Framework for Spatial Visual Design of Abstract Information.

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Abstract

Spatially-organized information can be accessed and operated on rapidly and effortlessly, especially when a spatial arrangement reveals the conceptual organization of information. Therefore, spatial perception plays an important role for cognitive processing when interacting with abstract information. The process of spatial information visualization is shaped by various factors including interactive, perceptual, navigational as well as organizational and metaphorical aspects and as such requires an interdisciplinary approach. Consequently, bringing the knowledge from different disciplines requires the development of a framework which can host and classify the interdisciplinary features important in designing effective spatial visualizations. In this paper we present a framework which manifests a holistic approach in designing spatial visualization of abstract information.

Keywords: spatial visualization, framework, information visualization

1. Introduction

Spatial perception plays an important role for cognitive processing when interacting with abstract information, since spatially organized information can be accessed and operated on rapidly and effortlessly, especially when a spatial arrangement reveals the conceptual organization of information. Therefore, an important benefit that improves quality of processing abstract data is the incorporation and use of spatial schemas while designing visual representation. It becomes even more crucial today when, due to the popularity of handheld devices, the size of the display is constantly decreasing whilst the amount of information which is expected to be displayed on the digital device is increasing.

In this paper we describe a framework which embraces features important for spatial interactive design of abstract information. This framework has already been successfully used to organize spatial design guidelines for information visualization [see 6].

2. Importance of spatial design for information visualization

Space is a crucial dimension of our everyday life. In space, we perceive and recognize objects and relations between them. In space, we manipulate these objects and we can move around to observe them. Depicting space has been used for a long time to convey concrete ideas. However, only recently it is being used to convey abstract ideas [38]. Tversky [38] notices that spatial schemas, by linking together elements, provide an organization which improves memory and can sometimes be a more powerful organizer of memory than time. Additionally, spatial manipulation is a largely subconscious activity that imposes very little cognitive load, hence offering very powerful functionality [21].

Abstract data is lacking inherent spatial mappings, and additionally, the relationship between the data value and the data view is multi-faceted [9, 10] As a result, it is challenging to create a spatial set up for this type of data since it requires applying interactively different views of the same data set or applying an operation of data spatial-filtering to compare different data sets. Consequently, effective spatial representation of data requires understanding the phenomena governing the perception of space.

3 Holistic approach to spatial visual information design

Spatial visualization depends on many aspects relating to data attributes and organization, design method, and available display technology. There is a need for organizing components required for guidance in spatial, interactive visualization and for investigating relations between them. The nature of such relations depends on a visualization goal envisioned by the designer and the cognitive tasks to be fulfilled by the user. Additionally, it is important to be aware of various levels that are involved in shaping the quality of spatial information visualization output. Some of these levels include perceptual, interaction and navigation levels as well as organizational or metaphoric levels. Until now, these aspects were investigated separately by various researches [7, 19, 26, 28, 29, 35, 36, 37]. Many frameworks focusing on different portions of design space have been proposed [3, 8, 9, 11, 22, 25, 27, 33, 39]. Many classifications have been created to help designers develop their works [10, 20, 23, 29, 36, 43]. Additionally, principles and rules for different aspects of information visualization design have been developed [2, 3, 4, 8, 17, 35]. Understanding the spatial visualization process in the digital domain requires an awareness of the holistic nature of the act of space perception. Furthermore, the process of reusing and sharing design expertise should be structured and open to facilitate sharing competencies among different design domains. Therefore, we propose a framework which manifests a holistic approach to designing spatial visualizations of abstract information. Additionally, an important part of the framework that classifies spatial visual cues is based on analysis of spatial visual properties for digital domain (see [6] for more details and examples).

4 Framework for spatial visualization design and its elements

The framework presented here integrates various aspects of spatial visualization. It encompasses elements of visualization pipeline as described in [12] by incorporating aspects of mapping data to geometry, assigning visual properties to geometry and integrating the user's visualization tasks together with the goals of the visualization designer. In the graphical representation of the framework (Appendix 1) we mark the contributions of various researchers with "patches". Properties and tree-structures of properties without a patch represent our contribution to the framework. We take a top-down approach to describe the main elements of the framework.

During the process of assigning properties to visualization objects we distinguish five elements, which define our "Digital Visualization Space". Three elements create the core of our classification:

- Object – a graphic element or geometry which is used to represent concepts in our world
- Context – a graphic space which is used to represent relations between elements [38]
- Order – definition of a choice of spatial arrangement of objects in the graphic space

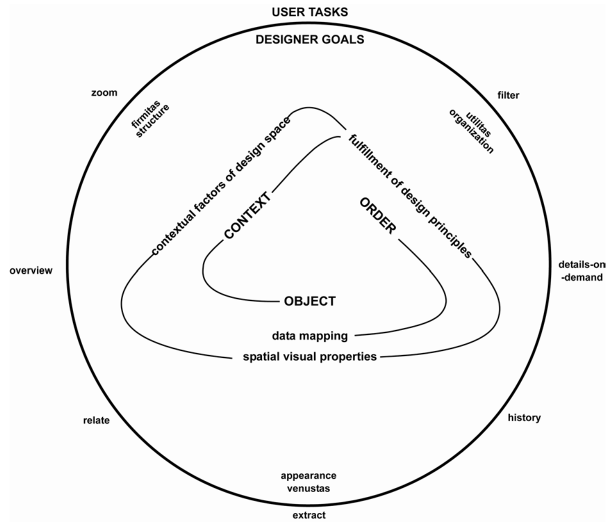

Figure 1. Five main groups of spatial visualization factors build framework for the spatial visualization of abstract information: User Task Group, Designer Goals Group, Context Group, Order Group, and Object Group. Additionally, relationships between Context, Order, and Object groups are visualized as lines connecting spatial design factors on different levels.

Designer Goals and User Tasks are two further classification elements which have an important influence on spatial visualization effectiveness. The influence of these components is represented as a circle embracing the Context, Order and Object elements in the graphical representation of this classification. For defining The User Tasks element, we adopted the cluster of tasks method formulated by Shneiderman [37] who defined seven items of "Information-Seeking Mantra" while working with the visualization environment. Please note that the visual examples of spatial framework elements can be found in [6].

4.1 Elements of classification model - Object Group

Within Object Group, we embrace three levels describing information visualization objects. We describe a visualization object in terms of its role within a visualization scene using taxonomy of graphical Simple Marks, Compound Marks, and Negative Space. Furthermore, we acknowledge the classification of the visualization object as a data object, process object and referential object. Finally, we classify visual properties of a visualization artefact which enriches the spatial visualization of abstract information.

Visualization object: graphical marks and negative space

Marks first introduced by Bertin [3] refer to graphical elements visible on a display medium; they describe the most primitive blocks which encode information: points, lines and areas (volume mark was added later by [8]). Senay [35] further extended the ordering of graphical elements by adding another group of marks called compound marks. They define *Compound Marks* as "collections of simple marks that form a single perceptual unit". On this level of classification we additionally introduce *Negative Space* which, in our opinion, is an important element of information visualization artefacts. Marcus [28] observes that "empty" or negative space is needed to provide emphasis for visual elements within the display space. Also, Arnheim [1] points out that the relationship between figures can only be understood if the spaces between them are designed as carefully as the figures themselves.

Data, Process, and Referential Objects

In this framework, we classify objects in terms of roles they play within a visualization artefact. We distinguish between three types of objects: Data Object, Process Object and Referential Object. By *Data Object*, we refer to any object that visually represents different types of data. *Process Object* refers to the type of object that supports interaction processes between a human and a machine on the visual level. We refer to *Referential Object,* which is based on the concept of Referential Component [35], as any type of visual object facilitating the proper interpretation of spatial qualities in a graphical scene but not encoding data items directly. The characteristics of a Data Object are determined by the type of data being visualized. We use the seven data types introduced by Shneiderman [37].

The Process Object group clusters Icon, Label, Filter, and Menu elements. We understand *Icon* as an object that graphically represents an item recognizable or learnable by the user. Icons can be used for communicating certain functions or processes within visualization artefacts. We refer to *Label* as an object attached to another object (data or process-related) describing this object, often using textual representation. *Filter* represents types of object used during the process of exploring visualized content for modifying the spatial and graphical parameters of objects (e.g. changing spatial configuration of objects according to the new rule established by the user). Finally, *Menu* refers to a wide range of processes collected in one set of functions available for use when working with visualization artefact. Within Object group we classify visual properties that influence spatial design in visualization of abstract information. For more detailed description of these properties (with examples) please refer to [6].

Spatial Properties

We have grouped selected properties for spatial information visualization in nine thematically organized groups. A group clusters properties of visualization artefact that share the same aim in supporting spatial visualization on a flat display or a group collects properties bearing similar perceptual characteristics to evoke a spatial illusion in a visualization artefact.

1. <u>Position Group</u> clusters properties that assemble techniques which visually define the position of the objects within a spatial environment. *Orientation* property points at the position of an object with respect to the observer's viewpoint for reading the spatial qualities of this object. *Dropped Line* property describes the use of supporting elements to clarify the geometrical position of visualization elements within a spatial scene. *Visual Frame* communicates the influence display borders have on reading spatial relationships within the visualization artefact. *Gravity* is an example of a force that can visually influence characteristics of the behaviour of visualization objects within the spatial scene. Elevation describes elements acting as reference for objects which are subjected to gravitational force within a visualization artefact. Finally, *Distance Association* illustrates the technique of defining the distance between objects based on the observer's knowledge of the size of these objects.

2. The <u>Sequence group</u> clusters properties supporting qualities of sequential occurrences in space and time. *Rhythm* describes a time-bounding property helpful in prolonging the user's attention to the visual presentation. *Disintegration* illustrates an art of composing elements on different planes in a spatial organization. Finally, *Level of Detail* conveys a technique that governs the detail's order of appearance within a visualization artefact. Detailed descriptions of these properties follow.

3. The <u>Layering Group</u> clusters properties describing the effects of relationships between objects positioned on the same visual surface. *Occlusion* describes spatial quality derived from the superposition of objects. *Figure/Background* underlines the importance of the relationship between objects and the background for spatial visualization. Finally, *Shape Contour* illustrates spatial effects that can be achieved by manipulating shapes of contours on the surface.

4. The <u>Symbolic Form Group</u> describes techniques that control spatial organization. *Pyramidal Space*

represents a technique for depicting spatial environment using rules of linear perspective. *Negative Space* illustrates issues related to the impact of an empty space on the spatial environment. Finally, *Distortion* presents an approach for manipulating the shape of objects with the goal to create a spatial scene.

5. Properties clustered in Kinetics Group explain techniques for conveying time-based events within computer-generated environments. *Temporal Sequence* describes the process of integrating time into the presentation of a phenomenon. *Point of View* describes a technique that involves the user in a time-based exploration of the visualization environment.

6. The Gradient Group depicts techniques that evoke the perception of space by differentiating the size or density of objects positioned near the observer from those positioned far away. *Relative Size Gradient* uses properties of familiar size for spatially positioning elements. *Textual Gradient* illustrates the use of elements building the texture in a spatial environment. Finally, *Relative Density* describes the use of density of objects as an aid for supporting the spatial quality of a visualization scene.

7. Properties in Brightness Group stress the role of light in modelling the spatial environment. *Value* describes the relationship between lightness and darkness of a colour. *Shadow* property explains the importance of shadow in defining spatial environment. *Lighting and Colour* properties illustrate the role of brightness in a spatial composition. The property of *Transparency* describes the effect of seeing through the objects involved in a spatial scene.

8. The Focus Group explores the effects of controlling the cognitive and vision-related focus of the user when viewing a visualization artefact. *Depth of Focus* describes how the illusion of depth can be modelled using blurred and sharp objects. The *Law of Visibility* presents rules that have an impact on a spatial visualization. *Atmospheric Perspective* illustrates the modelling of the spatial environment using different types of visual gradation.

9. The User Group collects properties of User Control and Continuity of Illusion which define the importance of the user's engagement in the spatial visualization environment. *User Control* focuses on the possibilities of the user for exploring the spatial organization of the visualization artefact. *Continuity of Illusion* refers to the spatial quality of a visualization artefact.

These nine groups are further classified into clusters which organize groups of properties according to the role they play within a spatial visualization artefact. Based on [3] vocabulary, we classify spatial properties into Positional Cluster, Temporal Cluster, and Retinal Cluster. Positional Cluster groups spatial properties, which describe character of the visualization scene depending on the spatial position of the object and relationships between objects with respect to the user's viewpoint. Temporal Cluster describes techniques for depicting space and time-based events within visualization environments. Finally, Retinal Cluster assembles properties which visually define spatial character of the object - its shape, the effect of light on it, or density of its texture.

Connection and Closure group are located on the level of Positional, Temporal, and Retinal Clusters in our classification and are described in more detail in [6].

During the design process of a computer-generated spatial visualization of abstract information, it is important to consider the impact of user action and technology on the visualization artefact. Therefore, we include in our classification additional clusters of properties: User Defined Cluster, Input Device Cluster, and Display Cluster.

Input Device Cluster differentiates between two types of devices: a natural and a synthetic one. We refer to the natural device as a device which facilitates the transfer of instructions or information into the computer for processing or storage, using natural human capabilities for communicating through voice, touch, gesture, body movement, eye contact, etc. Synthetic devices require from the user a special type knowledge of how to operate them (e.g. to enter instruction into the computer with help of mouse, keyboard, joystick, etc.)

Display Cluster includes items influencing the use of other visual spatial properties by the choice of display parameters such as size, resolution, and the use of colour. The higher the resolution, the more complex visual information can be presented on the display. Compare, the spatial character of Linear Perspective which can be diminished if the resolution of the display is low, since the diagonal lines may appear jagged and do not to convey the effect of objects disappearing in the space behind the display.

There are three strong categories emerging from the organization of spatial properties proposed until now. Connection, Closure and Position clusters group properties underlining the value of spatial relationships between objects. Temporal and Retinal clusters concentrate on describing the relationship between the spatial scene and its meaning. Finally, User Defined, Input Device, and Display clusters include properties illustrating the impact a presentation device and user involvement have in a spatial presentation. To complete our classification of visual spatial properties, we use visual semiotics. Using the approach of [16] and [28] we distinguish three categories: Visual Syntax, Visual Semantics and Visual Pragmatics.

Visual Syntax refers to the quality of arrangements of signs used for spatial communication. It therefore includes Connection and Closure as well as Position Clusters.
Visual Semantics deals with relationships between signs and what they refer to [5]. In our classification, spatial properties that stress relationships between the type of technique chosen for creating a spatial scene and the communication purpose of this visualization scene belong to this category. We include Retinal and Temporal clusters into this category. Finally, Visual Pragmatics deals with the relation between the signs and their users [5]. Similarly to [28], we extend this definition to include technical conditions influencing the process of communicating the signs. For the purpose of our classification we include User Defined, Input Device, and Display clusters into this category. These clusters group properties that define the limitations of visual spatial communication (e.g. size and resolution of the display) as well as direct the influence the user has on the spatial visualization scene (see Appendix 1).

4.2 Elements of the framework - Context Group

Perception is not an entirely stimulus-driven process. Our perception is influenced to some extent by "cognitive constrains: higher level goals, plans, and expectations" [32]. Here we propose to include factors that influence context of spatial visualization. We refer to them as contextual factors. Until now, we have only explored their visual features in spatial information visualization environments.
Contextual factors describe components affecting user's spatial exploration of information on the following levels: user, community, and environment levels. "User level" represents the attributes a cognitive model user is using when interacting with a particular visualization. Cognitive attributes describe the task and role of the user in the visualization environment. "Community Level" - defines characteristics of a digitally-based social space formed in a multi-user visualization setting. "Environment level" encompasses visualization components or methods that define and characterize an environment dedicated for user exploration in a perceptible way. The following elements belong to this group: 'spatial container', 'orientation', 'interaction', and 'expression'. Spatial container embraces a structure that visually identifies the user's exploration space. Orientation represents a set of characteristics defining the act of navigating through the information space. Interaction describes the group of techniques, which allow the user to influence visualization. Finally, expression specifies the metaphorical concept used for spatial visualization.

User level - Mental Model

Mental Model is an important component of user interface. After [42] we refer to Mental Model as a basis for "understanding the system, for controlling its action and predicting its future behaviour". Mental Model represents the organization of data, functions, activities, and roles that users inhabit within computer-based environments of work or play. We distinguish two factors of the Mental Model group which have been already introduced by [13]: Pattern of Presence and Pattern of Association. *Pattern of Presence* is a mental map (or model) of the user's presence within a visualization environment. *Pattern of Association* is understood as a conceptual map created by the user representing the community formed within the user's spatial system which would otherwise have no visible manifestation in the physical world.

Community level - Social Space

Social Space is a group of factors defining social aspects of a spatial multi-user environment. This group includes: Digital Portrait, Digital Conversation, Digital Crowd, and Social Networks. After [13] we refer to *Digital Portrait* as a representation of the user within a spatial multi-user environment. Digital Portrait has a visual form which demonstrates the user's presence as a member of social space (through the actions he provokes and takes) within the environment. As already noted by [14], Digital Portrait depicts "a culture as well as an individual which tells far more about its subject than just what he or she looked like". *Digital Conversation* in newsgroups, chatrooms, wikis and mailing list forms is referred to by [14] as the foundation of Social Space in online environments. Digital Conversation describes space and time-dependent conversation taking place between users of an online environment (synchronous and asynchronous conversations). *Digital Crowd*, an expression coined by [30] describes visualization of users simultaneously visiting spatially-defined environments of online documents or websites. Minar [30] lists three important requirements for visualizing a digital crowd: a map of the digital environment (e.g. documents visited by users) for providing a spatial structure for a digital crowd, a representation of individual users to show visitors of the site, and an animated demonstration of crowd dynamics. Crowd dynamics describe methods for distinguishing between popular and less popular groups of websites by mapping users accessing or leaving these websites. Finally, *Social Networks* (netvis.org) are patterns of relations or connections among individuals. A spatial visualization of such networks allows for conducting analysis of network behaviour.

Environment level

Spatial Container encloses factors which describe qualities of constructs defining visualization scene. *Background* refers to the visual character of the background against which all elements of the visualization are placed. Using a polychrome or monochrome background for the visualization artefact influences the way in which the user perceives the rest of the visualization scene. Additionally, since Background is an element which only rarely changes its visual character, it can be classified as the type of visual experience that responds to the phenomenon of visual adaptation [32]. The *Spatial Setting* group describes the setup of the Spatial Container used in visualization artefacts. By using the Inner Space of the container, the background image is not influencing the visual character of the spatial composition. By using the Outer Space of the Spatial Container as a component-creating scene for the visualization, the Background starts to play an important role as an element of the spatial composition.

Orientation relates to the set of factors influencing a user's ability to explore spatial visualization. We defined two groups of factors: View Point and Navigation. *View Point* clusters in.world and out.world which describe the manner in which the spatial information of the visualization environment is presented. An, element called in.world describes types of spaces resulting from the user's activity directly within a particular multi-user environment. Out.world refers to the type of space inhabited by the representation of the users' group activity within the environment as a community [40]. *Navigation* factors describe user movements between pieces of information. We distinguish three aspects of navigation after [15]: Spatial, Semantic and Social Navigation. Spatial Navigation refers to the user movement from one item to another within a computer-generated structure based on spatial relationships (e.g. right, left, above, outside). In Semantic Navigation the user movement through the environment is performed according to semantic relationships between items (e.g. bigger, faster, similar, and alike). Social Navigation plays an important role in systems supporting multi-user collaborative activity. It refers to the user movement from one item to another which is provoked by the activity of other users. Examples of Social Navigation include moving "towards" other users or starting an activity because other users are performing it.

For the Interaction cluster, we adopt the taxonomy of interaction styles developed by [36]. Shneiderman distinguishes Menu Selection, Form Fill-in, Command Language, Natural Language, and Direct Manipulation as interaction styles.

Finally, Metaphor in the computer environment helps to achieve a mapping between the digital environment and a reference system known to the user from the physical world [31]. It is one of many communication techniques, which Marcus [29] is often referred to as a "rhetoric". However, since Metaphor balances between "expectation and surprise" it can often provoke confusion in the user. Within the Metaphor group, "Association of Organization" refers to the similarity of structure, objects or attributes (e.g. metaphor of a tree with roots, branches, leaves). "Association of Operation" refers to the similarity of processes or actions (e.g. selecting objects by touching them, grabbing items, or sliding items).

4.3 Elements of the framework - Order Group

The Order Group classifies design principles we found important in creating spatial environments for visualizing abstract information. To organize this group of properties, we adopt the classification set of 'visible language' principles introduced by Marcus [29]. He distinguished three clusters (Organize, Economize, and Communicate) to group principles which provide guidance for designing user interfaces. We use this type of grouping to propose clusters of principles helping to achieve effective spatial visualizations. In our framework we use the term Organization to describe groups of principles which provide users with consistent and clear spatial structures. Economy groups concepts maximizing the effectiveness of spatial, visual expression using minimum input. Finally, Communication represents principles which help to match a spatial presentation with the perceptive capabilities of the user.

Organization

For the spatial visualization of abstract information, we find it important to include gestalt principles of perceptual grouping within the *Organization* group. These principles form a basis for techniques used for arranging objects in spatial configurations. We distinguish seven items within this group: Continuity, Proximity, Closure, Similarity, Common Region, Synchrony, Connectedness and Mathematical Structure of design. For more detailed discussion of gestalt principles see [32, 41]. The Mathematical Structure of Design based on a nested hierarchy of symmetries (e.g.

a square is described as the following nested hierarchy of symmetries: Point.Translation.90°Rotations) [24].

Economy

We break down the group of Economy into four major subtopics: Attention Management, Praegnanz, Common Fate, and Consistency. Attention Management [2] supports the use of multiple views in information visualization. Attention Management refers to techniques such as animation, movement, sound etc. used in information visualization to guide user attention and ensure that "user attention is in the right place at the right time". This principle saves time used for exploring a spatial visualization. Praegnanz is one of the gestalt principles of organization which refers to subjective feelings of simplicity, order, and regularity that arise when a certain object is observed. The work of [18] demonstrated that 'good' figures can be encoded and stored more efficiently than 'bad' ones (the shape of a figure can be coded in fewer bits of information). The Principle of Common Fate also belongs to the gestalt principles of organization and describes the tendency of grouping together units (objects) that move with the same velocity (direction and speed). This principle is particularly effective in conveying the spatial organization of a large amount of particles within a visualization artefact. In proposed framework we assign the principle of Consistency to promote the same visual convention and rules to all objects belonging to the Economy cluster. Following conventions and rules as well as avoiding causal differences (without a strong motivating reason) allows the user to work faster and more effectively with information within a spatial environment [42]. Additionally Distinctiveness, [42] promotes the use of visual techniques to direct the focus of the user to important objects or parts of the scene.

Communication

The Communication group comprises the following factors: Symbolism, Emphasis, Graceful Transition, and Legibility. Symbolism refers to the specific principles of design objects where graphical symbols are used for communicating the message. Designing graphical symbols (or symbolic spaces) requires adopting the essence of the message and translating it into the visual object or the spatial configuration. Emphasis refers to the visual process of accentuating important messages to the user. This factor is related to the property of Attention Management in the Economy group, since emphasis helps to direct user attention to an important event or scene within a visualization artefact. Graceful Transition [42] refers to the quality of representing changes over time. Changes within the visual environment, if presented to the user in an abrupt manner and with lack of continuity, may be disorienting and fail in communicating the message. The Legibility factor refers to the visual quality of textual elements. To be able to communicate effectively, legibility of the textual elements has to be secured. This can be achieved by using typographic design chosen with regard to the visual scene in which these objects are placed, the technical possibilities of the display (size, resolution, colour), and the software used for generating the text on the display (especially in 3D environment).

4.4 Elements of the framework - Designer Goals Group

We have chosen the Vitruvian Triad of Firmitas, Utilitas, and Venustas as a classification instrument for defining the goals of a designer of spatial information visualization artefacts. As already discussed by Schmitt [34], we believe that creating environments for abstract information presented and shared through online networks can fulfil the criteria of designing physical architecture.

Firmitas - Firmness and Structural stability

In this classification we define the firmness or the structural stability of a visualization artefact as an essential constituent of a spatial scene or formation of objects. We distinguish three types of structure representation: Exterior, Interior, and Compound. Exterior structure refers to the type of representation when the focus is put on an external part of the scene or arrangements of objects. By using this type of representation, not all characteristics of the structure are revealed to the user. Interior structure refers to the representation of the structure when the focus is on its interior characteristics. In this case, the user does not obtain an immediate overview of the structure as a whole. Compound structure compromises the interior and exterior representation of the visual structure of the scene by combining them in one arrangement demonstrating both the structural characteristics of the whole scene and its spatial details.

Utilitas – Utility

We define Utility as a logical arrangement of spaces planned for the convenience and comfort of users. The logic of Utility can be expressed using various modes of spatial visual appearance. We distinguish three types of arranging objects or spatial scenes: elementary, symbolic, and relational. An elementary type of arrangement is characterized by objects or scenes embraced into a simple spatial arrangement with an easily recognizable pattern of interrelationships. The symbolic type of arrangement focuses on objects or spatial scenes by assigning to them additional meaning (e.g. associative or conventional in nature) conveying the character of the arrangement. Finally, relational arrangement focuses on the character and arrangement of connectors between objects or spatial scenes to demonstrate the nature of the spatial relationships between objects or scenes.

Venustas – Appearance and Beauty

We refer to Appearance as to the group of aesthetic features defining the visual character of the object or scene. Appearance groups three types of properties important for spatial visualization: Entertainment, Engagement, and Ambience. The importance for entertaining the user while he is visually exploring information has been already pointed out by [37], who stresses the importance of information exploration as a joyful experience. We refer to Entertainment as a spatial definition of a scene or group of objects, which users watch with pleasure, and which helps to engage users into the discovery process. Engagement refers to methods supporting the user in focusing on the spatial exploration of information while working within visualization artefacts. Design aspects of visual, spatial engagement enable the user to work faster and more effectively with the visualization objects. Finally, by Ambience we understand a particular visual 'climate' created for the purpose of visually influencing the user's exploration of visualization artefacts. Ambience can operate on the "periphery of human perception" and requires minimal attention and cognitive load.

4.5 Elements of the framework - User Tasks Group

During the spatial exploration of information, users perform a sequence of tasks allowing for the optimal discovery of patterns, clusters, and relationships between visualized items. The kind of tasks which allow for effective information searching or browsing is strongly interrelated with the spatial character of visualization proposed by the designer. Therefore, we find it important to include User Tasks as an element of the framework. The importance of involving user control in the visualization artefact design process was already pointed out by Shneiderman. For the User Task Group we adopt his seven tasks of "Information-Seeking Mantra" that information visualization applications should support. Shneiderman's cluster of tasks includes the following: overview, zoom, filter, detail-on-demand, relate, history, and extract. These well-known principles have been described in [37].

4.6 Relationships between elements of the framework

As already mentioned before, it is important for us to demonstrate the significance of a holistic approach to the spatial design of abstract information. Therefore, the proposed framework stresses interrelations between all five groups: Context, Object, Order, Designer Goals and User Tasks. As demonstrated in Figure 1, User Tasks embrace all groups of factors we created for spatial visualization, meaning we believe the tasks performed by users while exploring a visualization influence the kind of spatial design and vice versa. The next layer positioned closely to User Tasks in our graphical representation of the framework is the Designer Goals Group. We believe that the spatial factors involved in creating spatial information visualizations will effectively interact with each other when the spatial visualization scene is designed according to the principle described by the triad of Vitruvius or the coexistence of three factors: firmitas, utilitas, and venustas. Relationships within the 'circle' composed by Design Goals and User Tasks are created between three elements: Context, Object, and Order. We draw relationships between Object and Context groups on two levels.

The first relationships created within the framework on the level of primitive objects used in visualization artefacts are Simple Marks, Compound Marks and Negative Space (see Appendix 1). We see Negative Space as a classification item in which visual presence is influenced by factors present in both Object and Context groups. Although Negative Space is defined by the objects surrounding it, we believe that this classification item requires that it be operated on as any other visualization object represented by graphical marks. The second relationship is created on the level of the function of the object, namely Data Object, Process Object and Referential Object. Referential Object serves as a visual reference within a visualization artefact. It is an important element in creating the context for the whole visualization artefact and its presence is determined by properties applicable to any other visualization object.

We draw relationships between Object and Order groups on the level of primitive objects (Negative Space, Simple and Compound Marks) as well as on the level of the process of Data Mapping. The design principles influence graphical marks to secure optimal visual communication between the designer and the user of visualization artefacts. Consequently, mapping data to geometry should reflect the design principles foreseen for any particular visualization artefact. Additionally, we draw relationships between the

Context, Object, and Order groups on the level of Spatial Visual Properties, Design Principles and Contextual Factors of Design Space. At the same time, we see Spatial Visual Properties as influencing the visual quality of contextual factors. On the other hand, contextual factors can strengthen or weaken the influence of visual properties on the effectiveness of a visualization artefact. The design principles used in spatial visualization influence the choice of spatial properties to secure the most effective visual communication. For the same reason, design principles should also control the use of contextual factors in visualization artefacts.

5 Qualities and limitation of the framework

For a designer who is literate in visual spatial creation, a holistic approach to the spatial design embedded in the framework is attractive. This approach, already used in architecture and product design, allows for bringing together important properties which are shaping the quality of spatial information visualization. By using a spatial design framework designed this way, the designer is aware that the overall spatial quality of the visualization artefact can be reviewed along dimensions of structure, function and visual appearance and also by the designer's goal and the definition of the user's task. Furthermore, a designer can simultaneously consider his visualization product in terms of factors shaping the quality of the visualization object (in Object Group), contextual factors shaping design space (in Context Group) and the fulfilment of visualization design principles (in Order Group). For designers not familiar with aspects of spatial design, an important quality of the proposed framework is the possibility to investigate properties and factors important for spatial design, taking the bottom-up as well as top-down approach. Another significant characteristic of the framework is its topological openness, which allows for adding new design taxonomies or extending the existing ones at the top as well as at the bottom level of the proposed classification. In addition, this framework already serves as a map for the spatial design guidelines presented already elsewhere [6] and guidelines which may be developed by others. Finally, it reveals design areas where no guidelines have been formulated up to now.

Apart from the qualities described above, it has to be said that the framework we propose possesses certain limitations. This framework is created only for the visual part of spatial design. We do not focus on audio or tactile interaction with visualization. With this proposed framework, we captured the process of spatial visualization design on a high level, therefore the granulation of the detail may not necessary satisfy all designers using this framework to shape their visualizations. However, we believe that the structural openness of this framework allows for its further development on an interdisciplinary, collaborative basis or even to adaptation, which can be triggered by further improvements of display technology or extending the exploration of spatial information visualization.

A major challenge is to follow the path of classifying spatial properties by moving towards the development of an automated approach in spatial visualization of abstract information. We hope that our contribution can serve as an initial map in the development of a such system.

Conclusion

We have addressed the importance of spatial design for visualization of abstract information. Spatial design is a challenging issue in information visualization. It requires the sharing of expertise among visual design oriented disciplines, computer science as well as social fields of study. We have stressed the significance of the framework which incorporates properties from diverse present lines of research which influence spatial visualization. We have proposed a holistic approach in designing a framework which builds an extendable base for an infrastructure which is a step towards augmenting the quality of spatial information design.

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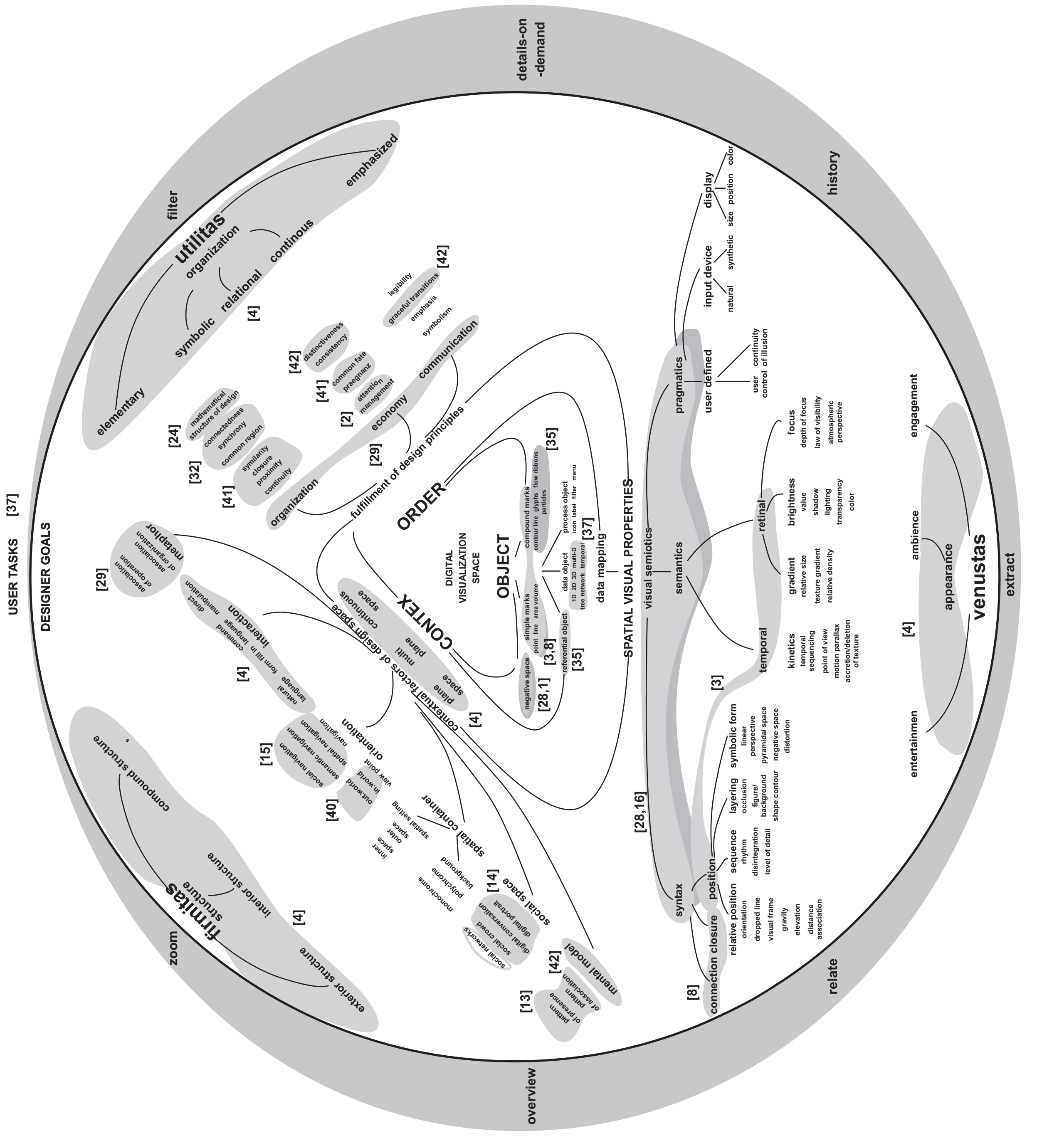

Appendix 1. Framework for spatial visualization of abstract information.
Grey patches mark the contributions of various researches (see list of references).
Elements without patches mark the contribution of the author.