# Ontology-Based Adaptive Interfaces for Colorblind Users

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**Abstract.** Nowadays, the utilization of colors is essential in the design of rich interactive interfaces. However, the widespread use of colors on the web affects the accessibility of colorblind users. Existing proposals in literature fail in not considering the various types of pathologies and individuals' needs and preferences. This article defines techniques for the development of adaptive interfaces that might facilitate the interaction of colorblind people with web systems. Our research explores the use of ontologies, as suitable artifacts for representing knowledge about types of colorblindness, recoloring algorithms, accessibility guidelines and users' preferences. We define a framework and software architecture that employs such ontology. Prototypes and scenarios illustrate the application of the framework. Obtained results allow determining and automatically applying the best recoloring techniques suited to adapting interfaces for colorblind users.

**Keywords:** Accessibility · Colorblind · Ontology · Adaptive interfaces

## 1 Introduction

The recognition of colors plays a central role in users' experience when accessing and interacting with web systems. Colorblindness refers to the inability to perceive certain colors in their natural representations or to make confusions between colors [1]. This pathology affects the functioning of the retina, and consequently, how human eyes interpret colors. This requires improving accessibility of web interfaces for colorblind users. Many typical solutions are exclusively based on increasing the contrast of colors. Nevertheless, these solutions fail in considering individuals' needs and preferences, including aesthetics, devices, culture, hedonic, among other aspects.

Colorblindness hampers users' accessibility in computer systems, which mostly rely on colorful interface elements as design alternatives to represent different aspects of information. When designers and interactive solutions do not take into account their barriers, colorblind users might experience limitations and face difficulties, even in simple tasks. For instance, these users cannot distinguish the colors of visited links in


M. Antona and C. Stephanidis (Eds.): UAHCI 2016, Part I, LNCS 9737, pp. 27–37, 2016.
DOI: 10.1007/978-3-319-40250-5_3

websites and textual information can easily turn out unreadable [2]. While literature has investigated techniques to make systems more accessible to colorblind people (e.g., [3–5]), existing approaches are still insufficient for adequately dealing with various interaction limitations.

This research investigates adaptive users' interfaces to improve the quality of the interaction of colorblind people with web systems. We propose an original framework to enable the adaptation of user interfaces based on ontologies and recoloring algorithms. The framework relies on ontologies referring to syntactic structures that formally express the semantics of domain knowledge. Ontology represents knowledge about design options, users' preferences and algorithms capabilities exploring Web ontology language description and rule languages.

Relying on static and dynamic users' information like their informed preferences, type of pathology, as well as information captured from the interaction context (e.g., the webpage controls activated), the framework performs queries and inferences in the ontology to select instances of adaptation options. Reasoning strategies are employed to leverage the quality and completeness of query results. They express the selected interface elements, algorithms and applicable parameters in order to modify the interface in a specific context.

Our technique explores these facts to automatically perform modifications (e.g., recoloring) on interface elements like imagens, texts and background according to the modeled algorithms and retrieved parameters. This study presents the software architecture that implements the framework and a prototype that illustrates the application and benefits of the proposal for colorblind users. The obtained results highlight the possibility of a more efficient and satisfactory interaction with web systems.

The remainder of this article is organized as follows: Sect. 2 presents the related work on colorblind accessibility; Sect. 3 thoroughly describes the framework and the proposed software architecture; Sect. 4 presents interface prototypes as well as a scenario of use to illustrate the applicability of the proposal; Sect. 5 wraps up with concluding remarks and outlines future research.

## 2 Research on Colorblind Accessibility

Human Computer-Interaction (HCI) research on colorblind accessibility ranges from the study of theoretical aspects of interaction to new recoloring algorithms. In this section, we focus on related work distributed in four overlapping categories according to their focus: (1) proposal of design accessibility solutions for colorblind users; (2) proposal of software frameworks for adaptive interfaces; (3) studies on recoloring algorithms and strategies; and (4) studies on ontology-based interface adaptation.

The first category includes works that emphasize design methods and techniques to improve the development of accessible interactive solutions. Neris [6], for instance, proposed design principles and method for inclusive adaptive solutions. Their work deals with issues on the inclusive design, such as: how to design adaptive interfaces with users' participation, and how to promote accessibility using adaptive interfaces. Although their investigation contributes providing high-level design principles in the design of interfaces for colorblind users, it does not emphasize specific aspects of recoloring and adaptations for colorblind.

Studies in this category also focus on the definition of tools and technologies for the design of adaptive interfaces for colorblind user's needs (e.g., [7, 8]). These adaptations take place at design time by developers with technical skills, differing from our study that proposes the runtime adaptation according to the several types of color blindness and dynamic aspects regarding users' preferences.

The second category includes research of frameworks for the development of systems with the capability of recoloring according to the users' needs in a (semi)automatic way. Many studies in this category propose alternatives to change the interface colors. For example, the use of constraint-based annotations for express the intended color effects [9], service-based users' preferences adaptation [10, 11], and individualized models based on color calibration [12]. Other investigation uses context information, rules or norms to define adaptation parameters (e.g., [13]).

The majority of the studies in the second category conceives a solution for a specific type of colorblindness (deuteranomaly), and usually changes (or calibration) to support unforeseen situations are complex. Furthermore, the "generic" frameworks remain abstract (or theoretical) and fail in deeply dealing into details with specific situations, which requires recoloring changes. Our proposal constructs a conceptual domain model from the generic concepts to specific and technical aspects of adaptation.

The third category involves recoloring algorithms to improve the perception of web pages, images and other resources by colorblind users. Several studies rely on WC3 standards to propose algorithms that calculate the color distance for representative color, and use interpolation for the remaining colors [14]. Alternatively, other proposals preserve the original colors when the users perceive them well [4].

Performance refers to a recurrent issue investigated by researches of recoloring algorithms, particularly when real-time recoloring is required [15]. One of the open challenges stands for the way of conciliating time performance [16] with perceptiveness [17] and subjective quality of the recoloring results. Other studies explore novel technologies to improve the colorblind using wearable solutions [18].

One key limitation of the studies in the third category is the validation by simulators or experiences limited users' studies in controlled environments (e.g., considering illumination and/or video quality) to evaluate the qualitative aspects of the solutions. We propose to organize (using ontologies) and represent features to reuse the existing algorithms according to the users' needs and preferences; however, it is out of the scope of this article to investigate new algorithms.

The last category includes interface adaptation techniques using ontologies focusing on web accessibility. Semantic Web techniques have been used to provide adaptive interfaces and personalized information [19]. Ontologies are used to represent various aspects of user interface adaptation, including web page structure, users' profile information and context information. For instance, existing studies propose a unified web document model based on specialized ontologies [20]. Their models aim at improving blind users' experience on the web. Further studies propose an ontology to formally represents users' contexts interaction processes, including users' physical, environmental and computational contexts [21].

Other studies emphasize the users' characteristics and needs to provide adaptable interfaces for users with disabilities [22]. This approach employs ontologies to represent the user's profiles and needs, as well as for reasoning proposals. These models are combined with contextual service information to provide automatically adapted interfaces for users with disabilities. Although the research in this category presents several advances regarding adaptive interfaces, which proves to be a promising approach, the analyzed literature still lacks specific aspects on ontology modelling for adapting interfaces for colorblind users.

We argue that a solution considering aspects from the fourth categories (in a proper design) may produce better results for colorblind users. Our research faces issues in smoothly respecting the particularities of each type of colorblindness and preferences of each individual in a seamless way. Adaptive interfaces can be a key component for accessibility [5]; however, studies exploring ontologies for this purpose still deserve further research. Our approach differs from literature by modeling (using ontologies) strategies of design, adaptation and algorithms for colorblind accessibility, which are matched with users' needs and preferences aiming to determine the most suitable recoloring options of adaptation.

## 3 Framework for Interface Adaptation Based on Ontologies

Firstly, this section presents the proposed framework (Sect. 3.1), including its elements for interface adaptation. Afterwards, Sect. 3.2 describes a software architecture that implements it using web technologies.

### 3.1 Proposed Framework

We first define an ontology that represents: (i) characteristics and preferences of colorblind users (e.g., types and attributes of color blindness and aesthetics preferences); (ii) aspects of techniques for color adaptation (e.g., rich web interfaces structures, properties of coloring algorithms and contrast modifications); as well as (iii) accessibility guidelines and design issues concerning color requirements. The latter represents W3C success criteria regarding the combination and perception of colors.

The core concepts of the ontology refer to key elements of the proposed framework (cf. Fig. 1). In the first step, colorblind users access a web interface to obtain some content. The INPUT element (top of Fig. 1) involves both static and dynamic relevant parameter data regarding to the user. As the static data, users assign their type of pathology and color preferences. The dynamic part includes parameter related to changeable items according to the context of use, e.g., the current visualized interface components. The context might include, for instance, images, bottoms, background, etc.

The item #5 of the framework (Fig. 1) considers the input data to implement search and inferences in the ontology, which represents colorblindness knowledge. The outcome came from the interpretation of axioms and rules that indicate the procedure and interface setting for adaptation, for example, to change the color of a bottom or to apply a recoloring algorithms to an image.

The element RUNTIME ADAPTATION (bottom of Fig. 1) aims at executing (applying) the interface adaptation techniques according to the results from the ontology and the interaction context. This involves the *application of recoloring algorithms* (6.1) – e.g., change of images' colors; *modification of page elements* (6.2) – e.g., alter color of background, bottoms and menus; and *change of contrast* (6.3) – e.g., highlighting details of an image.

The final output (step 7 of Fig. 1) renders the web page with the adapted interface elements based on the ontological knowledge regarding types of colorblindness as well as users' preferences.

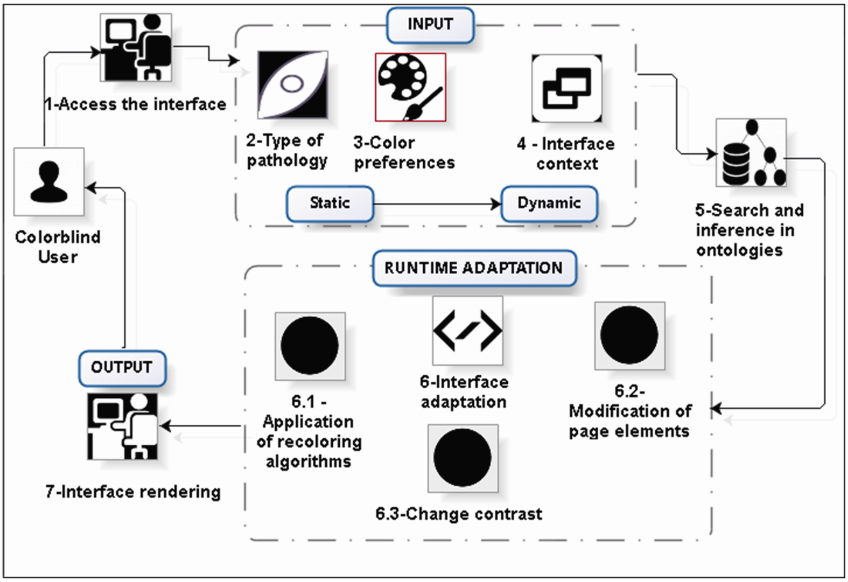


**Fig. 1.** Framework definition

### 3.2 Software Architecture

Figure 2 presents the proposed architecture defined with the aim of structuring the development of a software prototype. The architecture involves three main components including: (I) user interface component; (II) algorithms and techniques of adaptation component and (III) data access component.

The data access component stands for storing information of the type of colorblindness and users' preferences about color changes, accessibility standards and ontology data. The component for adaptation makes modifications in web pages via specific algorithms and techniques; it mostly explores PHP functions, Javascript (jQuery) and DOM. For example, we can change the color of all links in a page with a simple jQuery code: *$("a").css("color", "red");* or invoke complex algorithms for recoloring a map. The component II modifies the content to be presented in the user interface (component I) according to the formal statements and rules that analyses the information stored in the data access component. As shows Fig. 2, the interface component allows the rendering of adapted web pages (implemented in HTML and CSS).

In an overview of the interaction workflow, a user accesses the interface and performs his/her authentication (#1 in Fig. 2). Algorithms and adaptation techniques, which perform propositions of adaptation (#2 in Fig. 2), receive data on the user's type of pathology and his/her personal preferences. In addition, the solution relies on the content and rules for adaptation and accessibility, declared in the ontology. Using the outcome with facts about the adaptation, the component I renders the modified interface (#3 in Fig. 2).

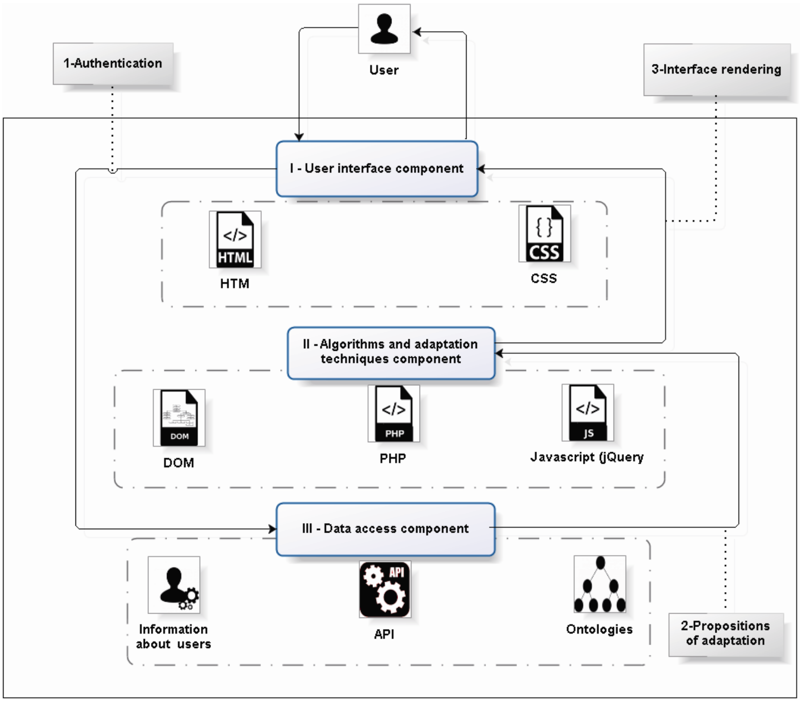


**Fig. 2.** Software architecture

## 4 Interface Prototype and Scenario of Application

This section describes the prototypes of interface mechanisms that explore the proposed framework and architecture (Sect. 4.1). In addition, we present an example of execution illustrating the proposed solution and ontology (Sect. 4.2).

### 4.1 Interface Mechanisms of Adaptation

Figure 3 presents the designed interface prototype, which explores interface adaptation in the context of meteorological images systems. As the basic feature, the prototype allows users to introduce the static data via a registration form typing information related to name, date of birth, username, password and type of his/her pathology, i.e., the type of colorblindness (item 2 in Fig. 3). Based on the available information and content from the underlying ontology, the system then provides alternative colors to be selected by the users according to his/her preferences. This list of alternative colors is determined by the type of pathology and accessibility standards modeled in the ontology (item 3 in Fig. 3). The item 4 (Fig. 3) shows a page with a meteorology image adapted using the most suitable technique to such context of interaction (i.e., meteorological images) and individuals' preferences.


**Fig. 3.** Software prototype (Color figure online)

## 4.2 Scenario of Illustration

Figure 4 shows an example of practical scenario to illustrate the execution of our solution. In this scenario, the user needs to access a web page with meteorological information. The system presents a climate map exploring several colors regarding weather events and subtitles to identify them. A user with a normal vision is able to recognize the different colors and the associated events, which is not the case for a colorblind user. For example, such user might observe the map as presented in item 2 of Fig. 4. We may notice that colors of yellow and red tones are confused and the meteorological phenomena represented by the color green remains hardly recognizable in the map. It also makes difficult the identification of subtitles.

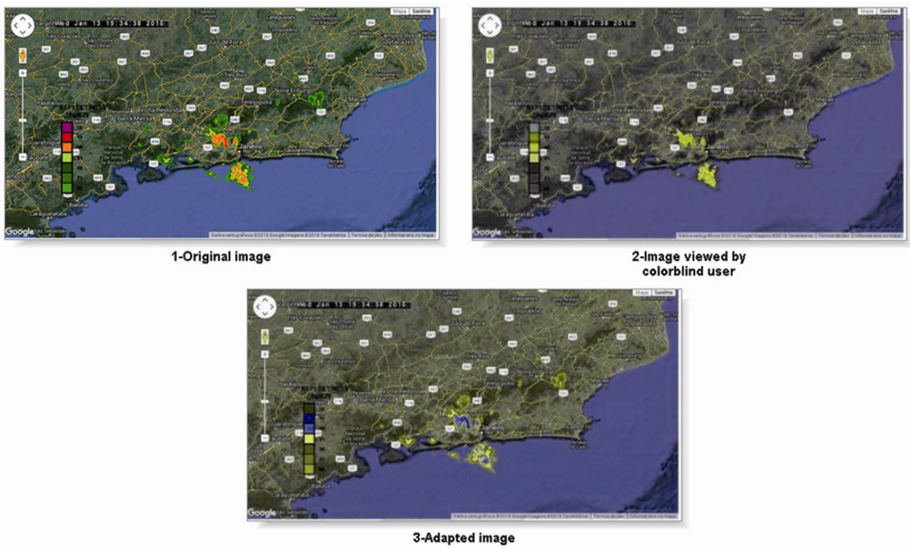


**Fig. 4.** Example of application (Color figure online)

Figure 5 presents part of a preliminary ontology defined according to our interface adaptation proposal and illustrate the current scenario. In this ontology, an adaptation technique is related to supported standards, useful users' preferences to setup parameters (e.g., of a recoloring tool), pathology types supported by the adaptation techniques, and the access contexts in which the adaptation techniques are applied. Figure 5 also illustrates the hierarchy of classes, including examples subclasses of adaptation techniques: color filters, recoloring algorithms and contrast changes. Note the set of subclasses modeled for the types of colorblindness.

In the present scenario, the system determines the adaptation solution according to the given parameters and ontology, which includes: pathology type (*Defteranopia*); interface context (weather map image); usage context with colors not noticeable in the interface (green and red); and, preference of alternative colors chosen by the user (blue). The system searches for the adaptation techniques described as instances in the ontology of Fig. 5. A simple query (e.g., using Sparql language) in the ontology eliminates algorithms that is not suitable for these parameters. In our scenario, the recoloring algorithm presented in [4] was considered suitable to all the parameters. After applying the execution of adaptation actions (the reprocessing of the image with the algorithm chosen), the new modified image appears to the user in runtime (item 3 in Fig. 4). Colorblind users can more easily distinguish such modified image.

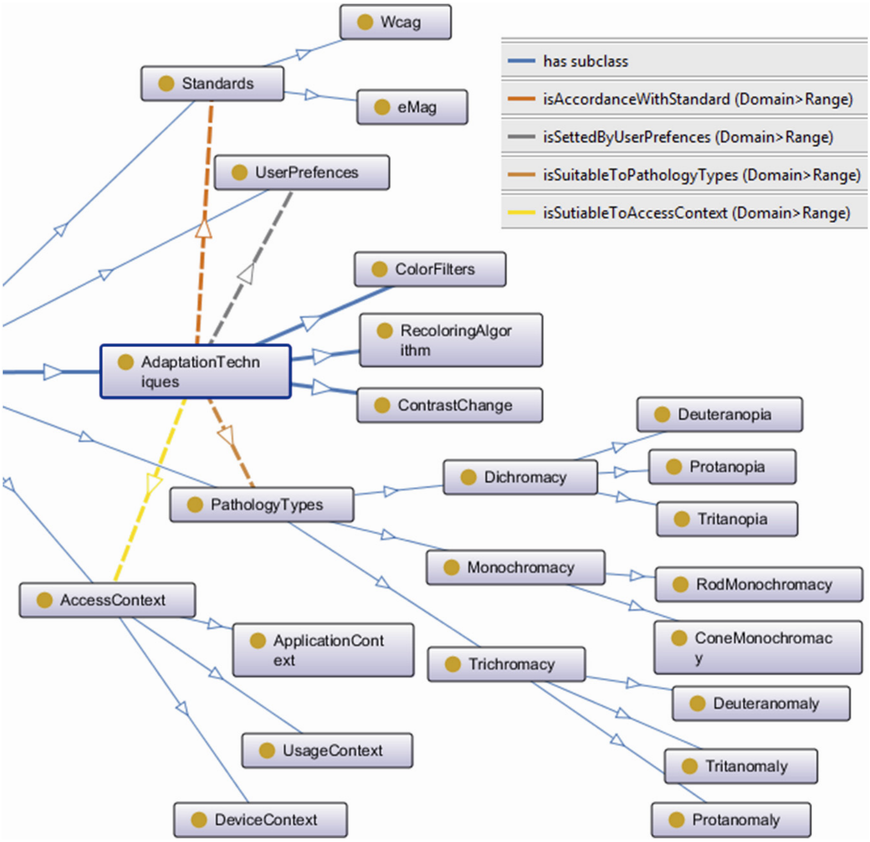


**Fig. 5.** Excerpt of colorblind ontology for user interface adaptation (Color figure online)

### 4.3 Discussion

This research obtained a conceptual proposal for interface adaptation and a software prototype elaborated with the aim of providing adaptation mechanisms according to interaction contexts to meet the colorblind users' accessibility needs. The main advantage of the solution is to consider multiple factors that influence on accessibility. This includes several types and subtypes of colorblindness, as well as the users' preferences in the adaptation results.

The proposed framework allows exploring and selecting more suitable adaptation techniques for each situation, such as the adequate recoloring algorithm, according to the domain knowledge formally expressed with ontologies. This meets users' color discrimination needs, while respecting their personal satisfaction. On the other hand, the proposal requires the heavy representation of knowledge and adequate query and reasoning techniques to obtain the adaptation actions. Further studies are needed to investigate additional adaptation mechanisms and scenarios of application.

## 5 Conclusion

Colorblind users need adaptive interfaces suited to modify colorful elements in web pages to make digital information more accessible and pleasant to them. In this article, we conceptualized a framework that makes use of formal representation of knowledge with ontologies to select and obtain adequate interface adaptation actions according to the interaction context and users' preferences. Our investigation defined a layered software architecture to implement the framework and achieved a functional prototype implementing adaptation mechanisms. The application scenario reveled that ontologies can be useful to achieve complex and complete scenarios of user's interface adaptation. Future work involves the refinement of the adaptation techniques and the research of further ontological properties for supporting the adaptation process. We also plan to conduct thorough experimental evaluations to examine the adaptation results according to the judgment of real colorblind users.

**Acknowledgment.** We thank São Paulo Research Foundation (FAPESP) (Grant #2014/14890-0) (The opinions expressed in this work do not necessarily reflect those of the funding agencies.).

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