The Narrative Approach to Personalisation

Owen Conlan, Athanasios Staikopoulos, Cormac Hampson, Séamus Lawless and Ian O'Keeffe

Knowledge and Data Engineering Group,

School of Computer Science and Statistics,

Trinity College Dublin, Ireland

Owen.Conlan@scss.tcd.ie

The Narrative Approach to Personalisation

This article describes *The Narrative Approach to Personalisation*. This novel approach to the generation of personalised adaptive hypermedia experiences employs runtime reconciliation between a personalisation strategy and a number of contextual models (e.g. user and domain). The approach also advocates the late binding of suitable content and services to the generated personalised pathway resulting in an interactive composition that comprises services as well as content. This article provides a detailed definition of the Narrative Approach to Personalisation and showcases the approach through the examination of two use-cases: the personalised digital educational games developed by the ELEKTRA and 80Days projects; and the personalised learning activities realised as part of the AMAS project. These use-cases highlight the general applicability of the narrative approach and how it has been applied to create a diverse range of real-world systems.

Keywords: personalisation, narrative, adaptive hypermedia

1. Introduction

Personalisation attempts to ensure that content and services are tailored to individual users' personal preferences, goals and context while at the same time making the reuse of such media easier (Brusilovsky *et al*. 2007). Personalisation not only enhances the user's experience, but also assists content and service providers in dynamically (and automatically) repurposing their offerings for different users or contexts – thus making reuse more easily achieved. Typically, personalised information portals have tended to focus on the tailored identification and ranking of relevant content or services (Agichtein 2006, Teevan 2005, Dou 2007) or simplistic 'personalisation' of the content presentation by including the user's name, historical information/recently used references, or simple augmentation of screen layout (Ankolekar 2007). However, some adaptive web systems, particularly in application domains such as Education, and Tourism have attempted to provide deeper, more sophisticated personalisation (Grapple

2011, Brusilovsky 2007, Conlan *et al*. 2003). Such systems have achieved adaptive content selection, composition and navigation (Wade 2009). However, reusing existing content and services in realising personalised systems still presents a significant problem, as the majority of such personalised systems use bespoke or 'tailor-made' content and services.

Over the last thirteen years the Knowledge and Data Engineering Group of Trinity College, Dublin has been developing and evolving *The Narrative Approach to Personalisation* which seeks to address the limitations of the approaches to personalisation described above (Conlan 2001). The narrative approach supports the creation of adaptive systems that employ reconciliation with contextual models (e.g. user and domain) at runtime. The approach also advocates the late binding of content and services to the resulting personalised pathway. The term 'narrative' has been used to characterise this approach since its inception and was intended to represent the adaptive flow of concepts that are woven together to make a coherent offering to a user. This offering does not necessarily take the form of a traditional "storyline", but rather can be a conceptual or logical grouping of related resources.

The narrative approach has evolved over this period through PhD work and through several international research projects. The basis of the approach was explored as part of the European Commission-funded EASEL FP5 project (2000-2002) (Conlan *et al.* 2002). As part of this project a basic form of the approach, which included a concept level narrative, a Knowledge Space Theory (Albert 1994) inspired competence model for the user and a service-based deployment, was developed. This adaptive service could be launched from a learning management system (LMS) and used the AICC specification (AICC, 1999) to handle communication with the LMS.

The iClass FP6 project (2004-2008) (Turker *et al.* 2006) carried forward the work by introducing a higher degree of user scrutiny into the approach, thus facilitating personalised self-regulated learning (PSRL). iClass also expanded the number of constituent models that informed the narrative approach. This led to the first explicit separation of a pedagogical model from the concept model, as part of the narrative approach, thus enabling different pedagogies to be applied for different learners in the same concept space. Through self-regulation learners could examine and modify their models and (for advanced learners) determine which pedagogical approaches best suited their needs.

From here the application of the narrative approach was carried forward by two European Commission-funded projects in the area of game-based learning, ELEKTRA (2006-2008) (Conlan *et al.* 2009), and 80Days (2008-2010) (Conlan *et al.* 2012). This expanded the approach to handle highly dynamic, Digital Educational Game (DEG) settings with a high number of personalised decisions being made at runtime, thus moving beyond the application of the narrative approach in traditional Adaptive Hypermedia. In ELEKTRA the adaptive engine that was developed, continuously interpreted, modelled and evaluated the incoming information from the game engine in order to make personalised intentions. This form of micro adaptation was achieved in the context of highly dynamic gameplay, but was against the backdrop of a static storyline. 80Days introduced a dynamically evolving story that required balancing storytelling needs and learning objectives. The adaptive service worked in coordination with a storytelling engine to negotiate the balance of story and learning objectives, thus realising macro concept-level adaptation in a game setting. These projects and their influence on the narrative approach are detailed in this article.

The Science Foundation Ireland-funded AMAS project (2010-2014) (Staikopoulos *et al.* 2012), also described in this article, has expanded the approach to fully integrate learning services. This has enabled collaborative activities to be created where learners engage in learning activities and each other, whilst still benefitting from personalised support. In AMAS the narrative approach has been used to dynamically compose and reuse content and services to generate learning activities that meet the learning objectives of individual learners (Staikopoulos *et al.* 2012, O'Keeffe 2012).

Moving forward, the Centre for Next Generation Localisation (CNGL) research centre is further developing the narrative approach by researching the next generation of automatically harvested intelligent content that by be leveraged in a variety of contexts (Steichen 2011). The FP7 CULTURA project (Hampson *et al.* 2012) is investigating the interplay between narrative and an explorative research environment, where the guided narrative driven elements are used to introduce novice users to more complex concepts and themes in the information space they are exploring.

For all of these projects the resulting offerings may be considered as adaptive hypermedia with a variety of different media types and services also included in the personalised pathways. Some of these projects (80Days and ELEKTRA) had a specific focus on enhancing digital educational games (DEGs). The DEG domain has a strong correspondence to adaptive hypermedia, as adaptation and personalisation techniques are employed to guide users in a non-linear fashion to relevant content and activities, in order to enhance both their learning and gaming experiences. Generally, in the narrative approach, the result of the personalisation is an adaptive hypermedia navigation structure that combines content and services in accordance with a strategy and through the reconciliation of a suite of models. Through these disparate applications the broad applicability of the narrative approach to personalisation has been evaluated and proven.

Despite the large body of published work on the application of the narrative approach across a wide range of applications, no formal definition or exploration of the approach has ever been published. This article provides such a discrete definition and exploration of the Narrative Approach to Personalisation. It then showcases the approach through the structured description of two quite distinct use-cases: the personalised digital educational games developed in the ELEKTRA and 80Days projects; and the personalised learning activities realised as part of the AMASE system from the AMAS project. These use-cases highlight how the narrative approach has been applied to create real-world systems. The article continues with a discussion of the role of vocabulary in realising the narrative approach and then concludes with an outlook for the future of such systems.

2. The Narrative Approach to Personalisation

This article describes the Narrative Approach to Adaptive Hypermedia. The term 'narrative' was first used by the authors to characterise this approach in the year 2000 (Conlan 2000) and was intended to represent the adaptive flow of concepts that are woven together to make a coherent offering to a user. Individual concepts may be grounded with either content or services, or may be further refined with the execution of a sub-strategy. While the approach has been used in conjunction with storytelling techniques (as outlined in the ELEKTRA/80Days use case described later), it is primarily intended as a means of achieving appropriate micro and macro adaptations to fulfil a user's personal information need.

The narrative approach to personalization facilitates a powerful mechanism for offering adaptation that can alter and compose content, services or storylines across a variety of granularities. Moreover the narrative approach promotes a separation of concerns, e.g. concepts, models and logic that also empowers the authoring process, thus making adaptive experiences easier to create and recompose (Grapple 2011). This section defines narrative and the key constituents that make up the narrative approach to personalization.

2.1. Definition

*A narrative encapsulates strategies through which relationships between **concepts** in a domain are created and selected, in order to fulfil **objectives** within that domain. At design-time this **strategy (or strategies)** is **authored** in order to represent the variety of conceptual paths that comprise all potential experiences, and how models influence these paths. During execution, this strategy is **reconciled** with the appropriate **contextual models** (e.g. user model) to produce a conceptual pathway, tailored toward the specific instantiations of those models. The generation of each individual user's experience involves the runtime **binding** of specific content and services to concepts in this pathway, or the further refinement of a concept through sub-strategy.*

This definition introduces the high-level terms, shown in bold, that constitute the narrative approach. There are some inherent flexibilities in this definition, but so too are there a set of questions that should be answered in order to realize a specific adaptive system. For example, how is the objective, or objectives, expressed, and what is its relationship to both the domain concepts and strategy that aims to achieve it? What is the minimum set of models necessary to allow the strategy to make critical choices (conceptual and binding) in order to achieve the objective(s)? How are similar content and services differentiated such that binding may be realized? The following sections attempt to answer these questions and provide detail on the high-level terms highlighted in the definition of the narrative approach.

2.2. Concepts and Objectives

The concepts that make up a domain, including their description, hierarchy and relationships, are of particular importance to the narrative approach. The domain is considered to be the conceptual space in which the objectives of the experience being created are defined and has sufficient coverage, through concept relationships, to specify the likely start points from which a strategy may initiate an adaptive experience. The domain, and the concepts from which it is formed, is often expressed as an ontology of some form. Concepts may be expressed as a hierarchy, with high-level concepts potentially being described by many sub-concepts layered below them. The hierarchy is one form of common relationship that may be used to define the domain. Other forms of relationships may be more focused to the adaptive experience desired. For example, in an educational setting the pre-requisite relationships between learning concepts may be defined in the domain (Conlan & Wade 2004). A single domain may contain several different types of relationships. An advantage of at least including hierarchical relationships between concepts is that the strategy has flexibility in choosing concepts that are both appropriate to the contextual model (e.g. a learner's knowledge model) and to the granularity of content/services available during binding.

The domain of concepts may be used at both design time, as an input into an iterative authoring process and/or used at runtime as a contextual model in its own right. The objectives are often expressed with reference to the domain and usually include reference to one or more concepts. This requires that either the strategy has been authored with specific reference to those concepts or it has runtime access to the domain model. The objectives also typically have a descriptor to indicate how to determine whether an objective has been successfully achieved. For example, for a domain with the high-level concept of *Newton's Third Law* the objective *Understand Newton's Third*

Law would be appropriate. In this instance the *Understand* descriptor relates to something that is measurable within the strategy. Thus an objective should relate concepts within a domain to the strategy in a way that the successful attainment of the objective may be ascertained.

2.3. Strategy, Contextual Models and Reconciliation

Strategy may be considered at two discrete levels: the means by which measured decisions are made as to which concepts should be included in an adaptive experience; and the means through which the binding of concepts and content/services is achieved. In this section the former is discussed and specifically how strategy at this level leverages contextual models to make decisions. Binding is discussed in section 2.4.

A strategy is an approach (e.g. a set of logic or group of policies) that uses contextual models and the desired objectives to identify an appropriate conceptual pathway and set of guidelines in order to achieve those objectives. The strategy may perform this iteratively depending on the specific application. For example, in a personalized technology enhanced learning application the strategy (or strategies) employed would be based on appropriate pedagogical approaches.

The domain is often used heavily in the authoring process, creating strategies that directly embed specific concepts. For example, the strategies underpinning the personalized SQL course offered in the AMAS project (Staikopoulos *et al.* 2012) describe the various sequences of different SQL concepts (e.g. *The Relational Model*) and the suitable learning activities that may be offered to realize different learning objectives.

The strategy should remain agnostic to the content/services that will be used to realize the constituent concepts and it may be, though not always, created independently to the domain. For example, the Theory of Knowledge Spaces (Albert 1994) uses the prerequisite relationships between concepts in the domain and a model of a learner's knowledge to determine the next concept (Conlan et al 2001). In this example the design-time creation of the strategy does not directly reference specific concepts in the domain. The domain may be considered as a contextual model when it is referenced during the runtime operation of a strategy.

Contextual models provide evidence for the strategy to make decisions. They may also be used to guide the binding process. Contextual models may be both dynamic, updated in parallel to the execution of a strategy, and static, existing before the strategy is executed and not altered during its execution. For personalization the most common dynamic model is that of the user. The actions of the user directly or indirectly alter their model, which is used by the strategy as the basis of decisions. These actions may offer the user very direct control over how the strategy executes, thus leading to a more adaptable and scrutable experience (Bull and Kay 2010).

The output of the strategy execution is a specific concept pathway through the domain towards one or more objectives, that has been tailored to the contextual models and which may also contain guidelines to support binding. The execution of the strategy across a set of contextual models is referred to as reconciliation as the data in the individual models needs to be reconciled with the strategy to decide a concrete pathway. It is worth noting that strategies may produce quite short-lived outputs and may be either continuously iterated or lead to other strategies being executed when they are completed.

2.4. Binding

The final step in the realization of an adaptive experience is the binding of concepts to specific assets, e.g. content and/or services, to fulfil them. This may also be considered as a strategic step as there may be many candidate assets that could suitably realize the concept. Contextual models and the metadata describing the assets may also need to be consulted to achieve this step. For example, the capabilities of a particular device may need to be considered when attempting to deliver specific content.

Binding may also lead to no assets being identified as the concept could be too high-level to find an appropriate candidate. In this instance a solution may be to return to the strategy execution phase to break the concept down into sub-concepts from the domain.

After binding has been completed it is possible to deliver the adaptive experience to the user as the concepts have been realized with real content and services. The strategy may continue to monitor contextual models, and potentially the user's progress, to identify if an alteration of the adaptive experience is necessary to accommodate changes.

3. Illustrative Use-Cases

This section showcases The Narrative Approach to personalisation using two illustrative use-cases: the personalised learning activities realised as part of the AMASE system from the AMAS project; and the personalised digital educational games developed in the ELEKTRA and 80Days projects. These use-cases highlight how the aspects of the narrative approach described in the sections above, have been applied to create real-world systems, which deliver tangible benefits for their users. Each use-case first provides an overview of the context in which the narrative approach was applied, the evaluation methodology and some highlights of the evaluation results. This is then followed by a discussion of how the three 'aspects' of the approach, Concepts and Objectives, Strategy, Conceptualisation and Reconciliation and Binding are applied in the specific use case.

3.1. The AMAS Project

Personalised learning environments (Magoulas and Chen 2006) dynamically customise educational experiences according to a learner's preferences, needs and context. There are many examples of where this has been successfully applied to learning environments, such as GALE (Smits & De Bra 2011), ADAPT2 (Razmerita *et al.* 2003) and APeLS (Conlan & Wade 2004). However, such environments do not go far enough in addressing the particular needs and (learning) requirements of a learner and are limited by their closed nature (Dagger *et al.* 2007). Instead, the next generation of personalised learning environments need to: provide even more engaging and interactive experiences; enable the utilisation of open content; and dynamically combine and personalise web hypermedia and services in a unified manner (De Bra *et al.* 2006).

In general, the notion of "Learning activities" has been widely accepted as means to provide greater engagement of the learner. Several popular commercial environments have focused exclusively on supporting learning activities such as LAMS (Dalziel 2003) as well as research projects such as LADIE (Jeffery *et al.* 2006) and DialogPlus (Bailey *et al.* 2006), which have investigated their pedagogical benefits. Personalised learning activities provide all the benefits of traditional learning activities but with the significant advantage of providing web media and services which are dynamically tailored to the individual's preferences, needs and context.

The AMAS project[1] (Staikopoulos *et al.* 2012) which stands for "**A**daptive **M**edia **a**nd **S**ervices for Dynamic Personalisation and Contextualisation", tries to address many aspects of these emergent requirements. In particular, the goal of AMAS is to provide innovative techniques and technologies in the area of "adaptive technology

---

1 AMAS SFI project, please refer to http://kdeg.cs.tcd.ie/amas

enhanced learning" that dynamically adapt and personalize web media and services to offer pedagogically driven learning activities that re-purpose existing content and services. In this context, a learning activity can be considered to be an educationally-driven sequence of user-centric tasks and associated support material. For example, a peer-review activity that combines appropriate authoring and collaborative services to the learner in a structured manner as well as providing supporting content that describes the procedures of how learners should review the work of their peers.

AMAS builds upon personalised learning activities to further enhance the learning experience, to offer a more interactive and engaging experience and also to repurpose existing content and services for different users and contexts. The learning activities can be used to effectively support both self-directed and group-directed activities across a range of contexts from formal to non-formal learning and including Self-Regulated Learning. More specifically, AMAS represents a novel approach (see figure 1) to developing a highly dynamic and adaptive framework that automatically generates personalized learning activities (pathways) using a combination of rule-based and workflow techniques. The actual resources (web hypermedia and services) are reused by selecting and tailoring them according to the user's preferences, needs, learning requirements and context. Details of the actual AMAS process and its components are given in the following sub-sections.

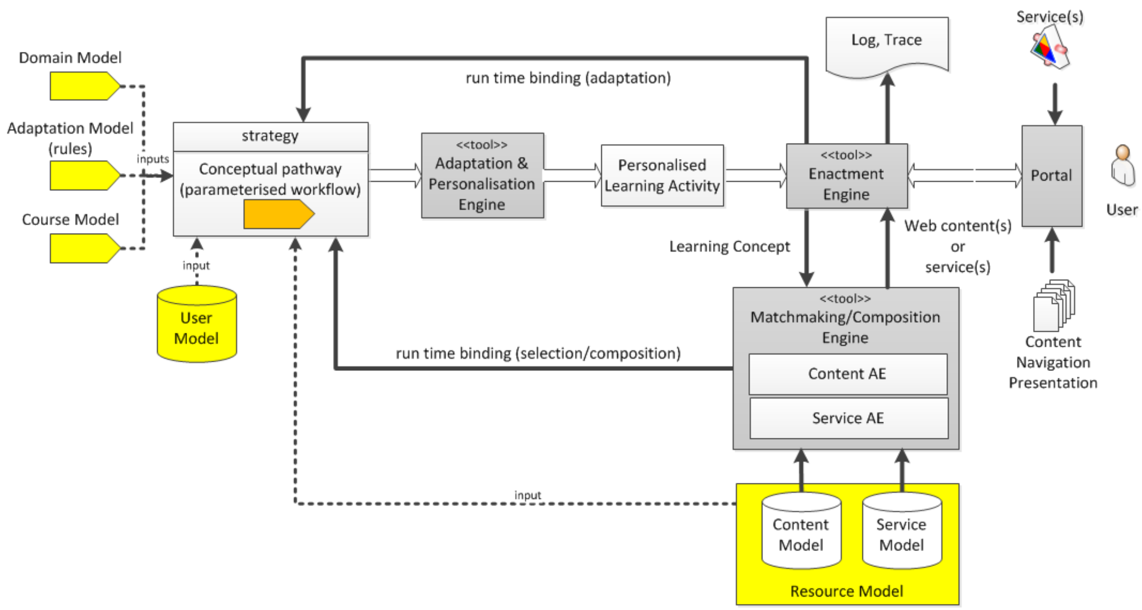

Figure 1: AMAS Narrative Approach and Components

The AMAS project has applied the narrative approach to personalisation resulting in a number of key benefits and adaptive features to support activity-based learning. For example, the narrative approach allowed AMAS to effectively manage and support the highly dynamic and adaptive nature of real-world applications that are driven by pedagogical strategies and learning objectives. It also allowed AMAS to address the individual's needs, preferences and context across different requirements and scenarios. Furthermore, it enabled the provision of an agnostic binding, where the actual content and services are selected on the fly to realise a particular learning concept of the generated pathway and re-purpose (reuse) existing web media and services.

From an engineering perspective the narrative approach to personalisation facilitated the organisation and separation of the contextual models from the adaptation logic (rules). Finally, it supported the authoring of new courses and pedagogical strategies, through the reuse of contextual models (domains) and predefined rules.

In order to provide an authentic evaluation of the AMAS framework, the research is being applied in contrasting applications based on personalised learning activities in Schools (K12) and Higher Education. As an example, personalised activities have been used to teach SQL and Relational Databases as part of 3rd and 4th year undergraduate courses in Computer Science and Computer Engineering at Trinity College Dublin. In this case a learner has to first answer a number of simple questions in order to create their personalized learning profile (User Model). Then the system will build a personalized version of their SQL activity as shown in figure 2. The activity provides a forum service to support class discussions and a sandbox environment in which learners can practice SQL commands in an example database and Quiz. Upon the successful completion of the SQL Quiz, learners participate in a group-based WebQuest task, in which learners work together in a collaborative environment to find and bookmark resources about a specific subject. As part of the next task, the system processes these bookmarks and provides the learners with a list of further recommended reading based on the resources discovered during the WebQuest. At the same time the learner will also be given an assignment involving the design and implementation of a database. Upon the completion of this assignment, the learner will have to electronically submit a report via the learning portal. Finally, once the projects are submitted the learners are automatically assigned a number of reports to review as part of a peer review task.

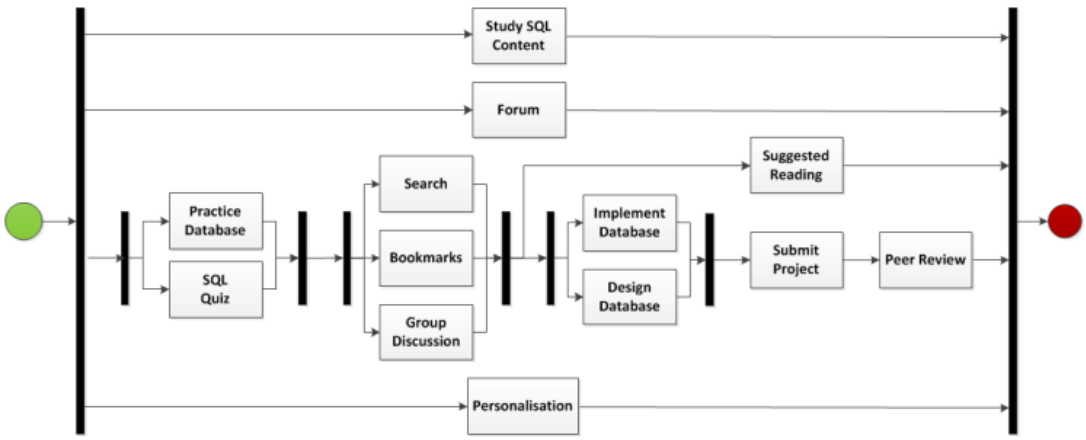

Figure 2: Example of an SQL learning activity

This is the second year that the SQL personalised activity has been used (see figure 3). Initial evaluation results were based on 69 students who took the course last year have published (Staikopoulos *et al.* 2012) with an additional 101 students taking the course this year as part of on-going evaluations. Based on the results and feedback from the previous year there were significant updates to the system including a complete redesign of the user interface and use of visualizations to track the student's progress though their assigned activity. The three primary objectives of the evaluation were to evaluate a) the students perception on how the system assisted them in learning, b) the students perception of the personalisation delivered and c) usability. Overall the student's response was positive. For example the majority of students found the activity helpful to their learning (58% of students), the personalised learning activity generated for them reflected their answers (90% of students) and the objectives of the generated course were clear (65% of students).

Finally, a log analysis was performed in order to evaluate the system from a usability perspective, in terms of the student's interactions and study time. Upon the completion of the analysis it was found that 93% of students completed all of the tasks assigned. In addition, on average, each piece of content (273 in total) provided was visited 44 times by each student over the three month period the course was given. Both these results indicate that students found the course both usable and engaging.

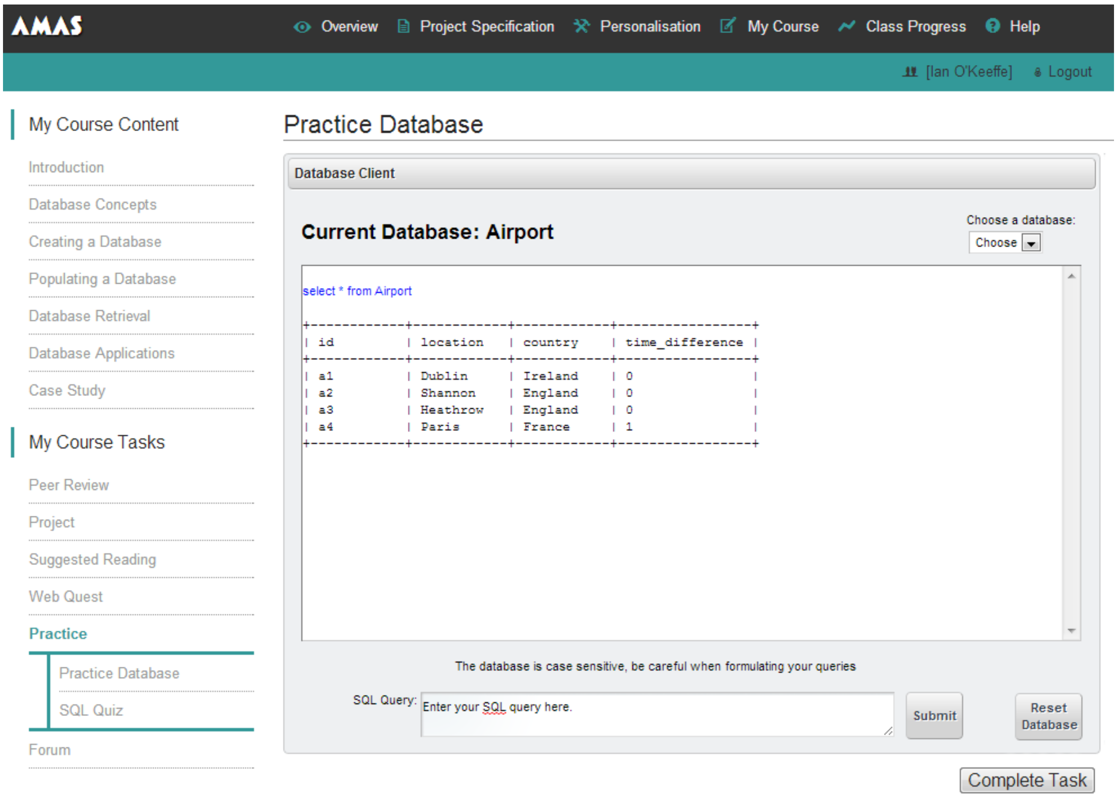

Figure 3: AMAS Learning Portal for an SQL learning activity

The following sections explain in more detail how the narrative approach to personalisation has been applied to the AMAS project with a focus on addressing the questions posed in section 2.

3.1.1. Concepts and Objectives

Initially, an educational designer captures the domain model with a graphical tool. In AMAS the domain model specifies a conceptual namespace where concepts and relationships are defined and identified uniquely. In particular, concepts can be defined across multiple domains, meaning that concepts can be organised together within specific topics. In that way, conceptual entities for Newtonian Physics and Astronomy can be organised into different domains, however they can be combined together in a learning activity to teach specific aspects of a course.

The AMAS adaptation framework has been specifically designed to support extensibility and to combine different types of content and services in a unified manner. As a result, based on a common and abstract definition of a concept, different specialisations are specified to support for example LearningTasks and LearningTopics, which are related to specific learning objects and which satisfy particular learning requirements. Similarly, there are concept specialisations for SimpleTasks and SimpleTopics that can refer to any general type of web media resource and service. In general the concept definition specifies a name, a description, a set of keywords and a potential reference to an ontological description. The ontological description of a concept allows AMAS to provide more elaborate decision making based on description logic and related reasoners.

Similarly, AMAS has been specifically designed to operate upon various different types of relationships and hierarchies that are specified among concepts. In particular, based on abstract relationship types that specify Directed (1-1), Undirected (1-1), Complex (n-m) and Directive (1) relationships, particular specialisations are defined such as for PreRequisite, PostRequisite, and AnyOf relationships. During the authoring phase an educational designer uses these constructs to specify relationships among the domain concepts. For example, a PreRequisite relationship among the "Design Database" and the "Implement Database" concepts will result in a personalised learning activity where the "Design Database" precedes the "Implement Database" task, even if that task was not part of the initial strategy description. Similarly, different types of Hierarchies such as the SubContent and the SubTask relationships can be defined between LearningContent and LearningTasks respectively. For example the "Populating a Database" has SubContent the "Insert Statement" LearningContent. These relationships play a particular role on the generation and customisation of the navigation model as well as to handle the higher level concepts as composite entities. Once such relationships are specified and used from a strategy, specific adaptations and selections are applied to support the generation and personalisation of a learning activity.

After the concepts and relationships of the domain have been specified, it is then necessary to define the activity objectives. In AMAS these objectives are mainly categorised as learning objectives that are fulfilled by the selection and enactment of specific learning concepts that have been used to provide the activity's conceptual pathway. Based on the learner's preferences, needs and context these specific learning requirements can be realised differently for each learner. Various in-place monitoring and logging mechanisms trace the learner's progress throughout the enactment of their personalised learning activity. In that way it is possible to ascertain if learners have successfully completed the learning requirements of a course. Usually the learning requirements of an activity are reached with the completion of the learner's personalised learning activity. Finally, AMAS can dynamically handle the change of (learning) requirements for example from an educator, and trigger further strategies that will cause new adaptations to satisfy the new requirements at run time.

3.1.2. Strategy, Contextual Models and Reconciliation

In AMAS, the narrative approach to personalisation is used both for the dynamic generation/construction of a learning activity (pathway), as well as for the on the fly (run time) binding of the learning activity. In this approach the strategy encapsulates a set of relationships and abstracted pathways that are to be instantiated specifically for each user, in a particular context, to generate a personalised learning activity or experience.

At design time, the strategy is authored (captured) at a high level of abstraction by an educational designer with a dedicated graphical tool. The educational designer does not need to be an expert on adaptive authoring in order to use the authoring tool and model an adaptive activity such as for an "SQL Database". Instead the authoring tool abstracts many of the implementation details and simplifies the authoring process, so for an educational designer minimal training or experience is required. The actual strategy is captured as an abstract learning activity (conceptual pathway) model. In effect, the abstract learning activity reconciles the domain model to specify sequences of content and tasks, the adaptation model to apply specific adaptation and personalisation rules, and the user model to influence the adaptation and personalisation rules according to the user's preferences, context and needs. In AMAS, a course can be associated with many different abstract learning activities, so under the evaluation of certain conditions, a different starting point can be selected for a specific learner or a group of learners.

In AMAS, a number of contextual models can either explicitly or implicitly influence the adaptation strategy. More specifically these are: 1) the *domain model*; 2) the *user model*; 3) the *resource model*; 4) the *adaptation model*; and 5) the *course model*. The *domain model* is used to preserve and enforce the relationships among the concepts used by an abstract learning activity. The *user model* captures the competencies, preferences and needs (learning objectives and goals) for each learner. Various different elements can be captured and used on the adaptation and personalisation process such as scores from tests, the level of expertise, preferences on subjects and tools (e.g. MySQL over ORACLE), the level of interaction with the system, prior knowledge and learning goals. The user models are stored in a repository, such as an eXist database. The *resource model* contains metadata about the hypermedia content and services that are available to the system. Different resource types are associated with different metadata. For example, hypermedia content can be associated with Dublin Core and Learning Object Metadata (LOM), whereas services may be associated with invocation semantics that need to be met in the form of Inputs, Outputs, Pre-Conditions and Effects (Klusch *et al.* 2006). The *adaptation model* specifies the rules and models that are to be applied for an adaptation or selection (binding). In particular three different types of adaptations are supported. Model-based rules that depict graphically the conceptual relationships and the patterns to match and replace on a strategy and rules that are specified programmatically at low level of detail with a rule language. Concrete rules are implemented with a specific rule language such as Drools. Graph rules provide a more general and flexible mechanism in which educational designers specify their own complex adaptation rules graphically, similar to Graph Transformations rules (Baresi and Heckel 2002). In general these types of rules are provided by the authoring tool and used by an educational designer to specify and personalise the adaptation strategy according to different pedagogical requirements and individual needs. Finally, there are Relationship rules that specify relationships among Concepts and learning Activities and which trigger adaptations. For example, a replaceWith rule replaces one concept or activity with another and a hasPrerequisite rule applies a learning concept/activity before another. Finally, the *course model* can provide additional metadata that is related specifically to a course, such as restrictions on group formations, deadlines etc.

Next in AMAS the adaptation and personalisation engine will interpret the strategy, reconcile the appropriate contextual models, apply the adaptation rules and generate an executable personalised learning activity (*conceptual pathway*) as discussed previously. The actual adaptation process is based on a hybrid approach combining the advantages and capabilities of workflow and rule-based systems. Rules are used to specify and evaluate the adaptation conditions as well as to trigger adaptations, while workflows are used to support the composition and coordinated execution of learning tasks.

As a result of the adaptation process, a Personalised Learning Activity is generated as a Business Process Model and Notation (BPMN) workflow specification (OMG 2011), ready for execution. At this stage the activity has been personalised but remains abstract, as the appropriate content and services have not yet been selected in order to instantiate the tasks. The next step is to deploy the personalised activity to the Enactment Engine, so that it can be executed and made available to the learner. The Enactment Engine is a jBPM based workflow engine (Cumberlidge 2007) that supports the concurrent execution of multiple learning activities (BPMN workflows) assigned to individual as well as collaborating users. Learning activities are also stored in a repository so they can be reused and further customised for different domains and contexts. The current state of an executing learning activity is also persistent and stored in a database, so long-lived activities can be supported.

3.1.3. Binding

In AMAS the learning steps of the generated conceptual pathway are bound to specific content and services at runtime by the Matchmaking/Composition component. More specifically, as learners interact with their personalised learning activity (conceptual pathway) via a Learning Portal, the requests are sent to the Enactment Engine in order to retrieve the appropriate content and services for a given learning step (concept). At this point the requests are passed to the matchmaking/composition service, which selects and composes if necessary, the appropriate content and services on a "just in time" basis. The user's model is also used on the matchmaking process to influence the selection of content and services according the preferences of a learner. The service provides an interface for querying and composing available resources (content and services) based on the metadata descriptions that are stored in the resource repository. If the query returns a set of results, the service will either compose content and services (based on a template) or select the most appropriate ones (based on specific selection directives such as for any, all or best matches). The decision to compose or select a service is based on the availability and the operating semantics of the service.

Finally, in AMAS it is also possible to define (sub)narrative descriptions that will cause new adaptation strategies to be dynamically evaluated and applied at run time, once a learning activity has been uploaded and executed. In this case, the Enactment Engine would interpret the adaptation strategy, evaluate the adaptation rules and accordingly will trigger an adaptation to further refine the executing learning activity.

3.2. The 80 Days and ELEKTRA Projects

Digital Educational Games are one area where the narrative approach to adaptivity can be applied to support effective experiences. One of the main difficulties in the development of DEGs (Digital Educational Games) is the challenge of balancing gaming and learning experiences. Failure to get a correct balance can result in both experiences negatively impacting each other e.g. an over-focus on motivational gameplay devices, such as fast-paced or action-rich game elements, may be of detriment to the underlying learning objectives. Conversely, by placing an over-emphasis on learning objectives, the gameplay may become more dull, leading to a higher drop-out rate (Kickmeier-Rust *et al.* 2007). In order to directly address this challenge within the DEG domain, the ELEKTRA (Conlan *et al.* 2009) and 80Days (Conlan *et al.* 2012) projects applied the narrative approach to personalisation.

The main focus of the ELEKTRA project was to produce an immersive 3D game that used personalisation techniques to help students learn various concepts from the physics domain. The ELEKTRA game places the player in the role of George the nephew of a kidnapped scientist. In order to rescue his uncle, George must overcome challenges and prove his abilities to an interactive NPC (Non Playing Character) represented by the ghost of Galileo Galilei (see figure 4). The challenges involved are all pertinent to the game's storyline as well as encouraging learning through experimentation.

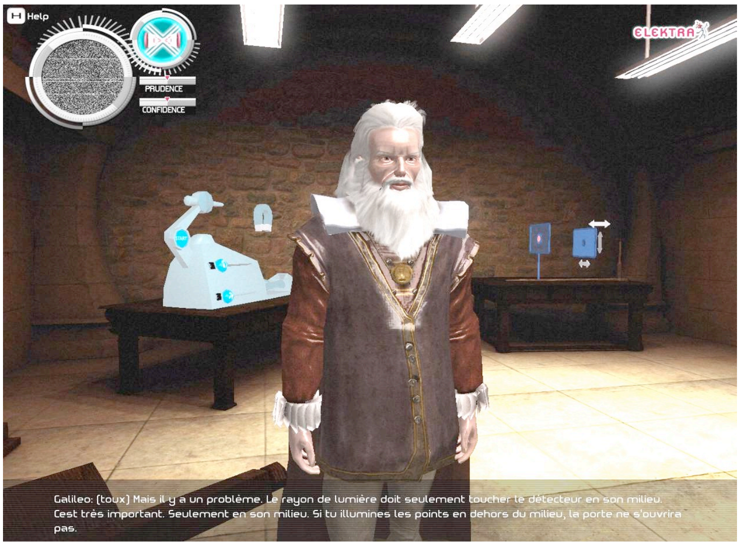

Figure 4: Screenshot from ELEKTRA Digital Educational Game

The 80Days project directly extended the work of ELEKTRA by advancing the adaptive techniques utilised, increasing the scalability of the approach and introducing a more sophisticated mechanism for adapting storylines. 80Days produced an adventure game (see figure 5) in which the user takes the role of a human child who is visited by an alien named Feon (an NPC who fulfils the role of a learning buddy). The player assists the alien in exploring the planet and in creating a report about the Earth and its geographical features. This is accomplished by means of flying to different destinations on Earth, exploring them, and collecting and acquiring geographical and environmental knowledge. Importantly, the various learning objectives are interwoven into the game play and storyline.

Figure 5 A screenshot from the 80Days Digital Educational Game

Both personalised DEGs produced were successfully evaluated with cohorts of secondary school students. For example, ELEKTRA was evaluated with 49 school students in Paris where the learning content formed part of their assessable physics curriculum. The experiment determined (1) the perceived invasiveness of the adaptation, (2) the effectiveness of challenge personalisation, and (3) the motivational impact of the adaptations provided. Each experiment was preceded by a questionnaire designed to gauge the student's competency in the learning topics covered. A post questionnaire was also used to assess learning impact, and to assess qualitative player experience in terms of game difficulty, flow experience, and the perceived invasiveness of adaptations. Comprehensive logs were also automatically recorded that detailed every action taken by the user within the game and every adaptation performed.

Important results (Peirce *et al.* 2008) were obtained for the evaluation of the ELEKTRA game, with the user group who received the most adaptive interventions found to have had a:

- higher amount of invested effort and degree of absorbedness
- higher relatedness with the Galileo NPC
- higher confidence in their own learning achievement
- better handling (lower Extraneous Cognitive Load) of the slope device

The learning outcome and flow experience for the ELEKTRA game with adaptive hints was positive and encouraging, and represented a step forward in adaptive educational games.

In addition to the evaluation of ELEKTRA, the 80Days demonstrator was tested by 71 secondary school students (35 Austrian and 36 English). Three categories were evaluated: Learning efficacy, usability and user experience. Overall the results in all three categories indicated the game to be beneficial towards the learning effect (Koidl *et al.* 2010). Furthermore, the usability of the game scored as satisfactory allowing the interpretation that the non-intrusive nature of micro and macro adaptive interventions did not result in usability shortcomings. These results were assessed based on evidence from the statistical differences in scores related to pre and post assessments of learning questionnaires on domain specific items. The following points summarize the evaluation findings:

- There is a clear indication throughout the evaluated group that the game promoted knowledge gain in the subject area.
- Several students expressed their appreciation about the educational value of the game play.
- The level of cognitive load or frustration was generally low.
- The motivation to continue playing can be indicated as high with most students wanting to play the next level.

- The NPC Feon communicating the micro adaptive interventions was successfully accepted by the students.

As discussed in sections 2 and 3.1,3.1 the narrative approach to personalisation has been successfully utilised in traditional eLearning portals (Conlan and Wade 2004), however game-based environments are substantially different and require the introduction of new adaptive concepts, specific to learning environments with large degrees of freedom. These new concepts, defined by the ELEKTRA project, were micro and macro-adaptivity (Kickmeier-Rust *et al.* 2007, Kickmeier-Rust and Albert 2010). Macro-adaptivity refers to traditional techniques of adaptation, such as adaptive presentation and adaptive navigation on the level of learning situations within a DEG. On the other hand, micro-adaptive interventions are non-invasive (meaning that an overall storyline is not compromised) and affect the presentation of one specific learning situation. Macro adaptivity (adjusting the pace of the entire game, presenting further learning/gaming situations to the user etc.) helps reconcile the pedagogical and story strategies outlined at design time (see section 3.2.2), whereas micro adaptivity (see section 3.2.3) can be characterised as a runtime sub-strategy that refines the presentation of a specific concept to the user.

Within personalised DEGs such as ELEKTRA and 80Days, learning tasks are deeply embedded within the storyline of the game, which is in contrast to intelligent tutoring systems. Thus, any personalisation offered must remain cognisant of the storyline structure, whilst also presenting the educational material in a meaningful manner. For instance, if the reordering of learning tasks in a game makes educational sense, it must also be ensured that it does not result in an implausible rearrangement of the game's plot elements. Due to the nature of immersive DEGs, the adaptation within such games needs to be continuous and less periodic. This issue can be resolved by integrating micro-adaptivity into the environment, where adaptation occurs within the various learning situations as opposed to around them. Micro-adaptivity creates challenges of its own due to the speed in which appropriate adaptations must be selected and rendered to the user, and the necessity to note the impact that game world changes can have on a player's experience.

Both of these forms of adaptation are performed dynamically within the 80Days game. The macro-adaptation tends to happen on a slightly longer time frame as the need for more or fewer learning objectives emerges. In contrast, the micro-adaptation happens rapidly as the learner interacts with the game. In both forms the information about the learner and their needs are inferred through observing their behaviour and interaction with the game. Interrupting the game to explicitly query the learner about their needs would break the immersion of the game and disrupt its flow. Through the application of the narrative approach to personalisation, both the 80Days and ELEKTRA projects were able to produce successful DEGs in the Geography and Physics domains respectively. How the various aspects of the narrative approach to personalisation specifically pertained to these DEGs is discussed in the following sections.

3.2.1. Concepts and Objectives

In developing the ELEKTRA and 80Days DEGs, school curriculums were examined so that appropriate and relevant learning content would be covered within the games. It was important that the range and granularity of the concepts covered were sufficient from both an educational and gaming perspective, which meant co-operation was necessary between pedagogues and game designers. In the context of the ELEKTRA project, the game focussed on a subset of physics content suitable for 13-15 year olds (light waves and magnetism). In terms of the 80Days game, a set of concepts were covered in the geography domain appropriate for 12-14 year olds (human impact on environments and European geographic features). Once each subset of each curriculum was chosen, the key concepts in that domain were defined using pre-requisite relationships (e.g. in the maths domain knowing about addition of numbers is a prerequisite of knowing about multiplication of numbers) and then encoded as an ontology in OWL format.

Once the concepts for the domain had been selected, it was then necessary to define specific objectives for users of the game to attain. These objectives could be categorised as game objectives and learning objectives. For instance, an overall game objective of 80Days was to prevent the aliens from destroying earth, which was broken down into more specific game objectives such as completing tasks within set times, getting responses from certain in-game characters, or navigating a spaceship to a specific European location. These game objectives were central to motivating users to continue through the game. Central to DEGs, is that these game objectives were interwoven with learning objectives related to the domain model. For instance, within ELEKTRA learning objectives included understanding the propagation of light and how magnetism affects different materials; and in 80Days leaning objectives included understanding how humans can impact their environment (e.g. poor urban planning increasing flood risks) as well as gaining geographic knowledge of the cities and rivers of Europe. By monitoring a user's progress through in-game experiments in a non-invasive manner (see section 3.2.2), as well as through explicit assessments, it was possible to ascertain whether users had reached their targeted learning objectives. In accordance with the narrative approach to personalisation, once the concepts and objectives for a DEG are defined, the strategies, contextual models and how they reconcile at runtime must be specified.

3.2.2. Strategy, Contextual Models and Reconciliation

Authoring of personalised DEGs is a complex process that involves the co-operation of different stakeholders (e.g. game designers, educationalists and storytellers). To help facilitate this process, the StoryTec authoring tool (Mehm *et al.* 2010) was developed within the 80Days project to enable key game strategies (pedagogical and storyline etc.) to be more easily designed. Information authored within the StoryTec environment is exported as an ICML (INSCAPE Markup Language) file (Zagalo *et al.* 2006), which is one of multiple contextual models that need to be reconciled at runtime, in order to provide a seamless and engaging experience to users.

As outlined in section 3.2.1, the domain models in ELEKTRA and 80Days are encoded at design time in OWL, and include pre-requisite relationships between concepts. These pre-requisites are central to Competence-based Knowledge Space Theory (CbKST) (Conlan *et al.* 2006), which is an efficient strategy for determining a user's current skill level within a domain. Thus by employing CbKST as the key pedagogical strategy within ELEKTRA and 80Days, it was possible for a probabilistic skill model for each user to dynamically update as they progressed through the games. 80Days also included a motivational model for each user, which estimated a user's attention and confidence at any particular time in the game. The user model encompassed both the skill and motivational models, as well as including detailed data on their progression through the game, the interventions that were triggered, and their response to these adaptive hints.

By updating the skill and motivational models as a user progressed through the 80Days game, it meant that a coherent model of the learner could be built dynamically. To achieve this modelling in a non-invasive manner, the Learning Engine (LE) component within 80Days had two sub-components – the Skill Assessment Engine

(SAE) and the Motivation Assessment Engine (MAE). These sub-engines determined the skills the learner was acquiring and their degree of motivation by analysing evidence received from the Game Engine (GE) e.g. a player not moving after several prompts from an onscreen character could decrease a user's attention value in the MAE, and a user consistently trying to alter the course of a wooden ball using a magnet would decrease the probability that the concept of "magnetism" had been learned.

In consideration of the large quantity of evidence accumulated, potentially dozens of items per second, the use of XML based models, a traditional approach in many Adaptive Hypermedia Systems such as APeLS (Conlan & Wade 2004) and iClass (Turker *et al.* 2006), becomes impractical due to manipulation and reasoning speed. Consequently all data was accumulated in a working memory provided by the Drools rule engine. The use of the Drools rule engine provided an efficient means to reason over large data sets using declarative logic. This logic enabled the timely and appropriate updating of the MAE and the SAE, as well as the reconciliation of multiple complementary strategies, which is paramount to the narrative approach to personalisation.

In terms of storytelling strategy, the Hero's Journey (Vogler, 1998), which is well proven in the field of learning games, was identified as the most appropriate story model for both 80Days and ELEKTRA. The Hero's journey enables a combination of both linear and modular concepts to be presented to players, which fits well with integrating micro and macro adaptivity into DEGs. For instance, a linear cinematic intro and tutorial can be followed by different quests which can be visited in different orders, and various endings occurring depending on the choices and performance of the player. However, it is important that these story paths are cognisant of the CbKST model, so that learning material interwoven with the story is not presented to the users inappropriately. This is achieved at runtime by reconciling the pedagogical and storytelling strategies and referencing the various contextual models on demand. Furthermore, information about the current game state and the adaptations that have already been triggered is gathered. This information is important to ensure consistency and appropriateness of future adaptations that may be recommended.

Another key aspect to the narrative approach to personalisation is that specific content, appropriate to the path the learner is on, is only selected and rendered to the user at runtime. This is especially useful to DEGs where user actions within the game can rapidly change how they are modelled. By only selecting and binding to content at runtime, it means that up-to-date information and context are involved in the decision process, and it is more likely that appropriate adaptations are rendered, providing users with a more engaging and believable experience. How this runtime binding was achieved in 80Days and ELEKTRA is described below.

3.2.3. Binding

In order to inject appropriate adaptations within the 80Days game (manifesting micro-adaptivity), the Learning Engine (LE) needed to have an a priori abstracted understanding of the adaptations possible. Within the LE these adaptations are negotiated with the Story Engine (SE) and are represented as Adaptive Elements. An Adaptive Element consists of an identifier which represents the corresponding skill and type of intervention such as "B2337_CE" (B2337 being the skill identifier for the location of Budapest, and CE - standing for a Competence Explication - being the identifier for this specific type of cognitive intervention). Apart from a range of cognitive interventions, there were also different types of meta-cognitive interventions and motivational interventions which could be selected. These interventions could contain quite specific information relevant to a particular scene or skill, or else be more generic and suitable for rendering in multiple locations within the game (e.g. the motivational intervention “You really know what you’re doing!”). Based on the Adaptive Element identifiers, the SE could decide which dialog from a pool of content should be rendered in the game engine. An example CE Adaptive Element in the 80Days would be the NPC Feon giving a cognitive intervention such as, “Okay, that’s Budapest – the capital of Hungary”. Likewise, an example meta-cognitive intervention rendered to users in 80Days was “Keep focusing on the goal of the task – we want to explore how to reduce the flood risk”.

Both 80Days and ELEKTRA implemented their Adaptive Elements using the ALIGN system (Peirce *et al.* 2008) which uses a flexible rule-based approach. The resultant design of the LE and the use of the narrative approach to personalisation meant that DEGs such as 80Days and ELEKTRA were decoupled from the learning personalisation, which enabled the reuse and independent authoring of both components. Moreover, by using constraint rules, only feasible and appropriate Adaptive Elements are made available for selection in the binding stage. The selection of Adaptive Elements is achieved through adaptation rules that examine the accumulated learner data (stored in the skill and motivational models discussed in section 3.2.1), the domain model, the story model and the available Adaptive Elements. This approach ensures only pertinent, appropriate, and non-invasive adaptations occur within the game, whether on a micro or macro level. As stated in section 3.2, macro adaptivity helps reconcile the pedagogical and story strategies outlined at design time, whereas micro adaptivity can be characterised as a runtime sub-strategy that refines the presentation of a specific concept to the user.

4. Discussion: Authoring, Vocabulary and Granularity of Concepts

This section outlines a number of lessons learned during the years of refining the narrative approach. The first main lesson learned has been in the area of the different stakeholders involved in the authoring process. To take 80Days as an example, the development of the personalised DEG involved game designers, pedagogues, instructional designers, subject matter experts, cartographers, storytelling experts and computer scientists. This is an extreme example, but the process of developing personalised experiences in inherently multidisciplinary in nature. The narrative approach supports such creation processes through the separation of the strategy, that embodies the permutations of concepts which may be assembled, from the models used to tailor the strategy and the content or services that will ground the individual concepts. This enables individual components to be authored separately and reused. Tools, such as the Adaptive Course Construction Toolkit (ACCT) (Dagger *et al.* 2004) and the GRAPPLE authoring tool (Grapple 2011) have been developed to support such an authoring process.

A second lesson lies in the use of vocabulary, specifically, in the makeup of the domain model, the formulation of objectives and how models may be reconciled. All of these facets use concepts to relate to each other. The domain model is responsible for defining, at minimum, the vocabulary of a particular adaptive application. This may be simply expressed in the form of a constrained taxonomy of terms that must be used when describing other models and how they relate to each other. Early implementations of the Narrative approach, such as that seen in EASEL (Conlan et al. 2001) took this simplistic approach. The advantage of this approach is that the strategies employed can be highly flexible, as the domain does not impose a structure or set of relationships to which they must adhere. More structured approaches to the domain model were explored in subsequent work, by using pre-requisite relationships (e.g. Theory of Knowledge Spaces (Albert 1994)) and ontologies. Introducing a higher degree of structure in the domain model can alleviate some complexities from the strategy creation as the strategies can rely on the relationships expressed in the domain model.

Also of consideration with regards to the domain model is the granularity at which the domain concepts are expressed and whether the domain model is expressed as a curriculum, i.e. it may also embed objectives as well as concepts. The granularity of the concepts and the vocabulary of objectives are important for both constructing suitable detailed personalised pathways and for the later binding of content and services to those pathways. An important thing to consider in the granularity of concepts is at what level actions of the user can be correlated to concepts. This speaks directly to how models are constructed and reconciled. In order to work at a conceptual level all models must contain, or at least be mapped to, a common conceptual vocabulary at a granularity that can be reconciled or matched. For example, if a learner performs actions in a learning environment those actions should translate to updates, at the conceptual level, to their learner model. Moreover, the specific actions should also map to objectives and the learner's progress towards them. It is the role of the strategy, either dynamically or in spurts, to adjust the personalised pathway by reconciling the concept and objective vocabulary in the available models. In order to realise the pathway with actual content and services the binding needs to have access to metadata expressed at the appropriate granularity.

5. Conclusions and Outlook

The majority of traditional Adaptive Hypermedia systems are "closed" in nature. They operate upon closed sets of content resources, where the system is aware of each individual resource, and any relationships between resources, in advance. This means that in order for experiences to be generated for each user, bespoke content and services must be authored in advance specifically for use in that system. There must also be sufficient content and services to satisfy the range of possible experiences that can be generated by the system to meet the user's objectives.

The closed nature of these systems has a number of consequences, for the content authored, for the experiences generated and for the user. The content resources and services which are created, are typically authored for use in a specific AH environment, conforming to a proprietary structure and as a result are not easily portable or reusable. To scalably support the system flexibility and dynamism required to produce personalised experiences, the AH system requires access to large volumes of content which is varied in structure, language, presentation style, etc. The result of operating upon a restricted pool of resources is that the range of potential experiences that can be generated to meet a user's needs is reduced. This can mean that the AH application is less reactive to each user's individual needs.

The narrative approach to personalisation addresses this problem through the complete decoupling of content, authoring, contextual models, strategy, execution and binding. The narrative approach enables a new form of Adaptive Hypermedia where the pathway followed by an experience is not dictated by the content that is available, or by the links contained within that content, but by runtime reconciliation between a strategy and a number of contextual models. This enables the dynamic generation of an experience to meet a specific individual's needs and preferences. The narrative approach also advocates the late binding of suitable content and services to the resulting personalised pathway resulting in an offering that comprises activities as well as content. This also creates the potential for content and services to be included in adaptive experiences regardless of how, or where, they were authored.

The narrative approach to personalisation is a novel methodology which supports the creation of Adaptive Hypermedia systems which are flexible, dynamic and, ultimately, more responsive to users' needs and objectives.

Acknowledgements

This research is co-funded by Science Foundation Ireland as part of the Centre for Next Generation Localisation (Grant 07/CE/I1142) and the AMAS project (Grant 08/IN.1/I2103), and the 7th Framework Programme of the European Commission as part of the CULTURA project (Grant 269973) at Trinity College Dublin.

References

Agichtein, E., et al.,2006, "Improving Web Search Ranking by Incorporating User Behaviour Information", Proceedings of the 29th annual international ACM SIGIR conference on Research and development in information retrieval, Seattle, Washington, USA 2006, 19-26.

Albert, D. (Ed.). (1994). *Knowledge Structures*. New York: Springer Verlag.

AICC, (1999). Aviation Industry CBT Committee (AICC) Computer Managed Instruction (CMI) Guidelines for Interoperability, Revision 3.0.1.

Ankolekar, A., et al., 2007 "The two cultures: Mashing up Web 2.0 and the Semantic Web", in Web Semantics: Science, Services and Agents on the World Wide Web, Volume 6, Issue 1, Elsevier Science Publishing, ISSN:1570-8268.

Bailey, C. et al., 2006. Panning for gold: designing pedagogically-inspired learning nuggets. *Educational Technology and Society*, 9(1), pp.113–122.

Baresi, L. & Heckel, R., 2002. Tutorial introduction to graph transformation: A software engineering perspective A. Corradini et al., eds. *Graph Transformation*, 2505, pp.402–429.

Brusilovsky, P., 2004. KnowledgeTree: A distributed architecture for adaptive e-learning. In Proceedings of the 13th International World Wide Web Conference, WWW. 104-113.

Brusilovsky, P. 2007 “Adaptive Navigation Support” in The Adaptive Web eds. P Brusilovsky A Kobsa, W Nejdl Springer LNCS 4321 State of the art survey, 2007

Bull, S. & Kay, J., 2010. Open Learner Models. In R. Nkambou, J. Bourdeau, & R. Mizoguchi, eds. *Advances in Intelligent Tutoring Systems*. Springer Berlin Heidelberg, pp. 301–322.

De Bra, P., Aroyo, L. & Chepegin, V., 2006. The next big thing: Adaptive web-based systems. *Journal of Digital Information*, 5(1).

Conlan, O., 2000 Novel components for supporting adaptivity in education systems - model-based integration approach, in Proceedings of the eighth ACM international conference on Multimedia - MULTIMEDIA ’00, pp. 519–520.

Conlan, O., Hockemeyer, C., Lefrere, P., Wade, V., & Albert, D. (2001, September). Extending eductional metadata schemas to describe adaptive learning resources. In *Proceedings of the 12th ACM conference on Hypertext and Hypermedia* (pp. 161-162). ACM.

Conlan, O., et al. 2002. Metadata driven approaches to facilitate adaptivity in personalized eLearning systems. The Journal of Information and Systems in Education, 1, 38-44.

Conlan, O. & Wade, V., 2004. Evaluation of APeLS – An Adaptive eLearning Service Based on the Multi-Model, Metadata-Driven Approach. In Paul De Bra & W. Nejdl, eds. *Third International Conference on Adaptive Hypermedia and Adaptive Web-Based Systems (AH2004)*. Springer Berlin / Heidelberg, pp. 291–295.

Conlan, O., et al., 2006. Using Knowledge Space Theory to support Learner Modeling and Personalization, Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2006, Hawaii, USA, October 2006, edited by T. Reeves & S. Yamashita, 1912-1919

Conlan, O., et al., 2009, Realtime Knowledge Space Skill Assessment for Personalized Digital Educational Games, ICALT 2009, Riga, Latvia., 15-17, 538 – 542

Conlan, O., et al., 2012. Realizing Just-in-Time Personalization - A Technology Overview, An Alien's Guide to Multi-Adaptive Educational Computer Games, Informing Science Press, 105-121

Cumberlidge, M., 2007. Business Process Management with JBoss jBPM. , p.220.

Dagger, D., Wade, V., Conlan, O., (2004), "Developing Adaptive Pedagogy with the Adaptive Course Construction Toolkit (ACCT)", published in the workshop proceedings of the AH2004 conference (online), Third International Conference on Adaptive Hypermedia and Adaptive Web-Based Systems (AH2004) Proceedings, Eindhoven, The Netherlands (2004)

Dagger, D. et al., 2007. Service-oriented e-learning platforms: From monolithic systems to flexible services. *Internet Computing, IEEE*, 11(3), pp.28–35.

Dalziel, J., 2003. Implementing Learning Design: The Learning Activity Management System (LAMS). In G. Crisp et al., eds. *Learning*. ASCILITE: www.ascilite.org.au, pp. 593–596.

Dou, X. Song, R. and Wen, J. 2007 "A Large-scale Evaluation and Analysis of Personalized Search Strategies" Proceedings of 16th International Conference on World Wide Web (WWW16), Banff, Alberta, Canada

Grapple 2011, Generic Responsive Adaptive Personalized Learning Environment, EU FP7 Project, available at http://www.grapple-project.org/

Hampson, C., Lawless, S., Bailey, E., Yogev, S., Zwerdling, N. and Carmel, D., 2012. CULTURA: A Metadata-Rich Environment to Support the Enhanced Interrogation of Cultural Collections. In the Proceedings of the 6th Metadata and Semantics Research Conference, Cádiz, Spain, pp. 227-238

Jeffery, A., Conole, G. & Falconer, I., 2006. LADiE Project Final Report. Available at: http://misc.jisc.ac.uk/refmodels/LADIE/www.elframework.org/refmodels/ladie.html.

Kickmeier-Rust, M. et al., 2007. Immersive Digital Games: The Interfaces for Next-Generation E-Learning? In C. Stephanidis, ed. Universal Access in Human-Computer Interaction. Applications and Services. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg

Kickmeier-Rust, M. and Albert, D., 2010. Micro-adaptivity: protecting immersion in didactically adaptive digital educational games. Journal of Computer Assisted Learning, 26(2), 95-105.

Klusch, M., Fries, B. & Sycara, K., 2006. Automated semantic web service discovery with OWLS-MX. *Proceedings of the fifth international joint conference on Autonomous agents and multiagent systems - AAMAS '06*, p.915.

Koidl, K., et al., 2010, Dynamically adjusting Digital Educational Games towards Learning Objectives. In Proceedings of the 4th European Conference on Games based Learning (ECGBL), Copenhagen, Denmark

Koidl, K., Conlan, O., & Wade, V. 2011. Towards user-centric cross-site personalisation. Web Engineering, 391-394.

Magoulas, G. & Chen, S., 2006. *Advances in Web-Based Education: Personalized Learning Environments*, Idea Group Inc (IGI).

Mehm, F., et al., 2010. Bat Cave: A Testing and Evaluation Platform for Digital Educational Games. In: Bente Meyer: Proceedings of the 3rd European Conference on Games Based Learning, 251-260, Academic Conferences International..

O'Keeffe, I., 2012 Adaptive Composition of Personalised Learning Activities, Thesis (PhD), Trinity College Dublin

OMG, 2011. Business Process Model and Notation (BPMN 2.0). *Object Management Group*, (formal/2011-01-03). Available at: http://www.omg.org/spec/BPMN/2.0.

Peirce, N., Conlan O., and Wade, V., 2008, "Adaptive educational games: Providing non-invasive personalised learning experiences." Digital Games and Intelligent Toys Based Education, 2008 Second IEEE International Conference on. IEEE.

Razmerita, L., Angehrn, A. & Maedche, A., 2003. Ontology-based User Modeling for Knowledge Management Systems P. Brusilovsky, A. Corbett, & F. De Rosis, eds. *Architecture*, 2702(Springer), pp.213–217.

Smits, D. & De Bra, Paul, 2011. GALE: a highly extensible adaptive hypermedia engine. In *Hypertext 2011*. pp. 63–72.

Staikopoulos, A. et al., 2012. AMASE: A Framework for Composing Adaptive and Personalised Learning Activities on the Web. In E. Popescu et al., eds. *Advances in Web-Based Learning - ICWL 2012*. Springer Berlin Heidelberg, pp. 190–199.

Steichen, B., 2011. Personalisation in the Wild - Providing Personalisation across Semantic, Social and Open-Web Resources, 22nd ACM conference on Hypertext and hypermedia (HT '11), Eindhoven, The Netherlands, pp. 73-82.

Teevan, J. Dumais, S.T., and Horvitz, E. 2005. "Personalizing search via automated analysis of interests and activities" 28th International ACMIR Conference on Research and Development in Information Retrieval, Salvador, Brazil

Turker, A., Görgün, İ., and Conlan, O. 2006. The challenge of content creation to facilitate personalized e-learning experiences. International Journal on E-Learning, 5(1), 11-17.

Vogler, Christopher. 1998. The writer's journey: Mythic structure for writers. Vol. 2007. Studio City, CA: Michael Wiese Productions.

Wade, V., 2009. Keynote Address, "Challenges for the Multi-Dimensional Personalised Web", User Modelling, Adaptation and Personalisation (UMAP)

Zagalo, N., et al., (2006). Inscape: Emotion expression and experience in an authoring environment. Technologies for Interactive Digital Storytelling and Entertainment, 219-230.