Authoring Model for Quality of Experience-aware Adaptive Hypermedia Systems

Cristina Hava Muntean[1], Gabriel-Miro Muntean[1], Jennifer McManis[1]
Alexandra I. Cristea[2]

[1] Performance Engineering Laboratory, RINCE, School of Electronic Engineering, Dublin City University, Glasnevin, Dublin 9, Ireland
{havac, munteang, mcmanisj}@eeng.dcu.ie
[2] Faculty of Computer Science & Mathematics, Eindhoven University of Technology, Postbus 513, 5600 MB Eindhoven, The Netherlands
a.i.cristea@tue.nl

Abstract. This paper presents a novel authoring framework for Quality of Experience (QoE) aware Adaptive Hypermedia Systems. It extends the LAOS authoring model in order to consider delivery performance issues. The paper formalises and exemplifies the newly proposed QoE extensions for the LAOS Adaptation and Presentation Models that include QoE Characteristics and QoE Rules layers.

1 Introduction

The Internet offers the opportunity for a vast number of people to access Web material. These people have diverse preferences, objectives, goals, aptitudes or special needs. Adaptive Hypermedia Systems (AHS) allow Web material to be tailored to the individual needs of the users. Many AHS have been proposed, including: AHA! [1, 2], Guide [3], ApeLS [4, 5], INSPIRE [6], AES-CS [7]. These systems address various issues related to personalisation such as: content and navigation support adaptation, user profile modeling, system usability evaluation, etc. Recently, due to the increase in types of devices and variety of networks used to access Web content, the delivery performance has been recognized as important and the material must now also be tailored to the user's access capabilities. In this context, the QoE-layer for AHS [8, 9, 10] focuses on performance issues arising from the user's network environment.

A major problem faced by 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 it has been shown that authoring for adaptive environments differs substantially from authoring for static ones [11]. However, as AHS transition from academic proof-of-concept research to industry-based research and development of personalised information delivery systems, much more attention is given to the

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authoring process itself. First, a few authoring toolkits and systems [12, 13] were developed and used with a given AHS. Later on, more general models for adaptive authoring that facilitate re-use of the material were proposed [14, 15]. Currently, research is performed towards the development of converters [16, 17, 18] that allow a material developed with an authoring tool to be delivered with various AHS. The primary goal of these authoring solutions is to enable the creation of user personalised content only.

The diversity of network-enabled devices and network technologies which are now available require that the authoring process should consider the performance impact of this technology on content delivery. The adaptive material should be such created to enable fast network transfer and good display on various devices. This opens the way in AH authoring to the **"create once, use many, use anywhere"** authoring paradigm.

This paper proposes a QoE-aware extension to the five-layer adaptive authoring model LAOS [12] that allows for performance-aware adaptation. The remainder of the paper is structured as follows. Section 2 briefly describes LAOS, and indicates that its Adaptation (AM) and Presentation models (PM) will deal with performance adaptation issues. Section 3 presents those factors having the greatest impact on QoE, and Section 4 is dedicated to the description, formalisation and exemplification of the proposed QoE-aware extensions to LAOS. Section 5 proposes a representation for Web content performance-related characteristics, whereas the last section presents the conclusions.

2 LAOS

LAOS is a layered model for adaptive hypermedia authoring [15]. The model extends the three layers of the AHAM [19]: User Model, Domain Model, and Adaptation Model with two new layers:

- Goal & Constraints Model (GM), between Domain (DM) and User (UM) models
- Presentation Model (PM) on top of the Adaptation Model (AM).

The five layers of the LAOS function as follows.

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, figures, multimedia presentations or a combination of those. A set of algebraic operators divided in four categories [15]: *constructors* (e.g. create, edit), *destructors* (e.g. delete), *visualization* (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).

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 [15]. 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 relations attributes, as well as weights for the OR relations. A set of algebraic operators similar with the one for DM was also defined for the GM [15].

User Model (UM), described in more details in [19], follows the principle defined in AHAM. 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.

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 PM were not specified in LAOS.

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 [20] as a model for authoring the adaptive behavior of the AHS.

- **low level adaptation** for defining the traditional techniques for content adaptation (e.g. insert/remove fragments of information, stretchtext, 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, GENERALIZE, etc.). It groups elements of the previous layer into typical adaptation mechanisms and constructs.
- **high level adaptation** that 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 Factors Affecting Quality of Experience

The latest advancements in computer and communications-related technologies have brought to the wide consumer market many network solutions and a variety of network-enabled devices. Various types of networks enabled by different wired solutions such as DSL, ADSL, Ethernet or wireless such as WiFi (IEEE 802.11) and WiMax (IEEE 802.16) offer network connectivity with different 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. All these strongly influence users experience during their interaction with the systems, which is known as end-user Quality of Experience (QoE).

QoE focuses on the user and is considered in [21] 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. QoE metrics may have a subjective element to them and may be influenced by any sub-system between the service provider and the end-user.

Lately diverse mobile and fixed network-enabled devices have been launched. These devices differ in overall 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. Therefore, apart from personalising Web content to user needs and goals, AHS should also consider content delivery performance and quality of displayed material.

4 Quality of Experience-aware Extension for LAOS

In this paper we extend LAOS in order to address the delivery and display-related performance issues. The proposed 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 Web content includes material of continuous nature such as multimedia which is delivered over a long period of time. The QoE extension to LAOS involves the addition of two new QoE layers to AM and PM respectively. The first extension - **the QoE Characteristics Layer** - located at the level of PM - defines in abstract manner classes representing those factors that have an impact on performance, including the Device and Network Characteristics Models. The second extension - **the QoE Rules Layer** - located at the level of AM - defines QoE-related adaptive rules that make use of the PM's QoE Characteristics Layer information in order to propose QoE presentation adaptations.

4. 1 QoE Characteristics Layer for the LAOS PM

4.1.1 Formalisation

The new PM QoE Characteristics Layer is formally introduced in this section by means of a number of definitions.

Definition 1. We define QoEPM as a **performance characteristics class set** *SC*:

$$SC=\{C_i\}$$

Definition 2. We define a **class of performance characteristics** C_i an abstract term identified by the tuple:

$$C_i=<C\_Name_i, C\_LCD_i>,$$

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 a performance characteristics class. Among them could be device properties, network characteristics, etc.

Definition 3. A **class descriptor** CD_{ij} is defined by the tuple:

$$CD_{ij} =<CD\_A_{ij}, CD\_LVT_{ij}>,$$

where CD_A_{ij} is an attribute associated with the class descriptor 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 4. A **value term** VT_{ijk} is defined by the tuple

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

where VT_V_{ijk} is the value and VT_P_{ijk} the probability the value VT_V_{ijk} is associated with the attribute CD_A_{ij} describing the class C_i.

4.1.2 Exemplification

Next a potential exemplification of the QoE Characteristics sub-layer is shown. It includes device property-related ($C^D{}_i$) and network characteristics-based ($C^N{}_i$) classes.

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*, *{<160x120, 0.3>, <320x240, 0.4>, <640x480, 0.3>}*>
$CD^D{}_{12}$ =<*battery power*, *{<1100, 0.5>, <1500, 0.3>, <1800, 0.2>}*>
$CD^D{}_{13}$ =<*color depth*, *{<32, 0.3>, <64, 0.6>, <128, 0.1>}*>
$CD^D{}_{14}$ =<*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>}*>

Possible values associated with an attribute can be obtained from the device specification. For example the majority of handheld devices have battery with a power of 1100mAh, but more powerful batteries (e.g. 1500mAh) 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*, *{<640x480, 0.3>, <800x600, 0.4>, <1024x768, 0.3>}*>
$CD^D{}_{22}$ =<*battery power*, *{<2400, 0.2>, <3200, 0.5>, <3800, 0.3>}*>
$CD^D{}_{23}$ =<*color depth*, *{<128, 0.3>, <256, 0.6>}*>
$CD^D{}_{24}$ =<*multimedia enabled*, *{<0, 0.1>, <1, 0.9>}*>
$CD^D{}_{25}$ =<*CPU power*, *{<1.0, 0.3>, <1.5, 0.4>, <2.0, 0.3>}*>

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*, *{<1152x864,0.3>,<1280x1024,0.5>,<1600x1200,0.2>}*>
$CD^D{}_{32}$ =<*battery power*, *{<5000, 1.0>}*>
$CD^D{}_{33}$ =<*color depth*, *{<256, 0.1>, <512, 0.6>, <1024, 0.3>}*>
$CD^D{}_{34}$ =<*multimedia enabled*, *{<0, 0.0>, <1, 1.0>}*>
$CD^D{}_{35}$ =<*CPU power*, *{<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 color space in kilobytes and CPU processing power in GHz.

Network characteristics classes:

The same principle can be applied for 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 $1 \le i \le 4$
$CD^N{}_{11}$ =<*bandwidth*, *{<0.03, 0.2>, <0.128, 0.6>, <0.384, 0.2>}*>
$CD^N{}_{12}$ =<*loss rate*, *{<5, 0.4>, <15, 0.5>, <25, 0.1>}*>
$CD^N{}_{13}$ =<*round trip delay*, *{<300, 0.3>, <500, 0.6>, <800, 0.1>}*>
$CD^N{}_{14}$ =<*download time*, *{<12, 0.2>, <16, 0.4>, <20, 0.4>}*>

$C^N_2 \; = <\text{"Wireless Broadband Networks"}, \; \{CD^N_{2i}\}>,$ with $1 \le i \le 4$
$CD^N_{21} = <\text{bandwidth}, \{<1, 0.1>, <5, 0.3>, <11, 0.2>, <24, 0.3>, <54, 0.1>\}>$
$CD^N_{22} = <\text{loss rate}, \{<1, 0.4>, <10, 0.5>, <20, 0.1>\}>$
$CD^N_{23} = <\text{round trip delay}, \{<100, 0.4>, <150, 0.6>, <200, 0.1>\}>$
$CD^N_{24} = <\text{download time}, \{<8, 0.3>, <10, 0.6>, <12, 0.1>\}>$

$C^N_3 \; = <\text{"Wired Broadband Networks"}, \; \{CD^N_{3i}\}>,$ with $1 \le i \le 4$
$CD^N_{31} = <\text{bandwidth}, \{<10, 0.1>, <100, 0.8>, <1000, 0.1>\}>$
$CD^N_{32} = <\text{loss rate}, \{<0.1, 0.3>, <0.5, 0.6>, <1, 0.1>\}>$
$CD^N_{33} = <\text{round trip delay}, \{<20, 0.4>, <50, 0.4>, <80, 0.2>\}>$
$CD^N_{34} = <\text{download time}, \{<6, 0.2>, <8, 0.6>, <10, 0.2>\}>$

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.

4.2 QoE Rules Layer for the LAOS AM

4.2.1 Formalisation

The new AM QoE Rules Layer 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 rules that belong to the classic User Personalisation Layer of the LAOS AM were applied. ECA events indicate changes in either device properties or network-related performance characteristics and can happen anytime during Web session, 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 [19].

Next both CA and ECA rules are formally presented:

Definition 5. 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 '=' (EQUAL) or '≅' (APROXIMATELY EQUAL). 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 $1 \leq i \leq L$, 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 6. 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.

4.2.2 Exemplification

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 the LAG language [20] (variables overlays are made in LAG clear; therefore, variables starting with '*PM.*' refer to the parameters of a given presentation, which can be fixed or changeable during the interaction with the user).

***"Handheld Devices"* device characteristics class:**

IF (*PM.battery power < 1100)* THEN *{PM.bitrate= 0.512}*

IF (*PM.resolution == 320x240)* THEN *{PM.picture resolution = 320x240}*

IF (*PM.CPU power < 0.5 AND PM.color depth < 64)*

THEN *{PM. bitrate = 0.384; PM.framerate=12; PM.no colors=8}*

***"Wireless Broadband Networks"* network characteristics class:**

IF (*PM.bandwidth =5)* THEN *{PM.bitrate= 2}*

IF (*PM.download time > 12)* THEN *{PM.no objects = 3; PM.objects size= 50; PM.page size = 10}*

WHEN *(PM.loss rate > 10)* IF *(PM.bandwidth < 1)* THEN *{PM.bitrate, 0.384); PM.framerate = 8; PM.no colors = 8}*

These numeric figures can be heuristically determined or by using the Perceived Performance Model part of the QoE-layer for AHS described in [9].

5 Web Content Features

Based on the rules defined in the AM QoE Rules Layer, if the conditions are true, actions are performed. These actions involve the modification of one or more features that characterize the Web content to be delivered to the user in order to suit user device characteristics and/or network properties. This section presents a classification of Web content and discusses some of their features.

There are two main classes of Web content that differ in terms of their characteristics: Web pages and multimedia streams.

Web pages consist of a main page and a number of embedded objects, many of them images. 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, so that the delivery process can be considered 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.

Multimedia content is either streamed or downloaded and then played at the destination at user 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 being 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.

Regardless of when and how the QoE-related presentation adaptation is performed, it affects Web content features. Next these features are formalized in relation to both Web page and multimedia content.

5.1 Formalisation

Definition 7. Web page features are formalized as a set of tuples:

$$F^W=\{<F\_Name^W_i, F\_Value^W_i>\},$$

with $1 \leq i \leq N^W$ where $F\_Name^W_i$ is the name of Web page feature i and $F\_Value^W_i$ is the value associated with this feature.

Definition 8. Multimedia content features are formalized as a set of tuples:

$$F^M=\{<F\_Name^M_i, F\_Value^M_i>\}$$

with $1 \leq i \leq N^M$ where $F\_Name^M_i$ is the name of multimedia feature i and $F\_Value^M_i$ is the value associated with this feature.

5.2 Exemplification

This subsection presents examples of possible feature sets that describe particular Web content from two main categories: Web pages and multimedia content.

Web-page

F_1^W*={<page size, 10>; <page length, 500>; <no objects, 10>; <pictures resolution, 160x100>; <objects size, 50>}*

F_2^W*={<page size, 12>; <page length, 200>; <no objects, 4>; <pictures resolution, 160x100>; <objects size, 30>}*

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

Multimedia content

F_1^M*={<bitrate, 1>; <framerate, 25>; <resolution, 320x240>; <no colors, 24>; <encoding, MPEG4>}*

F_2^M*={<bitrate, 0.384>; <framerate, 16>; <resolution, 160x120>; <no colors, 16>; <encoding, MPEG4>}*

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

6 Conclusions And Future Work

This paper proposes a theoretical framework for Quality of Experience (QoE)-aware authoring. Its goal is to extend the authoring paradigm of “create once, use many” to one of **“create once, use many, use anywhere”**.

A QoE extension to the LAOS authoring model was proposed that allows for the description of performance-related characteristics and adaptation rules. The paper also introduces Web content representation updates with performance attributes in order to be used by the proposed QoE extension.

Specifically, the new QoE Characteristics Layer of the LAOS Presentation Model was defined to provide classes that describe performance entities such as network and device. The novel QoE Rules Layer of the LAOS Adaptation Model was also introduced to provide rules for adjusting content to suit current content delivery and display conditions.

An example of QoE extension layers is presented that can be used as a basis for default representation of performance. Alternatively, it can be either modified or, more likely, be overridden by a new model created by the author.

The next step in this work is to incorporate the proposed QoE-aware presentation Model into MOT [22], 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.

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