An Architecture for Dynamic and Adaptive User Activity Planning Systems

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Abstract: A plan is an organized set of activities that are performed to achieve certain goals. Changing environments have multiple requirements: users have diverse needs and preferences, the context may be different for each user, depending on the time, location, and access devices (e.g., mobile devices, desktop computers). Above all, these types of environments have a key element in common: they require the creation of dynamic and adaptive plans, which can address different situations and provide the best set of activities for each user and context. This paper proposes an architecture for the creation of dynamic and adaptive planning systems that can address specific user needs and contexts. This specification encompasses the main components of a planning process and can be translated into more concrete implementations. As part of the validation of this approach, this paper describes the prototyping effort and an ongoing case study of an educational web application.

1 INTRODUCTION

A *plan* is "a detailed proposal for doing or achieving something" (Oxford-University, 2014), while *dynamic* is something "characterized by constant change, activity, or progress" (Oxford-University, 2014). A third important concept is *adaptation*, the ability of a system to automatically change its behavior and appearance to better satisfy the specific needs of each user and the context in which the user interacts with the system (Stewart et al., 2008; Casteleyn et al., 2009). This research unifies all of the above concepts into *dynamic and adaptive planning*, to create plans especially suited for the requirements of each user and context and that is able to evolve over time.

In today's world, there are many situations that require dynamic and adaptive planning. For instance, in the classroom students are diverse, they have different learning needs and preferences (Brusilovsky and Millán, 2007). They also have different access devices and location. Therefore, it is necessary to especially tailor learning plans for each of them (Sangineto et al., 2008). Moreover, as students progress in their learning, their characteristics change, which may require the modification of their learning plans. Another similar situation occurs in physical training. There is also a diversity of people who require different training activities and as they progress they require change in their plans to accommodate to their physical improvement.

Overall, multi-user systems that guide users in the execution of a plan may significantly benefit from dynamic and adaptive planning. This paper proposes ASHYI, an architecture for dynamic and adaptive planning systems. The word ASHYI in Quechua language means to search, to investigate. ASHYI defines the most important structures and processes required for these kinds of systems and provides a way to translate those specifications into a more detailed and concrete design. To illustrate the applicability of this approach, this paper also describes the design and prototyping effort of an educational application and an ongoing case study that utilizes this application in a university course.

The remainder of this paper describes ASHYI and its validation. Section 2 discusses related work. Sec-

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tion 3 explains the main components of ASHYI. Section 4 describes the design of ASHYI-EDU, an instantiation of ASHYI for the educational domain. Section 5 describes an ongoing case study to validate ASHYI-EDU in a university course. Section 6 concludes and discusses future work.

2 RELATED WORK

Table 1 summarizes the analysis of the related work. The (+) symbol means that the approach fully supports the given criterion. The (-) symbol means that the approach does not support it. The (#) symbol means that the criterion is supported to a certain degree. The (?) symbol means that it is not possible to determine whether that criterion is supported or not.

There are several works in dynamic activity planning. The first group includes proposals for planning activities in specific contexts. Nejad el al. (Nejad et al., 2011) (1) propose a dynamic activity planning system for a manufacturing process. Using multi-agents and negotiations based on decision-rules, the system manages resources and resolves conflicts among elements of the plan. Finally, Auld and Mohammadian developed a system to plan travel activities through a multi-agent system and an activity-based model (Auld and Mohammadian, 2012) (2). In this work, horizontal planning is performed to characterize each activity and its environment to predict activities to perform in the short term. The plan adapts to external constraints, past experiences, and user needs.

The second group of proposals define generic systems or frameworks to create dynamic plans. Wang (Wang, 2006) (3) presents a dynamic activity planner that integrates a general plan and plans associated with different roles who share resources. Planning is resource-centered, so it uses negotiation to organize activities. Another project created by Cavazza et al. (Cavazza et al., 2008) (4) proposes a dynamic planner for daily activities. A physical device interacts with the user to determine his/her opinion and behavior. Using that information, together with the user, preferences, activities, and context profiles, the system adapts and updates the user's daily activity plan.

In the same way, Nijland et al. (Nijland et al., 2009) (5) propose an application to plan daily activities utilizing a multi-agent system and a user needs model, which includes social, personal, home needs, among others). The system proposes and plans activities and events. The utilization of needs and context information assists the prediction of an event and to re-plan the user activities, according to their usefulness for the user.

The last group includes proposals specifically designed for learning environments. The approach of (Rytikova and Boicu, 2014) (6) utilizes a set of resources provided by a teacher to create a course. Students perform an initial test to measure competences. This test is utilized by the system to convey different information to students, based on their specific characteristics. Lecomp5 (Limongelli et al., 2008) (7) is a system to plan student activities, based on their knowledge (initial and goal), learning style, course progress, and learning objects and their prerequisites. Lecomp5 provides tools to manage content, realize different teaching strategies, and provide learning sequences to students. Finally, Capuano et al. (Capuano et al., 2008) (8) propose LIA, an intelligent e-learning system to provide personalized planning to students. A generation algorithm utilizes teaching and learning preferences and cost constraints to select a set of learning activities that address all of the concepts that the student has not learned until that moment. The work of (Bahmani et al., 2011) (9) is a system for course recommendation to students that utilizes some student attributes and context.

Table 1: Related Work Comparison.

Criterion	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Activ. Analysis	-	+	#	+	+	+	#	#	-
Res. Mgmt.	+	-	+	-	-	#	-	-	#
User Adapt.	-	#	-	+	+	+	+	+	+
Plan Feedback	-	+	-	+	-	+	?	-	?
Role Mgmt.	+	-	+	-	?	?	-	-	+
Re-planning	+	+	+	+	+	-	+	+	?

Most approaches do not take into account detailed user adaptation aspects that can affect activity execution. Only two works provide feedback to the plan from the user, which limits their ability to improve the plan. In addition, several of them do not take into account activity resources and the way these resources affect activity execution. All of the related works were developed for specific environments, which limits the user and context characteristics.

Taking into account the above analysis, the contribution of our approach is two-fold:

1. Unlike other planning approaches, ASHYI is both dynamic and adaptive. ASHYI is adaptive, since is able to change create specific plans for each user, based on context and user characteristics. It is dynamic, since it is able to analyze its interaction with users, determine the way users and context change over time, and perform re-planning if necessary. In addition ASHYI can also dynamically assign resources, based on availability.

2. Above all, ASHYI is conceived as a generic architecture for dynamic adaptive planning systems. This means that ASHYI has the potential to be seamlessly reused in different projects that require to dynamically plan according to specific user and context characteristics. In this sense, our contribution is to clearly identify the most common features of these types of adaptive systems, which facilitates the understanding of the overall planning problem in adaptation.

3 THE ASHYI ARCHITECTURE

ASHYI was conceived to facilitate the design of systems that require dynamic and adaptive planning. As such, it provides a high-level specification of all of the main processes and entities required to perform adaptation of a plan and the ways to dynamically adjust them over time.

Figure 1 is an overview of the main processes of ASHYI and data flows between them. The following sections explain this figure in detail.

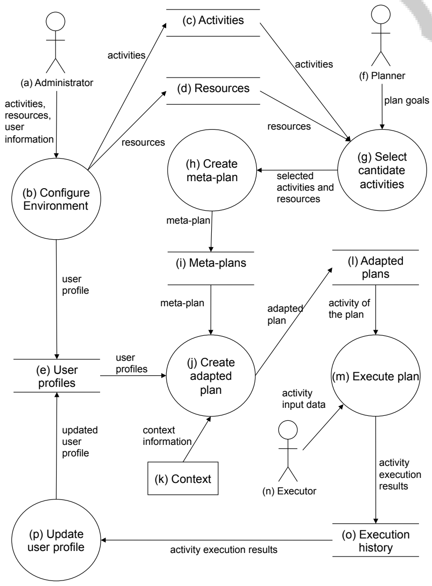

Figure 1: Processes and Data Flows of ASHYI.

The Configure environment (b) process of Figure 1 focuses on defining the specific planning elements. In particular, the Administrator (a) specifies: activities, resources, and user characteristics.

The specified activities include: a description of the actions to perform as part of the activity, preconditions (assertions that must be true in order to properly execute the activity), and postconditions (assertions that are expected to be true after the successful execution of the activity).

Each activity may require resources to be performed. The Administrator also specifies the available resources for each activity and the context conditions that determine their availability. For instance, if the user needs to access a journal paper that is accessible only within the network of a university that is subscribed to that journal, the paper may be unavailable if the user tries to access it from an outside network.

The Administrator can also specify the user information, i.e., the individual user characteristics that are used by the system to decide which activities are the most suitable for each user. For instance, based on information collected directly from users, the administrator may specify which users have some specific competencies. This information may also be collected by automated surveys and tests (not shown in the figure).

An important principle of ASHYI is that every plan must achieve a set of predefined goals, which means that each goal must be satisfied by one or more activities of that plan.When the Planner (f) user asks the system to create a plan, he/she must specify the goals of that plan. Based on that information, the system selects (g) those activities and resources that can satisfy the given goals when combined together.

Using the selected activities and resources, this process (h) creates a *meta-plan*, a structure from which all of the possible different plans can be extracted. For instance, if one wants to create plans with strict pre and post condition precedence, one can utilize the GraphPlan algorithm (Blum and Furst, 1997), which yields the meta-plan in the form of a graph that condenses all of the possible plans that could be obtained from the input activities. Of course, this is not the only option. The prototype described in this paper (see Section 4) utilizes a different structure to store a meta-plan.

The meta-plan is the base to create specific plans adapted to each user. This process (j) navigates through the meta-plan to extract an *adapted plan*. This plan is an instantiation of parts of the meta-plan that includes activities specially tailored for a given type of user. The set of activities in the adapted plan must satisfy the goals given by the Planner (f) user. Overall, the selected activities and resources in this plan are the best suited for that particular user, based on his/her profile and context, and according to domain-dependent criteria.

ASHYI provides to the Executor (n) user the activities that he/she must execute to accomplish the plan. Depending on the planning algorithm utilized in processes (h) and (j), these activities may be provided in a strict sequence, or the user may have the freedom to choose the execution order of some or all of them.

Each activity executed by the user provides specific results that are stored by the system in a history repository (o) to later provide feedback to the user.

This process (p) utilizes the activity execution log of a specific user to update the user profile. This updated information is further utilized by ASHYI to recreate the adapted plan for that user, if necessary.

For instance, if the Executor user performs a learning activity, he/she may gain new specific competences or, if the activity is not successful, he/she may only gain a subset of the expected competences that are postconditions of the learning activity. If the latter happens, the current adapted plan for that user may not be the optimal, since that plan may have been created under the assumption that the user successfully executed all of his/her activities. From the updated user profile information, ASHYI can infer that the user needs a new plan, so it executes process (j) again and yields a new adapted plan.

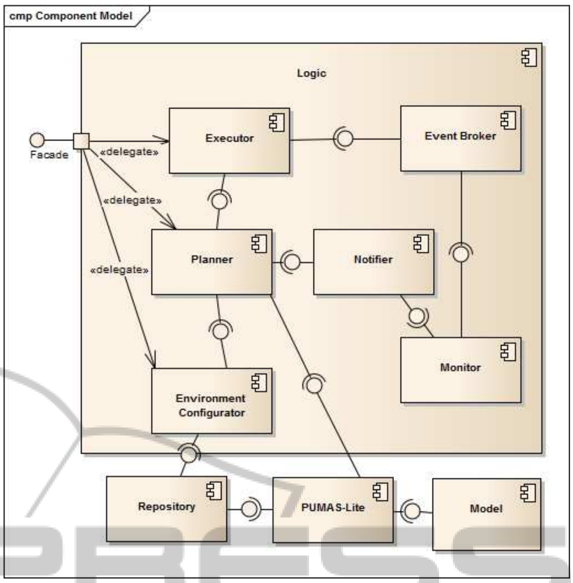

Figure 2: ASHYI-EDU Component Model.

4 ASHYI-EDU

The ASHYI Architecture provides the basis to create dynamic adaptive systems. To validate our proposed approach, we instantiated ASHYI into a specific design of a system called ASHYI-EDU. ASHYI-EDU is a software component that enhances web-based Learning Management Systems (LMS) with dynamic adaptive planning. ASHYI-EDU can be used to specify learning activities within a course and it can generate adaptive plans for each student, based on their specific competences, skills, and learning styles. ASHYI-EDU can automatically modify plans when students have not correctly learned the required competences and skills of each activity, and can suggest remedial activities to facilitate future learning within the course.

This section focuses on illustrating the process of instantiating the ASHYI architecture into the design of a dynamic adaptive system. For more details about the implementation of ASHYI-EDU, the reader can refer to (Jaime Pavlich-Mariscal and Martin, 2015)

ASHYI-EDU's design is based on ASHYI, thus each of the relevant roles, processes and repositories of Figure 1 are concretely defined for the educational domain.

ASHYI-EDU defines a specific component model to realize the ASHYI architecture, as shown in Figure 2. The Logic component contains all of ASHYI-EDU's business Logic. The Environment Configurator component lets the Teacher to specify the activities, resources, and students of a course . The selection of candidate activities is performed by PUMAS-Lite. The Planner utilizes PUMAS-Lite to retrieve activities and resources and create the meta-plan and the adapted plans. Plan execution and profile updating are performed by several components. The Executor assists the students in the execution of their assigned activities. The Event broker connects the Executor and the Monitor using a publish-subscribe approach. The Monitor supervises the events generated by activity executions and utilizes the Notifier to trigger a re-planning process in the Planner component, which also may delegate to the Environment Configurator to update the profiles.

The overall functionality of ASHYI-EDU is described as follows.

4.1 Roles

In the ASHYI-EDU, the ASHYI roles are specialized for the educational domain. The roles in ASHYI-EDU are the following:

Teacher. This role combines the roles Administrator (a) and Planner (f) from Figure 1. The Teacher can specify activities, resources, and students who participate in the course, and can also indicate the goals that ASHYI-EDU requires to create adapted plans for students.

Student. This role is equivalent to the Executor (n) role of Figure 1.

4.2 Plan and Execution

The instantiations of processes (g), (h), and (j) are highly interrelated in ASHYI-EDU, thus they are explained as a whole.

For process (g), the module of ASHYI-EDU that selects activities for a meta-plan is called PUMAS LITE. This is a simplified version of PUMAS (Carrillo-Ramos et al., 2007), a multi-agent framework for nomadic users. PUMAS provides users with information adapted to the specific user and context characteristics, regardless of the access device (mobile or not). PUMAS provides a method to query different sources of information (e.g., servers, plain text files in clients, etc.). In addition, PUMAS can automatically act as a broker between mobile devices and servers, depending on the query information; the agents can autonomously connect and disconnect from PUMAS.

PUMAS LITE focuses on selecting activities and resources, based on given goals for specific plans. The result of this selection is a set of activities and resources that satisfy the goals provided by the Teacher.

For process (h), the meta-plan may be structured in several ways. One option that was analyzed was GraphPlan (Blum and Furst, 1997), which models activities with hard pre and post conditions and is able to chain them into plans that satisfy specific goals. However, in the specific context of ASHYI-EDU, it is expected that some students should be able to execute latter learning activities even if they fail previous ones. Therefore, pre and post conditions should not be hard, but flexible.

Instead, the meta-plan is structured as a multipartite graph, as shown in Figure 3. Each node represents an activity with its corresponding resource set. Columns surrounded by an ellipse correspond to the *main activities*, i.e., activities that can be used to accomplish a specific learning goal in a course. Each of these columns is aligned to a particular course goal. For instance, nodes A_i in Figure 3 are all of the different activities that can satisfy goal A. Columns surrounded by a rectangle correspond to remedial activities that the student may execute between main activities.

All of the main activities in each column are connected with all of the remedial activities of the adjacent column on the right and also to all of the main activities of the column adjacent to the right of the remedial activities (the latter are not shown for space reasons). For instance, in Figure 3 each node A_i is connected to all of the nodes R_j of the contiguous column and is also connected to all of the nodes B_k.

The process (j), to create the adapted plan,

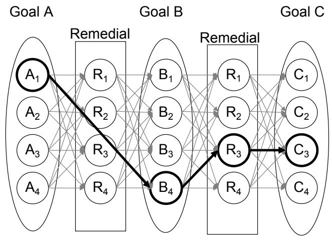

Figure 3: ASHYI-EDU Meta-Plan and Adapted Plan Example.

searches for the shortest path in the graph, which will include at least one main activity per learning objective and zero or more remedial activities. Figure 3 shows an example adapted plan as nodes and connections with bold outlines. The weight of each graph connection is given by a similarity measurement between the profile of a given student and the activity to which the connection is pointing. For instance, assume that –after successfully executing activity A_1– the similarity measure between the student profile and activity B_4 is 5.23. Then, in figure 3, the weight of the connection between activity A_1 and Activity B_4 is 5.23. The similarity formula is outside the scope of this paper and it is described in (Jaime Pavlich-Mariscal and Martin, 2015).

4.3 Matching Students to Activities

To determine the similarity measure between users and activities, both have a common profile structure, shown in Figure 4. The structure is a vector of numeric values between 0 and 1. Each number represents the degree to which a certain attribute is present in a student or whether it can be satisfied or required by activities.

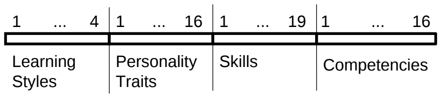

Figure 4: Student and Activity Vectors.

The attributes include 16 competences, 19 skills, 4 learning styles, and 16 personality traits. If a user profile has a specific attribute value greater than zero, it means that the student has that attribute, i.e., the user has a particular competence, skill, learning style, or personality trait.

Activities have two of those vectors, one for preconditions and another for postconditions. If an attribute has a value greater than zero in the preconditions vector of the activity profile, it means it is desirable that a student has that attribute to execute the activity successfully. If an attribute has a value greater than zero in the postconditions vector of the activity profile, it means that the successful execution of the activity will enrich the student on that attribute.

The similarity measure between a student and an activity is given by a function that combines different distance metrics between the student vector and the activity preconditions vector. This measure represents how appropiate is the activity for the student, according to his/her profile. The lower the distance, the more recommendable is the activity for the student.

4.4 Context

Whenever the context makes some activities unavailable, the ASHYI-EDU automatically creates a new plan. For instance, if a given resource in an activity is not available, ASHYI-EDU automatically creates a new plan that may include that same activity, but using an available resource.

Currently, ASHYI-EDU determines resource availability, based on two variables: access device and location. Resources that cannot be adequately opened in mobile devices are marked as unavailable if the student tries to access them from a limited mobile device. Similarly, location also determines if a resource can be used or not. For instance, if a given resource is an URL that can only be accessed from the University's internal network, it cannot be used if the student is accessing from outside the campus.

Overall, ASHYI-EDU detects the access device and IP of the device and marks the corresponding resources as unavailable. Based on this information, ASHYI-EDU creates a new adapted plan for the student in which activities that use those resources are excluded from the planning process.

5 CASE STUDY

ASHYI-EDU is currently being validated in a university course for students of the career of Primary School Teacher. The first part of the validation is an undergrad elective course called "Learning to Learn in the Web", offered during the Fall semester of 2014. The course utilizes blended learning and its goal is to give the student tools to learn in the web. The study involved all of the course 29 participants: 6 men and 23 women. The students are from different backgrounds (Education, Accounting, Information Sciences, Psychology, Software Engineering, Business Administration, and Microbiology).

To effectively utilize ASHYI-EDU in the classroom, this component was integrated into Sakai (Apereo-Foundation, 2014), a web-based LMS. In particular, we modified the lesson builder component to include ASHYI-EDU's dynamic planning facilities.

The course is divided into several learning units, each covering coherent groups of topics. Each learning unit has its own dynamic adaptive plan. Teachers specify learning goals for each learning unit. The PUMAS LITE component automatically selects the activities that match those goals and are taken as input by ASHYI-EDU to create the multipartite planning graph. Figure 5 shows a planning graph as it is generated by the tool for the teacher. Main activities are colored orange, while remedial activities are colored blue.

In addition, student profiles were initially built from surveys completed by the students. These surveys are based on the Chaea questionnaire (Alonso et al., 2009) and can be used to determine the student learning styles.

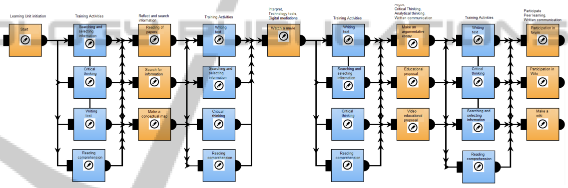

Figure 5: Planning Graph Example in ASHYI-EDU.

Using this information, ASHYI-EDU utilizes the process indicated in Section 4.2 to automatically create the best plan for each student to complete the goals of each learning unit.

To illustrate the capabilities of ASHYI-EDU, consider two students with different profiles:

Student A. Skills: Comprehension, relating reality with the environment, interpreting and analyzing information, observation, interest and initiative to learn, agility and adaptability, interpersonal relations and managing emotions and feelings. Personality: extroversion, intuition, thinking, judgment. Learning styles (max. score: 20): Active - level: 13, Pragmatic - level: 11, Reflexive - level: 12, Theoretical - level: 12.

Student B. Skills: Comprehension, expression of ideas, relating reality with the environment, interpreting and analyzing information, generating new ideas, raising critical reflection questions, answering based on knowledge and experience, interest and initiative to learn, agility and adaptability, interpersonal relations, and managing emotions and feelings. Personality: extroversion, intuition, feeling, judgment. Learning styles: Active - level: 8, Pragmatic - level: 6, Reflexive - level: 14, Theoretical - level: 16.

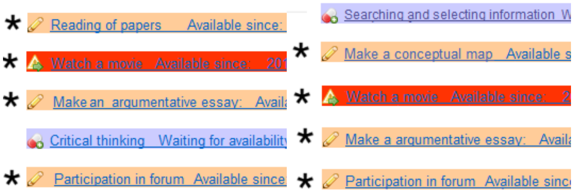

Figure 6: Adapted Plan for Students A and B.

When students access a learning unit in ASHYI-EDU, a different plan is shown for each of them. Figure 6 shows the adapted plans for Student A and B.

Each student plan has some main activities and, in some cases, remedial activities. These adapted plans depend on the student's characteristics so they differ for both students. For instance, the first activity of Student A is designed for people with active and pragmatic learning styles, while the activity for Student B addresses individuals with theoretical learning style. In both cases the activities address the main learning style of each student.

Remedial activities are included when the student needs to strengthen some attribute that is required by a main activity. For Student A, the system plans a remedial activity to strengthen critical thinking before the last class activity (see Figure 6). For Student B, the plan includes, before the first activity, a remedial activity to strengthen search and selection skills.

ASHYI-EDU supports a simple workflow that teachers and students can follow when executing an activity. This process is summarized as follows:

When the Student opens the learning unit, the system shows the adapted plan to the student, which highlights only those activities the Student is allowed to perform, according to the plan (see Figure 6). Activities not yet available are marked with an hourglass icon. Activities in progress are marked with a pen icon. Finished activities are either marked with a happy face or a sad face, depending on the teacher's feedback.

The Student can complete an activity and send his/her answer to the Teacher, using simple web form. The teacher receives the activity, and uses the same form to grade it, send feedback, and indicate which attributes (competences, skills, learning styles, or personality traits) the student has acquired after executing the activity. The system updates the Student profile with the acquired attributes and creates a new adapted plan, if necessary.

The student can later see the Teacher's feedback through that same form, or can choose to perform new activities that may become available thereafter. This cycle continues until the student has finished all of the planned activities for the learning unit.

5.1 Overview of the Results

Students utilized the system an average of 11.6 times during the semester, which is close to the total amount of learning goals of the course (there are 11 learning goals in the course). Students were interviewed to determine their satisfaction. Overall, the results were positive. Students felt that the course effectively adapted to their particular characteristics and chose the most adequate activities for them.

Teachers, on the other hand, had to invest more time preparing the course, since they had to create more than one activity per learning goal, in addition to the remedial activities. There was an additional effort to characterize each activity vector (see Section 4.3). However, this effort should be significantly reduced as the activity and resources repository is expected to grow as more teachers utilize the system and share their materials.

6 CONCLUSIONS AND FUTURE WORK

This paper presented ASHYI, an architecture to design dynamic adaptive systems. ASHYI specifies a set of processes to create adapted plans that are aligned with the specific user characteristics and his/her context information to achieve a specific goal.

The structure of ASHYI is sufficiently abstract to address different types of adaptive planning systems, but at the same time it is sufficiently specific to provide the essential design elements to instantiate it into a specific domain of application.

We illustrated the capabilities of ASHYI through ASHY-EDU, a component integrated into the Sakai LMS to provide dynamic adaptive planning for university courses, which is currently being utilized in a university course as a case study. Although the case study is still in progress, the current tests on the application demonstrate that the system is able to capture the essential student characteristics and provide an adapted plan according to their specific attributes.

Even though ASHYI-EDU focuses on education, the overall graph-based plan structure and the planning process as an optimal route search, have both a high reuse potential for other problems with clearly-defined phases, but multiple choices of activities to perform. Nevertheless, the architecture behind ASHYI-EDU (i.e., ASHYI) is sufficiently generic to be applied to other problems in which the design of ASHYI-EDU may be inadequate.

Future work is to complete the case study and analyze the strengths and weakness of ASHYI and

ASHYI-EDU, then execute a new case study the Spring semester of 2015.

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