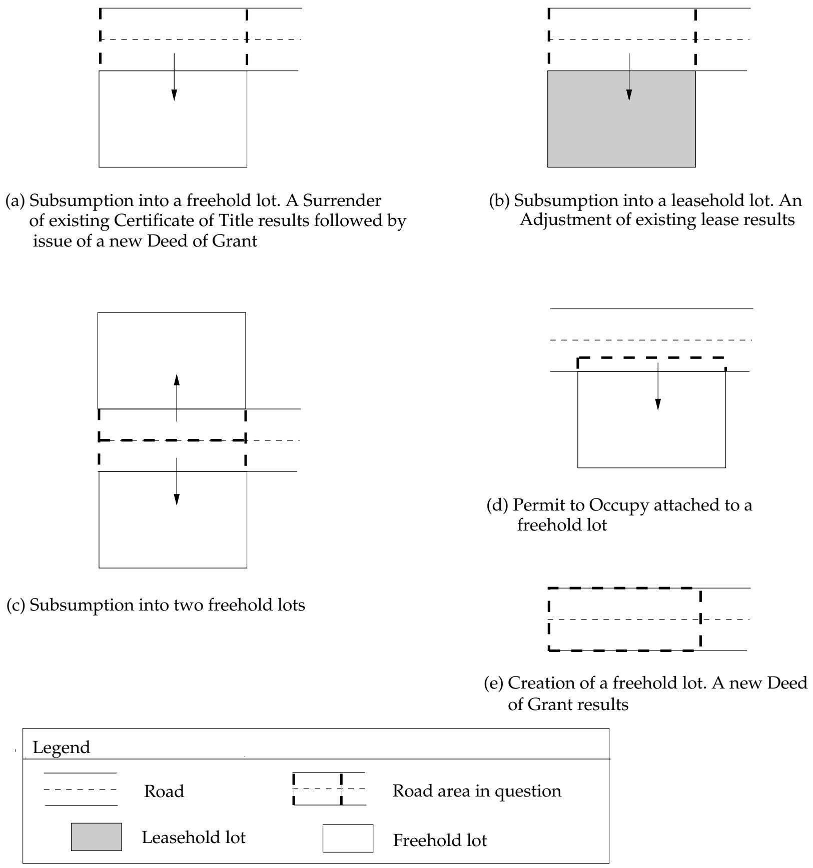
The closure of roads is a particular instance of tenure allocation. Under the Lands Act, the Minister for Lands approves road closures. This responsibility may be delegated to specific persons. Apart from the legal reasons, the approval (and for that matter the disapproval) of road closures carries important ramifications. For one, the general public have certain rights and expectations to roads. A road should not be closed for reasons which include the current or potential blockage of dedicated access to another parcel(s), the compromise of the transportation network, environmental degradation (e.g. some roads form important corridors and refuges for flora and fauna) and the existence of Native Title[4]. Figure 1 contains different examples of road closures.

A road may be closed permanently or temporarily. If permanent, it may be subsumed into one or more adjoining parcels as depicted in (a), (b) and (c). A subsumption into a freehold tenured parcel (a) involves a *Surrender* of the existing title, i.e. a *Certificate of Title*, and the issuing of a new title, i.e. a *Deed of Grant*[5] over the "new" parcel. A subsumption into a leasehold tenured parcel (b) involves an *Adjustment* of the existing lease. For temporary closures, a *Road License* (not illustrated) or a *Permit*

[3] Lands Act 1994; i.e. last issued in 1994.

[4] Under the Native Titles Act (Queensland) 1993, ammended in 1994, parcels without any allocated tenure are deemed to have Native Title, i.e. their use is determined by the Aboriginal people of Australia.

[5] A Deed of Grant is a title which signifies the first tenure of a parcel.



(a) Subsumption into a freehold lot. A Surrender of existing Certificate of Title results followed by issue of a new Deed of Grant

(b) Subsumption into a leasehold lot. An Adjustment of existing lease results

(c) Subsumption into two freehold lots

(d) Permit to Occupy attached to a freehold lot

(e) Creation of a freehold lot. A new Deed of Grant results

Figure 1: Road closure examples

to Occupy (d), may be issued over an area, where the State retains the right to re-dedicate the area at any subsequent time. In the case of a Permit to Occupy, the road does not lose its status and the public's access cannot be impeded completely, e.g. a side walk cafe. Roads may be created into parcels without subsumption (e), in which case a Deed of Grant is issued. A complex road closure example (not illustrated) occurs during the development of new estates where a developer wishes to restructure a grid-like parcel arrangement into one which has a more irregular arrangement, typically with cul-de-sacs. This attracts more buyers. For this, the existing roads first need to be closed and the surrendered land needs to subsumed into the existing parcels. This is provided through the Road Closures business transaction. The newly designed road then needs to be opened, through another business transaction.

3.2 Object Modelling

The object (data) modelling technique of Aquino is based on the Conceptual Data Modelling Kernel (CDM) [CP96]. It extends the Object-Role Model (ORM) kernel [BBMP95] to not only allow modelling of ORM schemas, Entity-Relationship and (structural) Object-Oriented schemas. Its applicability is therefore fairly wide. It achieves this through the provision of a generic mechanism for *abstraction*. In particular, set of object types can be clustered together to form abstractions for different structural constructs, e.g. specialisation heirarchies and aggregation.

The highest level object model for the road closures business domain is depicted in Figure 2. The three object types, Application, Parcel and Tenure, are of schema abstractions. These further decompose into object models.

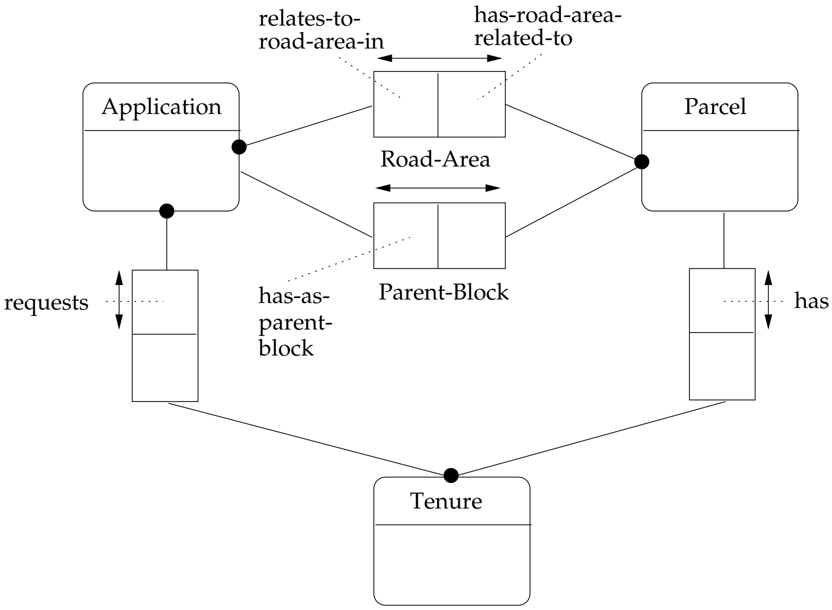


Figure 2: A highest level object model

An Application plays a role, relates-to-road-area-in, with a Parcel through a binary relationship (a split rectangle with each box representing a role). The converse role has-road-area-related-to is also depicted. A uniqueness constraint (a double headed arrow over both roles) indicates that this relationship is many-to-many while a mandatory role (a black dot) indicates that the corresponding role must be played. In other words, each Application must have at least one road area. A parent block may also pertain to an Application. Road areas and parent blocks have the same classification, namely Parcel. The junction of roles on the mandatory role constraint of Parcel indicates that it inclusively plays one role or the other. Road Area and Parent Block denote fact types; i.e. the object types and the relationship types involved. This allows fact instances as a whole to be referred to. Fact type names will not be further depicted. A Parcel (typically) has Tenure while an Application requests a Tenure. Both relationships involve a one-to-many uniqueness constraint (a double headed arrow over one role only).

None of the decompositions other than that for Application in Figure 3 are shown. At the top, the reference type is indicated in parentheses, namely System File Reference. It represents the way in which each Application is identified. YY/NN is the format for the reference, in this case, denoting a year followed a two digit number. Each Application has-as-applicant a Party (i.e. a generic for a person or an organisation). An Application also is-of a type, A-Type, should-have-views-sought-from a set of Stakeholders (a double lined object type indicates its occurrence elsewhere), has-documents-stored-in a File, has dates when it was written-on, received-on, lodged-on, rejected-on, gazetted-on and has-road-inspected-on, and an indication of whether the department is to seek views from the Stakeholders, described through the unary role dept-to-seek-views. The lines without roles attached to Date's mandatory role constraint indicates that all roles (including those not relevant in this schema) played involve mandatory inclusive disjunction.

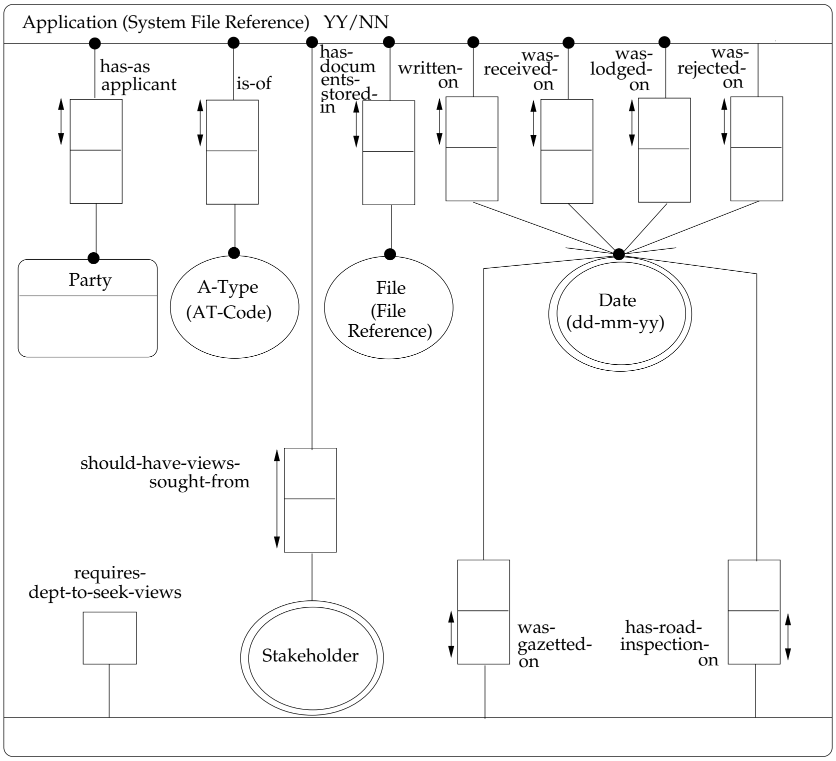


Figure 3: An object type decomposition

3.3 Process Modelling

The Aquino process modelling technique extends Hydra's transaction modelling [Hof93] which incorporates Task Structures and LISA-D, to include structured process modelling (e.g. DFD) concepts, messaging similar to [HH96], complex decisions, temporal aspects and operational error handling.

The processing of road closures commences with the arrival of a letter of application and relevant documents, i.e. Application Documents, at a Service Centre. The Application Lodgement depicted in Figure 4, is the first of the three high-level business processes to be executed. In it, an Application File, formed to contain the documents, is sent to the relevant Regional Office where it is filed away in the Application Files by Store Application. An actor role, Service officer, is indicated for the Application Entry. The convention we have adopted is that an actor role applies to the indicated process object (a process or a decision) and the process objects which are triggered subsequently, until another actor role is indicated.

The process model resembles, in part, a Hydra task Structure. Processes (boxes) including an initially executed process (denoted by the bent arrow), together with execution triggering (arrows between processes) are shown. Through the depictions of Application Documents and Application File, it can be seen that we have introduced messages. Both are hard-copy messages. Application Documents has been depicted to arrive asynchronously (a small arrow embedded in a process). This means the the

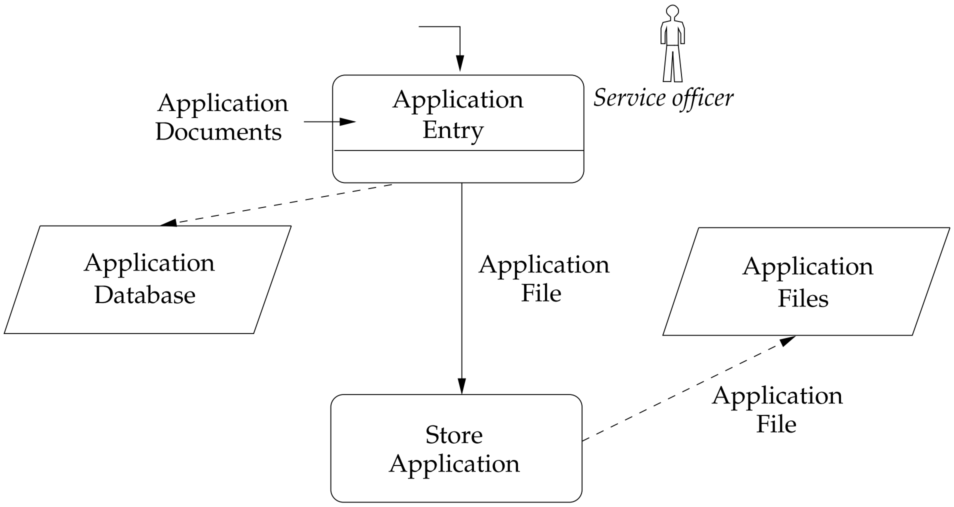


Figure 4: An example of structural processing extensions for a behavioural process model

receipt (sending) of the message does not suspend any processing. (In section 3.4, we will describe the orthogonal issue of how the arrival of a message - as an event - triggers the execution of a process). The messaging mode of Application Files from Application Entry to Store Application is also asynchronous. We have adopted this variation of notation for intra-model messaging between processes.

In general, the semantics of messaging do not follow those of triggering. In business transaction processing, afterall, messages are not "aimed" directly at processes but at containers, e.g. an in-tray or a mail-box. The retrieval (sending) of messages from (to) containers is described in the process specification. To provide a treatement of *transient* storage , we have extended the interaction of Hydra buffers. In Hydra, buffers permit a FIFO (first-in first-out) queuing protocol. In Aquino, this has been generalised for any such protocol: LIFO (last-in first-out), random or any predicate specifiable order. An equivalent representation for Figure 4 which makes message buffering explicit is depicted in Figure 5. This representation is more preferable when the buffers add to the comprehensive value to the model. Notice, the name of a message need not be repeated throughout a process model. Naming on its initial occurrences (through messaging or creation in a process) and final occurrences (through messaging or storage) is sufficient. In this case, the initial occurrence of Application File is created by a process while the final occurrence involves storage. Application Documents also occurs through inbound messaging but its final occurrence is not apparent, since it is contained in Application Files.

Included in process specifications are pre- and post-conditions and component actions for database access. A major benefit of using *tightly-coupled* integrated techniques such as Hydra lies in the increased expressiveness available for their conceptual specification languages. In general, such expressiveness is necessary to capture more fully process semantics. As a basic example, consider the following LISA-D formulation for capturing details of an Application:

```
ADD Application: Current-App has System File Reference: Current-File-Ref
ADD Application: Current-App has-as-applicant PartyWITH Name = Current-Applicant
. . .
ADD Application: Current-App lodged-on Date: $Today
```

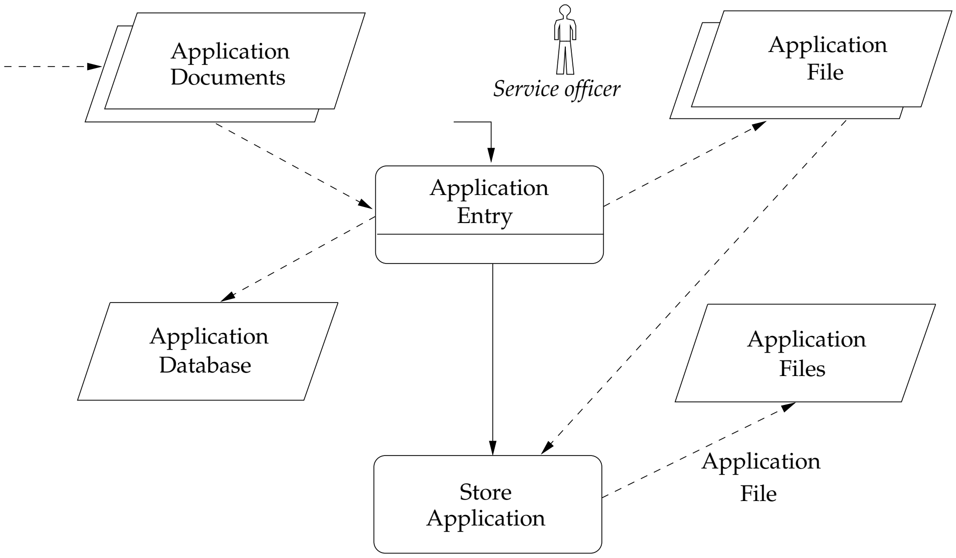


Figure 5: An example of explicit message buffering

The schema assigment of Application to the Application Database makes this possible. Of course, the variables Current-App, Current-File-Ref etc., permit temporary storage during the data entry. For the data entry, HCI points have been introduced (slots on the lower part of process symbols). The description of the form/screen of the application being used, may be contained in this slot. The (actual) names have been omitted from the discussion (much like a CAiSE tool where certain textual details in a model may be "clicked" on and off). Of course, object schemas are required to be assigned to HCI points and messages. Like databases, they are storage entities and so require an information grammar.

A more complicated process model is depicted in Figure 6 for Application Investigation. In brief, it consists of a number of internal checks to determine whether the Application is valid, a Preparation for a more detailed investigation, Seek Views and Process Views of the Stakeholders as a part of the detailed investigation, and a Site Inspection as another part. A decision is then made to Approve (an) offer which if negative, results in either a rejection or request for further information/action through Suspend Processing, or if positive results in a preparation to make the offer through Effect Offer Approval. In the description that follows, only Initial Review Passed?, Preparation and Seek Views are further elaborated on.

The example of the internal checks presents the need for an extension to decision handling in traditional modelling. Under Hydra Task Structures for example, decisions yield either a positive or negative outcome, given their rules. Moreover an outcome can terminate execution, returning control to the supertask. It is evident through this part of road closures, as depicted in Figure 7, that decisions in real-world business transactions may be based on sub-decisions. In this example, the *complex* decision is refined into *simple* decisions, each of which is executed in parallel, with an implied synchronisation of their outcomes.

It is possible to build up powerful complex decisions as depicted in Figure 8. This is an example of a decision network consisting of simple and possibly further complex decisions with execution triggers (i.e. dependencies) between them. Unlike the example of Figure 6, not all decisions need be evaluated as also seems evident in decision-making of real-world business transactions, among others. For this,

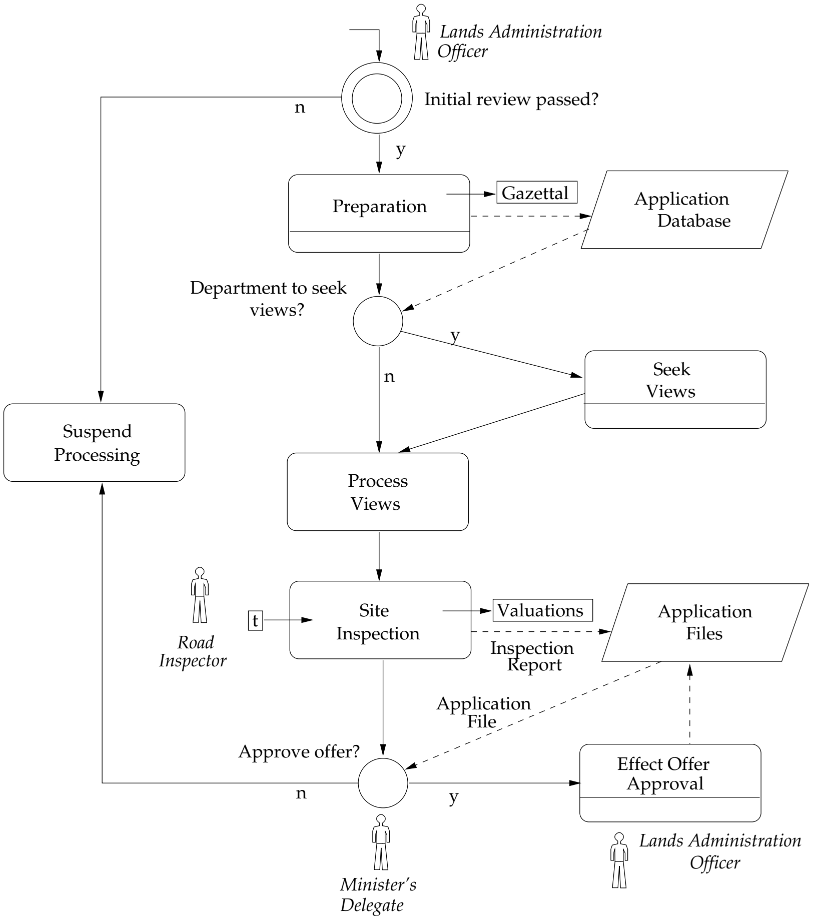


Figure 6: An example of further process modelling extensions

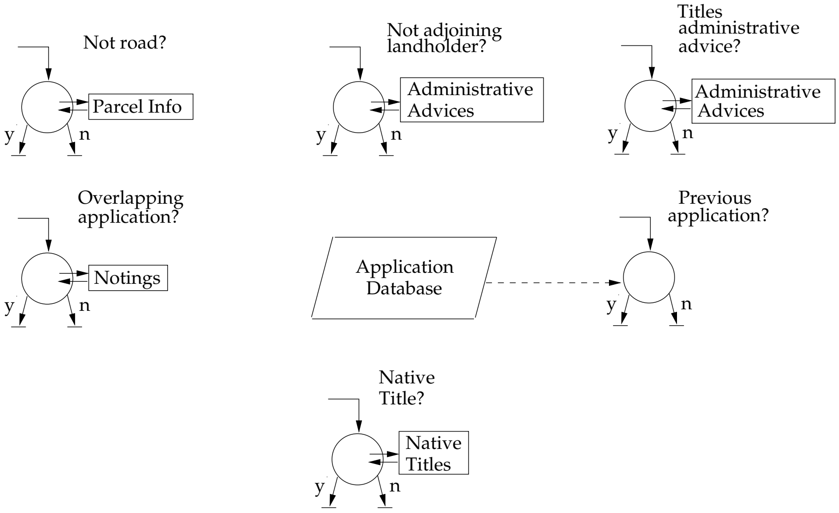


Figure 7: An example of a complex decision

we propose terminating *aborts* for decision outcomes which when executed terminate complex decision processing. Decisions D and E have these. Furthermore, note the differences in decision dependency. D is triggered by an outcome of A, while E is triggered by outcomes of B or C (and therefore may be invoked twice). On the other hand, outcomes from both A and B are required for F. The Task Structures synchroniser construct (triangle) caters for this.

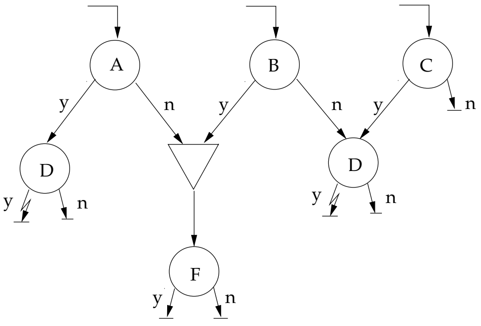


Figure 8: An example of a decision network based on a complex decision

A further extension to decision processing is the accommodation of messaging. In Figure 7, most decisions require data from messages for the decision rules. Also the messaging of "remote" services (boxes attached to the messaging arrows) is illustrated. Unlike the previously discussed form of messaging which was *asynchronous*, the depicted messages are *synchronous*. That is, a message is sent out and an incoming message is anticipated (hence two embedded arrows). From the time that the message is sent out to the time that the message is received, no execution proceeds. Again through LISA-D, we illustrate how highly expressive conceptual specification languages allow quite sophisticated decision rules to be formulated. In general, LISA-D expressions are built from *paths* between object type names and role names. The following decision rule pertains to the positive outcome of Previous Application? (assuming a two year threshold):

```
LET previous-app BE Application(has-as-parent-block Parcel CONTAINING Lot
                                elementary-surveyed-unit-of Parcel
                                has-road-area-related-to Current-App
                                AND ALSO
                                received-on Date < Date marks-receipt-of Current-App
                                AND ALSO
                                 received-on Date ≥ Date marks-receipt-of Current-App − 2 years)
```

Like a simple decision, the result of a complex decision is either a positive or negative outcome. In this example, a negative outcome results in the execution of Suspend Processing which is depicted in Figure 9. In brief, it either results in a rejection of the Application or a request for further information, both of which result in the appropriate outgoing notifications sent to the Interested Stakeholders. Rejecting an Application not only means updating the state of object, but ultimately terminating the workflow associated with the Application instance. In section section 3.5, the subject of our treatement of the *Execution Resilience Principle*, we discuss how this type of operational error and other types, are handled. An interesting feature of this example is the use of *recursive* decomposition, i.e. Suspend Processing invokes itself. Unlike a pure structured decomposition as adopted in structured process modeling techniques (e.g. Data Flow Diagrams), the control-flow nature of this technique permits this.

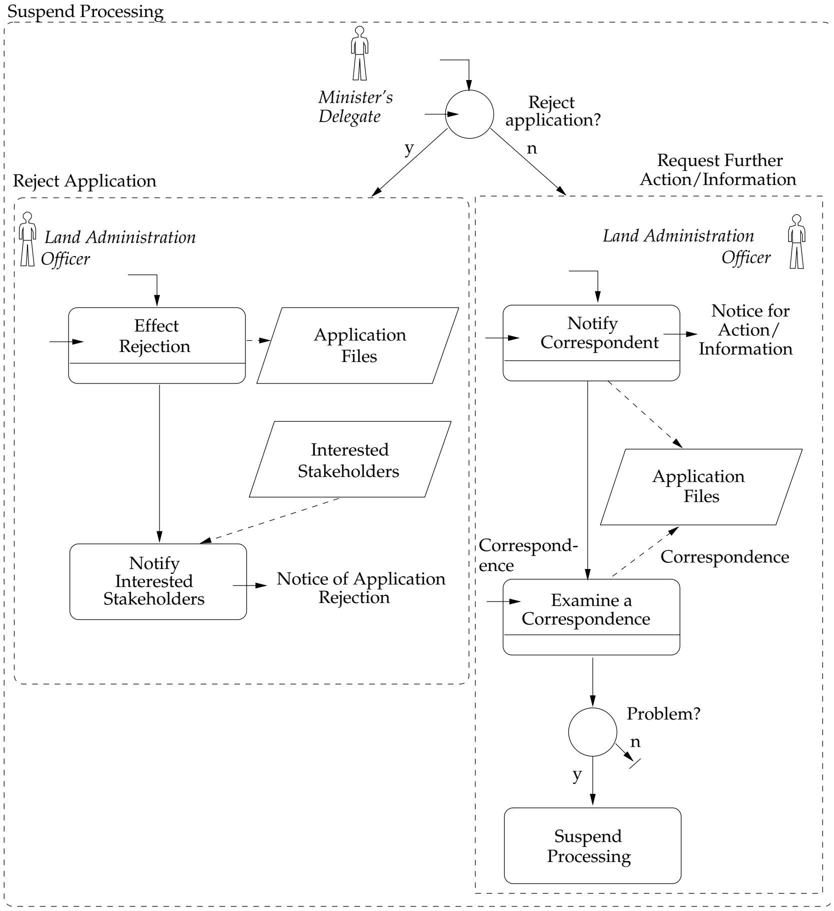


Figure 9: An example of recursive decomposition

Returning to Initial review passed? in Figure 6, its positive outcome results in the Preparation for a detailed investigation of the Application. This involves publication of the road closure intention in the Government Gazette; done through the Gazettal service (external to the department). The department seeks the views of stakeholders if it is required to do so. This is done through Seek Views, depicted in Figure **??**. First the Candidate Stakeholders need to be determined. These are obtained through Parcel Info (an external service which accesses a cadastral database identifying the surrounding parcels, utilities etc.). Then the contents of the message needs to be inserted into the Candidate Stakeholders object store. As an alternative to performing this through a HCI, as would ordinarily be the case, it is possible to automate the message transfer. This requires that the target object store schema and the source message schema both be compatible. The message's schema is illustrated in Figure 10.

Using the fact type denotations, Contact and Location, both of which also apply for the Candidate Stakeholders object store, the following LISA-D statement illustrates the automatic message transfer:

ADD Contact **IN** Candidate Stakeholders **TO** Contact
ADD Location **IN** Candidate Stakeholders **TO** Location

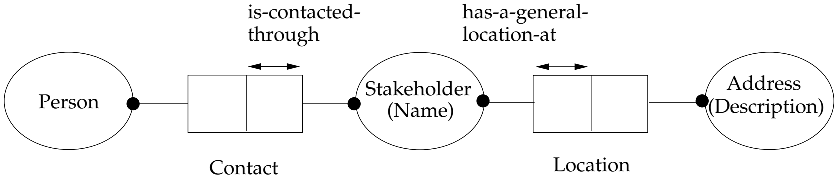


Figure 10: Schema associated with the Candidate Stakeholders message

A Notice of Road Closure is then sent to each Stakeholder, illustrating how *bulk* messaging (the analogue of bulk database updates) can be incorporated in LISA-D:

SEND Notice of the Road Closure **TO EACH** Person is-contact-for Stakeholder s
AT Address is-contact-for Stakeholder s

Now the sending of the messages is required to occur no later than one day after the date of gazettal. This illustrates the need for a *temporal constraint* in the postcondition in Seek Views:

END-DATE(Seek Views) $\leq$ Date is-gazetted-date-of Application Curr-Application $+ 1$

As an example of a temporal constraint on preconditions, a Site Inspection is not allowed to occur more than prior to two months before the intention for road closure has been "gazetted":

START-DATE(Road Inspection) $\geq$ Date is-gazetted-date-of Application Current-App $+ 2$ months

START-DATE and **END-DATE** indicate the need for temporal functions which provide the start and end dates (times) of process object execution. This implies that certain execution statistics about process objects should be maintained. This allows time durations to also be used within constraints, for example, for "timeouts". Also process execution dependency can further be qualified through temporal constraints. For example: run a number of processes at some time, simultaneously (parallelism); or within a time duration of each other (sequence); run a process repeatedly within a certain time period or cyclically at time points (repetition). Such constraints can apply to messaging as well, e.g. contingent service access for process objects if messages have not returned within certain times.

3.4 Service Model

So far features of Aquino's object and process modelling techniques have been presented. In this section, the last and most pivotal of the models, the service model is described. The service modelling technique of Aquino is entirely a new proposal. It allows business services to be explicitly modelled such that, in accordance with the *Service Information Hiding Principle*, service requests are insulated from the resultant business processing. Recall (from section 2.3) that the key determinant of what business processing is required for a given service request, is the state of the service. In turn, a particular service state is dependent on the success of the elapsed business processing. Of course, the states of a service should describe the *lifecycle* of a service in a way which is meaningful to its stakeholders, and should not be used as a business processing "log".

It can be seen that a convenient way to model a service is an object. Objects, afterall, encapsulate processes, and their behaviour is described through a lifecycle of states and state transitions (see e.g. [RBP$^+$91, SM88]). That is, for a given state, an object reacts to a set of events through the activation of actions, possibly if certain conditions are satisfied. Applied to business services, service requests are specified as events while the actions represent business processes. In general, events represent occurrences which signify changes of state in the business scope. Examples of events include the receipt of a message, changes in time and the termination of process/decision and the occurrence of an abort. A business service's state-dependent reaction to an event includes the triggering of a process model object. Process model objects, of course, trigger other such objects, produce messages or effect updates and retrievals from object stores. As the workflow progresses, different events are raised, and again, the service object may react to these, further propagating processing.

It can be seen that in Aquino, the *state-centric* modelling cognition of the service model complements the *process-centric* modelling cognition of the process-model. This, in effect, represents a declaritive versus imperative appropriation in specifications to effectively capture business processing semantics. That is to say, the higher levels of business processing are described declaritively through service models wheras at lower levels are decribed (more) imperatively through process models. The exclusive adoption of one dynamic modelling paradigm is considered unsuitable. A complete state-centricity leads to complete object-orientation which has the disadvantage of turning each process model object into an "island" specification. On the other hand, a complete process-centricity would result in complex business service specifications, given the permutations of exceptions of process invocations for the different events.

The service model for the road closures business transaction is depicted in Figure 11. The service model consists of: normal states (large polygons), e.g. Lodged, Initial review passed and Application rejected; special states indicating the "birth" of a service (small unshaded polygon) and the "death" of a service (small black-shaded polygon); and state transitions (arcs). The special states allow transitions to the first possible state(s) (Lodged) and last possible state(s) (Application rejected and Title issued) to be specified within the same service context (otherwise some global service would be required to undertake these). Of course, this issue relates to the suitability and comprehensibility rather than the expressive power of the technique.

The event-condition-action (ECA) paradigm which has been adopted for active rule specification in database systems, e.g. [CN90], and conceptual specification languages, e.g. [LMS$^+$91], is adapted for event specifications. These, of course, are attached to the service object state transitions.

The first event is the arrival of the message Application Documents. This is an example of a *messaging event*. It is distinguished from an actual external event e.g. the signing of a contract for an estate development. In general, the inclusion of such external events do not seem necessary for workflow specifications, although they could be captured through an event dependency formalism separate to the workflow specification. This first event leads to the service object (instance) creation in the "birth state". Upon this creation, it sends the message to Application Entry thereby triggering the workflow described in Figure 4:

> **WHEN** Application Documents **RECEIVED**
> **THEN SEND** Application Documents **TO PROCESS** Application Lodgement

The transition to the Lodged state occurs when the Application object is first entered into the Application Database (2) - an example of a *database state event*. The expression is formulated using LISA-D

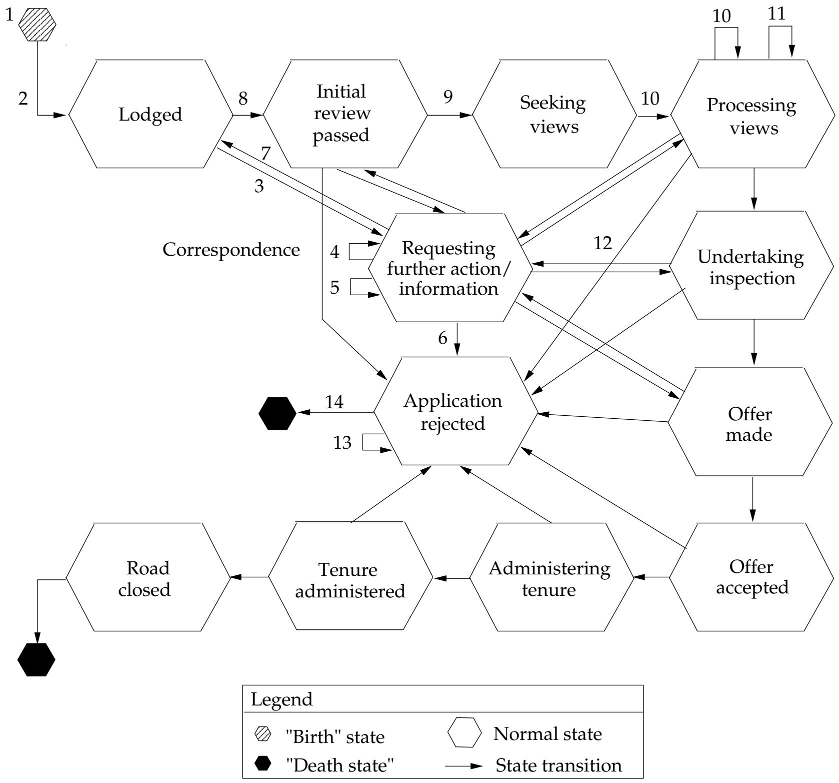


Figure 11: Service Model for Road Closures

demonstrating how conceptual data specification languages can be used by ECA languages. The predicate, in this case, is an arbitrary fact type with a mandatory role since this will evaluate to “true” after the Application is stored in the database. No **THEN** part follows since the workflow execution still continues (without the need for invoking further processing). This further illustrates the importance of service states capturing the required perceptions of service stakeholders, independent of the underlying workflow execution:

WHEN Application received-on Date

A problem may be found in the Application (this relates to the internal checks done as part of the decision Initial review passed? described in Figure 7). In this case, a Request Further Action/ Information may executed. Its issue of a Notice of Further Action/Information message - a messaging event but this time outgoing - is detected by the service object for the next state transition (3):

WHEN Notice for Further Action/Information **SENT**

The subsequent Correspondence, like all incoming messages from the environment, is sent to the service object, and so the service object further activates processing. The Correspondence should be examined, and so no state change results (4):

WHEN Correspondence **RECEIVED**
THEN SEND Correspondence **TO PROCESS** Examine a Correspondence

Although not included in the process model description, Correspondence may not be satisfactory in which case the Suspend Processing may be reinvoked with the Minister's Delegate's decision to Reject Application? - a *processing event* involving negative decision termination:

WHEN DECISION Reject Application? **REJECTED**

or a positive decision termination resulting in the transition to the Application rejected state (6):

WHEN DECISION Reject Application? **ACCEPTED**

The above ECA rules provide some indication of the types of events which a service can react to. In the full case study, the need for the following further events types was identified, e.g. when: process objects commence execution; process objects fail to commence execution over a range of times; terminating aborts occur. Also for temporal constraints, we have identified the need for the **START-DATE** and **START-TIME** of service states, the **SENT-DATE**, **SENT-TIME**, **RECEIVED-DATE** and **RECEIVED-TIME** of messages. (Recall the **START-DATE**, **START-TIME**, **END-DATE** and **END-TIME** of processes are also required to be known). Nevertheless, we recognise that the expressive completeness and suitability of service ECA language are an open issue.

3.5 Exception modelling

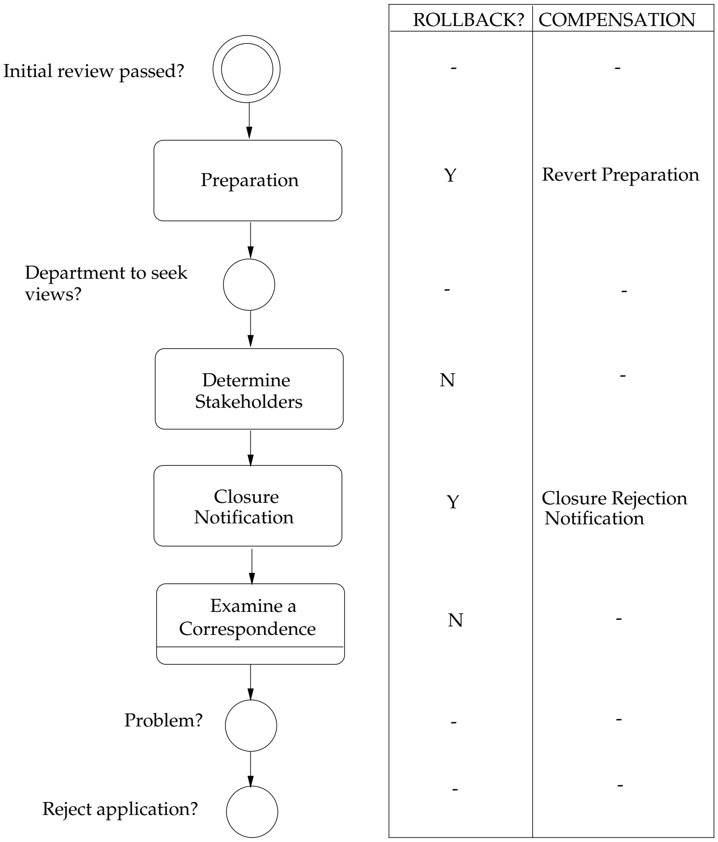
In Figure 12, an example of a rollback recovery is depicted for road closures. In it, the workflow has progressed to the point where an abort has been raised to reject the Application during *Process Views*. The elapsed workflow includes the initial investigation and the preparation, the seeking of views and the processing of one incoming and problematic view (e.g. a stakeholder's rejection of the application is not reconcilable). A rollback therefore has to occur. The rollback specification of each process object is presented in the table. It indicates whether a rollback is required, and if so whether a particular compensation applies.

From the table, it appears that decisions do not require rollbacks. This seems intuitively acceptable since decisions are simple processes. In a complex decision having a terminating abort, other decisions are merely terminated. Also, of course, when no rollback is to be performed, no compensation applies. However, when a rollback is required, a compensation may apply (when the process is not in the current commit grain and therefore when an undo cannot be performed). In this example, the rollback strategy is running Closure Rejection Notification involving messaging containing corrective information and Revert Preparation involving an idempotent database update. This illustrates how error handling can be localised into process objects as opposed to the traditional approach which centralises error handling into a single routine; clearly a gain in comprehensibility and suitability.

The modelling of rollforward recovery is not discussed.

4 An integrated conceptual modelling kernel

Following the motivation and illustration of Aquino's modelling concepts and techniques, its definition including a formal syntax is now provided. In Section 4.1, the main concepts are described and placed



	ROLLBACK?	COMPENSATION
Initial review passed?	-	-
Preparation	Y	Revert Preparation
Department to seek views?	-	-
Determine Stakeholders	N	-
Closure Notification	Y	Closure Rejection Notification
Examine a Correspondence	N	-
Problem?	-	-
Reject application?	-	-

Figure 12: Rollback recovery example for road closures

into the context of the business scope. The process modelling technique is described in section 4.2 while the service modelling technique is described in section 4.3. The object modelling technique has not been changed from that described in [CP96], and so no definition is provided here. Axioms for inter-model consistency are not provided, nor is a definition of the formal semantics. Both are the subject of future research.

4.1 Business Scope

In its broadest sense, Aquino provides a set of kernel techniques which allow the domains of business transaction workflows to be modelled in an integrated fashion. The techniques involve object, process and service modelling. The notion of *kernel* means that the techniques are not necessarily concrete techniques, although they may be applied as such. Rather they provide a set of *abstract* concepts and features from which concrete techniques may be specialised and further developed.

At the outset, we consider it important to establish the various *scopes* from which the concepts belong. This serves to discern a technique's highest level of perception of a domain; an important factor during the initial phases of analysis. In other words, the basis for *organisational embedding* should be clear. For Aquino, the highest possible scope is a business scope. It is partitioned into a business domain, which is the focus of the modelling, and the business environment, which is required so that the business domain's external interaction may be modelled. A business scope is, in itself, a concept, aggregrating all other concepts. It exists within an absolute scope - a universal space say - which may contain other types of scopes. The set of concepts which are relevant to Aquino, are not only bounded "vertically" by a business scope and all the possible concepts relevant to a business scope, but also "horizontally" to type of phenonemon of relvance. This, of course, is that type processing which we have characterised as operational business transaction workflows. As depicted in Figure 13, the intersection of this "vertical" and "horizontal" universal space represents the set $\mathcal{CP}$ of concepts relevant to Aquino.

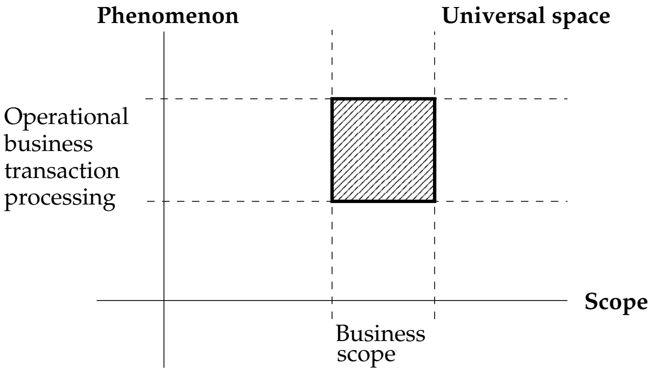


Figure 13: Framing Aquino's concepts within universal space

The concepts that we begin with are those which assist in Aquino's organisational embedding. In other words, these concepts are enterprise (or business) concepts which may be refined into further concepts within the specific technqiues. As an example, the enterprise concept process is refined into process, decision and synchroniser in the processing modelling technique. At the same time, it should be understood that there is no fundamental difference in the concepts used for the enterprise and detailed IS modelling, as in, for example, [Ram94]. Rather we follow an observation made by the FRISCO Group [FHL$^+$98], that ISs are organisational (sub)systems, and so the conceptual basis for IS modelling is also relevant for organisational (sub)systems; and an IS implementation platform, workflows reduce the traditional gaps of their respective cognitions.

A convenient mechanism for determining the set of concepts which belong in a business scope, a business domain and a business environment, is the set of organisational units $\mathcal{OU} \subseteq \mathcal{CP}$. This is because organisational units are the means by which processing and storage entities are dispersed within an organisation. This is defined through the relation $\mathsf{Structure} \subseteq \mathcal{OU} \times \mathcal{CP}$. An organisational hierarchy is structured as a rooted directed acyclic graph of organisational units where the "top" of each graph is an organisation. The relation $\mathsf{SubOf} \subseteq \mathcal{OU} \times \mathcal{OU}$ allows parts of a number of organisations to be pertinent for a workflow, and so represents a "forest". As scopes over the "forest", a business scope $\mathcal{BS}$, a business domain $\mathcal{BD}$ and a business environment $\mathcal{BE}$ are all subsets of business concepts. This is depicted in Figure **??**.

The degree of workflow modelling in a business domain is whole while that in the business environment is only partial. This is alluded to by the *Service Information Hiding Principle* which aims to encapsulate workflow specifications where possible. Of course, some concepts may be used in both the business domain and the business environment. For this, a concept qualified as *internal* means that it exists in the business domain while that qualified as *external* means that it exists in the business environment.

The remaining types of concepts are:

1. A set $\mathcal{AC}$ of actors. An actor is instrumental in undertaking business transactions. Actors, as such, do not undertake the processing, but (as described below) do so in roles. Only internal actors are of relevance[6]..

2. A set $\mathcal{RL}$ of roles. A role is a particular functional charter required for one or more business transactions. Actors are assigned to roles. This is given through the relation $\mathsf{Assign} \subseteq \mathcal{AC} \times \mathcal{RL}$). As with actors, the only roles of relevance are the internal ones.

3. A set $\mathcal{PR}$ of processes. Processes are *prescriptive* units of functionality which allow business transaction processing, among others, to be described. Typically, processes involve human(manual) actions, computerisable actions such as reading, writing and updating data and undertaking dialogues whether human or computerised. As directly apparent from the *Service Information Hiding Principle*, the only processes of relevance are the internal ones.

   Actor roles are required for to undertake processes. This is described by the relation $\mathsf{Undertake} \subseteq \mathcal{RL} \times \mathcal{PR}$). Moreover, actors should only be allocated to roles required by processes which are in organisational units that the actors are assigned to. This is defined using the following axiom, noting that $\circ$ represents a relation composition:

   $$\mathsf{Assign} \circ \mathsf{Undertake} \circ \mathsf{Structure} \subseteq \mathsf{Structure}$$

4. A set $\mathcal{SV}$ of services. Services are *descriptive* units of functionality which allow business transaction processing, among others, to be described. In fact, a service represents a mechanism by which business transactions are accessed, without, as described by the *Service Information Hiding Principle*, knowledge of how the business transactions are undertaken. It follows that both internal and external services are of relevance.

5. A set $\mathcal{OB}$ of object types. Object types are either informational or material. An informational object, e.g.$\mathsf{Application}$ is abstract having static (but not behavioural) properties. A material object, e.g. $\mathsf{Application\ Files}$, is tangible having no further properties of interest. The only object types of relevance are the internal ones.

   Although we have not provided the definition of Aquino's object modelling technique, it goes without saying that an object belongs to a schema definition(s). This is given by the function $\mathsf{Schema}\colon \mathcal{OB} \rightarrow \wp^{+}(\mathcal{SCH})$, where $\mathcal{SCH}$ is the set of schema names.

6. A set $\mathcal{OS}$ of object stores. Object stores provide a persistant, structured storage for objects. Of course, they may store material object types, e.g. a car pool, or informational object types, e.g. a paper general ledger or a database, but not both. Some object stores are distributed e.g. distributed databases, and so may reside in a number of fragments. This is given by the partial function $\mathsf{Fragment}\colon \mathcal{OS} \rightarrowtail \mathcal{FG}$ where $\mathcal{FG}$ is the name of the fragment.

   The only object stores of relevance are the internal ones. Note, the fragments of a distributed database which lie outside the boundary of an organisation, are considered to still be part of a business domain. This is because a distributed database is a single logical entity. This is not true of a federation of databases accessed by a given process. Any database in the set may be autonomous and may reside outside the business domain. Access to any such external database should occur through services.

[6] This is philosophical rather than fundamental. For example, this view would be not be acceptable for techniques adopting actor-centric paradigms

7. A set $\mathcal{ME}$ of message types. Messages are used to transfer data during processing. They may contain structured data (objects) or unstructured data. Both internal and external messages of relevance; the relevance of external messages follows that of external services.

8. A set $\mathcal{MB}$ of message buffers. Message buffers provide a transient, unstructured storage of messages, e.g. an in-tray, an electronic mail box or a set of "pigeon holes". Message buffers may be allocated to particular message types, given by the relation $\mathsf{MesAlloc} \subseteq \mathcal{MB} \times \mathcal{ME}$.

   The storage (retrieval) of messages to (from) a message buffer follows a message protocol. This is given by the function $\mathsf{MesgPro}: \mathcal{MB} \rightarrow \mathcal{MP}$, where $\mathcal{MP}$ is the set of message protocol names. Instances of it include FIFO and FILO queues, a random order or an order specified by a predicate.

9. A set $\mathcal{EV}$ of events. An event is a discrete and instantaneous occurrence representing a change of state within the business scope. In its broadest sense, events result from: interactions between processeses producing, or produced during, business transaction execution; changes in time and changes in object states (as a result of database updates). Interactions are discussed in more detail in section 4.2.

   It follows that the events which a domain can perceive are internal to the domain, since these result from interactions on processes (recall, only internal). So, for example, the event of an arrival of an Application and not its caused event of the establishing of a contract for the development of an estate, is perceived by the Road Closures domain.

In general, the name of a concept is determined through the function $\mathsf{Name}: \mathcal{CP} \rightarrow \mathcal{V}$, where $\mathcal{V}$ is the set of names.

4.2 Process modelling technique

The process modelling technique, allows the prescriptive aspects of business transaction processing to be modelled. This means that processing which results directly or indirectly from service requests. In its broadest sense, a process model consists of a set $\mathcal{PM}$ of processing entities, a set $\mathcal{SE}$ of storage entities and their interactions between these which characterise the modelling of the processing.

Processing entities and interactions

$\mathcal{PM}$ generalises not only processes (which are visible at the business level) but also concepts which refine processes, namely decisions and synchronisers. In fact, $\mathcal{PR}$, $\mathcal{DS}$ and $\mathcal{SY}$ partition $\mathcal{PM}$. Decisions allow "moments" of processing uncertainty where a (possibly non-deterministic) choice of execution paths may be followed, depending on the outcome of the decision. Synchronisers allow "moments" of synchronisation. A common example of synchronisation, like that depicted in Figure **??**, requires a number of execution paths to be reached, prior to further processing being executed. A further application of a synchroniser is depicted by the example of a share purchasing process of Figure 14. Here, a decision is made to determine whether Sufficient funds? (from a "dynamically" updated account) are available to Purchase a share portfolio (shares from a number of types). If not, basic shares are purchased, i.e. Purchase shares. In either case, when the processes are "forked" off for the purchase, control is returned to the decision to ensure that the purchasing process is continuous.

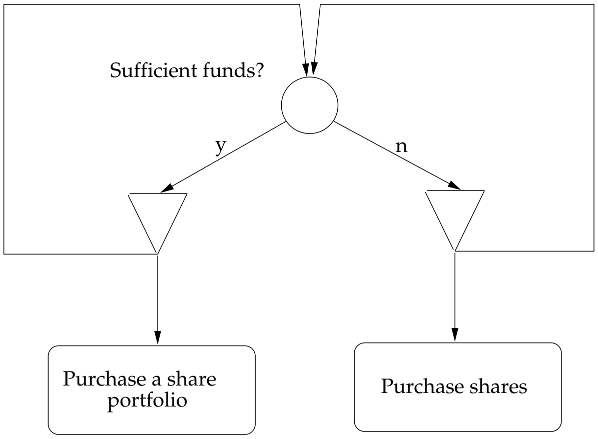


Figure 14: Implementing a “fork” using a synchroniser

Interactions between processing entities are specialised as *triggering* and *messaging*. Triggering serves to activate execution, i.e. control flow. This is defined through the relation $\mathsf{Trig} \subseteq \mathcal{PM} \times \mathcal{PM}$, where $x\mathsf{Trig}y$ means that x is triggered by y.

Messaging, as (just) described above, serves as a communication mechanism, i.e. data flow. In particular, it involves the sending or receiving of messages, which while having some effect on execution control, is an issue orthogonal to it. Only processes and decisions may be involved in messaging, hence the definition of the set of non-synchronisers $\mathcal{NS} = \mathcal{PM} - \mathcal{SY}$. Figure 15 illustrates the different messaging modes.

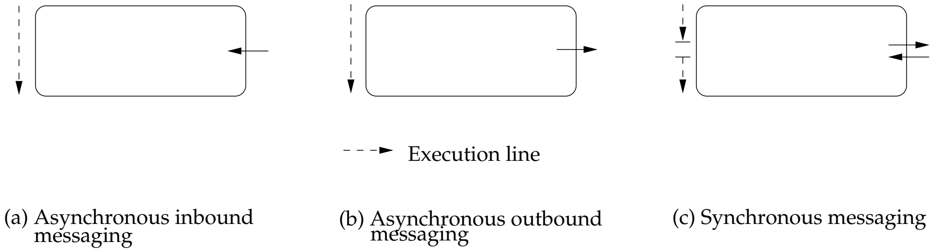

Execution line
(a) Asynchronous inbound messaging
(b) Asynchronous outbound messaging
(c) Synchronous messaging

Figure 15: Messaging modes

Asynchronous messaging involves the sending (a) or or receiving (b) of a message at some stage during the execution of a processing entity afterwhich execution continues. Messaging may also be synchronous in which case a message is sent and execution is suspended until a message is received (c). Note, any messaging involving a message receipt first, is automatically asynchronous since no suspension of execution relates to it. In other words, synchronous messaging involves message sending first only.

Three disjoint subsets of non-synchronisers involved in messaging are defined: the set $\mathcal{NS}_{\mathcal{IA}}$ involving asynchronous inbound messaging, the set $\mathcal{NS}_{\mathcal{OA}}$ involving asynchronous outbound messaging and the set $\mathcal{NS}_{\mathcal{S}}$ involving synchronous messaging. The function $\mathsf{Message}$:$\mathcal{NS}_{\mathcal{IA}} \cup \mathcal{NS}_{\mathcal{OA}} \cup \mathcal{NS}_{\mathcal{S}} \to \wp^{+}(\mathcal{ME})$ yeilds the messages involved; the power set signifies the fact the multiple messages may be involved. Moreover, messages are received either from the service local to the non-synchroniser or from another non-synchroniser in the same process model. In other words, messages received from the environment are always received via the local service. Messages may be sent to other non-synchronisers in the process model, the local service or remote services. Figure 16 depicts this scope of messaging interaction. The function Mesg: $\mathcal{PM} \cup \mathcal{SV} \to \mathcal{PM} \cup \mathcal{SV}$ describes the messaging interaction.

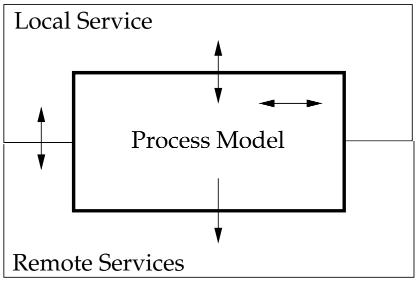


Figure 16: Scope of messaging interaction

(??? Interaction points which have dialogue specifications and protocol - and types HH, CC and HC ??? Should structural aspect of dialogue specifications have a schema defintion much like “view” objects).

Decomposition

A feature of process models is decomposition where processes and decisions may be refined in detail. Hydra allowed processes to be decomposed, however the decomposition of a decision, i.e. a *complex* decision, is a new proposal. We illustrated complex decisions in Figure 7 and Figure 8.

In general, decompositions allow parts of a process model to be modularised and reused. For this the partial function Sup: $\mathcal{PM} \rightarrowtail \mathcal{V}$ is defined to provide the name of the decomposition that the processing entity belongs to. If $\mathsf{Sup}(x) = v$, this means that processing entity x is part of the decomposition of v. Of course, the names of decisions and processes at the same level of decomposition should not be the same:

$$x \in \mathcal{PR} \wedge y \in \mathcal{DS} \Rightarrow \mathsf{Name}(x) \neq \mathsf{Name}(y)$$

Also, unlike a process decomposition, a decision decomposition is only permitted to have decisions:

$$\mathsf{Sup}(x) = v \wedge \exists_{d \in \mathcal{V}} [\mathsf{Name}(d) = v] \Rightarrow x \in \mathcal{DS}$$

So that processing entities are “rooted”, a process model is required to have a unique process at the top of the decomposition heirarchy:

$$\exists!_{p \in \mathcal{PR}} [\mathsf{Sup}(t)\uparrow]$$

Within each decomposition, a process model is required to have a set of initially executed entities (if more than one, parallel execution follows). For this, the partial function $\mathsf{Init} \subseteq \mathsf{Sup} \cap \mathcal{PM}$ is defined.

Decomposition hierarchies do not have a cyclic constraint (e.g. the “downwards” only decomposition of data flow diagrams), but may include recursive decomposition. Figure 9 contained an example of this. Two contraints apply to interactions across decompositions. Firstly, triggers should not cross decomposition boundaries:

$$x_1 \mathsf{Trig} x_2 \Rightarrow \mathsf{Sup}(x_1) = \mathsf{Sup}(x_2)$$

Secondly and similarly, intra-service messaging should not cross decomposition boundaries:

$$x_1 \mathsf{Mesg} x_2 \Rightarrow \mathsf{Sup}(x_1) = \mathsf{Sup}(x_2)$$

where $x_1, x_2 \in \mathcal{NS}$.

Storage entities

Storage entities $\mathcal{SE}$ are used to generalise messages, message stores and object stores. $\mathcal{ME}$, $\mathcal{MB}$ and $\mathcal{OS}$ partition $\mathcal{SE}$. A schema provides a definition, pertinentto the storage entities. For messages and object stores, it represents the information grammar. For message buffers, it incorporates characteristics about the message stores, e.g. types of messages permissible, message quantities. A partial function, $\mathsf{Schema}\colon \mathcal{SE} \rightarrowtail \mathcal{SCH}$, provides the schema definition.

Of course, processes and decisions access data through storage entities. Following from the above discussion, *direct* storage entity access implies storage entities within the same level of decomposition. For convenience, the *decomposition names* are distinguished from $\mathcal{V}$ as those having at least one processing entity in them:

$$\mathcal{V}_d = \left\{ v \in \mathcal{V} \;\middle|\; \exists_{x \in \mathcal{PM}} \left[\mathsf{Sup}(x) = v\right] \right\}$$

Storage entities can then be assigned to decompositions having at least one processing entity through the function $\mathsf{Locse}\colon \mathcal{V}_d \rightarrow \wp(V ar)$. To assist in the expressive power of the processing, local variables may also be defined within a decomposition, hence the function $\mathsf{Locvar}\colon \mathcal{V}_d \rightarrow \wp(\mathit{Var})$. Processes and decisions may access those storage entities and variables within their level of decomposition and lower. They cannot access those in higher levels of decomposition. Hence, storage entities and variables have a scope in the same sense as scopes of variables in programming languages such as ALGOL (see e.g. [WMP$^+$76]). To avoid naming conflicts, the names of local variables and storage entities in that decomposition should differ, i.e. $\mathsf{Locvar}(v) \cap \mathsf{Locse}(v) = \varnothing$. Also, processes may reference and change data but decisions are only permitted reference (this is formalised in the respective sections below).

In addition to variables, data may be passed between processes through message buffers. Messages may be consumed from, or produced into, a message store. This is defined through the functions $\mathsf{Cons}\colon \mathcal{PR} \rightarrow \wp(\mathit{Var})$ and $\mathsf{Prod}\colon \mathcal{PR} \rightarrow \wp(\mathit{Var})$ respectively. If $v \in \mathsf{Cons}(p)$, then process p consumes from message store v. Note that if a process p does not consume from any message store, then $\mathsf{Cons}(p) = \varnothing$. Processes may only consume from, and produce for, message stores which are part of the same decomposition:

$$\mathsf{Cons}(p) \cup \mathsf{Prod}(p) \subseteq \mathsf{Locse}(\mathsf{Sup}(p))$$

Processes

The assignments, reads, writes and updates which typify process specifications are expressed in LISA-D. In Hydra, a sequence of these may be assigned into a LISA-D transaction classified as the LISA-D syntactic category *Transaction*. This should be extended to include Aquino's message sends oustide the decomposition scope (as distinct from producing messages in message stores within the decomposition). Since processes may be composed, only atomic processes are assigned a LISA-D transaction, i.e. $\mathsf{Trans}\colon \mathcal{V} \setminus \mathcal{V}_d \rightarrow \mathit{Transaction}$.

Sometimes, processes should not be able to start or terminate when certain conditions are not fulfilled. These conditions can be expressed by means of pre-condition and postcondition. Pre- and postconditions are expressed by means of LISA-D predicates which in Hydra are classified into the LISA-D *Predicate* category. Hence the functions $\mathsf{Pre}\colon \rightarrow \mathit{Predicate}$ and $\mathsf{Post}\colon \rightarrow \mathit{Predicate}$ respectively. The predicates may reference the names of storage entities and local variables. Also the special LISA-D predicate true can be used to indicate that there is no pre- and post-condition.

Exclusive processes (called transaction tasks in Hydra) are processes which run isolation, i.e. no other process can run when an exclusive process is running. Hence the set $\mathcal{E} \subseteq \mathcal{PR}$. The notion of exclusive processing should not be confused with exclusive locking which does allow a concurrent execution of procceses albeit that an exclusive lock on an object *blocks* any other lock until the exclusive lock is released. Typical examples of exclusive processes are systems maintenance jobs involving database checkpoints and systems backups, or systems configuration involving installations and upgrades. Prior to starting an exclusive process, all active processing entities should be *quiesced*. This, of course, is an issue of formal semantics.

Decisions

To allow "moments" of uncertainty to be specified, decisions have output triggers - one for a postive outcome and one for a negative outcome - which are are assigned LISA-D predicates. These decision rules can be compared to *guarded commands* as introduced in [Dij75]. As with guarded commands the decision rules of a decision are not necessarily disjoint. Therefore, nondeterministic choices can be modelled.

The predicates may refer to values of variables and object instances of object stores and messages. Synchronous and asynchronous messaging is allowed by decisions so that object instances of messages may be referenced. The output triggers of a decision may terminate, hence the subset $\mathcal{DS}_t \subseteq \mathcal{DS}$. Some decisions signal an abort message which signify the intention to terminate a complex decision, hence the subset $\mathcal{DS}_{t\,a} \subseteq \mathcal{DS}_t$. For those decisions which do not terminate, a processing entity can only be triggered by a decision if a trigger exists from that decision to that processing entity while the associated decision rule evaluates to true.

Decision rules are recorded by the function:

$$\mathsf{Choice}\colon ((\mathcal{DS} \times \mathcal{PM}) \cap \mathsf{Trig}) \cup (\mathcal{DS}_t \times \{\multimap\}) \rightarrow \mathit{Predicate}$$

$\mathsf{Choice}(k, \multimap) = d$ means that k is a terminating decision that may lead to termination if d is fulfilled.

Recovery

To fulfill the *Execution Resilience Principle*, the detection of operational errors are signalled by two forms of abort messages. The first is a failure abort, which as the name suggests, results from failures such as system crashes. The second is non-failure aborts which are (deliberately) produced within a business transaction e.g. by a process, decision or service. Note, aborts used to terminate decisions are not a type of non-failure aborts. Their function is more restrictive. The denotation of these aborts is described in $\{\text{‘}\mathsf{F\text{-}Abort}\text{’}, \text{‘}\mathsf{NF\text{-}Abort}\text{’}\} \subseteq \mathsf{Name}(\mathcal{ME})$.

As described in section 2.5, the recovery strategy for the errors involving failure aborts is a *rollforward recovery* whereby a *redo* operation is applied to a “crashed” processing entity. If the processing entity does not start after numbers of restart attempts, after time periods or after combinations thereof, other processing entities should be started. Another processing entity is called a *contingency*. Rollforward recovery is captured through the irreflexive function $Rollf\colon \mathcal{NS} \rightarrow \{\text{‘}\mathsf{Redo}\text{’}\} \times \mathcal{NS}$. Contingencies are defined through the relation $\mathsf{Cont} = \mathcal{NS} \times \mathcal{NS} \times \mathbb{N} \cap \mathsf{Rollf}$. This denotes the fact that a contingency for a processing entity x is another processing entity y, i.e. $x \neq y$, if x has failed to start n times. Depending on the number, a number of contingencies are possible. If n equals infinity, then then x is said to be*forcible*, i.e. it has to start at some stage. Forcibility is a requirement in distributed transaction processing, particularly for compensations (see below).

The recovery strategy for failures involving non-failure generated aborts is a *rollback recovery* whereby an either an *undo* or a *compensation* or in fact nothing is applied to each processing entity within the execution path of that service state. An undo simply removes object store updates provided that they are uncommitted, i.e. the process was not committed on completion of its execution. A compensation is required if a commit occurred. Nothing occurs if the effect of the process is considered uncritical. Rollback is defined through the irreflexive function $\mathsf{Rollf}\colon \mathcal{NS} \rightarrow \{\text{‘}\mathsf{Undo}\text{’}, \text{‘}\mathsf{Null}\text{’}\} \times \mathcal{NS} \times \mathcal{NS}$. Compensations are defined through the relation $\mathsf{Comp} = \mathcal{NS} \times \mathcal{NS} \cap \mathsf{Rollf}$.

4.3 Service Model

A service model allows the descriptive aspects of a business transaction workflow to be modelled. Said otherwise, services encapsulate business transaction workflows. Services are modelled as objects where object behaviour modelling enables a declaritive approach for service specification.

Services have a set $\mathcal{ST}$ of states which define its lifecycle, e.g. Lodged, Initial review passed. Of course, states are named, given by the function $\mathsf{SName}\colon \mathcal{ST} \rightarrow \mathcal{SN}$. States are used to determine what processing entities of the workflow are triggered for given events. As a result of that part of the workflow being executed, a transition between the states occurs. In general, transitions are defined through the relation $\mathsf{Transition} \subseteq \wp^{+}(\mathcal{ST}\ x\ \mathcal{ST})$. The powerset indicates that multiple transitions can exist between the same set of states (recall states (4) and (5).

Attached to each transition is an ECA rule. This represents an event specification.

5 Conclusion

The Application Database being absorbed into the Tenures Administration System

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