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# Understanding WCAG2.0 Colour Contrast Requirements Through 3D Colour Space Visualisation

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**Abstract.** Sufficient contrast between text and background is needed to achieve sufficient readability. WCAG2.0 provides a specific definition of sufficient contrast on the web. However, the definition is hard to understand and most designers thus use contrast calculators to validate their colour choices. Often, such checks are performed after design and this may be too late. This paper proposes a colour selection approach based on three-dimensional visualisation of the colour space. The complex non-linear relationships between the colour components become comprehendible when viewed in 3D. The method visualises the available colours in an intuitive manner and allows designers to check a colour against the set of other valid colours. Unlike the contrast calculators, the proposed method is proactive and fun to use. A colour space builder was developed and the resulting models were viewed with a point cloud viewer. The technique can be used as both a design tool and a pedagogical aid to teach colour theory and design.

**Keywords.** Universal Design, colour contrast, readability, point cloud visualisation

## 1. Introduction

The goal of universally designed computer systems is declared in both the UN Convention on the Rights of Persons with Disabilities [1] and the legislature of several countries [2]. In Norway the goals of the legislature is implemented in a more specific regulation [3]. One of the documents referred to by the regulation is the W3C Web Content Accessibility Guidelines WCAG2.0 [4]. WCAG 2.0 gives general advice on aspects related to how to communicate information and sensory disability, how to allow for input for individuals with motor disabilities, how to make content understandable for individuals with reduced cognition and advice on seamless interoperability between assistive technologies and general computer systems.

This study addresses low-vision users. It is estimated that 95.9% of the Finish population has as visual acuity of 20/40 or better, 1.6% have a visual acuity of 20/80 while 0.5 are technically blind [5]. Similar statistics are likely in other geographical

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areas. Visual acuity tends to decay with aging [6] and will eventually affect most individuals. Despite reduced vision, users often prefer visual stimuli and primarily rely on visual cues. Visual elements should therefore be designed to be perceivable by low-vision individuals.

Vision is the ability to perceive relative differences in the visual channel as humans are generally not good at perceiving the absolute colour of objects. In order to spot that two objects are different the difference needs to be above a certain threshold. The threshold depends on several factors including the angular size of the object, the visual acuity of the viewer and individual sensitivity of the receptors in the human visual system. The smaller the angular size of an object is, the larger the difference, or contrast, needs to be.

Text is probably the most important information carrier in user interfaces, and the goal is thus to achieve sufficient contrast between the text and the background. WCAG 2.0 provides very specific advice on contrast. Section 1.4.1 is the most elementary criteria (Level A) that warns against the use of hue alone and mainly relate to colour blindness: "Colour is not used as the only visual means of conveying information, indicating an action, prompting a response, or distinguishing a visual element".

Sections 1.4.3 and 1.4.6 address contrast specifically for individuals with 20/40 vision (Level AA) and 20/80 vision (Level AAA), respectively. The level AA criteria 1.4.3 states: "The visual presentation of text and images of text has a contrast ratio of at least 4.5:1". Moreover, headings with larger typefaces needs a contrast of at least 3:1.

The strictest Level AAA criterion defined in section 1.4.6 states that "The visual presentation of text and images of text has a contrast ratio of at least 7:1". Here, larger headings need a contrast of at least 4.5:1. WCAG2.0 provides a mathematical definition of contrast that is relatively easy to compute, but hard to understand.

It is relatively easy to check whether a design adheres to these WCAG criteria. One may for instance use one of the web-based contrast calculators to check that there is sufficient contrast between a given text and its background. It is somewhat harder to internalise these requirements from a design perspective. The contrast limits are non-intuitive and does not give a designer any idea about the available choices. Designers thus have to rely on either trial and error during the design, or to check a design after it is finished [7]. Typical colour picking interfaces give the designers total freedom and access to all colours, with no clues about which colours that are WCAG2.0 compliant.

This work is motivated by the following: First, designers need to be provided with a method to help better understand colour contrast and the effects of colour choices. Second, designers need a simple method for choosing WCAG compliant colours during the design phase. Third, a pedagogical tool to convey knowledge about colours and contrast is needed to educate the new generation of designers.

## 2. Background

The research on the legibility of text is vast, from the early work on printed text [8, 9] to text on computer screen [10, 11, 12], colour and the web [13, 14, 15], polarity [16] and more recently digital paper [17, 18]. The designers colour choices affect all users being it the private sphere such as the web, or public spaces such as information boards and self-service kiosks [19, 20, 21, 22].

The process of choosing colours during design has received comparatively less research attention. A handful of studies have addressed colour selection interfaces [23].

Van den Broek et al. [24] studied several colour selection interfaces and concluded that they are difficult to use. Developers often prefer the hardware-centric RGB models, while designers may prefer variations on models based on hue, saturation and brightness that more closely matches the human visual system. Douglas and Kirkpatrick however found that visual feedback is more important than the actual colour model used [25]. Colour palettes that help designers avoid choosing colours indistinguishable for individuals with colour blindness has also been proposed [26].

Sandnes and Zhao proposed a colour picker that catered for WCAG2.0 contrast requirements by displaying all colours that are allowed given a selected first colour and a given contrast requirement [27]. However, it was challenge to present the available colours intuitively using a 2D representation. They therefore developed a tool presenting the colours according to hue, saturation and brightness as well as colour harmony rules [28]. Although this was an improvement over the basic colour selection scheme, it is still hard to understand the relationships between the chosen colour and available colours. This study thus adopts a similar concept, but instead presents colours directly in 3D colour space allowing the user to explore the complex relationships.

The RGB colour space [29] and basic HSB colour space have been criticised for not being perceptually uniform and able to represent all colours. Perceptual uniform means that there is correspondence between a perceived change in colour and the distance travelled in the colour space. A large number of colour spaces have been proposed as better alternatives such as CIEXYZ [30], Colouroid [31], Munsell [32] and the more recent CIECAM02 [33]. All these 3D models can be used with the proposed method.

## 3. Method

Given an RGB colour a model three-dimensional model is built by traversing the entire colour space. For each point in the colour space its contrast with the given point RGB is computed using the WCAG2.0 contrast definition [4]. If the contrast is above the desired threshold the point is included in the model, otherwise it is discarded. The coordinate in the colour space is used as the coordinates in the model. That is, point $r$, $g$, $b$ is positioned at point $r$, $g$, $b$ with colour $r$, $g$, $b$. The colour space is thus a cube spanning the point 0, 0, 0 (black) to 255, 255, 255 (white).

The selected colour is indicated on the colour space using a cube centred at $r$, $g$, $b$ with colour $r$, $g$, $b$. The cubes shown herein have a dimension of 10×10×10. A black frame outlining the edges of the colour space was added in some examples to show the bounds. The colour space modeller was implemented in java. A point cloud viewer [35] was used to visualise the colour models. The images shown herein were rendered using CloudCompare, an open source point cloud and simple polygon mesh viewer. Cloud compare allows the size of the points to be altered as well as simple lighting, shading and free navigation around the model.

## 4. Visualising Contrast

Figure 1 shows a visualisation of the full RGB colour cube and the resulting colour cube after selecting red with a contrast level of 3 viewed from different angles.

Obviously, the red colour is marked in the red corner of the cube and valid contrasting colours can be found in and around the black, cyan, white and yellow corners.

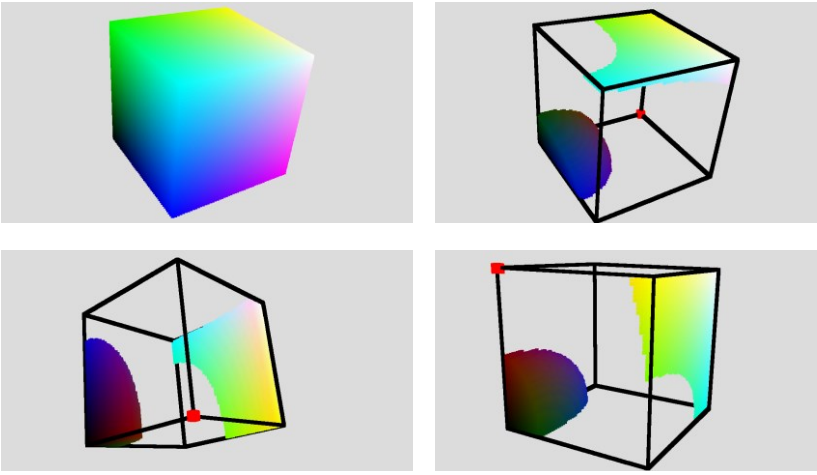

**Figure 1.** a) the colour cube before selection, b) after selecting red (255, 0, 0), c) after rotation and d) further rotation.

Figure 2 shows the effect of selecting different colours from red to yellow. The figure clearly illustrates that the contrast has different sensitivities to green and red and that the non-linear nature of the valid shapes are complex. When the selected colour is closer to the red corner there are valid colours in the area of both the black corner and the yellow corner. As the colour is moved towards yellow, the allowable yellow colours disappear. Valid colours around the black corner expand and include the blue corner as the colour is changed from red to yellow.

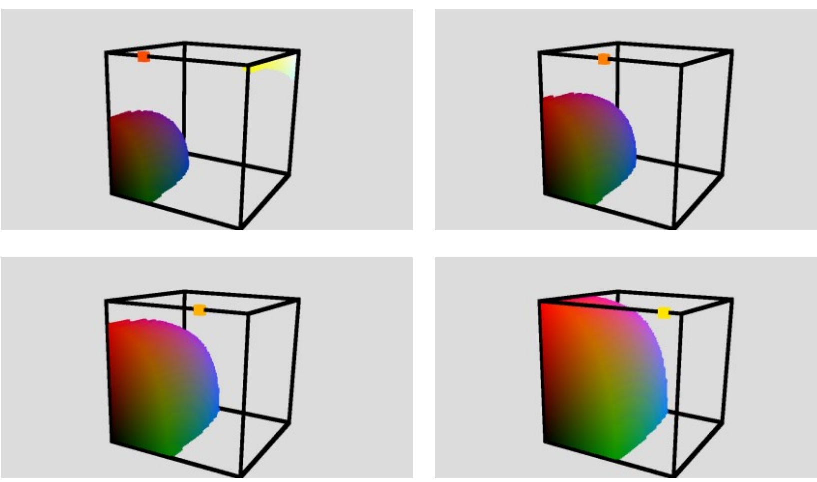

**Figure 2.** Colour spaces after selecting red (255, 76, 0), red-orange (255, 127, 0), orange (255, 178, 0) to yellow (255, 225, 0) with a contrast of 3.

Figure 3 illustrates the effect of setting different contrast levels. Clearly, with lower contrast levels, more colours are available and the set of available colours decrease as the contrast is increased. With low contrast limits there are more allowable colours than with high contrast limits. The set of illegal colours constitute a curved slice through the middle of the colour cube.

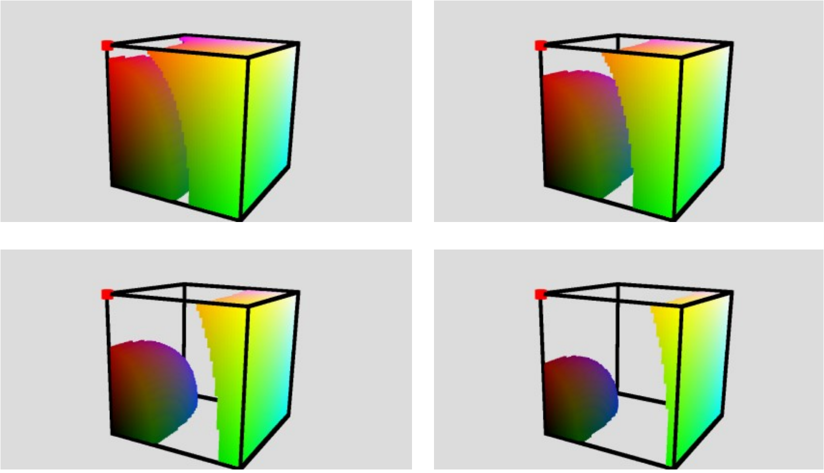

**Figure 3.** Colour spaces after selecting red (255, 0, 0) with contrast levels of 1.2, 1.5, 2.1 and 2.7, respectively.

### *4.1. RGB to HSB Relationships*

Most developers are familiar with the RGB colour model as it is the most common representation used in programming and the coding of web sites. Designers may be more accustomed to the HSB model as it is perceptually easier to relate to specific hues and attributes of these hues, namely the level of saturation and brightness. The mapping between the two are actually quite simple although not well known.

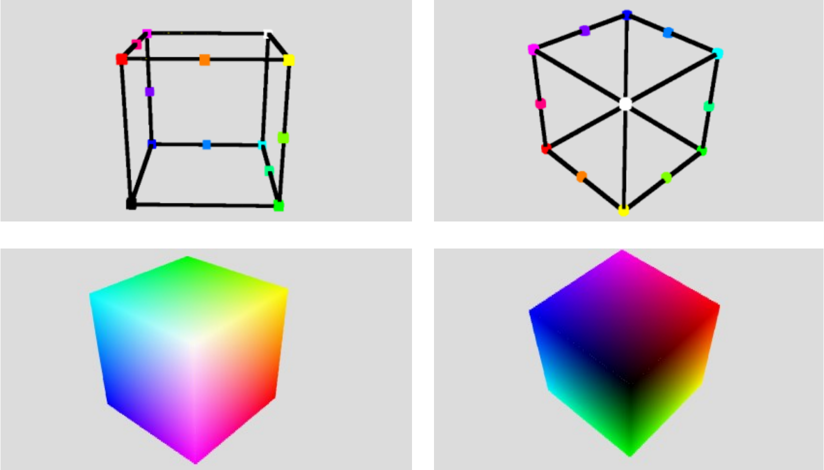

**Figure 4.** Relationship between the RGB and HSB colour models, a) the main colours in the colour cube, b) the main colours projected on the grey normal and c) the colour cube projected onto the grey normal plane viewed from the white side and d) the colour cube projection viewed from the black side.

The three-dimensional visualisation of the colour cube makes the connection between RGB and HSB clearer. Figure 4 shows the main saturated colours mapped along the edges of the colour cube, while the top right illustration shows the colour cube projected onto the plane with the grey vector as normal, that is, the vector going from black via all the greys to white along the diagonal of the colour cube. The resulting projection shows that these colours nicely resemble the colour wheel of hues.

The bottom left image some the same projection of the full colour cube where the edges around the hexagonal shape are the fully saturated hues and the same colours become less saturated towards the centre of the hexagon. The bottom right rendering shows the same projection viewed from the back, where the saturated hues are positioned around the edges of the hexagon and the centre of the hexagon is darker than the edges.

### *4.2. Colour Matching*

Figure 5 illustrates how to compare a colour to one of the compliant colours. First, the colour cube is rotated such that the selected colour is facing the viewer. Then, the colour cube is rotated such that the selected colour hoover over, or is next to, the desired set of colours. The selected colour is the foreground and the available colours further away in the colour space are the background in the projected view. Once a desirable combination is found the designer can select the desired colour, for instance by taking a screenshot and reading off the colour using some standard image processing application.

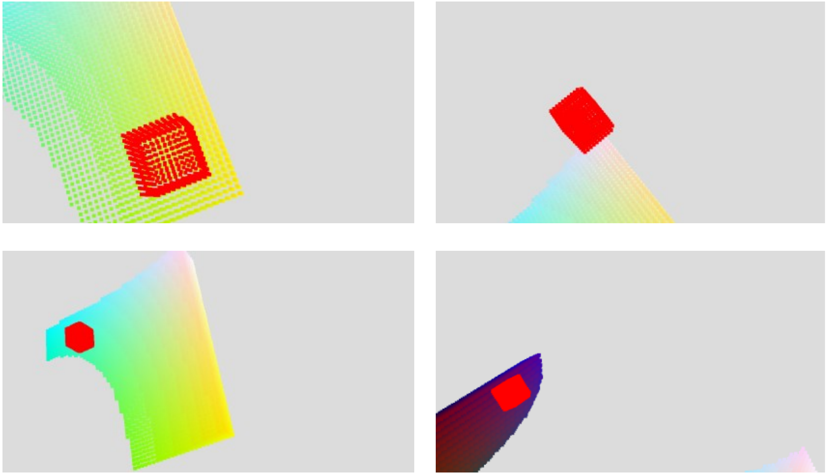

**Figure 5.** Colour matching using the perspective projection.

The observable colour pairs thus represent combinations that satisfy the minimum contrast settings. If a stronger contrast is needed the designer simply selects a point further away from the observer, that is, a point “beneath the surface”. The example shows how the red is matched against the valid yellow-green (top left), pink (top right), cyan (bottom left) and dark purple (bottom right).

### *4.3. Colour Harmonies*

A colour harmony filter was implemented to demonstrate the relationships between valid colour contrast in the colour space and colour harmonies. Colour harmonies are generally simple rules relating to how different hues fit together. The current implementation includes monochrome colours, analogous colours, complimentary colours and triads.

Each colour pair was considered to belong to the same monochromatic colours if their difference was less than 15 degrees. Similarly, a colour pair was considered analogous if their difference was less 45 degrees. A complimentary check was performed by checking the angle within 15 degrees, or within 15 degrees of the colour in the opposite direction on the colour wheel (180 degrees). Similarly, the triadic colour filter was implemented by checking that colours 120 degrees apart within a limit of 15 degrees.

Figure 6 shows the effect of applying the colour harmony filters after selecting red. The monochromatic view (top left) shows the slice valid darker red colours and a slice of bright and unsaturated reds in the opposite side of the colour space. The analogous view (top right) is very similar to the monochrome view apart from the slice of valid colours the dark and unsaturated sides of the colour space are three times as wide.

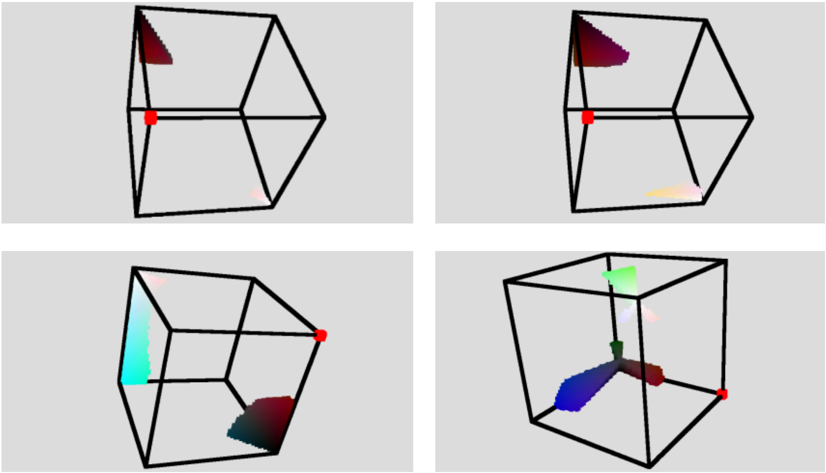

**Figure 6.** Colour harmonies: a) monochrome, b) analogue c) complimentary and d) triads.

The complimentary view (bottom left) shows a slice of both unsaturated bright colours in the red direction and cyan direction. Here, the cyan part is larger than the red part. This is due to the different weighting of the different colour components. The view also shows that there is a region of dark valid colours in the black corner of the colour cube.

The triad colour scheme demonstrated in the bottom right view shows that there are bright-unsaturated green, red and blue components. Clearly, the green slice is much larger than the blue and the red slice, while red being the smallest. There are also a dark green, dark blue and dark red slices in the back corner of the colour space. Here, the blue component is largest and green is the smallest.

### 4.4. Perceptually Uniform Colour Spaces

Figure 7 illustrates the technique applied to the CIElab colour space that approximates the human visual system and attempts to achieve perceptual uniformity. The top two views show the full CIElab colour space from two angles. The fixed renderings does not fully do the visualisation justice, as when viewing the colour space rotated in real time its shape becomes very obvious. Rotating the CIElab shape reveals a distorted colour-cube-like shape. The visualisation does show that the three-dimensional visualisation can help remove some of the mystique surrounding the more complex colour models that are hard to capture using 2D renderings.

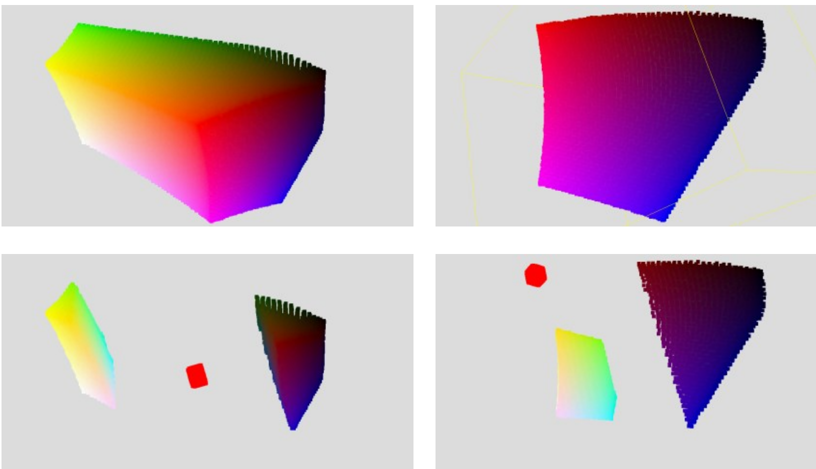

**Figure 7.** CIElab colour space visualisations.

The two bottom views show the available colours after selecting red. The result confirms that the CIElab colour space is a perceptually better representation of perceivable colours since the set of available colours are distributed more evenly in the unsaturated area and the dark area.

## 5. Conclusions

Three-dimensional colour space visualisation was explored as a mechanism for understanding how certain colour choices affect contrast and thus to help select WCAG2.0 compliant colour combinations. The method allows designers to explore the contours and shape of the allowable colours that can be selected through simple rotations and navigation of the model. The projective view of the selected colour on top of the allowable colours allows easy comparison to any of the allowable colours. The method also can also easily be applied to other perceptually uniform colour models. The model can be used for teaching colour theory and universal design.

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