Quality of Experience-LAOS: create once, use many, use anywhere

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Abstract: This paper proposes QoE-LAOS, a Quality of Experience-oriented adaptive authoring model that enables performance-aware adaptation. It extends the existing LAOS authoring model in order to consider display and delivery performance issues. QoE-LAOS involves the addition of three new QoE sublayers: QoE Content Features sublayer, QoE Characteristics sublayer and QoE Rules sublayer. These proposed QoE sublayers are deployed at LAOS's Domain, Adaptation and Presentation Models, respectively. This paper formalises and exemplifies QoE-LAOS and discusses authoring-related issues in relation to each new sublayer.

Keywords: user quality of experience; authoring model; delivery performance; Quality of Experience; QoE; learning technology.

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1 Introduction

Adaptive Hypermedia (AH) researchers acknowledge that a 'one-size-fits-all' approach is not suitable for modern web-based information delivery systems. Nowadays, it is widely accepted that web users have diverse preferences, objectives, goals, and aptitudes for processing information, or special needs (*e.g.*, disabled people) and that these users desire content that is best suited to them as individuals. Therefore, research in AH seeks to identify users' personal characteristics and individual requirements, and accordingly to provide personalised content, thus enhancing users experience with the hypermedia systems.

In the last decade the AH community has gone though a period of rapid growth owing to the high demand for personalised content, mainly in the area of education. As a result, many Adaptive Hypermedia Systems (AHS) have been proposed such as: AHA! (De Bra and Calvi, 1998; De Bra, 2002), Guide (Cheverst *et al.*, 2002), ApeLS (Conlan *et al.*, 2002; Conlan and Wade, 2004), INSPIRE (Papanikolaou *et al.*, 2003) and AES-CS (Triantafillou *et al.*, 2002). The proposed systems address various issues related to personalisation such as: content and navigation support adaptation, user profile modelling, system usability evaluation, *etc*. Additionally, owing to the increase in types of devices and variety of networks used to access web content, delivery performance has also been recognised as being crucial to user satisfaction. Therefore the material must now also be tailored not only to the user's preferences, but also to their access capabilities. In this context, the QoE-layer for AHS (Muntean and McManis, 2006a–c) has been developed to address performance issues arising from the user's network environment.

A major problem faced by the current AHS is content development and its reusability. The development of the adaptive content used by an AHS is a complex and time-consuming task and often materials authored for a given system can be used and delivered only by that system. On the other hand, adaptive hypermedia is at the point of breakthrough from the academic proof-of-concept type of research to industry-based research and development that involves wide-range and scalable solutions for personalised information delivery systems (Cristea, 2005). In this context much more attention must be given to the authoring process itself as it has been shown that authoring for adaptive environments differs substantially from authoring for static ones (Cristea, 2003). Only in the last couple of years have solutions been proposed for automating the complex authoring task not only for a given system but also allowing for reusability and portability of the material between different AHS, sustaining the paradigm 'create once, use many'. First, authoring toolkits (Weber *et al*., 2001; Murray, 2003) were developed and used with a given AHS. These authoring tools allow for learning objects creation, pedagogical adaptation rules definition, content adaptation rules definition, *etc*. For example, the authoring tool integrated with ALE e-learning environment (Kravcik and Specht, 2004) allows the authors to create learning objects, structure them and assign attributes such as metadata. OpenMath, a web-based adaptive e-learning environment for mathematics described in Manzoor *et al.* (2005) also supports content authoring though an XML-based content editor. Later, more general models for adaptive authoring that facilitate reuse of the material were proposed (Aroyo *et al.*, 2002; Cristea and de Mooij, 2003). Currently research looks at converters (De Bra *et al*., 2003; Arteaga *et al*., 2004; Power *et al*., 2005) that allow web materials developed with a specific authoring tool to be delivered by various AHS.

All these authoring solutions allow for creation of content, definition and specification of content adaptation rules that are used by the AHS in order to deliver user-personalised information. As the latest network-enabled devices such as PDA, laptop, *etc*., and network technologies such as WiFi (IEEE 802.11 wireless family) become affordable, people seek to access content in a wide range of environments. The authoring process must now consider the type of device used for displaying the information and the characteristics of user network connectivity. It is unrealistic to expect personalised material provided by the current AHS, displayed on any device and delivered over any network to offer to the user the same Quality of Experience (QoE). Therefore the authoring should enable performance-aware adaptivity in order to have content rapidly transferred over various network types and optimally displayed on diverse devices. This is a step forward in the AH authoring from a ‘create once, use many’ paradigm towards a ‘create once, use many, use anywhere’ authoring paradigm.

This paper proposes *QoE-LAOS*, a QoE-aware extension to the five-layer adaptive authoring model LAOS (Cristea and de Mooij, 2003) that allows for authoring to enable performance-aware adaptation. The paper is structured as follows. Section 2 briefly describes LAOS, and indicates that its Domain (DM), Adaptation (AM), and Presentation Models (PM) will deal with performance adaptation issues. Section 3 presents those factors that have the greatest impact on QoE during content delivery and display. The proposed QoE-LAOS is described in general terms in Section 4, which also introduces its main components: the QoE Content Features sublayer – deployed at the DM level, the QoE Characteristics sublayer – located at the PM level and the QoE Rules sublayer – placed at the AM level. Sections 5, 6 and 7 are dedicated to the description, formalisation and exemplification of the proposed QoE-LAOS components. Special discussions on authoring are also introduced in all these sections. The last section of this paper presents the conclusions and plans for future work.

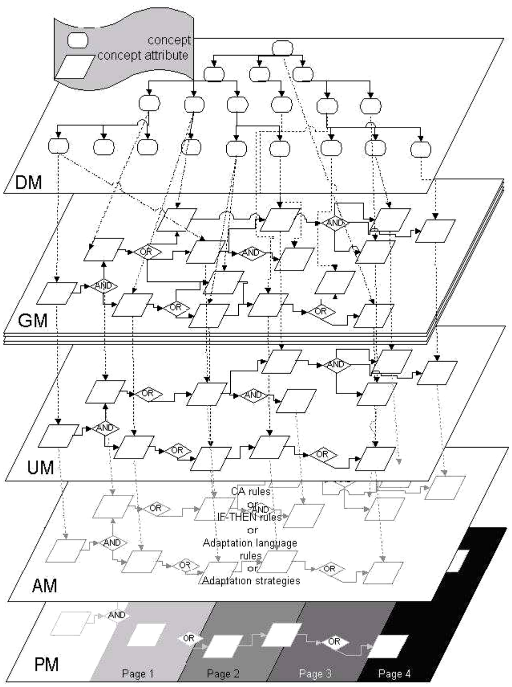
2 LAOS

LAOS is a layered model for adaptive hypermedia authoring (Cristea and de Mooij, 2003). The model extends the three layers of the AHAM (Wu, 2002) – User Model, Domain Model, and Adaptation Model – with two new layers (see Figure 1):

1 Goal and Constraints Model (GM), between the Domain (DM) and the User (UM) models

2 Presentation Model (PM).

Figure 1 LAOS five-layer architecture



The five layers of the LAOS function as follows:

1. The *Domain Model (DM)* represents the author's view of the application domain. It is described as a collection of concepts (atomic and composite) with their respective attributes, plus a set of links that may exist between concepts. A concept may have as a counterpart a physical representation that consists of text, image, multimedia presentation or a combination of those. This physical representation is referred to as an item. A set of algebraic operators divided into four categories (Cristea and de Mooij, 2003): *constructors* (*e.g.*, create, edit), *destructors* (*e.g.*, delete), *visualisation* (*e.g.*, list, view, check) and *compositors* (*e.g.*, repeat) was defined in order to create and manipulate the DM objects (*e.g.*, concepts or links).
2. The *Goal and Constraints Model (GM)* allows the author to define goals – in order to give a focused presentation, and constraints – to limit the space of the search for the suitable concepts for a given user profile (Cristea and de Mooij, 2003). The main goal is to filter, regroup and restructure the domain model by considering a delivery purpose. It allows the author to order the attributes of a concept and to define AND/OR relation attributes, as well as weights for the OR relations. A set of algebraic operators similar with the one for the DM was also defined for the GM (Cristea and de Mooij, 2003).
3. The *User Model (UM)*, described in more details in Wu (2002), follows the principle defined in AHAM. The UM expresses individual user data (*e.g.*, preferences, age) as well as knowledge level, interests or learning styles; it can be an overlay to either the GM or DM.
4. The *Presentation Model (PM)* takes into consideration the physical properties and environment of the presentation. Adaptive features regarding presentation means (*e.g.*, page length, figure display properties, figure format, *etc.*) are specified at this layer. However, details about the PM were not specified in LAOS.
5. The *Adaptation Model (AM)* provides the adaptive functionality of the AHS. It consists of a set of adaptation rules used to determine which information will be presented to the user, making use of the DM, GM, PM and UM. A three-layer granularity model (LAG) was proposed (Cristea and Calvi, 2003) as a model for authoring the adaptive behaviour of the AHS.
   - *Low-level adaptation* defines the traditional techniques for content adaptation (*e.g.*, insert/remove fragments of information, stretch text, sorting) and link adaptation (*e.g.*, link sorting, hiding, removal, annotation). These adaptation rules have an IF-THEN format and were introduced in the AHAM.
   - *Medium-level adaptation* provides an adaptation language that increases the level of semantics of rules (*e.g.*, WHILE-DO, FOR-DO, GENERALISE, *etc.*). It groups elements of the previous layer into typical adaptation mechanisms and constructs.
   - *High-level adaptation* provides support to define various adaptation strategies (*e.g.*, teaching or pedagogic strategies).

The whole LAOS structure is designed to work together with an Adaptation Engine (AE) – the core of the adaptive hypermedia application that interprets all the designed adaptation rules and strategies, and updates the information from the UM.

3 User quality of experience

The latest advancements in computer and communications-related technologies have provided ordinary consumers with access to multiple networks over a variety of network-enabled devices. Diverse wired and wireless network solutions such as DSL, ADSL, Ethernet, WiFi (IEEE 802.11) and WiMax (IEEE 802.16) offer network connectivity with widely differing characteristics. Available bandwidth, one of the most important characteristics, differs not only among different types of networks, but also for the same network type depending on users' type and number, traffic type, pattern and size, environmental conditions (mainly for wireless), *etc*. This variability significantly affects transport capacity and quality of delivery regardless of content type. End-user QoE reflects the influence of this variability on users' experience during their interaction with a system.

QoE focuses on the user and is considered in Odence (2004) as the collection of all the perception elements of the network and performance relative to expectations of the users. The QoE concept applies to any kind of network interaction such as web navigation, multimedia streaming, voice over IP, *etc*. Different QoE metrics that assess users' experience with the systems in term of responsiveness and availability have been proposed in general and specifically in the ITU-T G.1010 standard (ITU-T, 2001). QoE metrics may have a subjective element to them and may be influenced by any subsystem between the service provider and the end-user.

Lately diverse mobile and fixed network-enabled devices have been launched with varying characteristics such as size, processing power, screen size, memory capacity, battery power, *etc*. All these device characteristics significantly influence the quality of both reception and display of user-accessed web content (especially if it is rich media-based) and potentially affect their users QoE.

Thus, QoE may be seen as being influenced by three factors: the user's content preferences with respect to needs and goals, the network over which the content is accessed content, and the device with which the user connects to the network. AHS must consider all three of these factors when seeking to deliver content optimised to a user's current state. A first step in this process must be the support of authoring to enable adaptations according to delivery and display-related performance characteristics.

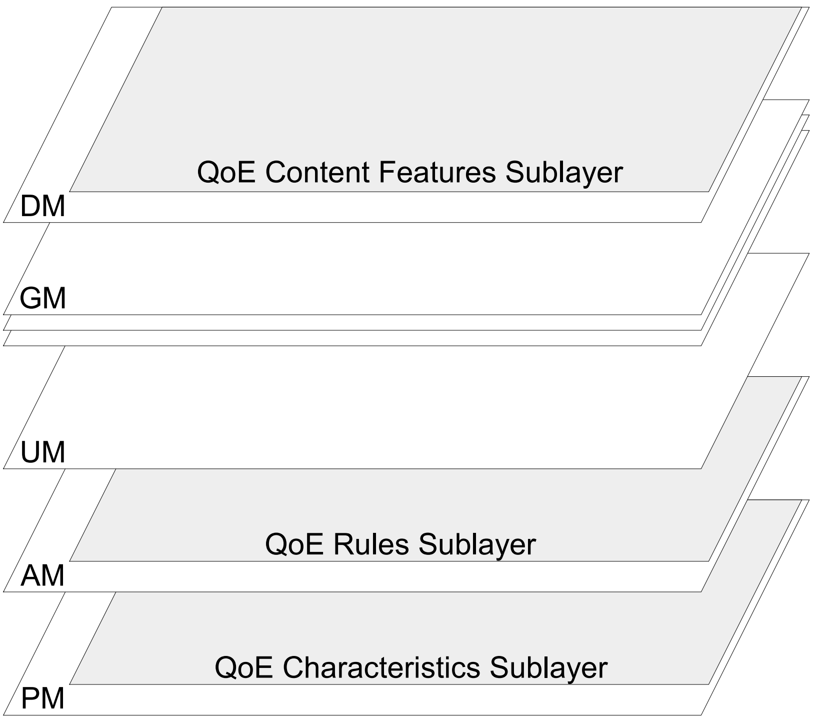
4 QoE-LAOS

This section describes in detail QoE-LAOS – an extension of the classic LAOS authoring model (Cristea and de Mooij, 2003). QoE-LAOS was first introduced by Muntean *et al.* (2006) and was proposed in order to address delivery and display-related performance issues. The QoE-aware approach assumes the availability of real-time monitoring of both user device and access network in order to adjust the content to match current delivery conditions in relation to both user device characteristics and network status. This is especially important when content includes material of continuous nature, such as multimedia, which is delivered over a long period of time. It is also significant for web navigation sessions of average and long durations.

QoE-LAOS adds three new QoE sublayers: the QoE Content Features sublayer to the DM, the QoE Characteristics sublayer to the PM, and the QoE Rules sublayer to the AM, as illustrated in Figure 2.

- *The QoE Content Features sublayer* – located at the level of DM – associates metadata to each concept from the DM that has a physical representation in the form of a text, image or multimedia clip. Metadata is an abstract representation of the most significant features that characterise those instances of text, image or multimedia and affect in any way their delivery or display performance.
- *The QoE Characteristics sublayer* – located at the level of PM – defines in an abstract manner classes representing those factors that have an impact on performance. These classes should belong to certain characteristics models, such as device and network for example.
- *The QoE Rules sublayer* – located at the level of AM – defines QoE-related adaptive rules that make use of the PM's QoE Characteristics sublayer information in order to propose QoE presentation adaptations. The adaptation-related suggestions are expressed in terms of performance-related features as described by the DM's QoE Content Features sublayer.

Figure 2 QoE-LAOS – additional three QoE sublayers



5 The QoE Content Features sublayer

The QoE Content Features sublayer is located at the level of the DM and associates QoE-related metadata to each concept from the DM, which has a physical representation. These concepts are called items. There are three main classes of items that differ in terms of their characteristics: text, images and multimedia streams. Web pages represent a fourth class of content that may include text, images and multimedia. The following is a brief description of the main features of these content types in relation to their delivery and remote presentation.

1. *Text* items consist of at least a paragraph, written in plain text or formatted using a language such as HTML. These items can be delivered as such after users request or put together in a composition step based on users' goals and constraints and then delivered. Therefore a text performance-related adjustment can only be performed before the text is transmitted to the user.
2. *Image* items represent pictures, drawings, graphs, *etc*. and can have a variety of formats such as jpg, png, gif and bmp. The images can be transmitted stand-alone to the users at their request, but more often are part of web pages and are delivered automatically when the web page is requested. Image performance-based adaptation is also only possible prior to delivery.
3. *Multimedia content* is either streamed or downloaded and then played at the destination at the user's request. It is continuous in nature and its delivery involves server and client applications. Following the user request for multimedia content the client application receives the data stream while in direct contact with the server. Feedback can be used to inform the server about device and network characteristics and consequently the server application can modify in real time some features of the multimedia stream that is being delivered.
4. *Web pages* consist of a main page and a number of embedded objects, usually including images and possibly multimedia. The main page and all the embedded objects are transferred to the web user as a result of a single request. For each new web page transfer a new user request is required. Thus the delivery process can be considered to be discrete. Once the transfer of web page components starts, their features cannot be modified anymore. Therefore the adjustment of the web page presentation has to happen following the user request.

5.1 Formalisation

When the performance-related presentation adaptation is performed, it affects some content features described in the DM's QoE Content Features sublayer. Next this newly introduced sublayer is formalised.

Definition 1 *Content features are formalised as a set of tuples:*

$$F=\{<F\_Name_i, F\_Value_i>\},$$

with $1 \leq i \leq N_i$ *where* F_Name_i *is the name of content performance-related feature i and* F_Value_i *is the value associated with this feature.*

5.2 Authoring

In terms of QoE-aware authoring at the DM level, the most important goal is to enable the association of performance-related features to each content item in the form of metadata. This association can be performed in three phases. The first phase requires the identification of major QoE features that can influence an item's performance during its delivery and display. As there are four item types that have different characteristics (*i.e.*, text, image, multimedia and web page) and consequently will have different performance-related features, the authors will be asked to define different sets of features for each type. These sets will be denoted F_t – for text, F_p – for pictures/images, F_m – for multimedia and F_w – for web content. For all content items from the DM, the second phase involves identification of their type and association with the corresponding set of QoE features determined in the first phase. During the last phase, individual characteristics related to the physical content data (items) are analysed and the corresponding performance-related feature *F_Value*-s are determined.

Authoring at this level can have different degrees of automation. The authors can be allowed to choose between a manual, semiautomatic, or fully automatic authoring. In the manual approach the authors have to provide input at all phases and it is recommended only to those authors who have significant authoring and delivery and display performance-related knowledge. The semiautomatic approach allows the authors to specify which features they want to be included in the metadata associated with the content items; in the automatic case they are given a default set of features. In both the automatic and semiautomatic case, the association between the set of QoE features and the content items is performed automatically based on file extensions. Also, the computation of the most common feature-related values is performed automatically by examining the content files. However, in the semiautomatic case, the author may customise the association of values to the QoE features.

Figure 3 Hierarchical architecture of the DM's QoE Content Features layer

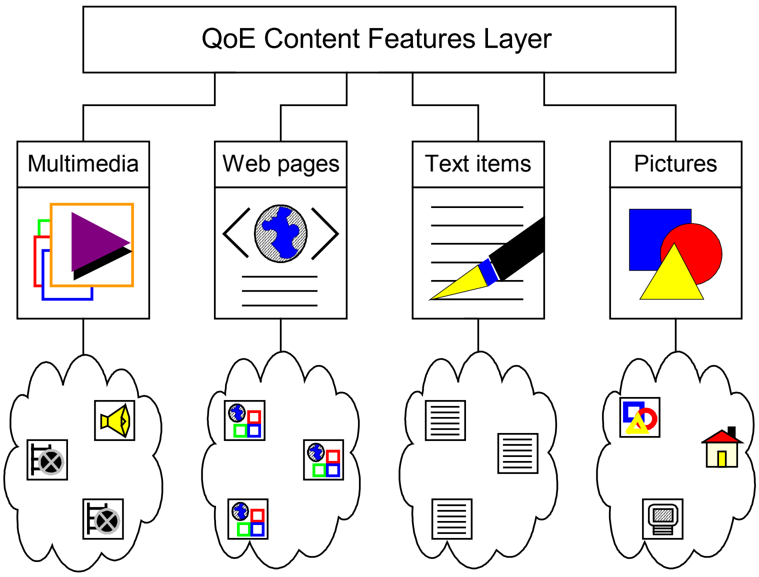


Figure 3 illustrates the hierarchy involving content items classified based on their type and the QoE Content Features sublayer that stores item type-specific metadata. The structure of the metadata differs both in the number of content performance-related features associated and in their type across different classes. The metadata associated to the actual content items within each class differs only in the values associated to the features that characterise this class of items.

5.3 Example

This subsection presents examples of possible feature sets that describe particular content from the four main categories: text, image, multimedia and web page content.

1 Text

F_t^1*={<size, 0.1>, <length, 10>, <format, 0>}*
F_t^2*={<size, 2>, <length, 200>, <format, 1>}*

Text-related features may include size expressed in kilobytes, text length measured in equivalent words, and format – represented as a code in which 0 is associated with plain text and 1 with HTML.

2 Image

F_p^1*={<size, 20>, <format, 0>, <resolution, 160x120>}*
F_p^2*={<size, 40>; <format, 2>, <resolution, 320x240>}*

Features associated with the image type may include size expressed in kilobytes, format – represented as a code in which 0 may indicate jpg, 1 – png, *etc*. and resolution – expressed in pixels.

3 Multimedia content

F_m^1*={<bitrate, 1>; <framerate, 25>; <resolution, 320x240>; <colors, 24>; <encoding, MPEG4>}*
F_m^2*={<bitrate, 0.384>; <framerate, 16>; <resolution, 160x120>; <colors, 16>; <encoding, MPEG4>}*

Multimedia features include average bit rate expressed in megabits per second, frame rate measured in frames per second, resolution measured in pixels, number of colours represented in bits required for encoding and encoding scheme.

4 Web page

F_w^1*={<size, 1>; <length, 500>; <tsize, 100>, <objects, 10>}*
F_w^2*={<size, 2>; <length, 200>; <tsize, 25>, <objects, 4>}*

Web page features include the main page size expressed in kilobytes, web page length measured in equivalent words, total page size including embedded objects and number of embedded objects.

6 The QoE Characteristics sublayer

The QoE Characteristics sublayer is located at the level of the PM and defines – in an abstract manner – classes representing those factors that have an impact on the performance of content delivery and/or display. These classes belong to two main models: the Device Characteristics Model, which deals with performance and quality of content display; and the Network Characteristics Model, which focuses on the performance of content delivery. The characteristics models are formalised in a unified way as follows.

6.1 Formalisation

The new PM QoE Characteristics sublayer is formally introduced in this section by means of a number of definitions. These definitions describe the sublayer in terms of a set of performance classes, each class having associated a number of performance characteristics. For each of these characteristics, apart from their name, there is a list of pairs: attribute–probability. The attributes are values the performance characteristics may take, whereas the probability represents the likelihood for the performance characteristics to take the indicated attribute value.

Definition 2 *The QoE Characteristics sublayer consists of a performance characteristics class set SC:*

$$SC=\{C_i\}.$$

Definition 3 *We define a class of performance characteristics C_i as an abstract term identified by the tuple:*

$$C_i=\langle C\_Name_i, C\_LCD_i\rangle,$$

where C_Name_i is the class name and C_LCD_i denotes the list of class descriptors:

$$C\_LCD_i = \{CD_{ij}\}.$$

The class descriptors, in number of N_i ($1 \le j \le N_i$), describe class C_i in terms of performance characteristics. Among them could be device properties, network characteristics, etc.

Definition 4 *A class descriptor CD_{ij} is defined by the tuple:*

$$CD_{ij} = \langle CD\_A_j, CD\_LVT_{ij}\rangle,$$

where CD_A_j are attributes associated with the class descriptors (the same set of attributes is used by all classes) and CD_LVT_{ij} a set of M_{ij} value terms. For $1 \le k \le M_{ij}$, we have:

$$CD\_LVT_{ij}=\{VT_{ijk}\}.$$

Definition 5 *A value term VT_{ijk} is defined by the tuple*

$$VT_{ijk} = <VT\_V_{jk}, VT\_P_{ijk}>,$$

where VT_V_{jk} are the values (a set of values is constant across all classes) and each VT_P_{ijk} is the probability of the value VT_V_{jk} associated with the attribute CD_A_j that describes class C_i.

6.2 Authoring

The main goal in relation to QoE Characteristics sublayer authoring at the PM level is to define classes of characteristics that would describe significant categories of devices and networks. Different content adaptation can be performed according to which of the device and network classes the current delivery and display conditions are closest to.

The authoring is performed in four steps for each of the Device and Network models. In the first step the author creates a number of classes that correspond to a group of devices and network conditions. The aim of the second step is to list all characteristics that best illustrate different performance-related capabilities or properties of the device or of the network. In the third step the author has to associate to each of the characteristics indicated in the previous step a list of possible values. In the fourth and last step, the author has to indicate – for each class defined in the first step and for each characteristic within that class – the probability with which the characteristic will have the indicated value.

Different degrees of authoring automation can be imagined including manual, semiautomatic or fully automatic processes. In the manual approach the author is responsible for all their actions, including the consistency of characteristics assignment to different device or network classes, the meaningful choice of probability values and their normalisation.

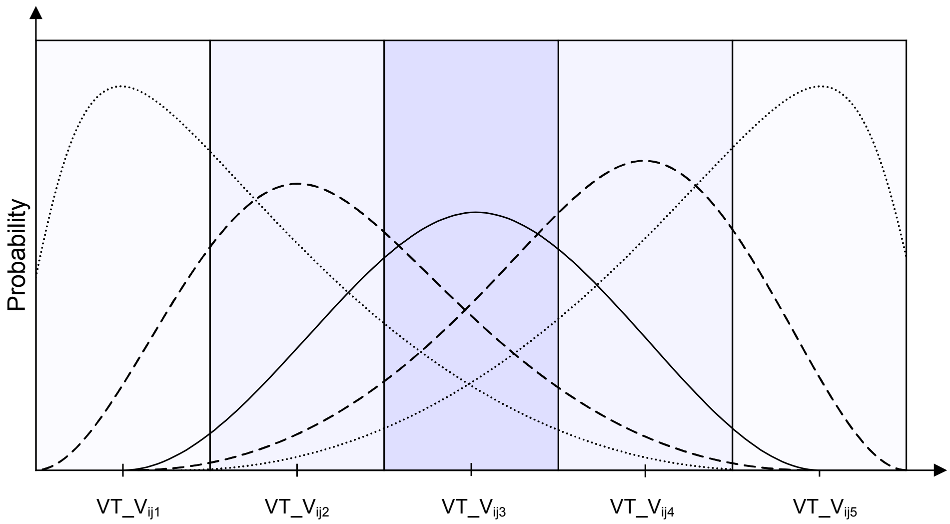
Different levels of automation are possible. In one semiautomatic approach, the author focuses on characteristics selection, but the association to classes can be done automatically. The author must input probability values, but either the verification of normalisation followed by notification or automatic normalisation of inputted values is machine-driven. In another semiautomatic approach, default classes of devices and networks can be suggested, helping the author in this regard. These classes may be already populated with significant characteristics related to devices and networks. The two possibilities related to probability value verification and notification or automatic normalisation can also be considered.

In the fully automatic approach, the author uses default classes of devices and networks predefined with the help of an expert in performance and QoE-related issues of content display on various devices and delivery over heterogeneous networks. The expert suggestions are used to define the significant performance-related characteristics of each class and to associate possible values to all these characteristics. In this context the author is only asked to associate probability weights to these values. Two approaches are envisaged: a manual association of probabilistic values, with automatic normalisation and an automatic approach.

6.2.1 Automatic calculation of probability values

The automatic association of probability values (VT_P_{ijk}) can be performed according to the author's choice based on the normal distribution if the probability distribution function has a bell-like shape or on poison distribution if the probability distribution function has a long-tail. Figure 4 shows how for the same list of values VT_V_{ijk}, with $1 \le k \le 5$, five different characteristics classes could have different probability distribution functions.

Figure 4 Probability distributions for full automatic authoring of the QoE Characteristics sublayer



6.3 Example

Potential default classes for the QoE Characteristics sublayer are shown in the following example. These classes consider a wide range of devices and network types and could be used for the automatic authoring. The QoE Characteristics sublayer exemplified next includes device property-related ($C^{D}{}_{i}$) and network characteristics-based ($C^{N}{}_{i}$) classes.

6.3.1 Device characteristics classes

The following class defines handheld device characteristics:

$C^{D}{}_{1}$ = <'Handheld Devices', {$CD^{D}{}_{1i}$}>, with $1 \le i \le 5$

$CD^{D}{}_{11}$ = <resolution,
{<160×120,0.3>, <320×240,0.4>, <640×480,0.3>, <800×600,0>, <1024×768,0>, <1280×1024,0>, <1600×1200,0>}>
$CD^{D}{}_{12}$ = <battery power,
{<1100,0.5>, <1500,0.3>, <1800,0.2>, <2400,0>, <3200,0>, <3800,0>, <5000,0>}>

CD^{D}_{13} = <color depth,
{<32,0.3>, <64,0.6>, <128,0.1>, <256,0>, <512,0>, <1024,0>}>
CD^{D}_{14} = <multimedia enabled,
{<0,0.3>, <1,0.7>}>
CD^{D}_{15} = <CPU power,
{<0.1,0.3>, <0.3,0.4>, <0.5,0.3>, <1.0,0>, <1.5,0>, <2.0,0>, <2.5,0>, <3.0,0>}>.

Possible values associated with an attribute can be obtained from the device specification. For example, the majority of handheld devices have batteries with a power of 1100 mAh, but more powerful batteries (*e.g.*, 1500 mAh) can be purchased at extra cost.

Next, a portable device class is defined:

C^{D}_{2} = <'Portable Devices', $\{CD^{D}_{2i}\}$>, with $1 \le i \le 5$

CD^{D}_{21} = <resolution,
{<160×120,0>, <320×240,0>, <640×480,0.3>, <800×600,0.4>, <1024×768,0.3>, <1280×1024,0>, <1600×1200,0>}>
CD^{D}_{22} = <battery power,
{<1100,0>, <1500,0>, <1800,0>, <2400,0.2>, <3200,0.5>, <3800,0.3>, <5000,0>}>
CD^{D}_{23} = <color depth,
{<32,0>, <64,0>, <128,0.1>, <256,0.3>, <512,0.6>, <1024,0>}>
CD^{D}_{24} = <multimedia enabled,
{<0,0.1>, <1,0.9>}>
CD^{D}_{25} = <CPU power,
{<0.1,0>, <0.3,0>, <0.5,0>, <1.0,0.3>, <1.5,0.4>, <2.0,0.3>, <2.5,0>, <3.0,0>}>.

A large screen device class can be defined as follows:

C^{D}_{3} = <'Large Screen Devices', $\{CD^{D}_{3i}\}$>, with $1 \le i \le 5$

CD^{D}_{31} = <resolution,
{<160×120,0>, <320×240,0>, <640×480,0>, <800×600,0>, <1024×768,0.3>, <1280×1024,0.5>, <1600×1200,0.2>}>
CD^{D}_{32} = <battery power,
{<1100,0>, <1500,0>, <1800,0>, <2400,0>, <3200,0>, <3800,0.2>, <5000,0.8>}>
CD^{D}_{33} = <color depth,
{<32,0>, <64,0>, <128,0>, <256,0.1>, <512,0.3>, <1024,0.6>}>
CD^{D}_{34} = <multimedia enabled,
{<0,0.0>, <1,1.0>}>
CD^{D}_{35} = <CPU power,
{<0.1,0>, <0.3,0>, <0.5,0>, <1.0,0>, <1.5,0>, <2.0,0.3>, <2.5,0.4>, <3.0,0.3>}>.

Screen resolution is measured in pixels, battery power in mAh, depth of the colour space in kilobytes and CPU processing power in GHz.

6.3.2 Network characteristics classes

The same principle can be applied to defining classes of networks with various characteristics. An exemplification for three possible network classes is presented.

C^{N}_{1} = <‘Cellular Networks’, {CD^{N}_{1i}}>, with $1 \leq i \leq 4$

CD^{N}_{11} = <bandwidth,
{<0.06,0.2>, <0.128,0.6>, <0.384,0.2>, <1,0>, <11,0>, <54,0>, <100,0>, <1000,0>}>
CD^{N}_{12} = <loss rate,
{<0.1,0>, <0.5,0>, <1,0.1>, <5,0.25>, <10,0.6>, <50,0.15>}>
CD^{N}_{13} = <round-trip delay,
{<10,0>, <20,0>, <50,0>, <100,0.1>, <200,0.2>, <500,0.7>}>
CD^{N}_{14} = <download time,
{<6,0>, <8,0>, <10,0>, <12,0.2>, <16,0.4>, <20,0.4>}>

C^{N}_{2} = <‘Wireless Broadband Networks’, {CD^{N}_{2i}}>, with $1 \leq i \leq 4$

CD^{N}_{21} = <bandwidth,
{<0.06,0>, <0.128,0>, <0.384,0>, <1,0.1>, <11,0.6>, <54,0.3>, <100,0>, <1000,0>}>
CD^{N}_{22} = <loss rate,
{<0.1,0>, <0.5,0>, <1,0.1>, <5,0.3>, <10,0.5>, <50,0.1>}>
CD^{N}_{23} = <round-trip delay,
{<10,0>, <20,0.1>, <50,0.3>, <100,0.5>, <200,0.1>, <500,0>}>
CD^{N}_{24} = <download time,
{<6,0>, <8,0.3>, <10,0.6>, <12,0.1>, <16,0>, <20,0>}>

C^{N}_{3} = <‘Wired Broadband Networks’, {CD^{N}_{3i}}>, with $1 \leq i \leq 4$

CD^{N}_{31} = <bandwidth,
{<0.06,0>, <0.128,0>, <0.384,0>, <1,0>, <11,0.1>, <54,0.3>, <100,0.6>, <1000,0>}>
CD^{N}_{32} = <loss rate,
{<0.1, 0.3>, <0.5,0.6>, <1,0.1>, <5,0>, <10,0>, <50,0>}>
CD^{N}_{33} = < round-trip delay,
{<10,0.1>, <20,0.4>, <50,0.4>, <100,0.1>, <200,0>, <500,0>}>
CD^{N}_{34} = <download time,
{<6,0.2>, <8,0.6>, <10,0.2>, <12,0>, <16,0>, <20,0>}>.

Bandwidth considered is measured in megabits per second, the loss rate is expressed as a percentage of the total data sent, round-trip delay is indicated in milliseconds and the expected download time for a regular web page in seconds.

7 QoE Rules sublayer

The main purpose of the proposed QoE Rules sublayer – located at the level of the AM – is to define performance and consequently QoE-related adaptive rules that make use of the PM’s QoE Characteristics sublayer information in order to propose QoE presentation adaptations on content. The adaptation-related suggestions are expressed in terms of performance-related features as described by the DM’s QoE Content Features sublayer. Based on the rules defined in the QoE Rules sublayer, if the conditions are true, actions are performed. These actions involve the modification of one or more features that characterise the content to be delivered to users in order to suit user device characteristics and/or network properties. This section presents formalisation and authoring details regarding the QoE Rules sublayer as well as an example.

7.1 Formalisation

The AM QoE Rules sublayer consists of Condition–Action (CA) type rules – applied at every user access – and of Event Condition Action (ECA) rules that are triggered by events. They are applied after the user personalisation rules that belong to the original LAOS AM. ECA events indicate changes in either device properties or network-related performance characteristics and can happen anytime during web sessions, including during the transmission of a multimedia stream. In CA rules, when a condition becomes true, the associated action is executed. In ECA rules, an event triggers a rule and an associated action is executed only if the condition is true. These rules can be associated with a certain device or network characteristics class or can be general across all the classes. More details about the syntax of the CA-based adaptation rules are presented in (Cristea and Calvi, 2003).

Next, both CA and ECA rules are formally presented.

Definition 6 *The CA rules have the following format:*

IF (COMPLEX_COND) THEN COMPLEX_ACTION

where COMPLEX_COND is a complex condition that can comprise either one simple condition SIMPLE_COND or more simple conditions connected by logic operators such as AND and OR. Next COMPLEX_COND recursive definition is shown:

COMPLEX_COND = SIMPLE_COND [logic_operator COMPLEX_COND]

SIMPLE_COND represents a condition between a value COND_VALUE associated with an attribute CD_A_{ij}, from performance characteristics class C_i, $1 \le j \le N_i$ and one of the values VT_V_{ijk}, $1 \le k \le M_{ij}$ predefined in one of the attribute's value terms from the performance characteristics class definition. The condition involves a relational operator such as '<' (LESS), '≤' (LESS OR EQUAL), '=' (EQUAL), '≅' (APROXIMATELY EQUAL), '≥' (GREATER OR EQUAL) and '>' (GREATER). The latter is defined in comparison with the other values listed in the value terms associated to this attribute. The formal definition for SIMPLE_COND is presented below:

SIMPLE_COND ={COND_VALUE relational_operator VT_V_{ijk}}

COMPLEX_ACTION indicates a complex presentation-related adaptation action to be performed on content in order to answer to existing performance-related constraints. It consists of a set of simple actions $SIMPLE\_ACTION_i$, where $1 \le i \le L$, as indicated in the definition below:

COMPLEX_ACTION = {$SIMPLE\_ACTION_i$}

Any $SIMPLE\_ACTION_i$ affects one important feature of the content to be delivered to the web user. The $SIMPLE\_ACTION_i$ formal definition is presented next:

$SIMPLE\_ACTION_i$= Cont_Feature=Cont_NewValue

where Cont_Feature represents one of the web content features such as size or bitrate and Cont_NewValue indicates the new value for the indicated content features.

Definition 7 *The ECA rules have the following format:*

WHEN COMPLEX_EVENT IF (COMPLEX_COND) THEN COMPLEX_ACTION

where COMPLEX_EVENT is a complex event that can comprise either one simple event SIMPLE_EVENT or more simple events between which logic operators such as AND and OR are applied. Next is the COMPLEX_EVENT recursive definition:

COMPLEX_EVENT = SIMPLE_EVENT [logic_operator COMPLEX_EVENT]

A SIMPLE_EVENT is an external event that modifies operational environment of the user causing changes in the device characteristics (e.g., battery-power level, resolution, etc.) or network characteristics (e.g., network loss rate, round-trip delay, etc.). The formal description of the SIMPLE_EVENT is indicated next:

SIMPLE_EVENT = CD_A_{ij} relational_operator EVENT_VALUE

where EVENT_VALUE is a value of certain significance related to an attribute CD_A_{ij}, $1 \leq i \leq N_i$ associated with the performance characteristics class. The relational operator could be: '<' (LESS), '≤' (LESS OR EQUAL), '=' (EQUAL), '≅' (APROXIMATELY EQUAL), '≥' (GREATER OR EQUAL) and '>' (GREATER).

COMPLEX_COND and COMPLEX_ACTION have the same formal description as in the definition of the CA rules.

7.2 Authoring

The goal of a performance-aware adaptation algorithm is to increase users' QoE when interacting with the system that deploys it. A content adaptation algorithm has three major phases. The first phase requires constant monitoring of the conditions in which the content is being delivered to users as well as those in which it is being displayed to them. An important aspect here is that both performance and QoE-related information is collected. The second phase requires regular passing of the information gathered in the monitoring phase to the server. In some of the cases, this phase involves the server receiving feedback from the client devices; in other cases remote monitoring enables the server to collect this information. When client feedback is used, the information can be collected automatically and the reporting will include either measurements of objective metrics only or these measurements combined with subjective information obtained from users explicitly giving their opinion regarding their levels of QoE. Note that there has to be a balance between the accuracy of the monitoring and result gathering, on one hand and the resources spent during this process in terms of device CPU, network bandwidth, *etc*., on the other hand. The third and most important phase involves the server analysing the results gathered and adapting content accordingly. The algorithm indicates what content-related features need to be modified and how to improve content delivery performance and/or user QoE.

Authoring in relation to the AM's QoE Rules sublayer aims to formally describe the adaptation rules according to either an *ad hoc* scheme or to a predefined adaptation algorithm. Regardless of the approach chosen, it is very difficult to involve automation in this process as it is highly dependent on what information the authors choose to include in the DM's QoE Content Features and the PM's QoE Characteristics sublayers and on what and when adaptive actions are to be taken. The formalisation can be performed using any language, but languages such as LAG (Cristea and Calvi, 2003) may make authoring easier. This is the case as variable overlays are made clear in LAG clear, indicating the layer from LAOS authoring model they relate to. For example the variables starting with 'PM.' refer to the parameters from the presentation model and those starting with 'DM.' indicate features described in the domain model. However, some degree of help can be provided to the author. For example, a user-friendly graphical user interface can restrict input of rules to those whose format conforms to Definitions 6 and 7. Also when inputting features, after typing the layer's coded name, automatically the list of existing characteristics or features can be provided and the author can make an easy selection. A similar selection-based approach can be used for the introduction of relational operators, but it cannot be employed for the input of values. Currently the authors must construct (or select from various existing solutions) a suitable adaptation algorithm and translate this algorithm to the format required by the QoE Rules sublayer. However, potential performance or QoE-aware adaptation algorithms do exist, such as one that adjusts static web content and was proposed in Muntean and McManis (2006b) and the Quality-Oriented Adaptation Scheme (QOAS) that adjusts multimedia content and was described in Muntean (2006).

It is important to note that there is a tension between adaptation for user interests (which might indicate the inclusion of content such as high resolution video) and adaptation based on performance (which might indicate that the content can only be delivered at a lower resolution or cannot be delivered). Currently, the author has to be aware of such potential conflicts and to resolve them. This task is made more difficult as the delivery engine may choose to apply the adaptation rules in different orders (or even iteratively) and may even choose to deliver different content. In this context a simulation tool that allows the author to view the result of various customisations would be invaluable.

7.3 Example

This subsection presents some possible QoE rules that consider the device properties and network characteristics classes previously given as example. 'Handheld Devices' and 'Wireless Broadband Networks' classes are selected and the actions involve modification of features for both multimedia and web page content. The examples are written in LAG.

'Handheld Devices' device characteristics class:
IF (PM.battery power < 1100)
THEN {DM.bitrate = 0.512}
IF (PM.resolution = 320×240)
THEN {DM.resolution = 320×240}
IF (PM.CPU power < 0.5 AND PM.colour depth < 64)
THEN {DM.bitrate = 0.384; DM.framerate = 12; DM.colours = 8}

'Wireless Broadband Networks' network characteristics class:
IF (PM.bandwidth = 5)
THEN {DM.bitrate = 2}
IF (PM.download time > 12)
THEN {DM.objects = 3; DM.tsize = 50; DM.size = 10}
WHEN (PM.loss rate > 10) IF (PM.bandwidth < 1)
THEN {DM.bitrate, 0.384); DM.framerate = 8; DM.colours = 8}.

These numeric figures can be heuristically determined, by using the Perceived Performance Model part of the QoE-layer for AHS described in Muntean (2006) or by using QOAS.

8 Conclusions and future work

This paper proposes QoE-LAOS, a Quality of Experience authoring model that extends LAOS (Cristea and de Mooij, 2003) in order to enable performance-aware adaptation. Its goal is to extend the authoring paradigm of 'create once, use many' to one of 'create once, use many, use anywhere'.

The QoE extension to LAOS allows for the description of performance-related content features, definition of delivery and display environment characteristics, and performance-based content adaptation rules. Specifically, it introduces three new sublayers. The QoE Content Feature sublayer of the QoE LAOS provides content representation updates with performance attributes in order to be used for QoE adaptation. The QoE Characteristics sublayer of the QoE-LAOS Presentation Model was defined to provide classes that describe performance characteristics related to network conditions and device properties. The novel QoE Rules sublayer of the QoE LAOS Adaptation Model was introduced to provide rules for adjusting content to suit current content delivery and display conditions.

This paper formalises and exemplifies each of the three new sublayers of the QoE-LAOS and presents authoring-related discussions in relation to each of them.

The next step in this work is to incorporate the proposed QoE-aware presentation Model into MOT (Cristea and Kinshuk, 2003), an adaptive hypermedia authoring system developed according to LAOS specifications. Tests will evaluate the benefits of the proposed QoE extension for LAOS in the educational area. Additionally, substantial research remains in the area of automating the performance adaptation procedure to enable non-experts to develop performance-aware adaptive content.

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