Towards A Periodic Table of Visualization Methods for Management

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ABSTRACT
In this paper, we describe the effort of defining and compiling existing visualization methods in order to develop a systematic overview based on the logic, look, and use of the periodic table of elements. We first describe the current fragmented state of the visualization field. Then we outline the rules and criteria we applied in conducting our research in order to present a revised periodic table of 100 visualization methods with a proposition how to use it.

KEY WORDS
knowledge visualization, knowledge visualization methods, periodic table, problem solving, classification, selection framework, visualisation types

1 The Realm of Visualization Methods

The discipline of visualization studies is an emergent one and as such represents a so far still highly unstructured domain of research that includes scholars from such distant domains as human-computer interaction, graphic design, management, or architecture. Thus, there are many parallel, unconnected streams and development activities in this field that may move forward without mutually acknowledging or integrating efforts under way elsewhere. In order to contribute to the consolidation of these efforts and to the emergence of a distinct field that achieves cumulative research progress this article proposes an integrative overview on one aspect of the visualization field, namely the development of easily applicable visualization methods, that is to say systematic graphic formats, that can be used to create, share, or codify knowledge (in the sense of insights, experiences, contacts, or skills). In this paper, we present a simple structure, inspired by the use, look, and logic of the periodic table of elements developed in the domain of chemistry. There are numerous benefits that can be achieved through such a structure: First, it can provide a descriptive overview over the domain [1, p. 12] and can function as an inventory or repository like a structured toolbox. In this way this structure can also become a problem solving heuristic [2, p. 68] that relates possible visualization methods to visualization challenges. Thus this structure reduces the complexity inherent in choosing a visualization method for a particular application context. As a further benefit, it helps to recognize the similarities and differences among different types of visualization methods as well as to compare different types of visualization methods along pertinent criteria. Its main purpose is therefore to be user-centered in its focus to assist researchers and practitioners in identifying relevant visualization methods and assess their application parameters. Our understanding of a visualization method is, in a first step, an ample one, as we strive to develop a preliminary broad compilation of methods (that employ visual means to structure information). We use the following general formula as a working definition for visualization methods:

> A visualization method is a systematic, rule-based, external, permanent, and graphic representation that depicts information in a way that is conducive to acquiring insights, developing an elaborate understanding, or communicating experiences.

Prototype members of this category of elaborate visualization tools are, in our view, methods (from realms as diverse as education, requirements engineering and argumentation theory) such as concept mapping, evocative knowledge diagrams, argumentation diagrams, or rich visual metaphors. In this paper, however, we only focus on methods with potential applicability in the realm of management. In management the key for better execution is to engage employees. To succeed the communicator not only needs to convey the message, but also needs to tailor it to the recipient's context, so that he can re-construct the knowledge, integrate it and put it to meaningful action. Therefore we see a high potential of complimentary visualizations to engage different stakeholders. Unfortunately in management very few visualization methods are used, and little is known about visualization methods of other domains with potential to management, their requirements, benefits and application areas.

2 Methodology: Identifying, Selecting, and Organizing Visualization Methods

The methodology that we have applied for this paper can be separated into three steps. The first step consisted of *identifying* potential candidates for inclusion in the visualization compilation. The second step consisted of *selecting* those methods that best meet the requirements of visualization for the realm of management. The third step consisted of *structuring* the compiled methods in a logical and accessible way. With regard to the first step we have consulted the following sources to gather visualization methods:

- Websites focusing on compilations of visual methods for problem solving, learning, or management (such as www.mindtools.com, visual-complexity.com, knowledge-visualization.org, 4managers.de, valuebasedmanagement.net etc.)
- Seminal books focusing on visual methods (such as the works of Tufte [3, 4, 5], Wurman [6], Chen [7], Mok [8], Horn [9, 10], and others)
- Articles from scientific journals in the areas of management, psychology, education, computer science, design, or philosophy proposing, discussing, or applying visual methods

In these sources we have found approximately 160 visual methods. We have reduced these to a set of a hundred methods, by applying the following selection criteria:

1. The method must be fully documented in all its steps.
2. The method must have been previously applied in real-life, preferably organizational, settings.
3. The method must be fit to represent knowledge-intensive, complex issues.
4. The method must be applicable by non-experts.
5. The method should have been evaluated before in some way or other.

The resulting hundred visual methods that have met these criteria were then analyzed with regard to the following properties: *graphic format* employed (i.e., quantitative chart, qualitative diagram, cartographic map, visual metaphor, tables) , typical *content type* (e.g., concepts, problems, people), *application context* (e.g., management, engineering, counseling etc.) and *scope* (narrow vs. wide), *difficulty* of their application, *originating discipline*, vicinity over overlaps to other visual methods.

We have derived these distinguishing dimensions from existing visualization taxonomies [11, 12, 13, 14] and consequently use them as candidates for organizing principles in our periodic table of visualization method.

It was central in our classification effort to find dimensions with a granularity that fit managers: They should be easy to use and have proven benefits. The dimensions should address challenges related to managerial thinking (cognitive challenges), managerial communication and coordination (social challenges), and the managers' ability to motivate and engage their peers and employees (emotional challenges). The visual representation of information, on the other hand offers many cognitive (e.g., perspective switching [25]), emotional (e.g., create involvement and engage people's imagination [26]) and social (e.g., ideally suited for communication and presentation purposes [9]) advantages that can be put to use in management.

The organization principles should also relate to the situation in which the visualization is used (when?), the type of content that is represented (what?) the expected visualization benefits (why?), and the actual visualization format used (how?) [20]. We then classified the visualization methods according to those challenges and requirements and came up with the following five dimensions.

- *Complexity of Visualization:* **Low to High,** referring to the number of rules applied for use and/or the number of interdependences of the elements to be visualized.
- *Main Application or Content Area [how?, what?]:* **Data, Information, Concept, Metaphor, Strategy, Compound Knowledge.** Furthermore members of this group can also be ranked according to their knowledge intensity, going from explicit, objective knowledge visualizations (like Data Visualization) to more tacit, subjective knowledge visualizations (like Compound Knowledge Visualization).
- *Point of View [when?]:* **Detail** (highlighting individual Items)**, Overview** (big picture)**, Detail and Overview** (both at the same time).
- *Type of Thinking Aid [why?]*: **Convergent** (reducing complexity) vs. **Divergent** (adding complexity)**.**
- *Type of Representation [what?]*: **Process** (stepwise cyclical in time and/or continuous sequential), **Structure** (i.e., hierarchy or causal networks**)**

Then we organized these dimensions in an easily accessible table reminiscent of the Periodic Table of Elements, thus signaling the main purpose of meaningfully organizing elements that can be combined for use.

3 The Periodic Table of Elements

The periodic table of the chemical elements is a tabular form of displaying the chemical elements, first devised in 1869 by the Russian chemist Dmitri Mendeleev. Mendeleev conceived the table to illustrate recurring ("periodic") trends in the properties of the elements. Mendeleev's key insight in devising the periodic table was to lay out the elements to illustrate recurring ("periodic") chemical properties (even if this meant some of them were not in mass order), and to leave gaps for "missing" elements. Mendeleev used his table to predict the properties of these "missing elements", and many of them were indeed discovered and fitted the predictions well.

In order to illustrate recurring properties, Mendeleev began new rows in his table so that elements with similar properties fell into the same vertical columns ("groups"). Groups are considered the most important way of classifying the elements. In some groups, the elements have very similar properties and exhibit a clear trend in properties down the group — e.g. the alkali metals, halogens and noble gases. Each horizontal row ("period") in the table corresponds to the filling of a quantum shell of electrons. Although groups are the most common way of classifying elements, there are some regions of the period table where the horizontal trends and similarities in properties are more significant than vertical group trends — e.g. the lanthanides and actinides (the two bottom rows in the table).

The periodic table is now ubiquitous within the academic discipline of chemistry, providing an extremely useful framework to classify, systematize and compare all the many different forms of chemical behavior [15].

As the periodic table hangs in thousands of classrooms across the globe, it has in itself become a visual metaphor and serves now as a template for presentation of knowledge in various domains. For some nice alternative appropriations of the periodic table see [16] or [17].

The periodic table is also a prototypical example of Ben Shneiderman's visualization mantra of *Overview first, zoom and filter, then details on demand* as it presents in the overview the structure and the details on demand when clicking on a symbol in web-based versions [15] or in a printed version when you look closer. Of all the visualization methods presented in our periodic table, it itself most closely resembles an Infomural. According to Shneiderman's definition an Infomural has the following attributes: 2D, miniature representation, representing an entire information space, using visual attributes such as color and intensity to portray information density.

In the next section of this paper, we will show how we converted each of these dimensions into a facet of the periodic table, namely the position in the table, the color of the element, as well as its grouping and its indicative field numbers and codes.

4 Results: A Periodic Table of Visualization Methods

The periodic table is constructed along two dimensions: Periods and groups. Of the five dimensions we deemed most relevant for a pragmatic classification of visualization methods, we found the dimension of *complexity of visualization* most fitting for "periods" and *application area* most fitting for "groups".

As we classified the visualization methods along those two dimensions we also tried to organize them in a similar way. That means as you move down a column, you will find similar methods for similar purposes but getting more and more complex. This is an ordinal measure within a group, meaning you will find in one period different amounts of complexity. This is for pragmatic reasons as we didn't want to leave any empty spaces in the table. For example, a line chart is a more complex visualization method than a spectrogram (a single line having two extreme poles). On the other hand a tensor diagram is more complex than a spectrogram.

Additionally we have tried to put similar visualization methods or application areas in one column. For example *argument slide*, *toulmin map* and *IBIS argumentation map* are argumentation visualization methods grouped in order of their complexity. For project management it is the column starting with the *metro map*. Furthermore we have subdivided the application area dimension ("groups") into the following categories and distinguished them by background color:

- **Data Visualization** includes standard quantitative formats such as Pie Charts, Area Charts or Line Graphs. They are *visual representations of quantitative data in schematic form (either with or without axes)* [18], they are all-purpose, mainly used for getting an overview of data. We have mapped them to the Alkali Metals which most easily form bonds with non-metals, a correspondence might be the combination between data visualization (answering "how much" questions) and visual metaphors (answering how and why questions).
- **Information Visualization**, such as semantic networks or treemaps, is defined as *the use of interactive visual representations of data to amplify cognition. This means that the data is transformed into an image; it is mapped to screen space. The image can be changed by users as they proceed working with It* [19]. We have compiled the most widely used IV application formats in this group.
- **Concept Visualization,** like a concept map or a Gantt chart; these are methods to elaborate (mostly) qualitative concepts, ideas, plans, and

analyses through the help of rule-guided mapping procedures. In Concept Visualization *knowledge is usually presented in a 2-D graphical display where concepts (usually represented within boxes or circles), connected by directed arcs encoding brief relationships (linking phrases) between pairs of concepts. These relationships usually consist of verbs, forming propositions or phrases for each pair of concepts.* [22]

- **Metaphor Visualization,** like metro map or story template are effective and simple templates to convey complex insights. Visual Metaphors fulfil a dual function, *first they position information graphically to organize and structure it. Second they convey an insight about the represented information through the key characteristics of the metaphor that is employed.* [20]
- **Strategy Visualization,** like a Strategy Canvas or technology roadmap is defined *"as the systematic use of complementary visual representations to improve the analysis, development, formulation, communication, and implementation of strategies in organizations."* This is the most specific of all groups, as it has achieved great relevance in management.
- **Compound Visualization** consists of several of the aforementioned formats. They can be complex knowledge maps that contain diagrammatic and metaphoric elements, conceptual cartoons with quantitative charts, or wall sized infomurals. This label thus typically designates the complementary use of different graphic representation formats in one single schema or frame. According to Tufte they result from two (or more) spatially distinct different data representations, each of which can operate independently, but can be used together to correlate information in one representation with that in another. [3, p.133], [4, p.24].

Some visualization methods can belong to more than one category. If we take the periodic table as example, then it is clearly a compound visualization. But in our appropriation it becomes also a visual metaphor. Many methods of Strategy Visualization are clearly visualizations of concepts. What sets them apart is their higher degree of Complexity of Visualization as they presuppose more management or domain specific knowledge.

In the periodic table of chemistry, all other dimensions are put in the box of the element. In our table, we put the three other dimensions on top of the method symbol and used the following pictorial representations:

- **Task and Interaction:** Depending on the task, visualization can emphasize certain aspects of the data. Furthermore complex diagrams may require physical interaction, even to read or explore them in detail. Here we take up Mintzberg's insight that (strategic) thinking can be conceived as different kinds of *seeing* [23] and group the methods accordingly:
  - **Overview [☼],** most visualization methods are good in providing an overview.
  - **Detail AND Overview [۞],** those methods adhere in one way or another to Shneiderman's visualization mantra *Overview first, zoom and filter, then details-on demand*[12].
  - **Detail [¤],** those methods are good in providing (additional) insights from single bits of data. *Detail* visualization methods are mostly used for reasoning with the *backwarding heuristic*, i.e. thinking backwards from the desired outcome to the present position [13, 24], thereby spelling out all the subproblems, e.g. Nassi-Shneiderman diagram.

- **Cognitive Processes:** Visualization methods can help the user to articulate implicit knowledge (as in a visual metaphor) and to stimulate new thinking (like with a mindmap). Two simple and established categories to employ in this context are [e.g. 24]:
  - **Convergent thinking [><]** is a mode of critical thinking in which a person attempts to reduce complexity through analysis and synthesis.
  - **Divergent thinking [<>]** is a mode of thinking in which a person generates many unique, creative responses to a question or problem.

- **Represented Information:** The information to be represented has also been classified by various researchers [11, 12, 7, 14, 21], The most striking distinction for us is between
  - **Structure** [in black], such as hierarchies or networks
  - **Process** [in blue], either stepwise cyclical in time and/or continuous sequential.

A key benefit of the periodic table of chemistry lies in the fact that it not only reveals the organizing principles of chemistry, but that it helps building chemical compounds. E.g. if you have an alkali metal as sodium, you know that you can combine it with any other element of the halogen group, like chloride. With our table we do not mean to reveal the organizing principle of visualization methods, but we want to highlight the fact that there might not be only one appropriate visualization method for a given requirement. Rather, there is the potential of employing a combination of different methods to enhance the achieved results. Such synergistic results could be achieved when combining divergent and convergent methods, structure and process methods, as well as overview and detail methods. As in the periodic table of chemistry, we think that data visualization methods could synergize well with Visual Metaphors and could therefore be considered complimentary. We put the compound visualization methods in the category of the noble gases as they could incorporate different visualization methods. This applies even more to other dimensions. In project planning you could start with a Mind Map which fosters divergent thinking and then plan it with a Gantt chart. Or you could start a programming problem with a Rich Picture to get an overview and then work out every solution implementation with a Nassi-Shneiderman diagram. Or if you want to logically structure ideas and thoughts, like the *Minto pyramid technique*, you can go up or down the column to see if the *square of oppositions* or the *synergy map* would be more adequate to provide insights. As they are detail AND overview, overview or detail AND overview respectively. It could also be possible that the combination of square of oppositions and Minto pyramid technique could complement each other and provide you with even more insights.

5 Conclusion: Implications and Limitations

Our efforts in structuring the vast domain of visualization methods cannot be seen as a close adaptation of the periodic table of chemical elements. It is rather a functional, metaphoric homage to it. The choice of methods included as well as the order criteria cannot be considered exhaustive. Nevertheless, it does provide an overview over more than hundred useful visualization methods of great variety and by organizing them assists researchers and practitioners alike in choosing adequate visualization methods for their needs. On demand the user is provided with further useful information through signs. We encourage the reader to playfully explore the different properties of the visualization methods presented. So he may consider more than one method for his next visualization requirement and to use them in a combined, complementary manner. This may not turn lead into gold, but turn complex issues into accessible explanations.

6 References

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