Notational Characteristics of Visual Notations Used in Decision Management

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***Abstract*— The visual representation of Information System (IS) artefacts is an important aspect of the practical application of visual representations. However, important and known visual representation principles are often undervalued, which could lead to decreased effectiveness in using a visual representation. Decision Management (DM) is one field of study in which stakeholders must be able to utilize visual notations to model business decisions and underlying business logic, which are executed by machines. In the current body of knowledge, few contributions focus on evaluating visual representation principles to identify the suitability of visual notations for stakeholders. In this paper, the Physics of Notations framework of Moody is operationalized and utilized to evaluate five different DM visual notations. The results show several points of improvement with regards to these visual notations. Furthermore, the results show the authors of DM visual notations that well-known visual representation principles need to be adequately taken into account when defining or modifying DM visual notations. Additionally, operationalization is added extending on the work of** [1].

Keywords-Decision Management; Visual Notations; Evaluation; Physics of Notations (PoN)

I. INTRODUCTION

Decisions are amongst the most important assets of an organization [2], and therefore should be managed adequately. A decision is defined as: "*A conclusion that a business arrives at through business logic and which the business is interested in managing*" [3]. Furthermore, business logic can be defined as "*a collection of business rules, business decision tables, or executable analytic models to make individual business decisions*" [4]. Examples of decisions are: 1) diagnose a specific illness a patient has, 2) determine the loan default risk factor for a specific customer, or 3) determine the maximum credit rating of an organization. If an organization cannot consistently make and execute the right decision(s), large risks are taken that can eventually lead to high costs, reputation damage, or even bankruptcy. Following the previous example, imagine what will happen when an MD makes the wrong decision continuously or a customer with a high-risk classification gets a low-risk classification.

One important aspect of Decision Management (DM) is modelling decisions and business logic using a visual representation. Such visual representations are often referred to as notations or modelling standards. An example of a notation to model decisions is the Decision Modeling and Notation (DMN) proposed by the Object Management Group [3] or The Decision Model, defined by von Halle and Goldberg [5].

While empowering the semantic modelling capabilities of notations is desirable, notations also need to be cognitively effective [6]. Cognitive effectiveness, in the context of visual notations, refers to ‘‘*the speed, ease and accuracy with which a representation can be processed by the human mind*’’ [7]. Important and known visual representation principles are often undervalued in the design of visual notations, which could lead to decreased cognitive effectiveness [8], [9]. Furthermore, these notations are usually not designed with all stakeholders and their different expertise in mind. For example, someone who never modelled on the one hand (Decision modelling novice) to a Decision modelling expert on the other hand [7]. Modelling novices do have different requirements in comparison to users who are considered an expert [7], [10]. An expert will need more advanced functionalities in comparison to a novice, however, a novice should be able to learn the notation quickly to get started.

This paper examines the cognitive effectiveness of current notations designed for the DM domain. As, to the knowledge of the authors, no earlier studies exist that focus on evaluating multiple DM notations. To do so, a proper framework to evaluate known visual representation principles needs to be selected.

Several frameworks to evaluate visual notations exist, for example, the Cognitive Dimensions (CD) frameworks [11]–[13], Ontological Analysis (OA) frameworks [14], and the Physics of Notations (PoN) framework [7].

OA frameworks consist of a two-way mapping between the visual notation and an ontology. The interpretation mapping describes the mapping from the visual notation to the ontology and the representation mapping describes the inverse comparison [18], [19]. Bunge-Wand-Weber (BWW) ontology is the leading ontology and represents OA frameworks in this study. Multiple OAs have been conducted on different software engineering notations, e.g., [20]–[23]. When conducting an OA, there should be a one-to-one correspondence between a concept in the ontology and the construct in the visual notation. When this is not the case one or more of the following four anomalies will occur [18]: 1) Construct deficit exist when no construct exists which corresponds to a concept during this occurrence the notation is said to be incomplete, 2) Construct overload exists when a single construct can represent multiple concepts, 3) Construct redundancy exists when multiple constructs can represent a single concept, 4) Construct excess when a construct does not correspond to a concept. Ontological clear and complete notations are predicted to be more effective [22]. OAs evaluate the semantics of notations and specifically excludes aspects of visual representation, preferring content above form [7]. OAs cannot distinguish between notations with the same semantics but different syntax. A framework with the ability to differentiate syntax is preferred in the context of evaluating visual notations.

The goal of the CD frameworks is to evaluate the usability of information artefacts and to serve as a guide to create new artefacts [11]–[13]. CD frameworks have theoretical and practical limitations when dealing with the evaluation and designing of visual notations [15]: The frameworks are not created specifically for visual notations, only as a special case (particular class of cognitive artefacts) [16], the dimensions are not specific enough for evaluation, leading to confusion or misinterpretation [16], [17], theoretical and empirical foundations are poorly defined [16], the operationalization of the dimensions is lacking, which makes the application subjective [16], [17], visual representation issues are excluded and are mainly focused on structure [11], evaluation is not supported, the dimensions only define properties and cannot be specified as correct or incorrect [11], [13], design is not supported due to the fact that the dimensions are not guidelines and effectiveness is left out of scope [11], [13], the general level of the CD frameworks excludes specific predictions [11] (unfalsifiable). Due to these limitations, the CD Frameworks do not provide a scientifically fundamental basis for the evaluation of DM visual notations.

The PoN theory [7] is partly based on CD frameworks, which were the predominant theoretical paradigm in visual notations research [24]. PoN is developed and devoted to design, evaluate, and compare visual notations and is based on theory and empirical evidence obtained from different disciplines, such as perceptual psychology, cognitive psychology, cartography, graphic design, human-computer interfacing, linguistics, and communication theory. The PoN framework was specifically developed for visual notations compared to other frameworks which are adapted for this purpose [7]. Therefore, it reduces its generality but supports detailed prescriptions and predictions [7]. Multiple limitations exist for the CD frameworks and the OA frameworks and are developed into mitigating elements of the PoN framework which are the following [7]: 1) symbol-by-symbol analysis is supported in detail, 2) principles are justified explicitly supported by theory and empirical evidence, 3) principles are defined, in detail, and operationalization is supported by evaluation procedures and metrics, 4) desirable properties of visual notations are defined which supports evaluation and makes comparison possible, 5) visual notations could be designed and improved by the provided prescriptive guidelines, and 6) predictions can be generated and empirically tested (falsifiable).

Multiple studies have focused on applying the PoN framework for evaluating visual notations [24][25]. This study focusses on clarifying the criteria of operationalizing the PoN framework. Since we selected the PoN framework to evaluate DM visual notations, the following research question is stated: "*How do the selected DM visual notations score with regards to the PoN framework?*"

The remainder of this paper is structured as follows. First, the theory underlying visual notations and PoN are elaborated upon in the background and related work. This is followed by the research method utilized to conduct the research presented in this paper. Then, the data collection and analysis processes are explained. Next, in the results section, the PoN scores for the selected visual notations are presented. Lastly, the paper concludes with a discussion, conclusions, and directions for future research.

II. BACKGROUND AND RELATED WORK

DM notations can best be categorized by their complexity and linguistic power. Complexity refers to the ease of understanding the DM notation and linguistic power refers to the number of results it can produce, indicating its richness [26]. Five different types of DM notations have been defined [27]: 1) labels, 2) graphical aids, 3) structured languages, 4) constrained natural languages, and 5) pure natural languages, see Fig. 1.

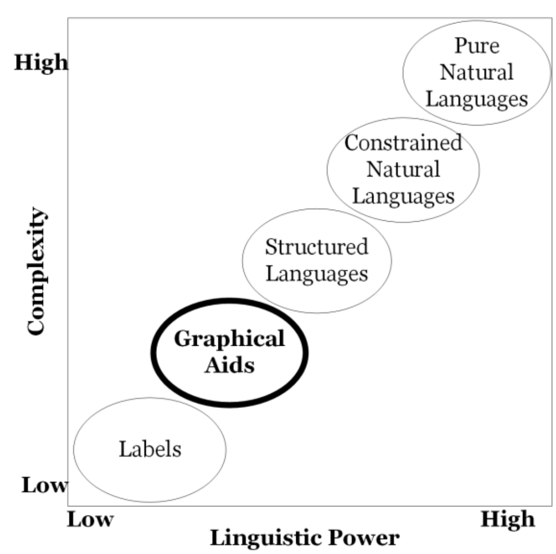

Figure 1. DM notation categorization [27]

The PoN framework attempts to evaluate notations (graphical aids) based on their visual representation, as these are often undervalued principles. It offers nine different principles by which the visual representation of a notation is measured against. The principles are as follows [7]:

Semiotic Clarity refers to every symbol having a one-to-one correspondence to its referent concept. When this is not the case one or more of the following four anomalies will occur: 1) symbol redundancy occurs when multiple symbols can be used to represent the same concept, 2) symbol overload occurs when different concepts can be represented by the same symbol, 3) symbol excess occurs when symbols do not correspond to any concept, and 4) symbol deficit occurs when there are concepts that do not correspond with any symbols.

Perceptual Discriminability refers to the ability to differentiate symbols based on their graphical appearance. This can be improved by increasing the number of graphical attributes a symbol represents. For example, adding colour, additional shapes, or text to a notation can improve the ability to differentiate between symbols.

Semantic Transparency refers to the extent to which the meaning of a symbol can be inferred from its appearance. For example, an icon of a calculator representing a formula has a high Semantic Transparency, while a rectangle representing a decision has a scarce Semantic Transparency.

Complexity Management refers to the ability of a visual notation to represent information without overloading the human brain [7]. The complexity our brain can handle can be improved by the usage of different concepts [21]. Modularization can be used to reduce the complexity of a large system by dividing it into smaller parts or making use of subsystems [21], [28], as shown in Fig. 2. Additionally, a hierarchy can be incorporated into the notation by representing information on different levels of detail.

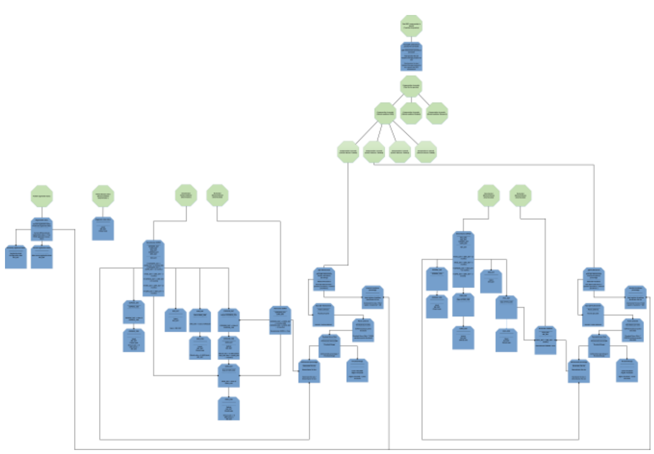

Figure 2. Example of the utilization of modularization in TDM notation [5]

Cognitive Integration refers to the extent to which a notation enables multiple diagrams to represent a system without overloading the human brain. This can be supported by two concepts, conceptual integration and perceptual integration [7]. Conceptual integration can be achieved by providing a summary diagram as a whole or parts of the diagram or by contextualization, a technique where contextual information on each diagram is showing its relation to elements on other diagrams [29], [30]. Perceptual integration is achieved by providing navigational tools in the notation [31]. Commonly used navigational tools are, for example, lines to provide direction of the flow or a map in which the entire diagram is shown if only a part of the diagram is to be shown on the screen.

Visual Expressiveness is defined as the number of visual variables used in a notation [7]. If a notation has a high number of visual variables, the Perceptual Discriminability increases, making the notation easier to use. Visual variables are size, brightness, colour, texture, shape, orientation, and text [7].

Dual Coding refers to the use of both visual and textual attributes in a notation [7]. For example, the Semantic Transparency can be increased by adding a keyword of the semantic concept to the visual representation of the symbol, consequently achieving Dual Coding.

Graphic Economy refers to the number of graphical symbols used in a notation [7]. The human brain can discriminate around six categories simultaneously, defining the limit of graphical symbols a notation should contain [32], [33]. There are three concepts by which excessive graphic complexity can be reduced: 1) reduce semantic complexity, 2) introduce symbol deficit, and 3) increase Visual Expressiveness.

Cognitive Fit refers to the Cognitive Fit theory, which states that different methods of representation of information are suitable for different tasks and different audiences [7]. This can be respected by creating multiple visual filters for, for example, expert-novice differences or representational mediums [34]–[37].

III. RESEARCH METHOD

The goal of this research is to evaluate DM visual notations with regards to the PoN framework [7]. When selecting an appropriate research method, one should take into account the maturity of the research domain [38]. Research with regards to visual notations to express business decisions and business logic is scarce [11]. Therefore, a qualitative research approach is selected as our research method.

Based on the available evaluation frameworks, we selected the PoN framework as the most suitable regarding visual notation evaluation. Based on the PoN framework, the researchers constructed a template (see Appendix A) which covers the nine principles of visual notations indicated in [7]. Each of the nine principles consists of specific elements characterizing each principle, e.g., the principle '*Semiotic Clarity*' has four elements of which one represents '*symbol overload*'. Every principle, and its containing elements, are represented by a question of whether the principle is present in the visual notation and, if present, to what extent. This is evaluated with a five-point Likert-scale or indicated with a percentage.

Instead of a purely quantitative approach to evaluate the DM visual notations, it is more appropriate to use a mix of quantitative collection and analysis with qualitative thematic coding, as our template also aims to collect motivations of researchers evaluating the visual notations and fits with the goal of operationalizing the PoN framework. The coding of the evaluations for the selected visual notations consists of three rounds of pre-defined coding based on a template [39]. During the coding rounds, four researchers coded the five graphical aids-type notations separately from each other. The results of the coding rounds were compared and their meaning discussed among the four researchers. The process of data collection and analysis is described in more detail in the following section.

IV. DATA COLLECTION AND ANALYSIS

Before the data collection and analysis started, the research team needed to decide which visual notations to evaluate. For this study, the number of visual notations to evaluate was five. The DM visual notations are selected based on the following criteria: 1) the notation should be applied in practice by multiple organizations, 2) the documentation for the notation should be accessible to be able to evaluate it in detail, 3) the notations are not a related visual notation (e.g., family of UML) and 4) the notation should be a DM graphical aid type. The following five DM visual notations are randomly selected out of a set of 42 visual notations fitting the previous described criterion: *Beinformed* [40], *Berkeley Bridge* [41], *Decision Model and Notation (DMN)* [3], *The Decision Model (TDM)* [5], and *Visual Rules* [42].

The data collection for this study occurred over a period of two months, between March 2018 and April 2018. The data collection is conducted by four researchers representing different levels of expertise on visual notations. Two researchers representing the expert group (researcher 1 and 2) and two researchers representing the novice group (researcher 3 and 4). Separating the coders increases the inter-reliability in the coding [43] and the internal validity of the research [44]. Besides increasing inter-reliability and inter validity, their position of evaluating if a visual notation can be utilized by an expert or novice should be evaluated as an actual expert or novice. The separation of being an expert or novice user of visual notations is based on the difference of years of research experience and their position in academia [34]–[37], [45], [46]. The most important novice-expert differences are: novices have more difficulty in discriminating symbols [34], [47], novices have to consciously remember the meaning of a symbol [35], complexity affect novices more than experts, as the lack strategies to handle this complexity [48]. Researcher 1 is a lecturer and associate professor with eight years of practical and research experience in the field of DM; Researcher 2 is a PhD-candidate with six years of practical and research experience in the field of DM; Researcher 3 is a Master student with five years of practical and research experience in the field of DM; Researcher 4 is a Master student with three years of research experience in the field of DM. The experts have experience with visual notations and completed at least two or more projects in which DM models had to be produced to be utilized in practice and the novices had little to no experience in actual DM notation projects. It took the research team a week to gather all data required to evaluate the visual notations. The data consisted of webpages, client case documents, learning documents, meta-models, demo applications, and video repositories with tutorials.

A template (included in Appendix A) is created and utilized by the researchers to cover the nine principles of Moody [7]. Every principle with each their own characteristics is further specified in the template with questions to guide the operationalization of the PoN framework. For each element, a five-point Likert-scale ranging from 1) very poor; 2) poor; 3) neutral; 4) good; 5) very good is used. Additionally, the value 6) Not Applicable (NA) could be chosen. If NA was chosen it needed to be further specified why. Therefore, the dataset represents a total of four filled-in templates for each of the five visual notations selected.

The data analysis comprised three rounds of pre-defined coding based on the data analysis techniques described by Strauss & Corbin [39]. The first round of coding identifies the symbols and constructs of each notation, e.g., the different node-types as part of the BeInformed visual notation or the transition-types as part of DMN.

TABLE I. EXAMPLE CODING NOTATION.

		Visual notation: BeInformed			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Perceptual Discriminability	**Redundant coding**	4	4	4	4
	Perceptual popout	3	4	3	2
	Textual differentiation			2	3
	Iconic differentiation	2	1	3	4

The second round of coding refines and differentiates concepts that are already available and code them into categories [49]. This coding round consisted of the indication of the values (using a five-point Likert-scale) for each visual notation together with the principles of Moody [7], as shown in Table I.

The first and second coding rounds were based on knowledge derived from sources described earlier, however, the coders did not follow courses or applied the visual notation in practice for this specific research.

The third and last round of coding represents the identification of functional categories [49]. This round included the identification of any consistencies or inconsistencies (using the colour grey) within the notations or difference in expertise (expert/novice), as shown in Table I.

The five-point Likert-scale is used to enable calculation of averages used for the comparison of notations, and to create a standard quantification mechanism for the coders to use during the coding of the notations. If doing any quantitative analysis, the Likert-scale is the most accepted and used scale for this purpose [50].

V. RESULTS

In this section, the results from the data collection and analysis phase are shown and further discussed. The results include the differences in values, based on percentages or a five-point Likert-scale, by the coders of different expert levels (expert/novice). The main reason that a five-point Likert scale is utilized is to express the difference of the visual notations for each principle. Table II shows the average of all the analysed visual notations against the nine principles mentioned by Moody [7]. Further on in this section, the results of each PoN principle are discussed in detail. The average totals of the DM notations are influenced by the presence of excess and redundant symbols which is for each a minus one on the total sum before average calculation. Exceeding the graphic economy threshold of six also results in the deduction of minus one on the total sum before average calculation. Different perspectives exist between coders and therefore the occurrence of missing values (no value provided) exists during the evaluation of a notation. This results in the fact that missing values are possible, as shown in Tables III-VI, and X.

TABLE II. CODING RESULTS

		Beinformed	*Visual Rules*	*DMN*	*TDM*	*Berkeley Bridge*
Average Total		**2.87**	**2.97**	**2.38**	**2.89**	**2.53**
Cognitive Integration		2.88	3.83	3.00	2.67	1.92
Cognitive Fit		2.75	2.25	4.13	4.50	3.88
Dual Coding		4.25	4.00	N.A.	N.A.	N.A.
Graphic Economy		16 (-1)	13 (-1)	9 (-1)	4	2
Visual Expressiveness		3.13	4.00	2.25	4.50	1.50
Complexity Management		4.17	3.33	3.83	2.17	3.50
Semantic Transparency		2.88	2.71	2.92	3.56	4.40
Perceptual Discriminability		3.06	2.69	1.50	2.83	2.53
Semiotic Clarity	**Excess**	18.75% (-1)	7.69% (-1)	N.A.	N.A.	N.A.
	Redundancy	18.75% (-1)	N.A.	N.A.	N.A.	N.A.

- **Semiotic Clarity**

A notation with high semiotic clarity does not have any Excess, Deficit, Redundant, or Overload in symbols. Therefore, any occurrence in this is seen as a negative (as shown in Table III). The Beinformed and Visual Rules notation have excess, and/or redundant symbols. The researchers identified 18.75% of the BeInformed symbols as Excess and Redundant, as shown in Table III. The Visual Rules notation was identified with a 7.69% Excess in symbols.

TABLE III. SEMIOTIC CLARITY

		BeInformed			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Semiotic Clarity	**Symbol excess in %**	18.75	18.75	18.75	
	Symbol redundancy in %	18.75	25.00	18.75	18.75

An example of a notation with high Semiotic Clarity is Berkeley Bridge as shown in Figure 3; the Berkeley Bridge notation only consists of two symbols.

Figure 3. Example a of notation with high Semiotic Clarity [41]

- **Perceptual Discriminability**

Perceptual Dscriminability covers the use of text, icons, and visual spacing, in order to stimulate faster identification of the different symbols. Therefore, a higher value is an indication that the notation has a high perceptual discriminability and thereby consists of symbols that are identified faster. The BeInformed notation with a 3.06 (as shown in Fig. 4) has the highest Perceptual Discriminability of the analyzed notations, compared to the DMN notation with a 1.50 (lowest). Fig. 4 shows the comparison of the Product, Decision, and Condition symbols used in BeInformed [40] showing the discriminability between the symbols of BeInformed by using text and icons.

Figure 4. Example of notation with high Perceptual Discriminability [40]

The coding of the Perceptual Discriminability of BeInformed is shown in Table IV.

TABLE IV. PERCEPTUAL DISCRIMINABILITY

		BeInformed			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Perceptual Discriminability	**Redundant coding**	4	4	4	4
	Perceptual popout	3	4	3	2
	Textual differentiation			2	3
	Iconic differentiation	2	1	3	4

- **Semantic Transparency**

Semantic Transparency covers if the visual appearance of the symbols suggests their meaning. A higher value in this principle is an indication that the notation seems to have semantic transparent symbols. The Berkeley Bridge notation has the highest Semantic Transparency (as shown in Fig. 5) with a 4.4. This seems the result of the low number of symbols, which is two. The BeInformed (as shown in Fig.5) notation seems to be affected by its high number of symbols, and therefore BeInformed is together with Visual Rules then notation with the lowest Semantic Transparency (BeInformed 2.88, and Visual Rules 2.71).

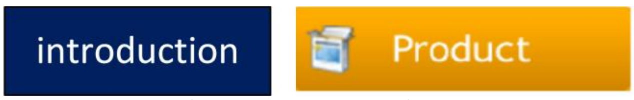

Figure 5. Example of notations with high (left) [41] and low (right) [40] Semantic Transparency

The coding of the Semantics Transparency of Berkeley Bridge is shown in Table V.

TABLE V. SEMANTICS TRANSPARANCY

		Berkeley Bridge			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Semantics transparency	**This symbols are well chosen**	5	4	5	5
	The symbols have to be learnt	5	5	4	4
	The symbols meaning are not obvious				3
	Better symbols should be found				6

- **Complexity Management**

The Complexity Management principle covers the ability to scale the notation for a clearer overview for the user. A higher value in this principle is an indication that the notation is useful with regards to larger systems with multiple diagrams by utilizing modularization and hierarchical structuring. The BeInformed notation has the highest value (4.17) in Complexity Management and is better when dealing with large scale systems with multiple diagrams. The TDM notation seems to be impacted by the low number of symbols in their notation to score the lowest (2.17) in Complexity Management. The coding of the Complexity Management of BeInformed is shown in Table VI.

TABLE VI. COMPLEXITY MANAGEMENT

		BeInformed			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Complexity Management	**Moduralization**	4	4	5	5
	Hierarchically structuring				3

TDM is an example of a notation with low Complexity Management as shown in Figure 6.

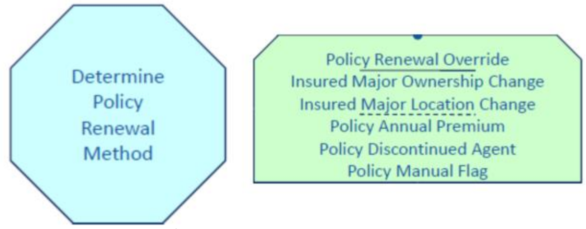

Figure 6. Example of notation with low complexity management. [5]

- **Visual Expressiveness**

The Visual Expressiveness principle covers the use of visual variables (colour, 3d symbols, and textual encoding). A higher value indicates that the notations are visually expressive. The TDM notation has a total score of 4.5 and thereby he highest-scoring notation in Visual Expressiveness, compared to the Berkeley Bridge notation with a 1.5 (lowest). The coding of the Visual Expressiveness of TDM is shown in Table VII.

TABLE VII. VISUAL EXPRESSIVENESS

		TDM			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Visual Expressiveness	**Color**	5	5	4	4

An example of a difference between a high and low Visual Expressiveness notation is shown in Fig. 7. TDM (left) has a high Visual Expressiveness (different colours, the shape of symbols and different use of textual encoding) and Berkeley Bridge (right) a low Visual Expressiveness (one shape symbol and no difference in textual encoding).

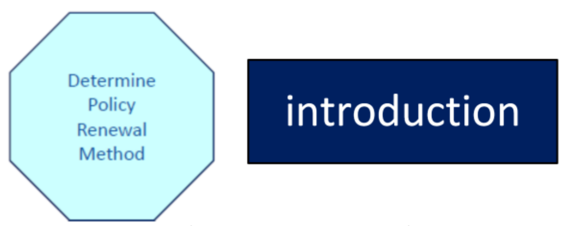

Figure. 7. Example of notations with high (left) [5] and low (right) [41] Visual Expressiveness

- **Graphic Economy**

The Graphic Economy principle covers the number of symbols a human brain is able to discriminate between, this number is estimated to be limited to six. A value above six would be a negative impact on the Graphic Economy of the notation, which is the case for BeInformed (16), Visual Rules (13), and DMN (9). The coding of the Graphic Economy of BeInformed is shown in Table VIII.

TABLE VIII. GRAPHIC ECONOMY

		BeInformed			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Graphic Economy	# symbols	16	16	16	16

Berkeley Bridge is an example of a notation with a low number of symbols (2), as shown in Figure 3.

- **Dual Coding**

The Dual Coding principle covers the complement of graphics with text, which is more effective than using each of them on their own. A higher value in this principle indicates that the notation utilizes Dual Coding. The Beinformed (4.25) and Visual Rules (4.00) notations are the only notations, out of the analyzed five notations, where Dual Coding was identified. The coding of the Dual Coding of BeInformed is shown in Table IX.

TABLE IX. DUAL CODING

	BeInformed			
	Coders			
	Expert		Novice	
	R1	R2	R3	R4
Dual Coding	4	5	4	4

Visual Rules (shown in Figure 8) is an example of a notation that utilizes Dual Coding.

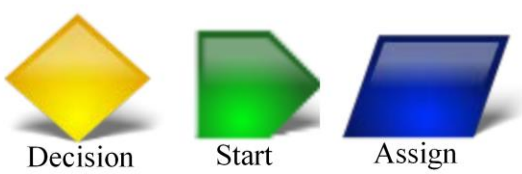

Figure 8. Example of a notation which uses Dual Coding [42]

- **Cognitive Fit**

The Cognitive Fit principle covers the theory that different representations of information are suitable for different audiences. The difference in experience between coders is utilized and classified as expert (R1 and R2) and novice (R3 and R4). The expert and novice coders stated from their experience perspective if there is an expert-novice difference and to what extent (as shown in Table X). The Visual Rules notation scored the lowest with a 2.25, compared to that of TDM, which scored the highest with a 4.50. The coding of the Cognitive Fit of Visual Rules is shown in Table X.

TABLE X. COGNITIVE FIT

		Visual Rules			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Cognitive fit	expert-novice differences - difference?	YES	NO	NO	YES
	expert-novice differences - expert/novice?	4	4	3	2
	Representational medium	2	1	1	1

A comparison of notations with high and low Cognitive Fit is shown in Figure 9. TDM (left) with a high Cognitive Fit is indicated by the researchers to be, out of the five notations, the best fit for experts and novices. Visual Rules (right) with a low Cognitive Fit is indicated by the researchers to be, out of the five notations, the least fitted for experts and novices to be utilized.

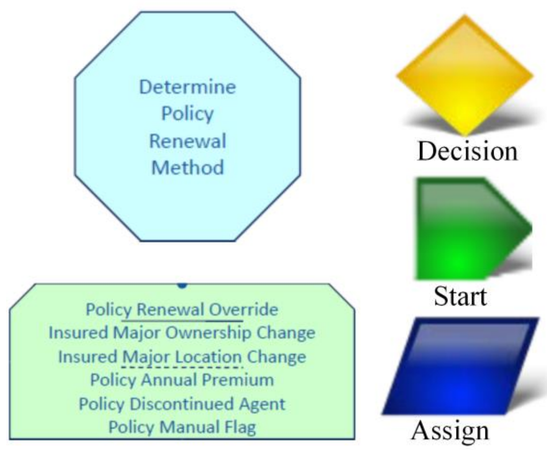

Figure 9. Example of a notation with high (left) [5] and low (right) [42] Cognitive fit

- **Cognitive Integration**

The Cognitive Integration principle covers the range of mechanisms available for dealing with multiple diagrams thereby, helping the reader assemble information from separate diagrams. Concepts supporting are Conceptual Integration (e.g., a summary diagram) and Perceptual Integration (e.g., navigational tools). A higher value indicates that the notation has the mechanisms available to help the reader assemble information when multiple diagrams are shown. The Visual Rules notation (as shown in Fig. 10) has the highest value (3.83) in Cognitive Integration, compared to the Berkeley Bridge (as shown in Fig. 10) notation (1.92) which does not have the mechanisms to support the reader when dealing with separate diagrams (lowest).

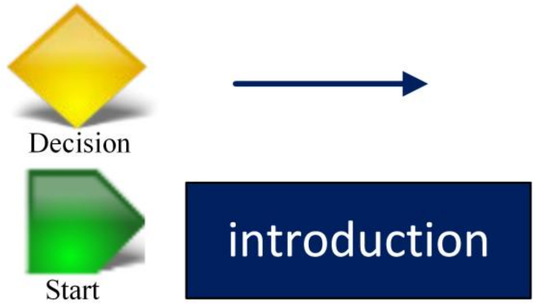

Figure 10. Example of a notation with high (left) [42] and low (right) [41] Cognitive Integration

The coding of the Cognitive Integration of Visual Rules is shown in Table XI.

TABLE XI. COGNITIVE INTEGRATION

		Visual Rules			
		Coders			
		Expert		Novice	
		R1	R2	R3	R4
Cognitive Integration	**Perceptual integration**	4	4	4	4
	Conceptual integration				3

- **Difference expert/novice**

Taking into account that having experience in the use of a visual notation, in this case, a modelling language, influences the attitude towards several of the Moody principles. For example, a notation could be more complex for a novice but not for an expert. Therefore, a difference is made between the results of the expert researchers and novice researchers. The coding of the difference between expert and novice is shown in Table XII.

TABLE XII. RESULTS DIFFERENCE EXPERT/NOVICE

	Expertise:	Average Total Expert/Novice	Average Total
Beinformed	**Expert**	2.79	2.87
	Novice	2.95	
Visual Rules	**Expert**	2.99	2.97
	Novice	2.96	
DMN	**Expert**	2.25	2.38
	Novice	2.51	
TDM	**Expert**	2.92	2.89
	Novice	2.86	
Berkeley Bridge	**Expert**	2.39	2.53
	Novice	2.67	

VI. CONCLUSION, DISCUSSION AND FUTURE RESEARCH

In this paper, a study is conducted in which five DM visual notations, namely: Visual Rules, Berkeley Bridge, Decision Model and Notation, The Decision Model, and BeInformed, were evaluated using the PoN framework [7]. From our analysis, Visual Rules scores best according to the average total of all PoN framework principles. From a theoretical perspective, our study and its results give meaning to the operationalization of the PoN framework. Furthermore, it will enable further exploration of the application of the PoN principles, as well as other DM visual notations not included in this study. Moody [1, p.772] describes the theoretical interactions between the described principles. Our results show that these interactions are, to a large extent, verified. From a practical perspective, the results presented in this paper contribute towards a better awareness for taking into account validated visual notation principles and guidelines. Our results could be utilized by organizations to either evaluate for themselves which visual notation is most adequate or to utilize a visual notation based on our results.

This study has multiple limitations. The first limitation concerns the research team that carried out the evaluation of the visual notations using the PoN framework. This study included evaluations of four researchers, two novice level researchers and two expert-level researchers on the DM topic. Therefore, one could argue that the results and conclusions are potentially biased by a low amount of data points for the evaluation of the visual notations included. However, most studies conducted with a focus on evaluating one or multiple visual notations are often centred on the evaluation of the visual notation using one or two researchers [24], [25], [51]. Future research should focus on evaluating visual notations utilizing a larger sample of participants that will add to the generalizability of the results and conclusions about the evaluated visual notations.

The second limitation concerns the method and framework utilized to evaluate the visual notations, the PoN framework and its operationalization by creating and utilizing a template with the goal to structure data collection and analysis. Utilizing the PoN framework is an explicit choice, however, limits the results because the PoN framework represents a specific lens. Future research could, therefore, focus on applying other frameworks and theories that focus on uncovering and describing essential notational principles, e.g., Guidelines of Modeling (GoM) [52]. Furthermore, the operationalization of the PoN framework described in [7] is left open for interpretation and perception of the researchers applying it, a good example is the lack of weighting of the nine PoN principles. Therefore, our template is another limitation. This phenomenon becomes clear in the work of [6], which shows that the operationalization of the PoN framework by different research teams often do not always seem to take into account all principles described. This is tackled by utilizing the created template in this study, see Appendix A. Future research, however, should focus on how these principles are best measured in practice, i.e., whether Likert scales or other less quantitative measurements are adequate or not. A first step is taken with the addition of user scenarios to support the operationalization of the PoN framework.

The last limitation concerns the visual notations selected. Although we choose two well-known visual notations, as well as three visual notations applied in the DM practice a lot, the selection of visual notations could coincidentally have resulted in bias and affect the generalizability of our results. We argue that this risk is more or less mitigated as most studies conducted that utilize the PoN framework focus on only one visual notation, see also [6], while this study reports upon the evaluation of five visual notations. Future research could also focus on evaluating additional DM visual notations.

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APPENDIX A – TEMPLATE CHECKLIST GRAPHICAL NOTATIONS

I. INTRODUCTION

This is the template for the checklist. The checklist is based on the theory of "The Physics of Notations" [7]. Therefore, before using this template it is required to have read "The Physics of Notations" [7] paper. The structure of this document is derived from the following figure:

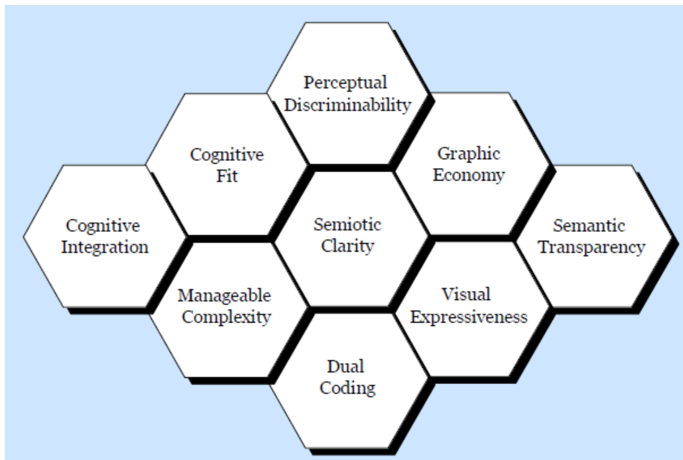


Figure 1 - The Physics of Notations [7]

In addition, this template makes use of a five-point scale for the assessment of the properties of the notations, wherein the numeral 1= very poor, 2=poor, 3= poor/good, 4=good, and 5=very good. Some concepts start with a question if the concept occurs in the notation, these questions should be answered with yes or no. If the answer is yes, the 5-point Likert scale should be applied.

At the end of the document, we inserted a section named “Additional notes”. In this section you can provide us extra information besides the information needed by the template about the notation.

II. SEMIOTIC CLARITY

According to Goodman’s theory of symbols, for a notation to satisfy the requirements of a notational system, there must be a one-to-one correspondence between symbols and their referent concepts. When there is not a one-to-one correspondence between constructs and symbols, one or more of the following anomalies can occur:

- **Symbol excess** occurs when graphical symbols do not correspond to any semantic construct.
- **Symbol deficit** occurs when there are semantic constructs that are not represented by any graphical symbol.
- **Symbol redundancy** occurs when multiple graphical symbols can be used to represent the same semantic construct.
- **Symbol overload** occurs when two different constructs can be represented by the same graphical symbol.

Step 1: List all the symbols used by the notation.

Symbol

Step 2: Name the symbols to their corresponding semantic construct.

Number	Symbol construct	Symbol(s)

Step 3: Link construct types to their symbols and symbol construct

Symbol construct	Construct type	Symbol(s)	Number

Step 4: Semiotic clarity analysis (calculate defects)

- **Symbol excess** occurs when graphical symbols do not correspond to any semantic construct.
- **Symbol deficit** occurs when there are semantic constructs that are not represented by any graphical symbol.
- **Symbol redundancy** occurs when multiple graphical symbols can be used to represent the same semantic construct.
- **Symbol overload** occurs when two different constructs can be represented by the same graphical symbol.

Semiotic clarity summary:

Defect	Occurrences	Percentage
Symbol excess		
Symbol deficit		
Symbol redundancy		
Symbol overload		

III. Perceptual Discriminability

Perceptual discriminability is the ease and accuracy with which graphical symbols can be differentiated from each other. This relates to the first phase of human visual information processing: perceptual discrimination. Accurate discrimination between symbols is a prerequisite for accurate interpretation of diagrams.
To describe the notation's score for this principle, perform the following step(s):

- **Step 1:** Gather the visual variables per symbol.
  Describe the symbols VV's (Visual Variables) in the following table(s).

Symbol construct	Symbol	Visual variable values		Semantics carrier
		(x, y):		
		Shape:		
		Colour:		
		Brightness:		
		Size:		
		Orientation:		
		Texture:		

* A table should be completed for each symbol, when more are needed, copy the table above.

A. Redundant coding

Redundancy is an important technique in communication theory to reduce errors and counteract noise. The visual distance between symbols can be increased by redundant coding: using multiple visual variables to distinguish between them. As an example, colour could be used to improve discriminability between entities and relationships in ER diagrams

- **Step 2:** Describe redundant coding.
  Describe the possibilities regarding redundant coding in the following table(s).

Redundant coding present in notation?	Grade	Motivation

B. Perceptual popout

According to feature integration theory, visual elements with unique values for at least one visual variable can be detected pre-attentively and in parallel across the visual field. Such elements appear to "pop-out" from a display without conscious effort. On the other hand, visual elements that are differentiated by unique combinations of values (conjunctions) require serial search, which is much slower and error-prone.

- **Step 3:** Perceptual popout
  Describe the possibilities regarding perceptual popout in the following table(s).

Perceptual popout present in notation?	Grade	Motivation

C. Textual differentiation

SE notations sometimes rely on text to distinguish between symbols. For example, UML frequently uses text and typographic characteristics (bold, italics, underlining) to distinguish between element and relationship types.

- **Step 4:** Textual differentiation
  Describe the possibilities regarding textual differentiation in the following table(s).

Textual differentiation present in notation?	Grade	Motivation

D. Iconic differentiation

Icons are symbols that perceptually resemble the concepts they represent. This reflects a basic distinction in semiotics, between symbolic and iconic signs. Iconic representations speed up recognition and recall and improve intelligibility of diagrams to naïve users. They also make diagrams more accessible to novices: a representation composed of pictures appears less daunting than one composed of abstract symbols. Finally, they make diagrams more visually appealing: people prefer real objects to abstract shapes.

- **Step 5:** Iconic differentiation
  Describe the possibilities regarding iconic differentiation in the following table(s).

Iconic differentiation present in notation?	Grade	Motivation

IV. SEMANTICS TRANSPARENCY

Semantic Transparency is defined as the extent to which the meaning of a symbol can be inferred from its appearance. While Perceptual Discriminability simply requires that symbols should be different from each other, this principle requires that they provide cues to their meaning (form implies content). The concept of Semantic Transparency formalizes informal notions of "naturalness" or "intuitiveness" that are often used when discussing visual notations, as it can be evaluated experimentally.
To describe the notation's score for this principle, perform the following step(s):

- **Step 1:** Transparency regarding the notations symbols.
  Describe the transparency of the symbols used by the notation in the following table(s).

Symbol		
	1. This symbol is well-chosen 2. The symbol has to be learnt 3. The symbol's meaning is not obvious 4. A better symbol should be found	
	Grade	
	Motivation	

* A table should be completed for each symbol, when more are needed, copy the table above.

V. COMPLEXITY MANAGEMENT

Complexity Management refers to the ability of a visual notation to represent information without overloading the human mind. Complexity is also one of the defining characteristics of the SE field, where complexity levels exceed those in any other discipline.
To describe the notation's score for this principle, perform the following step(s):

A. Modularization

The most common way of reducing complexity of large systems is to divide them into smaller parts or subsystems: this is called modularization.

- **Step 1:** Modularization within the notation.
  Describe the possibilities regarding modularization in the following table(s).

Modularization possible in notation?	**Grade**	**Motivation**

B. Hierarchically structuring

Hierarchy is one of the most effective ways of organizing complexity for human comprehension as it allows systems to be represented at different levels of detail, with complexity manageable at each level. This supports top-down understanding, which has been shown to improve understanding of SE diagrams.

- **Step 2:** Modularization within the notation.
  Describe the possibilities regarding hierarchically structuring in the following table(s).

Hierarchically structuring possible in notation?	**Grade**	**Motivation**

VI. VISUAL EXPRESSIVENESS

Visual Expressiveness is defined as the number of visual variables used in a notation. This measures utilisation of the graphic design space.
To describe the notation's score for this principle, perform the following step(s):

- **Step 1:** Describe Visual Expressiveness
  Describe the notation's Visual Expressiveness by filling in the following table(s).

Is colouring used in the notation? (YES/NO)		**Grade**	
Motivation			

Are 3d symbols used in the notation? (YES/NO)		**Grade**	
Motivation			

Is textual encoding of information used in the notation? (YES/NO)		**Grade**	
Motivation			

Are there visual dependency variations in the notation? (YES/NO)		**Grade**	
Motivation			

VII. Graphic Economy

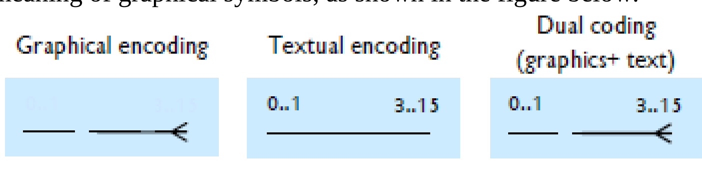
Graphic complexity is defined by the number of graphical symbols in a notation: the size of its visual vocabulary.
To describe the notation's score for this principle, perform the following step(s):

- **Step 1:** Describe the Graphic Economy.
  Describe the notation's Graphic Economy by filling in the following table(s).

Amount of basic shapes	**Amount > 6**
#	Yes/no
Motivation	

VIII. Dual Coding

Perceptual Discriminability and Visual Expressiveness both advise against using text to encode information in visual notations. However, this does not mean that text has no place in visual notation design. Pictures and words are not enemies and should not be mutually exclusive. According to Dual Coding theory, using text and graphics together to convey information is more effective than using either on their own. Textual encoding can be used to reinforce and expand the meaning of graphical symbols, as shown in the figure below.



To describe the notation's score for this principle, perform the following step(s):

- **Step 1:** Determining the possibilities of Dual Coding.
  Describe the possibilities regarding Dual Coding in the following table(s).

Dual Coding possibilities within notation?		**Grade**	
Motivation			

IX. Cognitive Fit

Cognitive Fit theory states that different representations of information are suitable for different tasks and different audiences. Problem-solving performance (which corresponds roughly to cognitive effectiveness) is determined by a three-way fit between the problem representation, task characteristics and problem solver skills.
To describe the notation's score for this principle, perform the following step(s):

A. Expert-novice differences

One of the major challenges in designing SE notations is the need to develop representations that are understandable by both business and technical experts. This adds to the difficulty of the task as in most engineering contexts, diagrams are only used to communicate among experts.

- **Step 1:** Describe the differences between novice and expert users.
  Describe the possibilities regarding expert-novice differences in the following table(s).

Is there a difference between novice and expert use? (YES/NO)		
How do you grade the use as an expert or novice?	**Grade**	
Motivation		

B. Representational medium

Another situation that may require different visual dialects is different representational media. In particular, requirements for sketching on whiteboards or paper (an important use of visual notations in early design stages), are different to those for using computer-based drawing tools. Some of the most important differences are:
Perceptual Discriminability: discriminability requirements are higher due to variations in how symbols are drawn by different people. As within-symbol variations increase, between-symbol differences need to be more pronounced.
Semantic Transparency: pictures and icons are more difficult to draw than simple geometric shapes, especially for the artistically challenged.
Visual Expressiveness: some visual variables (colour, value and texture) are more difficult to use (due to limited drawing ability and availability of equipment e.g., colour pens).

- **Step 1:** Determining the difficulty of transferring information between users in the notation's language.
  Describe the possibilities (and difficulty) regarding the notation as a representational medium in the following table(s).

Representational medium	**Grade**	
Motivation		

X. COGNITIVE INTEGRATION

Cognitive Integration only applies when multiple diagrams are used to represent a system. This is a critical issue in SE, where problems are typically represented by systems of diagrams rather than single diagrams. It applies equally to diagrams of the same type (homogeneous integration) – for example, a set of levelled DFDs – or diagrams of different types (heterogeneous integration) – for example, a suite of UML diagrams or ArchiMate views.
To describe the notation's score for this principle, perform the following step(s):

A. Perceptual integration

Perceptual integration: perceptual cues to simplify navigation and transitions between diagrams. There are a range of mechanisms that can be used to support perceptual integration, which draw on the design of physical spaces (urban planning), virtual spaces (HCI) and graphical spaces(cartography and information visualization). Whether navigating around a city, a website, an atlas, or a set of diagrams, wayfinding follows the same four stages:

- **Orientation**: where am I?
- **Route choice**: where can I go
- **Route monitoring**: am I on the right path?
- **Destination recognition**: am I there yet?

Step 1: Determining the perceptual integration.
Describe the possibilities regarding perceptual integration in the following table(s).

Perceptual integration possible?	**Grade**	
Motivation		

B. Conceptual integration

Conceptual integration: mechanisms to help the reader assemble information from separate diagrams into a coherent mental representation of the system. One important mechanism to support conceptual integration is a **summary (longshot) diagram**, which provides a view of the system as a whole.

- **Step 1:** Determining the conceptual integration.
  Describe the possibilities regarding conceptual integration in the following table(s).

Conceptual integration possible?		**Grade**	
Motivation			

XI. ADDITIONAL NOTES
