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Novel Visual Metaphors for Multivariate Networks

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As visualization researchers we are often in search of new designs. In particular, when the data is huge, and there are many variables, it is challenging for the developer to imagine new designs that would be effective. As well as imagining a new visual projection methodology, developers need to create designs that enable users to explore, interact and perceive the data. While this design challenge is a broad issue in the subject of data visualization, multivariate network data offers specific challenges to the developer and designer. Users wish to understand network data that contains many nodes and edges, with many variables at each node and on each edge. In fact, the graph visualizations that are often used with this type of data contain many thousands of nodes and edges and are complex to understand.

Consequently, traditional visualization methods soon breakdown. One solution is to represent the data as a three-dimensional network. For instance, colored spheres are located in a three-dimensional space, that are connected to each other by straight lines. However these types of visualizations are ineffective, because they contain much occlusion. So it is therefore difficult for a user to visually understand routes or connections that are located within the networks. Certainly many clever clustering algorithms have been created, but it is still demanding for users to perceive clusters in these huge and complex networks.

Because of these challenges, users of these graphs often name them 'birds nest', 'hairballs', 'cat hairs', or 'balls of yarn'. They are a tangled and complicated mess of lines and nodes. Labels form another challenge. Label everything, and the screen becomes a mess of overlapping text, while label nothing and the data could be meaningless.

All these issues provide a huge challenge for visualization designers. They also offer a massive opportunity for designers to think differently. This leads us to ponder many questions. How can developers create novel depictions of multivariate network data? What design processes can be used to guide the development of new visualization solutions? Where can inspiration come from?

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In particular, inspiration for *novel design ideas* can come from a variety of sources. Psychologists and designers have had many discussions over the *ideation*[1] process. Their goals are to make the process more prescriptive and predictable. Indeed, while these processes do provide a general framework, there is no straightforward solution that will guarantee success. In addition, their processes are universal: they are general processes that can be used to help develop new design ideas on a range of topics.

Our goal, however, is to help develop new ideas for data visualization, specifically for multivariate network data. Our ideas were initiated during discussions that were held in the Dagstuhl Seminar #13201 [22] that resulted in this book. Through sharing our experiences over the creation of novel designs for multivariate network visualization, and from our knowledge of visualizing multivariate network data, we realized that there are several principles and concepts that can help designers. In fact, we noticed that there were several inspirational designs that were *metaphorical*. We therefore gathered and collated these concepts from our own experience of crafting solutions for multivariate network visualization and also from the literature.

Consequently our hypothesis is that new ideas can be inspired by transferring ideas that occur in one domain to another, i.e., they can be formed by looking at other 'things'. These design ideas are *metaphors*. Often these inspirational concepts are constructs; they are structures that we can 'hook' our visualization ideology onto.

In this chapter we focus on metaphors for the visualization of multivariate network data. These are 'ideas', where aspects of the concepts are *characteristics* of something else. They may be *derivatives* and therefore abstract, but they are derived from something. Indeed they may appear to be extremely 'far from the original', or removed from their original inspiration, or may be adaptations and therefore are not identical in every aspect to the object that brought about the inspiration.

7.1 Background

7.1.1 Semantically Rich Data

Multivariate network data is semantically rich. It not only forms a connected structure where nodes are linked to each other, but the nodes have several attributes. This means that the network can be displayed in different configurations, i.e., there are several valid arrangements of the data. This not only brings forth an opportunity for creativity, but also creates a design challenge (i.e., how to display different configurations). We encourage the reader to view the tasks chapter (5) for more information on tasks with multivariate network data.

[1] Ideation is the process of 'idea generation'.

There is an interesting phenomenon that is highlighted through prior work. Most of the novel metaphors are designed for specific applications. For example, PeopleGarden [48] and Chat Circles [44] target on-line interaction environments such as web-based message boards and chat rooms; Thread Arcs [21] was developed for email visualization; NetLens [19] and CiteVis [39] aim to visualize content-actor networks such as citation networks. This phenomenon suggests that the ideation of novel metaphors is often *task-driven*.

The different views certainly enable several *tasks* to be completed by the user. Chapter 5 on tasks for multivariate network visualization expands these features. In that chapter, Pretorius, Purchase and Stasko highlight that users can locate, distinguish, categorize, cluster, (analyze) distributions, rank values, compare different parts of the network, associate and correlate. Investigating what tasks the user needs to perform is important. Indeed, it is clear that specific visualizations enable the user to investigate different tasks. Subsequently it may be that different metaphors enable various tasks to be performed better.

Multivariate data is found in several fields. While in this chapter we do not focus on specific data types, rather look across the subject domains, at multivariate network visualization solutions that utilize a metaphoric approach, we refer the reader specifically to related chapters that do investigate specific domains: Chap. 2 where solutions to visualize multivariate network data in software engineering are discussed, and Chap. 4 where multivariate bioinformatics network data is explored, and Chap. 3 that focuses on social media data.

7.1.2 Where Ideas Come From?

Inspiration for a particular design can come from many sources. For instance, Johnson [17] mentions that ideas develop by looking at lots of other ideas. It is through looking at many different concepts that better ideas are formed. In fact, inspiration can come from nature; consequently, bio-inspiration, or bio-mimicry is a popular topic. Taking ideas from nature is commonly used by designers.

Let's work through an example. Consider a tree. A tree has a trunk and off this main upright big branches are formed. These in turn generate smaller branches then smaller branches still, and finally leaves. This gives inspiration to many ideas in computing. It is a hierarchy. It is a natural structure. It has many facets. Subsequently, there are many tree-like objects in computing in general, and visualization specifically. For example, binary trees as data-structures [34], quad-trees in computer graphics [34], Card's cone-tree hierarchical visualization technique [32], or the treemaps [37] visualization method. Whether the visualization designer explicitly thought of trees when they were designing their visualization is a matter for discussion. However trees are ubiquitous, and would have been in the subconscious mind, whether or not they provided a direct inspiration.

Let us take the 'tree' metaphor further. Trees are not just *structural* phenomena, there are many other aspects of trees as a *metaphor* that could provide inspiration. For instance, trees are large and long-lived plants that compete for light, they drop seeds that then can grow into other trees, and many trees often grow together into a forest. The forest has an ecosystem and therefore other 'life' depends on the trees. On the ground, fallen leaves and decaying branches provide habitat, while trees give protection for animals and wind protection for humans and buildings. Fungi and bacteria also rely upon trees. They provide food for animals, their sap can be tapped for food and made into products, and the trees have many different parts: roots, branches, bark, leaves, and so on. Trees don't grow constantly throughout the year. They often drop their leaves in the fall and grow new buds in spring; the speed of growth depends on the growing conditions of that year (hence dendrochronology is possible).

So thinking deep and thinking comprehensively about a topic can engender different and more ideas. For instance, we may think further about *dependency*, where perhaps aspects of a visualization may depend on others. In fact, this happens in a parallel coordinate plot, where the perception of the data from one axis depends on it's neighbors. Perhaps we may then think how we can design a parallel coordinate plot that does not have this dependency. Take another tree-like facet: the *parts* of a tree. Roots and branches are similar, yet opposites. The root structure is a hierarchy that goes downwards in search of water, while the leaves are on the stems that grow upwards in search of light. A designer could consider a tree-like visualization in two parts. Perhaps statistical information of a population could be displayed in a tree, with female participants displayed upwards, and male downwards. This would allow comparison of male and females, and many subjects could be represented by a forest. Finally, tree rings could be used as a direct metaphor, with time progressing outward from the centre, and the width of the rings dependent on another variable.

There is a clear link between metaphors and visualization. Not only do the metaphors drive inspiration, but they are used in comprehension. Ziemkiewicz and Kosara [54] suggested that the "process of understanding a visualization therefore involves an interaction between these external visual metaphors and the user's internal knowledge representations". Their work proposes that metaphors work both ways: they both inspire, and are needed for interpretation. Their work also used trees as an exemplar metaphor.

Just by thinking about a tree in more depth, we can start to imagine how metaphors can help. In fact, this is *lateral thinking* [9]; it is not only a matter of considering the principle concept (a tree, in this case), but delving deeper into the concepts, and considering processes, connections, colors, environment, and so on, as well as the structures of these concepts. As we shall see, ideas are formed through a long study, careful consideration, joining concepts together, looking at opposites, and so on, and rarely form as a *eureka* moment.

Metaphoric concepts are not the only method of ideation. Sketching and doodling are also important techniques that are used to create and craft new visualization designs [31]. Ideas can be easily explored through sketching. In fact, merely the act of putting the ideas on paper can help the designer to hone his ideas. Sketching acts as a refinement methodology. Users can share thoughts and can easily adapt these ideas.

Even discovering solutions that don't work can help inspire solutions that do work. These unworkable 'solutions' often act as a catalyst that inspire a better result. This is similar to another concept generation method: *provocation*. Johnson [17] suggests finding *dissimilar* ideas and joining them together; through this joining up of different thoughts new ideas can be formed. de Bono, in his book "Six Thinking Hats" [8], under 'green-hat thinking', suggests choosing a random number for a page in a dictionary, and selecting a random word on that page. That random word can be used to provoke different solutions and novel ideas.

Ideas and solutions are sometimes formed from disasters, or mishaps, or errors. For example, Wiseman [47] tells the story of PostIt-note^{TM} glue being an accident, or commonly referenced as a 'solution without a problem', and the discovery of penicillin, by Alexander Fleming in 1928, was serendipitous. Each of these ideas were originally accidents that became answers to specific problems over time.

7.1.3 The Ideation Process

In one respect, design-work is a journey. Ideas come and go, some ideas *stick*, are more memorable, others are easy to understand and maybe easier to communicate. Ideas become refined by cognition and discussion with other researchers; they are honed by mulling them over and are extended through interaction with people, or through different personal experiences.

Good ideas occur by *slow* and *careful* thought over a long period of time. Johnson, in his book "Where Good Ideas Come From" [17] talks about 'slow hunches'. Often people cite a 'eureka' moment as the derivation of their idea, however, while a single instance can bring a specific idea to the fore, in reality the idea is usually something that has been considered for a while by the designer, and draws on their previous experiences and knowledge.

While each of these methods offers a solution to the thinker when he or she is stuck, we need a process to follow to create new ideas in a systematic way. Young [52] in his seminal book explains a succinct process of producing ideas: first gather materials both specific and general. Second, think, make connections and write down every idea. Third, relax. Go do something else and let your subconscious work on the problem. As soon as the idea appears, write it down. Fourth, rework the idea. Refine the concept and make it appropriate for the purpose. Expand and contract the idea to make it robust.

De Bono's [9] 'Lateral thinking' method includes many of these techniques. It consists of seven techniques: consider **alternatives** and look beyond the ideas. **Focus** on your problem and discipline your thoughts. **Challenge** yourself, and try to break away from traditional thinking. Use un-connected ideas, to provide a **random entry** to new ones. Use **provocation** statements to engender and develop new ideas. Note-take, record and journal all your ideas so as to **harvest** the ideas. Know how to **treat** your ideas and fit them into the place where they are required.

In visualization specifically a few models have been presented, including Munzner's [28] Nested Model for Visualization Design and Validation, and Roberts' Five Design Sheet (FdS) method [31]. Whatever the process that is followed, it is clear that *lateral thinking* and inspiration from metaphors are beneficial to the design process.

7.1.4 The Visual Mapping Process

The ideation process goes hand-in-hand with the any software development process. As ideas change and develop through reflection and contemplation, so does the software develop through many iterations. The metaphors and original ideas change as they are implemented into a software solution. Indeed, software is often developed through an iterative strategy. In Agile software development methodologies, mixed teams of software developers, clients and end-users, create solutions in an iterative and incremental way. This is a sensible development strategy. Not only are ideas refined when they are sketched, and written down, or through consideration, but the ideas are refined when they get developed and used by a user [31].

Particularly, the effectiveness of the metaphor may be understood when the user actually uses the tool to perform a task. By changing the metaphor in small or even major ways, it may become more effective. Consequently, it is a good strategy to get end-users involved from the very start of the process [28]. Then the created software will be better suited to the needs of the users. Users can test the solution to see if they understand the metaphor, and whether they can perceive the data correctly.

Through this *iterative* ideation and development process, there are many practical design choices that the developer (or team) need to make. For example, developers need to ascertain which structures and components of the metaphor to use? What is the task the user is to perform? How to interpret the metaphor into a visualization tool that would perform a given task? What parameters to include? What sub-structures of the metaphor to use? What retinal variables to use to depict the data? etc.

Consequently, developers need to interpret the metaphor to fit their needs. They have to translate the concepts of the metaphor into a fully functional and working visualization tool. It may be that the developer chooses a certain aspect of the metaphor for their purpose, or adapts it for their need. They also need to ascertain how different components, structures or sub-elements of the metaphor represent the data, and how it is mapped to the retinal variables. The data is then encoded by adapting the properties of the retinal variables. For instance, a person could be represented by a branch of a tree, the length of their life is encoded as the length of that branch. Children are represented by other sub branches.

As developers, we need to think about the data, how the metaphor is understood by a user, and finally how the user interacts and changes the visualization. Therefore there are several concepts: data transformation, visual transformation, and visual mapping that developers need to consider.

Data Transformation

There are many different types and configurations of datasets. Some are structured and dense, while other data could be sparse or unstructured. Add in free text fields or formatted text and it is clear that users' information varies a lot among different applications. Being aware of this variation and understanding the tasks of the user for a particular application is important. These aspects change the requirements on the data transformation.

Some tasks require summaries to be generated, where lots of data can be summarized into a few values. In this case, non-node link diagram metaphors become a natural choice for non-node-link essential information units. It is possible also to imagine that these aggregated values could be mapped to aspects of objects that take up more real-estate (for instance). Indeed, such data aggregations often occur over time, and consequently the summed-data could be visualized as rings of a tree; where there is a linear progression from the early rings (the center ones) to the external rings.

Other tasks require that individual items in the data remain intact in the visualization depiction. The data transformation therefore is 1:1. In this situation, the identity of the individual entities need to be directly passed through to the mapping process, where individual items can be mapped to individual entities of the visualization. In other data, sub-structures or sub-graphs may exist in the data. Consequently, metaphors that reflect these constructs should be designed.

For example, PeopleGarden [48] aims to help new users find appropriate on-line interaction groups to participate in and people to interact with. To achieve this goal, data portraits, namely the abstract representations of interaction histories of individual users, are identified as essential information units. Novel visual metaphors are then inspired by the data model. In particular, a flower metaphor is used to represent the data portraits, and a garden metaphor is used to combine the portraits to represent an on-line environment.

Visualization Transformation

When we select visual metaphors for representing the information units identified in the previous step, many issues need to be considered, such as: Are the metaphors familiar to the target users? If unfamiliar metaphors are used, how significant is the learning curve? Is the mapping from the information units to the metaphors consistent with common knowledge of the users? If it is inconsistent with common knowledge, to what extent will it hinder the users from effectively conducting the tasks?

For instance, Chat Circles [44] considers the social presence and activities of individuals as essential information for conveying the dynamics of on-line synchronous conversation. It therefore maps individuals to circles whose visual attributes represent their identities and activities. Moreover, a hearing range is defined for a user and only conversations of people within the hearing range are visible in the visualization. These metaphors mimic a cocktail party, which is familiar, and the mapping is consistent with common knowledge of on-line conversation users. Therefore, the resulting visualization is intuitive to the users.

Visual Mapping Transformation

Most visualizations are interactive, which means that users can interact with the visual metaphors to conduct tasks. The ideation of novel metaphors can happen when answering the following questions: How can the users manipulate the visual objects? How will the visual objects react to user input?

Wise [46] explicitly describes this method as an "ecological" approach. There is an intimate relationship between the human being and their environment; all our senses work together to gain a holistic perception of what is being viewed. This approach is inspired by Gibson's view of perception [14], where there is an intimate relationship between a human being and their environment. Some concepts *afford* certain uses. For instance, a bowl is concave and therefore it can hold water and be used to drink from. Likewise, the positions of the leaves on a tree depend on the structure of the branches, and other branches are subordinate to the trunk. So, if this structure is used for the visualization, a user may assume a similar relationship to the data. A fun example is the Collapsible Cylindrical Trees (CCT) [7]. CCT uses a telescope metaphor to produce a compact hierarchy visualization for fast navigation of web page hierarchies. The descendants of a node are represented by a cylinder. Users can pull out/collapse a cylinder into its parent cylinder to roll up/drill down the hierarchy. They can also rotate a cylinder to browse the siblings.

Indeed, the tree metaphor is a powerful design structure, and provides many levels of detail. For instance, as a user moves away from a tree, on the one hand, individual leaves are difficult to observe, but on the other hand, the overall shape of the tree can be better seen. Perception changes as the user moves towards or away from an object. This concept is neatly explained by Gibson, who writes "From an ecological point of view, the color of a surface is relative to the colors of adjacent surfaces; it is not an absolute color . . . For the natural environment is an aggregate of substances . . . the colors are not seen separately, as stimuli, but together as an arrangement" [14]. It is clear that human beings have developed a succinct *model* of the world, from thousands

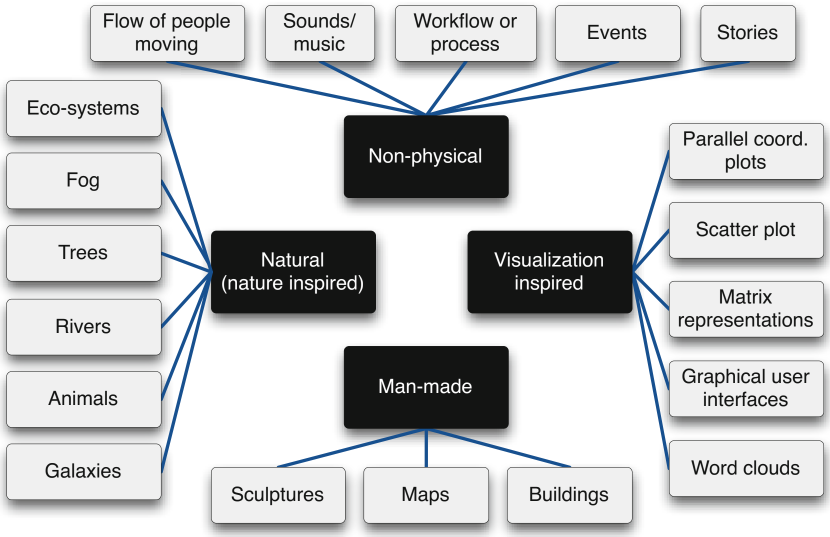

Fig. 7.1. We classify the metaphors into four types: Natural, non-physical, man-made and visualization inspired

of years of existence, and by being nurtured on Earth. This model can help visualization scientists develop succinct and effective visualizations. We can assume that a user will know the concepts (and indeed the *model*) of the natural world (say) and utilize this knowledge to immediately understand how we have transformed the data from an unseen version, into an appropriate visual mapping.

7.2 Classes of Metaphors

We group the metaphors into four categories: natural, non-physical, man-made and visualization inspired (see Fig. 7.1). While, these classifications provide a useful structure for this chapter, they can also be a mechanism for ideas. They can permit designers to 'think laterally' about different designs. For instance, a developer could ideate a visualization design 'inspired by a galaxy' and then provoke a different design by considering how the data could be displayed by a building.

7.2.1 Nature-Inspired

Many researchers have used objects from nature as inspiration for multivariate data and networks. The natural world contains very many concepts that could be used to ideate; these ideas range over massive scales from (say) the formation of galaxies and movement of tectonic plates to the growth of mold or the veins of a leaf. We use the term *natural* to represent things of the physical universe. For instance, we include geology and the Earth itself, wildlife that lives on our planet, and also some processes (such as weather) that affects the environments in which we live. Thus we include physical objects such as oil, sand, water, rocks, animals or rain, and also inanimate objects, such as wind, thunder, magnetism (as the Earth's magnetic field), gravity or weather. We exclude objects that have been substantially adapted by humans, such as plastics or glass, which we classify and include in the "man-made" category (Sect. 7.3), and also exclude non-physical processes that are not attributed to nature. For instance, the movement of humans through a building would be included in the "non-physical" category.

Natural metaphors offer convenient features that are often desirable to produce effective network visualizations. Nature is efficient. It utilizes the space economically. For instance, in a forest new trees spring up when old trees fall. They appear because light floods in from the canopy onto the forest floor, encouraging seeds that have fallen to sprout. Nature is also competitive. These new trees need to reach to the canopy roof as fast as they can. Nature is thus 'greedy'. The fittest and the fastest, or the strongest survive. In visualization we could imagine that the strongest cues or most representative data (to some metric) are pushed to the top of the visualization display, making them more noticeable. Nature is efficient. For instance, animals forage for food, they move in an efficient manner and cover the least amount of distance so to conserve energy. Nature utilizes the space efficiently. For instance, grasses grow to fill the space. Likewise, we can imagine that these positive effects can be used to make efficient desired space-filling techniques in visualization. Nature has therefore inspired several network visualizations, as discussed below.

Flowers provide a good source of inspiration for network visualization. Not only are they hierarchical, but also they are beautiful. For example, Chau [5] developed a flower metaphor for displaying web search results. The petals correspond to the number of key words, the leaves convey the number of outgoing links, the stem represents the length of the document, and the supporting ground indicates the number of incoming links. User studies showed that for complex data, the glyph outperformed a numeric based display. In fact, many other researchers have used the flower metaphor. Xiong and Donath [48] showed user interactions over time on a web messaging board, with time conveyed by the angle of the flower petal and color conveying the type of message. The stem length indicates how long a user has been at the message board. Zhu [53] used flower metaphors for both the people involved in communications as well as the discussion threads, while Van Loocke [43] used fractals to generate flowers and trees for multivariate binary data.

Grasses have also given inspiration. Although the examples of the Drift-Weed metaphor [33] were not on network data, this work provides a good example of using nature to inspire a visual metaphor for interactive analysis of multivariate data. The work enables different variables to be displayed along a line, with piecewise segments. The data is allocated onto the angles and lengths of the segments. Although individual grasses are difficult to understand, the overall effect appears as a single structure: a conglomeration of individual elements making one textured object. The overall texture object provides the user with an understanding of how the data trends.

As mentioned earlier, trees and plants have been used as inspiration for data visualization for many years. In 1991, Robertson, Mackinlay and Card presented 'Cone trees' [32]. Their seminal work visualized 10,000 files in the Unix file system using a vertical set of labels connected like an idealized three-dimensional tree. Their description of the system also included appropriate metaphoric language, writing "we provide operations for pruning and growing the view of a tree, collectively called gardening operations". In 2004, Shen and Eades [36] use a direct tree metaphor, in their MoneyTree system, where the trunk of the tree displaying trade volume and the leaves showing trade value, as shown in Fig. 7.2. Theron [42] used the rings of a tree to convey a hierarchical temporal data set. Data points are placed in rings based on their time stamp, and lines connect points that are part of the same branch of the hierarchy. While, recently Ma [25] used a tree as an egocentric depiction of a social network, where a 2D tree is divided left and right by the gender of the tree/person's contacts. The height of branches correspond to the age of the contact. Each leaf is a contact, and its position along the smallest branches indicates the date of the contact. Color and size of leaves can communicate additional information, as well as circular fruit along the small branches (see Fig. 7.3).

One of the more interesting dynamic behaviors one sees in nature is the flocking of birds, shoaling of fish, swarming of insects and herding with animals. Several researchers have used this notion to convey multivariate data and its relations. It is possible to utilize simple rules, such as separation, cohesion and alignment to create these behaviors. Vande Moere [27] used standard rules for flocking (collision avoidance, velocity matching, flock centering) and data relations (data similarity and dissimilarity) to render animations of stock market data over a period of time. Surfaces were wrapped around obvious clusters to both separate groups with different behavior and to expose outliers. Similarly, Yang et al. [51] use a flocking algorithm to examine networks of computers to help detect intrusions and other unusual behaviors. One view shows the topology of the network, and a second view flocks the network nodes based on a set of attributes associated with behavior and performance. Tekusova et al. [41] also focused on dynamics of stock market data. They combined flocking rules with data relations, much like Vande Moere. People flock as well, though in addition to the normal flocking rules, each individual may have a specific goal. Braun et al. [3] created a simulation of crowd motion that captures these two distinct types of goals (group, individual). They show how a crowd of virtual people can eventually exit a room with a single door. While these examples are not strictly used to inspire novel

Fig. 7.2. An example of MoneyTree, from Shen and Eades [36]. Top figure showing data from the 38th August 2003 at 10.50am, while the lower figure shows the stock market situation one hour later.

visualization designs, they do show that more elaborate rules can be used to drive the dynamics of the visualization.

Natural landscapes have inspired many visualization designs. Fabrikand, Montello and Mark [11] provide a useful critical analysis of different landscapes of the geographic domain, and we refer the reader to this work for a wider look at the use of landscape metaphors for information visualization in general. Designs that are positioned over a landscape provide an approachable metaphor for the user. Novice (and expert) users instantly understand

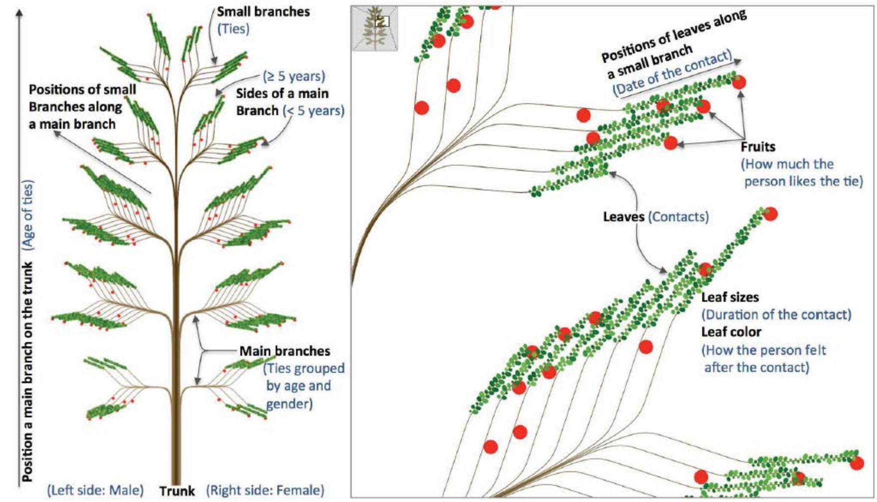

Fig. 7.3. An example of a ContactTree, showing the contacts of a single individual [25]

the metaphor and intuitively know how the information is presented in the space. They can start to make judgements over the position of data elements because position and nearness criteria are encoded in the information. In fact, many of the data presentations are naturally non-spatial. Developers are merely using this metaphor as a convenient way to display the data [38].

Wise [46], when referring to text visualization, names this an "ecological approach". There is a natural relationship between different parts (or organisms) to each other, and in the environment. In his work, the landscapes emerge because of the data, not because a designer has stipulated that the landscape will be of a particular form, but that the designer has encoded rules that determines the type of the visual depiction. For instance, the clusters with his Galaxies view, or the mountains of the ThemeScape^{TM} visualization [46] are created using self-organizing maps, which were trained on a sample set of documents. For network data specifically, Gansner et al. [12] display author collaboration data on a map layout. Xu et al. [49] present GraphScape, which they used to visualize multivariate network data of protein-protein interactions. Finally, the data from the development of large software systems has been displayed using the landscape metaphor. Balzer et al. say that "The familiar landscape metaphor facilitates intuitive navigation and comprehension [and their hierarchical approach enables] a clear representation of the relationships between the subsystems" [1].

It is clear that 'landscape' is a useful metaphor. In fact, secondary concepts such as water flow, or the natural flow and movement of something, has inspired developers. ThemeRiver represents an obvious example that follows a river metaphor. In their paper, Havre et al. [15] present a visualization technique that displays changes overtime, where larger effects are displayed in a wider bar. Symmetry is used to make the visualization more attractive. In their seminal paper, they use metaphoric language, describing the visualization as "directed flow from left to right", and "[the] width, of the river indicates a collective strength of the selected themes".

7.2.2 Non-physical

The idea of using rivers and flowing water leads us naturally to "non-physical" metaphors. We interpret the meaning of non-physical as something that does not contain physical matter; something that lacks substance and cannot be touched. In fact, many of the metaphors that we have already discussed, and the concepts that we are about to discuss in following chapters, have a physical space and are tangible in some way. They may be geographical (such as the nature inspired metaphors in Sect. 7.2.1), or created from man-made structures (in the next Sect. 7.3) or even visually tangible from the visualization-inspired section (Sect. 7.4). However there are many concepts that do not have a physical presence, which we consider in this section.

Let us consider our senses. The classic categorization is to describe five basic senses: vision, touch (including kinaesthetic and tactile), smell, taste, and sound. Obviously 'touch' is something physical, however let's also include vision as an artifact that is tangible (albeit on a computer screen). This leaves us with smell, taste and sound. Each of these senses encourage us to think emotionally. We could imagine therefore using these senses to inspire designs. For instance, consider being immersed in a soundscape of high quality audio sounds. The sounds could move around from the left to the right. This swaying could inspire a fluid visualization style where fluid is shown to flow around a network. We could imagine also ideas that were inspired from eating different foods. Carrots are crunchy, while mashed potatoes are smooth. We could imagine a visualization type that has smooth lines to represent one variable with angular parts mapped to another parameter. Before the reader concludes that the authors have lost sight of their objectives, we remind the reader of Eduard de Bono's [9] 'Lateral thinking', especially regarding provocation.

Other non-physical concepts that may be useful include: abstract processes, events, storytelling, motion of objects, and magnetism. In fact, storytelling is a good example of a useful non-physical metaphor. Stories are succinct forms of communication that are often interesting to hear, and therefore can be more memorable and easier to assimilate than other forms of communication. Gershon discusses what storytelling can do for visualization [13], suggesting that visualization is about finding effective visual metaphors; especially when presenting visualization results, stories can enable the developer to build the picture through a series of visualizations. Some visualizations are better to set the mood, place and time, while others build the story from disparate pieces of information to a final conclusion [13]. This style of visualization has been used to display different types of data. For instance, Walker et al. [45] use a comic-style storyboard to layout visualizations of microblog data. Segel and Heer [35] provide a systematic review of narrative visualization characterizing the designs with the narrative flow determined by the graphical interface and story discovery. Different stories appear from different users. In Chat Circles, Viegas and Donath [44] utilize simple metaphors or chatrooms to convey different social interactions from the online data.

7.3 Man-Made

It is easy to imagine that many man-made objects can be inspirational for network visualizations. Man-made objects contain many convenient and useful properties that can provide inspiration for visualization designs.

Let's start by looking at man-made structures and buildings. Designs for these objects benefit from properties of symmetry, regularity, repetition and recursion (self similarity). For instance, consider the design and construction of a modern house. These type of dwelling places are often built on a rectangular plan, with windows placed symmetrically: with windows on the ground-floor spaced directly below the windows on the first-floor. The brickwork is organized in regular and consistent patterns, and town housing or estates are constructed by a single contractor using only a few designs: the designs are used over and over again. Rooms within the buildings provide separation of content and often have specific roles (kitchen to cook, living area to relax, bedroom to sleep). 3D/Rooms by Card, Mackinlay and Robertson puts this idea into practice [4]. Each room holds different types of data. Users see an overview of all the rooms and choose where to go; they can locate objects of interest and walk through the rooms to another room.

Put many buildings and houses together and they form cities with many different types of buildings, some low and others very high. Earlier, in Sect. 7.2.1, we reflected on natural landscapes, but likewise man-made city landscapes and urban metaphors provide a useful structure to inspire network visualization designs. Such cityscapes have inspired several visualization designers. For example, Eick et al. [10] used the city metaphor to display software visualization of the quantity of changes indexed by developer in columns and module in rows, with a result that looks like a 3D bar-chart arrangement, while Keskin and Vogelmann use the cityscape metaphor to visualize hierarchical network data [23]. Finally the visualizations in the 'Selective Dynamic Manipulation of Visualizations' work by Chuah et al. [6] are shown as skyscrapers on a landscape.

Other man-made objects have caught the imagination of the visualization designer. Threads in fibers have inspired email visualization methods [21], and telescopes have inspired cylindrical visualization of hierarchical data [7].

Many of these visualizations are artistic. In fact, art, in general, and specifically artistic media such as oil paints and their brush strokes, have inspired many fluid flow visualization methods [24]. In addition to fluid flow visualization, various researchers have discussed the use of textures to represent multivariate data. For instance Interrante [16] discusses how different textures from paints can be used to depict multivariate data on a map. Different styles of illustration and drawings have been used in visualization, especially scientific visualization. For instance, Joshi et al. [18] use illustrative techniques inspired from art to display hurricane data, or caricaturistic-inspired visualization [30].

It is not only man-made physical objects, but also man-made non-physical processes can be inspirational. Pang uses a spray-can metaphor (spray, cut etc.) to interact with the visualization [29] while annealing in metallurgy (the process of heating and controlled cooling of the material to reduce artifacts) has inspired graph drawing algorithms to layout multivariate network data.

7.4 Visualization-Inspired

Finally, it is possible to conceive that visualization designs can be inspired by other visual designs. In sv3D [26], the authors write: "The sv3D Framework is a software visualization framework that builds on the SeeSoft metaphor". In this section we focus on three specific examples: glyphs, lists, and coordinated tag clouds and pixel oriented displays.

Brandes and Nick [2] work on exploring the evolution of dyadic (i.e., pairwise) relations in longitudinal social networks capturing asymmetric relations. Since dyadic evolution is the focus of the study, they propose gestaltlines, an intuitive visual metaphor to convey an entire dyadic evolution. The gestaltlines are gestalt-based use of glyphs in sparklines for multivariate sequences. They form a character-like visualization for each dyad and thus can be integrated into a matrix representation of all dyads in the network. The introduction of the glyph metaphor in this example allows depicting a longitudinal social network using a single, static image.

Jigsaw [40] is a visual analytics system aiming at helping analysts investigate the connections between entities across a report collection. The semantics of the entities are considered important, and an effective strategy toward the goal is to identify entities of interest and then conduct progressive exploration starting from them. A connected list metaphor is employed to achieve these requirements. In the List View of Jigsaw (see Fig. 7.4 for an example), the entities are organized into orderable lists by type. The links are displayed upon requests: after a user selects entities from the lists, all entities connected to them are highlighted and links are drawn between connected entities in adjacent lists. This intuitive view provides several functions that are critical for the goal: users can browse entities of a desired type, sorted either alphabetically or by frequency of appearance in different reports, to find interesting entities; they can investigate the immediate context of the interesting entities through interactive selections on the lists. It is difficult to

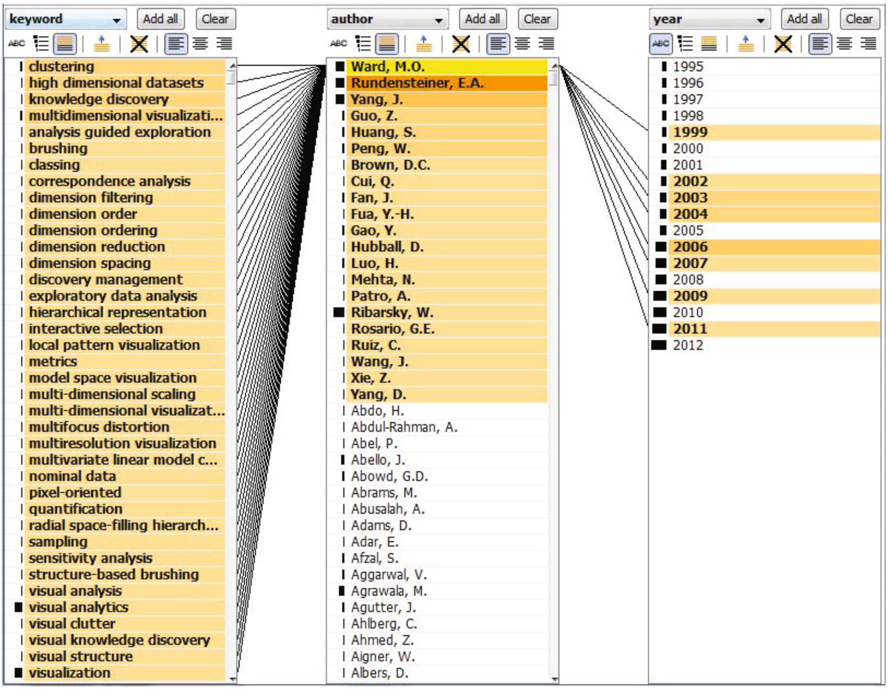

Fig. 7.4. An example of the List View of Jigsaw [40], showing the keywords, authors, and years relevant to Matthew Ward in a collection of InfoVis and VAST papers

conduct those tasks, especially the browsing task, on a node-link diagram, since the semantic contents will quickly clutter the display when the number of entities grows large.

Using tag clouds and pixel-oriented techniques, PIWI [50] helps analysts conduct Community-Related Tasks (CRT) for graphs with text labels. Examples of CRT include browsing the text labels of member nodes of many communities, exploring the relationships among multiple communities, analyzing the relationships between node attributes and the community structure, and selecting nodes according to attributes and the community structure. Since PIWI has a clear focus on community-related tasks, it picks communities as its information units. Two familiar visualization metaphors, namely tag clouds and pixel-oriented techniques [20], are then assembled to convey the semantics, structural, and attribute information of a graph (see Fig. 7.5 for an example). In particular, a community is represented by a tag cloud of text labels of its member nodes and a set of pixel-oriented node plots revealing the neighborhood information of the community. Thus, a graph is untangled into a set of communities that can be displayed row by row in a scrollable window.

Fig. 7.5. An example of PIWI [50]. The members and direct neighbors of a research community in a co-author network are highlighted in colorful tags. The tag cloud in a row displays the names of researchers in a community. The node plots besides the tag cloud depict the neighborhood information of the community and can be used for scalable selection.

In this way, a graph with thousands of labeled nodes becomes readable. The node attributes are also displayed using pixel-oriented node plots. By allowing users to conduct selections based on the node plots and integrate multiple selection results through Boolean operations, the users can conduct selection based on complex structural and attribute criteria. Since the users can interactively construct new communities and explore their contexts, progressive exploration is then supported. The novel metaphor of PIWI is inspired by the identification of communities as the essential information units according to the target tasks.

7.5 Proposed New Ideas

An effective metaphor is one in which a viewer can grasp instinctively how the information is being conveyed. Thus in considering new metaphors for multivariate graphs and trees we need to examine the human experience to find instances where the embedding of node and link/relation attributes requires little training. Below we outline a number of possibilities that, to the best of our knowledge, have not been used for this purpose. Clearly, many others exist; this is just a sampling based on the brainstorming of the authors.

7.5.1 Graphs/Networks

Many scenes we observe on a daily basis or have an intuitive feel for can be used to convey attributes of a multivariate network:

Students walking to class: For those of us in academia, a common scene is that of students moving along paths as they move from class to class. Each student can represent a node, and those nodes can have numerous attributes, such as gender, race, size, clothing color/style, hair color/style, and so on. They can move along paths (one link in, one link out) or stand at junctions (directional or non-directional links). The links themselves can convey relation attributes, using color, width, material type, and others to represent attribute values.

Cars on streets: Similar to students on paths, cars on streets is a regular phenomena that can be used for multivariate network visualization. Clearly the cars are nodes and the roads are links, with numerous attributes onto which data and relations can be mapped. To better convey the street metaphor, the dominant layout should be a grid, though as can be found in most cities, there are often roads that run diagonal to a grid or even form an overlay to the grid. Nodes and links that change their attributes are easily accommodated, though the addition/removal of nodes may result in a change in topology that might not be easy to incorporate. Removal of links would be comparable to closing a road due to construction.

Caves: While a cave requires the user to incrementally build an understanding of the entire graph/network, many games are based on the notion of exploring cave-like environments to discover connectivity and identify features of both nodes (rooms in the cave) and links (features of the tunnel). Node features could include the area or shape of a room, the height of the ceiling, or markings on the walls or floor. Link attributes could be the width or height of the tunnel, the texture of the floor or walls, the existence/frequency of lights, and so on. An interesting experiment would be to ascertain whether a graph learned via cave exploration is easier to remember than one shown as a traditional node-link diagram, given comparable time to explore it.

7.5.2 Hierarchies

Hierarchies/trees are also a common phenomena in what we see on a regular basis, and thus could be a vehicle for conveying a multivariate hierarchy. Some examples include:

Towns and buildings: Most cities and towns are laid out in hierarchies; a city contains neighborhoods or zip code areas, and these in turn consist of blocks bounded by streets. Buildings on these blocks can also be seen as hierarchies, as each building can have multiple floors, and each

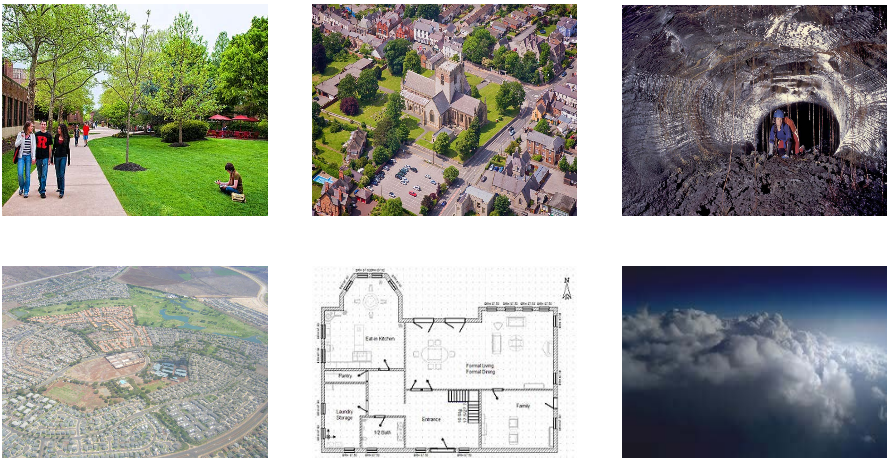

Fig. 7.6. Some images of real scenes that might be usable to convey multivariate networks. All images courtesy of Wikimedia Commons.

floor can have multiple rooms. Rooms can contain many objects (e.g., furniture) that can be used to convey node information at the terminus of the hierarchy. Data for intermediate nodes and the links can be embedded in the hierarchy, using color, size, shape, and textures, for example. For deeper hierarchies, you can envision states containing multiple cities/towns, countries containing many states (different sizes, shapes, and positions), and countries forming nodes of a hierarchy rooted at the continent level. Clearly a single visualization could not adequately convey all these levels, but it would be relatively simple to provide navigation that would allow users to drill-down and roll-up for different levels of detail. Aggregation or summarization methods could be used to indicate the amount of information contained in the lower levels.

Clouds: Many types of cloud configuration can be viewed as a hierarchy, with smaller, nearer clouds being contained within larger, more distant clouds. While generally there is a fair amount of overlap between clouds at a comparable level (and of the same type), it would not be unheard of to have clouds at a given distance to be disjoint. Again, shape, color, size, texture, and opacity could all be used to embed information about nodes and relations. The resulting images may not look like real clouds, but would likely have sufficient similarity to reality to make viewing intuitive and interesting (we'd imagine that most people at some point in their lives have stared at clouds and wondered about their causes and relations).

7.6 Summary and Conclusions

In this chapter we described the use of metaphors as a mechanism to design and develop novel (non-node-link diagrams) methods for the visualization of multivariate networks. After defining what metaphors are and why they help us in developing new and often intuitive approaches to solving problems, we attempt to categorize different classes of metaphors that have been used to date to visualize graphs and hierarchies. We don't claim that this categorization is complete, but provides a good starting point for researchers in this area. We also suggest some ideas for metaphors that we don't believe have been used to date, yet are sufficiently familiar to people that we expect there would be only a modest learning curve for users to grasp the contents and relationships in visualizations generated via the metaphors.

The possibilities for new and intriguing metaphor-inspired interactive visualization system for network data is only limited by the imagination of the designer. The wealth of experiences we have been exposed to enables us to quickly draw analogies between our abstract data and phenomena we are exposed to on a regular basis, whether it be objects in our natural world, manufactured entities such as buildings and highway systems, non-physical objects and processes such as stories and magnetic forces, or even visualization methods not originally intended for network data. As multivariate networks are an abstraction on data values and relations, there are no preconceived notions of the best or most intuitive ways of projecting that information into a visual form. All that is needed is a creative mind and a willingness to think outside the box.

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