- Graphic design and constraints -
Creating harmonious and legible colour schemata in the automated generation of multimedia presentations

Amit Sharwan Kumar Manniesing

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Abstract

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Graphic Design

3.1 Introduction

In Cuypers, the temporal and spatial constraints are already implemented. When dealing with an automatic presentation generator there are other graphic design factors which need to be automated as well. One important factor is the use of colours and the combination when using with text. Everybody has got some intuition about these aspects, but trying to make this implicit knowledge explicit can be very hard. In the following sections, we try to make some sense of this intuition by starting from the very basics and we will build a foundation from where explicit rules can be derived.

3.2 Colours

Making design decisions when dealing with colours is hard because of varies of reasons. There are for instance millions of colours to choose from, and say, we've chosen one colour, how can we choose a colour that goes well with the one we choose before? Making such design decisions, partially based on aesthetics, can be made easier by *understanding* colours. Therefor this section starts with some physics about colour and a description about how we perceive colours. To work with colours we have to put colours in some sort of model, in the section after the perception of colours some important colour models will be put forward. After that it is time for the cognitive aspect of colours. We then should have enough knowledge about colours to set a base for design decisions, which implies trying to model some implicit aesthetic rules. This will be done in the last part of this section, with the use of colour harmony schemes.

3.2.1 Physics

In 1665 Sir Isaac Newton set the base for the first colour wheel [7], with the now well known *experimentum crucis*. In those days it was already known that light could be split in the colours of the rainbow by using a prism. However people thought that the incoming light was modified someway. Newton separated one of the colours and let this colour go through a second prism, but this light did not split up, see figure 3.1. He concluded that the incoming light was split up in elementary colours by the prism. By recombining the colours through a reversed prism he could recreate the incoming light, his conclusion was that white light is the result of adding all visible colours. Thus he stated that colour was in the light and not in the prism and he also concluded that white light was a mixture of refrangible rays.

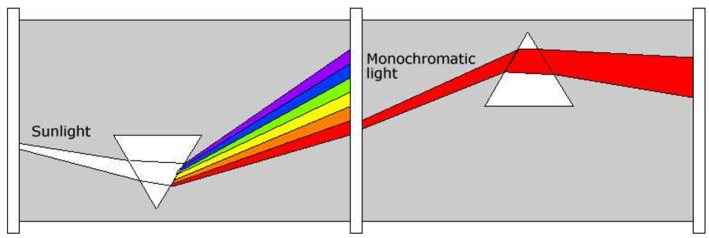

Figure 3.1: Newton's experimentum crucis

Less than one hundred years later James Clerk Maxwell showed that light was a form of electromagnetic energy which travels in waves. The wavelength of electromagnetic waves is measured in very small units called Ångstrøm, these are one tenth of a nanometer (1 nm = 10^{-9}m). Both Ångstrøm and nanometers can be used as measurement units for the electromagnetic spectrum.

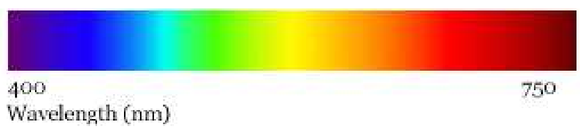

Figure 3.2: The electromagnetic visible spectrum

A wide range from 400 nm (violet) to 750 nm (red) is the range of visible colours, see figure 3.2.

Newton was a great music lover and due to his belief that music and light should be treated harmonically, he treated the light on a Dorian music scale and divided it into 7 equal segments, because an octave displays seven sound iyntervals. Later on the seven colours remained but the intervals changed as seen in table 3.1.

colour	wavelength
violet	390-430 nm
indigo	440-450 nm
blue	460-480 nm
green	490-530 nm
yellow	550-580 nm
orange	590-640 nm
red	650-750 nm

Table 3.1: Colours and their corresponding wavelengths

In 1900 Max Planck suggests that Maxwell's electromagnetic energy comes in discrete amounts and is thus quantized. Partially based on Plank's ideas Einstein published in 1905 a paper called *On a heuristic viewpoint concerning the production and transformation of light.* He knew the wave theory from Maxwell was unable to explain photoelectric emissions and proposed a new theory of electromagnetic radiation.

Einstein stated light is composed of photons, also called quanta, little “wave packets”, carrying a fixed amount of energy. Arthur Compton later on confirmed the existence of photons.

Now knowing light exists of photons travelling in wavelengths, where each wavelength, or combination of wavelengths stands for a certain colour, we can continue by explaining how our eye responds to incoming light.

3.2.2 Colour vision

If we look at the eye, light enters through the pupil and shines on the retina. On the retina there are two types of photoreceptor cells, the cones and rods. These photoreceptor cells absorb the photons and generate neural signals that initiate vision. The rods and cones have the same architecture where photons are absorbed by a certain pigment. After absorbing these photons a chemical and electrical process takes place and the amount of recent absorberd photons is transmitted by the rod or cone to the brain.

The chemical and electrical process [1]

The pigment molecules are located near the outer segment of the photoreceptor cells. There are roughly 100 million of these molecules in one photoreceptor cell. These molecules are members of a class of receptor molecules which sense signals coming from outside themselves. This kind of molecule share the same architecture, where a single chain of amino acids (the protein) is embedded in a lipid membrane. In the centre of the molecule a chromophore is embedded, when a photon is absorbed by this chromophore the chromophore rotates at one of its molecular bonds. This effect is called *cis-trans* isomerisation, and is in fact the only direct effect the absorption of light has. When the chromophore rotates, it changes the three dimensional shape of the protein, which now has catalytic properties. In this state the protein activates another protein called transducin. This catalytic process produces hundreds of these transducin proteins.

These transducins activates a third type of protein called phosphodiesterase. This enzyme breaks down a messenger substance, cyclic GMP (cGMP) inside the outer segment of the photoreceptor cells. The substance cGMP causes in the membrane of the outer segment a *trapdoor* to open in which sodium (Na^+), magnesium (Mg^2+) and calcium (Ca^2+) ions can enter. This is balanced by an efflux through a natrium, calcium and kalium (K^+) exchanger at the outer segment [10]. The enzyme is breaking down the cGMP, resulting in the closing of the trapdoor, this means no calcium, sodium and magnesium ions can enter through the membrane, but the efflux continues. This finally results in a decrease of calcium ions and thus in a decrease of voltage inside the cell (hyperpolarization), causing the voltage of the cell becoming more negative within the entire cell compared to the “normal” nerve cells. When we see bright light the voltage can be -70 mV whereas in darkness it typically is -30 mV. The synaptic ending of the photoreceptor cell is also influenced by the voltage shift, causing the amino acid glutamate to be less transmitted to the bipolar cells. These cells passes this information to retinal ganglion cells located on the inner surface of the retina, see figure 3.3. From here the message is carried by long fibres over the optic nerve to the brain, where the processing takes place.

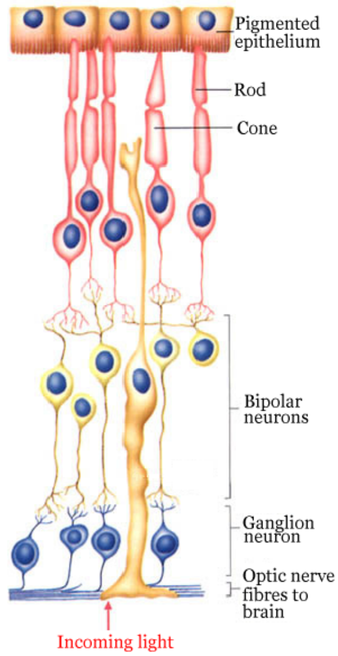

Figure 3.3: [8] A diagramatic cross section of the retina

Sensitivity and distribution Sensitivity is inevitably related to intensity, *the amount of absorbed photons on a certain surface in a fixed amount of time*. Rods are extremely sensitive and are able to response to a single photon. Cones are less sensitive and provide vision by ordinary daylight, these photoreceptor cells are responsible for colour vision. The chemical and electrical process explains the photoreceptor cells are not sending any wavelength information, they are only transmitting the amount of photons absorbed by the cells. So why all the fuzz about the wavelength?

The wavelength of the incoming light fixes the probability the photons of this light will be absorbed by the photoreceptor cell. Most human eyes have three type of cones and each of these types has a peak sensitivity, giving us the ability to separate three different parts of the spectrum, the red, green and blue parts. In table 3.2 the approximated peak sensitivity, taken from [9], of the three type of cones is described in nanometers, see also figure 3.4. The L, M and S stand for Long, Medium and Short, refering to the wavelength of their peak sensitivity.

name	wavelength	colour
L-cones	558 nm	red
M-cones	545 nm	green
S-cones	420 nm	blue

Table 3.2: The three type of cones

For the L-cones we can see that it's peak sensitivity is 580 nm, this means that light with a wavelength of 580 nm is most likely to be absorbed by this type of cone. The perception of what colour we are experiencing is thus determined by the combination of stimulated cones and the intensity they are stimulated with.

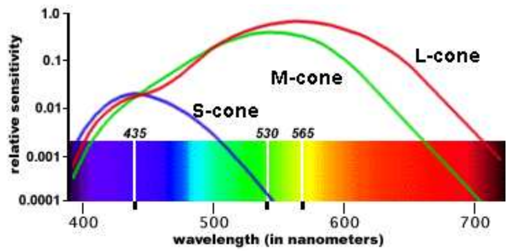

Figure 3.4: [8] The relative sensitivity of the cones

In figure 3.4 we can see the relative sensitivity of the cones plotted against the wavelength. The inserted electromagnetic spectrum gives us an idea of how the colours are perceived by using the three cones.

The above theory that states that colour vision is the result from the action of three cone receptor mechanisms with different spectral sensitivites is called the *tristimulus theory*.

The retina contains around 120 million rods and 6 to 7 million cones. The latter are much concentrated in the central yellow spot, in the center of this yellow spot lies the *fovea centralis*, a rod-free area with densely packed cones, the rods are dense elsewhere on the retina. The fovea centralis is the area where the highest visual acquity can be achieved. The 6 to 7 million cones can be divided into the red cones (64%), the green cones (32%) and the blue cones (2%). The green and red cones are concentrated in the fovea centralis, whereas the blue cones are mostly to be found outside the fovea. The blue cones are more light sensitive than the red or green ones, however this does not composate being outnumbered. This is reason to believe that there is some sort of a blue amplifier in the visual process of the brain.

The tristimulus theory is not only helpfull in understanding colour vision, it is also helpfull understanding colour blindness. There is a large percentage of people how suffer a form of colourblindness, because of the impact this may have on our design decisions we ought to take this into account.

Colour vision abnormalities Most people are trichromatics, this means they see colours using three kinds of colour sensors, the red, green and blue ones as described in the previous section and stated in the tristimulus theory. There is however a considerably large percentage of people who are so called colour blind. This doesn't mean they can't see any colour what most people would think, it means they suffer a certain abnormality in the eye's visual pigment. We can divide these colour blind people in a monochromats, dichromats, anomalous trichromats and tetrachromats.

Monochromats This type of colour blindness is very rare and people with this type of colour blindness are truly colour blind and only see lightness differences. There are two types of monochromats, rod monochromats and cone monochromats. Rod monochromats have no functioning cones on their retina and cone monochromats have only one type of cones on their retina, which often is the blue one.

Dichromats The dichromats only contain two types of cones instead of the normal number of three. This kind of colourblindness can be divided into three types, the protanopes, deuteranopes and the tritanopes. The protanopes lack the L-type cone, the deuteranopes the M-type and the tritanopes the S-type.

Cone type	Generic defect name	Weakness
L-cones	protan	red
M-cones	deutan	green
S-cones	tritan	blue

Table 3.3: Cone defects

Anomalous trichromats The people with this kind of colour deficiency have all three type of cones, but one of these cones is abnormal. The abnormal cone has a different characteristic in absorbing light, these abnormalities varies between individuals in a range from almost dichromats till nearly normal colour vision. Here we also have three types, protanomalous trichromats, deuteranomalous trichromats and tritanomalous trichromats. The protanomalous trichromats have abnormal L-type cones, the deuteranomalous trichromats have abnormal M-type cones and the tritanomalous trichromats have abnormal S-type cones.

Tetrachromats Colour blindness is a form of colour vision *deficiency*, a very rare colour vision abnormality is *tetrachromacy*. Tetrachromats have 4 type of cones instead of the normal amount of 3. Since 1948 this vision abnormality is discovered, recent testing by Gabriele Jordan resulted in finding people having the characteristics of a tetrachromat. The testing is however still a work in progress so Jordan still declines of having found a tetrachromat. This fourth cone should be an extra cone between the L-type and M-type cone[1].

Type of visual defect	Visual defect	Percentage of men affected	Percentage of women affected
Trichromats	None	92.002%	99.573%
Anomalous Trichromats	Protanomalous	1.08%	0.03%
	Deuteranomalous	4.63%	0.36%
	Tritanomalous[2]	0.0%	0.00%
Dichromats	Protanopes	1.01%	0.02%
	Deuteranopes	1.27%	0.01%
	Tritanopes	0.005%	0.005%
Monochromats		0.003%	0.002%

Table 3.4: Relative abundance of visual chromatic defects

Table 3.4 shows us the three types of colour vision deficiencies, it also shows us that colour vision defects affects more men then women. If we look at the genes it is

[1]http://www.redherring.com/mag/issue86/mag-mutant-86.html

very obvious. On the X chromosome the genes for the red and green photopigments are adjacent to eachother. The genes for the blue photopigments are on a whole different chromosome. Women have got 2 X chromosomes, so they've got 2 sets of green and red photopigment genes. Men only got one X chromosome, this X chromosome is created in the female embryo by mixing the X chromosomes from the mother and father of the female embryo. Because the genes of the red green photopigments are next to eachother they sometimes mix. This is normal, sometimes however the mixing goes wrong and the result can be a "defective" X chromosome. This "defective" X chromosome can result in the lack of the green or the red photopigment gene, two slightly different red photopigment genes or two slightly different green photopigment genes. If the egg containing this "defective" X chromosome becomes a male the this male will be colour blind[3].

We now know what we see when we see colours and how we can see colours. If we however want to work with colours, not only on a computer but also mentally, we have to make use of this knowledge, combine it and pour it into an applicable form, a *colour model*.

3.2.3 Colour models

Colour models are used to classify colours, to describe them in terms like hue, saturation, lightness, value or brightness and of course to work with colours on the computer and mentally. In this section the RGB , CMYK, CIE, YIQ and HSL colour models will be described.

RGB The RGB colour model is a so called additive colour system. This system is based on the emittance of light. We start here with a black color and by adding more colours we eventually get white. The RGB model is the most basic and probably best known colour system. The most important property of the RGB model is that it closely relates to the way we perceive colour with the red, green and blue cones on our retina. Most CRT displays (e.g. televisions and computer monitors) are working with the RGB model and this model is also used for web graphics.

A familiar aspect of this system are primary and secondary colours.

Primary colours Primary colours are the fundamental colours, they cannot be created by mixing other colours, all other colours created in the colour model consists of a mixture of these primaries.

Secondary colours Secondary colours are simply created by equally mixing two primaries. This means that there are also 3 secondaries.

The three primary colours for the RGB model are Red, Green and Blue. When these colours overlap they generate the secondary colours yellow, cyan and magenta, in figure 3.5 marked with the first letter of their names. In the same figure we can also see the starting colour black. With the combination of Newton's experimentum crucis

[3]One could imagine the tetrachromats getting their abnormal colour vision, by having two X chromosomes, with one "defective" X chromosome and one normal. This means only women can be tetrachromats and the "fourth" cone could be one with a slightly different green or slightly different red photopigment gene

and the definition of the primary colours above, we should be able to explain why the equal mixture of the three primaries result in white.

A 3D representation of the RGB colour model is called the colour space, see figure 3.5. On the axis of this colour space the primary colours are projected and in the origin we can see black. When coding colours with the RGB model there are some different methods, the most used is representing the colour by 3 values, each on a scale from 0 to 255 representing the amount of Red, Green and Blue. Another method is often used on webpages and is somewhat similar, the values are however hexadecimal, concatenated and is preceeded by a # symbol. Black can be presented as 0 0 0, or as #000000, whereas white is 255 255 255 or #FFFFFF, finally yellow can be presented as 255 255 0 or as #FFFF00.

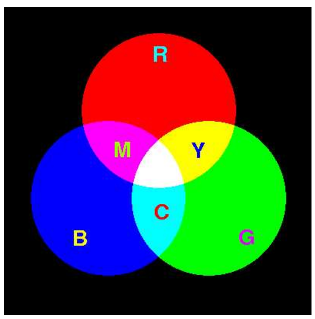

Figure 3.5: The RGB primary and secondary colours

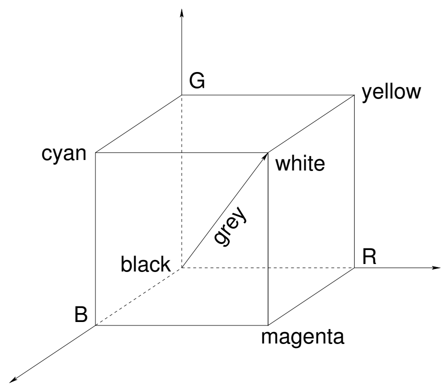

Figure 3.6: The RGB colour space

CMY(K) For printing, painting and drawing we should use a totally different colour system, because here we don't see emitted light, but we see reflected light. The object which reflects the incoming light absorbs all wavelengths except the one we see. In contrast to the RGB system, this system is called a subtractive colour system and consists of the primary colours yellow, cyan and magenta, by mixing these we get the secondary colours green, red and blue. In contrast to the RGB model the CMY model starts with white and by adding more colours it eventually results in black. However, the resulting black appears not to be deep black but more a dark brownish colour, because of this and due to the difficulty of creating grey tints, the colour black is added to the system. The name CMYK is the result of these four colours: Cyan, Magenta, Yellow and blacK Most people were taught the primaries to be red, yellow and blue, even in painting class. In most cases the actual used colours then were magenta, yellow and cyan.

The CMY colour space is presented in figure 3.8, one can see this has much resemblence with the RGB colour space. In fact, when using a scale from 0 to 1 for the axis, the transformation can be done with the following equation.

$$\begin{pmatrix} C \\ M \\ Y \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} - \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

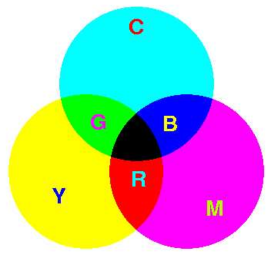

Figure 3.7: The CMY(K)primary and secondary colours

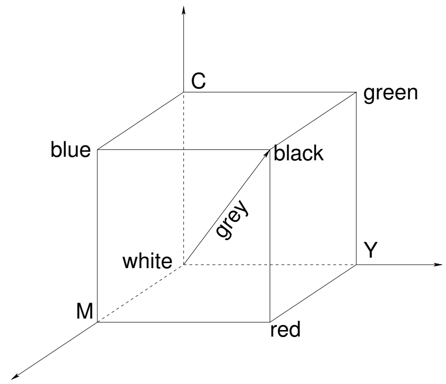

Figure 3.8: The CMY(K) colour space

CIE colour In 1931 the Commission International de L'Eclairage (CIE) developed a device independent colour system that was based on the tristimulus theory and thus on the human perception. The differential response of the three cones is measured in three variables X, Y and Z and this results in a 3D colour space. By projecting the Z coordinates to the X Y plane we get the CIE model, see figure 3.9.

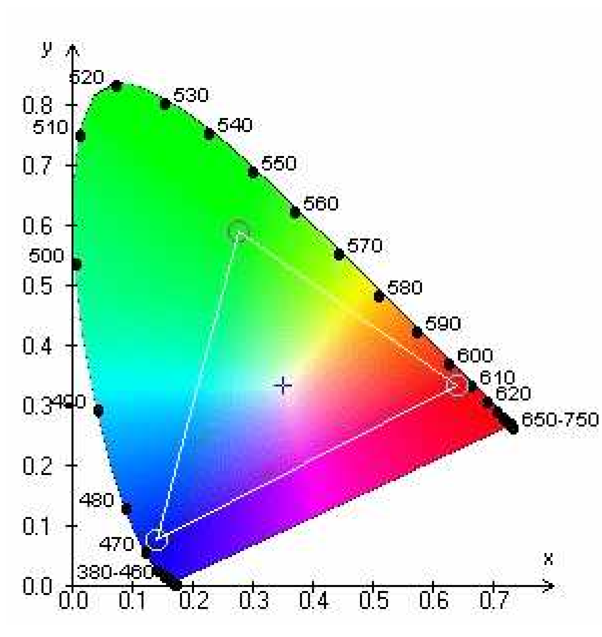

Figure 3.9: The CIE color model

At the perimeter edge the pure spectral colours and wavelengths are presented. Notice the purple colours at the bottom, these colours do not have a wavelength and are created by a mixture of violet and red. The colours in the inner part of the figure are also created by combining different wavelengths of spectral colours. White light is seen when all three cones are stimulated.

One way to use the CIE model is to display the range of colours a colour producer (e.g. a monitor or printer) can display. We call this range the *gamut*. In figure 3.9 we can see the example gamut of a typical television represented by the triangle, which is a lot smaller than all the possible colours we can see. Because all monitors are different we have to take into account that their gamut also differs and thus that the colours we want to display are to be displayed differently.

YIQ The YIQ model is a model used for recoding RGB values for the use of televisions, these televisions are referred to as NTSC standard televisions. This model is used in the US for commercial broadcasting because it is a more efficient way of transmission and it is downwards compatible with black/white television sets. It's downward compatible because of it's luminance (Y) component, this component captures our perception of the relative brightness of colours. The I and Q components are describing the color information and stand for Inphase and Quadrature. The black/white televisions sets thus only have to use the Y component. The conversion from RGB to YIQ is given by:

$$\begin{pmatrix} Y \\ I \\ Q \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.532 & 0.311 \end{pmatrix} \times \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

This model is here particularly used for its Y component to compare the luminance of different colours.

HSL The Hue Saturation Lightness colour system is a system that is more intuitive to artists and graphic designers. There is a variant of this system called the HSV system, where the V stands for Value.

If we look at the visible colour spectrum in figure 3.2, we can see that we are missing a colour: Magenta. This happens to be the mixture of wavelengths red and violet, the very ends of the colour spectrum, as seen in the CIE model. By using this knowledge we could easily create a colour circle by connecting red and violet together with magenta and filling in the inner part of the circle. Because white light is the addition of all spectral colours the center point is white. The color wheel is born! A colour on the wheel can be represented by a degree between $0°$ and $360°$, this we call the hue. Hue is a way of describing a colour in a relative way compared to its wavelength, like when we are describing colours like yellow, red, blue etc.

When we display the colour wheel in a 3D perspective as a dodecahedron, see figure 3.10, where the circle is displayed as a hexagon on the X and Y axes, the Z axis can be used to display the Luminance, or the darkness/lightness of the colour. From the central axis to the border of the colour wheel there is a difference in dominance of the hue of the colour. In the center we have a total desaturated colour, and at the borders we have a fully saturated colours. So the distance from the center to the border is a measurement system for the saturation. This 3D projection is the HSL colour space.

Hue A value representing a certain wavelength of a colour.

Saturation The amount of hue in a colour, if the saturation is 100% we've got a pure colour and at 0% we've got no colour and it is a grey tint.

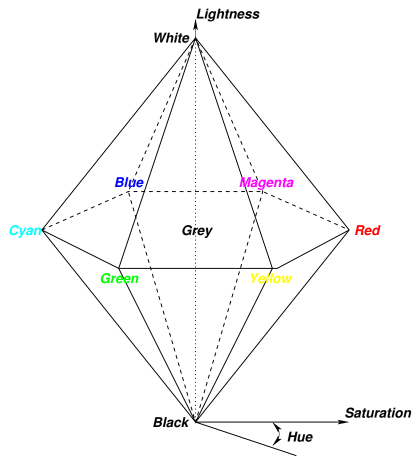

Figure 3.10: The HSL colour space

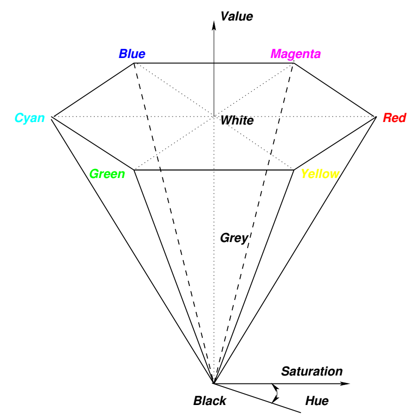

Figure 3.11: The HSV colour space

Lightness A measure of brightness of a colour, where 0% is pure black and 100% is pure white, both regardless of the hue or saturation. At 50% there is maximum colour saturation.

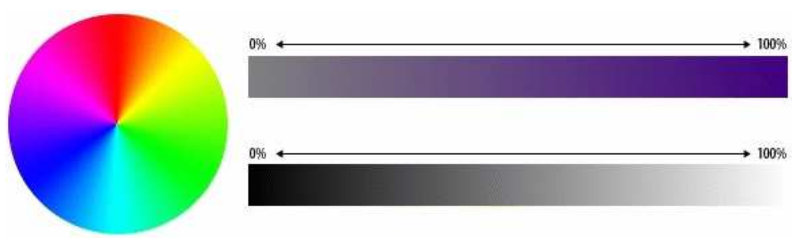

Figure 3.12: The Hue colour wheel (lightness 50%), Saturation and Lightness

In the HSV system at a value of 100% there is maximum colour saturation and at a value of 0% we've got pure black, regardless of the hue and saturation. To get white in the HSV system the saturation has to be 0% and the value has to be 100%, see also figure 3.11.

There is a simple conversion from HSL to RGB and vice versa, see Appendix C.1. Notice the transformation is not linear like the CMY ↔ RGB conversion.

One important factor of the different colour models is the ease to use them. Conversion from one colour space to another is very easy so the need to use a model representing the output's hardware isn't necessary. A very intuitive colour space is the HSL space. We can lighten a colour by adding white, or darken it by adding black and fully saturated colours are found on the equiteral plane. In the next sections when talking about colour models or spaces, one should assume one's dealing with the HSL space, except when there is explicitly referred to another model.

3.2.4 Cognitives on colour

Everybody experience colours different. Studies however showed us that certain *feelings* about colours are common, even through different cultures. In this section the colours will be arranged according to physical and psychological definitions.

Colour temperature We can make a separation between warm and cool colours. Warm colours are often associated with fire and the sun, these colours produce feelings that are warm, cozy and inviting. Cool colours however, are often associated with ice and water and the feelings produced here range from calm and peace to sadness.. When using warm and cool colours together, one is able to notice cool colours tend to recede from the viewer and warm colours tend to move forward. When we go back to our colourwheel, see figure 3.13, we can simply define warm colours as an clockwise interval between red-violet and yellow. The clockwise interval yellow-green to violet tends to be called cool. This definition is partially based on user experiences, experiments and was already described in [4].

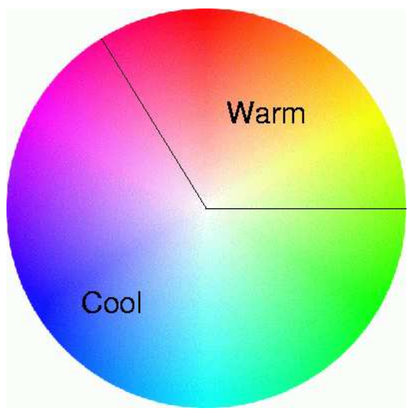

Figure 3.13: Warm and cool colours

Luminance of colours Colours can of course be separated into light and dark colours. At the very ends of light and dark colours we've got pure white and pure black. If we only stay in the white-black area, thus without using a colour, or with the use of a totally desaturated colour, we've got all different gray tones or shades. When we use colours it is harder to separate the dark colours from the light colours. Everybody has got a feeling of colours, e.g. blue is dark and yellow is light, but how can this be quantified? In [4] the luminance of a colour is described with the use of a figure like figure 3.14.

In this figure we see in the first row 16 equidistant steps from black to white. The other rows are the representation of 12 hues of the colour wheel with the same luminance as the grays. So every column has the same luminance[4]. These 12 hues differ 30° starting with 0° corresponding to the colour red. The trick is to spot the correct representation of the fully saturated colour belonging to its hue. In figure 3.14 we can see that fully saturated blue is approximately in the third column whereas fully saturated yellow is approximately in the 15th column. This thus means that yellow is brighter than blue. This can be done for all colours.

This method is not very useful to define the luminance of a colour in an automated presentation generation. In the paragraph describing the colour models, the YIQ model

[4]on screen

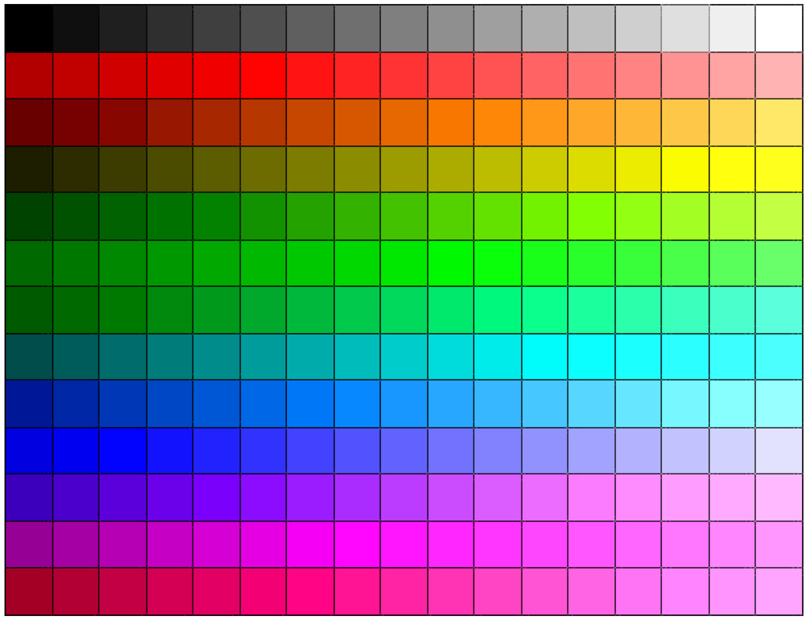

Figure 3.14: The Luminance of different hues

for the NTSC standard was described. In this model the Y component described the relative brightness of a colour and thus we can use this component to assign a number for the luminance of a colour. In fact, this Y component was used to create figure 3.14.

In figure 3.15 the Y component of the YIQ model is plotted, with the use of Matlab, against the hue and lightness value of a hsl-coded colour. When there is no saturation all colours will look the same (grey) and there will be no difference between different hues. With a saturation of 100% the difference between different hues will be maximal and that is why this graph is plotted at a saturation level of 100%. In this figure we can see that when we use the maximum lightness we have got the maximum brightness and vice versa. At a lightness level of 127, we've got the pure spectral colours, see figure 3.16. At hue value 60° there is yellow and we can see that yellow is the brightest colour, at 240° we can see that blue is the darkest colour.

3.2.5 Colour Harmony

The term harmony is not only used in music, it has a lot of areas which it applies to. In this thesis the definition used is *A pleasing combination of elements in a whole.* Colour harmony is therefore a pleasant combination of colours. But what can be called pleasing? It is obvious we are entering the subjective area of aesthetics. In this section we try to describe a way of defining harmonious colour schemes.

If a colour representation is not in harmony it can be boring to look at, it even can be tiring to look at. To keep one's attention the colours have to be in harmony. However, to obtain one's attention a non-harmonious colour selection can also be applied. The harmony of colours is thus mostly subjective. There is however a theory that is based on the equilibrium of the eye, which can be used to model colour harmony and thus can take the objective part of colour harmony into account.

Most people probably know the illusions where we have to focus or stare for about

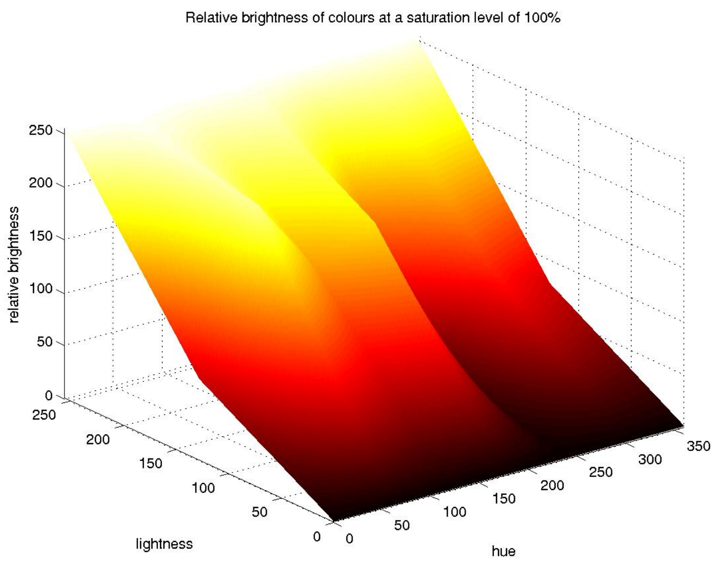

Figure 3.15: The Relative brightness of colours at a saturation level of 100%

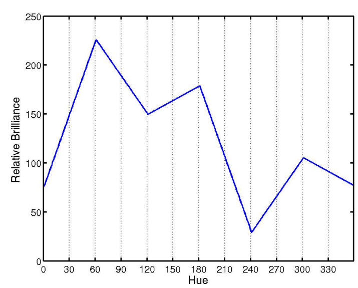

Figure 3.16: The Relative brilliance of the pure spectral colours

30 till 60 seconds to an image and then, when we look at a blanc paper we can see the afterimage. If you try to focus on the afterimage you can see it is the negative of the image we have been staring at. Even with coloured images this works and we see the complementary colours as a result. So if we focus on a cyan colour, see figure 3.17, and we then look at a white paper we will see red for a short time. This effect is due to the eye which seeks to restore its equilibrium. The effect of the afterimage that is created by the eye is called successive contrast. If we look at figure 3.18 we can see that the appearance of a colour is affected by what surrounds it, it actually is the same colour red. This effect is called simultaneous contrast.

Both kinds of contrast indicate that the eye tends to create a equilibrium by using complementary colours. According to [4]Count Rumsford published in 1797 an article in the Nicholson's journal about creating colour harmony. Colours are harmonious if they are white when they are mixed. It is obvious he was talking about an additive colour model.

When we focus on a black spot on a white background we get a white spot as an afterimage, the same for a white spot on a black background, this produces a black

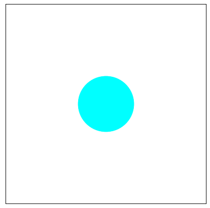

Figure 3.17: Successive contrast

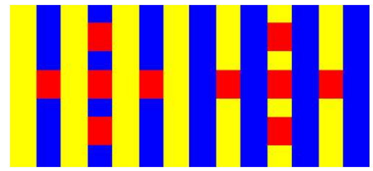

Figure 3.18: Simultaneous contrast

spot as an afterimage. This means the eye still seeks it equilibrium. The result of the research of physiologist Ewald Hering was that grey matches the equilibrium of the eye [4].

Colour harmony can be achieved by creating an equilibrium state for the eye, so the addition of the colours needs to be grayish. There are however several ways to create a harmonic colour representation. In the next paragraphs several different *Colour Harmony Schemes* will be described. The first two colour harmony schemes are not based on the equilibrium theory, they are mentioned because they are very often used in practice and because they are necessary for creating a complete colour design decision system. In [8] the first 4 schemes can be found and in [4] we can find all the equilibrium based schemes.

Monochromatic The monochromatic colour harmony scheme is used when we use a single hue. Different colours are created by adding more white or black to the colour, this means creating different tints and shades as described in the paragraph about tones, tints and shades. In figure 3.19 we can see several different colours with a hue of 240. When using no colour and thus only black, white and their intermediate tints we call this an achromatic scheme.

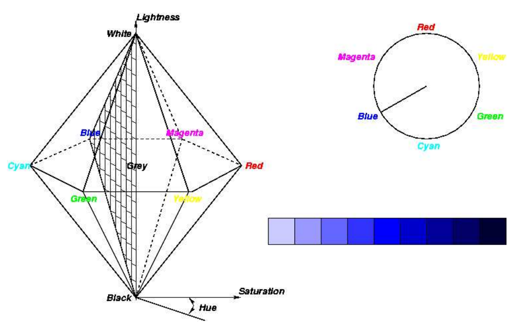

Figure 3.19: Monochromatic colour harmony scheme

Analogue An analogue scheme is created by using analogue colours. This means using colours which are next to each other on the colour wheel. When using an analogue scheme, one has to take into account that warm and cool colours shouldn't be mixed with eachother. The use of too many hues is also not advisable because of the danger of creating a too variegated presentation. In figure 3.20 there is an analogue scheme created by only using the fully saturated colours. It is also possible to use different tints and shades of the analogue colours.

Figure 3.20: Analogue colour harmony scheme

Complementary A complementary colour scheme is based on the theory of the equilibrium of the eye. This scheme is based on the use of 2 different hue's which are opposite of each other on the colour wheel and thus prodcucing a very high contrast, for example yellow versus blue. We have to choose a dominating colour for the background and use the other colour for the foreground. When we look at the 3D HSL model we can pick a point in the model and create it's complementary harmonious colour just by mirroring this point in the centerpoint of the 3D model. So the hue value of the colours differ by 180° (mod 360°) and the lightness is mirrored on the XY plane. In this colour scheme it is advisable to use cool colours as foreground and warm colours as background. When using colours with a low saturation level, the colours will be very near the centerpoint of our HSL-space, these colours will look very similar and the combination of these colours is not advisable as well.

A more flexible complementary scheme is the split complementary scheme. Instead of using a single hue we use a hue range for both colours where the centerpoints of these ranges are complementary. Here one shouldn't use low saturated colours as well.

Triad A triadic colour harmony scheme consists of 3 different hues. If we take the colour wheel and place a equilateral triangle we've got a harmonious triad. An example are the three primary colours, red, green and blue. Other triadic schemes are created by turning the equilateral triangle on the colour wheel. Each of the three hues selected to create the harmony scheme can be used as the center of a range of hues.

To give this scheme some extra flexibility we can also use an isoceles triangle instead of a equilateral trianglye. We then have to take into account, that the angle of the top of this isoceles triangle must be in the range from 0° till 90°, because of the equilibrium constraint. With this triadic colour scheme we also don't have to use the colour circle only, but we can use the whole dodecahedron to create a triadic colour harmony scheme. We only have to keep in mind that the point of intersection of the bisectors of the sides from the isoceles or equilateral triangle lies at the centre of the dodecahedron.

When using black we ought to use two complementary colours very near to white, but not completely white. The same with using white.

Tetrad The tetradic colour harmony scheme is based on the use of 4 hues, where we have two pairs of complementary hues. If we connect these 4 hues it is allowed to have a square, rectangle or a trapezoid for still being a colour harmony scheme. Here we also don't have to stick with the single hues but we can create a symmetrical range of hues around the chosen hue. The 4 hues can also be rotated in the dodecahedron keeping in mind the symmetry of the hues relatively to the centerpoint of the dodecahedron.

Pentad A pentad harmony scheme can be created by using an equatorial triadic harmony scheme and by adding white and black. The created colours are still in balance because we added black and white.

Hexad The same with a hexad colour harmony scheme, if we take an equatorial tetradic harmony scheme and we add white and black we still got a harmonious colour scheme. Another way of creating a hexadic scheme is by drawing a hexagon in the colour wheel, by turning this hexagon in our dodecahedron we can get a wide variety of harmonious hexadic colours.

Harmonic colour schemes in practice A well known example of the use of a colour harmony scheme are the works from Piet Mondriaan. In figure 3.21, we can see a pentad harmonic colour scheme. Many paintings can be captured in one of the above described harmony schemes. Van Gogh's painting in 3.22 can be described as using a tetrad scheme, he is using, cyan, red, blue and yellow. The last painting can also be described in a split complementary scheme, where yellow and blue are the two *main* colours.

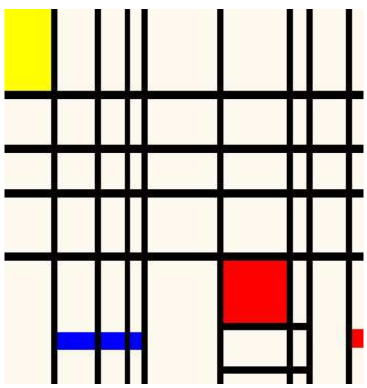

Figure 3.21: Composition with red, yellow and blue, Piet Mondriaan, 1939-1942

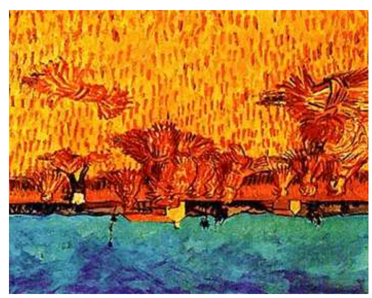

Figure 3.22: Wheat Field with Sheaves, Vincent van Gogh

If we want to use harmonic colour schemes for making our design decisions, we first have to know which scheme we are planning to use. A guideline for chosing the scheme is the amount of colours we want to use. Before doing this we first have to define some terms:

fixed colour When we have a colour without any flexibility we will call this a fixed colour, e.g. a corporate identity colour [H,S,L]:[60, 255, 127].

colour A colour is defined as a single hue, the different tones, tints and shades are all class of this colour.

colour range A colour range is a range of different colours, this means a range of hue's including their different tones, tints and shades.

relative colour Relative colours are a subset of the class of colour ranges. This subset can be given a single name which applies to it's whole colour range, e.g. blue, orange, warm, dark.

If we for instance want to use 2 colours we can choose a analogue or a complementary scheme, for three colours we can use the triadic scheme, but the analogue as well. When making design decisions, we often got a preferred colour, coming from the user model, or a corporate identity colour. When using such inputs the colour harmony scheme is almost automatically chosen. If the user for instance wants red and the corporate identity colour is a fixed blue and we need 4 colours, we can only use a tetrad harmony scheme, with blue, yellow, red and cyan. If we however needed three colours, then a triadic colour harmony scheme would have been a solution, but a very wide analogue scheme would have been a possible solution as well.

We now have set a basis for graphic design using colours, however, before we can continue with creating explicit design rules we have to take an important factor into account:

3.3 Typography

In the previous section we started with the basic colour theory and ended with harmonic colour schemes. Unfortunately we can't apply all these schemes when we use text in a presentation. In this section I try to describe why certain rules don't apply and there will be some basis created for our design decisions.

3.3.1 Introduction

The most important constraint of text on a certain medium is its legibility. If we somewhere place text, we want the viewer to be able to read this. One of the things we should not forget is the difference between text on a paper and text on the screen. Text on paper is *solid*, whereas text on a display is based on the emittance of light waves. The theory stated below applies on both mediums for displaying text.

3.3.2 Legibility

When dealing with text, one often think in terms like fonts, font sizes and font styles. Because of the different assumption one makes when talking about this, I would like to clarify some terms first

- typeface
  A typeface is a design for a set of fonts, and often come as a family of typefaces, e.g. bold, italic and other variations.

- typeface family
  A family of typefaces is thus a set of typeface variations.

- font
  When giving a typeface a certain size we have obtained a font. A font therefor is a set of text characters in a specific style and size.

Taking this all together: Courier is a typeface family, Courier italic is a typeface and Courier italic 12pt is a font.

Returning to legibility we can state that overall legibility depends on five basic factors, these partially originate from [6]:

1. The typeface family
   Typeface families are often especially created for onscreen or onpaper use. On-paper typeface families mostly are serif[5], whereas onscreen typeface families mostly are sans-serif[6].

2. The typeface
   When using italic typefaces for larger texts on screen or on paper, it can be very hard to read, when using bold typefaces however, the legibility can improve. This is mostly depending on the typeface family and size of the used typeface.

3. Fonts
   The size of the typeface is of course very important for the legibility of the used text. Because of the very low resolution of screens (around 72 dots per inch) compared to printers (up to 2400 dpi) very small typefaces can be very coarse onscreen while perfectly readable on paper.

4. Font composition
   Some elements of font composition are spacing (between characters and between lines) and the length of a line. Of course spacing shouldn't be too small or to large.

5. Font colour
   The colour of a font is perhaps one of the most important factors of legibility. We ought not to forget that we are not only talking about the colour of the font itself but also about the background colour of the font, and of course we have to take the harmonic colour schemes into account.

All these factors are somehow depending on each other. The typeface Geneva normal is for instance onscreen perfectly legible from 9 pts whereas the typeface Frutiger normal is legible from 12 pts. Another example is when the size of a font decreases, to keep the text legible we have to increase the saturation of the colour of the font. There is thus a wide variety of possible combinations to create a legible text. Time however, is setting limits to the scope of this research. This is the reason emphasize will be on the font colour for creating legible texts. We therefor have to fix the other basic factors for creating legible texts.

As mentioned before, sans-serif typeface families are often used onscreen, this is because the serifs tend to disappear on the computer screen. Serifs can however aid the reader by giving him more visual information about the shape of the letter and thus for legibility. Microsoft hired Matthew Carter to design a typeface family especially for the screen. He designed two families: Verdana and Georgia. Georgia is a serif typeface family with special features for onscreen display. Because it is a serif typeface it looks

[5]A serif is the little extra stroke found at the end of main vertical and horizontal strokes of some typeface families.

[6]sans: without (french)

also good on paper. The low screen resolution gives reason for text size greater than 10 pts. This put together is the reason to use Georgia normal 12 pts as the font used for doing further research on the effect of colours on legibility.

3.3.3 Font Colour

Most people got a very good intuition about what (not) to use for text and background colours. Here we try to capture that intuition and try to explain why we can or cannot use certain combinations. In the next section some general textcolour rules will be derived from this knowledge, where some are based on [2].

When we use colours for text and background it is easy to make bad legible combinations, here are some in the additive colour system:

- Yellow text on a white background.
- Blue text on a black background.
- Red text on a cyan background.
- Blue text on a red background

These are just a few of the infinite possibilities of creating a bad legible text. If we recall the harmonic colour schemes we can see that these combinations can all be fit in a certain scheme. Yellow on white and blue on black both fit in a monochromatic harmonic colour scheme whereas red on cyan fits in the complementary harmonic scheme. To fit blue text on a red background we can use a triadic scheme if we are allowed to use a third colour: green. But why are the above examples creating bad legible combinations?

- Yellow text on a white background.
  Both yellow and white are bright colours, if we recall the YIQ model we can calculate the Y component for both colours. If we assume we use fully saturated yellow we've got a relative Y component of 0.886, where the relative Y component of white is 1.000. The problem here thus is that the $|Y_1\text{-}Y_0|$ is too small.

- Blue text on a black background
  The same here as with yellow on white, except we have two dark colours, black got a Y component of 0.000 and the relative Y component of fully saturated blue is 0.114. Here we can also conclude that $|Y_1\text{-}Y_0|$ is too small.

- Red text on a cyan background.
  It was already mentioned that this combination can fit in the complementary colour harmony scheme. Using this scheme however for text and background colour is not advisable. The result of using complementary colours is a flickering effect, this effect makes it harder and more tiring to read. On paper this should also be avoided (e.g. green on red), onscreen this effect is amplified because the colours are made of light. This effect can be weakened in various ways, one is for instance by darkening the colour by adding black, another way is by desaturating the colours.

- Blue text on a red background
  Blue is obvious a cool colour, whereas red is warm. As already described in section 3.2.4, cool colours tend to recede from the viewer and warm colours tend to move forward the viewer, this latter makes warm colours more suitable for text than cool colour, see also-[2].

When using bright colours on dark colours we have to take into account *type glow*. This is the effect which only appears in the additive colour system where the edges of fonts appear thinner than they really are. This is caused due to the fact that white or very bright areas are on screen much brighter than on paper. An example is the use of a white background and the use of black fonts, we have to avoid this.

With the knowledge of what not to combinate we can create some general rules for creating legible text.

3.3.4 General typography colour rules

In this section we try to define some general colour rules, these will be made explicit in the next chapter:

When using text we thus have to avoid colours with a low relative difference in luminance, too much difference can also have a negative effect on legibility: $x_0 \leq |Y_1\text{-}Y_0| \leq x_1$

When picking a background colour, one has to avoid bright colours (afterglow). The use of a complementary harmony scheme, with saturated colours should also be avoided. Finally, when using a warm/cool colour contrast, use warm colours for text.

3.4 Conclusion

Graphic design and colours is a very broad topic, especially when considering the physical, biological and cognital aspects. When reading elsewhere on the same subject one should keep the above theory in mind, because when doing this research many errors were found on the web and in books. Even in [4], considered as a *bible* on colour theory, a fundamental error was found.

When dealing with colours in graphic design it is inevitable to treat the use of text in a presentation different. Colour harmony schemes can't guarantee us text is legible. And whenever we use a colour harmony scheme we have to make a difference between the additive and subtractive colour schemes.

The theory described in this chapter gives us enough knowledge about graphic design to create a system which can make colour design decisions for us, given some constraints as input. We've got colour harmony schemes to select a harmonious colour combination and we've got some global constraints for our colours when using text in our presentation. With this knowledge we can continue and start implementing!

Chapter 4

Graphic design, Constraints and Cuypers

Chapter 5

Conclusion

5.1 Future work

Appendix A

Documents, types and formats

A.1 SMIL

A.2 RDF(S)

A.3 DAML+OIL

A.4 RuleML

Appendix B

Constraint Satisfaction Problems

B.1 Introduction

B.2 Rules

B.3 Eclipse

Appendix C

Conversion

C.1 HSL ↔ RGB

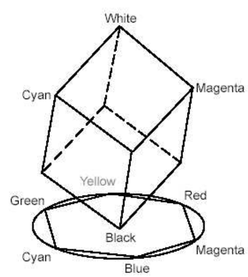

Figure C.1: Visualisation of conversion from RGB to HSL

The conversion from HSL to RGB and vice-versa can be visualized with figure C.1. With the use of **S***pe***L**, see [5], the conversion is described below, this conversion is originally from [3].

$HSL =$ `record of`
$hue : \mathbf{R}^+$
$saturation : \mathbf{R}^+$
$lightness : \mathbf{R}^+$
`end`

`inv` $mk - HSL(hue, saturation, lightness)\underline{\Delta}$
$hue \leq 1 \wedge saturation \leq 1 \wedge lightness \leq 1$

$RGB =$ `record of`
$red : \mathbf{R}^+$
$green : \mathbf{R}^+$
$blue : \mathbf{R}^+$
`end`

`inv` $mk - RGB(red, green, blue)\underline{\Delta}$

```
    red ≤ 1 ∧ green ≤ 1 ∧ blue ≤ 1

HSL2RGB : HSL → RGB
HSL2RGB(hsl) △
    let mk − HSL(hue, saturation, lightness) = hsl in
    if lightness ≤ 0.5
       then let temp2 = lightness × (saturation + 1) in
    else let temp2 = lightness + saturation − lightness × saturation in
    let temp1 = lightness × 2 − temp2 in
    let red = Hue2RGB(temp1, temp2, hue + 1/3) in
    let green = Hue2RGB(temp1, temp2, hue) in
    let blue = Hue2RGB(temp1, temp2, hue − 1/3) in
    mk − RGB(red, green, blue)

c Hue2RGB : R × R × R → R
Hue2RGB(temp1, temp2, hueraw) △
    if hueraw < 0
       then let hue = hueraw + 1 in
    else if hueraw > 1
          then let hue = hueraw − 1 in
    else let hue = hueraw in
    if hue × 6 < 1
       then temp1 + (temp2 − temp1) × hue × 6
    if hue × 2 < 1
       then temp2
    if hue × 3 < 2
       then temp1 + (temp2 − temp1) × (2/3 − hue) × 6
    temp1

RGB2HSL : RGB → HSL
RGB2HSL(rgb) △
    let mk − RGB(red, green, blue) = rgb in
    let max = Max(red, green, blue) in
    let min = Min(red, green, blue) in
    if max = min
       then let saturation = 0 in
          let hue = 0 in
    let lightness = (max + min)/2 in
    if lightness < 0.5
       let saturation = (max − min)/(max + min) in
    else let saturation = (max − min)/(2.0 − max − min) in
    if red = max
       then let hue = (green − blue)/(max − min) in
    if green = max
       then let hue = 2.0 + (blue − red)/(max − min) in
    if blue = max
       then let hue = 4.0 + (red − green)/(max − min) in
```

$mk - HSL(hue, saturation, lightness)$

$Max : \mathbf{R} \times \mathbf{R} \times \mathbf{R} \to \mathbf{R}$
$Max(a, b, c) \underline{\triangle}$

```
if a ≥ b
   then if a ≥ c
      then a
else if b ≥ c
   then b
else c
```

$Min : \mathbf{R} \times \mathbf{R} \times \mathbf{R} \to \mathbf{R}$
$Min(a, b, c) \underline{\triangle}$

```
if a ≤ b
   then if a ≤ c
      then a
else if b ≤ c
   then b
else c
```

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