A Model for Universal Usability on the Web

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ABSTRACT

This paper presents a theoretical model to study the universal usability of the Web, i.e., how usable websites are to a wide range of audiences. We define a set of universal usability metrics (UUM) to be applied into Web portions (e.g., websites, clusters) at different abstraction levels. Model instances afford studying evolution patterns of the Web (e.g., *Reachability*, *Verticality*) from a universal usability perspective. This leverages new knowledge that can be used to both explain adequacy of websites to the particularities of users, as well as pointing out future directions for Web standards.

Categories and Subject Descriptors

H.1.2 [**Models and Principles**]: User/Machine Systems—*Human factors*; H.5.4 [**Information Interfaces and Presentation**]: Hypertext/Hypermedia—*User issues, Theory, Navigation, Architectures*

General Terms

Human Factors, Theory, Measurement.

Keywords

Web Science, Web Interaction Environments, Universal Usability, Web Metrics, Web Evolution

1. INTRODUCTION

The Web, as a medium, plays an important role on people's lives. It is used for disparate purposes, such as information gathering, communicating, or performing transactions. One important part of the Web is inherently interactive, it is its *visible side*. It is the entry point upon which users begin their Web experience, by opening their preferred Web browser and typing some address, selecting a bookmark or enter a query in a search engine. From this point, users navigate from link to link as a way to meet their goals.

Within this context, we are facing with an increasing diversity of users and devices accessing the Web. The typical interaction environment of a non-impaired user surfing the Web in a desktop computer is being replaced by universal and ubiquitous access to information. However, Web front-ends are still developed mostly towards the common case scenario. Even further, as end-user generated content practices are increasing (e.g., wikis, blogs, etc.), tools are still scarcely providing help to cope with such diversity.

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The typical way to handle multiple audiences and scenarios is either by delivering horizontal solutions, such as a single front-end properly accessible and usable by anyone in any situation, or vertical solutions, e.g., desktop *vs.* mobile versions of a website. These two solutions are both, respectively, at the beginning and the end of the spectrum of mass-individualisation, which is the ultimate goal of *Universal Usability* [14]. This vision encloses systems that can cope with each user's needs, usage situation, and surrounding environment, through tailored user interfaces, navigation schemes, and accessible content, helping users meet their goals in an effective and optimised way.

Based on the original Web science vision [1], Shneiderman [15] has argued that universal usability is another crucial aspect to study the Web and predicting its evolution. There is a need to understand how websites cope with the particularities of a specific audience or heterogeneous environments comprising several audiences. When scaling this type of analysis to the Web as an entity, new findings can come to the surface, based on the inherent linking structure between webpages. Such analyses will provide guidance on the evolution of Web standards and best practices, in order to provide the basis to develop better user experiences to all users in all situations.

This paper proposes a model for universal usability on the Web, encompassing different abstraction levels that help studying and understanding the Web both at micro and macro scales. This model is used to propose a set of patterns of "discovery" towards universal usability on the Web extracted from the analysis of hyper-structures. Lastly, a discussion is made on how these patterns can help guiding implementing large-scale observatories of universal usability of the Web, and how can the model be used to provide guidance on the evolution paths of Web standards.

2. REQUIREMENTS

Usability evaluations of interactive software applications have the goal of understanding the adequacy of a user interface to users [13]. Viewed from its interactive side, the Web is also a target for usability evaluation procedures [9]. These studies provide answers regarding the quality of websites from the perspective of a set of users (chosen as representative of a website's audience). However, the democracy of publishing information on the Web more often than not results on neglecting these studies [6, 11].

Universal usability concepts further enlarge the spectrum of applicability of such procedures. Understanding how websites can cope with less standard audiences is a concept that is being explored mostly in two fronts, accessibility guidelines [3] and mobile Web [7]. Still, understanding how universally usable websites are is a complex task. Often, results are representative of distinct users viewed as a homogenous audience. To dismiss this type of problems, in [18] the authors propose a way to detect individual requirements and tailor accessibility evaluation tasks. In spite of that, these studies still require manual expert analysis and real users, in order to yield good results. Consequently, are only applicable in limited scopes, such as those of micro-scale analysis of small portions of the Web.

In [19], the authors have shown that the evolution of Web standards influences the way users navigate and interact with websites. While these type of studies bring to light important issues about user experience on the Web, they are limited by intrusion (e.g., installing software on each computer), privacy (i.e., monitoring website visits), and scalability concerns.

Consequently, all of these factors pose severe difficulties on understanding how universal usability is implemented at the macro-scale of the Web. While some studies afford analysing the Web at macro scales [4], including fitting hyper-structures to increase the usability of websites [2], little or none is known about universal usability of the Web (as usability evaluation procedures are costly, take time, and are hard to scale).

Hence, the following goals should be supported by a model that affords studying the Web from a universal usability point-of-view:

- *Multi-scale*: understand the synergies between the micro and macro scale effects of universal usability, particularly the influence of a user interface feature in a website (e.g., taking into account a particular device feature) and how it fits into macro scale scenarios;
- *Evolution independent*: the Web is in constant evolution, on its structures, technologic advancements, and audiences. Consequently, to study such evolutions with the model, it should be independent from these constraints.

Such goals allow the characterisation of the Web regarding the disparity of user audiences and technology advancements. However, a set of requirements must be fulfilled in order to accomplish them, including:

- *Universal*: the model must provide support to study different type of audiences and how websites are properly usable by each audience. However, as the model must cope with the *evolution independent* goal, it cannot be directly tied to specific user categories, etc.;
- *Fully automated*: due to the amount of information that must be processed, macro scale studies have to be performed in a fully automated fashion in order to scale. Hence, the model must be built from the ground up through automated usability evaluation practices;
- *Non-intrusive*: the model must not depend on intrusive practices on individuals, such as installing monitoring software, which also introduces scalability issues. Moreover, intrusiveness lead to privacy concerns, which might limit a model's spectrum of applicability and objectiveness.

3. WEB INTERACTION ENVIRONMENTS

The first contribution of this paper is the definition of a multi-layered model for specifying heterogeneous audiences and studying the way websites are able to cope with them, named *Web Interaction Environments* (WIE). The model is layered three-fold, as depicted in Figure 1: *Characteristics*, *Class*, and *Graph*. Each layer builds upon the lower ones through abstractions and corresponding mapping functions, in order to study the increasing complexity of the impact of universal usability on the Web.

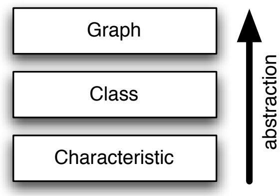

Figure 1: WIE abstraction layers

Each one of the layers provides support for studying different interaction aspects that influence user experience within different Web portions either at *single resource* (i.e., one webpage) or *multiple resources* (i.e., webpage cluster, website, or website cluster) levels. Analysing both perspectives will open the way on to performing different universal usability studies (both micro and macro scale), as further detailed in Section 4. While it is not the purpose of this paper to provide a quantifiable metric for universal usability, the WIE model must map directly into a Web portion through quantification processes, such as usability metrics for Web quality assurance [10] and Web accessibility metrics [17].

Hence, in order to be applied in concrete contexts, the model must be instantiated with specific parameters:

$$M_i = \langle T, w, \mathcal{F}, G \rangle$$

Where M_i represents the model instance, T represents a taxonomy of characteristics, w is a weighting function which measures the relevance of characteristics within the taxonomy, $\mathcal{F}$ groups all functions that quantify specific universal usability metrics (directly mapping into individual characteristics), and G represents the upper layer of the model, *graph*. Next, each layer of the model is further detailed bottom-up.

3.1 Characteristic

The ground basis for studying universal usability on the Web is the definition of which characteristics of the Web interaction environment are relevant for the study. A characteristic's role is to represent a class of concepts which influences interaction and cannot (in fact, should not) be directly dictated or enforced by a website. Such characteristics can be perceived either as inherent (i.e., immutable during a session) or transient (mutable during a session) in four domains:

- *User*, encompasses intrinsic user diversity characteristics, such as physical and cognitive (dis)abilities, age, gender, or even cultural aspects (e.g., language);
- *Device*, provides support for technology variety, such

as input and output modalities, networking capabilities, user agent media acceptance, etc.;

- *Usage situation*, affords putting the *user* interacting with a *device* in a real environment. Such characteristics include network connectivity, device handling, environment constraints (lightning, noise, privacy);
- *User intention*, introduces concepts of user interaction intentions on the Web [8], including information gathering, communications, transactions, etc.

Characteristics might represent more abstract or more concrete concepts. For instance, a *vision disability* characteristic defines a broad class of impairments, whereas *totally blind* represents a more precise concept. The affinity between characteristics can be exploited through the inherent relationship between them, particularly *is-a* mappings (e.g., *totally blind* is-a *vision disability*). Recursively, this relationship between characteristics is mapped into a taxonomy that organises them at different levels of abstraction. By being taxonomically organised, the *is-a* mapping yields a unique root concept (the common denominator between all characteristics), as well as a unique path between the root and any characteristic c, composed by all the ancestors of c (i.e., all abstractions of c). c, hence, inherits the *semantics* of all of its ancestors.

Furthermore, the *is-a* mapping inherently affords the comparison between two characteristics, through its taxonomical topology. By assigning a weight to a characteristic within the taxonomy, a quantification is attainable. Consequently, analysing a Web portion from the point of view of a more specific characteristic might yield a higher significance (in a broad sense) than an abstract characteristic.

However, characteristics by themselves do not convey any information about a particular Web portion. Therefore, the mapping between both items should be conveyed through quantifiable metrics. We propose the following formula:

$$UUM(c,p) = w(c)f_c(p)$$

Where UUM stands for *Universal Usability Metric*, c represents a particular characteristic to be verified according to a particular criterion $f_c \in \mathcal{F}$ (i.e., the quantification process), against a singular webpage p. The universal usability metric is weighted by w, according to the level of abstraction of c in the taxonomy. When analysing a Web portion $S = \{p_1, ..., p_n\}$, its universal usability metric is the average for all webpages it encloses, i.e.:

$$UUM(c,S) = \frac{1}{n}\sum_{i=1}^{n} UUM(c,p_i), p_i \in S$$

In both situations, the weight w and universal usability quantification criterion f_c functions of a particular characteristic c must be defined in each experiment (inherent to a model instance). These functions must yield results in the $[0,1]$ range (i.e., percentage), where $w(c) = 1$ represents the maximal weight of a characteristic (e.g., along the lines specificity within the scope of the taxonomy) and $f_c(p) = 1$ represents the complete universal usability validation of a webpage p according to the f_c criterion. For practical reasons, $\mathcal{F}$ might not include criteria for all characteristics within the taxonomy. Consequently, assuming that b is an ancestral characteristic of c, the universal usability metric can be used with the criterion f_c by applying the corresponding weight $w(b)$. This ensures that a more abstract characteristic can use more specific criteria with decreased weight (as $w(b) < w(c)$, per definition).

This results on an independence of the model from specific taxonomies of characteristics, as well as from evaluation criterions. These taxonomies might be composed by different concepts, or tailored to particular domains of universal usability. It is the purpose of w to weight the relevance of a characteristic within the taxonomy it is enclosed, thus making this layer of the model taxonomy-aware, while remaining taxonomy-independent.

Lastly, the introduction of an arithmetic mean for a Web portion helps making statistical analysis (e.g., standard deviations, distributions, etc.) of the application of universal usability metrics. Such capabilities provide a solid ground for further explorations of universal usability studies of the Web at higher abstraction layers of the proposed model.

3.2 Class

Building upon the definition of the characteristics layer, the class layer provides support for multi-characteristic audiences (hence more rich and complex). When analysing the universal usability of a Web front-end, an audience must be studied from multiple points of view, e.g., characteristics from the four domains. Therefore, they should not be dissociated when describing an audience: *users* use *devices* in particular *usage situations* to access a Web portion with a particular *intention*. By changing any of these factors, there will be an impact on the usability of a Web portion.

The purpose of the class layer is, consequently, to analyse Web portions from the point of view of coherently grouped characteristics. For instance, a class referring to the typical scenario of a visually impaired person might aggregate the *totally blind*, *screen reader*, and *keyboard* characteristics.

Based on the universal usability metric for characteristics presented previously, the corresponding class-based metric for a webpage is the following:

$$UUM(\alpha,p) = \prod_{i=1}^{n} UUM(c_i,p), c_i \in \alpha$$

Where $\alpha = \{c_1, ..., c_n\}$ stands for a class aggregating a set of characteristics. The product calculation of the class metric corresponds to its conjunctive nature for characteristics, modelling the influence that all characteristics have on each other.

Analogous to applying the characteristics metric to a Web portion $S = \{p_1, ..., p_n\}$, the class-centric universal usability metric for a Web portion is:

$$UUM(\alpha,S) = \frac{1}{n}\sum_{i=1}^{n} UUM(\alpha,p_i), p_i \in S$$

Theoretically, a class could aggregate all the characteristics present in the taxonomy and the universal usability metric would still yield a result. However, its interpretation would be an analysis on how all characteristics within the taxonomy influence each other in a Web portion (i.e., due to a class' conjunctive nature). To dismiss this issue, the selection of which characteristics must be aggregated into a class should be one of the following:

- *Expert analysis*, where a usability expert selects a set of characteristics that must be analysed from the point of view of a (not) commonly found audience. This approach affords testing for the universal usability of both concrete and idealised audiences;

- *Threshold definition*, where a value t is defined as the minimum UUM accepted value for each characteristic present in a taxonomy T, i.e.:

$$t \leq UUM(c_i, p) \Rightarrow c_i \in \alpha, c_i \in T$$

  This approach supports discovering the audience α whose characteristics are above a specific threshold;

- *Range definition*, where two values t_{min} and t_{max} are defined, respectively, as the minimum and maximum UUM values for each characteristic present in a taxonomy T, i.e.:

$$t_{min} \leq UUM(c_i, p) \leq t_{max} \Rightarrow c_i \in \alpha, c_i \in T$$

  This way different audiences can be studied within specific quality scopes.

Other methods for characteristics selection and grouping might be envisioned, but they are out of the scope of this paper. Nevertheless, these methods will often lead to recurrent classes, as developers tend to conform to a a limited set of target audiences. The finding of these patterns are further explored in Section 4.

3.3 Graph

The last layer of the proposed model is based on establishing relations between several classes, and exploiting characteristic and class topologies for studying the universal usability of Web portions. Typically, a Web portion might support (either implicit or explicitly) more than one class, e.g., *desktop computer*, *mobile*, *partially blind*. Consequently, with the support for different audiences by a Web portion, characteristics might be shared by different audiences.

To build a *Web Interaction Environment* graph, two types of elements must be defined: nodes and arcs. Each node represents a class (as defined in the previous Section), whereas arcs establish a directed *extension* relationship between classes. If two classes α and β are related to each other through the relationship $<_e$, $\alpha <_e \beta$ implies that β is an extension of α. Dually, α generalises β. The semantics of this relationship is two-fold:

- *Explicit*: all the characteristics of α not generalising any characteristic of β are always present in β *explicitly* (similarly to traditional object-orientation practices);

- *Implicit*: every characteristic of α that generalises a characteristic on β is said to be *implicit* in β (opening the way to the application of criteria with different weights, as explained earlier).

This extension mechanism offers a limited use when applied to a single child class. However, when applied to multiple child classes, it fosters sharing characteristics between them, leveraging which concepts are common within a subset of the graph. Following the relationship semantics as previously explained, a parent class represents both the implicit and explicit characteristics of its children. Similarly to characteristic selection when defining a class, the process of determining which classes should be (recursively) generalised into parent classes should be (not an exhaustive list, as well):

- *Expert analysis*, where a usability expert creates a set of classes according to specific criteria, such as representing disparate audiences, and explores the synergies and differences between them;

- *Threshold definition*, where a value t is defined as the minimum UUM accepted value for each class within the graph, i.e.:

$$t \leq UUM(\alpha_i, p) \Rightarrow \alpha_i \in H$$

  where $\delta <_e \alpha_i$ holds. H aggregates all classes of G above the threshold, and δ represents the parent class yielded from this process;

- *Range definition*, where two values t_{min} and t_{max} are defined, respectively, as the minimum and maximum UUM values for each class within the graph, i.e.:

$$t_{min} \leq UUM(\alpha_i, p) \leq t_{max} \Rightarrow \alpha_i \in H$$

  where $\delta <_e \alpha_i$ always holds. Similarly, H aggregates all classes of G within the $[t_{min}, t_{max}]$ range, and δ represents the resulting parent class.

In any of these processes, two properties must be guaranteed at the graph level of a model instance: (1) acyclic extensions, where no class can be its own parent, directly or indirectly, and (2) singular ancestries, i.e., if $\gamma <_e \beta$ and $\beta <_e \alpha$, α cannot extend γ directly (as it is already guaranteed by the semantics of $<_e$ and β).

Having setup a Web Interaction Environment graph within a model instance, the universal usability metric can be studied from two perspectives: the quantification of the minimum usability it supports in any class, and its dual, the maximal usability it supports in all classes.

When quantifying the minimum universal usability of a Web portion, all the classes that do not have a parent class form the core of this metric. As these typically generalise more specific classes within the graph, there might not be a criterion within $\mathcal{F}$ to match each one of the generalised characteristics they enclose. Consequently, the universal usability metric for these characteristics must reflect the application of existing criteria:

$$UUM(c, p) = w(c)\frac{1}{n}\sum_{i=1}^{n} f_{c_i}(p), f_{c_i} \in \mathcal{F}$$

Where f_{c_i} represents the criteria correspondent to the characteristics with the semantics of c (every c_i) present in all classes extending a parent class containing the generalised characteristic c. Similarly, when analysing a Web portion $S = \{p_1, ..., p_n\}$, the universal usability metric reflects their average value as explained in Section 3.1. Based on this metric for characteristics, the minimum universal usability metric of a graph is:

$$UUM \downarrow (G,p) = \frac{1}{n}\sum_{i=1}^{n} UUM(\alpha_1, p), \neg\exists\beta <_e \alpha_i, \alpha_i, \beta \in G$$

Opposing to the minimum universal usability metric for Web portions, the leaf classes within the Web Interaction Graph represent latent information about the maximum universal usability supported by Web portions. This is expressed dually, regarding the previous metric, as follows:

$$UUM \uparrow (G,p) = \frac{1}{n}\sum_{i=1}^{n} UUM(\alpha_1, p), \neg\exists\alpha_i <_e \beta, \alpha_i, \beta \in G$$

For both cases, when applying to a Web portion $S = \{p_1, ..., p_n\}$, the universal usability metric is the similar to every other case:

$$UUM \downarrow (G,S) = \frac{1}{n}\sum_{i=1}^{n} UUM \downarrow (G,p), p_i \in S$$

$$UUM \uparrow (G,S) = \frac{1}{n}\sum_{i=1}^{n} UUM \uparrow (G,p), p_i \in S$$

Next follows a discussion about the possibilities of emerging patterns that can be studied with the presented Web Interaction Environments model.

4. EMERGING PATTERNS

All perspectives of defining the universal usability metric (UUM) require a subset from a model instance's graph (e.g., a characteristic, a class, or an entire graph), as well as a Web portion (a webpage or a black-boxed set of webpages). As the outcome of UMM yields a value in the interval $[0, 1]$, it can be used in different ways to find universal usability graph patterns both within and between Web portions. Moreover, by taking UUM snapshots of Web portions at regular time intervals, the evolution of universal usability on the Web can be studied. All of these aspects are presented next.

4.1 Web Portions

The first set of patterns that can be explored with the Web Interaction Environments model relates to the inherent properties of a single Web portion, whether it relates to a single webpage or to a set of webpages.

4.1.1 *Characteristic UUM Comparison*

At the characteristic level of the WIE model, a Web portion might be more adequate to some characteristics than to others. It is common, for instance, to have a front-end that might be usable by partially-sighted users but not adequate to small screens. The purpose of this pattern is to study how a selected set of characteristics $C = \{c_1, ..., c_n\}$ part of a model instance's graph compare to each other in the context of a Web portion S. The set of all UUM applied to the Web portion S is represented by $V = \{v_1, ..., v_n\}$, is given by:

$$v_i = UUM(c_i, S), \forall c_i \in C$$

Based on the results, V can be analysed from several points of view, including:

- Compare two characteristics in C, to understand which one is better implemented in the Web portion S;
- Calculate the minimum and maximum UUM supported by C, and evaluate the proximity of each characteristic to both values;
- Determine the average UUM and corresponding standard deviation of all characteristics in C, and analyse how each characteristic compares to both values.

4.1.2 *Class UUM Comparison*

Similarly to characteristic UUM comparison, class UUM comparison tasks can leverage patterns of adequacy of a Web portion S to a selected set of classes $X = \{\alpha_1, ..., \alpha_n\}$. The selection of these classes is based on the set of leaf classes inherent of a model instance's graph G (i.e., those that represent more concrete audiences), or a subset of this. Accordingly, the set of all UUM applied to S is represented by $V = \{v_1, ..., v_n\}$, where each v_i is:

$$v_i = UUM(\alpha_i, S), \alpha_i \in X$$

The same analysis presented in the previous pattern yields similar outcomes, but targeted to the classes of G, thus providing clues on how the Web portion S fits to the audiences represented in G.

4.1.3 *Random Class Adequacy*

This pattern studies the unpredictability of which users might access a Web portion S. While analysing the classes within a pre-constructed WIE graph, it is expected that it covers a subset of the possible combinations of characteristics, in order to represent expected audiences. Hence, this pattern centres on the definition of a set of randomly generated classes $Y = \{\rho_1, ..., \rho_n\}$. Each class of Y should include characteristics from different domains, in order to cover a broad spectrum of possible audiences. Afterwards, *Class UUM Comparison* is performed with Y, dictating the level of adequacy of S to unpredictable audiences.

4.1.4 *Class UUM Distance in Graph*

One important aspect that can yield interesting results is the indirect comparison of two classes through their closest common ancestor. This pattern yields the improvement of supporting each class, based on the UUM of their common ancestor, according to a Web portion S. Assuming α is the ancestor class, and β_1 and β_2 represent two descendant classes, two patterns can be leveraged. First, the improvement i of a single class (e.g., β_1) in comparison with the ancestor α, given by:

$$i = UUM(\beta_1, S) - UUM(\alpha, S)$$

If $i > 0$, then there is an improvement of usability for the audience represented by β_1. However, when $i < 0$, it states that some characteristics are not properly taken into account in S, which results on a decrease level of usability for the audience. The second pattern compares relatively both β_1 and β_2. While their absolute value might represent appropriate levels of usability, their relativity to α might yield different outcomes (improvement *vs.* deterioration).

4.1.5 Minimum vs. Maximum Graph UUM

The last pattern presented for a single Web portion relates to the comparison between its minimum and maximum graph UUM. Similarly to the previous pattern, this comparison verifies whether there is an improvement on usability if more specific audiences of a graph G are taken into account in a Web portion S, i.e.:

$$i = UUM \uparrow (G, S) - UUM \downarrow (G, S)$$

If $i > 0$, then in fact there is an improvement of specialising to the specific audiences represented in G. However, if $i < 0$, these audiences were not taken into account (which typically results of having the Web portion targeted to a particular audience, instead of coping with several of them).

4.2 Linked Web Portions

The second aspect of finding the hidden patterns of the Web regarding universal usability relates to the way Web portions are linked to each other. By exploiting these hyper-structures, more complex patterns can bring to light the influence of each Web portion in the way users navigate between them. These patterns typically use the building blocks provided with the analysis made on single Web portions. Assuming the tuple $\mathcal{W} = \langle \mathcal{S}, \rightarrow \rangle$ represents this hyper-structure, $\mathcal{S} = \{S_1, ..., S_n\}$ represents the set of Web portions, and $\rightarrow$ a hyperlink between two Web portions of $\mathcal{S}$. This definition will be used in the next patterns.

4.2.1 Common Characteristics

The base analysis of a hyper-structure of linked Web portions concerns inferring the adequacy of characteristics to it. The analysis of which characteristics are shared within $\mathcal{S}$ is two-fold: first, the characteristics UUM for each Web portion is calculated; afterwards, boundaries can be set in the following manner:

- *Threshold*: a value t is defined as the minimum UUM for each characteristic to be supported. Thus, t divides characteristics in two clusters: those which are supported in $\mathcal{S}$ (above threshold), and those which are not. This is equivalent to the range $[t, 1]$;
- *Single range*: two values, t_{min} and t_{max} define, respectively, the minimum and maximum UUM thresholds for each characteristic to be supported. This method also divides characteristics in two clusters: those which are supported in $\mathcal{S}$ (i.e., $t_{min} \leq UUM \leq t_{max}$) and those which are not ($t_{min} > UUM$ or $UUM > t_{max}$);
- *Multiple ranges*: a set of value pairs is defined, where each value pair corresponds to a *single range* selection. Each range establishes a quality level, correspondent to its inherent set of characteristics.

After boundary definition, each range will have its corresponding set of characteristics. This way, the hyper-structure $\mathcal{S}$ is characterised according to different quality levels.

4.2.2 Common Classes

Similarly to the previous pattern, the adequacy of classes to a hyper-structure $\mathcal{S}$ yields the audience for which it is tailored, at different quality levels. In this case, the minimum UUM has to be calculated for classes, as explained earlier in this paper.

4.2.3 Common Grounds

This pattern relies on understanding what is common between the different audiences supported by a hyper-structure $\mathcal{S}$. When calculating the class UUM for each Web portion within $\mathcal{S}$, the outcome might be a set of different classes $C = \{\beta_1, ..., \beta_n\}$, representing a specific quality level (also defined through threshold, single range, or multiple range). Assuming that these classes form a new WIE graph G, a parent class α is leveraged, such that $\alpha <_e \beta_i, \forall \beta_i \in C$.

Through α, this pattern leverages the audience (and corresponding set of characteristics) that embodies the synergies between all the classes of C, for each defined quality range.

4.2.4 Characteristic Reachability

An important property of a hyper-structure $\mathcal{S}$ is the reachability of a characteristic. This can be done by calculating ranges for a selected characteristic (analogous to what has been described for *Common Characteristics*) and, for each range r, select $\mathcal{S}_r$, its corresponding sub-graph of $\mathcal{S}$ that encompasses the subset of Web portions for which UUM is in the range r. The significance of finding $\mathcal{S}_r$ relates to several properties for the specific characteristic and the selected quality range, including:

- Whether all Web portions remain reachable from any starting point;
- If disconnected clusters of Web portions are formed, by finding out *weak* Web portions in $\mathcal{S}$ (those that break reachability of Web portions in the hyper-structure);
- If the shortest path between any two Web portions has changed, reflecting whether a user with the chosen characteristic has to follow a bigger path in order to maintain her expected usability quality.

4.2.5 Class Reachability

Analogous the the previous pattern, the reachability between Web portions of a hyper-structure $\mathcal{S}$ is an important property to be studied for WIE classes. Its relevance increases, as classes aggregate characteristics representing more complex audiences (thus closer to *real users*). The way reachability is calculated is the same as the explained previously, apart from using a predetermined WIE class to calculate ranges. The same set of properties can be studied.

4.2.6 Graph Reachability

Along the lines of the previous two patterns, WIE graphs can be used to study the reachability between Web portions of a hyper-structure $\mathcal{S}$. In order to do so, a set of classes $C = \{\alpha_1, ..., \alpha_n\}$ must be chosen first, according with one of the two UUM available at the graph level of the WIE model. Afterwards, the set of corresponding sub-graphs $\aleph = \{\mathcal{P}_1, ..., \mathcal{P}_n\}$ is obtained, by applying either $UUM \uparrow$ or $UUM \downarrow$ appropriately.

In both cases, the overlap between the sub-graphs reveals which Web portions are usable with regard to each audience represented by C. However, if using $UUM \downarrow$ (i.e., finding out the sub-graphs for each minimum usability classes) the *Common Grounds* pattern can be applied to C, yielding a parent class β for all elements of C. The conjunction of all sub-graphs of $\aleph$ represents the sub-graph of $\mathcal{S}$ which is usable for β. This sub-graph reveals the set of Web portions that have a minimum usability quality for any user belonging to an audience that is taken into account within $\mathcal{S}$.

4.2.7 Inward Linking Quality

This pattern explores the quality of all Web portions S_i within a hyper-structure $\mathcal{S}$ that point to a fixed Web portion P, i.e., $S_i \rightarrow P$. This process is performed by selecting an appropriate *UUM* (i.e., choosing at which level this is to be explored), the corresponding subset of the graph to be analysed (a single characteristic, a class, or set of classes), and calculate the *UUM* for each Web portion. Afterwards, the outcomes can be explored by calculating the average UUM for all S_i, in order to perceive the usability of Web portions that link to P, and calculate the distance between their average and the *UMM* of P. These results can be used, for instance, as audience-aware usability weights in website ranking algorithms.

4.2.8 Outward Linking Quality

Dually to the previous pattern, this one centres on exploring the quality of a single Web portion P, and how it influences all other Web portions S_i of a hyper-structure $\mathcal{S}$ it links to, i.e., $P \rightarrow S_i$. The average *UUM* of all S_i, along the side of the *UUM* for P, dictate the quality of linking outside the scope of P. Apart from ranking algorithms, for instance, this pattern yields whether a user represented by an audience might avoid following a hyperlink to a given Web portion S_i, if it does not comply with a predetermined usability quality level.

4.2.9 Verticality

The analysis of the verticality of a hyper-structure $\mathcal{S}$ relates to the overlap of sub-graphs of $\mathcal{S}$ correspondent to different WIE classes. In order to study this pattern, *Class Reachability* is applied for a set of classes $C = \{\alpha_1, ..., \alpha_n\}$ and a common set of ranges. This results in a set of corresponding sub-graphs $\aleph = \{\mathcal{P}_1, ..., \mathcal{P}_n\}$. The level of clustering between each one of the sub-graphs, i.e., the amount of Web portions that are common between sub-graphs, characterises the level of verticality of $\mathcal{S}$:

- *High overlap*: represents a hyper-structure that is universally usable by heterogeneous audiences in (almost) all Web portions it comprises;
- *Low overlap*: portrays a hyper-structure with specific clusters of Web portions that are highly specialised to particular audiences (e.g., distinguishing mobile vs. desktop tailored Web portions).

4.2.10 Universally Usable Clusters

This pattern is used to find out whether if a hyper-structure $\mathcal{S}$ is clustered according to quality levels. This is performed by selecting an appropriate *UUM* level to be studied and a set of quality ranges $\mathcal{R} = \{R_1, ..., R_n\}$. Afterwards, the corresponding reachability pattern is applied and, for each R_i, a sub-graph $\mathcal{P}_i$ is obtained. The level of connectivity on each sub-graph allows studying which specific Web portions of a hyper-structure belong to a particular quality range, and how sub-graphs are connected to each other. This pattern can be viewed a *Verticality* pattern applied to quality ranges, instead of being audience-centric.

4.3 Monitoring Universal Usability

Orthogonally to all of the patterns presented previously, the dynamics of Web portions imply changes of content, linking structures, and front-ends in a time continuum. By applying a pattern to a single Web portion or a hyper-structure of Web portions, it is merely representative of the instant that the snapshot was made.

Consequently, the application of a pattern in regular time intervals Δt leverages the dynamics of the changes made to Web portions. This monitoring capability inherent of applying a WIE model instance to a Web portion or hyper-structure affords studying the evolution of universal usability on the Web both at micro (single Web portion) and macro (hyper-structures) scales.

5. DISCUSSION

Universal usability strives for the adequacy of user interfaces to each individual, despite the device used, the surrounding environment, and knowledge about a subject. This adequacy entails both traditional usability practices and making sure that information can be accessed without any kind of barriers. Both concepts cannot be disassociated, as they are truly complementary [12, 16]. This paper presented a model that affords the specification of audiences and study how websites are properly usable, and leverage this knowledge to understand hidden patterns that are still implicit on the structure of the Web.

Current practices of defining Web standards that have impact on universal usability aspects, simply view users as a homogeneous crowd, instead of being tailored to each particular characteristic. In order to meet this goal, Web standards must be studied from the point of view of their evolution, at large scales. This type of information provides critical support on how to evolve existing Web standards to cope with more audience requirements and new devices, without jeopardising proper usability for each individual. This life cycle of the evolution of universal usability on the Web is depicted on Figure 2.

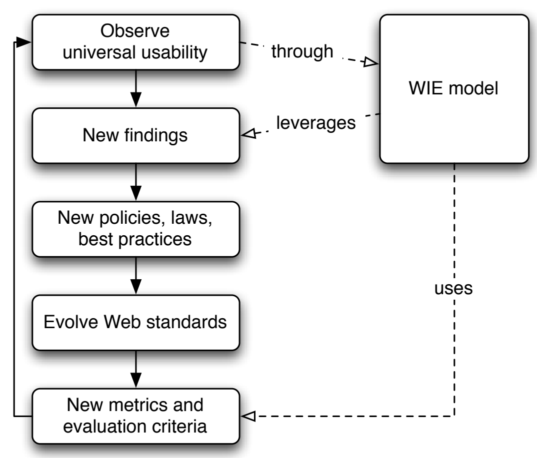

Figure 2: Universal Usability life cycle on the Web

The first two steps in this life cycle are directly related to the WIE model, since observing universal usability is one of its goals (as explained in Section 4.3), which yields new findings about the Web (in the form of the different patterns presented). These findings allow the definition of policies, laws, and best practices which results in new requirements for Web standards, thus triggering their evolution. Consequently, new universal usability metrics and evaluation criteria have to be further developed to cope with this evolution, and fed back to the WIE model (more precisely, to a model *instance*) and used in new observation tasks, thus completing the life cycle.

However, current state-of-the-art practices provide insufficient aid to fully understand universal usability on the Web. Therefore, the following set of challenges must be pursued:

- Further research automated usability evaluation methodologies (as surveyed in [5]). While this type of methods do not substitute traditional evaluation procedures, automation allows studying the Web at a large scale and its grasping by software agents;
- Formally define evaluation criteria for a large set of characteristics to be covered by universal usability;
- Expand browser capabilities to afford heterogeneous interaction environments (as it limits non conventional usage scenarios);

Lastly, our research work on universal usability of the Web is currently being expanded in different fronts, including:

- The definition of a taxonomical ontology that covers a wide range of characteristics in the four domains discussed (user, device, situations, intentions);
- Providing a set of methods to verify the semantics of WIE classes (e.g., requiring certain device characteristics for a certain type of user, or invalidating incoherent modelled classes);
- Exploring cognitive models of different audiences and how hyper-structures are properly usable (yielding a set of criteria to be applied in a WIE model instance);
- The application of WIE model instances in several case studies, leveraging new facts about the universality of usability practices on the Web.

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