A model based approach to systems requirements for event driven enterprise architecture

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Abstract

Business and ICT strategic alignment remains an ongoing challenge facing organizations as they react to changing requirements by adapting or introducing new technologies to existing infrastructure. Activity around Enterprise Architecture (EA) has increasingly become relevant to these demands and as a consequence numerous methods and frameworks for pursuing EA have emerged. However these approaches remain bloated, time-consuming and lacking in precision. This paper proposes a light-weight method for enterprise architecture and introduces a language for representing EA components that lends itself to modeling "As Is" and "To Be" EA with a concrete aim to providing a simulation environment that delivers an un-ambiguous description to what changes need to be made to an EA with respect to emerging requirements. The LEAP method and the language is illustrated with a detailed case study of business change currently being addressed by UK higher education institutions.

Categories and Subject Descriptors D.2.1 [*Requirements*]: [languages, methodologies]; D.3.1 [*Specification*]: Specifications—methods, languages, methodologies

General Terms Languages, Enterprise Architecture, Models

1. Introduction

Enterprise Architecture (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."[10]

A key objective of EA is being able to provide a holistic understanding of all aspects of a business, connecting the business drivers and the surrounding business environment, through the business processes, organizational units, roles and responsibilities, to the underlying IT systems that the business relies on. In addition to presenting a coherent explanation of the *what*, *why* and *how* of a business, EA aims to support specific types of business analysis including: alignment between business functions and IT systems; business change describing the current state of a business (as-is) and a desired state of a business (to-be); maintenance the de-installation and disposal, upgrading, procurement and integration of systems including the prioritization of maintenance needs; quality by managing and determining the quality attributes for aspects of the business such as security, performance to ensure a certain level of quality to meet the needs of the business; acquisition and mergers describing the alignment of businesses and the aspects on both when they merge; compliance in terms of a regulatory framework, e.g. Sarbanes-Oxley; strategic planning including corporate strategy planning, business process optimisation, business continuity planning, IT management [2, 7, 9, 12, 15].

EA has its origins in Zachman's original EA framework [20] while other leading examples include the Open Group Architecture Framework (TOGAF) [17] and the framework promulgated by the Department of Defense (DoDAF) [19]. In addition to frameworks that describe the nature of models required for EA, modeling languages specifically designed for EA have also emerged.

A number of specialized modeling notations have been proposed for EA modeling. In most cases these notations provide a number of views or layers that capture the enterprise from different perspectives. The notations provide domain specic modeling languages (DSMLs) for EA and as such provide a good conceptual t to the problem of representing EA domain elements and their relationships. A representative example of such a DSML is ArchiMate[8]. Accompanying methods for EA have emerged but remain mired in lack of adoption, and a sense of bloatedness. Riege et al note the evolving nature of method requirements and the need to tailor methods for specific scenarios[15]. Methods, where they have been used, tend to be available as overarching large frameworks (similar to TOGAF) often located within consulting divisions of large corporations. Examples of such methods include: the Oracle Enterprise Architecture Framework`http://tinyurl.com/bpzo2u2` and IBM's EA Consulting Method `http://tinyurl.com/cr4ph5m`. Both while attempting to be lightweight present large all-encompassing approaches to EA.

One area which existing method frameworks are not able to easily examine and address in a lightweight manner is the need to understand how to change an EA to meet a new requirement. Drilling down, the potential impact and change required would need to be promulgated as an impact analysis, a sliced view of the EA (of the systems affected), a gap analysis of missing functions and most importantly an equivalence analysis of an existing system and proposed changes. Method frameworks that have largely presented layered architectural models do not necessarily lend themselves to this type of modeling and analysis. Furthermore their bloated and document driven nature presents additional issues of complexity and places significant workloads on enterprise architects and those tasked with managing systems in large organization. The requirements for a lightweight method were discussed in detail in an earlier paper[5].

Another aspect that has potential to influence the use of an EA to address use case such as measuring alignment between business and IT, business change or integration of new systems is the different architectural styles that may be prevalent in a single organization. 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 [11] and [16], 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[14]. 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 [1] 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. Elsewhere we have described in detail the technologies for integrating EDA and SOA. [ref]. In that paper we presented a unified language for modeling architectures, a corresponding simulation language and an environment for exploring simulations. We use that technology supported a light weight method.

Our contribution in this paper is to provide an agile method for Enterprise Architecture that utilizes an integrated set of concepts derived from SOA and complex event processing that could easily be used as a standalone EA method or be integrated into larger EA frameworks. The underpinning concepts are well-formed with precise semantics that supports simulation of EA requirements. Of particular note, is that one of the key requirements facing enterprise architects, namely how to understand the mapping and therefore the solution space from an as is to a to be architecture is achieved through equivalence modeling. Our method is validated through the use of a case study that is based on genuine requirements facing IT directors in all UK higher education institutions in 2012.

Our intention is that readers understand the method and its application easily so we have chosen to integrate the method and illustrations of its use by drawing upon the case study. Thus the paper is structured as follows. Section II introduced the case study and presents the method firstly in overview form. Section II then continues to describe an experiment of the usage of aspects of the method in detail with illustrations of models derived from the case study. Section III provides a discussion of this experiment and Section IV concludes with an indication of future work.

2. A Lightweight Method for Event Driven EA

In this section we introduce our Lightweight EA method (LEAP) and the key technology concepts required for supporting agile EA development.

As we indicated in section, the motivation for developing a method to support EA was driven from our knowledge and experience of the prevailing EA methods, namely that existing methods were large, cumbersome, lacking agility and not based on well-defined concepts. Where methods have used modeling languages such as Archimate, the methods by being constrained by orthodox layering approaches (business layer, functional layer, deployment layer and so on), the layers prevented rigorous equivalence modeling in order to identify changes and new additions to an EA. The method in its simplicity also utilizes existing techniques and approaches as appropriate.

The figure below provides an overview of our proposed method.

Consisting with most approaches to EA methods where there is need to describe As Is and To Be models, there are two streams of activity which converge at key stages. The "To Be" analysis stream includes activities to **Model Requirements**. We do not prescribe how you might wish to derive the requirements in order to produce a model of requirements but as our method is based on UML, models will include artifacts such as business information models, process models and business use case models. Existing method approaches such as Catalysis [6] and its derivatives [4]could be used for developing information models whilst recommended approaches for process modeling could include Ould's approach [13].

In parallel to the **Model Requirements** step, the activities in the **Collate Physical Architecture** stage will bring together existing descriptions of systems and their configurations. Our experience of such descriptions are large pictorial based documentation captured using drawing tools such as Powerpoint. A key output of this stage is a description of the systems that exist in the organization. We recommend capturing the description of each system as UML Component to aid the migration to later stages of the method. Again, the method does not prescribe new approaches, it leaves it to the practitioner to determine how to produce the artifacts required.

The **Configure Physical Architecture** step is an agile and simple way of slicing a description of an EA to determine what system components are likely to be impacted by emerging requirements. Techniques that can be used to support this impact analysis includes use case maps[3]. A use case map is simply a trace of path of causal sequences of events across a set of system components representing an EA. The events are triggered by a business use case identified in the Model Requirements step. Alternative approaches that could be used in this step could be the use of CRC to help identify those system components that are (collaboratively) responsible for delivering a business use case[18]. The key output from this activity is an artifact expressed in system components that includes all the EA system elements that will be subject to some impact as a result of the emerging requirements.

Up to now, the steps in the method have utilized well-established notations and techniques. The subsequent steps in stage 2 incorporate an integrated set of concepts from SOA and complex event processing.

The **Define Logical Enterprise Architecture (L-EA)** step produces a model based description of a target logical EA - that is - the system components that are likely to be required as a result of the Model Requirements step. However, in recognition of the agile nature of the method, the Logical EA uses as a short cut, a candidate logical components from the Configure Physical Architecture step.

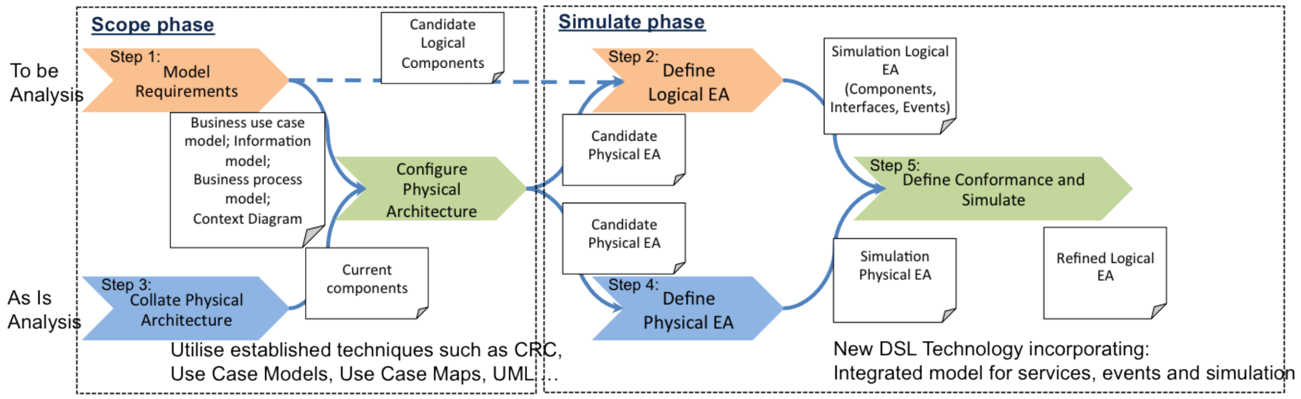

Scope phase
Simulate phase
To be Analysis
As Is Analysis
Step 1: Model Requirements
Candidate Logical Components
Business use case model; Information model; Business process model; Context Diagram
Configure Physical Architecture
Current components
Step 3: Collate Physical Architecture
Utilise established techniques such as CRC, Use Case Models, Use Case Maps, UML ...
Step 2: Define Logical EA
Simulation Logical EA (Components, Interfaces, Events)
Candidate Physical EA
Candidate Physical EA
Step 4: Define Physical EA
Step 5: Define Conformance and Simulate
Simulation Physical EA
Refined Logical EA
New DSL Technology incorporating: Integrated model for services, events and simulation

Figure 1: Method Overview

The Logical EA (L-EA) uses our integrated concepts derived from SOA and complex event modeling so the L-EA is expressed as components offering services, raised events, requested services and listened to events. Dependencies between components are thus expressed in terms of services request and fulfilments and event management.

The **Conformance** step uses simulation to produce and visualize results. The logical architecture describes what is required and the physical to-be architecture defines how existing systems can be used to satisfy the requirements. It remains to validate the physical architecture by showing that the behavior conforms to the requirements. If the simulation produces the same output when it is run with both the logical and physical definitions for `university` on a sufficiently large representative sample of data sets then we have confidence that the physical conforms to the logical. Such an approach presents a practical solution that is geared toward EA practitioners. Our EA design method produces a context and both a logical and a physical architecture description using the LEAP language.

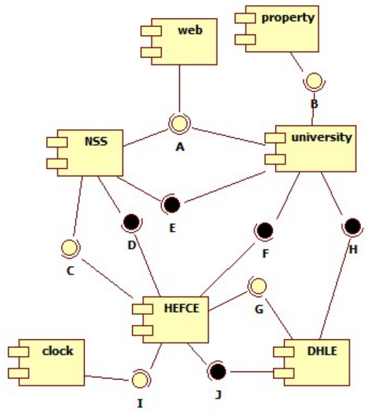


Figure 2: Context Diagram

3. Evaluatory Experiment

Having outlined the method and concepts, this section presents a genuine requirement faced by IT directors in UK higher education institutions to deliver key information sets (KIS) to applicants deciding on which course and which university to chose for study at under graduate level.

3.1 Case study description

Higher education institutions (HEI) in the UK are faced with a challenging and dynamic business environment where public funding of HEIs has been reduced by up to 70%. This lost funding is being replaced by the introduction of a new student fees regime beginning in 2012 following a bill introduced in the UK parliament in November 2010. The UK Government is of the view that students will require key information in order to make informed decisions regarding the selection of courses and institutions. Currently this information is not readily available in a consistent and easily accessible form. Consequently the Higher Education funding body (HEFCE) is coordinating the specification of the required information and how it is to be made available and at what time.

Briefly: HEFCE produces KIS data at a given census date each year. In order to be included in KIS, each university must register with both the NSS and DHLE government agencies before the census date. KIS information consists of NSS data, teaching and learning data from each university, financial data from each university (including university owned and private accommodation costs), employability data from the DHLE agency.

The NSS data is completed by students via a web portal. The details of the information go to the NSS agency and the university is informed of the completion for their records. Private property prices within the geographic area around the university are captured by monitoring RSS feeds from property companies.

Business requirement of KIS, HEFCE, UK etc. overview of requirement. <<STUFF HERE: SAMIA?>>

4. Applying LEAP

This section takes the reader through the key steps of the method. We provide illustrations of the use of the LEAP method from models constructed from the case study.

4.1 Step 1: Model Requirements

4.1.1 Contextual Analysis

Figure 2 shows the context of the KIS case study in terms of the systems that must interact with any university. Components offer interfaces represented by filled circles. Components can raise events and can also listen for events; this is represented by open circles. The context in which a university must satisfy the KIS requirements is described in terms of messages and events as described in the rest of this section.

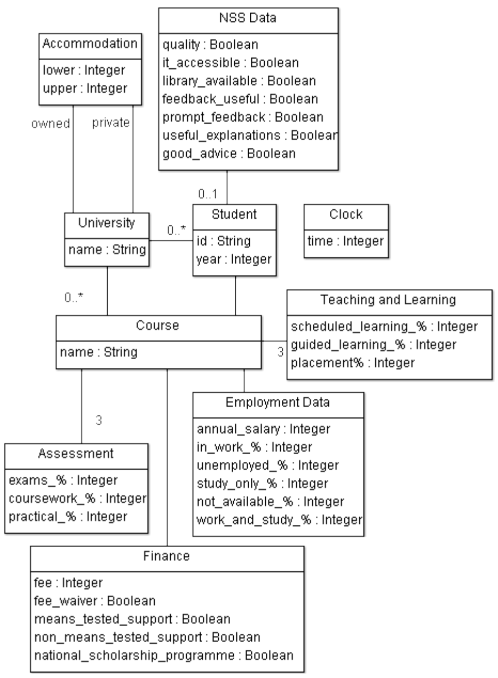


Figure 3: Information Model

A student uses a web-portal (web) to complete the NSS survey on-line. When this occurs an event is raised (A); the NSS government agency handles the event by recording the NSS data; the university simply records that a student has completed the survey.

A university must maintain information about the prices of private property in the local area. This is achieved via an RSS feed (property) that regularly generates an event (B) that is recorded by the university.

In order to participate in KIS, each university must register with both the NSS and DHLE agencies. Therefore, both agencies provide operations (E and H) for registration that cause a registration event to be raised (G and C). The registration events are processed by HEFCE *in any order*; both must be received before the KIS census date.

The KIS census date causes a timing event (I) that is processed by HEFCE causing it to request data necessary to build a KIS report. The NSS, University and DHLE components provide suitable operations (D, F and J) for requesting data.

4.1.2 Information Model

Figure 3 shows the information model for the logical architecture. Each University has a number of students with unique identifiers and in a particular year of study. Information is maintained on the cost of both University owned accommodation and private accommodation in the area. A student studies a course and optionally completes an NSS return in their third year of study; the NSS form allows students to comment on the quality of the University's provision of teaching and learning in terms of questions such as: '*Do you agree that you receive prompt feedback on formative assessments?*'. Each course is delivered in terms of scheduled, guided and practical teaching and learning components, and assessed in terms of exams, courseworks and practicals. Information is maintained nationally about employment statistics for particular courses, such as the salary of graduates and the percentage who are in work or unemployed 6 months after graduation. Each HE course in the UK has a cost and may involve various forms of financial support.

4.1.3 Component Specification

The LEAP simulation language uses components, records, operations and events to model an EA. Figure 4 uses these concepts to elaborate the components from the context diagram in figure 2 using the information concepts from figure 3. Each diagram shows an individual component (identified using the stereotype `<<component>>`), its associated data model, the events it expects (`<<eventin>>`), the events it produces (`<<eventsout>>`) and the operations that it supports.

Note that several information concepts occur in more than one component. In all cases, information is private to a component, and a system invariant is required if the information is to be consistent. For the purposes of our case study, full information on courses and students is maintained by the university and all other references to these concepts are the unique identifier.

4.2 Step 2: Define L-EA

4.2.1 Simulation Language

A key feature of approach is to simulate both a logical and a physical architecture in terms of components, operations and events. To achieve this we have implemented a simulation language as a Java interpreter. A simulation model consists of a collection of component definitions of the following form:

```
component name (montored components) {
  state { ...terms... }
  invariants { ...conditions... }
  operations { ...function definitions... }
  rules { ...rule definitions... }
  ...nested definitions...
}
```

Each component monitors the events raised by a list of named components. A component maintains a private state that is a list of terms (named records). The component defines an initial state and may add and delete terms. The invariant conditions are boolean expressions over the component's state; a message is displayed when an invariant becomes false. The operations of a component implement the business processes that form the component's interfaces; components invoke each other's operations by sending messages. A component monitors its state and the events it receives from components it monitors, using rules. Each rule has a collection of patterns that match the terms and events in the component's state. When all patterns are matched then the rule is ready to fire. The body of a rule is an action that can involve modifying the state or sending messages.

To save space in the rest of the paper we will not give the complete definition of each component. Instead, we will provide those elements of the `state`, `invariants`, `operations` and `rules` sections that are essential to understanding how the simulation works.

4.2.2 Context L-EA

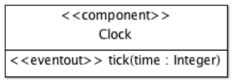
The following components define part of the logical EA that provides the context for simulating the university component.

Clock The initial state of a clock is the term `Time(0)`. The clock provides a single operation that is used to drive the simulation. The operation provides an example of a `new` command that adds a new term to the state of the component:

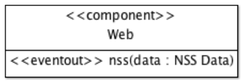
```
tick() { new Tick() }
```

A clock has a single rule that fires when the clock ticks. It increments the time and raises an event `Time(n)`, note the use of `delete` and `raise` to remove a term from the state of a component and to raise an event:

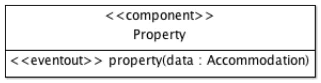
```
tick: t1=Tick() t2=Time(n) {
  delete t1,t2;
```



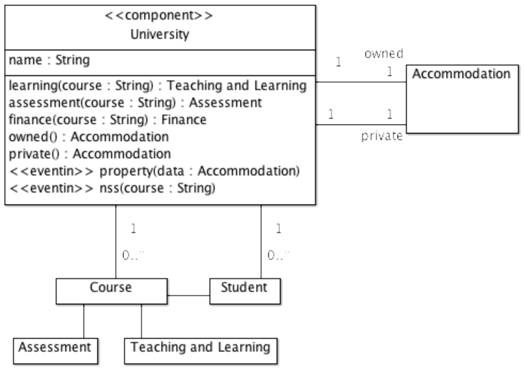
(a) Clock



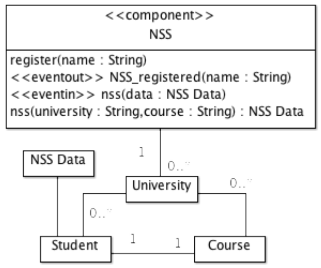
(b) Online NSS Portal



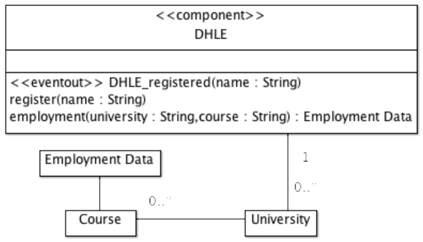
(c) Property RSS Feed


<<component>>
University
name : String
learning(course : String) : Teaching and Learning
assessment(course : String) : Assessment
finance(course : String) : Finance
owned() : Accommodation
private() : Accommodation
<<eventin>> property(data : Accommodation)
<<eventin>> nss(course : String)
owned
1
1
1
1
private
Accommodation
1
0..*
1
0..*
Course
Student
Assessment
Teaching and Learning

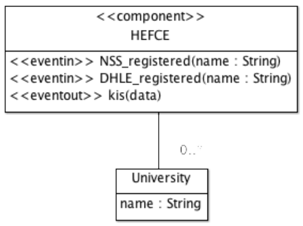
(d) University


<<component>>
NSS
register(name : String)
<<eventout>> NSS_registered(name : String)
<<eventin>> nss(data : NSS Data)
nss(university : String,course : String) : NSS Data
NSS Data
1
0..*
University
0..*
0..*
Student
1
1
Course

(e) NSS


<<component>>
DHLE
<<eventout>> DHLE_registered(name : String)
register(name : String)
employment(university : String,course : String) : Employment Data
Employment Data
1
0..*
0..*
Course
University

(f) DHLE


<<component>>
HEFCE
<<eventin>> NSS_registered(name : String)
<<eventin>> DHLE_registered(name : String)
<<eventout>> kis(data)
0..*
University
name : String

(g) HEFCE

Figure 4: Components

```
  raise Time(n);
  new Time(n+1)
}
```

NSS Web Portal A student uses the NSS web portal to complete the NSS survey. For simulation purposes the initial state of the web component contains terms defining the times at which students complete the survey, and the answers to the questions:

```
NSS(1,'s01','p01',true,true,true,true,true,true,false)
...
```

The web component monitors the clock events and has a single rule that raises two events when a student completes a survey. The first event is processed by the NSS agency and the second is processed by the university:

```
step: Time(t)
      NSS(t,id,cid,qual,it,lib,help,prompt,expl,advice) {
  raise NSS(id,cid,qual,it,lib,help,prompt,expl,advice);
  raise NSS_complete(id)
}
```

Property RSS Feed The property component simulates an RSS feed that supplies bounds on annual rental costs. The initial state is a collection of terms describing the times at which the data becomes available:

```
Property_Feed(5,6500,9750)
...
```

The property component monitors clock events and raises an event when the appropriate time is reached using the following rule:

```
tick: Time(n) Property_Feed(n,low,high) {
  raise Property(low,high)
}
```

Employment Data The DHLE agency is responsible for maintaining employment data on universities and courses. For the purposes of the simulation all employment data is part of the initial state:

```
Employment('UME','p01',21000,94,2,1,1,2)
...
```

The DHLE component implements an operation that allows a university to register. It raises an event when this occurs:

```
register(university) {
  new University(university);
  raise DHLE_Registered(university)
}
```

HEFCE will request employment data when it constructs a KIS report. The operation provides an example of the `find` construct that is used to select an element from a list (in this case the state of DHLE) that matches a pattern; the body of the `find` expression returns a new term:

```
employment(uni,course) {
  find Employment(uni,course,s,w,u,so,na,was) in state {
    Employment(s,w,u,so,na,was)
  }
}
```

National Student Survey The NSS component provides an operation for registering a university:

```
register(university) {
  new University(university);
  raise NSS_Registered(university)
}
```

The HEFCE component uses the following operations to request KIS data from the NSS component. In each case a list-comprehension is used, for example `[id | NSS(id,course,true,_,_,_,_,_,_) <- state]` processes each element of `state` in turn, matches it against the pattern `NSS(id,...)` and returns the `id` of each element that matches:

```
quality_score(course) {
  length([id | NSS(id,course,true,_,_,_,_,_,_) <- state])
}
it_score(course) {
  length([id | NSS(id,course,_,true,_,_,_,_,_) <- state])
}
```

The following NSS rule is used to handle the event raised by the NSS web portal:

```
nss : NSS(id,course,qual,it,lib,help,prompt,expl,advice) {
  new NSS(id,course,qual,it,lib,help,prompt,expl,advice)
}
```

4.2.3 HEFCE

HEFCE has a census date:

```
KIS_census(10)
```

In order for a university to be registered with HEFCE, it must have registered with both the NSS and DHLE components in any order as defined by this rule:

```
university: NSS_Registered(name) DHLE_Registered(name) {
  new University(name)
}
```

When the census date is reached the HEFCE component will make calls on NSS, University and DHLE components to get the KIS data:

```
kis: Time(t) KIS_census(t) {
  get_kis_data()
}
```

4.2.4 University L_EA

The component definitions above provide the context for the logical definition of a university given in this section. The initial state of a university is shown below. It defines several distinct types of information: the times at which the university registers with the government agencies; the financial, teaching and learning, and assessment patterns for each course; the cost of university owned accommodation; the cost of private accommodation; student records that assign a unique id to each student, assign them to a course, define their year of study and record whether or not they have completed the NSS survey:

```
Register(nss,2)  // Register with NSS at time 2.
Register(dhle,3) // Register with DHLE at time 3.

Course('p01',8500,true,false,true,false)
Learning('p01',[60,30,35],[20,20,50],[20,50,15])
Assessment('p01',[70,50,50],[10,20,30],[20,30,20])
...

Lower_Accommodation(7000)
Upper_Accommodation(9600)

Lower_Private(0)
Upper_Private(0)

Student('s01','p01',3,false)
Student('s02','p01',3,false)
...

NSS_census(5)
```

A university includes a number of invariant conditions that must be met at all times. The following is an example called `assessments` that requires the split between %-age values for examinations, courseworks and practicals in any given year to add up to 100% for each course. The condition uses the `forall` expression that matches a pattern against all elements in a list; the body of the `forall` must return `true` for each element in the list that matches the pattern (`trans` is defined in the operations section below):

```
assessments {
  forall Assessment(course,exams,coursewks,pracs) in state {
    forall [e_pc,c_pc,p_pc] in trans([exams,coursewks,pracs]) {
      (e_pc + c_pc + p_pc) = 100
    }
  }
} else 'all assessments must add up to 100 in each year.'
```

A second invariant encodes a business requirement that 50% of all students registered for a course must complete the NSS survey in year 3:

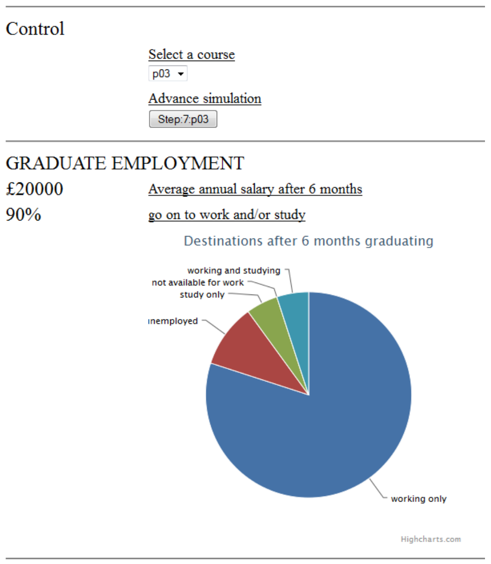
```
nss_50_per_course {
 forall Course(id,_,_,_,_,_) in state {
  find UniTime(t) in state {
   find NSS_census(t) in state {
    let nss = length([id | Student(_,id,3,true) <- state]);
        students = length([id | Student(_,id,3,_) <- state])
    in if students = 0 then true else ((nss/students)*100) > 50
   } else true
  } else true
 }
} else ' 50% of all students must complete the NSS.'
```

A *transposition* of a list of lists `[[a,b,c],[g,h,i],[x,y,z]]` is `[[a,g,x],[b,h,y],[c,i,z]]` and is defined using a recursive function as follows:

```
trans(lists) {
  if exists l in lists { l = [] }
  then []
  else [ head(l) | l <- lists ] : slice([ tail(l) | l <- lists ])
}
```

The following operations are used by HEFCE to access the data necessary in a university to produce the KIS report:

```
learning(course) {
  case find Learning(course,_,_,_) in state {
    Learning(n,sched,guided,plmnt) -> Learning(sched,guided,plmnt)
  }
}
assessment(course) {
  case find Assessment(course,_,_,_) in state {
    Assessment(n,exams,cw,pract) -> Assessment(exams,cw,pract)
  }
}
finance(course) {
  case find Course(name,_,_,_,_,_) in state {
    Course(n,f,fw,mt,nmt,sch) -> Finance(f,fw,mt,nmt,sch)
  }
}
```


Control

Select a course

p03

Advance simulation

Step:7:p03

GRADUATE EMPLOYMENT

£20000 Average annual salary after 6 months

90% go on to work and/or study

Figure 5: Simulation Part 1 (of 3)

A university has the following rules: `register` that registers with the appropriate government agencies when the appropriate time event occurs; `clock` that is used to keep a local record of time; `property` that is used to update the prices of private accommodation using events from the RSS feed; `nss` that is used to record the completion of an NSS survey by a particular student:

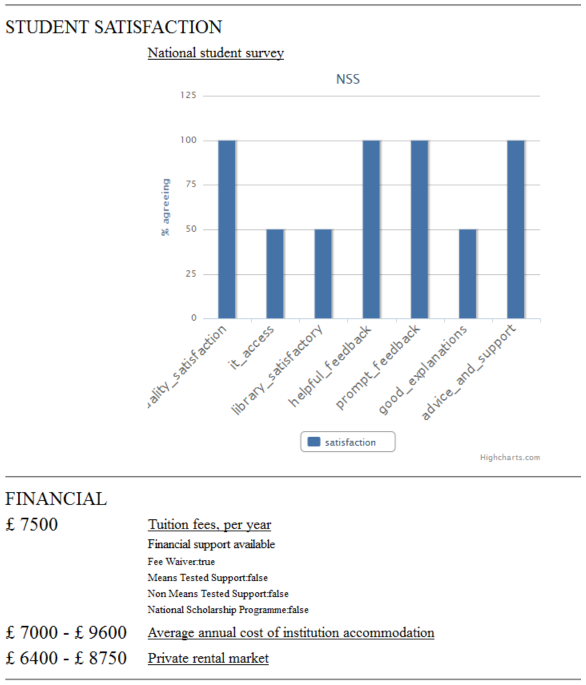
```
register: Register(target,time) Time(time) {
  send(target,'register',[self.name()])
}
clock: Time(time) {
   delete UniTime(time-1);
   new UniTime(time)
}
property: p=Property(low,high)
          l=Lower_Private(x) u=Upper_Private(y) {
   delete p,l,u;
   new Lower_Private(low),Upper_Private(high)
}
nss: NSS_completed(id) s=Student(id,course,3,false) {
   delete s;
   new Student(id,course,3,true)
}
```

4.2.5 Simulation

Our approach uses simulation to show that a physical architecture is consistent with the behavior required by a logical architecture. The SLEAP language for the KIS context and logical architecture has been defined in previous sections. SLEAP also provides features for generating a GUI that can be deployed on a web server and accessed via a web browser. We do not show the SLEAP code for the KIS GUI, but the output is shown in figures 5 to 7. The control section in 5 is used to step through the simulation by sending `tick()` messages to the `clock`. The `step` button shows the current time and the currently selected course; the rest of the GUI show KIS information for the course.

4.3 Step 3: Collate Physical-EA

The next step of our method involves reviewing the current physical as-is system architecture. Most organizations have a systems overview which is used as the input to this step. The result is an understanding of the currently capability of the organization in terms of systems, interfaces, information and events.


STUDENT SATISFACTION

National student survey

FINANCIAL

£ 7500 Tuition fees, per year

Financial support available

Fee Waiver:true

Means Tested Support:false

Non Means Tested Support:false

National Scholarship Programme:false

£ 7000 - £ 9600 Average annual cost of institution accommodation

£ 6400 - £ 8750 Private rental market

Figure 6: Simulation Part 2 (of 3)

We will use the University of Middlesex (Mdx), London, UK as the basis for our case study. Space limitations prevent us from providing a complete description of the Mdx physical architecture, however it is consistent with most UK HEIs and includes systems for registry, an asset management system that includes a sub-system for university accommodation, an examinations database, a library system, a financial management system called PAFIS, a teaching and learning system called OASIS, an alumni management system, a student portal, and a staff portal.

4.4 Step 4: Configure Physical-EA

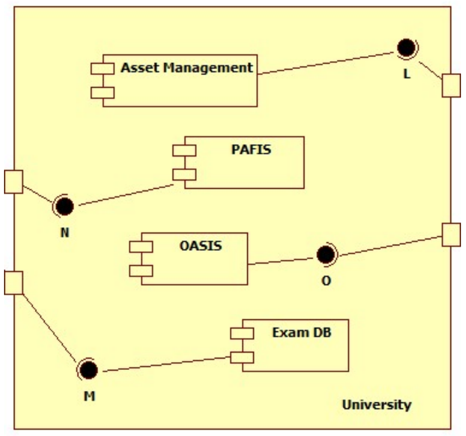
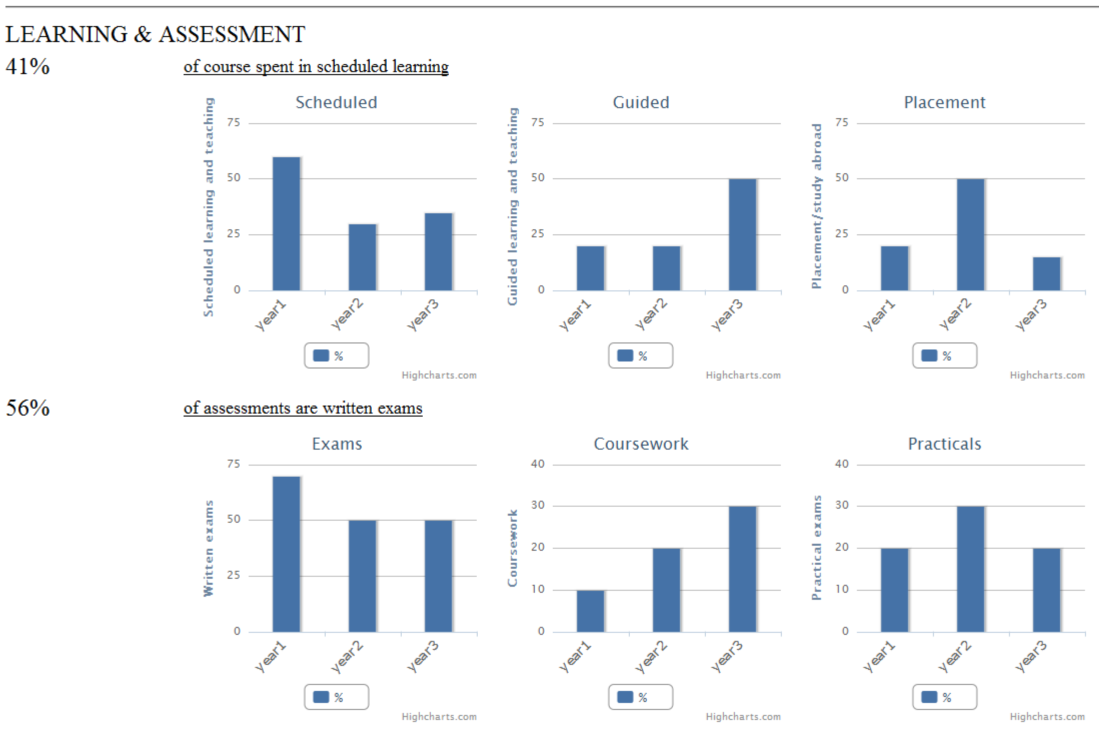


Figure 8: Physical Architecture

The next step of the method analyses the physical system of an organization and takes an appropriate *slice* to produce just those systems that will be involved in the required to-be architecture. In the case of supplying KIS data, we know that Mdx will need


LEARNING & ASSESSMENT

41% of course spent in scheduled learning

56% of assessments are written exams

Figure 7: Simulation Part 3 (of 3)

to provide student, accommodation, teaching and learning, assessment and financial information. Therefore, for example the P-EA will not include the alumni or library management systems.

The P-EA for Mdx is shown in figure 8 where interfaces have been introduced that support the appropriate delegation of the operations defined by the university component defined in section 4.2.4. The next section defines the components using SLEAP.

4.5 Step 5: Define Physical-EA

The previous section has identified the slice of the Mdx systems that are required to support the KIS case study. This section defines each component using SLEAP.

The asset management system must provide an interface for accommodation pricing:

```
component asset_management() {
  state {
    Lower_Accommodation(7000)
    Upper_Accommodation(9600)
  }
  operations {
    lower_accommodation() {
      find Lower_Accommodation(cost) in state { cost }
    }
    ...
  }
}
```

The part of the assessment information that was handled by the university in section 4.2.4 is delegated to the exams database:

```
component exam_db() {
  state { Exam('p01',[70,50,50]) ... }
  operations {
    find_exams(name) { find Exam(name,exams) in state }
  }
}
```

The Mdx financial management system PAFIS is used to handle information about course costs and support:

```
component pafis() {
  state { Course('p01',8500,true,false,true,false) ... }
  operations {
    finance(course) {
      case find Course(course,_,_,_,_,_) in state {
        Course(n,f,fw,mt,nmt,sch) -> Finance(f,fw,mt,nmt,sch)
      }
    }
  }
}
```

The Mdx teaching and learning system OASIS is used to handle the teaching and assessment patterns:

```
component oasis() {
  state {
    Learning('p01',[60,30,35],[20,20,50],[20,50,15])
    ...
    Assessment('p01',[10,20,30],[20,30,20])
    ...
  }
  operations {
    find_learning(name) { find Learning(name,_,_,_) in state }
    find_assessment(name) { find Assessment(name,_,_) in state }
  }
}
```

The definition of University is then modified to include the components defined above as sub-definitions. The resulting component is the physical architecture description of University and must include some new invariants. Firstly, information about courses is now distributed amongst a number of systems. We must ensure that the information is consistent, therefore we introduce a new university invariant `conformance` (`seteq14` is a predicate that holds between four lists when they all have the same elements):

```
conformance {
  seteq14(
    [id | Exam(id,_) <- exam_db],
    [id | Assessment(id,_,_) <- oasis],
    [id | Learning(id,_,_,_) <- oasis],
    [id | Course(id,_,_,_,_,_) <- pafis])
  } else 'inconsistent course information.'
```

Finally, information about assessment for a given course must add up to 100% in any year. The information is distributed between the OASIS and exams systems:

```
assessments {
  forall Assessment(course,coursewks,pracs) in oasis {
    forall Exam(course,exams) in exam_db {
      forall [e_pc,c_pc,p_pc] in slice([exams,coursewks,pracs]) {
        (e_pc + c_pc + p_pc) = 100
      }
    }
  }
} else 'all assessments must add up to 100 in each year.'
```

4.6 Step 6: Conformance

Our EA design method produces a context and both a logical and a physical architecture description using the LEAP language. The logical architecture describes what is required and the physical to-be architecture defines how existing systems can be used to satisfy the requirements. It remains to validate the physical architecture by showing that the behavior conforms to the requirements.

In general, conformance can be established using a number of approaches. The context defines a collection of system executions in terms of messages, events and state changes. It is possible to use inspection-based techniques to show that all required executions are handled appropriately by the physical architecture.

More precise approaches are possible. For example, we can define mappings from the physical architecture components to the logical architecture. In the case of the Mdx architecture, the `asset_management`, `exam_db`, `pafis` and `oasis` components are merged to become a single top-level `university` component. Providing that all operations, events and invariants are consistent then the physical architecture is conformant.

Another approach is to rely on simulation. SLEAP can be used to run the simulation to produce GUI output as defined in figures 5 to 7. If the simulation produces the same output when it is run with both the logical and physical definitions for `university` on a sufficiently large representative sample of data sets then we have confidence that the physical conforms to the logical. When we run the simulation with both definitions of university given in this paper, the output is the same.

Finally, if we require total confidence in conformance then we need to resort to formal methods such as model checking and theory proving. For large systems such as those found in EA, formal methods are often impractical in terms of complexity. That said, a formal semantics for SLEAP is an area fro future development in order to investigate whether formal methods could help.

5. Conclusion

Enterprise Architecture remains a confusing and constantly evolving collection of methods and frameworks which are generally characterized by an expansive outlook, lack of precision, a focus on diagrams and an emphasis on document management. The result is that existing approaches are difficult to use. This paper has presented an effort to reduce the scope of EA in order to pin down the core use cases of managing change and better understanding the impact of changing requirements on existing technical architectures of an organization. We have proposed a light weight EA method and its accompanying language that supports precise description of “To be” and “As is” EA. The language by virtue of its design can be used with a simple java based simulation environment to experiment with conformance of proposed EA changes. We recognise that there are several limitations with our current proposal but we have demonstrated using a detailed case study that there is merit and considerable potential in using such an approach understanding and managing EA.

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