Systemizing Colour for Conceptual Modeling

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Abstract. Colour is used in many conceptual models and is discussed intensively since MOODY has published his 'Physics of Notation'. Yet, choosing the right colour for a construct is difficult but crucial. Using a colour for a certain construct which is not appropriate can lead to visual stress as well as too much or too little emphasis on that construct. The aim of this paper is to give a systematization of colour for conceptual modeling by reviewing theories of colour vision, colour harmony and visual attention. Based on this review we provide colour combinations for different conceptual modeling colour scenarios.

Keywords: Colour, Hue, Conceptual Modeling, Pop-out, Perceptual Discriminability.

1 Introduction

Conceptual modeling constructs are mainly distinguished on the basis of the shape [1]. In BPMN 2.0, for example, shape (and to a small extent also texture) is used to derive the majority of constructs [2], which is useful, as shape has a significant impact on object recognition [3]. Yet, shape alone does not produce a high visual distance between modeling constructs and thus, leads to a low perceptual discriminability as only one visual variable is used to encode visual information. This makes it hard for model users to distinguish between constructs [1]. Redundantly using visual variables can help to increase perceptual discriminability and allows positive effects such as a faster detection of modeling constructs [1]. When visual variables are discussed for redundant coding, in most cases also the visual variable colour is included ([2],[4-6]). Colour is very powerful as differences in colour can be detected three time faster than shape and are more easily remembered [7-8]. Also experiments from visual attention confirm that colour dominates other variables [9-10].

So far, colour has been discussed to visually distinguish matching operators in Business Process Models (BPMs) [6], to produce a pop-out of chunks and of model elements [11] as well as to encode further information [12]. Colour has also been tested empirically for conceptual modeling in [6] and [13], who have shown that if colour is used, significant positive effects on comprehension for novices can be achieved. Yet, the application of colour still remains subjective. In studies that use colour for

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conceptual modeling, colour is not selected systematically. [13] argues that assigning a certain colour to a model element is very difficult due interrelations between hue and brightness. Even for designers choosing the right colour combination is very difficult. They often look for inspiration from sources such as art or colour palettes [14] and that way, try to avoid disharmonious colour combinations but rather create attractive ones which according to [15] works better than unattractive ones. Yet, designers of modeling grammars do normally not wish to spend time for being inspired which is why a systematization of colour for conceptual modeling would be helpful for them.

In this study we address the gap of a missing colour systematization for conceptual modeling by elaborating scenario-specific colour combinations that modelers can use during the modeling process if their modeling tool allows assigning a specific colour, that tool-designers can implement in their tools and that designers of modeling grammars can use when assigning colours to their constructs. We do not draw requirements for colour combinations from every possible perspective but limit our study to theories of Visual Attention (to derive scenario-dependent colours), of Colour Vision (to derive general and scenario-specific requirements) and of Colour Harmony (as in most cases several colours for several constructs are selected that should harmonize with each other). We do not discuss cultural-dependent colour perception as is recently discussed for conceptual modeling in [16] and remark that colour combinations of this paper are rather elaborated for a western context. We further do not treat semantics of colours which are also very cultural dependent.

This research uses design science [17] as research method. Following the research method discussed in [18] the paper is structured as follow: We start with a first initiative by reviewing conceptual modelling colour scenarios in section 2. Based on the colour scenarios we continue with a requirements analysis from theories of Visual Attention (section 3.1), Colour Vision (section 3.2) and Colour Harmony (section 3.3). Colour combinations for scenarios are presented as artefact and are implemented by giving an example in section 4. So far we have not evaluated the colour combinations but will present an idea of how this can be done in section 5, which further provides a short conclusion and an outlook of future research possibilities.

2 Colour in Conceptual Modeling

Colour has been used for different purposes in conceptual modeling: Production of a pop-out, a high visual distance as well as to encode further information (see table 1). [11] and [13] have used 3-4 colours to **produce a pop-out** of certain modelling elements and to visually distinguish further elements. While [11] made entity-types pop out from the rest of ERD-constructs, in [13] a pop-out effect is used for two chunks of BPMs. Also in [6] a pop-out of matching operators is discussed. Yet, in their model a great number of operators are visually distinguished by colour, which is why we argue that they rather aim to **produce a high visual distance** between operator pairs, as a pop-out can only be achieved for very few elements [13]. Further studies that use colour to produce a high visual distance for modeling constructs are [2], [19-21]. Colour is also used to **encode further information** in a non-redundant way in [12],[22-24]. The number of colours in these studies varies to 2-9 different colours.

Table 1. Colour application scenarios in conceptual modeling

Purpose of Colour Application	*# of colours*	*Mod. Gram.*	*Lit.*
Scenario 1: Pop-out of model elements and high visual distance of further objects			
Pop-out for important constructs: Pop-out for Entity-Types + high visual distance for Relationship-Types and Attributes	3	ERD	[11]
Pop-out for important chunks: Pop-out of parallel and alternative chunk + high visual distance for further chunks	4-6	BPM	[13]
Scenario 2: High visual distance			
High visual distance of *varying numbers* of operator *pairs:*	varying	BPM	[6]
High visual distance of a *fix number* of constructs:			
e.g. Gateways, DataObjects, Events	-	BPMN	[2]
e.g. Process, object, Team	9	UCM	[19]
e.g. Container, Link, Container Unit	2-9	WebML	[20]
e.g. Stages, WorkUnitKinds	4-8	SEMDM	[21]
Scenario 3: Encoding new information (non redundant application of colour)			
Start and Endpoint, nodes that require user's interaction	4	BPM	[22]
Debit and Credit information in places	4	Petri Nets	[23]
States of activities and delay indicator	5	BPMN	[12]
Coloured tokens and states	-	Petri Nets	[24]

3 Requirements for the scenarios

Requirements in this section are only discussed for scenario 1 and 2 as in conceptual modeling it is already consensus that colour should not be used in a non-redundant way [1-2]. In the next subsection requirements are derived from Visual Attention.

3.1 Requirements from Visual Attention

Colour is an effective variable to guide human attention [25], and can be used to produce a pop-out for the most important constructs of a model. A pop-out effect (as seen for the red entity types of fig. 1) is reached when visual variables are used in a way that parallel processing is facilitated [26]. In this case, visual information is perceived very fast, in less than 200ms, which allows working memory to efficiently process information. Yet, as shown by attention researchers such as [27], parallel processing is not a rigid state but a pole on a continuum, having serial processing as the other pole. Conditions for parallel and serial processing are discussed by [11] for conceptual modelling (see fig. 1). Colour can affect parallel or serial processing based on the number of unique values, its rang in feature hierarchy, its difference in value intensity and its similarity to other colours.

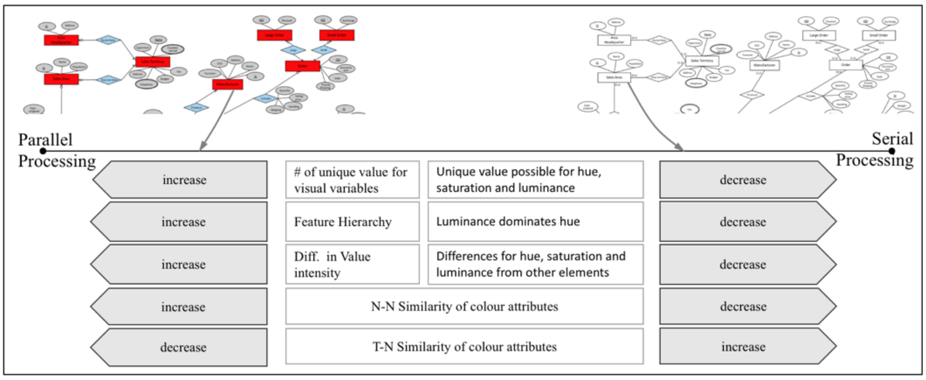


Figure 1. Continuum between parallel and serial processing on the basis of [11]

An element that is characterized with a unique value, such as circular for shape (fig. 2b), is in most cases further placed on the parallel side than an element with no unique values. That way, the circle in b) attracts more attention than the red circle in a), that does only have values which also appear in distractor elements. According to the theory of **Feature hierarchy** the visual system appears to have a hierarchy for visual variables (e. g. luminance dominates hue [25] and hue dominates shape [9]). That way, a unique value for hue (as in c) would lead to a more parallel place than a unique value for shape (as in b). A further condition concerns the **numbers of unique values**. In d) luminance is introduced as a further unique value besides hue (as in c). That way, the target element in d) is characterized with more unique values (hue und luminance) which leads to a more parallel position than the target element has in c). Working on the condition **differences in value intensity** does further help to move the element further to the parallel pole. In e) we have further increased the luminance difference between target and distractor elements and have, that way, increased parallel processing. When discussing differences in value intensity between target- and distractor elements, we implicitly talk about similarity (target-non-target similarity or T-N similarity). Besides T-N similarity also similarity between distractor elements matters (non target-non target similarity or N-N similarity) [27]. A target element is placed more on the parallel side with distractor elements having a high similarity (as is the case b-d) instead of having a lower similarity (such as in f).

For the two scenarios a different position of the modeling constructs along the continuum is required. For the pop-out scenario [13] discusses to place the constructs that should pop-out as far to the parallel side as possible (see fig. 3). Further constructs can be distinguished by giving them a position which is close to the serial processing side to avoid interferences with the pop-out constructs. For the high visual distance scenario all relevant constructs can be placed as much to the parallel processing side as possible. Based on the different positions within the scenarios the two scenarios require a different work on the conditions which are summarized in fig. 3 as requirements from Visual Attention.

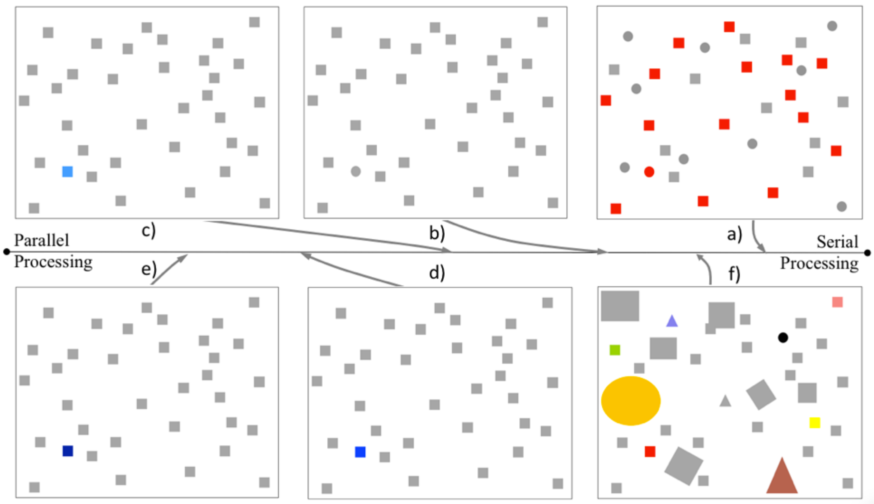


Figure 2. Examples to place elements along the continuum

For the pop-out scenario placing the most important constructs close to the parallel processing side can be achieved by creating a unique value for luminance which is highest in feature hierarchy and holding this value constant among other constructs. That way, a clear focus is achieved with the most important variable of the feature hierarchy (req. 1 & 2). Furthermore, a greater number of unique values should be created with hue and saturation (req. 3) and value differences should be set as high as possible (req. 4). If possible, sufficient differences in value intensity of non pop-out constructs should be regarded, too, to further visually distinguish these constructs (req. 5). For the high visual distance scenario, a pop-out is not required for the constructs but visual distances should be arranged as high as possible which requires unique values for those constructs with sufficient luminance and hue contrast (req. 1 & 2).

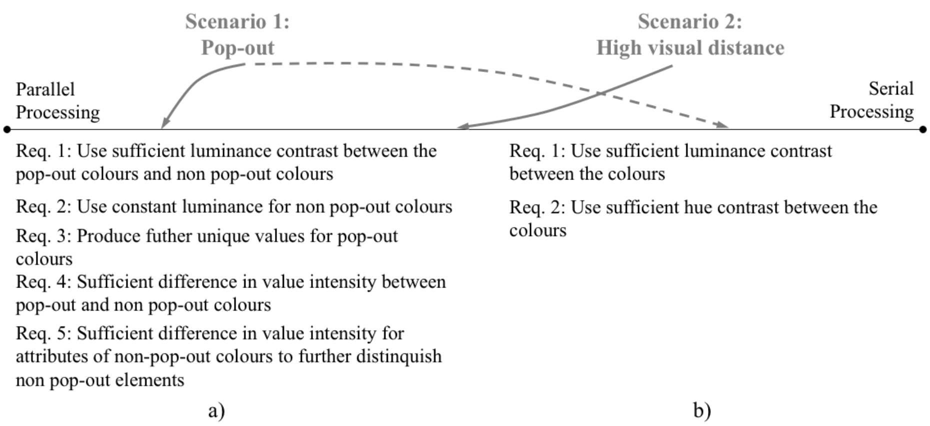


Figure 3. a) Scenario-related positions along the continuum and b) requirements from Visual Attention

3.2 Requirements from Colour Vision

Implications from colour vision have already been discussed within 38 guideline for computer graphics in [28]. In this work we discuss 13 of the more general guidelines of [28] which can also be applied for conceptual models (on papers and on screens) and whose focus fits to our domain.

Human colour vision is trichromatic [29]. The retina has three types of colour-sensitive photoreceptors that are referred to as S, M, and L cones, which are sensitive to **s**hort- , **m**iddle- as well as **l**ong-wavelength of the spectrum [30] and are usually termed blue, green and red. We perceive colour by combining the three receptor inputs into a unique triplet and thus, perceive colour depending on the ratio of the three cone-responses. S, M, and L-cones are not equally distributed among the retina but occur in relation of 1:20:40, which means that the sensitivity to red and green is much higher than to blue [31]. A difference in contrast sensitivity has also been measured for the neural channels that distribute colour information to the brain. In this process S, M and L-wavelength are transformed into an achromatic and two chromatic signals [32]. While the achromatic signal represents the sum of the cone responses, the two chromatic signals define colour differences in red-green and yellow-blue. These channels differ in contrast sensitivity, too. The achromatic channel offers highest contrast sensitivity and the yellow-blue channel the lowest, which can be explained with the relative distribution of cones in the central fovea [28].

In consistency with the chromatic and achromatic channels, HERING proposed his **opponent colour theory** of colour vision around 100 years ago [28]. He noted that certain hues never occur together such as red-green or yellow-blue in the sense that a colour is not described as reddish-green. Based on these observations HERING argued that there is something fundamental about those pairs of colours [30] and used these colours together with white and black to define a system of six elementary colours (see fig. 4a). Out of this system three perceptual dimensions can be derived to describe colour [30]: Hue, colourfulness and brightness. While hue defines if an area appears to be similar to red, green, yellow and blue or to a combination of those colours, colourfulness describes to what extend an area appears chromatic. Brightness gives information about the extend an area emits of reflects light [33].

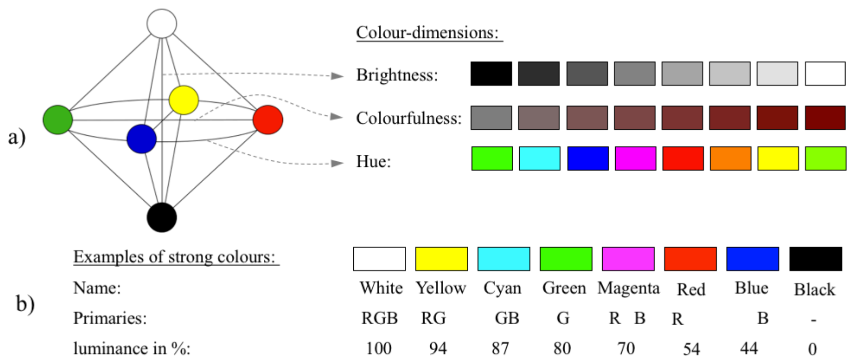
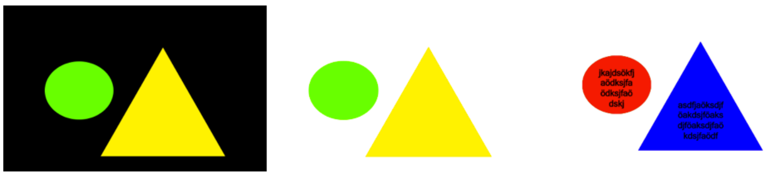


Figure 4. a) Colour dimensions, and b) examples of strong colours (on the basis of [28])

Further terms that are used in this paper are saturation (which defines colourfulness in relation to the brightness of similarly illuminated white [33]), and luminance (which determines brightness sensitivity of the human eye [34]). While green, red and blue represent primary colours that can directly be detected by S-, M-, and L-cones, secondary colours present a ratio of the primary colours [28]. In fig. 4b) saturated primary and secondary colours are ordered according to their luminance. These colours with luminances close to that of fig. 4b) are further referred to as strong colours. According to [28] bright **strong colours** can be used to claim for attention [28], which is also the aim of pop-out colours (see fig. 5a). Yet, these colours are discussed for a black background which allows sufficient luminance differences. In conceptual modeling a black background is not common, which is why strong colours should rather contrast to a white background (which is not achieved in b). Fig. 4b describes strong colours which are helpful to select a pop-out colour that offers enough contrast to the background. While a white background has a luminance of 100% a sufficient contrast is offered in saturated red (54%) or saturated magenta (70%). Saturated blue also offers a high difference, but if text is used inside the constructs, it cannot be read (c).



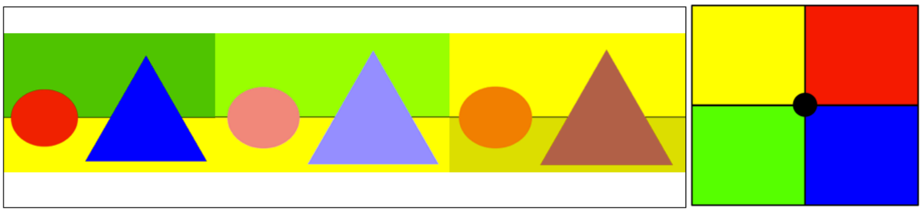
a) b) c)

Figure 5. a) Las Vegas effect: bright, strong colours on a black background, b) the same colours on a white background and, c) colours with a sufficient luminance contrast.

A certain colour appearance of an element does not only depend on the element's own colour attributes but also of colour attributes of neighboring regions or elements [28]. According to **simultaneous contrast**, colours shift in appearance when the colour of the background changes. These shifts follow HERING's opponent theory of colour vision. That way, a light background induces a stimuli to appear darker and smaller and a dark background induces a lighter and larger appearance. Furthermore, red induces green, green induces red, yellow induces blue, and blue induces yellow [30]. That is why [28] suggests to use a neutral mid-gray background, whenever accurate visual colour-judgment is required. Yet, since in conceptual modeling white has always been used as background and an accurate judgment of colours is in most cases not required, we have decided not to use the grey background as a colour guideline.

Looking at strong colours can fixate a coloured image on the retina, which temporarily reduces the sensitivity of photoreceptors and leads to **afterimages** [28]. This can be experienced when fixating the gaze on the black dot of fig. 6d) for at least 10s. When looking on a white paper afterwards an afterimage with the same layout but complementary colours can be observed. That way, in formerly red regions of the image cyan emerges because the response of long-wavelength (red) is temporarily suppressed which leads only the medium- (green) and short- (blue) wavelength to emerge [28]. This is why generally it is not recommended to use large areas of bright colour [35].

Strong colours can also lead to a **depth contrast**. When light is passing through the lens it is refracted into its spectral components. Depending on the wavelength, spectral components converge beyond (red) or in front of the retinal surface (green and blue). That way, to reach a focus on red colours the lens have to become more convex while a focus on blue or green colours requires the lens to become less convex like seeing an object which is far away. This is why, for most observers red appears to advance and blue to recede [36] which can lead to unwanted depth effect when putting strong red and strong blue on neighboring areas. Yet, this effect also can be used to impose colour contrast for a pop-out effect (see fig. 5c). While strong colours are very useful as pop-out colours, these colours should be used very carefully for the high visual distance scenario. In this case we need to place the constructs as far as possible on the parallel processing side without producing visual stress (which we accept for the pop-out scenario when moving the constructs even further to the parallel side). A strong colour combination used for large areas such as in fig. 6a) imposes visual stress due to too much contrast. We can avoid visual stress by using two strategies: First, using colours with a high luminances above the level described in fig. 4b does lead to a colour which is not strong and which would (due to the high luminance-level) not produce too much contrast to a white background (b). When using this strategy, colours should still have enough luminance differences as luminance is highest in feature hierarchy and is thus, important to discriminate between elements. Second, using low hue differences also leads to reduced contrast, which in turn reduces visual stress (c). Moreover, the size of the constructs matters. As visual stress occurs when using strong colours for large areas we should consider that colours for smaller areas need also to be stronger.



a) b) c) d)

Figure 6. a-c: Visual stress within the high visual distance scenario, and d) example for the afterimage effect

If **text** is required within a coloured object then legibility becomes important, which is usually facilitated with a sufficient luminance contrast ratio between text and background. If coloured text on coloured background cannot be avoided the luminance contrast ratio should be at least 3:1 and preferably 10:1 [28].

Human observers with nondeficient colour vision depart to some extend from the standard spectral responses which is why human observers do not see a given colour in exactly the same way [28]. **Colour blindness** further leads model users not to perceive colour the way it is intended it to be seen. Approximately every 12. male and every 100. female adult in Europe is colour deficient [37]. In most cases the kind of colour-deficiency is dichromatism, where one of the three cone pigments is missing.

Dichromats have problems discriminating hues [38], which is why it is recommended not to use hue alone to discriminate between elements. A further restriction of colour concerns the **number of colours** that should be used. Two factors restrict the number of colours [28]: The ability to simultaneously process a certain number of colours and the ability to discriminate between different colours. MILLER has estimated that humans can simultaneously process 7 +/-2 elements in working memory [39]. Recent research estimates this amount lower to 3-4 items [40]. According to research in psychophysics we can differentiate around 7-10 colours [41-42]. Based on those limitations a general limitation of 5-7 colours is given by [43], which seems reasonable based on the number of colours we can differentiate and process. Implications of the description of Colour Vision for conceptual modeling are summarized in table 2.

Table 2. General guidelines for colour application (based on [28])

1.	Be aware that strong colours in neighbouring and in big areas can produce visual stress from unwanted depth effects and afterimages.
2.	Do not use the blue-yellow channel alone for fine details.
3.	Do not use hue alone to encode information
4.	Be aware that colours of neighbouring areas change the appearance of colours.
5.	Do not use coloured text on coloured background.
6.	Limit the numbers of colours to 5-7.

Based on these general guidelines also implications for the pop-out scenario as well as for the high visual distance scenario have been discussed and are summarized in fig. 7.

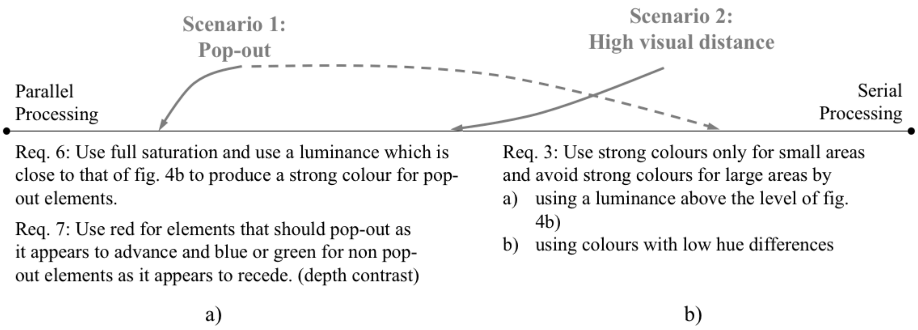


Figure 7. Scenario-specific requirements from colour vision

3.3 Requirements for an effective combination of colours

When applying the rules of section 3.1 and 3.2 there is still a lot of subjectivity in choosing the right colour combination for model elements. Yet, choosing harmonious colours is difficult and crucial [14]. Especially, when tasks need to be solved under stress a visual graphic, used for this tasks, works better if it is designed aesthetically and harmoniously [15]. Choosing the right colours has been challenged for already a long time starting with the ancient Greeks. Modern colour theory has began with the colour wheel that has been proposed by NEWTON and was further developed by

GOETHE. Later, hue templates on colour wheels were developed [44]. MATSUDA, for example, created a set of eight hue templates that describe areas on a colour wheel in which harmonious colours can be selected. Hue templates can easily be rotated around the colour wheel which leads different harmonic hue combinations to appear and are often used as a starting point by designers [14]. A plethora of colour theories address colour harmony beyond just hue. Many of these theories suggest that colours are harmonious if one colour attribute contrasts while the others remain fixed [14]. That way, the Munsell system suggests colour sets being fixed in value and hue but vary in saturation to be harmonious [45] while the Ostwald system proposes colours with equal white or black content as harmonious [46]. Those suggestions were only tested in recent years (see for example [47]) and have led to contradictory results although a few trends have been found [14]: Colours harmonize if they are characterized with same hue, equal or similar saturation as well as contrasting lightness value. In recent years a broad empirical basis through social colour networks, such as Adobe Kuhler [48] and COLOURLovers [49], has emerged that offer millions of colour palettes and have been used by colour scientists to test their theories. Both social colour networks allow their users to create colour themes consisting of 1-5 colours as well as rating, commenting and modifying them. Based on the contradictory results from theories of colour harmony we decided to use colour palettes from two social colour networks that have also been used in colour studies (Adobe Kuhler as well as COLOURLovers).

4 Colour combinations to create a pop-out and a high visual distance

To exemplarily show how colour combinations can be used for the different colour scenarios, we have searched colour palettes that have at least 100 “likes” or “loves” in COLOURLovers or Adobe Kuhler. These colour palettes have further been assessed according to the requirements of section 3 for scenario 1 (pop-out) and 2 (high visual distance). Those colour palettes that best fulfilled the requirements were chosen as colour combination for conceptual modeling. Fig. 8 and 9 give an overview of most appropriate colour combinations for the scenarios and shows to which extend these combinations fulfill the requirements. For the pop-out scenario we found 11 and for the high visual distance scenario we have extracted 22 colour palettes. The colour combinations for the pop-out scenario can be found on the left side of fig. 8 and are evaluated according to specific pop-out requirements as well as legibility as a general requirement of section 3 on the right side of fig. 8. We found two colour combinations that provide two pop-out colours (on the top of fig. 8) and nine colour combinations with only one pop-out colour (on the bottom of fig. 8). The remaining colours within these colour combinations can be used to visually distinguish elements that should not pop-out and are ordered from smaller to larger elements. Within the separation of one-pop-out colour combinations and two-pop-out colour combinations the colours are ordered according to how they fulfil the requirements of the section 3.

Scenario 1: Pop-out

Legend: pop-out colour (grey) | colour to produce visual distance (white)

X_z: criterion is fulfilled
O_z: criterion is partly fulfilled
z: min. luminance contrast in % in req. 1
max. luminance contrast in % in req. 2

					Use sufficient luminance contrast between pop-out and non pop-out colours (req.1)	Use constant luminance for non pop-out elements (req. 2)	Produce further unique values for pop-out colours (saturation and hue) (req. 3)	Pop-out colour is saturated (req. 6)	Use red hues for pop-out element and green or blue hues for non pop-out elements (Req. 7)	Sufficient difference in hue and/or saturation between non pop-out elementns (Req. 4)	Further discrimination between non pop-out elements is possible (Req. 5)	Readibility of black-coloured text
E8608C	71CBC4	CDD56E	FFBD68	FFF9F4	O_7	X	X	-	O	X	-	X
DB3026	7ABF66	F9E14B	EFED89	E88A25	X_{16}	O_3	X	-	O	O	-	X
FF2121	C2FC63	BCF7EF	D7EEFA	FD9A42	X_{33}	O_4	X	X	X	X	X	X
FF634D	FDEDD0	FFF0AA	BCF1ED	FD795B	X_{28}	O_3	X	X	-	X	X	X
FF3F7F	F1CC5D	D6DD54	ADDFE3	F1DC9D	X_{18}	O_3	X	X	-	X	X	X
FF2121	BCF7EF	D7EEFA	C2FC63	FD9A42	X_{36}	X	X	X	X	X	X	X
FB0C06	D7EDA	CEECEF	FFC52C	030D4F	X_{37}	O_2	X	X	X	-	O	X
CC0C39	C8CF02	95CFB7	F8FCA7	E6781E	X_{30}	X	X	-	X	X	O	X
FA2A00	D6D8A8	F2D694	86B8B1	3D1C00	X_{28}	O_2	X	X	-	-	O	X
AE2F27	85B394	A7BA59	F9F0D8	F9D890	X_{25}	O_2	X	-	X	O	O	O
B42310	B0E629	F7CF0A	FCE70D	FA7C07	X_{40}	O_2	X	-	-	X	X	O

Figure 8. Pop-out colour combinations

The colour combinations for producing a high visual distance are summarized in fig. 9 and are further distinguished in colour combinations for large (top of fig. 9), small (in the middle) and a combination of large and small areas (on the bottom). The colour combinations are further ordered based on how many colours they offer and on how they fulfill the requirements of section 3. The colour combinations on the bottom of fig. 9 for large- and small-area colours are further distinguished based on the application for large- and small-areas. That way, the small-area colours are presented on a gray background while the large-area colours are presented on a white background. In most cases not every colour of the palette fits into the scenario which is why these colours are depicted in black in fig. 8 and 9. For a better understanding of fig. 8 and 9 we exemplarily show how these colour combinations can be used for conceptual modeling. Therefore, we discussed the lifecycle diagram discussed in [21], p. 200 using the graphical notation of ISO/IEC 247744. This lifecycle diagram uses colour to visually distinguish the modeling constructs (scenario 2). In its original version on the left side of fig. 10a) this diagram imposes visual stress by using eight different colours (4 line and 4 background colours for the constructs). By limiting colours of the resulting model (on the right side of fig. 10a) to the background colours we have reduced visual stress. The original background colours further fulfils the requirement 3a) by using colours that are above the luminance level of strong colours.

Scenario 2: Large-area colours

X_z: criterion is fulfilled O_z: criterion is partly fulfilled
z: min. luminance diff. (%) in req. 4 and hue distance in degree in req 5

						Readability of black-coloured text	No use of strong colours (req. 3)	High luminance or low hue differences (req. 3a&b)	Sufficient luminance contrast between colours (req. 1)	Sufficient hue contrast (req. 2)
5 colours	D9B2FF	BAF3C3	F9FC9D	FFCBCF	DDE5FE	X	X	X	O_2	X_{45}
5 colours	D9ABFF	ABE4FF	FFABAB	DDFFAB	FFDAAB	X	X	X	O_1	O_{34}
5 colours	A7D3D2	D3DBB2	FFC6BC	FEDEA2	FFF9B8	X	X	X	O_1	O_{16}
5 colours	FFA398	9AD9D2	D0F7A6	FFC48C	FCE5C0	X	X	X	O_1	O_8
5 colours	F3BA2B	A2C5D6	D6DB89	FFD876	F6EFCD	X	X	X	-	-
4 colours	FFDAAB	DDFFAB	ABE4FF	D9ABFF	FFABAB	X	X	X	O_2	X_{50}
4 colours	93DFB8	FFC8BA	E3AAD6	B5D8EB	FFBDD8	X	X	X	O_1	X_{52}

Small-areas colours

X_z: criterion is fulfilled O_z: criterion is partly fulfilled
z: min. luminance diff. (%) in req. 3 and hue distance in degree in req 4

						Readability of black-coloured text	Use of strong colours (req. 3)	Sufficient luminance contrast between colours (req. 1)	Sufficient hue contrast (req. 2)
5 colours	AAFF00	FFAA00	FF00AA	AA00FF	00AAFF	X	X	O_3	X_{40}
5 colours	FF0012	FFD900	5BE300	0084B0	FF7D00	O	X	X_5	O_{22}
4 colours	D60000	FFC801	93C700	0E99DA	FF530D	X	X	X_{10}	O_{29}
4 colours	98C000	EA2E49	FFE11A	0CDBE8	3D4C53	X	X	X_{10}	O_{21}
4 colours	7B9EF8	EB5153	FBE230	A1E736	010101	X	X	X_9	O_{31}
4 colours	0FAAB1	EB265D	FF9326	B7E01F	332C1F	O	X	X_9	X_{43}
3 colours	FF007C	00FFFF	FFFF00	00FF00	FF5100	X	X	X_{14}	X_{60}
3 colours	54BFAC	F2E530	D94625	1BA68C	F2EDA7	X	X	X_{16}	X_{45}
3 colours	D80351	F5D908	00A3EE	929292	3F3F3F	X	X	X_{13}	X_{146}
3 colours	FFCD4A	E6503B	6AACB8	E5E4C7	FFFFEA	X	X	O_8	X_{36}

large and small-area colours

X_z: criterion is fulfilled O_z: criterion is partly fulfilled
z: min. luminance diff. (%) in req. 5 and hue distance in degree in req 6

Small-area colour Large-area colour

						Readability of black-coloured text	Large area colours: avoid strong colour (req.3)	Large area colours: high luminance or low hue differences (req. 3a&b)	Small-area colour: strong colour(req.3)	Sufficient luminance contrast between colours (req. 1)	Sufficient hue contrast (req. 2)
5 colours	E87657	98B4BF	FF9B6F	E8D495	FFF3D2	X	X	X	O	O_3	O_3
5 colours	ED7D7C	A3AC7D	D4C687	F2C778	F1DAA8	X	X	X	O	O_3	-
5 colours	F8F087	F39DD4	DBBAE5	B7E3C0	B8D0DD	X	X	X	O	-	X_{36}
4 colours	FE6960	FEBF97	D2FDFE	FEFAC2	AFFBFF	X	X	X	O	O_4	O_{20}
4 colours	45AAB8	F06B50	FAFABA	E1D772	394240	X	X	O	X	X	-

Figure 9. Colour combinations for producing a high visual distance

Yet, the combination of colours might not seem harmonious to every user. This is why we have chosen a harmonious colour combination from fig. 9b with higher luminances for the larger elements using FFF9B8 and FEDEA2 (ranging from 88 to 96%) and lower luminances for smaller elements using A7D3D2 and A7D3D2 (ranging from 79-83%) to produce a stronger contrast to the white background. For these colours the min. luminance difference is 4% and luminance is used in a range of 17%. Hue differences are not as high as in the original model. We have used a hue distance of at least 107° to other colours for the process kind, as this construct is probably the most important construct. The other hues only range about 33° and do that way not produce to much contrast, and hence visual stress.

Figure 10. a) example model discussed in [21] before (left) and after (right) using a harmonic colour combination, b) details of harmonic colour combination

5 Conclusion

With this paper we have discussed requirements from different fields of theories for two different conceptual modeling colour scenarios. These requirements were further used to assess harmonic colour combinations of two different social colour networks. Moreover, we have shown exemplarily how these colour combination can be used to assign harmonic colours to a conceptual model. We found that using harmonic colour combinations defined in social colour networks has advantages and disadvantages. On the one hand, by using only colours that have been rated as good we can make sure that the model that uses these colours appears harmonic which is important for problem solving [15]. On the other hand, requirements drawn in section 3 were often not fulfilled. That way, luminance differences between pop-out and non pop-out constructs as well as hue contrast between colours for producing a high visual distance can be optimized if colours are picked individually instead of using a colour palette. This trade-off of using colour-palettes still needs to be evaluated. The experiment described in [13] might offer a starting point (by using colours from fig. 8 in the experiment model) for an evaluation of effects that might result from using colour palettes for the pop-out scenario and might give further insights of the trade-off of using colour-palettes.

References

1. Moody, D.: The "physics" of notations: Toward a scientific basis for constructing visual notations in software engineering. Softw. Eng. 35, 756-779 (2009)
2. Genon, N., Heymans, P., Amyot, D.: Analysing the cognitive effectiveness of the BPMN 2.0 visual notation. In: Int. Conf. on Softw. Lang. Eng. pp. 377–396. Springer (2010).
3. Biederman, I.: Recognition-by-components: a theory of human image understanding. Psy. Rev. 94, 115 (1987)
4. Moody, D., van Hillegersberg, J.: Evaluating the visual syntax of UML: An analysis of the cognitive effectiveness of the UML family of diagrams. In: Softw. Lang. Eng. pp. 16 (2008)
5. Moody, D.L., Heymans, P., Matulevičius, R.: Visual syntax does matter: improving the cognitive effectiveness of the i* visual notation. Requir. Eng. 15, 141-175 (2010)
6. Reijers, H.A., Freytag, T., Mendling, J., Eckleder, A.: Syntax highlighting in business process models. Dec. Supp. Syst. 51, 339–349 (2011)
7. Lohse, G.L.: A cognitive model for understanding graphical perception. Hum.-Comp. Interact. 8, 353–388 (1993)
8. Treisman, A.: Perceptual grouping and attention in visual search for features and for objects. J. Exp. Psy. Hum. Perc. Perf. 8, 194 (1982)
9. Callaghan, T.C.: Interference and dominance in texture segregation: Hue, geometric form, and line orientation. Perc. Psychophys. 46, 299–311 (1989)
10. Snowden, R.: Texture segregation and visual search: A comparison of the effects of random variations along irr. dimensions. J. Exp. Psy. Hum. Perc. Perf. 24, 1354–1367 (1998).
11. Stark, J.: Perceptual Discriminability in Conceptual Modeling. In: Enterprise Engineering Working Conference. pp. 103–117. Springer (2016).
12. Momotko, M., Nowicki, B.: Visualisation of (distributed) process execution based on extended BPMN. In: Database and Expert Systems Applications, pp. 280–284 (2003).
13. Stark, J., Braun, R., Esswein, W.: Perceptually discriminating Chunks in Business Process Models. In: CBI, Paris, pp. 84-93 (2016)
14. O'Donovan, P., Agarwala, A., Hertzmann, A.: Color compatibility from large datasets. ACM Trans. Graph. TOG. 30, 63 (2011).
15. Norman, D.: Emotion & design: attractive things work better. Interactions. 9, 36–42 (2002)
16. Kummer, D.T.-F., Leimeister, P.D.J.M., Bick, P.D.M.: On the Importance of National Culture for the Design of Information Systems. Bus. Inf. Syst. Eng. 4, 317–330 (2012)
17. Hevner, A.R., March, S.T., Park, J., Ram, S.: Design science in information systems research. MIS Quarterly 28, 75–106 (2004)
18. Verschuren, P., Hartog, R.: Evaluation in Design-Oriented Research. Qual. Quant. 39, 733–762 (2005)
19. Genon, N., Amyot, D., Heymans, P.: Analysing the cognitive effectiveness of the UCM visual notation. In: Int. Works, on Syst. Anal. and Modeling. pp. 221–240. Springer (2010)
20. Granada, D., Vara, J.M., Brambilla, M., Bollati, V., Marcos, E.: Analysing the cognitive effectiveness of the webml visual notation. Softw. Syst. Model. 1–33 (2013)

21. Sousa, K., Vanderdonckt, J., Henderson-Sellers, B.: Evaluating a graphical notation for modelling software development methodologies. J. Vis. Lang. Comp. 23, 195–212 (2012)
22. Koschmider, A., Caporale, T., Fellmann, M., Lehner, J., Oberweis, A.: Business process modeling support by depictive and descriptive diagrams. IN: EMISA (2015)
23. Werner, M.: Colored petri nets for integrating the data perspective in process audits. In: Int. Conf. on Conceptual Modeling. pp. 387–394 (2013)
24. Jensen, K., Kristensen, L.M.: Colored Petri Nets: A Graphical Language for Formal Modeling and Validation of Concurrent Systems. Commun ACM. 58, 61–70 (2015)
25. Callaghan, T.C.: Dimensional interaction of hue and brightness in preattentive field segregation. Perc. Psychophys. 36, 25–34 (1984)
26. Healey, C.G., Enns, J.T.: Attention and visual memory in visualization and computer graphics. Vis. Comp. Graph. 18, 1170–1188 (2012)
27. Duncan, J., Humphreys, G.: Visual search and stimulus similarity. Psy. Rev. 96, 433 (1989)
28. MacDonald, L: Using color effectively in computer graphics. Comput. Graph. Appl. 19, 20–35 (1999)
29. Young, T.: On the Theory of Light and Colours, The Philosophical Transaction, 1801. Course Lect. Nat. Philos. Mech. Arts II. 613–632 (1801)
30. Fairchild, M.D.: Color appearance models. John Wiley & Sons (2013)
31. Hunt, R.W.G., Pointer, M.R.: Measuring colour. John Wiley & Sons (2011)
32. Wandell, B.A.: Foundations of vision. Sinauer Associates (1995)
33. ILV, C.: International lighting vocabulary. Vienna CIE. (2011)
34. ASTM. Standard Terminology of Appearance. E284-09a., (2009)
35. Murch, G.: Physiological principles for the effective use of color. Comp. Graph. Appl. 4, 48–55 (1984)
36. Thompson, P., May, K., Stone, R.: Chromostereopsis: a multicomponent depth effect? Displays 14, 227–234 (1993)
37. Birch, J.: Worldwide prevalence of red-green color deficiency. JOSA 29, 313–320 (2012)
38. Meyer, G.W., Greenberg, D.P.: Color-defective vision and computer graphics displays. Comput. Graph. Appl. 8, 28–40 (1988)
39. Miller, G.A.: The magical number seven, plus or minus two: some limits on our capacity for processing information. Psy. Rev. 63, 81 (1956)
40. Cowan, N.: The magical mystery four how is working memory capacity limited, and why? Curr. Dir. Psy. Sci. 19, 51–57 (2010)
41. Bertin, J.: Semiology of graphics: diagrams, networks, maps. Univ. of Wisc. Press (1983)
42. Stevens, S.S.: Psychophysics. Trans. Publishers (1975)
43. ISO 9241, Ergonomic Requirements for Office Work with Visual Display Terminals, Part 12: "Presentation of Information. ISO, Geneva, Switherland (1998)
44. Matsuda, Y.: Color design. Asakura Shoten. 2, 10 (1995)
45. Munsell, A.H., Birren, F.: A grammar of color. Van Nostrand Reinhold (1969)
46. Ostwald, W.: Colour science. (1931)
47. Ou, L.-C., Luo, M.R., Woodcock, A., Wright, A.: A study of colour emotion and colour preference. Colour emotions for single colours. Color Res. Appl. 29, 232–240 (2004)
48. Adobe Color CC, https://color.adobe.com/de (assessed 25/19/2016)
49. COLOURlovers, http://www.colourlovers.com/ (assessed: 25/10/2016)