A Common Basis for Modelling Service-Oriented and Event-Driven Architecture

Tony Clark
School of Engineering and Information Sciences
Middlesex University
London, UK
t.n.clark@mdx.ac.uk

Balbir S. Barn
School of Engineering and Information Sciences
Middlesex University
London, UK
b.barn@mdx.ac.uk

ABSTRACT

Component based approaches to Enterprise Architecture (EA) include Service Oriented Architecture (SOA) and Event Driven Architecture (EDA). Model-based approaches to EA support SOA in terms of components and services expressed as interfaces and messages. However, there are few model-based approaches that support EDA even though SOA and EDA are both based on components. UML has components, however there is no support for events and no support for component patterns (or *templates*). This paper describes a simple extension to UML that supports both SOA and EDA. Components have both operation and event interfaces. The modelling language is implemented using a higher-order simulation language where templates are defined as functions over component definitions. The languages are described using a case study that has been implemented in Java.

Categories and Subject Descriptors

H.4 [**Information Systems Applications**]: Miscellaneous; C.0 [**Computer Systems Organization**]: Systems Architectures

General Terms

Modelling, Enterprise Architecture

Keywords

Service Oriented Architecture, Event Driven Architecture, Model Driven Engineering

1. INTRODUCTION

Enterprise Architecture (EA) describes a collection of approaches that support the design and analysis of an IT infrastructure and how it relates to the goals, directives, processes and organization of a business. The approaches differ in details, but most involve the identification of logical or physical business units, or *components*, that manage their own data and resources, implement a collection of business processes, and communicate with other components using a variety of message passing styles.

EA aims to capture the essentials of a business, its IT and its evolution, and to support analysis of this information: '[it is] a coherent whole of principles, methods, and models that are used in the design and realization of an enterprise's organizational structure, business processes, information systems and infrastructure.' [1].

Several different styles of architecture are possible. A *Service Oriented Architecture* (SOA) involves the publication of logically coherent groups of business functionality as *interfaces*, that can be used by components using synchronous or asynchronous messaging. An alternative style, argued as reducing coupling between components and thereby increasing the scope for component reuse, is *Event Driven Architecture* (EDA) whereby components are event generators and consumers.

An important difference between SOA and EDA is that the latter generally provides scope for *Complex Event Processing* (CEP) where the business processes within a component are triggered by multiple, possibly temporally related, events. In SOA there is no notion of relating the invocation of a single business process to a condition holding between the data passed to a collection of calls on one of the component's interfaces.

As described in [2] and [3], complex events can be the basis for a style of EA design. EDA replaces interfaces with events that trigger organizational activities. This creates the flexibility necessary to adapt to changing circumstances and makes it possible to generate new processes by a sequence of events [4]. Whilst a complex event based approach to architectural design must take efficiency concerns into account, the primary concern is how to capture, represent and analyze architectural information as an enterprise design.

EDA and SOA are closely related since events are one way of viewing the communications between system components. The relationship between event driven SOA and EA is described in [5] where a framework is proposed that allows enterprise architects to formulate and analyze research questions including 'how to model and plan EA-evolution to SOA-style in a holistic way' and 'how to model the enterprise on a formal basis so that further research for automation can be done.'

Our claim is that system architectures should be based on both EDA and SOA. Therefore our aim is to provide a basis for modelling architectures based on both services and events. In the rest of the paper we will refer to *EDA lan-*

ISEC '12 Feb 22-25, 2012, Kanpur, UP, India.

guages which should be read as a basis for both event **and** service based architectures. Our contribution is to analyse the requirements for EDA and then to propose a modelling language and a corresponding simulation language. To achieve the most general basis possible and to take advantage of the large number of UML modelling tools available, the modelling language is based on UML. The simulation language is an extension to a general purpose functional language. In particular, the functional language allows us to capture architectural patterns as functions over components which is an essential, but underdeveloped, area of architectural design. The modelling language has been implemented as stereotyped UML elements and the simulation language has been implemented as an interpreter in Java.

The paper is structured as follows. Section 2 reviews complex event processing and EA modelling languages. Section 3 performs a domain analysis on EDA and describes an EDA modelling language. Section 4 describes a case study as an EDA model. Section 5 describes an EDA simulation language and provides an example by implementing the case study. The simulation language has been implemented in Java and is described in section 6.

2. EVENT DRIVEN EA

2.1 Service Oriented Architecture

Service Oriented Architecture (SOA) organizes a system in terms of components that communicate via operations or *services*. Components publish services that they implement as business processes. Interaction amongst components is achieved through *orchestration* at a local level or *choreography* at a global level.

Its proponents argue that SOA provides loose coupling, location transparency and protocol independence [6] when compared to more traditional implementation techniques. The organization of systems into coherent interfaces has been argued [7] as having disadvantages in terms of: extensions; accommodating new business functions; associating single business processes with complex multi-component interactions. These can be addressed in terms of CEP as described in the next section.

2.2 Complex Event Processing

Complex Event Processing (CEP) [8] can be used to process events that are generated from implementation-level systems by aggregation and transformation in order to discover the business level, actionable information behind all these data. It has evolved into the paradigm of choice for the development of monitoring and reactive applications [9].

CEP processes events in terms of business rules compared to SOA that implements operations using business processes. Typically, a business rule can depend on multiple, possibly temporally related, events, whereas a business process is invoked on receipt of a single operation request.

There are various proposals for how complex events can be used efficiently to process streams of data such as those generated in applications including hotel booking systems, banking on-line credit systems, business activity monitoring (BAM), real-time stock analysis, and real-time security analysis. Most proposals aim to address efficiency issues related to the scale and frequency of the information that is generated [10]. The current state of the art is described in [11] where the key features of an event driven architecture (EDA) are outlined as including an architecture diagram showing the processes of the system and their interconnections, a behaviour specification including the rules used to process events and to control data, and the specification of inter-process communications.

As described in [12] events can be extracted from services, database, RFID and activities. The events are processed by rules that detect relationships, including temporal, between events in order to transform multiple events over time into business actions. In [12] the authors describe the implementation of a complex event processing architecture that involves attaching an extractor to event sources and compiling event processing rules into complex event recognition tables. The language does not address modularity issues and how the complex event architecture maps onto modern approaches to EA. Wu et al [13] describe a language called SASE for processing complex events from RFID devices. The language is based expressing patterns of events over events in time-windows and the authors describe various optimizations that can be performed. The language is general purpose but does not implement negation or offer features for modularity.

The approach described in [14] is based on logic programming for complex event processing and in a way is the opposite to our forward-driven approach. The authors use Prolog-style backtracking to find solutions to goals.

3. EVENT DRIVEN MODELLING

An EA aims to represent an organization and its essential elements. However the complexity of the problem domain cannot be adequately addressed by one architectural style. In this paper we have proposed that two specific styles SOA and EDA have between them the necessary concepts that are able to provide more complete representation of EA. This section provides a overview of the unification of EDA and SOA by identifying the common features in section 3.1 and proposing a specialization of UML class models that support the features in section 3.2.

3.1 Features

Our aim is to provide a modelling and simulation language for EDA that is based on features provided by UML. In order to do this we need to identify characteristic EDA features. This section lists the features and the following section describes how they are to be implemented using UML class model stereotypes and an extension to OCL.

An EDA architecture is based on *components* each of which represents an organizational unit. Components map onto physical IT systems or organizational units. Each component manages local private *data* that maps onto databases (relational, files, etc). As in SOA, a component may offer *operations* that can be invoked by sending *messages*. An operation is specified in terms of *pre* and *post* conditions expressed in terms of the component's data. In addition to modifying local data, an operation may send messages and raise *events*. An event is used by a component to signify a significant change in state that may be of interest to any component that is *listening*. Components use *rules* to process events; a rule matches against local state and one or more events that are received by the component. The body of a rule is an action in terms of local state changes, events and messages. Components are designed in isolation, however global *invariants* place constraints on component state

synchronization and lead to implementation requirements in terms of event connectivity between components.

Thus the characteristics are drawn from established and well understood concepts from component based design, distributed architectures.

3.2 An EDA Modelling Language

Section 3.1 has outlined the key features that characterize EDA models. This section describes how each of the features are represented as a conservative extension to UML in a similar way to component models described in [15] and [16]. The extension is deliberately minimal in order that existing UML tools can support EDA models in terms of stereotypes and, where OCL cannot be extended, comments. Section 4 uses the extended UML to implement a case study and is a key contribution of the paper.

Figure 1 shows a simple meta-model and its extension for EDA modelling. The basic modelling language consists of packages of classes and associations. Each class contains a collection of attributes and operations. An operation is specified using pre and post conditions.

The EDA language extends the basic language with the following features. `CmpDef` is a specialization of `Package` that defines a single component. Each of the other classes contained in a `CmpDef` must be structured types since they cannot have any behaviour. All classes in a `CmpDef` must be associated directly or indirectly to the component. `Component` is a specialization of `Class` that has business rules and input/output events. A component listens for output events raised by other components; when an output event is produced it is received as an input event by the listening component. Components may be nested, a parent always listens to the events raised by its children. `CmpOperation` is a component operation specification that can involve an action that, in addition to pre and post-conditions, defines the events that are raised by the operation. `Action` is used in a component operation to specify the events that are raised when the operation completes. An action is either single event `Raise` or is a `Loop` through a collection of elements, where an action is performed for each member of the collection. A `BizRule` has a guard that must be satisfied before the rule can be fired. After the rule is fired, the post-condition of the rule is satisfied and the rule action is performed. A `Pattern` matches against the events that have been received by a component. A pattern may match a single event `EventPattern`, may be conjunctions or disjunctions of patterns, or may be a negated pattern.

The meta-model in figure 1 describes an extension to conventional UML class diagrams. Although, UML has components, they do not correspond to `Component` and `CmpDef` in the meta-model, so we use stereotypes to tag and extend the appropriate UML elements; this allows standard UML modelling tools to be used to support EDA component modelling. Component definitions are represented as UML packages (class diagrams) with exactly one class with the stereotype `<<component>>`. Components may have attributes and operations which are interpreted as standard class features although operations are invoked using messages in the sense of SOA.

Associations on the UML class diagram from the component to classes define the local structured data of the component. These classes may have attributes and associations, but do not have any operations since all execution is defined by component interaction.

In addition, a component may have operations with stereotypes `<<eventin>>` and `<<eventout>>` The signature of the operation defines the name and internal structure of events. An input event declares that the event will be received via some externally monitored component. An output event declares that the component will raise the event via an operation or a business rule.

Operations are specified using standard OCL pre and post conditions. A `CmpOperation` can be defined for operations that includes an action:

```
context C::o(arg*) pre exp post exp action
```

The action part of a constraint is used to specify the events that are raised by an operation (or a business rule). An action may involve a single event or may loop through a collection in order to raise several events:

```
action ::= raise name(exp*) |
           with name:type in exp [ when exp ] do action
```

Business rules monitor events received by a component. A rule may depend on multiple events and the current state of the component. The rule may cause a state change to the component and may raise events. We propose a new form of OCL that supports business rules that match event and data patterns such as those described in [17] as follows:

```
context C on pattern* pre exp post exp action
```

4. CASE STUDY

4.1 Overview

The use of shared services has become an increasingly important strategic driver in the UK. Our approach presents one possible technology for addressing some of the issues currently prevalent in this sector. A recent report into the use of IT in HE [18] argues that there is little high-level strategic impetus behind the integration and that the sector is struggling to get systems to talk to each other. The associated JISC report[1] describes the public sector support for SOA in HE with the intention of leading to shared services across the sector. It argues that EA can address problems relating to data silos, information flow, regulatory compliance, strategic integration, institutional agility reduction in duplication and reporting to senior management.

EA can be applied within an organization in order to determine how to comply with externally applied regulations. Models can answer questions about the reuse of existing components, the locality of regulatory information and to identify the need for new information sources. This section describes a case study which is typical of current issues facing the UK HE sector. We describe the case study and then use the EDA modelling and simulation languages to describe an EA for the application.

Requirement: The UK Borders Agency requires all Higher Education institutions to produce a report that details the number of points of contact between the institution and any student that has been issued with a student visa. This regulation places a requirement on the institution to ensure that the information is gathered at the appropriate points of contact. Furthermore, there is a business imperative for each

[1] `http://www.jisc.ac.uk/media/documents/techwatch/jisc_ea_pilot_study.pdf`

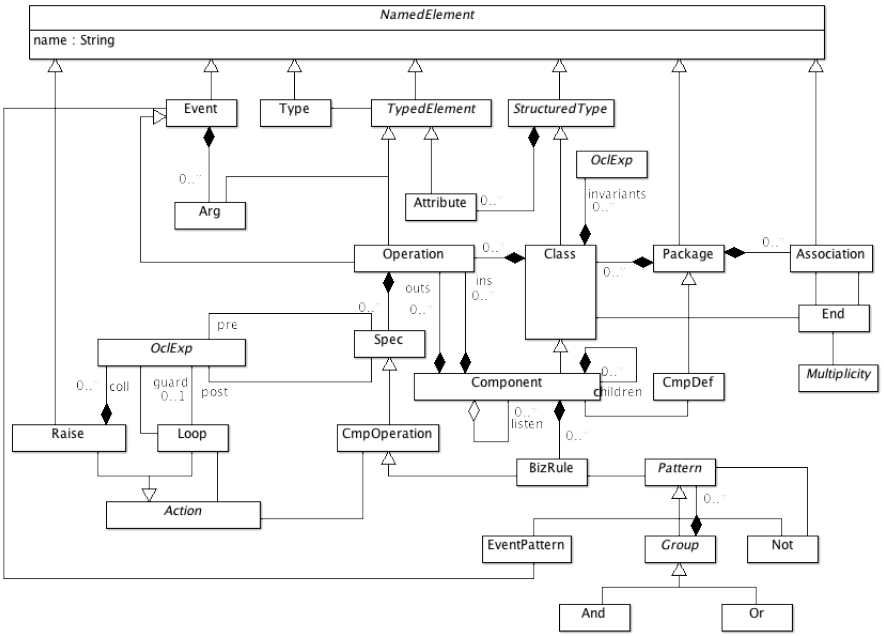


Figure 1: EDA Meta Model

institution to be able to detect students that may be likely to fail to record the required number of contact points in order to take remedial action and thereby avoid paying penalties with respect to *trusted status* whereby visas are granted via a lightweight process.

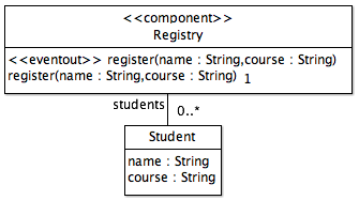
4.2 Components

The University of Middle England (UME) decides to construct an EA model in order to determine the components, data stores and interactions that are required to comply with the regulations and to generate simulations. The first step is to construct a model of the components that will be required. New components can be designed as part of the model, however reuse of existing components is preferred to keep costs down.

UME makes a list of existing systems that can be used to track student interactions: the Library; Departments; the Registry. Each department has a student office that handles student assignments, and a collection of lecturers. A new component, the Monitor, is required in order to aggregate the events raised by the components and to manage a point of contact database.

4.2.1 The Registry

The registry is responsible for managing the list of all UME students and their course of study. It is the first point of contact for any student where the student registers for a particular course:

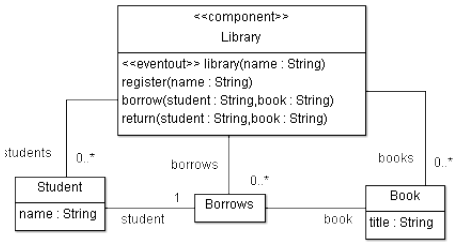


The `Registry` component manages a database of students containing the student's name (assumed to be unique) and the name of the course they are to study. Currently the registry does not inform any other UME system of a new registration. However, student registration is a point of contact and therefore our model requires that an event is raised:

```
context Registry::register(name:String,course:String)
  pre not students->exists(s | s.name = name)
  post students->exists(s | s.name = name)
  raise register(name,course)
```

4.2.2 The Library

Once a course has started, students use the library in order to access learning resources. Students must register with the library, after which they can borrow and return books. The current library system manages a database of registered students, books and borrowing records.



The current library system provides an interface of operations for registration and book borrowing. Each operation counts as a point of contact and therefore should raise events. The event just informs any listener of a library transaction for a particular student:

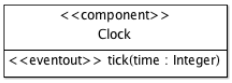
```
context Library::register(name:String)
  pre not students->exists(s | s.name = name)
  post students->exists(s | s.name = name)
  raise library(name)

context Library::borrow(student:String,book:String)
  pre students->exists(s | s.name = student) and
```

```
    books->exists(b | b.name = book and
                      not borrows->exists(b | b.book = b))
  post borrows->exists(b | b.student.name = student and
                           b.book.name = book)
  raise library(name)
```

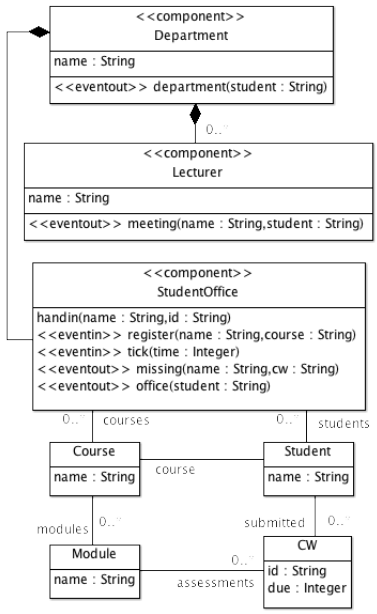
4.2.3 Time

The UK Borders Agency requires UME to report on students by a given date which we will measure in the number of elapsed weeks after the start of a course. Therefore, the UME IT architecture must be aware of how many weeks have passed and includes a timing component that *ticks* at the end of each week:



4.2.4 Departments

Each UME department has a student office and a numvber of academics. The student office manages student assignments and the lecturers have tutorial meetings with students; both of these count as points of contact. Late coursework is an indicator that things are going wrong for a student. A department is an example of how components nest:



A department contains a component that implements the student office and a collection of components that represent the information system that academics use to manage student meetings. The office maintains a database of all courses including modules and courseworks. Each coursework has a due date (measured in weeks).

Registration events can be processed by each student office in order to initialize a student with their department:

```
context StudentOffice
  on register(student:String,course:String)
  post students->exists(s | s.name = student and
                            s.course.name = course and
                            s.submitted->size = 0)
```

Coursework submission counts as a point of contact and therefore the student office is required to raise an event:

```
context StudentOffice::handin(student:String,cw:String)
  post students->exists(s |
    s.name = student and
    s.submitted->includes(
      s.course.modules.assessments->select(a | a.id = cw)))
  raise office(student)
```

The student office processes timing events by checking whether there are any outstanding coursework and generating late coursework events. Such events can be used to remind students that they have a deadline and thereby improve the number of contacts within the limits imposed by the UK BA. The following query operations calculate a set of records of the form `{name=n;cw=i}` where `n` is the name of a student and `i` is a coursework identifier:

```
context StudentOffice::missed(time:Integer) =
 students->iterate(s R=Set{} |
  let req = s.course.modules.courseworks->select(c | c.due<time)
  in R + missed(s.name,req,s.submitted))

context StudentOffice::missed(s,req:Set(CW),done:Set(CW)) =
  (req-done)->collect(cw | {name=s;cw=cw.id})
```

The student office generates a missing event for each missing coursework:

```
context StudentOffice
  on tick(time:Integer)
  with x:{name:String;cw:String} in missed() do
  raise missing(x.name,x.cw)
```

A lecturer may have a meeting with a student. The meeting is registered on the department's tutorial information system and raises an event:

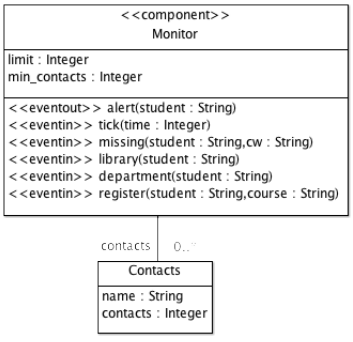
```
context Lecturer::meeting(student:String)
  raise meeting(name,student)
```

Since the `Department` component contains lecturer and office component it will automatically receive any evenets that they raise. The department conflates the contact messages into a single `department` event:

```
context Department
  on office(student) or meeting(lecturer,student)
  raise department(student)
```

4.2.5 The Monitor

Finally, UME requires a new component that monitors student contacts and generates alerts when the limit is reached:



When a student is registered, the monitor must initialize a local record:

```
context Monitor
  on register(name:String,_)
  pre not contacts->exists(c | c.name = name)
  post contacts->exists(c | c.name = name and c.contacts = 1)
```

When the student uses the library or hands in coursework, the monitor must increase the number of contacts:

```
context Monitor
  on library(name:String) or department(name:String)
  pre contacts->exists(c | c.name = name)
  post contacts->exists(c |
    c.name = name and c.contacts = c.contacts@pre + 1)
```

The monitor generates an alert when the number of contacts is insufficient and when time limit has been reached or when the student has missed a coursework:

```
context Monitor
  on tick(time:Integer)
  pre time > limit
  with c:Contact in contacts when c.contacts < min_contacts do
  raise alert(c.name)

context Monitor
  on missing(student:String,cw:String)
  pre contents->select(c |
    c.name = student and c.contacts < min_contacts)
  raise alert(student)
```

4.3 Invariants

The previous sections have defined modules in isolation. Each component contains a model of locally managed data, implements an interface of operations, generates events, and processes incoming events via rules.

The components must work together to enforce a collection of invariants. At the specification level we need not be worried about *how* the components manage the interactions, we just state the conditions that must be satisfied.

Each component may have several instances, although it is often the case in a component based architecture that each component is deployed once. Therefore, when writing invariants, we will associate a component name with its set of instances, and in the case of a singleton set with the instance itself. The following invariant ensures that the registry, student office and the library are all in-sync when a new student registers (note that not all students need to register with the library but if they do they must have been processed by the registry):

```
Registry.registered->size =
  Department->iterate(d | d.StudentOffice.students->size)
Registry.registered->size >= Library.students->size
Registry.registered->size = Monitor.contacts->size
```

The number of points of contact must be enforced by an invariant that takes into account the number of registrations, the uses of the library, tutorial meetings and coursework submissions. The total number of coursework submissions is maintained by the student office, however the total number of library interactions is not maintained since the borrowing record is removed when a student returns a book. Fortunately, each component maintains a list of raised and received events via special associations: `in` and `out`. Events are just normal data that can be processed via these associations:

```
Monitor.contacts->forall(c | c.contacts =
  Department.StudentOffice.students->select(s |
    s.name = c.name).submitted->size +
  Library.out->select(e | e.name = c.name)->size) +
  Department.Lecturer.out.size
```

5. EVENT DRIVEN SIMULATION

Figure 2 shows a *domain specific language* that has been defined to support EDA simulation. It is beyond the scope of this paper to describe the detailed semantics of the language;

```
exp ::=
  component [name] (exp*) { components, monitored
    [state { term* }]      local data (optional)
    [operations { op* }] methods (optional)
    [rules { rule* }]      event processing (optional)
    bind*                  fields
  }
| fun(arg*) exp            functions
| exp(exp*)                applications
| var                      variables
| atom                     integers, strings, booleans
| state                    local data
| self                     reference
| { exp* }                 blocks
| { bind* }                records
| [ exp | qual* ]          lists
| new term                 extension
| delete term              deletion
| if exp then exp else exp conditional
| raise term               event generation
| case exp { arm* }        matching
| let bind* in exp         locals
| letrec bind* in exp      recursive locals
| exp <- term              message passing
| exp . name               field reference
pattern ::=
  var                      variables
| name(pattern*)           term patterns
| atom                     ints, strings, bools
| name = pattern           pattern binding
| [pattern*]               lists
| pattern:pattern          cons pairs
| pattern,pattern          alternatives
| ? exp                    predicate
term   ::= name(exp*)
arm    ::= pattern -> exp
bind   ::= pattern = exp
qual   ::= pattern <- exp | ?exp
op     ::= name(arg*) { exp* }
rule   ::= name : pattern* { exp* }
```

Figure 2: EDA Simulation Language

we give a brief overview and then show how the UME case study is implemented in the language.

An EDA simulation consists of a collection of component definitions. Each component monitors events. The local data of a component is represented as a collection of terms of the form `Name(v,...v)`. Components have conventional OO methods that can be invoked synchronously (using `.`) and asynchronously (using `<-`). Component rules match patterns against events raised by monitored components and then perform expressions.

Rule and operation bodies are standard functional language expressions except for: sequenced blocks, local data modification (`new` and `delete`) and events `raise`. Access to the list of all local terms in a component is provided via `state`. List comprehensions are useful to process the local state, for example `[ name | Person(name,age) <- state, ?(age > 65) ]` constructs the names of all the people in the local data that are over `65`.

Component expressions contain local state, operations, rules and fields. An important feature of the language is that it allows component expressions to be nested, *i.e.* components can contain children and functions can return components. The latter feature allows a pattern of components to be implemented as a function over collections of components that can be *instantiated* by applying the function to arguments. This feature is called *component templates* and is used to implement departments the UME architecture.

An EDA system consists of a collection of named compo-

nents that publish their operation interfaces and that monitor events. Events generated by a component C are received by all components that monitor C. Component rule patterns match against received events and against local data. When all patterns have matched the rule is ready to fire; rules are fired in any order.

The registry is defined as a component with no initial state and no rules. The `register` operation allows new students to be added to the local data and raises a registration event. The `students` operation is used to query the registry database:

```
component registry
  operations {
    register(student,course) {
      new Student(student,course);
      raise Register(student,course)
    }
    students() { state }
  }
}
```

The following component defines a library. The local data declares all the available books. The `register` operation checks whether the student exists, if not then a new student is created and a library usage event is raised. The `borrow` and `return` operations are as expected. The library defines an operation `books` that calculates a list of books currently borrowed by a student; this will be used by the user interface component later. The library defines no rules.

```
component library() {
  state { Book('b1','Programming') Book('b2','Management') }
  operations {
    register(student) {
      if student?(student)
      then print(student + ' exists in Library.')
      else { new Student(student); raise Library(student) }
    }
    borrow(student,book) {
      if student?(student) and book?(book)
      then { new Borrows(student,book); raise Library(student) }
      else print(student + ' cannot borrow ' + book)
    }
    return(student,book) {
      delete Borrows(student,book);
      raise Library(student)
    }
    student?(name) { [ s | Student(s) <- state,?(s=name)] != [] }
    book?(id) { [ i | Book(i,n) <- state,?(i=id)] != [] }
    books(student) {
      [ book | Borrows(s,id) <- state, ?(s=student),
               Book(i,book) <- state, ?(i=id) ]
    }
  }
}
```

Each department defines a student office that manages assignments. Unlike the library the student registry, there are many departments, therefore many student offices, and the number of departments may change over time. No matter how many offices there are, they all perform the same tasks and only differ in terms of the courses that are available.

We take a *template* approach to defining departments where a function is defined whose parameters represent the variable elements of a component and where the body of the function returns the component. A `department` component is defined using three templates: `mk_academic` that creates an academic; `mk_student_office` that maps a list of courses to a component; `mk_department` that maps a department name, a list of courses and a list of academic's names to a department.

An academic is created using the following template that maps a name to a component. The component provides an operation that records a tutorial meeting between the lecturer and a student and raises an event:

```
mk_academic(n)
  component () {
    operations {
      student_meeting(student) { raise Meeting(name,student) }
    }
    name = n
  }
```

The student office template is defined below. The `coursework` operation queries the currently submitted assessments for a student. The `missed` operation calculates the assessments that are outstanding for all students. The `handin` operation is used to record each new assessment.The rule `time` uses the `for` operation to raise a missing event for each outstanding coursework. The `register` rule initializes a `Student` record in the student office, and the `missed` rule raises an event when the component detects that a student has missed a coursework deadline:

```
mk_student_office(courses) {
  component (clock,registry) {
    operations {
      courseworks(student) {
        [ id | Coursework(s,m,id,t) <- state, ?(s=student) ]
      }
      students() { state }
      missed(time) {
        [ {name->n;id->id} | Student(n,_,_) <- state,
              Course(course,modules) <- courses,
              ?(course=studying),
              Module(mname,assessments) <- modules,
              CW(id,due) <- assessments,
              ?(due<time), ?(not(member(id,cws))) ]
      }
      handin(student,module,coursework) {
        new Coursework(student,module,coursework);
        case [s | s=Student(n,_,_) <- state, ?(student=n) ] {
          [Student(s,c,cws)] -> {
            delete Student(s,c,cws);
            new Student(s,c,cws+[coursework])
          }
        };
        raise Office(student)
      }
      for(list,action) {
        case list {
          [] -> true;
          x:xs -> { action(x); for(xs,action) }
        }
      }
    }
    rules {
      missed: Time(t) {
        delete Time(t-1);
        self.for(self.missed(t),fun(x) raise Missing(x.name,x.id))
      }
      register : Register(student,course) {
        case [ x | Course(x,ms) <- courses, ?(x=course) ] {
          [ x ] -> new Student(student,course,[])
        }
      }
    }
  }
}
```

Each department is created using the following emplate that maps a department name, list of courses and list of academic names to a component. The component offers operations that query the courseworks for a student, hand-in an assignment, record a tutorial, and select an academic. The component monitors the events produced by the school office and academic sub-components and the rules map child-events to department-events:

```
mk_department(n,courses,academic_names) {
```

```
  component(self.academics,self.school_office) {
    operations{
      courseworks(student) { school_office.courseworks(student) }
      handin(student,module,coursework) {
        school_office.handin(student,module,coursework)
      }
      meeting(student,academic) {
        (get_academic(academic)).student_meeting(student)
      }
      get_academic(n) {
        case [a | a <- academics, ?((a.name) = n) ] { [a] -> a }
      }
    }
    rules{
      meeting: Meeting(lec,student) { raise Department(student) }
      office: Office(student) { raise Department(student) }
      missing: Missing(student,cw) { raise Missing(student,cw) }
    }
    school_office = mk_student_office(courses)
    academics = [ mk_academic(n) | n <- academic_names ]
    name = n
  }
}
```

UME decides to trial the new architecture with two departments: Computer Science and the Business School. Although each department has different courses and academics, the student monitoring system is created using the sme templates that are defined above:

```
computer_science = mk_department('Computer Science',[
  Course('Business and IT',[
    Module('Marketing',[CW('BIT_MCW1',4),CW('BIT_MCW2',6)])]),
  Course('Business Informatics',[
    Module('Marketing',[CW('BI_MCW1',3),CW('BI_MCW2',9)])])
  ],['Dr Piercemuller','Prof Plumb'])

business_school = mk_department('Business School',[
  Course('MBA',[
    Module('Marketing',[CW('MCW1',5),CW('MCW2',8)])]),
  Course('Business',[
    Module('Marketing',[CW('B_MCW1',6),CW('B_MCW2',9)])]),
  Course('Business and Marketing',[
    Module('Marketing',[CW('BM_MCW1',5),CW('BM_MCW2',11)])])
  ],['Prof Inglenook','Dr Who'])
```

The monitor component listens to events from all other components. It handles registration events by initializing a `Contact` record. Library and student office events increase the contact count by 1. A `Missing` event occurs when a student has not handed the coursework in on time and raises an alarm. An alarm is also raised when the required number of contacts have not been achieved by the required time.

```
component monitor
    (clock,registry,computer_science,business_school,library) {
  state { Limit(10) MinContacts(4) }
  operations {
    count(student) {
      case [ c | c=Contact(s,n) <- state, ?(s=student)] {
        [Contact(s,n)] -> n;
        x -> 0
      }
    }
  }
  rules {
    register: Register(s,c) { new Contact(s,1) }
    library: Library(s) c=Contact(s,n) {
      delete c;
      new Contact(s,n+1)
    }
    department: Department(s) c=Contact(s,n) {
      delete c;
      new Contact(s,n+1)
    }
    missing: Missing(s,cw) { raise Alarm(s,'COURSEWORK') }
    alarm: Time(t) Contact(s,n) Limit(t) MinContacts(m) ?(n<m) {
      raise Alarm(s,'CONTACTS')
    }
    time: Time(n) { delete Time(n-1) }
  }
}
```

6. IMPLEMENTATION

The components defined in the previous section respond to messages and events. This section describes how the simulation is controlled (section 6.1), presented to the user (sections 6.2 and 6.3) and how the language is implemented (section 6.4).

6.1 The Simulator Component

In order to run, the simulation must be seeded with some events that populate the components. For simulation purposes we define two new components: the `simulator` and the `screen`. The simulator component has a state consisting of a collection of terms each of which is a message to one of the UME components. The message contains a time and a simulation rule matches each clock tick against the time in a message term; when the time matches, the message is sent via the built-in `send` operation:

```
component simulator(clock,monitor) {
  state { Send(1,registry,'register',['stud01','MBA']) ... }
  rules {
    time: Time(n) { delete Time(n-1) }
    step: Time(t) Send(t,target,message,args) {
      send(target,message,args)
    }
    contact: Alarm(s,'CONTACTS') { raise Display(s,'red') }
    assess: Alarm(s,'COURSEWORK') { raise Display(s,'green') }
  }
}
```

In addition to sending messages, `simulator` monitors `Alarm` events. Each event contains the name of a student and a tag that describes the context of the alarm. The simulator generates events that describe the level of importance associated with each student: `green` means that the student is giving cause for concern and `red` means that the student may cause UME to fail to achieve a key business goal.

6.2 HTML

The implementation uses a web-server to display information about students. The information to be displayed is encoded as HTML using terms. Figure 3 shows part of the screen model that is used to encode HTML. Each class is encoded as a term, attributes are encoded as term data and associations are encoded as sub-terms. For example, to produce a screen that contains a single table with two students:

```
Screen(
  Table([[Text('s1'),Text('MBA')],[Text('s2'),Text('Business')]
  ])
)
```

A `Button` has a label and an action. The action is a function with no arguments; when the button is pressed in a web-browser, the function is called causing any actions in the body of the function to be performed.

A `Div` term acts like a `<DIV>` element in HTML. The record is used to set style attributes for the scope of the entries in the body of the div. The optional record attached to a `Table` performs the same function.

6.3 The Screen Component

The `screen` component is defined below:

```
component screen(clock,simulator) {
  operations {
```

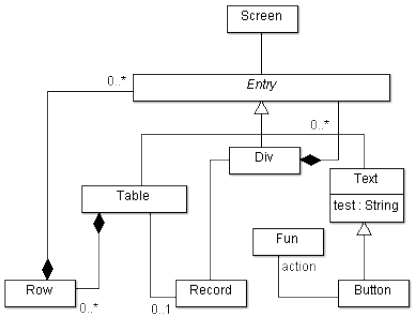


Figure 3: Screen Model

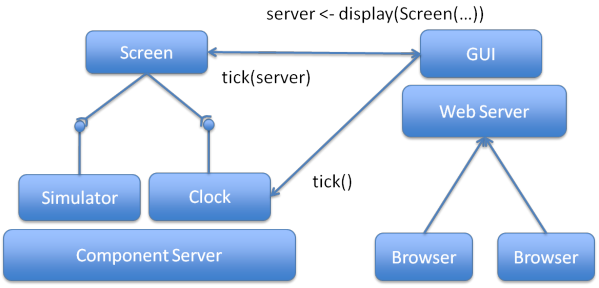


Figure 4: Implementation Architecture

```
  screen() { Table([[depts()],[Table([[step(),ticker()]])]]) }
  text(n,c,s) {
    Div({style->'font-size:'+n+'px; color:'+c+';'},[Text(s)])
  }
  headers(str) { text(22,'black',str) }
  display(name,s) {
    case [ c | Display(s,c) <- state, ?(name=s) ] {
      ['red'],['red','green'],['green','red']->text(16,'red',s);
      ['green'] -> text(16,'green',str);
      otherwise -> text(16,'black',str);
    }
  }
  level(name) {
    case [ c | Display(s,c) <- state, ?(name=s) ] {
      ['red'],['red','green'],['green','red']->Text('!!!');
      ['green'] -> Text('???');
      otherwise -> Text('.')
    }
  }
  courseworks(stud) {
    display(stud,list([d.courseworks(stud) | d <- departments ]))
  }
  student_details(name) {
    [level(name),display(name,name),display(name,course),
     display(name,monitor.count(name)),books(name),
     courseworks(name),
     Button('Contact ' + name, fun() {
       delete Display(name,'red');
       self <- update_display(name) })]
  }
  depts() {
     Table([
       [ Table([[Text(department.name)])],[students(department)] ]
         | department <- departments ])
  }
  students(department) {
    let body = [student_details(name) | Student(name,course) <-
                  department.school_office.students()]
    in Table([map(headers,cols)] + body)
  }
  books(stud) { display(stud,list(library.books(stud))) }
  list(l) {
    case l { [] -> '.'; [t] -> t; t:ts -> t + ', ' + (list(ts)) }
  }
  ticker () { Text('Time: ' + time()) }
  time() { case [ t | Time(t) <- state ] { [t] -> t; [] -> 0 } }
  step() { Button('Step',fun() clock <- tick()) }
  server() { case [ s | Server(s) <- state ] { [s] -> s } }
  update_display() { server() <- display(Screen(screen())) }
  tick(s) { new Server(s); s <- display(Screen(screen())) }
}
rules {
  tick_screen: t=Time(n) { delete Time(n-1); self.update_display() }
}
departments = [computer_science,business_school]
cols = ['LVL','NAME','COURSE','CONTACTS','BOOKS','CWK']
}
```

The life-cycle of `screen` is as follows. When the web-server first connects to `screen` it calls `tick` and supplies a web-server `server`. The server is stored in the local data of `screen` as the term `Server(server)` and is accessed using the function `server()`. When `screen` wants to update web-server, it sends a message `browser <- display(s)` where `s` is a screen (a term-instance of the model in figure 3). The initial screen contains a table of student information and a button created by the operation `step()`; the button-action is a function that sends a `tick()` message to the clock causing a `Tick(t)` event to be raised and received by all components monitoring `clock`. The rule `tick_screen` is fired when `screen` receives a `Tick(t)` event and causes the web-server to be supplied with a new screen via `update_display`.

6.4 Implementation Architecture

The implementation is written in Java and has an architecture as shown in figure 4. A standard web-server runs a servlet labelled GUI that processes a term-encoding of the model in figure 3. When the GUI starts, it supplies a handle to itself (`tick(server)`) to the screen component. The `screen` component informs GUI of a new screen `server <- display(Screen(...))` and prompts the clock to advance under user control via the button-action `tick()`.

A sequence of simulation snapshots is shown in figure 5; each snapshot is a browser screen-shot generated after several clicks of the `Step` button. Figure 5a shows the situation just after students have registered. Figure 5b occurs a little later and shows that student `stud02` has handed in coursework on time but that student `stud04` has missed the assignment deadline. Figure 5c shows the situation just after the UK BA deadline; students `stud03` and `stud04` have insufficient contacts to meet the regulations; student `stud01` has sufficient contacts, but has missed a deadline; `stud02` is doing fine. Figure 5d shows the situation where a member of the academic team has contacted `stud04` directly and has used manual override to change the status.

6.5 Summary

Event Driven Architecture is a style of system design that lacks modelling notation. We have analyzed EDA, identified its characteristic features, and have proposed a modelling notation and associated simulation language. The modelling language is defined as a conservative extension to UML so that existing tools can use stereotyped UML elements to support component models. The simulation language has been implemented as a Java interpreter[2]. Each component is deployed on a server that handles communication via sockets; so that each component can be written in the language or can be a wrapper around a pre-existing IT system. Any data, including functions and components, can be sent via

[2] `http://bit.ly/voEbod` and `http://bit.ly/vjNzX7`

Computer Science

LVL	NAME	COURSE	CONTACT	BOOKS	CWK	
.	stud02	Business and IT	1	.	..	Contact stud02
.	stud04	Business Informatics	1	.	..	Contact stud04

Business School

LVL	NAME	COURSE	CONTACT	BOOKS	CWK	
.	stud01	MBA	1	.	..	Contact stud01
.	stud03	Business	1	.	..	Contact stud03

Step Time: 2

(a) Student Registration

Computer Science

LVL	NAME	COURSE	CONTACT	BOOKS	CWK	
.	stud02	Business and IT	5	Programming	BIT_MCW1.	Contact stud02
???	stud04	Business Informatics	3	.	..	Contact stud04

Business School

LVL	NAME	COURSE	CONTACT	BOOKS	CWK	
.	stud01	MBA	3	Management	..	Contact stud01
.	stud03	Business	2	.	..	Contact stud03

Step Time: 5

(b) Missing Coursework

Computer Science

LVL	NAME	COURSE	CONTACT	BOOKS	CWK	
.	stud02	Business and IT	5	Programming	BIT_MCW2, BIT_MCW1.	Contact stud02
!!!	stud04	Business Informatics	3	.	..	Contact stud04

Business School

LVL	NAME	COURSE	CONTACT	BOOKS	CWK	
???	stud01	MBA	4	Management	.MCW1	Contact stud01
!!!	stud03	Business	2	.	..	Contact stud03

Step Time: 11

(c) Business Goal in Jeopardy

Computer Science

LVL	NAME	COURSE	CONTACT	BOOKS	CWK	
.	stud02	Business and IT	5	Programming	BIT_MCW2, BIT_MCW1.	Contact stud02
???	stud04	Business Informatics	3	.	..	Contact stud04

Business School

LVL	NAME	COURSE	CONTACT	BOOKS	CWK	
???	stud01	MBA	4	Management	.MCW1	Contact stud01
!!!	stud03	Business	2	.	..	Contact stud03

Step Time: 11

(d) Manual Override

Figure 5: Simulation

messages; Java serialization is used to pass information and global naming is used to manage component identities.

7. REFERENCES

[1] M. Lankhorst, "Introduction to enterprise architecture," in *Enterprise Architecture at Work*, ser. The Enterprise Engineering Series. Springer Berlin Heidelberg, 2009.

[2] B. Michelson, "Event-driven architecture overview," *Patricia Seybold Group*, 2006.

[3] G. Sharon and O. Etzion, "Event-processing network model and implementation," *IBM Systems Journal*, vol. 47, no. 2, pp. 321–334, 2008.

[4] S. Overbeek, B. Klievink, and M. Janssen, "A flexible, event-driven, service-oriented architecture for orchestrating service delivery," *IEEE Intelligent Systems*, vol. 24, no. 5, pp. 31–41, 2009.

[5] M. Assmann and G. Engels, "Transition to service-oriented enterprise architecture," *Software Architecture*, pp. 346–349, 2008.

[6] D. Barry, *Web services and service-oriented architecture: the savvy manager's guide*. Morgan Kaufmann Pub, 2003.

[7] G. Wang and C. Fung, "Architecture paradigms and their influences and impacts on component-based software systems," 2004.

[8] L. David, "The power of events: an introduction to complex event processing in distributed enterprise systems," 2002.

[9] A. Buchmann and B. Koldehofe, "Complex event processing," *it-Information Technology*, vol. 51, no. 5, pp. 241–242, 2009.

[10] J. Agrawal, Y. Diao, D. Gyllstrom, and N. Immerman, "Efficient pattern matching over event streams," in *Proceedings of the 2008 ACM SIGMOD international conference on Management of data*. ACM, 2008, pp. 147–160.

[11] D. Robins, "Complex event processing," 2010.

[12] C. Zang and Y. Fan, "Complex event processing in enterprise information systems based on rfid," *Enterprise Information Systems*, vol. 1, no. 1, pp. 3–23, 2007.

[13] E. Wu, Y. Diao, and S. Rizvi, "High-performance complex event processing over streams," in *Proceedings of the 2006 ACM SIGMOD international conference on Management of data*. ACM, 2006, pp. 407–418.

[14] A. Paschke, A. Kozlenkov, and H. Boley, "A homogeneous reaction rule language for complex event processing," *Arxiv preprint arXiv:1008.0823*, 2010.

[15] J. Cheesman and J. Daniels, *UML components*. Addison-Wesley, 2001.

[16] D. Lienhart, "Softbench 5.0: The evolution of an integrated software development environment," *Hewlett Packard Journal*, vol. 48, pp. 6–7, 1997.

[17] A. Barros, G. Decker, and A. Grosskopf, "Complex events in business processes," in *Business Information Systems*. Springer, 2007, pp. 29–40.

[18] E. Deeson, "The e-revolution and post-compulsory education–by boys, jos & ford, peter," *British Journal of Educational Technology*, vol. 39, no. 4, pp. 750–750, 2008.