Coloring support for process diagrams: a review of color theory and a prototypical implementation

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Research Report

Selim Erol

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1 Introduction

The usage of process diagrams to visualize dynamic aspects (e.g. work practices or business processes) of an organization can be considered a common practice in modern organizations Nolte et al. [2011]. Process diagrams can have different flavors reaching from simple hand drawn flow charts to fully fledged process models that were created by means of a software environment and adhere to a modeling standard like BPMN[1], IDEF[2], EPCs[3]. Process diagrams as the visual representation of process models (or an actual process) serve as mediating artifacts and communication aids for process (re-)design activities that involve a large community of stakeholders but may as well be simply used to graphically enrich textual process documentation. Moreover, process diagrams are often used to visualize the result of process mining van der Aalst and Weijters [2004]. Process diagrams consist of graphical elements that are used to denote the various types of entities involved in a business process, e.g. events and activities to model the activity flow of a process and entities that are closely related to activities (e.g. data objects, human actors, software systems). For an exemplary process diagram see figure 1.

In the light of Bertin's renowned *Semiology of Graphics*Bertin [2010] a process diagram can be seen as a graphic system consisting of a set of graphical components. Visual perception of each of these components is influenced through visual variables like *size, value, texture, color, orientation, shape*. While shape and orientation of graphical elements in process diagrams are largely prescribed by the modeling notation (and the implementation of this standard in the software tool) the actual color, texture, size and position of elements is mainly left to the (often unskilled) hands of a modeler. For instance, the BPMN specification is quite determined about the shapes to use for drawing BPMN diagrams but is very unspecific about the use of colors, textures and sizes for shapes and lines. Similarly, a review of state-of-the-art process modeling tools (e.g. ARIS BA, ADONIS, Signavio) reveals

[1]see http://www.bpmn.org
[2]see http://www.idef.com
[3]see Nüttgens and Rump [2002], Mendling [2009]

that only very limited guidance is provided for a modeler in choosing colors that are aesthetically pleasing and at the same time facilitate the readability and understandability of process diagrams.

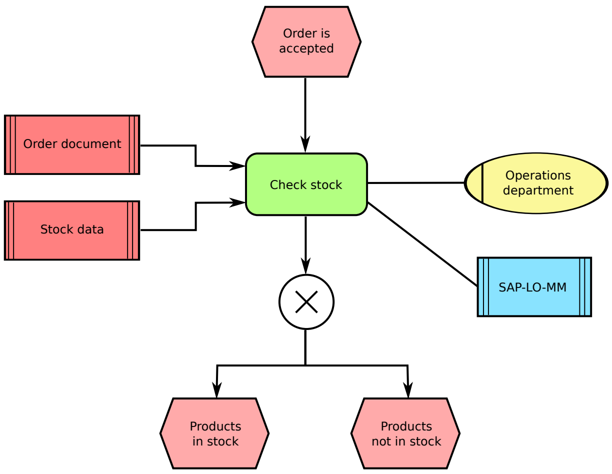


Figure 1: Exemplary process diagram based on ARIS EPC notation

The latter conclusion is strongly supported by our own observations from several years of teaching experience in process modeling courses. Throughout these courses students created hundreds of process diagrams both in individual sessions and in group sessions. We observed two kinds of behaviors. First, some students seem to have a need to color process diagrams whereas others do not. For some students this need emerges quite early as they create their first diagram, others start to color their diagrams in later sessions, others do not color their diagrams at all. Students used colors for pure aesthetical reasons – to beautify – , to emphasize certain parts of a process diagram, to distinguish parts of a process model or to label certain parts. The latter was often accompanied by a legend that explains the meaning (semantics) of colors used. The resulting process diagrams especially when created as part of a group task revealed a certain arbitrariness or inconsistency regarding the colors used. In fact, both from an aesthetical point of view and a technical point of view colors were often misused in a way that detracted readability, distracted from capturing important facts and in the worst case led to severe misunderstandings.

Driven by insights from prior research on the effectiveness of colors (see next section) and our personal observations we strive to initiate research in the effective use of colors in process visualizations with the goal to provide practical guidance for designers of modeling environments and modelers at the same time. In this paper we first reflect on the importance of color for human visual perception and cognition. Second, we elaborate on the theory of color harmony and it's potential application in process visualization. Finally we present an exemplary implementation of an assistive color selection feature in a process modeling environment.

The role of colors in human perception, cognition and emotion

From wavelength to color

Color is just one of many dimensions (e.g. shape, motion and depth) by which humans interpret their visual environment and create appropriate behavior [Nassi and Callaway, 2009]. From a pure physical point of view the color of an object is a human label for the wavelength of light emitted or reflected by the object under observation. As light is processed by the human eye and brain a wavelength gets associated to a human category for color [Roberson et al., 2005]. Humans in contrast to many other species are trichromatic, meaning that they reveal three kinds of retinal receptor cells that respond differently to specific wavelengths. Sensation of color is determined by which combination of these perceptors are excited and by which intensity. Humans are able to detect a rather large spectrum of light ranging from about 400nm to 830nm under normal viewing conditions [McEvoy, 2009]. Depending on conditions humans are able to discern between a hundred thousand to several millions of colors. Hence, the number of discernible colors is heavily discussed among researchers [Linhares et al., 2008]. The ability to distinguish colors does not apply to about ten percent of world population who have partial or full color deficiencies, e.g. red-green blindness .

The receptors a human's retina reveals differ in their sensitivity to certain wavelengths. Basically, three types of receptors are distinguished for normal daylight vision where one type is highly sensitive for light of short wavelengths (blueish), on type is highly sensitive for middle wavelengths (greenish) and the third type peaks at long wavelengths (reddish). Their combined stimulus produces an electrochemical cascadicing process [Milner et al., 2006; Nassi and Callaway, 2009] that results in a stimulus of brain areas and finally in our perception of color.

While the spectrum of wavelengths is continuous, humans' labels for colors are not. That is, we use discrete labels for ranges of wavelength we can perceive, e.g. violet, blue, green, yellow and red. Only few of the colors we may discriminate have been given concrete names. For example, the CSS3 standard [4] lists 147 named colors. Similarly, a large web based survey resulted in more than 130.000 unique color labels which was then semantically reduced to a set of 153 final color labels [Heer and Stone, 2012]. Color labels and language specific variations herein have been found to affect human perception and object classification which has led to a variety of theories describing how people associate names and colors (see for example [Kay and Regier, 2006; Regier et al., 2009]).

Colors and human cognition

Studies on human object recognition in the field of cognitive neuroscience and psychology state that under certain circumstances color is used by humans as a visual cue in identification of objects [Biederman and Ju, 1988]. For instance, [Price and Humphreys, 1989] found that colors are helpful in object recognition when color diagnosticity of the object is high, e.g. yellow is diagnostic for a *banana*. Natural objects – in comparison to artificial objects – are usually more consistent in their coloring and therefore are stronger related to a color category. Moreover, colors can improve object recognition when the perception of an object's shape is deteriorated because of similarity, occlusion or low vision [Wurm et al., 1993; Tanaka and Presnell, 1999]. Experimental observations of [Rossion et al., 2004] show that object recognition under normal conditions is facilitated by the presence of color information, and that a combination of shape and surface properties (color, textures) significantly improves object recognition. Complementary to simple (isolated) object recognition several studies do not state a substantial advantage of colors in object recognition in the context of natural scenes [Spence et al., 2006; Castelhano and Henderson, 2008]. Yao and Einhäuser [2008] have differentiated object recognition in detection and recall tasks. Their findings indicate that color modulates the subjective confidence in one own judgement of object recognition but has no effect on actual detection rates.

[4] http://www.w3.org/Style/CSS/current-work.en.html

Benbasat et al. [1986] studied the effects of color in graphical reports on managerial decision making processes. They found that individuals performed better when using multi-colored graphical reports as a basis for their decisions that those that had mono-colored reports at hand. An interesting finding in this early study is that the benefits of color for indidividuals performance in the decision making process dropped sharply in the course of the exercise, meaning that color was perceived less important for learning, comprehension, and information discrimination in the long run. A more detailed investigation on the effects of color in graphical data representations on time and accuracy performance in an information extraction task has been contributed by [Hoadley, 1990]. The study revealed that usage of color increases time and accuracy performance for certain types of graph based information extraction while it did not increase accuracy performance when tabular formats of information presentation were used. A more recent study found that combination of color and information location cues improve information selection and processing speed, along with user satisfaction [McNab, 2009].

The above cited empirical studies on the effects of color indicate that color plays a role in visual information processing. Especially in object recognition tasks, the extent to which and under which circumstances is still not well understood [Castelhano and Henderson, 2008] and seems to be dependent on other variables like the type of task to perform, the viewing conditions, the timespan available and other visual features of an object like shape and position. However, in information extraction and subsequent cognitive tasks an increase in speed and accuracy has been stated across several studies.

Colors and aesthetic response

As colors have ever since been used in art, architecture, product design and as well information visualization a stream of research has focused to provide insight in theories regarding human preferences for colors or humans' aesthetic response. All these studies assume that colors have a certain effect on the emotional or affective state of a human [Valdez and Mehrabian, 1994; Ou et al., 2004] and that this effect can be measured somehow.

The literature in the area of color preferences is vast and reaches back to early and often cited studies of Eysenck [1941] and Granger [1955]. Since then numerous studies have led to the insight that humans have innate preferences for colors which can be observed in infancy but change these preferences in later stages of development. The variables that are responsible for changes and differences in color preferences are partly identified but are far from being well understood and empirically validated. In the following several recent studies are summarized that build upon prior research in the field and therefore give an idea of the current state-of-research.

Lobue and Deloache [2011] give an account of the state of color preferences in early stages of human development. Accordingly, a general finding is that infants prefer primary colors (e.g. red and blue) over secondary colors (e.g. pink, orange). Some studies report infants preferences for blue while others report a general preference for red. Taylor et al. [2013] found that these discrepancies in infants' hue preferences are due to variations in lightness. Lobue and Deloache [2011] compared preferences of children throughout the first months and found that children older than 2.5years change their preferences dependent on their gender. This might indicate that social factors influence color preferences to some degree in later stages of development.

In [Palmer and Schloss, 2010] the authors provide evidence that adults have a general preference for colder (short wavelength) blue and purple hues over orange, yellow and greenish hues. This general order of preferences in adults has several restrictions which are partly explained by cone-contrast and gender differences [Hurlbert and Ling, 2007], or individuals' emotions regarding particular colors [Ou et al., 2004], or current associations of colors with objects [Strauss et al., 2013]. Recently, Taylor et al. [2012] evaluated theories of color preferences (see above) across two culturally distant groups of people (one Himba and one British) and found severe limitations in the applicability of these theories for non-industrialized non-consumer cultures.

Preferences for combinations of colors have been found to depend only partly on preferences on individual colors. Schloss and Palmer [2011] have evaluated perceptual responses to color combinations by measuring (1) people's aesthetic preference for a given combination, (2) their perception of harmony for that combination, and (3) their preference for its figural color when viewed against a colored background. These distinct concepts of preference were used as an answer to prior research which produced confusing results regarding color harmony. Their findings indicate that color pairs that are similar in hue are more preferred/perceived harmonious than colors which are strongly different in hue. Additionally, their studies revealed that cooler colors are preferred on warmer backgrounds and vice versa. In addition, colors placed on backgrounds with contrasting lightness are preferred. The factors that primarily influence pair preferences appear to be preferences for single colors (of the individual figural color and/or ground color), perceived harmony, lightness contrast, and figural preference against a colored ground. Nemcsics [2009] mainly confirms the above cited findings but found as well an influence of relative surface coverage of colors and demographic factors like gender, age cultural and social state of the observing subjects.

Again we can summarize that research is far away from a general theory on what influences humans' preferences for individual colors and to what extent it can explain individual differences. However, existing theories have revealed some of the determinants and mechanisms that drive humans' aesthetic response to individual colors and combinations hereof.

Models of color

Colors ever since have been used and reasoned about in art, craftsmanship and industry. In particular artists and naturalists alike strove to describe colors in a way that enabled the consistent naming of colors across different contexts of use. Fur this purpose indexes of colors (so called *color atlases*) were developed that contained physical examples of colors (e.g. flowers, fruits, minerals) and respective names (e.g. lemon, rose). Based on Newton's findings regarding the spectral composition of day light and identification of primary colors also more scientific approaches led to so called *color spheres* which arranged colors in a geometrically defined space. Geometrically defined space means that colors are described through a set of variables that can be quantified and mapped within a geometrically defined space. From Runge's color sphere to Munsell's color cylinder numerous models have emerged that emphasize different aspects of color creation or perception (for a complete account of historical and current color models see [Kuehni, 2003] and [Fischer et al., 2011]).

Probably one of the most fundamental achievements in color models is the insight that there exists a set of primary colors with which all other colors can be simulated through combination. For subtractive combination of colors – as usually practiced in painting or printing where material colors are mixed (e.g. pigments or dyes) to create other colors – the primary colors used are cyan (blue), magenta (red), and yellow. For additive combination of colors, as realized in light emitting devices such as CRT[5] displays, the primary colors are red, green, and blue.

A further achievement was the finding that colors in terms of primaries can best be mapped

[5] Cathode ray tube

to human perception of color through variables like hue, lightness and saturation which led to the modern color systems like the Munsell Color System or the HSL color space (for a in-depth discussion of historical background of color models see for example [McEvoy, 2009] or [Kuehni, 2003]). Each of these models is intended to specify colors through a set of measurable and independent variables and to place each color in a measurable or computable relation to other colors.

Color models are used across various domains. In art and design usually guidelines and principles for using colors are based on simple color models (also called color matching systems) like the RAL, Pantone system, or the Swedish Natural Color System (NCS). These standardized color models allow to specify or identify colors in an unambiguous way which is especially important in printing and manufacturing. Other models like the CIE family of models aims at specifying colors through amounts of the three primary colors (tristimulus values) and is mainly used as a reference for determining colors through physical measurement of spectral distributions.

Principles of color use

In art and related domains like architecture, product design, (computer) graphics and as well information visualization quite soon researchers and practitioners have focused on finding general principles in the specification, classification, creation and application of colors independent of subjective judgments. These efforts led to a variety of principles that claim to support practitioners in selecting aesthetically pleasing colors and combinations hereof. In art these principles are commonly subsumed under the term "color theory".

The first class of principles ranges from the concept of color temperature, where the long wavelength colors (reddish) are usually regarded to be warm colors and short wavelength (blueish) colors are attributed to be cold. Warm colors are often considered to make objects seem larger and closer in the eye of the beholder. Highly saturated hues and tints (color with a large proportion of white) usually can be used to emphasize an object among others that is why they are recommended to be used for foreground objects. Applying strongly saturated colors to an object attracts attention but can as well be tedious to look at for a longer time if not used sparsely Bleicher [2011]. Feisner [2006] outlines that cool colors for backgrounds increases the perceived depth of an image which is often referred to as atmospheric perspective. Background colors can amplify temperature of foreground colors, e.g. a warm background makes a cool foreground seem even cooler and vice versa. Feisner proposes to use colors in accordance with the general principles and elements of design: rhythm, balance, proportion, scale, emphasis, and harmony.

The second class of principles is concerned with color harmony. That is how colors should be used to be aesthetically pleasing. These principles have evolved through early works by Goethe, Itten and Birren [Kuehni, 2003] and have often been scientifically challenged [Schloss and Palmer, 2011; Nemcsics, 2012] (see also above).

Traditional color harmonies frequently found in art are mainly based on simple color models (color wheels) where hues are arranged in a circular manner. Harmonious colors are then obtained by variation of hue, saturation or lightness. In the following we will give some example of such principles. A comprehensive account of color application principles is given in sources like [Itten and Birren, 1970; Bleicher, 2011].

- **Monochromatic harmony** is made of a single hue that varies only in saturation and lightness.
- **Analogous harmony** assumes that neighboring hues on the hue circle with *equal or similar hues* are perceived harmonious.

- **Complementary harmony** is given if colors of *complementary hue* are used. Complementary in therms of the color wheel are colors that are roughly located on opposite sides. Any variation in lightness and saturation may be used as well.
- **Equilateral harmony** is reached through colors that form an equilateral polygon on the color wheel. In other words colors which are equidistant in hue.
- **Split complementary harmony** means color combinations that consist of a complementary color pair combined with analogous hues to one of them.

The above simplified summary of color harmony principles has been refined and extended by researchers in various ways. Several researchers have tried to provide empirical evidence for these rather dogmatic but frequently used principles. For example, [Munsell, 1912] postulated that harmonious colors are found along certain paths in his three-dimensional color space. Namely, along colors that reveal (1) an equal *value*, (2) an equal *value* and *chroma* or (3) an equal *hue* and *chroma*. According to Munsell also colors are harmonious that are obtained by equally varying the three variables regarding their sign and value. Nemcsics [Nemcsics, 1987, 2012] similarly suggests *hue*, *saturation* and *lightness* as variables and a mathematical model to compute a color space from variations of these variables. Based on this model Nemcsics postulates several color harmony principles: accordingly colors harmonize if (1) their differences in *hue* are in-between a certain interval, (2) their differences in *saturation* and *lightness* is equally distributed in value. His color model is driven by the insight that a designer is not so much interested in actual differences between colours as their harmonious interplay and that a model is needed that offers a systematic way of planning color combinations.

Truckenbrod [1981] and Murch [1984] where upon the first to discuss the effective use of colors for computer graphics. Truckenbrod [1981] points to the importance of colors as it has the potential to increase the amount of perceivable information that can be injected into, or extracted from, a visual image. Murch [1984] in contrast postulates several principles of effective color use on computer displays that take into account physiological aspects of the human eye. For example, he suggests to avoid red and green in the periphery of large-scale displays because the retinal periphery is insensitive to reds and greens. MacDonald [1999] extends this set of principles with regard to the purpose of a respective graphics. MacDonald provides a rather comprehensive set of guidelines but points as well to his finding that there are "no easy formulas guaranteed to work in all circumstances". In the domain of information visualization colors were quite early recognized as a means "to label (color as noun), to measure (color as quantity), to represent or imitate reality (color as representation), and to enliven or decorate (color as beauty)" [Tufte, 1990]. As a consequence many principles from art and design can be found as well in the context of information visualization. The domain of information visualization can be regarded as the primary point of reference for research in the effective use of colors for process visualizations (see for example [Ward et al., 2010; Ware, 2013]) as it combines peculiarities of computer graphics with general findings in graphics and art. Though, process visualizations in particular are not have several unique characteristics which we will discuss in the following section.

Aspect-oriented auto-coloring of process diagrams

Based on the findings from the literature review an approach is presented that allows for auto-coloring of process diagrams. The approach takes the various aspects a process diagrams reflects as a basis for computing a set of aesthetically pleasing colors and at the same allows to takes into account practical constraints that ensure readability and usability of a process diagram.

Aspects

Process diagramming is a particular technique for articulating models of a business process. Depending on the notation process diagrams may be able to reflect multiple aspects of a 'real-world" process (or process model), e.g. the flow logic of activities – that is their timely and logical sequence and alternatives hereof – but also organizational units and roles participating, software and hardware components involved, materials and energy consumed, data objects associated and messages exchanged during the flow of activities.

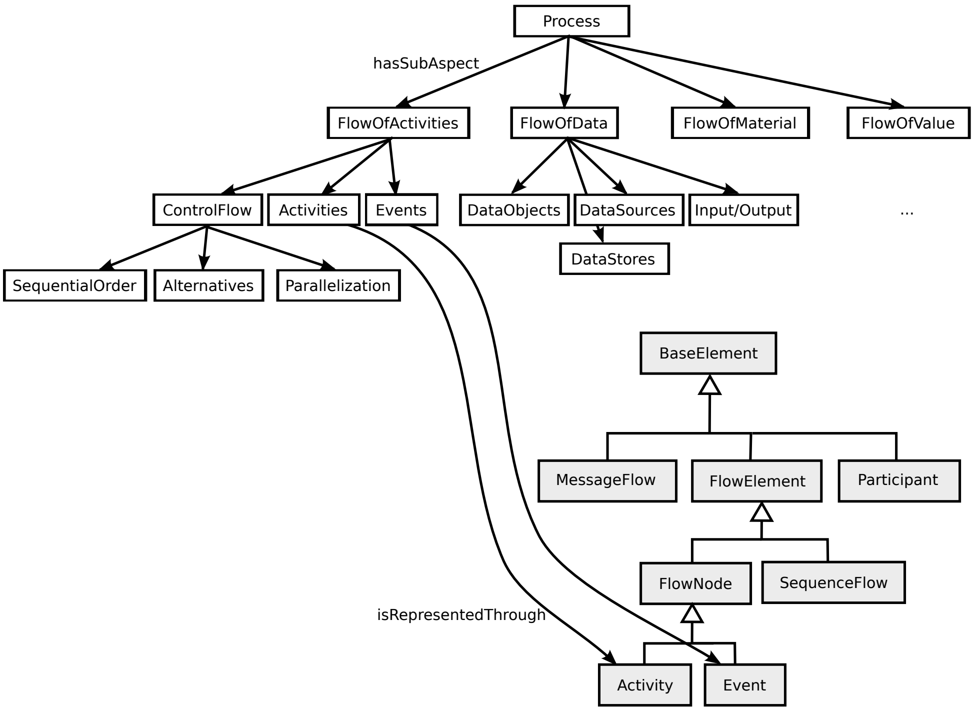


Figure 2: Possible aspects of a process and their relation to BPMN 2.0 concepts

For some purposes the meta-model a modeling language is built upon may be sufficient to derive aspects. For other purposes it makes sense to create a separate aspect model. In figure 2 an exemplary taxonomy of aspects is shown. Within this taxonomy various sub-aspects of a process (as the root aspect) are shown on multiple hierarchical levels. The aspects are shown in relation to BPMN modeling concepts that are relevant for a specific aspect. In the example the BPMN classes `Activity` and `Events` are chosen to reflect the `FlowOfActivities` aspect.

We consider an aspect a certain perspective or view on a process model that a user takes in a certain situation. We argue that current modeling languages do not sufficiently refer to the concept of aspects although a meta-model may provide a basis to derive key aspects of a model. We also argue that a specification of aspects is a prerequisite for any process visualization to be effective. Actually, an aspect taxonomy allows to systematically identify which aspects are expressed through which visual features of a graphical modeling notation and which aspects are not sufficiently covered by the notation. Additionally, an aspect taxonomy may be used as a basis to configure visualizations. For example, aspects may exhibit a `weight` attribute that enables a modeler to specify the relative importance of an aspect which in turn can be used to choose a respective visual feature.

Colors

Process diagrams typically are based on the concept of process graphs where nodes represent the conceptual building blocks of a process and edges are used to relate these concepts. In a diagram different node types (different concepts) are expressed through different shapes and edges (relations) are represented by lines or arcs to indicate a certain direction of a relation. The diagram itself is placed on a canvas which marks the visual borders and background of the drawing. Shapes have borders and fills which can be varied by color or texture.

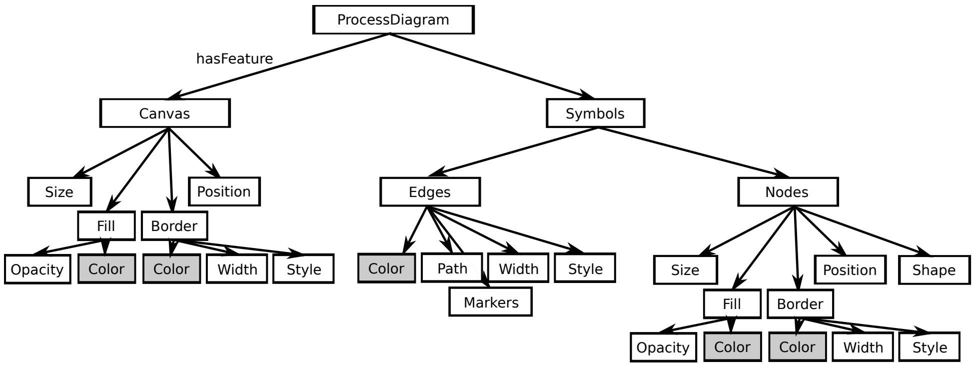


Figure 3: Visual features of process diagrams

Diagrams are a feature-rich means to represent a process model. In figure 3 features of a typical diagram notation are shown. Modeling languages like BPMN, IDEF and EPCs usually specify only shapes and their basic style to be used whereas modelers are free to choose size, color of shapes, text, borders and lines. For example, in BPMN 2.0 activities and events both part of the same aspect `FlowOfActivities` are distinguished by their shape, a rounded rectangle for activities and a circle for events whereas the higher-level aspects like `FlowOfActivities`, `FlowOfData` are not explicitly addressed by a visual attribute. Having an aspect taxonomy along with a feature model of a graphical notation allows us to map visual features to aspects. Thus, identifying the gaps of a graphical notation or the potential visual features that we can use to outline additional aspects.

As can be seen from figure 3 color is one visual feature among others that can be used to outline/distinguish aspects of a process model that are not covered by other visual features. In the approach presented here we focus on the shortcoming of process modeling notations and tools in providing user support for diagram coloring. We make use an aspect model to determine the number of colors needed to distinguish aspects from each other and as a means to emphasize certain aspects of a process visualization. The method proposed takes into account the number of aspects of a process model and the constraints of context, contrast and comfort to ensure usability of the resulting process diagram.

Constraints

Context constraints. Process diagrams are usually created as part of some higher-level activity such as a business process redesign, modeling or documentation activity. Artifacts (process manual, process pages in a process portal, presentation) resulting from these activities often need to adhere to corporate design guidelines that define the principal colors and fonts to be used. A process diagram therefore needs as well to follow these guidelines to be usable within a corporate context. A color usage guideline may vary from the specification of a set of foreground colors and background colors to a more relaxed specification of a principal color range. In our approach we assume that a foreground color range (shape fills and line colors) along with one background (canvas) color is sufficient to describe the color context. Using the HSL color model Joblove and Greenberg [1978] each color c can be specified through a vector in a three dimensional sphere. Thus, a single color is defined through it's hue h, saturation s and lightness l values, $c_{F,i} = (h_{F,i}, s_{F,i}, l_{F,i})$. Assuming the range of colors to be used is restricted we formulate a constraint where each color from a set of colors $C = \{c_{F,0}, c_{F,1}, ..., c_{F,n}\}$ (the color scheme) must lie within a certain range specified by respective min, max values for hue h, s and l as the lower and upper bounds of the foreground color range.

$$\forall c_{F,i} \in C : h_{F,min} \leq h_{F,i} \leq h_{F,max} \;\wedge\; s_{F,min} \leq s_{F,i} \leq s_{F,max} \;\wedge\; l_{F,min} \leq l_{F,i} \leq l_{F,max}$$

The background color c_B is defined through fixed values for it's hue h_B, saturation s_B and lightness l_B.

$$c_B = (h_B, s_B, l_B)$$

Contrast constraints. Contrast is defined as the difference between luminance of two different colors. In order to maintain the recognizability and readability of diagram elements against their background a certain contrast has to be maintained. In diagrams this constraint is of relevance both for shapes and text elements. To check each color combination whether it fulfills a minimum contrast we make use of a heuristic provided by the Web Content Accessibility Guidelines Version 2.0 [6]. The heuristic specifies a contrast threshold that needs to be satisfied. It proposes as well a model that allows to compute the contrast of a given color combination. The model suggests a method to compute the relative luminance of a color specified by it's RGB color components. Setting the relative luminance of a background color to it's font color gives a ratio that must not exceed the given threshold. The luminance of a color is computed from its corresponding RGB (red, green, blue) values.

$$lum(c_{F,i}) \coloneqq 0.2126 * r_{c_{F,i}} + 0.7152 * g_{c_{F,i}} + 0.0722 * b_{c_{F,i}}$$

where r, g and b are obtained through a transformation from h, s, l values. The transformation algorithm is described in Smith [1978]. Which leads to the formulation of the contrast constraint.

$$\forall c_{F,i} \in C : \frac{lum(c_{F,i}) + 0.05}{lum(c_B) + 0.05} \geq 4.5$$

[6] http://www.w3.org/TR/WCAG20, accessed on 2014-01-20

Comfort constraints. According to color theory a color scheme (a set of colors) that is perceived as aesthetically pleasing needs to adhere to the principles of color harmony as summarized in MacDonald [1999]. Accordingly, different models of harmonious color combinations exist that define relations between colors according to some color model. In our approach we make use of two principles: *equilateral harmony* where foreground colors (hues) are distributed evenly across the whole range of hues and *analogous harmony* where foreground hues must be distributed evenly across a hue range given. The first principle can be captured as a special case of the latter which we call equidistant color harmony. This principle allows to take into account a prescribed color range (e.g. from a contextual constraint) or any other hue range as a basis for computing a set of harmonious hues. We formulate this constraint as a condition for all colors $c_{F,i}$ of a color scheme C where the distance between neighboring hue values must equal the distance between the maximum hue value and the minimum hue value divided by the number of colors given.

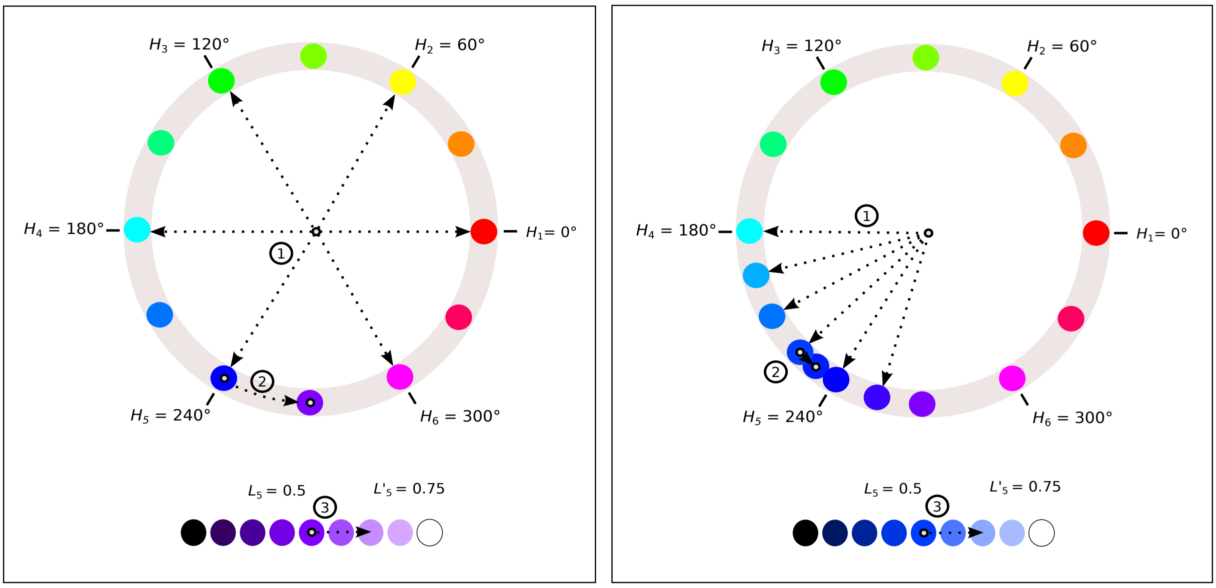
$$\forall c_{F,i} \in C : |h_{F,i} - h_{F,i+1}| = \frac{|h_{F,min} - h_{F,max}|}{n}, with\ 0 < i < n$$

Algorithm

As a formal basis for computation of colors we have chosen the HSL color model Joblove and Greenberg [1978]. The HSL color model uses three color making attributes (or variables): hue, saturation and lightness. *Hue* corresponds to the term color as used in common language. *Saturation* refers to the chromaticity of a color where saturation can vary between 0 (completely chromaless colors such as gray) – and 1 (intense or highly chromatic color such as pure red). Finally, *lightness* is related to reflectance evaluated against the reflectance of a white standard. In other words, the lightness of a color can vary between 0 (dark, perceived as black) and 1 (bright, perceived as white). The three dimensions used within HSL color model refer largely to the concepts commonly found in color theory (e.g. the Munsell color model) and heuristics regarding the effective use of colors. Furthermore, the HSL color model is mathematically transformable into the RGB color space [Joblove and Greenberg, 1978] which makes it possible to implement it in a respective software tool. The RGB color space is the basis for light emitting devices such as computer monitors. It is based on the assumption that any perceivable color can be additively mixed from three primary colors: *red*, *green* and *blue* and is therefore widely used in computer graphics.

Based on the HSL color space and the number of aspects within the process diagram an initial set of colors is determined. The number of aspects to be considered for computing a set of colors is automatically derived from the process diagram. To be more precise only the aspects from a preselected level are considered. For example, if the process diagram covers only the `FlowOfActivities` then all sub-aspects may be the level to be considered. If the diagram includes as well the `FlowOfData` aspect then only aspects on this level are considered for computing related colors. Theoretically a multi-level approach is as well appealing but increases the complexity of color selection.

In the following we limit our considerations to shape fills only to reduce complexity. For the background we assume white and for text fonts and shape borders we assume black color as the colors of choice. Figure 4 depicts the three dimensions of the HSL color model and the principal steps performed by the algorithm. For the initial step a set of equidistantly distributed hues is picked from the HSL color cylinder (→ ①) according to the number of aspects and the hue range given. Saturation and lightness are set to initial values as for example specified by contextual constraints. In a second step each color of the computed set of harmonious colors is evaluated against the contrast constraint and in case it exceeds the threshold color attributes are adjusted. This adjustment is performed by a slight variation of the hue. If a variation of the hue value does not fulfill the contrast constraint the lightness level of colors is varied until the contrast constraint is fulfilled (→ ③).



(1) (2)

Figure 4: Computation of a color scheme based on equilateral and equidistant distribution of colors within a given hue range

All steps are executed in an iterative manner, that is step 1-3 are repeatedly performed until a satisfying combination of colors is found. In the computation sketched above we assumed full saturation and an equilateral distribution of all hues on the color wheel. This is actually a special case where no contextual constraint is given, e.g. a principal foreground color that prescribes the hue range and saturation to be used. Such scenarios are actually special cases of the equilateral case where hue value must be picked from within a predefined hue range (see also figure 4). As a consequence hue values may be varied only to a very limited degree and the third step gains even more importance to gain sufficient contrast.

Implementation

The above described concept was implemented as a graphical user interface component for the graph modeling widget `graphel`. `graphel` is based on HTML, SVG and JavaScript. It is intended to be integrated into any web-based modeling environment and provides stencil sets for several process modeling notations, e.g. BPMN, EPCN. Process diagrams are rendered through SVG elements which can be interpreted by state-of-the-art web browsers.

The user interface component is visible through a button element that is integrated as an extension to the editors tool bar. It unfolds as a list with multiple lines where each line represents an aspect and a color palette. The aspects and color palettes are computed according to the above described approach. A user may then choose a color for each aspect manually or may request for a random suggestion. It is also possible to choose colors for selected aspects and subsequently trigger automatic

Input : n as integer, $h_{F,min}, h_{F,max}, s_0, l_0$ as vector, con_{min} as double
Output: C, c_F as vector
Data: h, l as integer

$d_F := (h_{F,max} - h_{F,min})/n$

$h := h_{F,min}$;
$c_F := c(h, s_0, l_0)$

```
//for each hue value check contrast constraint
while h ≤ h_F,max do
    //compute initial color value from new h and s_0, l_0
    c_F := c(h, s_0, l_0);
    //check contrast for c_F and increase until above threshold
    while con(c_Font, c_F) < con_min and l < 1 do
        //increase lightness value
        l = l + 0.01
        c_F := c(h, s_0, l)
    end
    //append to set of colors (resulting color scheme)
    append(c_F, C)
    //next hue
    h := h + d_F
end
```

Algorithm 1: Pseudo algorithm to compute a harmonious set of colors

assignment of colors to remaining aspects. Color choices are immediately applied to the diagram. The aspect model is specified through XML. This allows for a flexible extension regarding the modeling language concepts that realize an aspect. The aspect model specification along with the process model specification has been used to automatically derive the aspects for coloring.

Figure 5 shows a screenshot of the process modeling editor and the implemented color picker. It shows a situation where one color has been picked for the `FlowOfActivities` aspect only and all other colors have been automatically retrieved. The predefined relatively narrow color range in figure 5 leads to very balanced color combination. In contrast figure 5 shows a more vivid color combination. In figure 7 additional examples of renderings are shown both for a wide hue range and a narrow hue range. In the latter example only the low level aspects are taken into consideration, namely `Activities`, `Eventy`, `ControlFlow`.

Conclusion and Outlook

In the above presented sections principles from color theory were discussed with regard to the peculiarities of process diagrams. A modeling language independent aspect taxonomy is suggested as a basis for determining the number of colors to be used and to define the relative importance of an aspect. Along with the aspect model several general constraints are formulated that are subsequently used to derive a computational model for computing a set of applicable colors - a color scheme. Through a prototypical implementation the feasibility of the approach is demonstrated.

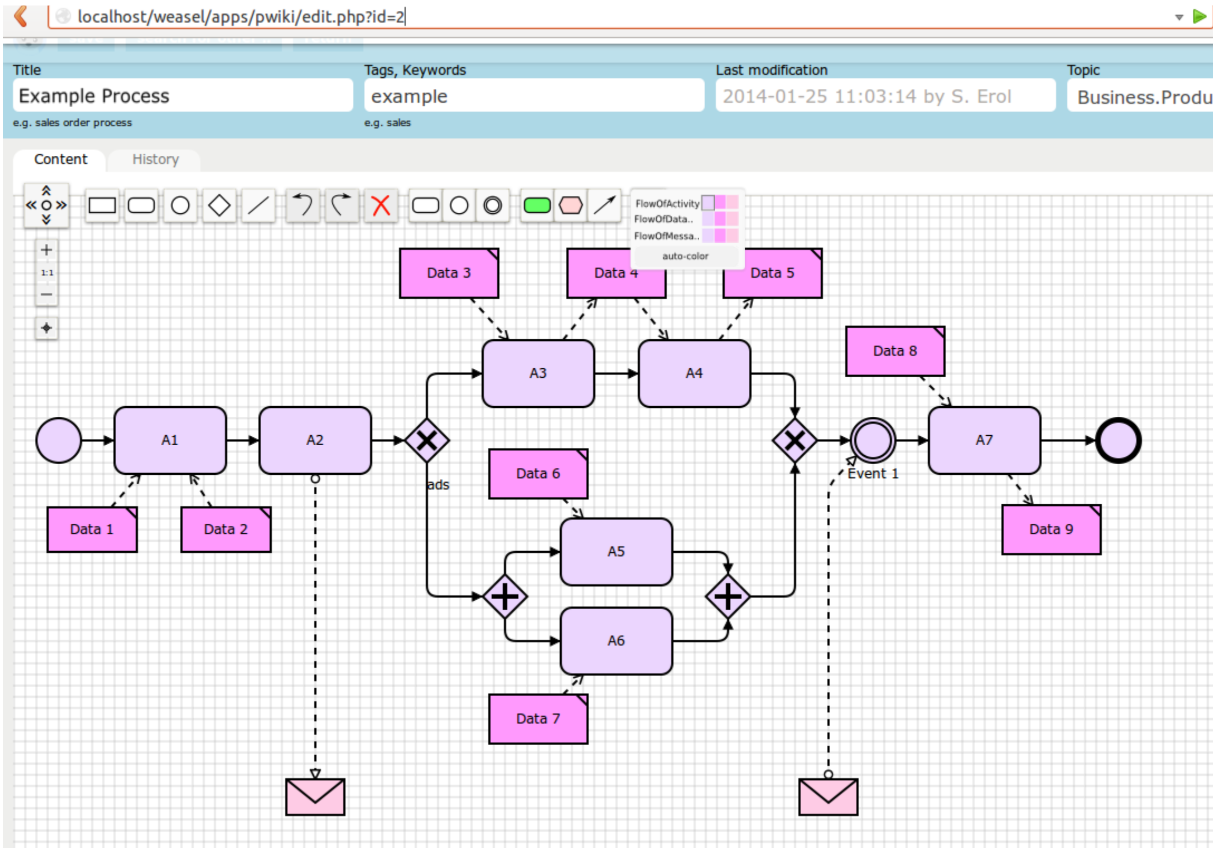


Figure 5: Screenshot of color picker. BPMN process diagram that containing three different aspects, `FlowOfActivities`, `FlowOfData`, `FlowOfMessages`, with repective coloring. The hue range used varies from $h_{F,min} = 272$ to $h_{F,max} = 360$.

The approach presented is a first step towards providing theoretical and empirical foundations for effective coloring support in process modeling environments. In this reort only a short account of color theory in the domains of art, design and graphics is given. Especially, the fields of information visualization and cartography need a more detailed review to identify potentially related work (see for example Harrower and Brewer [2003], Seyfang et al. [2013]). The color combinations computed according to our approach need thorough evaluation with regard to understandability, readability and usability. The implemented feature is restricted to suggesting color schemes for shape fills only whereas colors for borders, arcs and text are not considered so far. Another limitation is that only one color harmony model was integrated so far. The color picker as integrated in `graphel` needs as well evaluation regarding the effectiveness and efficiency of use. In future research activities the mentioned shortcomings will be addressed.

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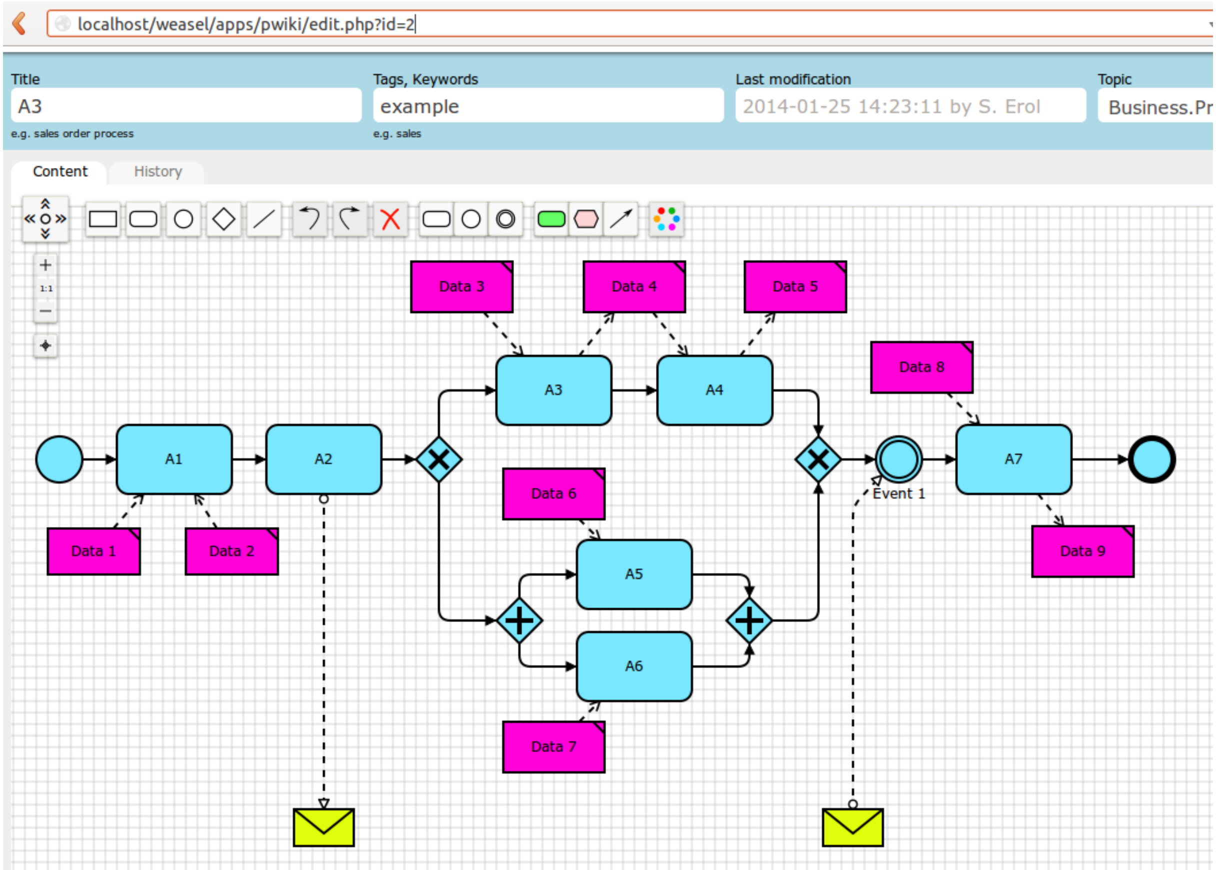

Figure 6: Screenshot of color picker. BPMN process diagram containing three different aspects, `FlowOfActivities`, `FlowOfData`, `FlowOfMessages`, with repective coloring. The hue range used varies from $h_{F,min} = 135$ to $h_{F,max} = 29$.

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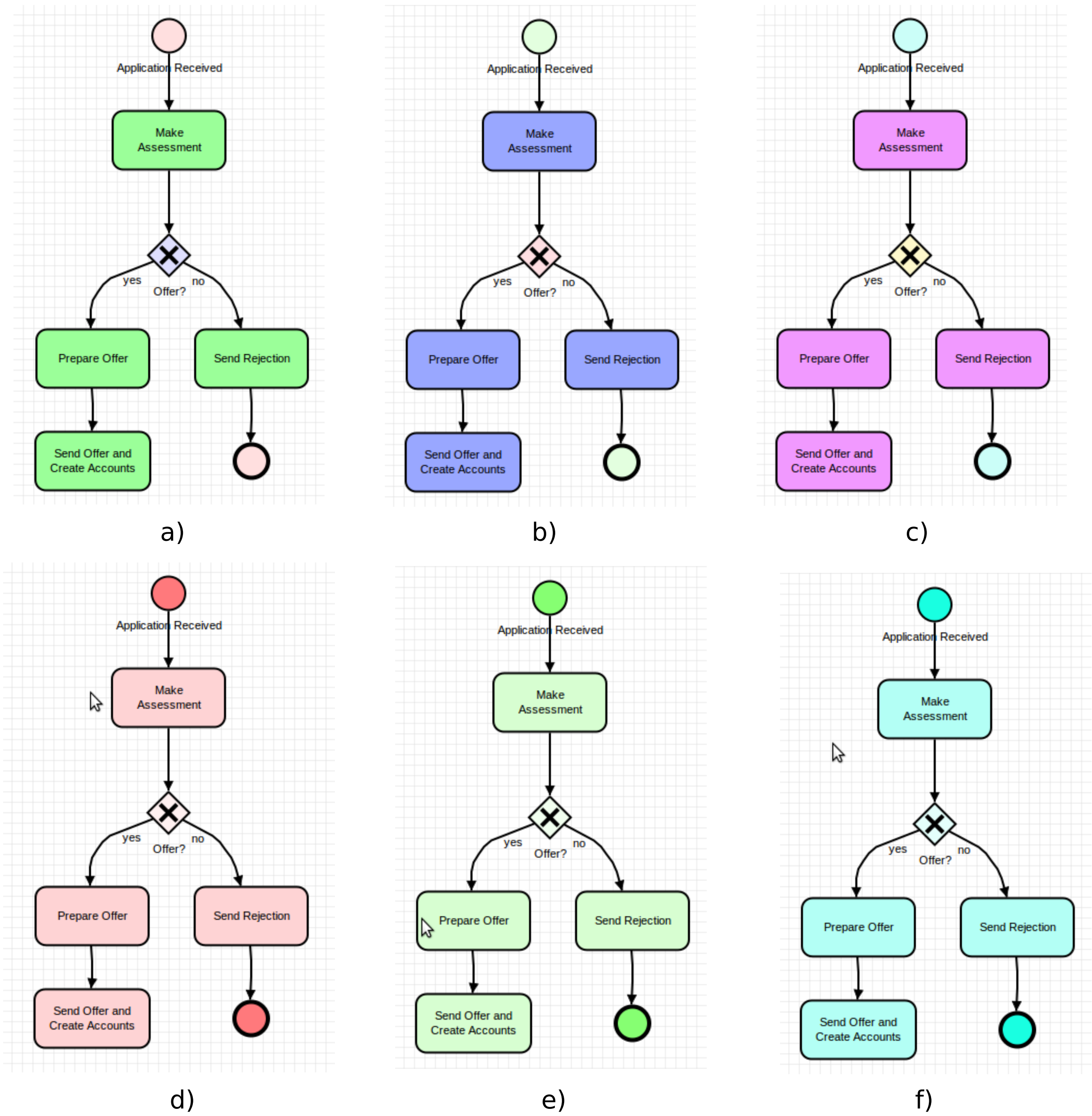

Figure 7: Examples of computed color sets applied to a process diagram:a)-c) without and d)-f) with predefined color range