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USING SECONDARY NOTATION TO IMPROVE THE COGNITIVE EFFECTIVENESS OF BPMN-MODELS

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Research paper

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Abstract

Almost every implementation of a modeling grammar uses secondary notation to further specify a modeling grammar. Yet, secondary notation is usually applied in an unsystematic way, might contradict what is specified in primary notation and implements research results that should rather be implemented in primary notation. With this work we aim at showing how secondary notation can be used to implement recent research results that are not yet available in primary notation without contracting what is already specified in primary notation. We demonstrate a systematic update of recent research of extended Perceptual Discriminability for BPMN secondary notation and that way, show how research results can quickly be made available for practice without contradicting primary notation. We choose Perceptual Discriminability as it can be used to focus the model user's attention on the most important constructs and can that way, improve model comprehension. For an update of BPMN secondary notation we first specify free BPMN variables and further show how these variables can be used to focus the model user's attention on those constructs that most foster comprehension.

Keywords: BPMN, Secondary Notation, Perceptual Discriminability, Pop-out.

1 Introduction

Business Process Models are increasingly used among practitioners to support information systems design, process improvement or shared understanding (Mendling, Strembeck, and Recker 2012; Indulska et al. 2009). In particular, the Business Process Modeling and Notation (BPMN), that has replaced competing standards and is maintained by the OMG, is widely used in industry (Genon, Heymans, and Amyot 2010). Practitioners who use BPMN are either method experts or method novices. In case they are method novices they require a modeling grammar that can easily be used and conveys information fast and accurately and which is thus, cognitive effective (Moody 2009; Mendling, Reijers, and van der Aalst 2010). GENON, HEYMANS, and AMYOT (2010) have analysed the cognitive effectiveness of BPMN 2.0. They acknowledge that BPMN visual notation does better than many other notations for the following reason: Before BPMN constructs were defined other notations had been reviewed and also a detailed description for BPMN 2.0 graphical notation is available (OMG 2011). However, GENON, HEYMANS, and AMYOT (2010) also discuss various problems including design choices that are not grounded in theory and several existing suggestions that were not regarded. Although there are a lot of ideas how to increase the cognitive effectiveness of BPMN (e. g. (Genon, Heymans, and Amyot 2010; Mendling, Reijers, and van der Aalst 2010), these ideas are not yet available in the formal definitions of the modeling grammar's visual notation (primary notation). There are several explanations for the missing integration of recent solution in primary notation: First, notation designers do usually not treat visual notations as important as semantics (Moody 2009) and it is common practice not to ground decisions for visual notations in theory (Genon, Heymans, and Amyot 2010). Second, integrating recent research requires notation designers to constantly review prior research which is very time-consuming and third, an update of an OMG standard requires to work on several steps each requiring its time (Morales-Trujillo, Oktaba, and Piattini 2015). As these reasons impede a fast update of primary notations, we are usually not able to design those cognitive effective models that are discussed in recent research papers.

Modelers do usually not use primary notations of modeling grammars, but rather use a tool-specific implementation. Such an implementation typically bases on the primary notation and can further offer improvements that go beyond what is defined in primary notation such as visual cues and layout (Schrepfer et al. 2009) which are addressed within secondary notation. Secondary notation treats issues that are 'secondary' to the formal definition of a language but that can be used to make structures explicit that are otherwise less accessible (Petre 1995). That way, secondary notation refers to the use of visual variables that are not specified in the primary notation (Moody 2009). It further offers possibilities to quickly implement research solutions. Yet, using secondary notation has also been criticized: Moody (2009), for example, argues that many changes that are recently implemented in secondary notations (such as mechanisms for explicit complexity management) should actually be included into primary notation. Genon, Heymans, and Amyot (2010) further argue that secondary notation should be used very carefully and should neither contradict specifications of the primary notation nor extensively use visual variables that are used to specify constructs within primary notation. We agree with Moody (2009) and Genon, Heymans, and Amyot (2010) but argue that those recent research ideas that do not contradict BPMN primary notation and that rather use visual variables which are not used in primary notation should be made available for practitioners as soon as possible. In that way, we follow Petre (1995) who emphasizes the value of secondary notations for cognitive effective graphics as it allows to apply visual cues which are normally not discussed within primary notation. Moreover, those changes in secondary notations that modelers and model users accept might also be included into primary notation. In that way, using secondary notation to improve the cognitive effectiveness of business process models can also support an implementation of accepted research results into primary notation.

With this research we show how recent research progress of a limited research field can be implemented within secondary notation without contradicting primary notation. We choose the field of Perceptual Discriminability as discussed in (Moody 2009) and its recent extensions that we have described in (Stark 2016a) and (Stark, Braun, and Esswein 2016a). Perceptual Discriminability describes the 'ease and accuracy with which graphical elements can be differentiated from each other' (Moody 2009), p. 763 which is in general determined by how much visual variables differ for the modeling constructs (Figl, Mendling, and Strembeck 2013). We have recently extended Perceptual Discriminability in (Stark 2016a) for conditions that allow notation designers to decide how much of a model user's attention should be drawn to a specific construct. In (Stark, Braun, and Esswein 2016a) we have applied this idea to the process flow of business process models and have shown that a carefully decision about how much attention should be drawn to a model element reveals significant positive effects for novices' model comprehension. In this study we investigate how much attention should be addressed to BPMN modeling constructs by analysing the importance of the constructs for model comprehension. Based on the results we decide for a certain amount of attention for each construct that is identified as important for comprehension and further show how this amount of attention can be assigned to the constructs in secondary notation without contradicting primary notation. This research contributes to theory and practice. For theory, we show that secondary notation is worth focussing at and further provide a hierarchy of important BPMN constructs for comprehension that can be used when implementing further research results. For practice, we provide a systematically derived design decision for BPMN secondary notation that can easily be implemented in modeling tools.

This research follows an argumentative-deductive approach and integrates a content analysis. Using the content analysis, we investigate the importance of BPMN constructs for model comprehension (section 2). Based on the results we define scenarios with important constructs for specific BPMN tasks. In section 3 we discuss free BPMN variables for secondary notation and work on attention conditions within the scenarios. Section 4 gives an example for secondary notation within the scenarios. In section 5 limitations of this research and implications for further research are discussed.

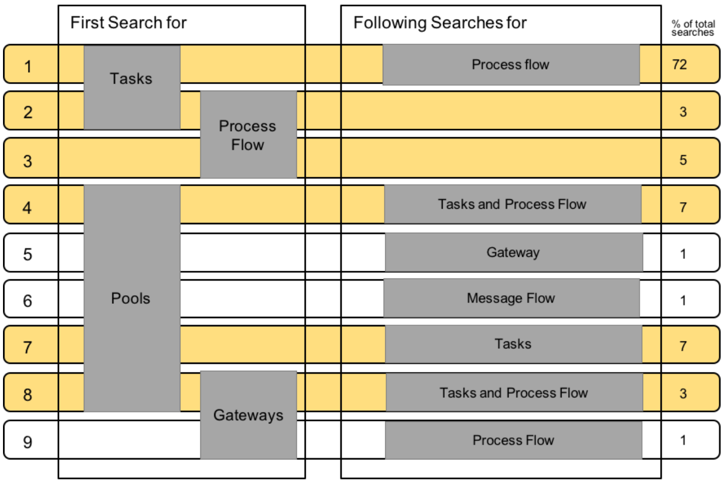
2 Task-related BPMN-scenarios

Quality Frameworks such as the one from (Lindland, Guttorm, and Solvberg 1994) usually include pragmatics when assessing the quality of a modeling grammar. Also Cognitive Fit indicates that different representations are useful for different tasks (Vessey and Galletta 1991). Pragmatics have so far only marginally been researched for visual notation design decisions. We integrate pragmatics by assessing what types of questions can be answered using BPMN models and which constructs need to be scanned throughout the model to answer the question. This assessment has been done with a content analysis according to (Krippendorff 2012) in summer 2016. We have focussed on experiments as models used within experiments usually provide a high quality and include questions that can be answered with the model. We have searched for “experiment” and “process model” or BPMN. We included IS-centric journals summarized in (Lowry et al. 2013), p. 51-54 and IS conferences by searching in IEEE Xplore and AIS electronic Library. We found many experiments of which we had to reject most as questions or models were not provided or the experiment did not match the right scenario.

IS-Journal / Conference	Lit.	Semantic Comprehension	Problem Solving	Cloze test
Dec. Supp. Systems	(Figl, Recker, and Mendling 2013)	schema-based		
	(Mendling, Strembeck, and Recker 2012)	schema-based		
Int. J. Hum. Comp. St.	(Figl and Laue 2015)	schema-based		
J. of Comp. Inf. Sys.	(Bera 2012)	schema-based	schema-based	
Com. Ass. for Inf. Sys.	(Recker and Dreiling 2011)	schema-based	inferential	recall
Eur. J. of Inf. Sys.	(Recker 2013)	schema-based		
IEEE Trans. on SMC	(Reijers and Mendling 2011)	schema-based		
Brazilian Symp. on SE	(Rodrigues et al. 2015)	schema-based		

Table 1. Experiments of IS-Centric-Journals and IS conferences

8 articles were left for further evaluation. Out of these articles we have assessed the type and content of questions and how model user have to scan the model to answer the questions. As described in table 1 these articles have used different questions within the experiments comprising semantic comprehension, problem solving, inferential problem solving and cloze test. These questions were either schema-based or recall-questions. In this study we have only integrated schema-based questions whose answering requires the use of the model, because our focus is on identifying question that can be answered with models. We found 74 relevant questions. For these questions we have analysed how answers can be derived and could summarize questions that require a similar approach to derive the answer into a question type (QT). We identified nine QTs (see fig. 1a). Usually the QTs included several searches to formulate an answer. QT 7, for example, first required to globally scan the model for relevant pools. Based on these pools we had to process a following search for specific tasks within the pool and were not required to scan the whole model again. This is why, in a similar analysis for ERDs in (Stark 2016), we distinguished between global and local search. Yet, this strategy could only be used for seven questions (QT 5-7). For the remaining questions the following searches required to scan the process flow which required again to scan the whole model. That way, in this case, we rather use the terms first and following search. For that reason, we also focus on what has been scanned in all searches. As can be seen on top of fig. 1b tasks and process flows have been scanned in 91% of all searches while pools have been scanned in 19%, gateways in 5% and message flows in 1% of all searches.



a)

All Searches	% of total searches
... for Tasks	91
... for Process Flow	91
... for Pools	19
... for Gateways	5
... for Message Flows	1

First Search	% of total first searches
... for Tasks	70
... for Pools	18
... for Process Flow	8
... for Gateways	4

Following Searches	% of total following searches
... for Process Flows	81
... for Tasks	17
... for Gateways	1
... for Message Flows	1

b)

Figure 1. Search Types analysed within a content analysis.

We decided to focus on those QTs that include at least two questions (orange in fig. 1a). Furthermore, we limit our study to those elements that have been searched for in most cases, which are tasks, process flows and pools. We do not include gateways and message flows as gateways are implicitly used within the process flow and the message flow has only been searched for in one question. Based on these limitations we derive four scenarios that summarize around 97% of all questions:

- **Scenario 1: Process flow only -** includes questions whose answers require to scan the process flow (QT 3) and amounts to around 5% of all questions,
- **Scenario 2: Tasks and Process flow -** includes questions whose answers require to scan tasks and the process flow (QT 1&2) and amounts to around 75% of all questions,
- **Scenario 3: Tasks, Process flow and Pools -** includes questions whose answers require to scan the process flow (that already include gateways), tasks and pools (QT 4&8) and amounts to around 10% of all questions
- **Scenario 4: Pools and tasks -** includes questions whose answers require to scan pools and tasks (QT 7) and amounts to around 7% of all questions

3 Free visual variables for BPMN secondary notation

In this section we discuss how we can use visual variables to influence the model user's attention and assess which visual variables are free for BPMN secondary notation in the sense that they are not yet used in primary notation. Visual Variables can be used to encode information (Bertin 1983) and have an impact on what we see with attention (Treisman and Gelade 1980; Wolfe 1994). According to the Feature Integration Theory which offers a first explanation for preattentive processing, we first detect visual variables from a graphical representation and sort them into individual feature maps (fig. 2a) such as red for hue. In a next step we detect structure and relationships among those variables and summarize this information within a master map (fig. 2b). On the basis of the master map we specify which visual variables occur together and where in the graphical representation they can be found (Treisman and Gelade 1980). Attention is now drawn to a certain part of information that we have perceived which is then selected for cognitive processing in working memory (Healey and Enns 2012). What information is seen with attention depends a) on how the visual variables are combined (Treisman and Gelade 1980) and b) on the goals with that we perceive a visual graphic (Wolfe 1994). Information from perceptual processing (fig 2a&b) as well as from goals are combined in an activation map (fig. 2c) (Wolfe 1994). Based on the activation map our gaze is guided within a fixation-saccade cycle (Healey and Enns 2012). Detailed information of visual variables can be gained from the region the eye is fixated on (Healey and Enns 2012). A first fixation of the eye usually happens at the point with the highest activation. To further receive information from other regions our eyes move within a saccade (Healey and Enns 2012; Yarbus 1967) which usually ends with a next fixation in the point with the next highest activation. As we do usually not influence the model user's goals but have an influence on how visual variables are combined we further investigate which visual variables are used within BPMN 2.0 primary notation and which are free to influence the fixation-saccade cycle.

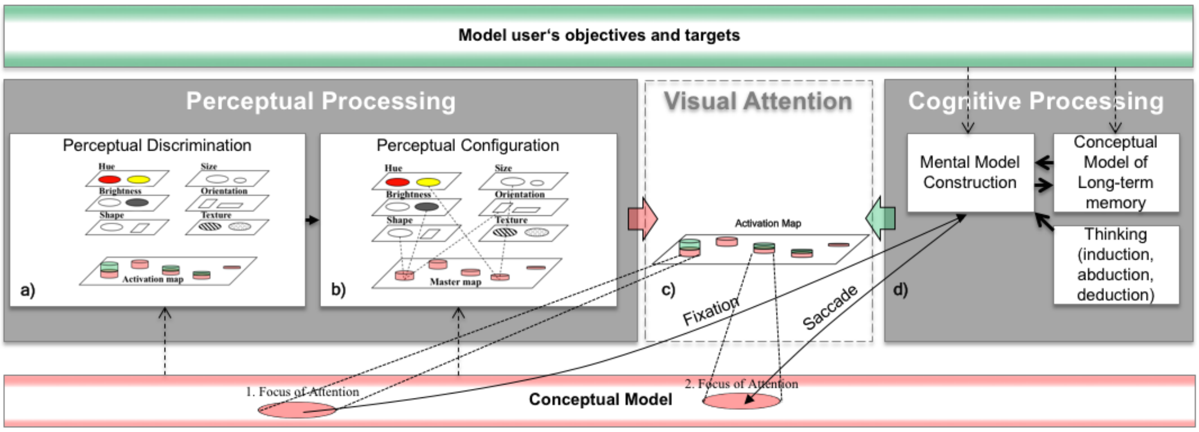
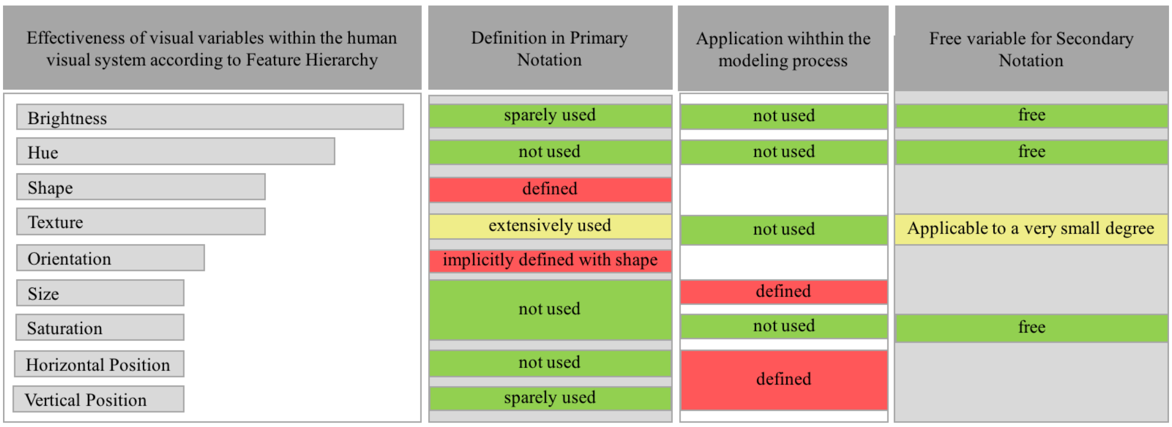


Figure 2. Human graphical information processing from (Stark, Braun, and Esswein 2016a).

3.1 Free visual variables in BPMN 2.0

Modeling constructs can be defined by specifying values for visual variables such as red for hue or rectangle for shape (Moody 2009). TREISMAN and other attention researchers have run experiments to test visual variables that can be detected preattentively (summarized in (Healey and Enns 2012), p. 3). A further source for visual variables is (Bertin 1983). As research in Conceptual Modeling uses the work of BERTIN for visual variables we also refer to this work. BERTIN distinguishes eight visual variables that comprise position, shape, size, colour, brightness, orientation and texture. We also include these variables for this work apart from colour (see fig. 3a). We rather focus on the colour attributes hue, saturation and brightness (Fairchild 2013) to avoid a duplication from colour and brightness which so far occurs when using the visual variables of BERTIN.



a) b)

Figure 3. a) hierarchy of visual variables and b) use of visual variables within primary notation, modeling process as well as potential as free variables for secondary notation.

Research in Visual Attention indicates that visual variables do not equally effect our visual system. Instead, a hierarchy for visual variables exists. To find the position of visual variables within the hierarchy attention researchers have shown that brightness dominates hue (Callaghan 1984), hue dominates shape (Callaghan 1989) and texture (Healey and Enns 1999) as well as hue plus depth (3D) dominate orientation (Snowden 1998) (fig. 3a). To our knowledge a systematization of size, saturation and position into the Feature Hierarchy did so far not occur.

Visual Variables that are used for BPMN 2.0 have already been assessed by GENON, HEYMANS, and AMYOT (2010) whose results we summarize to find out which variables can further be used in secondary notation: BPMN primary notation uses horizontal and vertical position, shape, texture, and brightness to encode semantic information. These variables are used to a different extent to encode semantic information. Horizontal and vertical position are only used to specify a symbol within another (enclosure). Also for brightness only two values (0% and 100%) are used to distinguish between filled and hollow markers. On the other hand, shape is defined for nearly every construct although only few categories (circles and quadrilaterals) are used. Texture, which was identified to determines the thickness and style of shape borders, is for example used to discriminate between different types of events and activities. Based on this analysis we assume that shape is defined for every construct which is why this visual variable should not be further used. As brightness and position are defined for a small range of possible values for only a small subset of constructs we argue that these variables might further be used. Texture, is defined for many constructs with several values which is why we argue that texture should not be used with what is already defined within primary notation. Orientation is seldom discussed for single constructs (not discussed in (Daniel Moody and van Hillegersberg 2008), left for secondary notation in (Genon, Heymans, and Amyot 2010), discussed as not used in modeling grammars in (Granada et al. 2013)). Yet, in (Moody, Heymans, and Matulevičius 2010) orientation of single constructs in *i** to indicate the direction of dependency is discussed. We argue that orientation and shape are closely related in modeling grammars. If shape is defined for a construct it usually comes together with a certain orientation. As the same shape does normally not appear a second time with another orientation we argue that shape and orientation are usually defined together. Using this argumentation orientation is not left but is implicitly defined together with shape for nearly every construct. To sum up: Shape and texture are explicitly and orientation implicitly defined within BPMN 2.0 primary notation. This might leave hue, size and saturation for a further analysis as free variables. We argue that also brightness and (horizontal as well as vertical) position should be assessed for a further application within secondary notation because these variables are only used for a subset of constructs.

As is sometimes discussed in Conceptual Modeling, visual variables are left for secondary notation if they are not used in primary notation. Yet, visual variables are sometimes also required to be specified within the modeling process and are that way not free to guide the model user’s attention. Modelers and also modeling tools usually adjust size according to the text within the construct (Genon, Heymans, and Amyot 2010) and to the size of other elements of the same construct. Adjusting the size does that way depend on the modeler’s choice within the modeling process or on the modeling tool. Also (horizontal and vertical) position depend on where the element should be positioned within the model, and that way, belong to the process flow which usually depends on the model user’s choice within the modeling process or on how layout is handled by the modeling tool. That way, size and position are not free to guide the model user’s attention to the most important constructs in secondary notation. As it is usually not necessary to use brightness, hue and saturation within the modeling process these variables are free for secondary notation. As texture is extensively used within primary notation, but is not necessarily adapted in the modeling process we argue that this variable can also (to a small extent) be used for secondary notation. Fig. 3 summarizes this discussion.

3.2 Effectively combining free BPMN-visual variables

According to section 3.1 we can use hue, brightness, saturation and to a small extent also texture to influence the model user's fixation-saccade cycle. How visual variables can be combined to influence this cycle is partly discussed within Perceptual Discriminability in (Moody 2009). Perceptual Discriminability defines the visual distance between constructs which indicates how easy constructs can be differentiated from each other (Moody 2009). In this principle MOODY recommends to use free visual variables to redundantly encode information and increase the visual distance between constructs. How free variables can be redundantly used to influence the fixation-saccade cycle is described in (Stark 2016a). In that work, we describe a continuum between parallel and serial processing (see fig. 4) along that constructs can be placed. Serial processing for a certain construct occurs when this construct does not have a high visual distance to other constructs and requires a time-intensive serial search of the model (e. g. white entity types of fig. 4). In contrast, parallel processing happens in less than 200ms (Healey and Enns 2012), and allows to immediately fixate the gaze on a construct such as on the red entity-types in fig. 4. That way, this construct appears to pop-out from the rest of the model. The pop-out is already introduced within Perceptual Discriminability (Moody 2009).

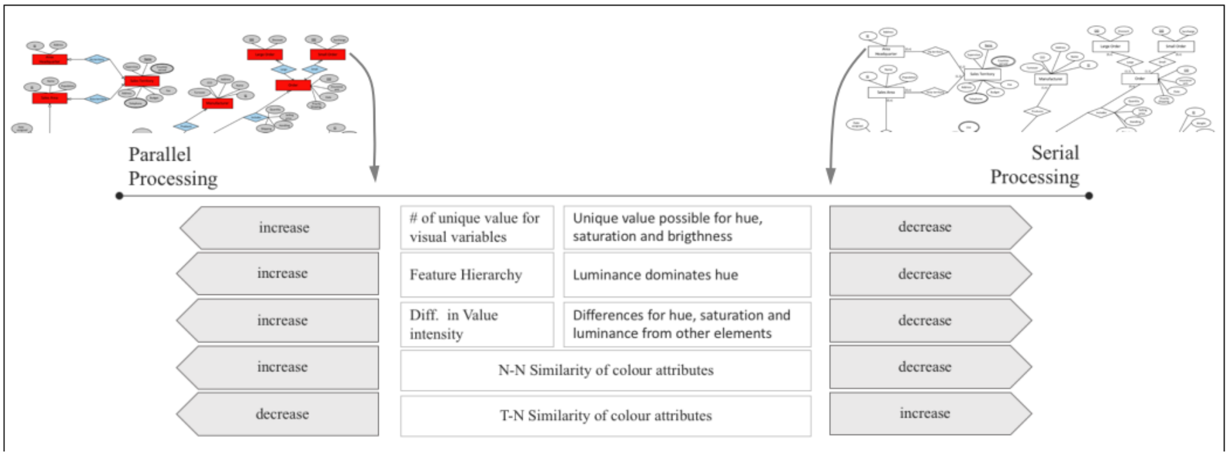


Figure 4. Continuum between parallel and serial processing and conditions to place modeling constructs along the continuum (Stark 2016a).

We further describes conditions from Visual Attention how constructs can be placed along the continuum in (Stark 2016a) which comprise the unique value for visual variables and similarity between the construct and other constructs. A construct has a unique value for a visual variable if for that visual variable the constructs differs from the other constructs (Treisman and Gelade 1980). An example for not having a unique value is given in fig 5a). In this figure the red circle (target) does not have a unique value since red and circular also appear within other elements. A unique value exists for the circle of fig. 5b) with circular for shape which allows to put this construct a further bit on the parallel side than that of fig. 5a). We can further move the construct to the parallel side if we produce a unique value of higher feature hierarchy. That way, we can use hue instead of shape as shown in fig. 5c) with the unique value blue for hue. Not only the positon in feature hierarchy but also the number of unique values as well as the differences in value intensity matter when influencing the position along the continuum. That way, producing a further unique value for brightness in fig 5d) would further move this construct to the parallel side. If we further increase value intensity (e. g. for brightness) of that construct we could reach a more parallel position. Furthermore, similarity between target and non-target constructs influences the construct's position alongside the continuum (Duncan 1989). As shown in fig. 5f) similarity between non-target constructs is very low which makes finding the target (red square) very hard. A high similarity between non-target constructs as for example shown in fig. 5b-e) makes finding the target easier.

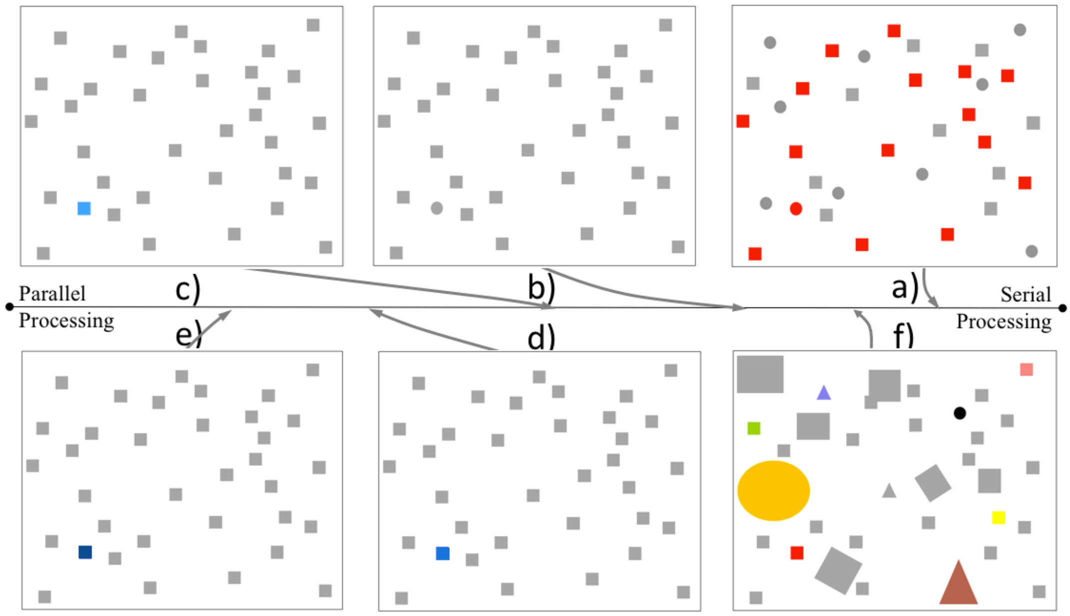


Figure 5. Examples for conditions to put constructs along the continuum between serial and parallel processing (Stark, Braun, and Esswein 2017).

In (Stark, Braun, and Esswein 2016a) we further argue that not every construct can be processed in parallel due to interferences from having too much contrast from the combination of visual variables. We rather need to decide which constructs are most important for model comprehension. Based on the analysis in section 2 we conclude that scanning the process flow and tasks are equally important for model comprehension, since both elements had to be identified in most searches. Although process flows and tasks are equally important to answer the questions we argue that the process flow should be placed on the most parallel position for the following reason: The process flow describes points in the process where parallel and alternative paths merge or split, which are in most cases expressed through gateways (Figl, Recker, and Mendling 2013; Verbeek, van der Aalst, and ter Hofstede 2007). These points most often lead to problems in understanding with practitioners (Mendling, Reijers, and van der Aalst 2010), which is why we decided to put most emphasis on the process flow (see fig. 6).

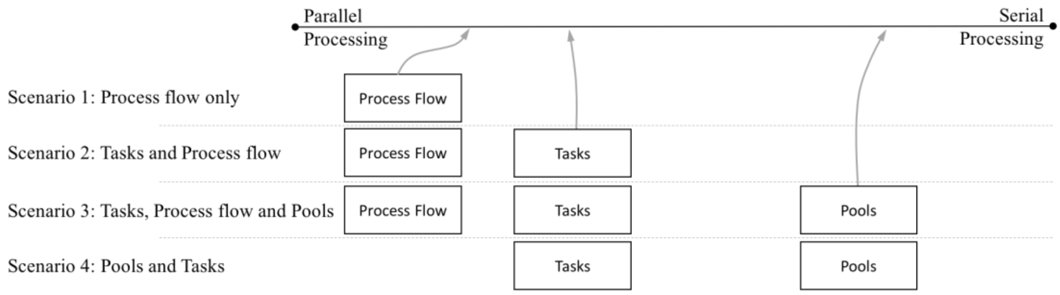


Figure 6. Placing important BPMN-elements along the continuum.

3.3 Choosing the right values for free BPMN-variables

As discussed in section 3.1 we can work on the visual variables hue, brightness, saturation which are colour attributes and to a small extent also texture to place the elements alongside the continuum. Colour attributes are very effective in influencing the fixation-saccade cycle as hue and brightness are highest in feature hierarchy and are more effectively detected than shape, orientation or texture (see section 3.1). Differences in hue can be detected three times faster than shape and are also more easily remembered (Lohse 1993; Treisman 1982). Yet, deciding for a hue combination that leads to a harmonious model is difficult (Stark, Braun, and Esswein 2016). On the other hand, a harmonious colour combination is important as for problem solving harmonious graphics work better (Norman 2002). So far no rules for how to derive harmonious colour combinations are researched for Conceptual Modeling. In (Stark, Braun, and Esswein 2016) we have approached a first systematization of colour for Conceptual Modeling by classifying harmonious colour combinations of social colour networks into two colour scenarios that comprise a pop-out and a high visual distance. The **pop-out scenario** uses colour to allow parallel processing for one or two constructs. In (Stark 2016a) entity-types have been placed on the parallel side of the continuum to provoke a first fixation on these constructs. In (Stark, Braun, and Esswein 2016a) colour is used to improve comprehension of the process flow. In this work we identified a combination of constructs that are processed together through available chunks in long-term memory to approach comprehension of the process flow. Furthermore, we identified parallel and alternative chunks as most important for model comprehension which are realized by AND- and OR-Gateways. We have further discussed a colour combination to make these chunks pop-out by using a colour with enough contrast for these two gateways and further used a colour-gradient to visually demark the boundaries of the chunks. When using colour for the **high visual distance** scenario, constructs are placed as far on the parallel side as possible without producing visual stress as visual stress prevents from a longer work with a visual graphic at hand (MacDonald 1999). We accept visual stress for a pop-out scenario as contrast, which induces the visual stress, helps provoking a fixation on a certain construct. We do usually not accept visual stress within the high visual distance scenario (Stark, Braun, and Esswein 2016).

For this work we decided to place the process flow on the most parallel place along the continuum (see fig. 6) and that way, follow the pop-out scenario of (Stark, Braun, and Esswein 2016). We further discriminate between pools and tasks by finding a colour that attracts as much attention as possible without producing too much visual stress and that way, we do also use the high visual distance scenario.

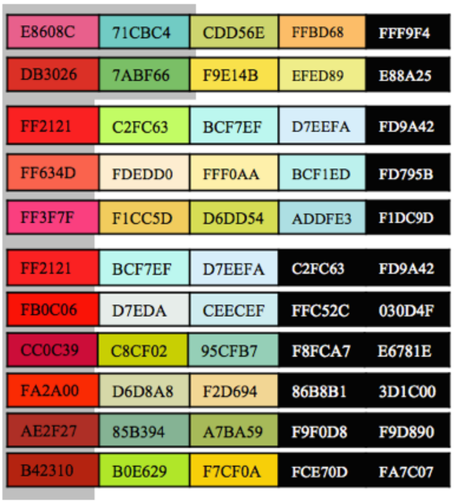
4 Suggestions for BPMN secondary notation

After having placed process flow, tasks and pools along the continuum we work on values for free visual variables to achieve the position of fig. 6. Before assigning values to the colour attributes we need to identify how many colours are required.

For Scenario 1 (Process flow only) we follow the decision of Stark, Braun, and Esswein (2016a) to highlight the process flow by a) assigning a certain hue, saturation and brightness to the gateways and b) using a colour gradient to highlight the chunk-boundaries with the same colour values that are used for the gateways. Using the colour gradient for texture allows using this variable in way beyond what is used in the BPMN primary notation. That way, we need two colours (one for the parallel and one for the alternative chunk) for this scenario. Scenario 2 (Tasks and Process flow) further requires to scan tasks, which is why we require a third colour. Answering questions of Scenario 3 (Tasks, Process flow and Pools) further requires model users to scan the model pools. We argue that two colours are sufficient to visually distinguish neighbouring pools. We do not use a colour for every pool as in this case we cannot specify the number of colours required. Scenario 4 (Pools and Tasks) does not require a further colour as answering questions requires to search for constructs that have already been searched for within the other scenarios. To sum up, we require two colours for the process flow, one colour for tasks and two achromatic colours for the pools.

As the process flow is on the most parallel position, the two colours that we use for the process flow should offer the most contrast to background and to other colours. This contrast should also be created by a specific brightness which is the highest value in feature hierarchy (see section 3.2). For tasks we need a colour that does not produce too much interference with the pop-out colours of the process flows and does hence not reduce the effectiveness of these colours. Furthermore, we do not want to impose visual stress, which means that we should use a colour with not too much contrast to the background. The two colours that we use to visually distinguish pools need to allow a position which is more on the serial processing side. Furthermore, pools are in general the largest elements within the model which is why colour can easily impose visual stress when applied to those large elements (Stark, Braun, and Esswein 2016). This is why we use achromatic values for pools. Based on this decision we require two pop-out colours and one colour to visually distinguish tasks and two further achromatic colours.

In (Stark, Braun, and Esswein 2016a) we have discussed different colour combinations for the pop-out scenario (see fig. 7a). We identified 11 pop-out colour combination. Two of these colour combinations provide two pop-out colours. The remaining colour combinations only provide one pop-out colour and are not relevant for this work. The values for the colour attributes hue, saturation and luminance of the two pop-out colour combinations are described in fig. 7b). For this paper we decided to use the colour combination on the bottom of fig. 7b) because the pop-out colours (DB3026 and 7ABF66) offer a higher contrast to the background and to non pop-out colours and are hence more on the parallel side. Furthermore, this colour combination offers a non pop-out colour (EFED89) with a very high luminance (89%) that does not produce much contrast to the background and does hence not produce much visual stress.



Hex	Hue	Saturation	Luminance	Type of colour
E8608C	341	75	61	Pop-out
71CBC4	175	46	72	Pop-out
CDD56E	65	55	79	Non pop-out
FFBD68	34	100	79	Non pop-out
FFF9F4	27	100	98	Not applicable

Hex	Hue	Saturation	Luminance	Type of colour
DB3026	3	72	49	Pop-out
7ABF66	107	41	65	Pop-out
F9E14B	52	94	86	Non pop-out
EFED89	59	76	89	Non pop-out
E88A25	31	81	63	Not applicable

b)

Figure 7. a) Pop-out colour combinations from (Stark, Braun, and Esswein 2017) and b) values for colour attributes for the two pop-out colour combinations.

In fig. 8a we have applied this colour combination to the individual scenarios. We have highlighted the process flow in **Scenario 1 (Process flow only)** by using DB3026 and 7ABF66. In **Scenario 2 (Tasks and Process flow)** we have further added EFED89 to highlight the tasks. For **Scenario 3 (Tasks, Process flow and Pools)** we have used EDEDED with a luminance of 93% and D9D9D9 with a luminance of 85% to visually discriminate neighbouring pools. Note that the decision to use colour for tasks and the process flow leads to an application of two colours for tasks that are also boundaries of important chunks such as parallel or alternative chunks of the process flow. That way (boundary-)tasks of Scenario 2 and 3 are characterized with two colours.

These suggestions can already be applied to secondary notation using a filter system that allows to use a certain scenario to process the model. We argue that the solution of scenario 3 can also be used for any other scenarios because the process flow, tasks as well as pools are visually distinguished in this case such as described in fig. 6. We argue that using one representation with a fixed combination of visual variables provides more advantages than using different colour scenarios as this would impose more complexity as requires model users to learn two colours (white or a specific colour of the construct of the scenarios) for a specific construct which also requires additional learn-steps (Stark, Braun, and Esswein 2016a). This is why we argue that the colour combination of scenario 3 is most effective for BPMN visual notation. If we contrast this proposition with a (black and white) model of BPMN primary notation (such as in fig. 8b) positive effects might be most visible.

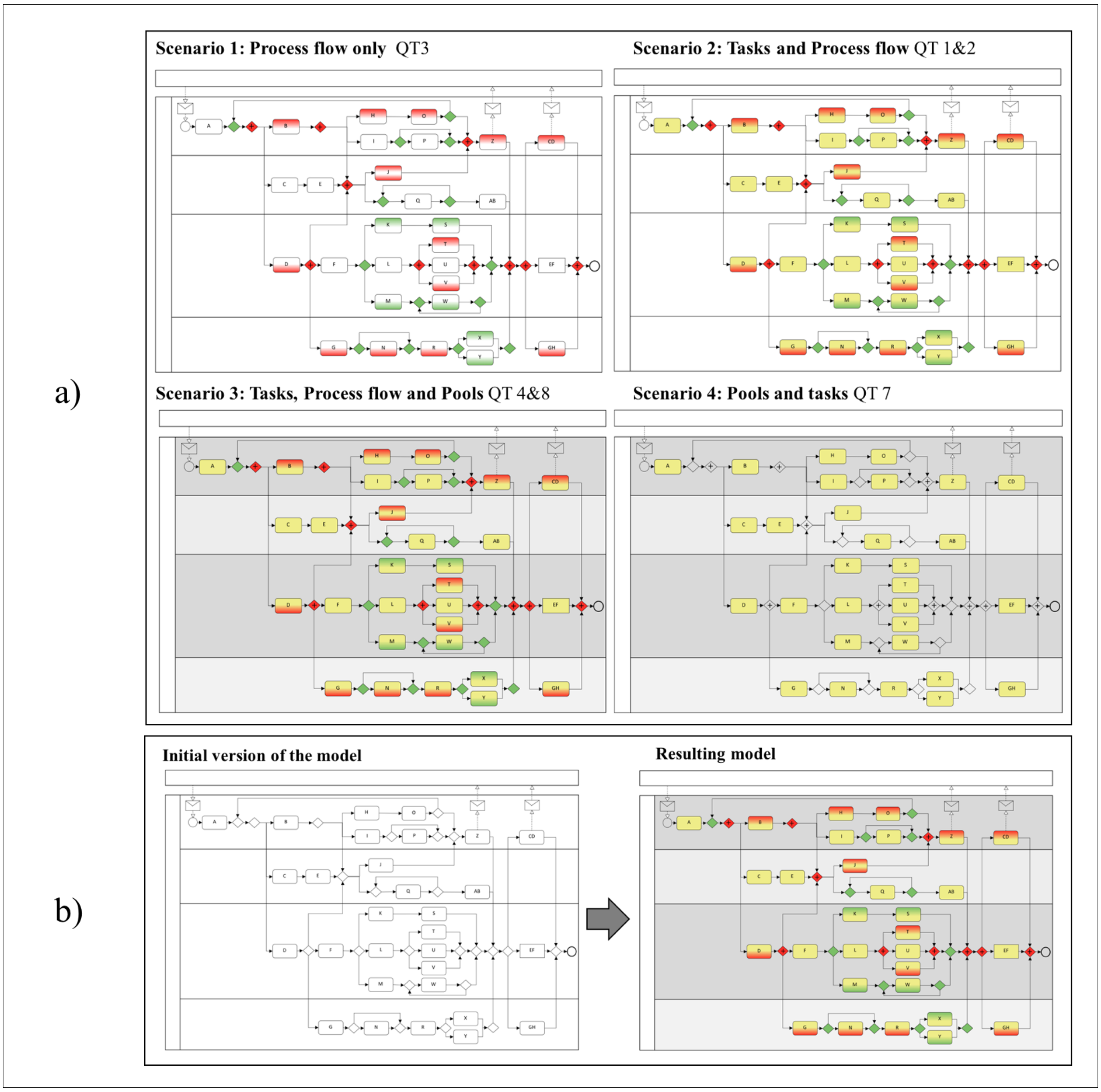


Figure 8. *a) Solutions for the individual scenarios and b) initial version of the model and solutions based on the scenario*

5 Limitations and Implications for Future Research

In this paper we argue that secondary notation can be used to implement recent research results that are not yet available for primary notation. We also argue that secondary notation should be used very carefully and should not contradict primary notation. To show how secondary notation can be used we have exemplary worked on BPMN secondary notation for extended Perceptual Discriminability, that can be used to focus attention on constructs that are most important for comprehension. The procedure that we have evolved to improve BPMN for secondary notation is summarized in fig. 9. We argue that this procedure can be adapted for (further) improvements of (further) modeling grammars. That way, this work can be used as prior research together with (Genon, Heymans, and Amyot 2010) to develop further design solutions for BPMN secondary notation. If design solutions should be developed for other modeling grammars this procedure can be used together with the discussion of free visual variables of further modeling grammars such as available in (Daniel Moody and van Hillegersberg 2008) for UML, in (Moody, Heymans, and Matulevičius 2010) for i*, in (Genon, Amyot, and Heymans 2010) for UCM, and in (Granada et al. 2013) for WebML. This publication can further be used as prior research for identifying important constructs for model comprehension. If this should be done for ERD constructs (Stark 2016) can be used as prior research, too.

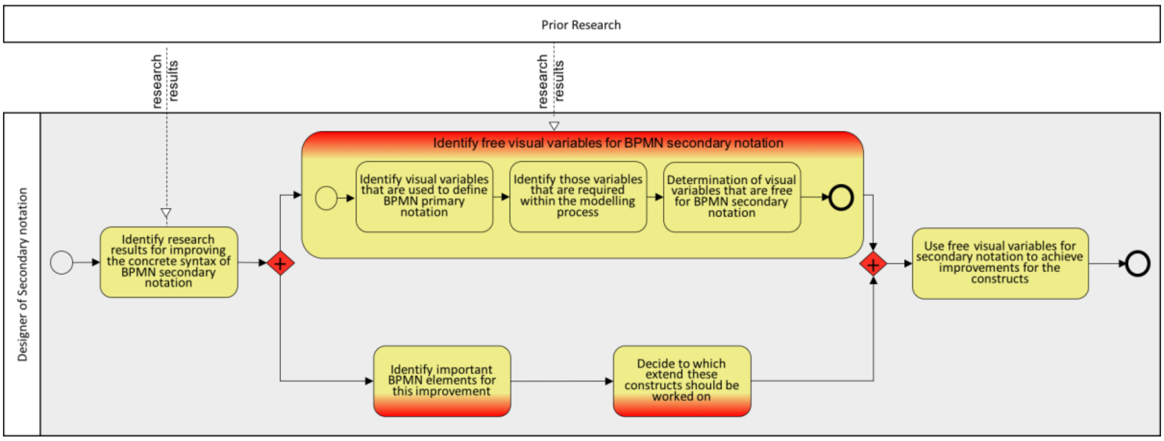


Figure 9. Procedure used for this research

Furthermore, we discuss experiments that have integrated visual cues on the basis of this research: Petrusel and Mendling (2013) showed with an eye-tracking experiment that experts solve comprehension tasks in business process models by fixating their eyes on a relevant region which provides the required information to solve the task. Based on their findings they visually discriminated elements of the relevant region by using strong red in (Petrusel, Mendling, and Reijers 2016). That way, they move elements of the relevant region close to the parallel processing pole. They show that colouring relevant model elements decreases the model user's mental effort and increases comprehension performance. They further show that the positive effect on comprehension performance stems from improvements in visual cognition and that eye-tracking is very effective to investigate the reasoning process in conceptual models in (Petrusel, Mendling, and Reijers 2017). These experiments are important because the authors show, that visual cues have an effect on comprehension performance. Yet, they designed their experiments in a way that modelers can hardly use. They used strong red for those elements that are necessary to solve the tasks and did not discriminate the other elements throughout the model. This design only gives model users support for solving a very specific question such as 'Is Q always executed before U' (Petrusel, Mendling, and Reijers 2017), p.11. However, conceptual models are usually not designed for sovling only one comprehension question but for a wide range of tasks which is why visual cues used in experiments should also support a wide range of tasks. This requirement is fulfilled for tasks that concern the process flow within three experiment in which colour attributes are used to highlight matching operator pairs of business process models (Reijers et al. 2011) are further used to highlight chunks within the process flow of business process models (Stark, Braun, and Esswein 2016b) and are used to assess cultural dependence of colour within Conceptual Modeling (Kummer, Recker, and Mendling 2016).

REIJERS ET AL. (2011) assess business process models to highlight matching operator pairs in an experiment and found support for understanding accuracy for novices. In their experiment they use colour attributes within the high visual distance scenario. In this scenario colour is used to perceptually discriminate several constructs without necessarily producing a pop-out. That way, the constructs are moved as far to the parallel processing side as possible without producing too much visual stress. For moving their constructs to the parallel processing side Reijers et al. (2011) use a predefined colour palette which can be created by the modeler itself. The advantage of their approach is that modelers can use colours they like and which seem advantageous to them. Yet this approach has also some disadvantages: Modelers can apply colours that do not necessary harmonize with each other and which can impose visual stress. Non harmonious colour combinations and too much visual stress can prevent from using the model (Stark, Braun, and Esswein 2016; Norman 2002). We argue that colour harmony and visual stress have an influence on solving experimental tasks which is why colour needs to be selected systematically. These disadvantages can also be found in the experiment we have conducted in a prior study in (Stark, Braun, and Esswein 2016a) in which colour is used to highlight the process flow and support was found for comprehension speed of novices. In this study we picked colour attributes according to requirements we draw from visual attention without discussing colour harmony and colour theory. We discovered that selecting colours is difficult which was our motivation for developing a first systematization of colours in (Stark, Braun and Esswein 2016). Kummer, Recker, and Mendling (2016) further investigated cultural dependence of colour in a multi-trial quasi-experiment with a systematic selection of colours that were preferred by Asians (such as bright background colours) and found that if colour matches the model user's preference he / she will also have positive effects in comprehending the model. We argue that the results of this study imply that visual stress and colour harmony should not be generalized across cultured but still need to be assessed for the cultural background of the model user. To sum up, when designing experiments that integrate colour, colour attributes should be selected systematically and perspectives such as colour harmony and visual stress should be addressed in relation to the cultural dependence of the model user. As PETRUSEL, MENDLING, and REIJERS (2016) have already shown that visual cues have an impact on model comprehension, colour should also support a wider range of tasks in future experiments.

In this work we did not include culture-dependency and colour semantics. A second limitation concerns the content analysis. We have based our analysis on articles of IS-centric journals classified by Lowry et al. (2013), p.51-54 and of the IEEE Xplore and AIS electronic Library in summer 2016. Recently, Figl (2017) has reviewed experiments that focus on comprehension of business process models that provides a broader basis for this kind of analysis. A third limitation comprises the missing evaluation of our results. We have evaluated preliminary results in (Stark, Braun, and Esswein 2016b) and found support for the comprehension speed of novices. Yet, in that experiment we did not include discussions about visual stress, colour harmony and important BPMN constructs. As this work goes beyond what is discussed in (Stark, Braun, and Esswein 2016a) a further evaluation is required. That way, also the trade-off between an overall version (less complex) and scenario-specific versions (adaption to scenario-specific needs but more complexity due to filter system) can be assessed.

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