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Merging Strategies for Authoring QoE-based Adaptive Hypermedia

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Abstract: Personalization is desirable, but writing the *adaptation behaviour description* to go with it is taxing. Even more challenging is the application of multiple adaptation strategies over the same static content. This paper focuses on recent work on *strategy modularisation and merger* development in the authoring process ofadaptive hypermedia. The reason for the *modularisation of strategies* is to break a complex adaptation decision into a number of simpler ones, which may be reused more easily and applied in different orders. The rationale for *strategy merger* is to be able to apply multiple adaptation strategies over the same content – a challenge which is not yet fully addressed in current adaptive hypermedia systems. To demonstrate the proposed method we present an example case study and sample strategies written in the LAG adaptation language. The case study is based on a recently proposed model for Quality of Experience in e-learning. This model exposes the complex interaction between a number of factors affecting QoE and hence presents a good candidate for the application of a strategy merger, as well as modularisation. We have then evaluated this approach via structured questionnaires used with a number of design experts of hypermedia content creation, especially in the domain of education. This allows us to draw generic conclusions for both our own further research, as well as for the community at large, interested in the area of reuse and modularisation of adaptation.

Keywords: LAG, Quality of Experience, Quality of Service, Multimedia Learning, Adaptive (Educational) Hypermedia, Adaptation, Strategy merger, Strategy modularisation
Categories: M.5, M.6, M.7, M.8

1 Introduction

In this paper, we are addressing the following questions: *Where does the need for adaptive strategy modularisation, merger and meta-strategies appear in adaptive*

hypermedia systems, specifically in relation with the term 'Quality of Experience'? We will briefly answer this question here and provide more detailed answers in the following sections.

We will start first with a number of definitions which describe the building blocks of the problem we target. Learner satisfaction, and, to some extent, the learning outcome, has been shown to be dependent on the *Quality of Experience (QoE)* of the user; in learning environments, this user is the learner [Wong and Csikszentnihalyi 91]. The Quality of Experience of the learner will strongly influence any future learning decisions [Dewey 97]: Will the student continue to enthusiastically interact with this system? Will they continue, but with an increasing sense of frustration; or will they finally give up entirely in their learning effort? It has long been established that it is particularly difficult to maintain student engagement with e-learning systems [Clark 02] and thus it is essential to maximise learner QoE wherever possible. Improvement of the QoE can be achieved in many ways, one of which is through an adaptation of material to maintain student interest, and maximise the quality of the material presented to them. We will consider two aspects of adaptation that may be used to improve the student QoE: *Quality of Service (QoS)* and *Media Mix*. Quality of Service is a term used in computer networking, and refers to the network parameters in data transfer, such as bit rate, delay, jitter, and their impact on quality of data delivery [Tanenbaum 02]. A simplistic assumption would be that, if adaptation is based on QoS only, an increase of QoS immediately results in an increase of QoE [Hava Muntean 08]. However, additional factors also impact on QoE. The interaction between the various factors, and the trade-off in optimisation of different factors is a subject of ongoing research. As our second factor, Media Mix has been identified as being potentially very important to the optimisation of QoE [Moebs 08]. Media Mix refers to giving students a mix of text, audio, video, and interactive material, in order to vary the presentation and maintain the student's interest. This mix and variation is important, as it has been shown that keeping to one media only has a negative effect on learner motivation [Hodges 04].

The trade-off between Media Mix and QoS optimisation requires complex adaptation which can lead to an equally complex adaptation strategy. This complexity limits the reusability of such a strategy. One way to enable the reuse of adaptive strategies is to break down large and complex strategies into *smaller modular strategies* which can be reused in different orders or in different combinations with other strategies to produce intelligent adaptation. The breakdown into modular strategies represents the *adaptive strategy modularisation*. The strategy which runs various modular strategies and places the conditions and the order between these modules is the *adaptive meta-strategy* (or *adaptive monitoring strategy*) [Stash et al. 07].

This paper outlines how to break down complex adaptation settings or a complex adaptation strategy into reusable parts, which can be triggered by a meta-strategy, and demonstrates this using the example of the QoE and Media adaptation strategies. The breakdown is explained in terms of how the merger is simplified by first modularizing the strategies, then merging them via a meta-strategy.

The overall objectives of this paper are thus to:

1. *demonstrate a method to break down large strategies into reusable modular strategies.*
2. *demonstrate how these modular strategies can be combined efficiently via meta-strategies.*
3. *demonstrate how the application of meta-strategies would benefit a strategy merger;*
4. *illustrate the above three authoring situations via a motivational scenario.*
5. *present the result of a survey of experts aimed at the evaluation of the above ideas and goals from the authoring perspective (in contrast to that of the learner).*

Section 2 presents related work of the research presented in this paper. A motivating scenario is outlined in Section 3. Section 4 describes a case study with a QoE strategy overview. The authoring process for QoE in adaptive e-learning is described in Section 5, addressing the issues of content & adaptive strategy authoring. It also gives the technical description and presents adaptation strategies for QoS and a Media Mix. Section 6 discusses reuse and combination of adaptation strategies. Section 7 provides an example how to create reusable modular strategies using the case study previously introduced. Section 8 presents hypotheses identified regarding the meta-strategy method. Structured interviews with e-learning authors were applied to evaluate these hypotheses. Section 9 describes the interviews, the results and discussion of the results. Finally we present conclusions & future work in Section 10.

2 Related Work

Quality of Experience model. QoE in a technical environment has been defined as the "overall acceptability of an application or service, as perceived subjectively by the end-user" [ITU 06]. Arguably, this definition falls short of covering all relevant aspects of user experience in learning systems, where learner experience is additionally influenced by learning-related factors.

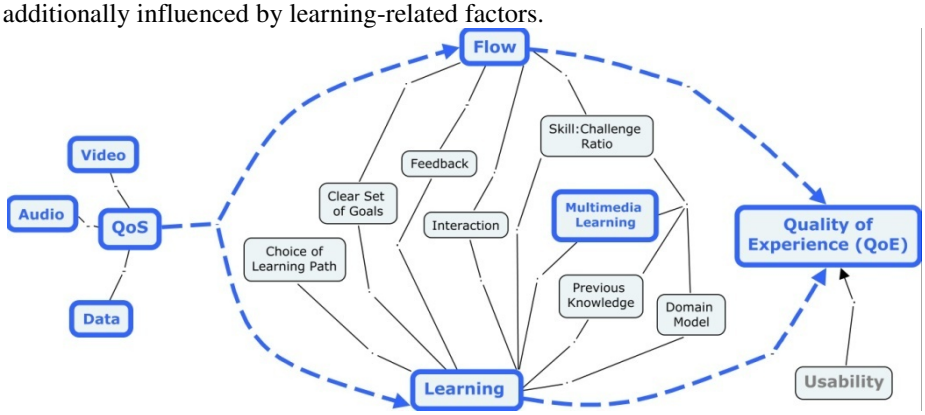

Figure 1: QoE Model for Adaptive E-Learning Systems [Moebs 08]

A recently proposed QoE model (see Figure 1) for adaptive e-learning systems expands on the idea that QoE is determined by learning experience and flow

experience [Konradt and Sulz 01]. It is proposed that these factors are in turn affected by a number of other aspects, including QoS parameters, and Multimedia Learning [Moebs 08]. Additionally to the main theme of modularisation, merger and meta-strategies, this paper examines how the QoS and learning aspects of this model can be translated into adaptation strategies, as part of the authoring process of adaptive e-learning. The background to these strategies is discussed below, and the details of the strategies are discussed in sections 4 and 5.

Quality of Service. Quality of Service describes the network parameters in data transfer, such as bit rate, delay, jitter, and their impact on quality of data delivery. Tolerance towards those QoS parameters depends on the application [see Tanenbaum 02]. These network performance parameters, loss, delay and bandwidth will be used to characterise the quality of network delivery conditions. This characterisation will then be used as input for adaptation decisions. Bandwidth can be considered the parameter most relevant for all multimedia e-learning applications, while the importance of loss, delay and jitter depends on the type of application. Adaptation to the QoS parameters is achieved by sending materials most suitable to the network conditions. Initial research on QoS in a learning context investigated QoE improvements in courses with illustrated text [Hava Muntean and McManis 06], whereas here we are using any type of media.

Media Mix. The Media Mix aspect combines basic elements of Multimedia Learning theory [Taran 05] and motivational techniques [Hodges 04].

Research on motivational techniques for e-learning shows the positive motivational impact [Hodges 04] of alternating delivery and format into the Media Mix strategy. The change of media format also adds an element of variability, which has been identified as another motivational stimulation technique [Taran 05]. A Media Mix that varies the media format, presenting one media type at a time, prevents overwhelming the learner and leaves room for visual rests [Clark 02].

Adaptation Strategy Authoring for Adaptive Systems. The authoring of adaptive courses can be a difficult process and various methods have been proposed in order to reduce the time and effort needed to create them.

Multiple adaptation frameworks, including ACE [Specht and Oppermann 98], AHAM [De Bra et al. 99], LAOS [Cristea and De Mooij 03b] and the GRAPPLE framework[1], have been created to improve the reusability of both the content and the adaptation specifications used in adaptive courses.

The reuse of adaptation specifications becomes simpler as the specification becomes more generalised and abstract. This is due to being able to apply the specification to new content domains without major modifications to either the specification or the content.

Hence, higher-level adaptation languages where the adaptation description can be completely generic, such as LAG [Cristea and Verschoor 04] and LAG-XLS [Stash 06] are more suited to be reused than 'assembly-level' adaptation languages such as those used in AHA! [De Bra et al. 06], Interbook [Eklund and Brusilovsky 99] and WHURLE [Moore et al. 03].

[1] www.grapple-project.org/

Even though higher-level adaptation languages are in a better position to be reused for different content domains, combining multiple adaptation strategies into a coherent overall adaptation strategy is still problematic.

We are thus using the MOT [Cristea and De Mooij 03a] authoring tool to demonstrate the creation of content as well as an extended version of the LAG adaptation language to describe the meta-strategy authoring process in further detail in Section 5.

3 Motivating Scenario

The following scenario demonstrates the need for QoS and Media Mix-based adaptive e-learning from the perspective of the learner, and the challenges it causes for the authoring process.

The learner perspective. Father Ted lives on the remote Craggy Island off the west coast of Ireland. He has decided he needs to learn German to keep up with current events in Rome, but access to face-to-face classes in higher education or professional training is very difficult if not impossible. So he signs up for an on-line class. Although he does not have the most stable and powerful Internet connection, he still enjoys the course. The course provides a mix of different materials and activities and a variety of videos, audio clips or illustrated text. Materials are easy to access at all times and he enjoys the course so much, he often finds himself spending more time than originally planned.

On a trip to a meeting he runs into a colleague who lives in Dublin, who has an excellent broadband connection, and who also signed up for the course. They are very surprised when they compare their experiences and realise that they both learned the same course, found the course equally enjoyable, but were not necessarily presented with identical material. Ted cannot remember all of the videos his colleague mentions, but he on the other hand recalls some very interesting audio clips his colleague seems to have missed. Nevertheless they both enjoyed the course a lot, because:

- they both reached their learning goals.
- they did not run into problems with excessively long download times of material.

Discussion: The *QoS* aspect is present in the different types of media presented to the two learners, supporting the same set of learning goals - each learner has been sent material appropriate to their network connection. The *Media Mix* aspect is present in the variety of media the content is presented in.

The author perspective. Professor X prepares a new online German course for international students. Her previous online course adaptation strategy varied the media format of the learning material and now she extends this strategy after receiving feedback from previous students. One aspect that had affected their learning experience was that, due to bad internet connections, the course was not always accessible or was only accessible with a considerable delay.

Professor X needs to add the adaptation of content based on network conditions to the previous adaptation strategy which varied the media formats. She has two possible methods to do this.

The first method is to write a single strategy which combines the two types of adaptation for the course. Professor X does not wish to use this method as she would be unable to easily reuse either of the two adaptation behaviours, either singly or with other strategies, in the future.

Instead Professor X decides to create individual modular adaptation strategies for each desired adaptation behaviour. She can then control their execution within the new course by using a meta-strategy. This enables her to easily reuse the modular adaptation strategies again in future courses.

Discussion: In this kind of setting we discuss how meta-strategies can support the combination of different strategies, using the example of Quality of Experience (QoE) adaptation [Moebs 08].

4 Case Study

In this section we describe the QoE and Media Mix strategies, as well as the authoring process for such a course.

4.1 QoE Strategy Overview

The decision of what material to present to the learner is based on a combination of constraints from the technical environment of the learner and multimedia theory. This is in reality a two step process: first the assessment of network conditions takes place, and then those conditions are mapped onto a media suggestion, which accounts for the principle of Media Mix. The first step results in suggestions about which media can be delivered, considering the network conditions (see column "Suggestion", ***Table 1***), while the second step takes into account previous media sent to the learner and aims at avoiding sending the same media type again (see column "Recommendation", ***Table 1***).

An initial assessment of the network conditions, representing QoS, considers available bandwidth only. Bandwidth is considered the most important parameter, because it not only affects all media formats, it also has a significant impact on loss and delay and therefore on jitter. A more detailed assessment could consider loss, delay and jitter. The values for the available bandwidth are taken from typical commercial products. Some formats may have to be ruled out because of delivery conditions. In this case, the format is as varied as possible. This is summarised in the suggestions. If the network profile is POOR, only text+images can be sent, no matter what the pedagogical restrictions are.

The decision of which media format is ultimately selected depends on the user's history of the *Media Mix*. According to the Media Mix theory, the media format used one step earlier is always excluded. We chose to use a predetermined ordering for the media, where audio is followed by illustrated text, illustrated text is followed by a video and video is followed by audio. These profiles allow for the selection of suitable media formats that can be expected to be delivered to the learner in good quality (see ***Table 1***).

	Bandwidth	Suggestion	Previous Media	Recommendation
POOR	Dial-up (38, 56 kbps)	Text+images (low)	Any	Text+images (_low)
MEDIUM	DSL1 (256, 340 kbps)	Audio at 96-128 kbps OR Text+images (high resolution)	Video	Audio at 96-128 kbps (audio_low)
			Audio	Text+images (_high)
			Text+images	Audio at 96-128 kbps (audio_low)
GOOD	DSL2 (700kbps, 1Mbps)	Audio at 192-256 kbps OR Text+images (high resolution) OR Video at ~700 kbps	Video	Audio at 192-256 kbps (audio_high)
			Audio	Text+images (_high)
			Text+images	Video at ~700 kbps (video_low)
EXCELLENT	DSL3 (2Mbps, 4Mbps)	Audio at 192-256 kbps OR Text+images (high resolution) OR video at ~1 Mbps	Video	Audio at 192-256 kbps (audio_high)
			Audio	Text+images (_high)
			Text+image	Video at ~1 Mbps (video_high)

Table 1: QoE Strategy

It should be noted that several assumptions have been made as to the application order and exceptions to the adaptation rules in order to arrive at a coherent policy. The policy presented combines two separate policies, and ideally, the initial QoS and Media Mix policies would be available separately, for reuse in different settings. To enable this adaptation strategy, a few points in the authoring process as outlined in the following are necessary.

5 Authoring process for QoE adaptive e-learning

5.1 Content Authoring for QoE adaptive e-learning

The authoring process essentially follows the usual authoring process in MOT [Cristea et al. 05]. This part of the paper simply points out a few key points relative to the development of a sample course which adapts based on QoS and Media Mix.

The sample course has a basic structure for each part; title, introduction, main content, conclusion. Title, introduction and conclusion are always text-based. The adaptation affects the main content area only.

In this particular case of a multimedia course, adapting not only to network conditions or QoS parameters, but also providing a mix of different media, it is necessary to provide all learning resources in three different types of media. We consider videos in H.264 / MPEG-4 format, audio files in MP3 format and illustrated text.

The QoS adaptation requires adding additional attributes in the domain model, clearly named according to the different formats and possibly the different quality

levels of the same content. An example for the authoring of these additional attributes is given in Figure 2, additional attributes are marked with an ”x”[2].

Figure 2: QoS and Media-mix based Attributes in MOT

The Media Mix adaptation can be enabled by adding labels in the goal and constraints (pedagogic) model, again named according to the different formats[3].

Next, adaptation strategies [Cristea and Verschoor 04] for the QoE adaptation are required. These strategies are described in more detail in the following sub-section. In the processing order it makes no difference if the strategies are written before or after setting up the course. Once the strategies are written, different content and courses can be used with these strategies. This requires that naming of attributes and labelling content follow the details in the strategies. Any other authoring activities follow the commonly known steps outlined elsewhere [Hendrix et al. 07]**.**

5.2 Adaptive Strategy Authoring

The case study in section 4 highlights the necessity for two different strategies to improve the Quality of Experience of the Learner, considering Media Mix and QoS changes. These strategies are introduced below. The case study also points out the necessity for reuse and the possibility to combine strategies; this aspect is explored further in the section 6. As sketched in the scenario, the combining of strategies can become very complex. Here, the strategies are first described. Next, the main problems with reuse and combinations of strategies are identified. Then we propose a method to create reusable modular strategies, using the case study as an example.
The adaptation strategies aim at two different goals, adapting the content to provide a Media Mix and adapting the content to changes in QoS.

[2] Which actually means these are user-defined attributes and thus can be removed by the user later, as opposed to imposed attributes determined by the system.

[3] This is just one of the ways this selection mechanism can be defined via the MOT tool. Here, we don’t go into details about alternative, perhaps more optimized, ways of content description in MOT.

The Media Mix strategy aims at providing a mix of different media in the main content area of the course, one type of media at a time. In this example we only consider video, audio and illustrated text, which could be further diversified into different quality levels for each media type.

The QoS strategy aims at adapting a course, depending on the changes in network conditions. Again, the adaptation applies to the main content area[4].

Example of a LAG strategy to provide a Media Mix:

An example snapshot of the delivery of the Media Mix strategy in the ADE adaptation delivery engine [5], showing text first, and then video, can be seen in Figure 3.

Figure 3: Multimedia Mix Strategy displaying Text and then Video

For this strategy, as well as others, some parts need to be always shown to the user. This is in order to make sure that something is always displayed, no matter of the strategy. In the case selected here, each concept has a textual introduction and textual conclusions. This guarantees that these two parts can be sent regardless what the network conditions are. This code should make them readable for all:

```
initialization(
  while true (
    if(GM.Concept.label=="introduction" OR
       GM.Concept.label=="conclusion")
    then ( PM.GM.Concept.show = True )))
```

The following code shows how the mix of the media is selected depending on the history of the user, the media s/he has previously used or seen. Media information is

[4] And thus not to the menu's, sidebars, etc. This latter type of adaptation is also possible, but not further discussed here.

[5] https://launchpad.net/ade

stored in the user model; and thus, depending on the previously seen media, a predefined media type will be shown next. If the media type seen previously is "video" then the next media type will be audio, if the media type seen previously is "audio", it will be followed by illustrated text and finally the media type "text" will be followed by video content, accordingly. This guarantees a constant rotation of different media types shown. On the other hand, because rotation does not vary, it might become easily predictable. The additional adaptation to QoS parameters might lead to a varied sequence of media types. This simple strategy is shown below[6].

```
implementation(
  if (UM.history == video)
  then (
         if (GM.Concept.label LIKE[7] *audio*)
         then ( PM.GM.Concept.show = True    ))
  else  if (UM.history == audio)
        then (
              if (GM.Concept.label LIKE *text*)
              then ( PM.GM.Concept.show = True    ))
```

Example of a LAG strategy to provide adaptation to changing QoS conditions:
An example snapshot of the delivery of the QoS strategy in the ADE adaptation delivery engine, showing video first, and then text, can be seen in Figure 4.

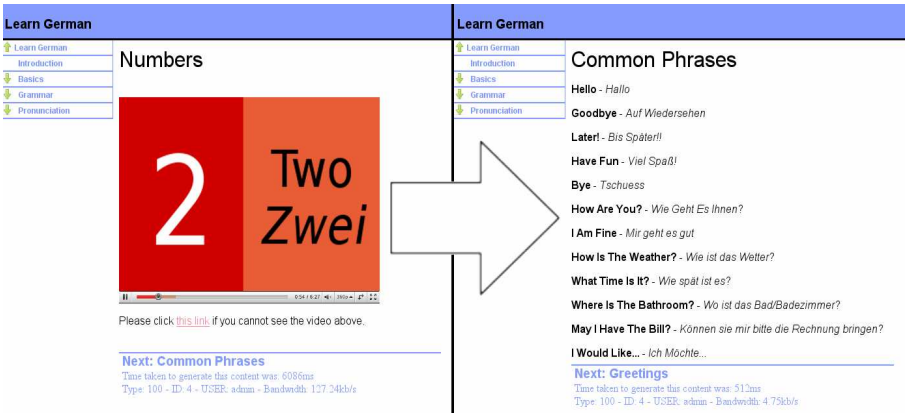

Figure 4: QoS Strategy showing Video then Text for fast and slow connections

Again, a part of the content is always shown. Here, similarly to the above, each concept has a textual introduction and conclusions, which should be readable for all (the code omitted as it is thus identical with previous initialization).

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[6] This is not the only way this strategy can be written, as in LAG, grouping of conditions is allowed via a programming construct called 'enough', as shown in following snippets of code.

[7] The 'LIKE' construct requires an extension of the LAG language, which has been introduced as an update in the conversion to the ADE system.

Next, the QoS profile is estimated, based on current QoS information. It checks whether the bandwidth profile is lower than all other three profiles. If not, the bandwidth determines the QoS profile; otherwise the QoS profile is the sum of the weighted QoS parameters bandwidth, loss, delay and jitter.

```
implementation(
 if(enough(PM.bandwidth_profile<=PM.loss_profile
           PM.bandwidth_profile<=PM.delay_profile
           PM.bandwidth_profile<=PM.jitter_profile,3)
 then (PM.QOS = 0)
 else (PM.QOS = (0.5 * PM.bandwidth_profile) +
                (0.5*((0.4*(PM.loss_profile +
                            PM.delay_profile)) +
                (0.2 * PM.jitter_profile))))
```

The following code initialises the visibility of concepts based on the above QoS profiles.

```
 if (PM.QOS <= 0.2)
 then ( if (GM.Concept.label LIKE *text*)
        then ( PM.GM.Concept.show = True    ))
 else if (PM.QOS <= 0.5)
      then ( if (GM.Concept.label LIKE *audio*)
             then ( PM.GM.Concept.show = True ))
      else if (PM.QOS <= 0.8)
           then ( if (GM.Concept.label LIKE *video-low*)
                  then ( PM.GM.Concept.show = True    ))
                  else ( if (GM.Concept.label
                               LIKE *video-high*)
                  then ( PM.GM.Concept.show = True    )))
```

The code above shows how content is selected depending on QoS conditions. Text is selected for the lowest QoS level, while audio, video in low quality and video in high quality are selected for medium, good and excellent conditions, respectively.

6 Reuse and Combination of Adaptation Strategies

The scenarios described in section 3 illustrate both a solution to our case study, as well as a common problem in Adaptive Hypermedia: often, a course will need to use or reuse multiple adaptation strategies in order to achieve the desired behaviour.

Although it is possible to manually combine the various strategies into one overall strategy, this does not aid a strategy author who requires reusing a particular behaviour from a previous course and/or combining it with a new one.

It would be more useful if the required adaptations could be described by modular adaptation strategies which could then be reused and combined in various permutations. This would reduce redundancy and aid the strategy authoring process for adaptive hypermedia systems.

6.1 Problems with reuse and combination of adaptation strategies

There are problems with reusing some adaptation strategies on different content domains, as they can be specialised to particular content which cannot be easily reprocessed without editing the course content. A method for solving this problem using the LAG strategy language has been described elsewhere [Hendrix and Cristea 08].

However, there are other problems with reusing adaptation strategies, which arise when multiple strategies are used at the same time. Although problems with multiple strategies can occur when an author has written them specifically for the same course, they most commonly occur when strategies from different courses are reused. While adaptation strategies may produce the desired behaviour if they are executed individually in isolation, when they are run together they can produce unforeseen behaviours which are not intended by the course author.

Some potential problems which occur when using multiple strategies are:

- **Execution Order**: Some strategies will work fine when they are run in one particular order but not if the order of execution is reversed or changed.

For example, Strategy 1 shows Concepts A, B and Strategy 2 hides Concept A. If the execution order is Strategy 1 and then Strategy 2, only Concept B is displayed. However when the execution order is reversed both Concept A and B are visible. This could potentially cause problems if Concept A and B were different versions of the same information. Other situations might result in no content being shown to the learner, which would a very undesirable situation.

- **Variable Clashes**: Unforeseen behaviour can be produced if multiple strategies access, and more importantly, update the same variable. For example if two strategies both have the following line (Example 1) in the strategy file then the system may report that the user has accessed the concept six times when the user has actually visited the concept only three times.

Example 1

```
UM.GM.Concept.beenthere += 1
```

- **Type Conflicts**: Multiple strategies use the same variable to store different types of value. For example one strategy (Example 2) may store a Boolean while another (Example 3) will expect an Integer when it accesses the same variable.

Example 2:

```
UM.GM.Concept.accessed = True
```

Example 3:

```
if (UM.GM.Concept.accessed > 2) (...
```

7 Creating reusable modular strategies using the case study

We would like to be able to combine the individual QoS and Media Mix strategies in order to automatically produce the QoE adaptation behaviour described in section 3. This is not as straight-forward as applying one strategy and then the next, but requires a more subtle approach. A discussion of the issues involved in combining these strategies follows.

To start, let us consider what happens when we run one strategy after the other. As an example, if we run the QoS strategy first and then the Media Mix strategy. This would cause a problem, because a user who had a medium quality connection and had just viewed a piece of text as part of the course would be shown next an audio file from the QoS strategy and both videos from the Media Mix strategy. This is not acceptable, especially as all three content parts would contain the same information.

This problem occurs because the two strategies both selectively display parts of the lesson contents as per the adaptation behaviour they envision. The strategies do this without any knowledge of what other parts of the lesson being displayed are shown or hidden. As this is a restriction of most current adaptation engines we will consider how to solve this problem without the adaptation strategies needing to know what other lesson content parts are visible.

The strategies both initialise and display lesson contents. As the individual strategies do not know what is visible at any single point as generated by another strategy, the overall strategy to achieve the behaviour would be to show one content part for video, audio and text, switch the quality of that content, as per the QoS theory, and then hide any content which doesn't fit the media type that needs to be shown by the multimedia theory.

We need to do this in a way that the strategies can then be reused to achieve the QoS or Media Mix behaviour in other contexts. In general, this can be done by identifying the main tasks that are needed for the overall strategy and writing the new strategies to perform these tasks. However, for some behaviour, it may not always be possible to do this, as the tasks themselves may clash. For example a “Show All” task would clash with a “Hide All” task. In this case we would need to create an additional task to arbitrate this situation. After these strategies are written, a meta-strategy would be created to combine them in a way that would produce the desired adaptation behaviours.

The proposed method, as described above, could be used as a generic method for creating reusable strategies using a task based approach and is summarised as follows:

1. Divide the overall behaviour into tasks that need to be performed;
2. List the areas where the tasks might clash and what assumptions are needed for the task to be carried out;
3. Write an adaptation strategy for each task; and
4. Write a meta-strategy to control when and how the strategies should be executed.

The main tasks that are needed for the QoE strategy are:

- Initialising the course content;
- Creating a default state for the lesson to be viewed;
- Switching the content quality to be shown as per the QoS; and
- Showing and hiding content as per the Media Mix theory.

The areas where these tasks could clash are in showing and hiding content. We do not want to show content without ever removing it. A simple solution is as follows. For every condition resulting in addition of content such as:

```
if (condition)
then ( PM.GM.Concept.show = true )
```

we would hide the content that we do not want displayed like:

```
      if (condition)
      then ( PM.GM.Concept.show = true )
      else ( PM.GM.Concept.show = false )
```

The initialisation task is performed in the course initialisation stage and the default setup task is performed in the course implementation stages. Hence they can both be contained in the same LAG file as follows:

Strategy – Initialisation and Default Setup

```
initialization(
  while true (
    if(GM.Concept.label==introduction OR
       GM.Concept.label==conclusion)
    then (PM.GM.Concept.show = True))
)
implementation(
  if (GM.Concept.label LIKE *video-high*) then (
    PM.GM.Concept.show = True
  ) else if (GM.Concept.label LIKE *text*) then (
    PM.GM.Concept.show = True
  ) else if (GM.Concept.label LIKE *audio*) then (
    PM.GM.Concept.show = True
  ) else if (GM.Concept.label==introduction OR
GM.Concept.label==conclusion) then (
    PM.GM.Concept.show = True
  ) else (   PM.GM.Concept.show = False
  ))
```

The code above initialises the course content to show the introduction and conclusion for each lesson as per the initialisation task. The implementation loop for the Default Content task sets the highest quality content to be displayed as the default; for the purposes of this paper we assume that text and audio have no quality differences. Everything else is hidden; this includes content labelled video-low which would be a low quality version of the video-high.

An example of the QoS code that deals with showing the correct video content quality is shown next:

```
// SWITCHING CONTENT QUALITY
if (GM.Concept.label LIKE *video-low*)
then (  PM.GM.Concept.show = True
) else if (GM.Concept.label LIKE *video-high*)
  then ( PM.GM.Concept.show = False)
```

This code would hide video-high content and show video-low content, switching the quality for that particular type. Variations on this would be run for different QoS values.

The code for the Media Mix task is composed of conditions similar to the following code.

```
  if (UM.history == video) then (
    if (GM.Concept.label LIKE *video* OR
        GM.Concept.label LIKE *text*)
    then ( PM.GM.Concept.show = False)
    else ( PM.GM.Concept.show = True )
```

The code above hides the content that shouldn't be displayed according to the Media Mix theory and shows other content. There would be variations on this code for the other possible UM.history values.

The full strategy code listings for the QoS and Media Mix tasks are given in Annex 1.

These strategies can now be run together or in different combinations to achieve the desired adaptation behaviours. The meta-strategy which would combine the above strategies to achieve the QoE behaviour is shown below.

```
initialization(
  Strategy-Setup.initialization
)
implementation(
  Strategy-Setup.implementation
  Strategy-QoS.implementation
  Strategy-MediaMix.implementation
)
```

Figure 5: Combined Strategy show Audio then Text for fast and slow connections

Automate the method. One drawback of the proposed method is that it is a manual process. To make it more useful the method needs to be automated as much as possible when input strategies are available. It may be possible to automate the first two steps by performing the following:

Step 1: Automate the identification of behaviour

- Analyze the variables used in the input strategies.
- Identify the different types of adaptation existing in the original strategies.
- Analyze the interaction between different layers of adaptation
- Map the adaptation behaviours to the variables that they depend on

Step 2: Verification of strategies

- Check if any single variable is responsible for multiple adaptation behaviours.

- Identify the dependencies of variables which are responsible for the adaptation behaviours.
- Analyze how and when variables cause an adaptation.
- Identify problematic patterns that could cause clashes.

A more detailed view on these topics is the focus of ongoing research.

8 Hypotheses

Given the solutions of strategy merger as described above, we have extracted a number of hypotheses that need tested, in order to best approach such a merger, as follows.

H1. Adaptation strategies and multiple adaptation strategy application are important for the roles of client/sponsor, subject matter expert, instructional designer, writer, graphic artist, interface designer, audio/video producer, and quality reviewer.

H2. It is useful to author (create content, order and annotate) via an adaptation authoring tool, such as MOT3.0.

H3a. An author with any of the roles above would be able and/or willing to write their (adaptive) pedagogical strategies in an adaptation language, such as LAG.

H3b. An author with any of the roles above would be able and/or willing to make small desired changes of their (adaptive) pedagogical strategies in an adaptation language, such as LAG.

H3c. An author with any of the roles above would be able and/or willing to use adaptive pedagogical strategies in an adaptation language, such as LAG.

H4. Designing meta-strategies for later reuse benefits the authoring for adaptive courses.

H5a. Designing meta-strategies for later reuse provides a less error prone way to author complex combined strategies compared to the method of detailed merge.

H5b. Designing meta-strategies for later reuse simplifies the authoring of large, complex strategies.

H6a. It is / will become necessary to use multiple strategies in real life e-learning systems.

H6b. There is a need for a method to break down large strategies into reusable modular adaptation strategies.

H6c. A visual drag&drop editor is useful to select between reusable modular strategies.

H7. Execution order issues and reuse are/will become important for the type of adaptation needed in an e-learning system.

9 Evaluation

An evaluation of the hypotheses and solutions presented by this paper needs to be approached from the different perspectives of the stakeholders involved: the *author* during the creation process and the *learner* during the delivery process. Clearly, separate mechanisms need to be used to obtain information for each of these perspectives.

The evaluation presented in this paper focuses on the first step of this process, the authoring perspective of the solutions described. This is primarily because the problems being solved are composed of authoring issues such as reusing and combining multiple adaptation strategies. This is not to say that the solutions to these problems do not impact the learner perspective. Indeed the issue of order execution and ensuring that the correct content is displayed to the learner is as much a problem of the delivery stage of adaptive hypermedia as it is to the authoring process. However, the learner perspective will also be heavily influenced by the purpose of the original adaptation strategies. Additionally, in terms of the use of meta-strategies the authoring perspective is of primary importance and as such this paper will focus on the authoring evaluation.

The main categories of authors in an e-learning application are usually: content authors and instructional designers. Content authors often combine the two roles of writer and subject matter expert, while instructional designers provide consultation on instructional strategies and learning techniques for e-learning. Ideally, both categories need to be involved in the design and evaluation of an authoring tool.

Our evaluation involved applying structured interviews to a number of authoring specialists, which we have classified amongst these as content authors, instructional designers or related roles.

9.1 Interviews

Interviews were arranged with authors who have at least two years of experience with authoring of e-learning courses, and who are actively involved in current developments in their professional area, either through research or professional work. Some of the authors also have considerable experience with educating other authors of e-learning in certified educational or training programs. The interviews were recorded and analysed afterwards.

The authors categorised themselves via a profile provided. The profile offered different roles related to e-learning content development, as defined by [Khan 04]: *subject matter expert* (SME), *instructional designer*, *writer*, *graphic artist*, *interface designer*, *programmer*, *audio* and *video producer* and *quality reviewer*.

9.2 Questions

The following questions were discussed with authors during one-hour long face-to-face interviews. The references to the hypotheses were not provided during the interviews. The questions asked during the interviews were designed to test the hypotheses listed above and involved answering questions such as:

- *What do you think about authoring a course as shown in the screenshots and the LAG strategies?* (reflecting on hypotheses H1, H2)
- *Would you be able and/or willing to write your own pedagogical strategy via an adaptation language, such as LAG?* (reflecting on hypothesis H3a)
- *Would you be able and/or willing to make small desired changes on a pedagogical strategy in an adaptation language, such as LAG?* (reflecting on hypothesis H3b)
- *Would you be able and/or willing to use the pedagogical strategy of your choice directly?* (reflecting on hypothesis H3c)

- *Does using meta-strategies benefit authoring situations as outlined in the scenario?* (reflecting on hypothesis H4)
- *Which method provides a less error prone way to author complex combined strategies - the method of meta-strategies or the method of detailed merge?* (reflecting on hypothesis H5a)
- *Does using meta-strategies simplify the authoring of large, complex strategies?* (reflecting on hypothesis H5b)
- *Do you expect it to be necessary for you to use multiple strategies?* (reflecting on hypothesis H6a)
- *How do you evaluate the necessity for a method to break down large strategies into reusable modular strategies?* (reflecting on hypothesis H6b)
- *Do you see possibilities to expand the method to include tools supporting the authoring of strategies?* (reflecting on hypothesis H6c)
- *Would execution order of the strategies be an issue for the type of adaptation you would need in an e-learning system?* (reflecting on hypothesis H7)

9.3 Results

We have interviewed five specialists in authoring. All interviewees are content authors. One author preferred to be categorised as experienced instructional designer and is also an accomplished trainer for e-learning content authoring.

The years of experience among interviewees range between 2-23 years with a median of 12 years and an average of 13 years. All interviewees are experienced in two or more of the e-learning authoring roles.

Although all questions as described above were asked, the interviews were conducted in a semi-structured fashion, thus allowing authors to express additional views and insights. Due to this, some questions have received definite answers (and thus clearly confirmed some hypotheses) and some not. However, the added value of this approach was that we have gathered some interesting insights into the way current authors perceive the development requirements of this field. Below, we summarize their feedback and discuss confirmed hypotheses, as well as additional insights. For hypotheses with less than five responses not all interviewees provided feedback (see Figure 6 and Figure 7). This summary of the results shows that a relevant number of hypotheses could be confirmed. For those which couldn't be confirmed, we discuss possible issues and matters arising.

Authors confirmed that working in a tool like MOT is familiar to them, and although this tool is designed more for content authoring than for adaptation, they saw a great similarity in look and feel to the tools for linear authoring, and thus would be able and willing to use such a tool (confirming hypothesis H2). This was especially interesting because the aspect of authoring for adaptation (here, for content) did not seem daunting to them. Additionally, it confirmed that the new revised look and feel of MOT3.0 allowed for authors to draw on their past experience.

Furthermore, the interviews confirmed that adaptation strategies and multiple adaptation strategies applications are important for instructional designers (hypotheses H6a and H7). Additionally, interviewees consistently pointed out that decisions concerning the need for a strategy and writing a strategy is part of the

concept phase rather than the content authoring phase and therefore a task for instructional designers (hypothesis H1).

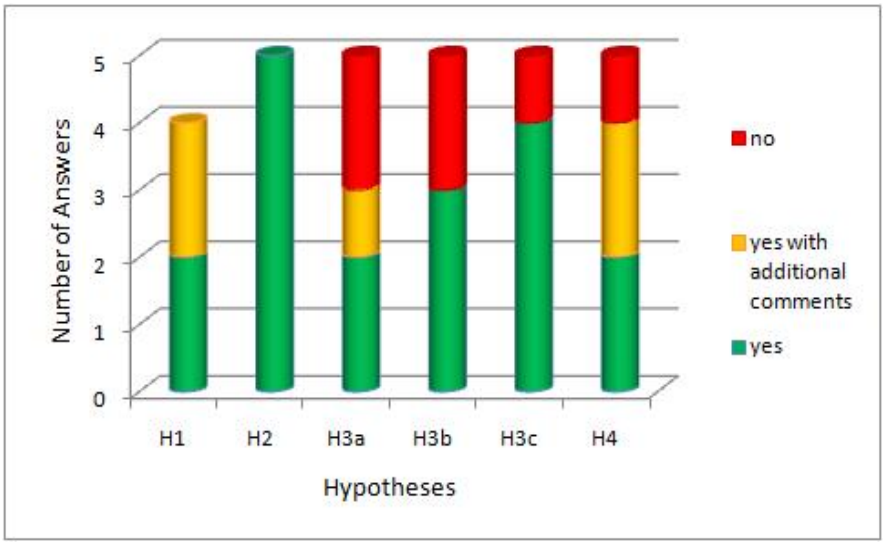

Figure 6: Summary of Results for Hypotheses 1-4

There was strong support for the idea that authoring, but more importantly, strategy authoring requires tool support to enable authors to use, change and apply strategies without having to necessarily write programming code in any programming language. The benefit of tool support was undisputed during all interviews (confirming hypotheses H1 and H6c). Tool support was considered state-of-the-art and one result of the interviews was a list of suggestions how to improve tool support. The initially suggested drag & drop feature together with a strategy library or repository got strong support (thus confirming hypothesis H6c).

The interviewees all agreed upon the aim that all tools should have a graphical user interface and actual code should be hidden from the authors, with an option to switch from a WYSIWYG interface to actual code. The latter was not directly part of the question set, but authors were asked to think of expansion of the facilities of adaptation behaviour description tools, and most of them independently came up with this suggestion.

Other possible features mentioned were tagging mechanisms for content (which again corresponds to how MOT3.0 works, and is in line with hypothesis H2) and the integration with authoring environments and delivery systems, e.g. a learning management system. The latter was not directly asked of them, but is again a main priority of authors. In fact, MOT3.0 already has the functionality to import content from current learning management systems, and can be loosely integrated in such systems. Previous research of integration of both authoring and delivery of adaptive

content has been performed and implemented via a previous EU Minerva project called ALS[8], but more such functionality clearly needs added and extended.

Keeping content authoring and strategy authoring separate as well as avoiding a lock-in of users by ignoring compatibility of authoring and delivery environments were seen as two basic principles that need to be considered. Again, this was not directly asked of them, but most of the interviewees saw this as related to the questions asked. This is interesting because not so long ago common misconceptions considered that content and strategy authoring could be performed together without any important side effects. This was visible in the adaptive hypermedia community, on one hand, where prerequisites, for instance, were directly bound to instances of content, and thus could not be reused for other content of a similar type. Similarly, also in the e-learning community, standards such as the LOM[9] still bind information about the content of a learning object with its usage instructions and target, thus limiting automatically the usage scope. Additionally, the perceived importance of the distinction between authoring and delivering, in terms of them being even placed on different environments, is a crucial step forward, as it shows that authors are aware that authoring should be generic, for various delivery systems. It also shows the importance of portable languages, such as LAG, to be able to exchange information between authoring and delivery system (instead of exchanging information via internal formats). It also implies (albeit indirectly) the fact that the principles of authoring and those of delivery systems for adaptation can and should be different.

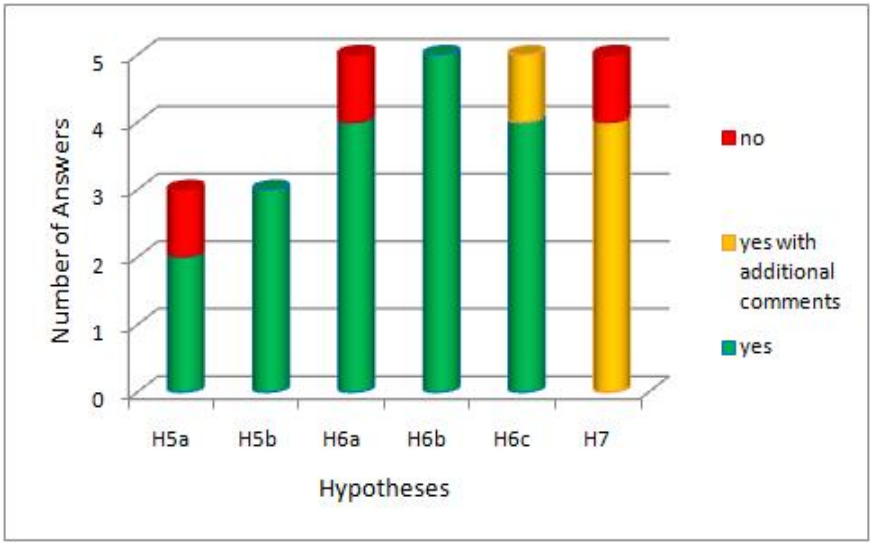

Figure 7: Summary of Results for Hypotheses 5-7

Content authors need the option to add strategies to a course, although they are not primarily authoring strategies themselves (hypothesis H3c). The general

[8] EU Minerva ALS (Adaptive Learning Spaces) http://als-project.edu
[9] LOM (Learning Object Metadata) standard, http://

conclusion was that even though some of the interviewees felt capable of writing or changing strategies in the LAG language themselves (as per hypotheses H3a and H3b), they would not be willing to do so and would prefer a wysiwyg editor[10], for example, that would also show the impact of the strategy on the content delivery. Furthermore, the interviewees reported that from their experience with training other content authors, they expect that most would not to be able to handle code-based strategy writing. Thus, hypotheses H3a and H3b cannot be confirmed. The use of existing strategies, on the other hand, was not considered problematic, provided tool support would be available, as discussed further below (confirming hypothesis H3c).

Meta-strategies and managing the application of more than one strategy were in general considered a less error-prone and easier way to construct adaptation than writing complex strategies by themselves (thus confirming hypothesis H5a and H5b). This has to be seen in combination with the demand for a user-friendly interface for any tool, e.g. a visual drag & drop editor (confirming hypothesis H6c).

Meta-strategies are seen as an opportunity to enable new forms of adaptation of e-learning systems (this confirms hypothesis H4). Some authors pointed out though that a lot of the state-of-the-art online courses are broken down into very small modules and were questioning the effects of adaptation strategies within these short modules. Another reflective comment was expressing concern about whether all the improvements in adaptation may reduce the content shown to the learner, to a point of avoiding necessary learning and skill challenges and thus leading to an over-optimisation of the delivery. This opinion may be based on a belief that motivation and difficulty (in terms of challenge) are related. This is actually supported by other educational researchers and practitioners, which also consider there should be a balance between support and challenge. A system which can create adaptation however can be adjusted to provide different levels of challenges, and thus can cover also these aspects of education and pedagogy.

Summarising, overall, the opinion was that the meta-strategy approach enables a break down into small, modular strategies, which conforms to the general trend to develop modular software and enables a more flexible adaptation (hypothesis H6b). The modular structure in combination with the meta-strategy is considered as a help for content authors to focus on a well-arranged course structure.

The importance of execution order issues (hypothesis H7) could not be confirmed, but the authors agreed that this would depend very much on further aspects, such as delivery, organisational environment and the specific content of a course.

9.4 Discussion

Most hypotheses were confirmed, usually with a mix of full confirmation and conditional confirmation. None of the hypotheses got completely refuted, but hypothesis H7, broaching the issue of execution order of the strategies, and hypotheses H3a and H3b, bringing the issues of strategy authoring and editing into focus, got weak support and some rejection. For hypothesis H7 the explanation given was the need to consider aspects such as delivery, organisational environment and the

[10] acronym for What You See Is What You Get, meaning content displayed during editing appears very similar to the final output.

specific content of a course. Most interviewees emphasized that hypotheses H3a and H3b target only a small number of roles in the authoring process, all of which they would consider part of the concept development rather than content development itself and therefore did not support these hypotheses fully.

Two hypotheses, H2 and H6, presenting the need for an authoring tool and for a method to create reusable modular strategies were uniformly supported during all interviews. Some of the hypotheses did not get a response in all interviews. In particular hypotheses H5a and H5b, both claiming benefits of the meta-strategy method compared to the current method to write new strategies each time, received very reluctant feedback. Interviewees pointed out that they would need to get more familiar with the method to fully support it.

The evaluation results have shown that visual authoring tools for creating adaptation strategies are preferred over manually authoring the strategies using an adaptation language. The interviewees indicated that choosing different adaptation strategies from a list or pool of pre-created adaptation strategies would be easier than creating the strategies from scratch or modifying existing strategies. This suggests that a drag & drop meta-strategy authoring tool would be a substantial improvement over current adaptation strategy authoring tools.

As discussed earlier in this paper, even though the use of meta-strategies solves the problems of reuse and combination of different strategies, it also introduces new problems of its own. Future adaptation strategy authoring tools would need to be able to predict and resolve problems which could arise from clashes between the different modular adaptation strategies in a meta-strategy.

Finally, the evaluation above has not taken into account the learner's perspective of meta-strategies, focusing instead on the authoring of such strategies. Further evaluation from the learner's perspective will need to answer questions related to the delivery of the content such as:

- Does the method provide strategies or strategy combinations which enable the desired adaptation?
- Does the QoE overall strategy improve the learning experience of the learners?

10 Conclusion and Future Research

The scenario outlined in the case study describes a typical problem in the authoring process of adaptive hypermedia. The paper proposes a method to improve the authoring process by breaking down the authoring of complex strategies into smaller steps and using meta-strategies to reconstruct them, based on different goals. Thus, in this paper we have tackled issues of *adaptive strategy modularisation, merger and meta-strategies*. Additionally, the paper presents the evaluation of these ideas and implementation by e-learning authors.

Combining strategies can cause clashes in the ways different strategies handle domain and program variables. This can result in strategy combinations which make important parts of an adaptive hypermedia course inaccessible to the user. For example, choosing media type before adapting to network conditions could cause no content to be displayed to the user. Further research is needed to find ways to avoid

these situations, warn strategy authors about possible problems and detect and avoid those situations as they arise in an adaptation delivery engine.

Research is needed to develop standards for writing modular strategies that can be reused in multiple environments and how to automate this process. Moreover, the authoring of meta-level strategies that dynamically manage the combination of simpler sub-strategies needs to be addressed.

The survey of the authors has highlighted three main aspects: the use of multiple strategies allows for better personalised adaptation, which is currently not available in tools in use today; meta-strategies are seen as an opportunity to enable the handling of multiple strategies in a less error prone way as compared to writing larger, complex strategies each time. Authors require tool support with a graphical user interface that includes a strategy library or repository to use, change and apply strategies without necessarily having to write programming code.

So far, the case study has been implemented, including a successful combination of the two strategies and the author evaluation of the method. Next steps will include incorporation of additional points arising from the survey into the tools developed and testing of the method, especially taking into account the learner perspective.

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