Spirograph inspired visualization of ecological networks

Katayoon Etemad,* Sheelagh Carpendale†and Faramarz Samavati‡
University of Calgary

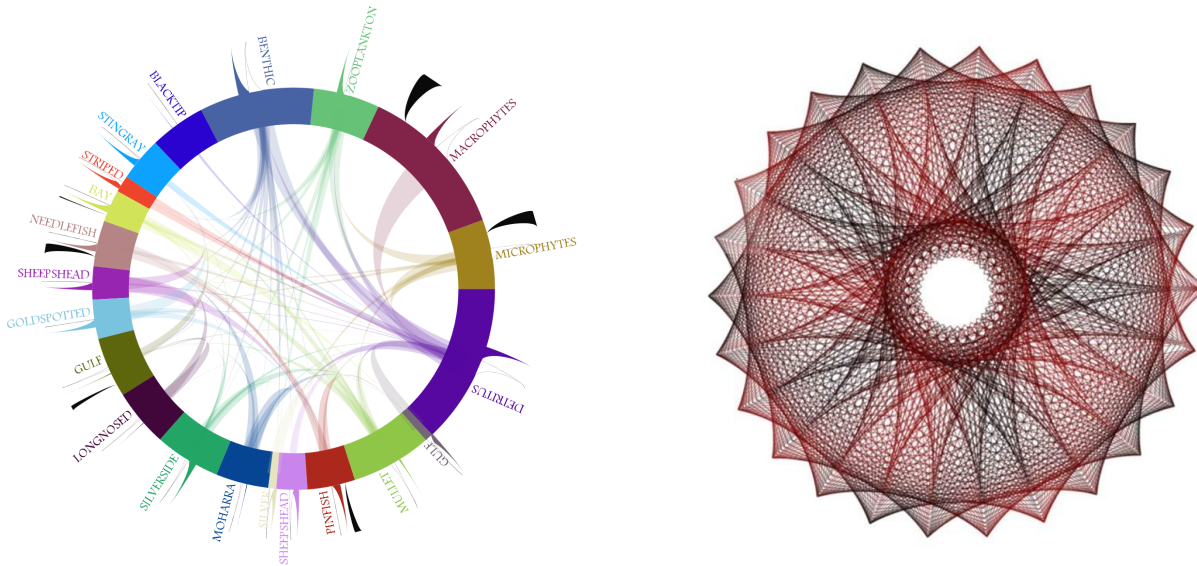**Figure 1:** *Aesthetic visualization of ecological networks, inspired by Spirograph.*

Abstract

Ecological networks are directed weighted graphs for representing direct and indirect relationships between species in ecosystems. These complex cyclic networks play an important role in understanding an ecosystem's dynamics. In this paper, we present a visualization layout inspired by Spirograph patterns, specifically designed for ecological networks. Our visualization supports both the direct and indirect quantities commonly required in ecological studies. The layout is circular to reflect the containment of the represented ecosystem and to clarify which connections are internal and which are external. In this layout, nodes are arranged along the circumference of a large circle as arcs, and edges are mapped to thorn-like shapes that represent the direction and the weight of the edge. Finally, we illustrate the use of this visualization on several example ecological networks.

CR Categories: I.3.8 [Computer Graphics and Application]: — [H.5]: Information Interfaces and Representation—;

Keywords: Visualization, Weighted Directed Graph, Ecological Network

---

*e-mail:ketemad@ucalgary.ca
†e-mail:sheelagh@ucalgary.ca
‡e-mail:samavati@ucalgary.ca

1 Introduction

Understanding ecosystems both from the perspective of necessary exchanges within the ecosystems and from their relationships and possible impact upon other external entities and systems is challenging. To improve our understanding, these systems are often studied at many different scales including the relatively small scale of just a few nodes. This is important because larger ecosystems are often composed of smaller ones and because even small ecosystems are complex. This complexity arises from internal and external exchanges, energy flows, cycles and dynamics. In working with this data ecologists are encoding many details in relative node masses and in relationship weights. This results in ecosystem formalizations that are directed, weighted graphs. While graph drawing is well established [Battista et al. 1998], relatively less attention has been paid to details of the visualization of weighted directed graphs, particularly in context of ecosystem dynamics. Commonly, these types of graphs are laid out using thickness of edges or labels to represent weights and arrowheads for indicating direction. We introduce an alternative graph-based representation for ecological networks. Our visualization displays the basic network and the associated flow of energy and matter between species in an ecosystem. The primary purpose of these networks is to support ecologists in their analysis and exploration of these ecosystems, and to use visualization to gain a better understanding of exchanges of nutrients and energy that form the dynamics and flow of the ecosystem [Ulanowicz 2004]. These ecosystem networks are directed weighted graphs often containing one or more cycles. Each node is a biological unit (i.e. a species) in the ecosystem. The size of the node represents the biomass as calculated by ecologists [Ulanowicz 2004]. The edges all have direction and associated weight, which contains information about the amount of material flowing from one node to the next. Figure 2 shows a simple five-node example of this type of networks. In this diagram the numerical values of the node

and edge weights are simply added as numerical labels. The weight of each edge shows the amount of material flow from one node to another. Directionality is shown via arrows. Based on the nature of the data, there can be different types of edges in these networks. Some edges represent transactions between species within the network, while others represent transactions external to the ecosystem. Note that even this very small five node ecosystem has complexities.
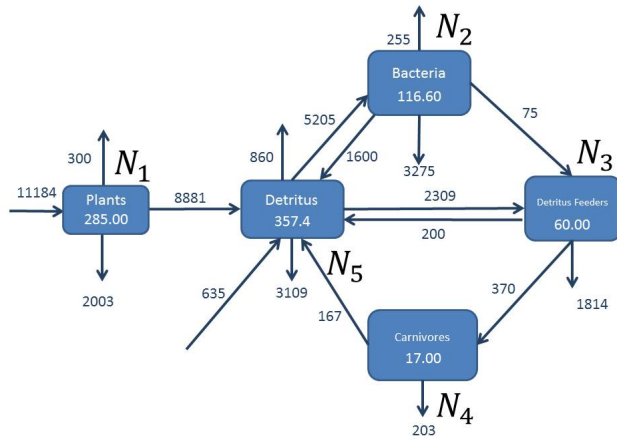

Figure 2: *Ecological network with five nodes. Nodes have weights, indicating the biomass of the species they represent. Edges have weights, representing the amount of energy or matter in the transactions. Some edges represent transactions between species within the network, while others represent transactions external to the ecosystem.*

In this work, we introduce a new layout for ecological networks. In this layout, the entire ecosystem is represented by a circular shape (See Figure 1). This circle has an organic form providing the impression of a closed ecosystem, which separates the environment into its internal and external spaces.

Nodes are represented by arcs on the circle, the lengths of which illustrate the nodes' weights (biomass). Inspired by Spirograph patterns [Wikipedia 2014], we use a thorn shaped Bezier curve for each edge (see Figure 1), whose thickness is proportional to the weight of the edge. Exports and imports from outside are shown with smaller thorns attached to the outer side of the circle.

The main contributions of this work are:

- Introducing a new layout for ecological networks that reflects data aspects of particular importance to ecosystems.

- Providing interactions tuned to ecosystems.

- Calculating and displaying indirect effects of ecosystem dynamics such as cycles and throughput.

The remainder of this paper is structured as follows. A short review of methods in visualizing weighted directed graphs and some research papers in this area are gathered in Section 2. Section 3 provides an overview of ecological networks. The challenges of designing a visualization for ecological networks is discussed in Section 4. The design of Eco-Spiro Vis, including the layout, visualization, interaction is explained in Section 5. The implementation details are discussed in Section 6. Finally, Section 7 contains a discussion, and we conclude the paper in Section 8.

2 Related Works

In this section we review some background works on Spirograph patterns, followed by a short discussion regarding some related research papers that deal with the challenge of visualizing directed weighted graphs, and aesthetic visualization.

2.1 Spirograph Patterns

Spirograph patterns are a fascinating class of curves created using a simple toy containing a set of circular gear-like rings of various sizes. Figure 1, right shows an example of Spirograph patterns. A simple web search reveals that there is significant interest in these patterns, as evidenced by the many software packages and art galleries of Spirograph patterns.

Mathematically the Spirograph creates hypotrochoid curves, which are rolling curves generated by fixing a point on a rolling circle inside another fixed circle (see Figure 3 [Tom 2014]). The vi-
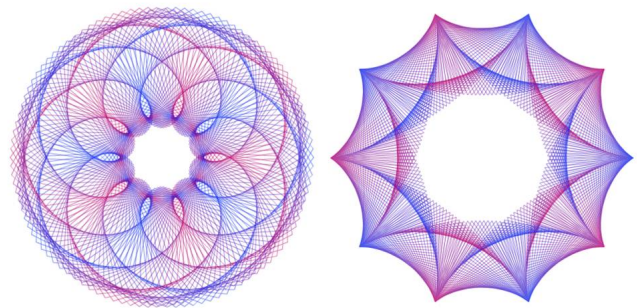

Figure 3: *Spirograph, creates rolling curves generated by fixing a point on a rolling circle inside another fixed circle.*

sual appeal and elegant geometric description of Spirographs motivated Lin and Vuillemot to use them for visualizing tweets [Lin and Vuillemot 2013]. In their work, many Spirograph patterns were created by tweaking control parameters in a drawing tool. Then a set of interesting patterns was identified and named. Finally, the distribution of tweets over time was mapped to the petals of selected Spirograph patterns.

2.2 Graph Visualization

Ecological networks are weighted directed graphs which may contain cycles. There are wide variety of graph visualization techniques available for visualizing graphs [Herman et al. 2000] [Von Landesberger et al. 2011]. However, directed weighted graphs are less well-studied. In particular, Holten and van Wijk [Holten and van Wijk 2009] provide some recommendations to improve the visualization of directed edges. These guidelines, resulting from a user study, suggest alternative illustration to the common arrow head edges in directed graphs, such as a gradual change of color or thickness.

There exist other data visualizations that might be considered similar to our system. Citation Patterns [Moritz 2014] is a visualization
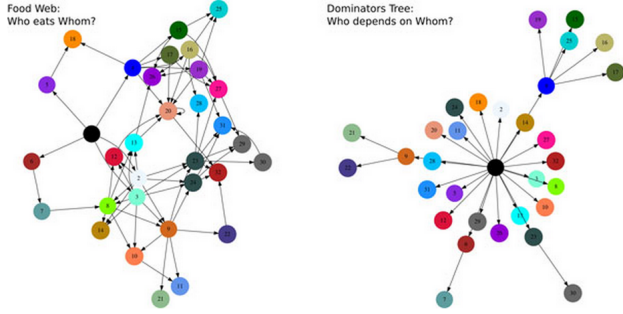
Figure 5: *Sankey diagram visualizing the energy system (image courtesy of H. Alemasoom and F. Samavati, University of Calgary).*

Figure 4: *An image of a current ecological network. This image shows a food web, which is a special kind of ecological networks. Food web shows the* who eats whom *part of the network [Allesina and Pascual 2009]*

project that gives an overview of the citation network. The orientation of nodes in this visualization is similar to Spirograph visualization, however the edge design is not based on repetitive curves like for Spirograph patterns. Also, as the direction and weight of edges was not important to the structure of the data used in their visualization, it was not included in their system. Krzywinski Et.at. [Krzywinski et al. 2009] introduced Circos, a visualization tool to assist the procedure of comparison of genomes. In this work, a similar circular layout is motivated and used for visualizing data with a high data-to-link ratio. However, the nature of our data is different. In ecological network this rate is usually small, but other external edges and indirect effects should be supported. Holten [Holten 2006] used a similar orientation of nodes in his hierarchical edge bundling visualization, and in 2009 Meyer and Munzner [Meyer et al. 2009] designed a multiscale browser for biologists to explore species' genome, chromosome, and block levels. In both visualizations, the direction and weight of the edges was not considered. Allesina et al. [Allesina and Pascual 2009] used a node-link layout to visualize food webs (See Figure 4), which are a special kind of ecological network where only connectivity (who eats whom) is presented, but the flow of energy (i.e. the weights of the edges) is not visualized.

Sankey diagrams are a type of layout used for weighted layered networks (see Figure 5). Riehmann et al. in [Riehmann et al. 2005] present an interactive visualization system for Sankey diagrams. The layered structure of these networks has been used to design a layer-by-layer layout. Despite its simple structure (acyclic), the visualization may be tangled. Given that ecological networks are generally cyclic, it is not clear how to customize Sankey in order to support cycles. Furthermore, the indirect quantities captured in Leontief [Leontief 1987] matrix should be provided (at least on demand).

2.3 Aesthetic Data Visualization

Nowadays, computers are fast enough to store and represent large data sets, but reading and extracting useful information remains a task to be performed by humans. It is challenging to present large graphs on a limited screen space, due to the possibility of node overlapping and edge crossing. This makes it tedious for a human to
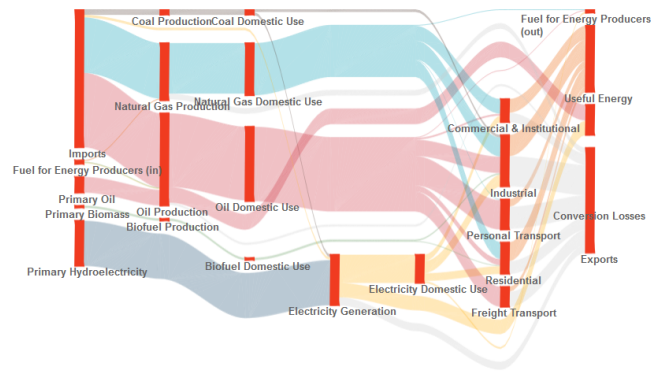
perceive the information presented by a large graph. Attractive and engaging graph representations can help analysts in their tedious exploration tasks. The effects of aesthetics in graph visualization have been studied in [Purchase 1997] by Purchase et al. They show that maximizing symmetry as well as minimizing node overlapping, edge crossing and edge bending have strong effects on understanding the graph structure. In the series of studies conducted by Purchase et al., in [Purchase et al. 2012], participants were asked to draw graphs in a more understandable way. The results indicated that the participants tried to follow the same criteria in their drawing: reducing edge crossings, edge bending and increasing symmetry. Bennett et al. in [Bennett et al. 2007] also explored the aspects of aesthetics in improving the graph visualization.

Taking an aesthetical perspective in visualization is not a novel approach. Recently, increasing number of data visualization researchers have been considering aesthetics in their designs. Examples are Informative Art [Miller and Stasko 2003] and InfoCanvas [Holmquist and Skog 2003] Pousman et al. in [Pousman et al. 2007] provides a review of the visualizations that have considered aesthetic patterns in their designs.

3 Ecological Networks

As demonstrated in Figure 2, an ecological network is a directed weighted graph in which nodes are species and edges represent the energy or material flow in the system. Each node's weight corresponds to the biomass of the associated species and each edge's weight represents the amount of energy that flows between the nodes in the system. There are usually three types of edges in these kinds of networks: exchange, input and output edges. Exchanges are simply edges between nodes. Input edges, enter the system from the outside, and output edges leave the system. In practice it is possible to have multiple types of outputs. In Figure 2, there are two types of output edges: energy and respiration (or breathing).

Ecological networks are important tools which ecologists use in quantifying the flow of energy/matter in the ecosystem. However, even for a moderately sized system (i.e. with 30 to 40 nodes) the network becomes very complex. Therefore, a proper representation of these networks is required for the study of whole ecosystems [Ulanowicz 2013]. In order to quantify indirect effects, it is necessary to evaluate and visualize measures beyond the weights of edges. For example, in Figure 2, it is important to know the total energy flow from N_1 to N_4. To evaluate this measure, it is necessary to find all pathways from N_1 to N_4, possibly including cycles (e.g. $N_2 \rightarrow N_3 \rightarrow N_5 \rightarrow N_2$). These quantities are usually computed using linear algebra [Ulanowicz 2004][Leontief 1987]. The

connectivity of the network can be captured by an adjacency matrix A where:

$$a_{ij} = \begin{cases} 1, & \text{if } i \text{ is connected to } j; \\ 0, & \text{otherwise.} \end{cases}$$

For example, if we ignore the input and output edges in Figure 2, its adjacency matrix will be:

$$A = \begin{pmatrix} 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 & 0 \end{pmatrix}.$$

The inputs and outputs can be included by introducing some extra phantom vertices. Note that the adjacency matrix has also been used as a layout for general graph visualizations [Henry and Fekete 2006] [Henry et al. 2007].

One can show that the powers of A can be used to calculate the indirect connections between vertices. For example; $A^3(i,j)$ shows the number of paths of length 3 from i to j. In order to include weights, a similar matrix $W_{n \times n}$ is defined where $w_{i,j}$ is the flow exchange from N_i to N_j. For instance, for the network in Figure 2, we have:

$$W = \begin{pmatrix} 0 & 0 & 0 & 0 & 8881 \\ 0 & 0 & 75 & 0 & 1600 \\ 0 & 0 & 0 & 370 & 200 \\ 0 & 0 & 0 & 0 & 167 \\ 0 & 5205 & 2309 & 0 & 0 \end{pmatrix}.$$

Similar to the adjacency matrix, $W_{i,j}^3$ shows the flow exchange between N_i and N_j, through paths with the length of three. Therefore, the entire throughput of the network can be found by summing all the powers of W:

$$S = W^0 + W^1 + W^2 + \ldots \tag{1}$$

However, in cyclic networks W^n does not converge to zero and, therefore S in Equation 1 is not well defined. To address this issue, W is normalized such that no entry in the matrix is greater than one. Let $G_{n \times n}$ be defined such that $g_{i,j}$ is the normalized flow from node N_i to the node N_j:

$$g_{i,j} = \frac{w_{i,j}}{E_j + \sum_{k=1}^{n} w_{kj}} \tag{2}$$

where E_j is the external input to the node N_j. For the network in Figure 2, we have:

$$G = \begin{pmatrix} 0.0 & 0.0 & 0.0 & 0.0 & 0.773 \\ 0.0 & 0.0 & 0.031 & 0.0 & 0.139 \\ 0.0 & 0.0 & 0.0 & 1.0 & 0.017 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.015 \\ 0.0 & 1.0 & 0.969 & 0.0 & 0.0 \end{pmatrix}.$$

Now the summation is well defined as:

$$L = G^0 + G^1 + G^2 + \ldots = [I - G]^{-1} \tag{3}$$

where I is the identity matrix and L is called the *Leontief* matrix (See [Ulanowicz 2004] and [Jorgensen and Fath 2008]). In 1973, Wassily Leontief earned the Nobel prize in economics for his input-output model related to L [Leontief 1987]. As an example, for the network in Figure 2 we have:

$$L = \begin{pmatrix} 1.0 & 0.933 & 0.933 & 0.933 & 0.933 \\ 0.0 & 1.169 & 0.201 & 0.201 & 0.169 \\ 0.0 & 0.039 & 1.039 & 1.039 & 0.039 \\ 0.0 & 0.018 & 0.018 & 0.018 & 0.018 \\ 0.0 & 1.207 & 1.207 & 1.207 & 1.207 \end{pmatrix}.$$

In this case, the total (direct, indirect) normalized exchange between nodes 2 and 4 is 0.201. In a cyclic network it is possible for entries to be larger than one. In summary, the matrix L provides very useful information for ecologists to study the network [Ulanowicz 2004] [Jorgensen and Fath 2008].

Note that Equation 2 is just one of many possible normalization equations. Other possibilities have been discussed in [Ulanowicz 2004].

4   Design Challenges

While it may be tempting to think that traditional graph visualizations would be adequate for ecosystem networks most of the details that are of particular interest to ecologists get suppressed, and as with all graphs the complexity of even small networks becomes visually overwhelming.

Currently variations on flow diagrams as used in computer hardware and software diagrams are in use. With these flow-based node-link diagrams, for simple networks the visual representation is helpful in establishing an overview of the network. Furthermore, it may be possible to capture some of the topological connections (who eats whom) and simple measurements of the flow. However, exploring indirect and more global effects commonly used by ecologists (see Section 3 for more details), such as qualifying cyclic fractions of the network or the total amount of flow from a node to another, is still challenging [Ulanowicz 2004]. In addition, as the system grows even moderately larger, this type of node-link layout quickly becomes cluttered, making it difficult to answer even simple and direct questions (e.g. discovering all adjacent nodes) (See Figure 6) [Baird and Ulanowicz 1989].

To create an interactive visualization that addresses some of the challenges faced by ecologists interacting with visualization we note the following challenges:

1. Providing an impression of a coherent system.

2. Offering a clear delineation of internal and external factors.

3. Representing node and edge weights visually in the layout.

4. Providing a powerful representation of directionality.

5. Offering appropriate interaction techniques via highlighting and filtering that are linked to common ecosystem questions such as: adjacency for incoming and outgoing connections; and revealing cycles of different lengths.

6. Providing options of exploring network structure independently of weighted network structure.
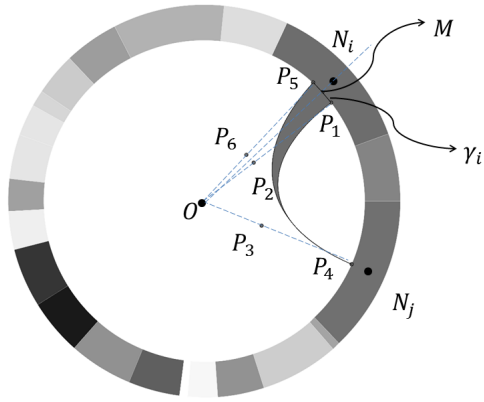
Figure 6: *Simple node-link diagram is not sufficient for presenting this data [Baird and Ulanowicz 1989].*

Figure 7: α *for each arc is proportional to the biomass of the species that it represents.*

7. Adding ecosystem specific analysis by making it possible to evaluate and provide indirect exchange quantities using the Leontief Matrix.

We use the above challenges to develop a more aesthetically pleasing layout for visualizing ecosystem dynamics.

5 Eco-Spiro Vis

In this section, we introduce our visualization method for ecological networks. In the first section we cover the layout of our visualization. Following that we will discuss the visualization design and explain the interaction tools that are provided in the system.

5.1 Layout

In our layout, we represent the entire ecosystem using a thick circle (see Figure 7). The closed nature of the circle is useful in implying the concept of the "closed" ecosystem. Although, other round shapes like ellipses can be used for this design, we choose circle to keep the symmetric overall look of the design. Each node is presented as an arc of the circle. Each arc is determined by a specific angle, which is proportional to the species' biomass (i.e. the node's weight). Let α_i denote the angle of the arc associated with N_i, which is proportional to N_i's biomass. The order of the nodes is usually the same as that provided in the input file. If it is necessary, we reorder the nodes for better distribution. To position the nodes on the circle, we start from a specific angle (say $\theta = 0$). Then we incrementally add new arcs to the end of the previous one (see Figure 7). More formally, if θ_i is the angular position for the center of N_i, then:

$$\theta_{i+1} = \theta_i + \frac{1}{2}(\alpha_i + \alpha_{i+1})$$

For the representation of edges, the direction and the weight of each edge should be visible. Therefore, techniques provided in [Holten and van Wijk 2009] do not work well since they do not consider weight requirement. We have tried several designs for edges. For example, a simple thick line or arrow between nodes is not an aesthetic choice. Our final design is a curved thorn/spike-like shape with variable thickness (see Figure 8). Thorns impose a natural direction on edges. The thicker part of the thorn is attached to the

source and the tip to the destination node. The thickness of the thorn is proportional to the weight of the corresponding edge. The structure of the thorn's curve is defined such that visual similarity (inspired by Spirograph patterns) is established between edges. To accomplish this, the tangent at the source and the destination and also the curvature of the thorn are controlled by the center of the ecosystem circle (see Figure 8). In our implementation, we have used cubic Bezier curves in order to construct thorns. As demonstrated in Figure 8, each thorn consists of three pieces: internal, external and the base. Let the control points of the internal and the external Bezier curves, from N_i to N_j, be represented respectfully by $\{P_1, P_2, P_3, P_4\}$ and $\{P_5, P_6, P_3, P_4\}$. The center of the circle is denoted by O and the weight factor of each edge is denoted by the angle γ_i. P_4 is simply the intersection of ON_j with the internal circle edge. Point M, used in the definition of P_1 and P_5, is determined as the intersection of ON_i with the internal circle edge (see Figure 8). Then P_5 and P_1 are defined by adding and subtracting $\frac{\gamma_i}{2}$ to M's angle in the polar coordinates. And finally we define:

$$
\begin{aligned}
P_2 &= \mu O + (1 - \mu)P_1 \\
P_6 &= \mu O + (1 - \mu)P_5 \\
P_3 &= \mu O + (1 - \mu)P_4
\end{aligned}
$$

where μ is a constant to control the curvature of the thorns. In our implementation we set μ to 0.625 (the golden ratio).

As mentioned in Section 2, ecological networks have external edges (input and output edges). In our layout, we use thorns attached to the outer layer of each node's corresponding arc to show these edges (see Figure 9). The length of these thorns is controlled by a phantom circle $C_{phantom}$ illustrated in Figure 9.

The Bezier curves of the input and output edges are constructed similarly to the exchange edges.

5.2 Visualization

Using the layout described in the previous section, we design and implement a visualization prototype for ecological networks. Figure 10 demonstrates our Spirograph visualization of the network in the Figure 2. Each node is represented by an arc with a specific color. The angle of the arc is proportional to the node's biomass.

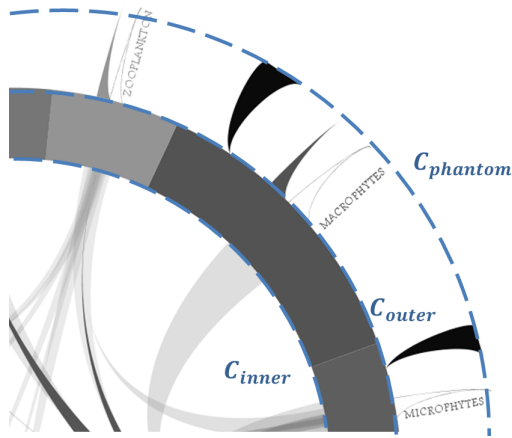**Figure 8:** *Arc point i is the origin of the thorn-shaped edge and arc point j is the destination of that edge.*

Figure 9: *External edges. For our implementation, the distance of $C_{phantom}$ and C_{outer} is the same as C_{outer} and C_{inner}*
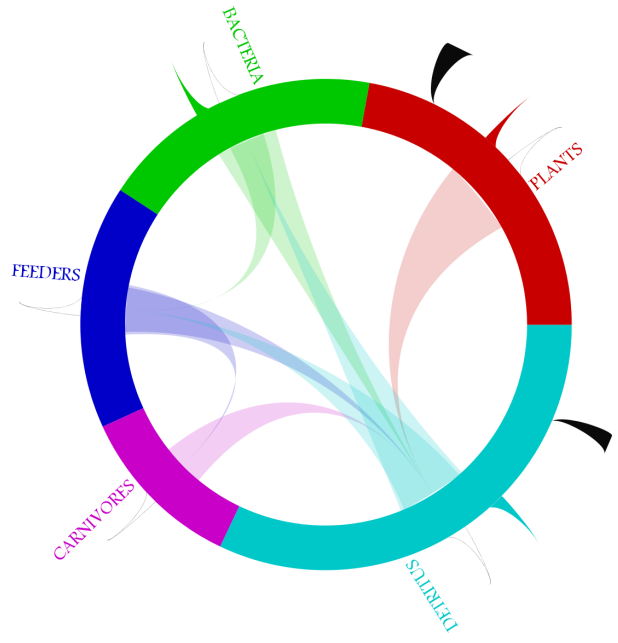

Figure 10: *Spirograph visualization of the example network in Figure 2.*

Figure 11: *The inputs, outputs and respiration edges. For the node "Plants" input is 11184, output is 2003, respiration is 300 and its exchange to other nodes in the network is 8881.*

Since the biomass numbers' range is wide, a logarithmic mapping is used to normalize the biomass.

As described in the layout section, edges are presented by thorns whose tip points towards the destination node and whose base identifies the source node. The color of each thorn is taken to be the same as the source node's color, but it fades along the edge. As shown in Figure 10, the weight of an edge is mapped to the thickness of its thorn. The edge from "Bacteria" to "Feeder" is smaller than the edge from "Plants" to "Detritus" (see Figure 10). Once again, we have used a logarithmic mapping to normalize the range of the edge weights.

External edges are identified by the directions of the thorns. The inputs are shown in black and the outputs are shown with the same color as each's original node. The color of the respirations is white, so that they are distinguishable among other edges (see Figure 11).

5.2.1 Interaction

To provide a practical tool for ecologists to achieve their goals from this visualization, we have designed some interaction possibilities.

Ecological networks may contain more than a hundred nodes. Con-

sidering the fact that nodes that represent species have different biomass amounts, presenting the thickness of all edge and node weights is not always practical. Therefore, in these cases the impact of these weights may be optionally ignored. It is up to the ecologist to decide whether to present the edges with their weights or not (see Figure 12).

Furthermore, in our implementation, when a node is selected with mouse/touch interaction, the nodes and all exiting edges are highlighted and their weights are reported with mouse hover (Figure 13).

Evaluating and displaying indirect connections and effects (e.g. paths, cycles, cyclic fractions, total exchange) are also important in ecological networks. In our visualization prototype, we have implemented some of these tasks to demonstrate the potential for Spirograph ecosystem visualization. Figure 14 shows how we display multiple cycles. In the network shown, which has fifteen nodes, there are two cycles that go through node "Mesozooplankton". The left image shows the first cycle and the middle image shows the
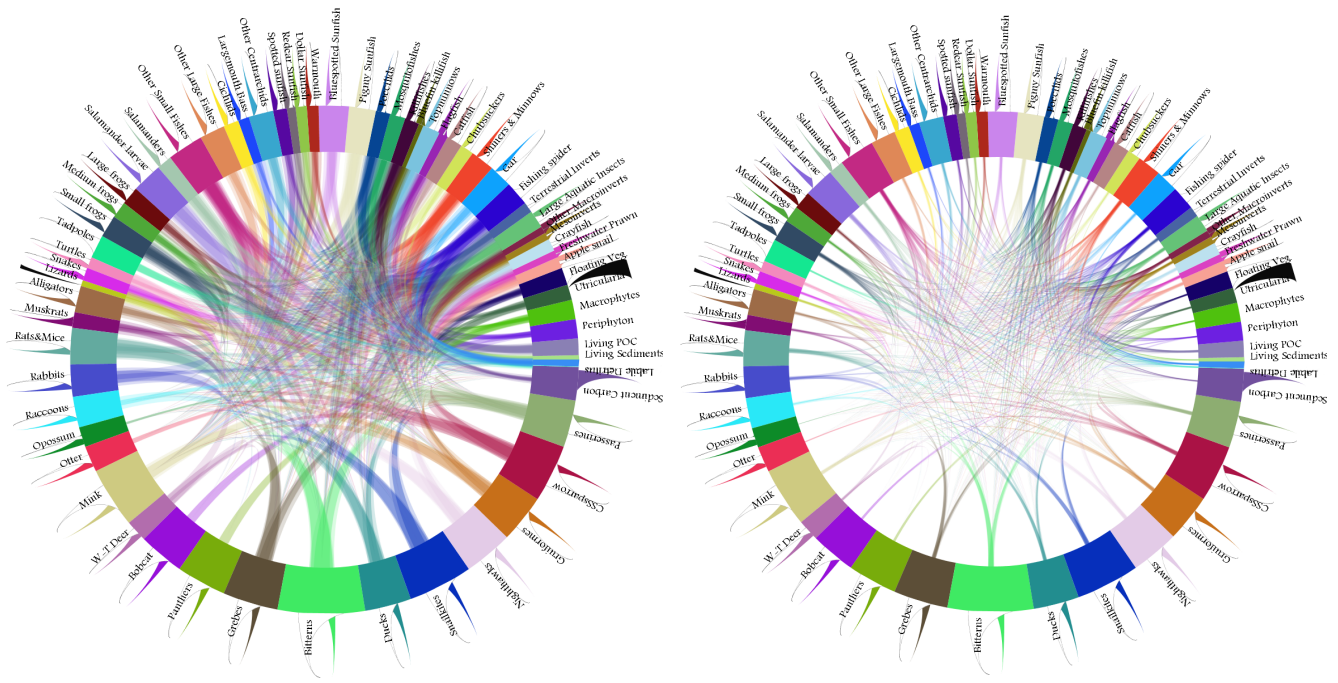
Figure 12: *The visualization may optionally ignore edge weights. In cases with larger number of nodes, edges weights are visible by selection.*

second cycle. The right image is the view of the network with both cycles highlighted. In path/cycle mode, all regular edges are faded and only the edges of the various cycles are highlighted. Each cycle has its own individual color.

Another important requirement for ecologists is the display of total flow between two nodes. To achieve this, we first evaluate the Leontief matrix from Equation 3. Our visualization provides a simple interaction tool for selecting two nodes, whose total exchange is displayed (see Figure 15).

6 Implementation and Data

We have used the Processing 2.12 development environment for the visualization tool. Forty eight ecosystem data files have been provided to us by Professor Robert Ulanowicz, Chesapeake Biological Laboratory, from the University of Maryland. The number of nodes ranges from five to one hundred twenty five. Thirty five data files contain less that fifteen nodes. Figure 16, shows a screen shot of one of these networks, with twenty on nodes visualized in our tests of the Eco-Spiro Vis. Each data file contains the following fields:

- Ecosystem name

- Number of nodes or species in the ecosystem

- List of node labels or the species names

- List of the nodes' weights or species biomass

- List of inputs

- List of outputs

- List of Respirations

- List of exchanges

We have used *Matlab* to compute the Leontief matrix L for all the ecosystems. Figure 17, shows how L can be used for all flow exchanges.

7 Discussion

In this work, our goal was to create a visualization that, integrates revealing as much data as effectively possible, with goals to design an aesthetically appealing visualization for ecological networks. Here we discuss our visualization in terms of our design challenges as formulated through discussion with ecologists (Section 4).

While each identified ecosystem is naturally embedded in larger ecosystems, maintaining a visual impression of it as a coherent system was deemed important. Since metaphorically, a circle both offers visual containment and a sense of completeness, we chose to work with a circle as our basic structure. Using this circle to hold the nodes within its rim, to contain the internal edges in its interior and to orient the external edges outwards, provides an overview of the system. The ecologists we have worked with told us that this global view of the adjacent nodes is helpful for realizing the overall structure of the network and as requested provides a clear distinction between internal and external energy flows in the system. One comment made about the overall impression of the visualization was "I delight in the lovely organic forms by which the information is conveyed"[1] Matching node and outgoing edge colors is one of the appreciated factors. The initial feedback from our ecological team confirms this by saying, "I like the colorful nature of the graphics it gives a good idea of adjacency".

Our visualization is able to present all node and edge weights by mapping them into graphical values: nodes are sized proportional to their biomass; and the wide end of the edge thorn is proportional

---

[1]quotes in this section are from personal communications (with Mishtu Banerjee) and are used with permission.
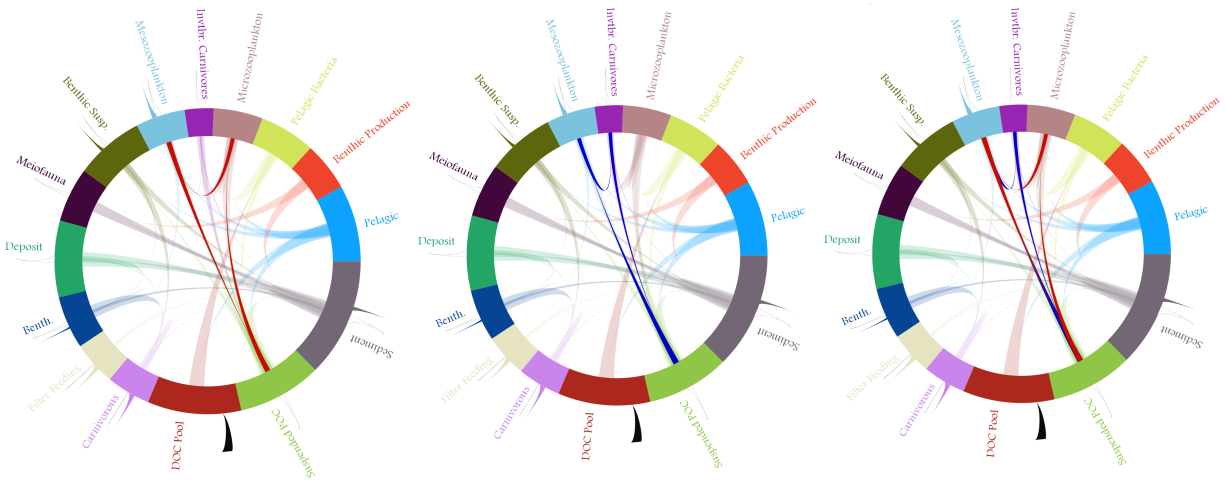
Figure 14: *Two cycles that include node "Mesozooplankton" are shown. This first cycle is shown in the left image with color red, the second cycle is shown in the middle image with color blue, and the right image shows both cycles together.*
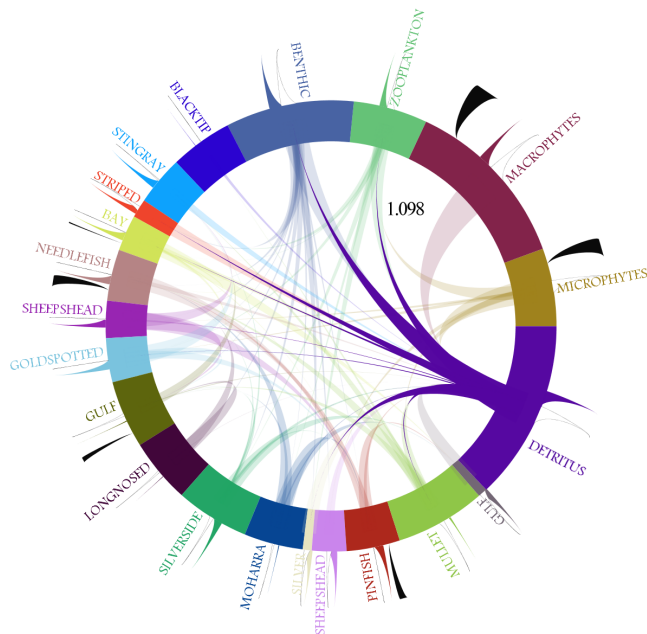

Figure 13: *Ecological network with twenty one nodes. The node "Detritus" with eight exiting exchange edges is selected .*

Figure 15: *Energy/matter flow from node "Benthic Susp" to the node "Deposit". These two nodes are not directly connected, but there is an energy flow between them through the network.*

to its weight. Also using the thorn or spike-shaped edges maintains clear visual directionality while reducing the clutter that caused by arrow heads. On the other hand, if desired, the ecologists can use the system with no edge weights, to consider connectivity only or while working with larger ecological networks.

As always in visualization, scalability is an issue. However, perhaps in part due to the complexity of ecosystems in general, it appears that often small ecosystems are studied. For example, of the forty-eight ecosystem data-sets we are working with only one is as large as 150 nodes and most are considerable less than twenty nodes. We recognize that our visualization is best suited for ecosystem data sets in these size ranges and would be challenged to display more than a couple hundred nodes. There are other scalability issues, for example, since the weight of the nodes are spread across

a large range of sizes with some extremely small and some very large, it can become challenging to create a data consistent display in which all nodes are visible. While these issues present interesting future challenges, our visualization is successful with our current data sets.

Our prototype visualization offers interactive tools for exploring ecological networks including highlighting, and various types of selections and filtering. These interactions are continually being refined through closer collaboration with ecologists and inclusion of more detailed descriptions of their task requirements. For example, this currently includes showing indirect exchanges of en-
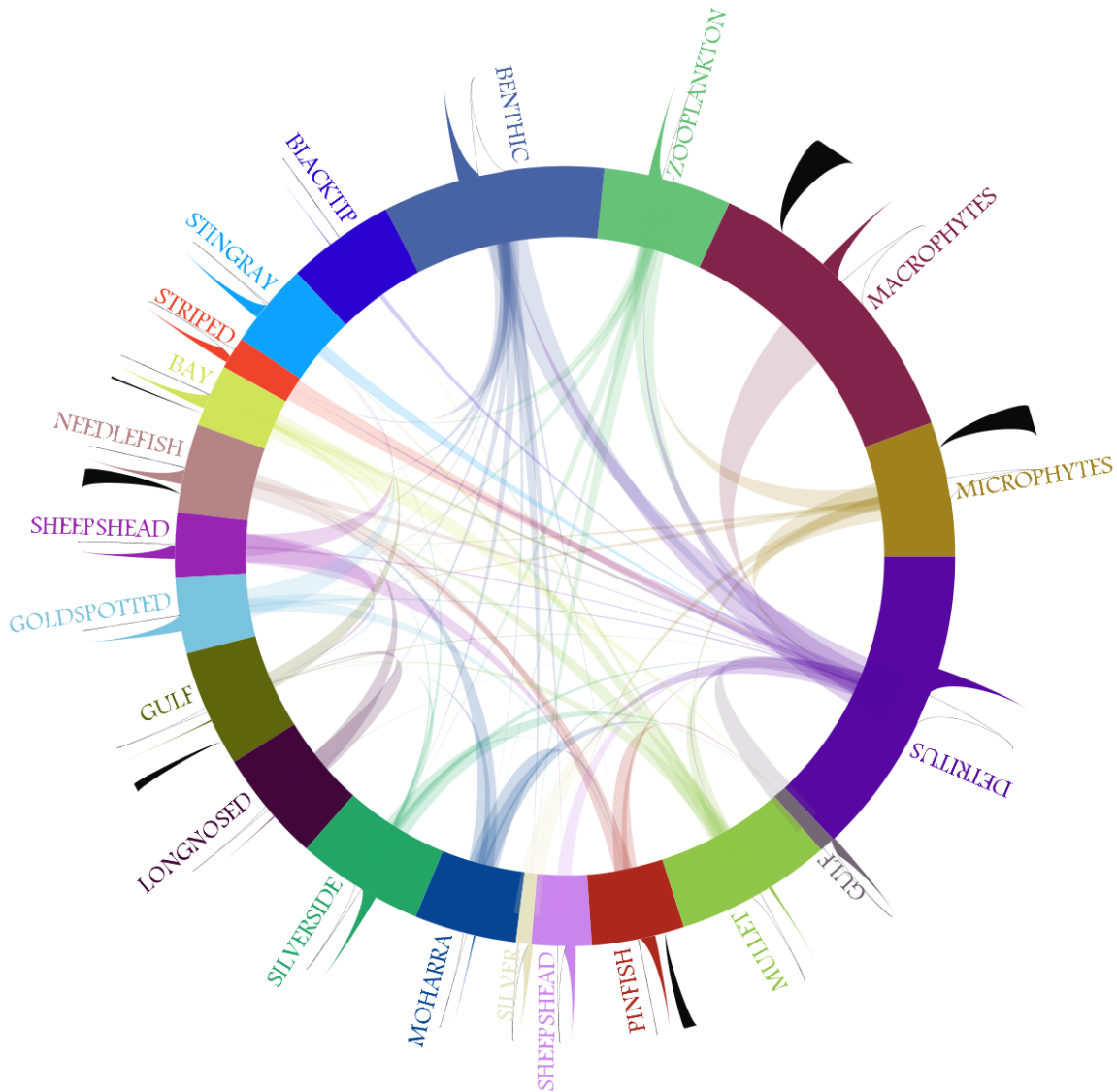
Figure 16: *Crystal River Creek, an ecological network with 21 nodes.*

ergy, which is important requirement for studying ecological networks [Ulanowicz 2004]. Our collaborating ecologist team has reiterated this same point noted in [Ulanowicz 2013]. We have addressed this in our visualization, the discussion of which is provided in Section 5. Our tool shows cycles and the total exchange of energy/matter between species.

8 Conclusion and Future Work

In this paper, we have presented Eco-Spiro Vis, a visualization specifically designed for ecological networks. Eco-Spiro Vis uses a circle as the basic layout structure to provide an impression of the coherent system. While nodes are colored distinctly, edges are colored to match the node from which they emanated. This provides clear visuals of single level links. The circle layout also provides structure to visually present a clear delineation of internal and external factors. Nodes are angularly sized proportionally to their biomass and similarly edge widths are set by their weights. Representing the numerical values visually helps to provide a vi-

sual overview of ecosystem dynamics. The tapered edges provide a representation of directionality. In addition, Eco-Spiro Vis offers interaction techniques for highlighting and filtering that are linked to common ecosystem questions such as showing adjacency for incoming and outgoing connections and for revealing cycles of different lengths.

Including ecosystem specific analysis makes it possible to show such factors as indirect exchange quantities using the Leontief Matrix [Ulanowicz 2004; Leontief 1987]. Also, by providing interactions tuned to ecosystems Eco-Spiro Vis can calculate and display indirect effects of ecosystem dynamics such as cycles and throughput. Our visualization tool interactively presents indirect quantities in addition to common aspects of direct weighted graphs. We have illustrated the use of Eco-Spiro Vis by visualizing several examples of real ecosystems.

A formal evaluation of our tool is a potential area of future work. Furthermore, other indirect quantities (e.g. trophic level, which is the position of the species on the food chain) could potentially be
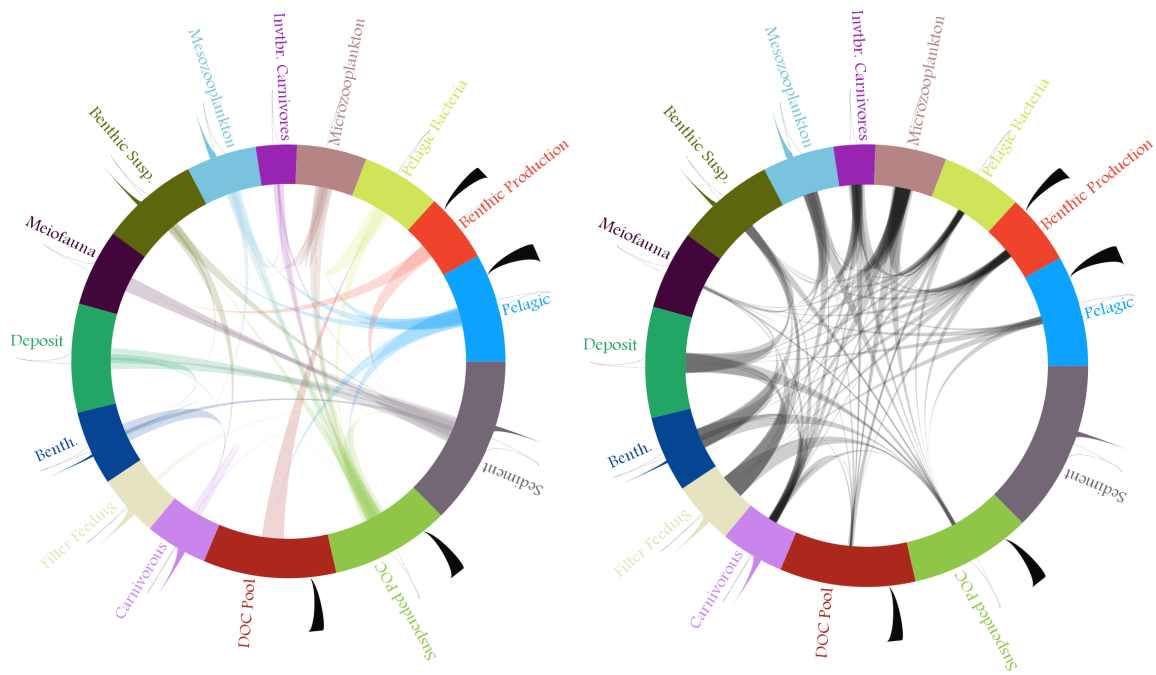
Figure 17: *Left image, an example network with fifteen nodes, all exchange edges are displayed. Right image, the same example with fifteen nodes, instead of exchange edges, energy/matter flow between nodes are presented.*

evaluated and displayed in the visualization tool. Currently, we use *Matlab* to compute indirect quantities. To extend this work and to support other indirect quantities, an integrated implementation would be required.

As mentioned in the Section 5, nodes can be rearranged. One aspect for future work is to include interactive rearranging of nodes.

In the current prototype the color of the nodes are generated iteratively. As a future work, color assignment can be improved by exporting color palettes from well-known artist paintings using tools like Colorvis [Lynch et al. 2012].

9 Acknowledgement

References

ALLESINA, S., AND PASCUAL, M. 2009. Food web models: A plea for groups. *Ecology Letters 12*, 7, 652–662.

BAIRD, D., AND ULANOWICZ, R. E. 1989. The seasonal dynamics of the chesapeake bay ecosystem. *Ecological Monographs 59*, 4, pp. 329–364.

BATTISTA, G. D., EADES, P., TAMASSIA, R., AND TOLLIS, I. G. 1998. *Graph drawing: algorithms for the visualization of graphs*. Prentice Hall PTR.

BENNETT, C., RYALL, J., SPALTEHOLZ, L., AND GOOCH, A. 2007. The aesthetics of graph visualization. In *Computational Aesthetics*, Citeseer, 57–64.

HENRY, N., AND FEKETE, J.-D. 2006. Matrixexplorer: a dual-representation system to explore social networks. *Visualization and Computer Graphics, IEEE Transactions on 12*, 5, 677–684.

HENRY, N., FEKETE, J., AND MCGUFFIN, M. J. 2007. Nodetrix: a hybrid visualization of social networks. *Visualization and Computer Graphics, IEEE Transactions on 13*, 6, 1302–1309.

HERMAN, I., MELANÇON, G., AND MARSHALL, M. S. 2000. Graph visualization and navigation in information visualization: A survey. *Visualization and Computer Graphics, IEEE Transactions on 6*, 1, 24–43.

HOLMQUIST, L. E., AND SKOG, T. 2003. Informative art: information visualization in everyday environments. In *Proceedings of the 1st international conference on Computer graphics and interactive techniques in Australasia and South East Asia*, ACM, 229–235.

HOLTEN, D., AND VAN WIJK, J. J. 2009. A user study on visualizing directed edges in graphs. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 2299–2308.

HOLTEN, D. 2006. Hierarchical edge bundles: Visualization of adjacency relations in hierarchical data. *Visualization and Computer Graphics, IEEE Transactions on 12*, 5, 741–748.

JORGENSEN, S. E., AND FATH, B. 2008. *Encyclopedia of Ecology, Five-Volume Set*, vol. 1. Newnes.

KRZYWINSKI, M., SCHEIN, J., BIROL, İ., CONNORS, J., GASCOYNE, R., HORSMAN, D., JONES, S. J., AND MARRA, M. A. 2009. Circos: an information aesthetic for comparative genomics. *Genome research 19*, 9, 1639–1645.

LEONTIEF, W. 1987. Input-output analysis. *The new palgrave. A dictionary of economics 2*, 860–64.

LIN, Y., AND VUILLEMOT, R. 2013. Spirograph designs for ambient display of tweets. *Proceedings of the IEEE VIS Arts Program (VISAP)*.

LYNCH, S., HABER, J., AND CARPENDALE, S. 2012. Colourvis: Exploring colour in digital images. *Computers & Graphics 36*, 6, 696–707.

MEYER, M., MUNZNER, T., AND PFISTER, H. 2009. Mizbee: a multiscale synteny browser. *Visualization and Computer Graphics, IEEE Transactions on 15*, 6, 897–904.

MILLER, T., AND STASKO, J. 2003. Infocanvas: A highly personalized, elegant awareness display. In *Supporting Elegant Peripheral Awareness, workshop at CHI03*, Citeseer.

MORITZ, S., 2014. Wel-formed eigenfactor.

POUSMAN, Z., STASKO, J. T., AND MATEAS, M. 2007. Casual information visualization: Depictions of data in everyday life. *Visualization and Computer Graphics, IEEE Transactions on 13*, 6, 1145–1152.

PURCHASE, H. C., PILCHER, C., AND PLIMMER, B. 2012. Graph drawing aestheticscreated by users, not algorithms. *Visualization and Computer Graphics, IEEE Transactions on 18*, 1, 81–92.

PURCHASE, H. 1997. Which aesthetic has the greatest effect on human understanding? In *Graph Drawing*, Springer, 248–261.

RIEHMANN, P., HANFLER, M., AND FROEHLICH, B. 2005. Interactive sankey diagrams. In *Information Visualization, 2005. INFOVIS 2005. IEEE Symposium on*, IEEE, 233–240.

TOM, B., 2014. Guilloche pattern generator.

ULANOWICZ, R. E. 2004. Quantitative methods for ecological network analysis. *Computational Biology and Chemistry 28*, 5, 321–339.

ULANOWICZ, R. E. 2013. *Circumscribed Complexity in Ecological Networks*. Wiley VCH Verlag GmbH and Co. KGaA, 249–258.

VON LANDESBERGER, T., KUIJPER, A., SCHRECK, T., KOHLHAMMER, J., VAN WIJK, J. J., FEKETE, J.-D., AND FELLNER, D. W. 2011. Visual analysis of large graphs: State-of-the-art and future research challenges. In *Computer graphics forum*, vol. 30, Wiley Online Library, 1719–1749.

WIKIPEDIA, 2014. Spirograph — Wikipedia, the free encyclopedia. [Online; accessed 17-Apr-2014].