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Abstract

Visualization is an important aspect of both exploration and communication of categorical as well as relational data. Graphical displays of policy networks are particularly attractive, since they enable authors to display in a compact way relevant actors in a network, how they are related to each other, and what the overall structure looks like. Sociograms were early companions of social network analysis, but have received surprisingly little attention during the following decades. Only in the last few years, easy accessibility of quality computing and graphic equipment has revived a now rapidly growing interest.

In this paper, we analyze the problem of visualizing policy networks. We first argue why network visualization is important, yet non-trivial. Then, we show that current methods are somewhat ad hoc in their attempt to convey information contained in a network. Our main contribution is a systematic approach to network visualization, closely following the general principles of information visualization. It provides a generic formalization which may serve as a guideline for further developments.

1 Introduction

The introduction of the policy network concept has been one of the major innovations in policy analysis in recent years (Kenis/Schneider 1991, Hérétier 1993, Börzel 1997) An important method for describing and analyzing policy networks is formal network analysis (Lauermann/Knoke 1987, Pappi et al. 1995). The main purpose of computer programs developed to conduct formal network analysis is to calculate aggregate measures on the centrality, density, etc. for the networks analyzed. However, some of these programs also include an option for graphical presentation of the structure of networks under study. Graphical displays of networks are particularly attractive since they allow to display in a compact way who the relevant actors in a network are and how these are related to each other. There are, of course, very different ways for visualizing one and the same policy network just as there are different ways of calculating structural characteristics of policy networks or different ways of theorizing about policy networks. Although there is considerably less literature on the problem of network visualization when compared to literature on calculation of structural properties or

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on theorizing about policy networks, there are at least three reasons why the visualization aspect in the analysis of policy networks should receive some more attention.¹

First, the function of network visualization goes far beyond "illustration". Network visualizations can help to improve communication about the data to third parties (such as policy makers); it can help the researcher to better explore specific properties of certain networks or facilitate the exploration of differences across several networks; or it could even serve to discover explanations for policies.²

Secondly, although numerous visualizations of social and policy networks can be found throughout the literature, systematic accounts of how visualizations are produced are very rare and, in general, techniques for creating visual representations of relational data have remained virtually unchanged since the study of social networks began (see Section 2.3 below).

Third, reflecting on the form and shape of visualized policy networks helps to critically evaluate existing ways of visualizing social networks (see Sections 2.2 and 3 below) as well as helps towards the development of objective standards of graphical excellence (see Section 4).

Ultimately, these contributions could and should be used as starting points for the implementation of formal instruments for appropriate visual presentation of social or policy networks, respectively, i.e. to develop automatic procedures for editing, analyzing, and presenting networks in a scientific way.

Consequently, the aim of the present paper is to illustrate the need for visualizations of policy networks and to present guidelines on how to assess and to improve their quality. The paper consists of three main parts building upon each other, each giving a concrete and specific argument. The first argument outlines why visualization is an important aspect of policy network analysis (see Section 2.1), but that, however, not every form of visualization is equally useful (Section 2.2). Section 2 also contains a brief review of the history and principal procedures of network visualization in the social sciences. The second argument then states that visual presentation of a network should be built upon a policy network's substance and described by some graphical design that is algorithmically converted into an image. It is shown that the State of the Art does not account for all of these aspects (Section 3). It is our third and final argument that there are ways to overcome these deficiencies by closely following the principles of information visualization. In Section 4, a systematic approach is proposed, consisting of a formal framework resembling the aspects identified in Section 3. An exemplary application of this approach is given in Section 5. Section 6 concludes with directions for further research.

¹What is hinted at here is a general phenomenon, not restricted to the area of network analysis. As Biderman observes: “The evolution of graphic methods as an element of the scientific enterprise has been handicapped by their adjunctive, segregated, and marginal position. The exigencies of typography that moved graphics to a segregated position in the printed works have in the past contributed to their intellectual segregation and marginality as well. There was a corresponding organizational segregation, with decision on graphics often passing out of the hands of the original analysts and communicator into those of graphic specialists—the commercial artists and designers of graphic departments and audio visual aids shops, for example, whose predilections and skills are usually more those of cosmeticsmen and merchandisers than of scientific analysts and communicators” (Biderman 1980 as cited in Tufte 1983: 181).

²On the basis of a number of historical examples, Tufte concludes that: “Those who discover an explanation are often those who construct its representation” (Tufte 1997: 9).
Figure 1: The adjacency matrix of a political network (reproduced from Doreian/Albert 1989). First try to explore the network’s structure by looking at its matrix, and then turn to its graphical presentation.

2 Network Visualization Reviewed

2.1 The Importance of Network Visualization

Data graphics can do much more than simply substitute for tabular descriptions. As put by Tufte: “At their best, graphics are instruments for reasoning about quantitative information. Often the most effective way to describe, explore, and summarize a set of numbers—even a very large set—is to look at pictures of those numbers” (Tufte 1983: 9). Graphical or visual presentations can not only describe data in different ways, but can also facilitate the comparison between different sets of data, stimulate scientific innovation, and even stimulate theoretical insights (Klovdal 1981, and Müller 1991).

In the case of network studies in general, and policy network analysis in particular, visualization of quantitative data becomes a very important instrument. A simple description of relational data by means of tables is extremely limited in its explorative power (even if compared to tabular descriptions of categorical data).

The above argument is illustrated in Figure 1. The adjacency matrix of a network of fourteen political actors and their strong political ties (Doreian/Albert 1989) is shown. Actors are labelled A to N, and the row of one actor contains a one in the column of another actor if they have strong political ties, and a zero otherwise. Obviously, a visual presentation of the same data is much easier to read when it comes to observing who is directly linked to whom, but it also reveals who is indirectly linked to whom—a type of information which could otherwise only be recognized by experienced matrix readers. Given the fact that already a simple description of the data in the form of a matrix is difficult to read, it seems obvious that an exploration of the data through tables becomes practically impossible.³ In contrast,

³Some improvements are possible by simultaneously rearranging the rows and columns (see e.g. Katz 1947).
by displaying a visual presentation of the network, basic features of the network as well as a great number of additional information on its structural characteristics can be observed. Although the details on how as well as which value can be added through the visualization of policy networks will be spelled out below, a brief look at the visualized presentation of the matrix in Figure 1 should be amply convincing to stress the importance of network visualization in general. For example, the visualization of the political network in Figure 1 gives us already some indications regarding such important questions as: Which political actor reaches most other political actors? Can every political actor be reached by every other political actor? Do some political actors only interact with one another? If one would moreover be successful in effectively combining the visualization of relational information with visualized information on attributes of the political actors following additional exemplary types of insights could be gained solely on the basis of a visualized presentation: Do political actors with overlapping membership networks have overlapping shared values? Are there common behavioural patterns? Do political actors with similar demographic characteristics interact more? Do communications between some political actors flow in one direction only (hierarchy)?, etc.

Assuming that visualization of network data is indeed an indispensable tool in its analysis and communication, a number of questions arise:

1. Does the way in which network data are visualized really matter?
2. What has been developed in this area so far?
3. Which principal procedures for visualizing networks have prevailed?
4. Are the results obtained from currently used methods satisfactory?

At least partial answers to the first three questions are given in the following subsections. The fourth question, and its implications, are the subject of the subsequent sections.

2.2 Relative Effectiveness of Visualizations

When Tufte states that "design is a choice" (1983: 191) he essentially points to the facts that data graphics of the same data can look very different, and that their quality can be very different. Consequently, if the conviction holds that visualization has tremendous explorative and communicative power and is not to be seen as an instrument to merely decorate numbers, some analysis should be invested in what determines quality in a visualized data matrix.

One problem with such an analysis is that there is little work to rely on, since not one piece of literature is known to us that deals with the quality of network visualization, even though their is a proven effect on perception.\footnote{Blythe et al. (1995) conduct a study proving the effect of node positioning to perception of network measures. Other studies (Purchase 1995, 1997) emphasize a presentation's general effect on the understanding of network structure. Note that Bertin (1983) does not reason about any particular, but arbitrary kinds of networks.} Even though there is a number of interesting articles addressing the question of network visualization, they rather concentrate on pointing towards "technological" innovations which are at hand to visualize networks. Examples are new computers, new printers, specific software packages, specific programming languages, new

However, we do not discuss such restricted forms of graphical presentation, since they appear to be too limited to meet the general purpose discussed in Section 3.
algorithms, increased processing capabilities of computers enabling colour, 3D and moving representations (see, e.g., Klovahl 1981; Freeman 1996 and 1997). Although these devices are important components for permitting visualizations, their usage hardly indicates the quality of a visualization produced.5

Before addressing the issue of how to assess the quality of visualized networks it seems important to illustrate how radical the quality of graphical presentation can differ. Since there is excellent work on this issue for categorical data by Edward R. Tufte, the point is illustrated by presenting one of his examples (see Figure 2).

This example clearly shows how the same data can be presented in very different ways. Apart from the fact that the second graph yields a much calmer view, leaving behind the distortion in the chartjunk of the first graph, it also does not generate the false impression of a substantial and continuous increase in spending. As Tufte convincingly shows, the first graph deploys several visual and statistical tricks—all working in the same direction, to exaggerate the budget which does not really increase when put in relation to population size. This is not the place to uncover the underlying graphical gimmicks (see Tufte 1983: 66–69) but rather to illustrate the point that not every way of visualization is equally useful. The second graph in Figure 2 is definitely more effective than the first. The question why one form of graphical presentation of categorical data is more effective than another has been analyzed in great detail by Edward R. Tufte (1983)6 and a number of other authors (e.g. Neurath 1991, Wainer 1984, and Müller 1991).

5To a certain degree one might even argue that computers and related techniques have generally led to a decrease in the quality of social science graphs (see for example the many examples of computer produced “chartjunk” graphs presented by Tufte (1983) and in contrast the graph produced by Charles Joseph Mainard in 1869, which may be, according to Tufte “…the best statistical graphic ever drawn” (Tufte 1983: 41).

6Tufte’s principles of graphical excellence are the following:

- Graphical excellence is the well-designed presentation of interesting data—a matter of substance, of statistics, and of design.
- Graphical excellence consists of complex ideas communicated with clarity, precision, and efficiency.
- Graphical excellence is what gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space
- Graphical excellence is almost always multivariate.
- Graphical excellence requires telling the truth about the data.
Figure 3: Two visualizations of the network from Fig. 1 found in the literature. (a) is from Krempel (1993), while (b) appears in Freeman (1996).

In the same way that graphical presentations of categorical data differ in quality, graphical presentations of relational data differ in quality. The problem is, however, the absence of literature assessing the quality of presentations, let alone of literature formulating principles for graphical excellence of social or policy networks.

Consider the graphical presentations of a political network in Figure 3. What becomes quite clear by assessing the two graphs presented—which can be considered representatives for current forms of social network visualization—is that Tuft’s principles of graphical excellence are often violated. This may have a number of reasons. First, it could be that—as already argued before—the quality of visualization is not taken very seriously as an issue, and that consequently, most graphical presentations violate the principles of graphical excellence. Second, it could be that the criteria drawn from the field of categorical data cannot be applied in the same way to the field of relational data. For example, in many visual presentations of non-weighted matrices (like Fig. 3a) the length of the links drawn varies significantly. This heavily violates Tuft’s principle of telling the truth about the data, because although every link means the same (i.e. the presence of a link with a score of 1), they are presented in different ways. Whereas this principle can easily be implemented in the case of categorical data (although here being very often violated as well) we will see later that in the case of relational data this principle cannot be completely satisfied in most cases. A third reason why the principles formulated by Tuft may not apply directly in this case could be that the type of contents which should be communicated7 is very different from the type of contents to be communicated in the case of categorical data.

Consequently, although one can expect that also in the case of relational data visualization some presentations are more effective than others, it is now apparent that we have hardly anything at hand to evaluate, not to mention guarantee, the quality of visualization solutions. The remainder of this paper aims at laying a base for such a discussion.

7Interesting aspects of the network shown in Fig. 3 are that the actors belong to two different camps, and that there is one highly central actor (Doreian/Albert 1989).
2.3 A Short History of Network Visualization

Given the importance of graphical representation for scientific development, it is astonishing how little attention the subject has received within the discussion and quantitative analysis of social networks in general, and of policy networks in particular. Kløvåhl's 1981 conceptual article *A note on images of networks* is one of the rare publications about this subject so far. Although interesting and very to the point, it was cited only four times between 1981 and 1996.\(^8\) The following outline mainly summarizes Kløvåhl's overview on the history of network visualization.

The sociogram, a visual representation of relational sociological data used by Moreno in the 1930s, was one of the earliest techniques for formalizing social configurations (see the many interesting examples in Moreno 1953) influencing—directly or indirectly—a number of subdisciplines of the social sciences (social psychology, social anthropology, sociology of organization, etc.). One of the major investigations popularizing this approach, according to Scott (1992: 18), was the Hawthorne study in which sociograms were used to describe social relations. In the diagrams of this study, actors are represented by circles placed on horizontal lines indicating their status, and the presence of a relationship of certain type is shown by an arrow. The layout of the diagrams seem to be influenced by organization charts and electrical wiring plans (see Roethlisberger/Dickson 1939: 500ff, or Fig. 4 for an example). Although these early forms of graphical representation were a great help in the structural analysis of society at all levels (from school classes to elite structure at the local and national level) and were considered a fruitful method of exploration, there had been very few improvements until the computer age opened up a completely new range of visualization possibilities. Before the broader introduction of computers, the researcher had to draw the images by hand in a very tiresome and time intensive trial and error process until the image was satisfying. Two major types of representation had been developed at that time for the design of sociograms. Firstly, arrow diagrams were drawn in which the most central actors were placed in the middle of the sheet and the researcher tried to reduce the number of cross-cutting connections as far as possible to achieve the best visual clarity. This idea was extended by Northway (1940), who introduced a variation in which nodes were grouped according to their centrality and then placed on concentric circles. The less central a node is, the farther outside it is placed (Kløvåhl 1981: 200). Secondly, out of the attempt to reduce the number of cross-cutting connections, a common technique was to construct the sociogram around the circumference of a single circle, such that all links could be drawn inside of this circle. Sometimes, different shapes and descriptors (see Fig. 4) for nodes were used to represent attributes. In the 1960s, the first three dimensional images were drawn (Laumann 1966).

Since the 70s a number of computer programs have been written that automatically generate visual presentations of relational data sets (Kadushin 1974, Levin 1976, Kløvåhl 1986; for more recent developments see Section 3). In general, concepts and techniques of visualization co-evolved with the elaboration of a tool of relational analysis in the social sciences which during the late 70s and early 80s increasingly had been covered under the label “social network analysis”. This type of structural analysis combines specific mathematical and statistical techniques to compute indices for network positions and total network structures with multi-purpose methods like multidimensional scaling (MDS) or cluster analysis. Therefore it is no surprise that parallel to the development and application of computer programs for sociograms multidimensional scaling has been used since the 1970s by a number of authors

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\(^8\) According to the Social Science Citation Index.
either to visualize the proximity and centrality of actors on the basis of their path distances or the similarity of their relational profiles (for example Laumann/Knoke 1987, Laumann/Pappi 1976). Just like the concepts used for the analysis of policy networks evolved from social network analysis, so did the techniques used for their visualization.

2.4 Principal Procedures in Policy Network Visualization

When applying the term policy network in political science context, a researcher takes at least one basic assumption for granted: “configurational” structure in policy, politics and polity matters. As the modeling of social structures as “networks” means choosing nodes and links as the basic units of analysis, in the analysis of policy networks or policy processes the nodes mostly represent political actors who are very often corporate actors (organizations), but may also be events or issues in a policy process. Links (edges) may represent different types of relations, such as links of communication, participation, resource exchange, social and political support, influence reputation, status relations, etc.

If one indeed agrees that these kinds of socio-political structures matter by restricting, and likewise enabling, actors in their behavior (Knoke 1990a), the precise description and detailed analysis of such relational structures are important steps in political analysis. However, political action and interaction is not only influenced by the actors’ relations with each other but also by their attributes such as legal form, size, organizational type, age of the organization, resources, interests, attitudes towards political issues, tasks, functions, nationality etc. Relational analysis therefore often is combined with the analysis of categorical data.

There is a small but growing family of quantitative studies on policy networks. Most of these are using graphical forms—besides matrices and tables—in the presentation of data and analytical results. The general advantages of visualization have been justified before. At least four visualization methods are currently in use. These are the sociogram, which is the most intuitive way of presenting structural positions of individual actors as well as their subgroupings in an overall configuration. Since the number of actors that can be displayed in a sociogram is severely limited, the MDS scattergram is taken as alternative solution, displaying the actor positions only in a two or three dimensional space without actually drawing the lines of their interconnections. Further techniques such as the dendrogram and the Venn
Figure 5: Examples of four different types of network data diagrams, taken from (a) Mayntz 1994, (b) Kriesi 1982, (c) Laumann/Knoke 1987, and (d) Scarini 1996.
diagram are simple ways to represent the hierarchical subgroupings of actors according to some criteria of similarity or dissimilarity in their relational profile or their affiliations into the same network subgroups (e.g. cliques, cores, clans, etc.). The following is a list of what seem to be the four most common methods of visualizing policy network data with citations of policy network studies using them (see also Fig. 5):

- the MDS-Scattergram (e.g. Knoke 1990b) for an application in international relations, Laumann/Pappi 1973, Laumann/Knoke 1987, Manigart 1986, Schneider 1992, Schneider 1993, Schneider/Werle 1991),
- the dendrogram (e.g. Schneider 1988, Scarini 1996),
- and the Venn diagram (e.g. Kriesi 1982)

The small number of examples of publications with images of policy networks reflects the fact that so far only few quantitative policy network studies have been conducted.

## 3 Fundamental Aspects of Visualization and the State of the Art

In the previous sections, it was argued why visualization is an important, yet non-trivial component of network analysis. Even though a fair amount of computer software is available to facilitate graphical editing, and even automatic layout of networks, the State of the Art is too heuristic to be satisfactory. This argument is grounded on the long established principle that every kind of information visualization should be accomplished according to an appropriately defined mapping of data to graphics. Even though this may seem a trivial statement, we indicate in this section how common methods for visualizing networks disregard some of the consequences arising from this principle. A systematic approach to overcome such limitations is proposed in Section 4.

### 3.1 The Three Aspects of Information Visualization

Information visualization consists of an appropriate transformation of input data to output graphics (Bertin 1983). That is, relevant information contained in the data is to be expressed by honestly generated visual clues. An ideal visualization would, in the shortest amount of time, reveal to its reader the information, the whole information, and nothing but the information contained in the data. We therefore argue that a visualization method is acceptable, only if it clearly identifies the relevant information, defines an appropriate mapping, and generates the image accordingly. We refer to these three aspects as **substance**, **design**, and **algorithm**, respectively, and discuss them in more detail below.

**Substance.** The purpose of visualizing networks is the communication of substance, either to the researcher herself, or to third parties. The substance of policy network data is not just any kind of information, but specific types of informational content of political structures.
Consequently, any visualization of a network should be concise and precise about the information it intends to communicate, and the means it uses to do so. Any “open”, i.e. unspecific, presentation of such data either produces a visual puzzle—also called a ‘crypto-graphical mystery’ (Tuft 1983)—or an ambiguous picture allowing many interpretations, some of which might even suggest false information. In Section 4.1, we provide a list of the most important network measures, i.e. typical substance of a network.

**Design.** Unlike the way it is commonly understood, design does not mean aesthetics, beauty, or elegance. As the famous British designer Terence Conran (1996) puts it, design incorporates 98% function and 2% aesthetics. The design of a visualized network is the specification of how its substance is mapped to graphical elements. The above statement implies that the most important aspect of choosing a specification is the effective communication of substance, rather than a beautiful and impressive picture. On the other hand, aesthetics may well play a role in speeding up the perception. We call the ease of reading the *ergonomy* of a visualization. The **effectiveness** of a design depends on how easily the substance is recognized in a visualization. Section 4.2 elaborates on the process of design specification.

**Algorithm.** The procedures used to realize a design specification for the substance of a given network constitute an aspect that is commonly overlooked. It is often not realized that perfect satisfaction of the requirements manifested in a design is impossible in many cases. Thus, any method applied to a network posing such problems necessarily introduces artifacts or misleading arrangements, even when it gives the best possible solution with respect to some deviation measure. Moreover, existing approaches often use an algorithm that does not implement a specified design, but implicitly defines one. Hence, it is important to be aware of the algorithm, and its peculiarities, underlying a visualization process. Some more detail is given in Section 4.3.

### 3.2 Current Approaches to Network Visualization

Nowadays, approaches to network visualization rather try to make use of what is available than stating what is desired and then asking for tools implementing these requirements. Consequently, recent work on the issue of visualization orient itself towards the applicability and usefulness of existing computer software. Here, we argue that the tools commonly used do not properly identify all three of the aspects described in the previous section, i.e. substance, design, and algorithm.

Available tools for network visualization fall into roughly four categories: General purpose graphical editors, two kinds of drawing programs developed for other than social networks, and tools and strategies that are meant to be used for visualizing social networks. The last category is most interesting, because, from a formal point of view, the substance of policy and social networks are comparable (see Section 4.1).

**General purpose graphical editors.** They are the least comfortable, yet most flexible tools, and are available for virtually every computer platform. They do provide a rich set of

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*Consider, for example, a design that requires all lines connecting different actors to be of the same length. This is a very reasonable requirement, when each link has exactly the same meaning. However, it can be proven that for many networks such a drawing does not exist, and even that it is extremely difficult to decide, whether it exists or not (Johnson 1982)."
editing functions, but almost no features tailored to networks. For example, when an actor is
moved on the screen, its links are not moved accordingly, because the program does not know
about structural issues. The burden of specifying and implementing a graphical design is put
on the user. Moreover, “manual” generation of a graphical presentation even for networks of
moderate size is a tedious, if not intractable, task.

Network drawing software from other disciplines. We distinguish two such categories.
One consists of those programs that draw specific networks other than social networks, like,
for instance, molecule structures.\textsuperscript{10} These provide means to position the nodes of the
network in certain, domain dependent ways. For example, atoms and bonds of a molecule are
arranged according to underlying energy laws. Obviously, such programs do not account for
the substance of a policy network. And because of that, they clearly do not specify an effec-
tive design. Their usefulness is limited to the fact that they, in general, produce drawings
that are pleasing from an ergonomic point of view.

The other such category consists of general purpose network drawing software. It contains
computer programs that typically are domain independent graph layout programs—programs
that arrange the nodes and links of a network—offering a variety of algorithms for different
layout styles (\textsc{Graphlet},\textsuperscript{11} \textsc{DaVinci},\textsuperscript{12} and many others). The design principles implemented
by these algorithms are usually ergonomic requirements like small drawing area, number of
line crossings, or number of bends in a line, that apply to any kind of network visualization.\textsuperscript{13}
Again, they do not account for the substance of policy networks, and hence make no attempt
to specify an effective design for it.

Software and strategies for social networks. This category comprises, for example,
routines for multidimensional scaling (e.g. Kruskal/Wish 1978) or spectral partitioning (e.g.
Molar 1991, Richards/Seary 1997) plots in analytical software packages, designated drawing
programs for social networks, and the only living tradition of drawing sociograms that could
be tracked down, circle diagrams.

MDS and spectral partitioning are arguably the strategies in network visualization for
which substance, design, and algorithm are most clearly identified. Both produce scatter-
grams: MDS plots reflect proximity in higher dimensional data (e.g. path distances) in fewer
dimensions, and spectral partitioning plots are produced according to eigenvectors of certain
network related matrices. Both methods take on a very distinguished interpretation of a
network’s substance and therefore display either one aspect of it, or we must assume that ev-
ery information contained in the network is comprehendable from Euclidean distances, which
form the basic information in a scattergram. The stress value (Kruskal/Wish 1978) of an
MDS provides a measure of how good the plot fits the design (“map proximity to Euclidean
distances”).

Drawing programs like \textsc{Krackplot}\textsuperscript{14} (Krackhardt \textit{et al.} 1994), \textsc{Pajek}\textsuperscript{15} (Batagelj/Mrvar

\textsuperscript{10}See \textsc{MOVIEMOL} (http://chem-www.mps.ohio-state.edu/~lars/moviemol.html) for a popular exam-
ple.
\textsuperscript{11}http://www.fmi.uni-passau.de/Graphlet/
\textsuperscript{12}http://www.informatik.uni-bremen.de/~inform/forschung/daVinci/daVinci.html
\textsuperscript{13}For a comprehensive survey on general graph layout see the annotated bibliography of DiBattista \textit{et. al}
(1994).
\textsuperscript{14}http://www.contrib.andrew.cmu.edu/~krack/
\textsuperscript{15}http://vlado.mat.uni-lj.si/pub/networks/pajek/default.htm
1997), or MultiNet\textsuperscript{16} are the most advanced tools available today. Besides actor positioning according to MDS and eigendecomposition, respectively, the first two also include refinements of the famous \textit{Spring Embedder} (Eades 1984), a heuristic for laying out arbitrary kinds of networks.\textsuperscript{17} Here, the design is a function of the algorithm rather than the substance. However, it is interesting to note that applying these algorithms seems very reasonable, if the substance is defined to be proximity in terms of path distances. The implied design is then similar to the design of MDS with some additional ergonomic criteria, e.g. nodes being distributed more evenly in the layout space. Krempel (1997) uses a similar placement algorithm, but has no generally available tool to offer.

The idea of circle diagrams is to place the actor nodes on an imaginary circle, which was assumed to make the pattern of lines more visible (Scott 1992: 149). This clearly defies any definition of substance. It is a design purely based on a doubtful ergonomic criterion (simplification through prescribed shape) and was proved to confuse the reader (Blythe et al. 1995). An extension to this design requires actors to be placed such that the total length of connecting lines is minimum over all possible arrangements (Krempel 1993). Even though dense subgraphs then tend to cluster within small arcs, there still is not even a precise definition of the substance thus revealed. Not to speak of whether this design is effective.

In summary, existing methods for policy network visualization do not clearly identify substance, design, and algorithm at the same time. The only exceptions to this observation are diagrams resulting from designated analytical tools, like multidimensional scaling or eigen analysis. However, they disregard ergonomics and have a very limited definition of a network's substance. Because the designs of MDS and partitioning methods are combined with ergonomic criteria, spring embedder variants seem to point into the right direction. Unfortunately, the substance that is conveyed by their design is defined only implicitly. It might turn out that the ergonomic criteria incorporated (in particular uniform node distribution and uniform edge lengths) work well enough in displaying many interesting aspects of a network (e.g. symmetry, cohesive subgroups, brokers, etc.). For now, this remains an open question that can only be answered by careful analysis of what one wants to show and the synthesis of an appropriate design to which the above procedures can then be compared, as well as by empirical validation. The following section provides a first step towards a sound basis for analysis and judgement.

4 A Formal Approach to Network Visualization

In the previous section, we divided the process of network visualization into three major components: substance identification, design specification, and algorithmic realization. We now propose a framework that is intended to serve as a guideline in producing visualizations and, even more important, tools for automatic visualization of networks. The framework respects the above subdivision and views a graphical presentation as a semiotic system for visual communication (Krampen 1990). Note that we do not propose a general solution to the problem of network visualization, but a basis for the analysis and comparison of existing approaches and a starting point for future developments.

\textsuperscript{16}http://www.sfu.ca/~richards/

\textsuperscript{17}The basic idea is to consider nodes of the network to be repelling rings. Those linked are joined by a spring and a positioning with low forces exerted on the rings is sought.
In the following subsections, typical network substance, the process of design specification, and the algorithmic realization of a design are discussed.

4.1 Network Substance

The different methods and strategies of network visualization are highly contingent on the general aim of policy network analysis and its specific use of the general “network analytic toolkit” (Kenis/Schneider 1991) for this purpose. The basic goal in the study of policy networks is the structural description of the actors and the analysis of relational configurations or “actor constellations” (Scharpf 1997) that are involved in the making of (primarily) public policies. A policy study using the network approach, first, is delineating the set of relevant actors engaged in this process (boundary specification), and, second, identifying the various relations among these acting units which are of particular significance and consequence for the outcome of a certain policy process. Relevant relations for this purpose may be the exchange of information and expertise (e.g. legal advice), the signalling of interest positions for coalition building, or the mutual support by financial and personal resources, etc. The guiding idea behind this analytical perspective is that a certain policy result may be explained by the structured interaction within the policy actor set. Structuring then is understood as an emergent effect which is restricting as well as enabling the actors to certain actions. For this task, policy network analysis borrows a number of formal concepts and statistical measures from the general methodological tool of social network analysis.18

Among the broad spectrum of network analytic methods we may distinguish between two types of structural analysis which are pursued at three different levels. On the one hand, there are structural methods aiming at a detailed description of whether and how the different actors in the network are connected to each other via direct and/or indirect links of communication, support, or other flows of policy resources. This analytical viewpoint may be called the connectedness perspective. The other type of structural analysis is less interested whether actors are directly or indirectly connected, but more into the similarity or dissimilarity of profiles of relations in which an actor is involved. Actors with an identical or nearly identical profile then are said to have structural equivalent network positions. Both types of structural analysis may be used to analyze quite different aspects of the overall network.

For a structural description at the actor level there is a bunch of methods measuring the relative positioning of actors based on their direct and indirect ties to all other actors in the network. On the basis of graph theoretical notions (e.g. reachability, path distance, and degree) some concepts try to assess how central or how peripheral an actor is located in a communication structure. Others are relying more on techniques stemming from input-output-analysis or status measurement in sociometry, to derive concepts indicating the “prestige” or the “prominence” of an actor in an overall actor constellation.

At the next level, the analysis is focused on the question, how a given network is structurally partitioned into sub-networks or subgroups. Such differentiations are possible from a connectedness perspective as well as from a profile perspective. The identification of subgroups based on connectedness is aiming to find collections of actors hanging more cohesively together than others. For instance, it tries to find out if the network is an integrated whole or if it is rather segregated into two or more subsets where the subunits entertain more intensive relations internally then between them. Related questions are, how many of such subsets exist.

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18For a comprehensive summary of social network analysis, its levels of analysis and its methodological tools see Wassermann/Faust (1994) or Scott (1991).
and how close these actors are connected to each other in each subset. Operational concepts that are helpful for this analysis are components, cliques, clans, cores, on the one hand, but also special locational properties such as the position as a "bridge" or a "broker" in a network linking the subgroups to each other. In contrast, subgrouping based on profile similarity tries to find "blocks" of structural equivalent actors, i.e. actors with identical or highly similar profiles of relations. A block then is interpreted as a social position fulfilling specific roles in an overall network. For the identification of these blocks, social network analysis provides for a still growing spectrum of aggregation and division methods (i.e. block modelling or cluster procedures).

At the highest level, the level of the network, structural analysis is trying to find out the different overall characteristics of the complete network structure such as how dense or how centralized a network is. For this purpose it is using concepts such as density or centralization to get aggregate measures on the total network that are useful for its comparison with other networks.

Since the structure of a given policy network is analyzed through specific measures of various structural properties, a visualization should make these properties visible. In order to better understand the possibilities and limitations of a graphical design that is to convey the relevant information, typical policy network substance is grouped into two main categories with four subcategories each (see Tab. 1). These distinctions may serve as a guideline how visualizations can enhance the understanding of complex multidimensional settings by separating different kinds of information.

The first of the two main categories comprises those measures which are solely dependent on the presence or absence of links in the network. They are called the *syntactical* attributes of the network, because they are completely determined by the underlying network structure, no matter what the network actually describes. On the other hand, there are properties which do not depend on the relationships constituting the network. These are called the *semantic* attributes, because they relate elements of the abstract graph to their real counterparts. Since they are closely related to the actual study, only examples of such attributes can be given.

The first three subcategories in both columns of Tab. 1 correspond to the three levels of interest: actor, group, and network. In policy network analysis, one is often interested in all three levels of aggregation simultaneously in order to explore or communicate properties in their context. Most desirable visualization techniques would therefore combine the associated perspectives in an information dense design that allows to switch between detail levels within a single image. In other words, they should allow for the kind of micro/macro reading described in Tufte (1990).

### 4.2 Graphical Design

The graphical design of a network visualization is the specification of how a network's substance would best be represented in graphical form. In mathematical terms, such specification corresponds, in general, to a constrained optimization problem, and it is hence the purpose of a design to specify the constraints and the objective function for this problem. Consequently, an algorithm would ideally produce a graphical representation satisfying all constraints and

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A fourth subcategory is introduced in order to account for properties which apply only in special cases. For example, every actor has a centrality score, and every actor belongs to some group or not, but it need not be shown, for almost every actor, that the actor is *not* a broker.
<table>
<thead>
<tr>
<th>Syntactical Attributes</th>
<th>Semantic Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Derived Attributes of Actors</strong></td>
<td><strong>Attributes of Actors, e.g.</strong></td>
</tr>
<tr>
<td>centrality (undirected networks)</td>
<td>- size of an organization</td>
</tr>
<tr>
<td>prestige / prominence (undirected networks)</td>
<td>- age of organization</td>
</tr>
<tr>
<td><strong>Structural Partitions</strong></td>
<td><strong>Attribute Partitions, e.g.</strong></td>
</tr>
<tr>
<td>cohesive subgroups</td>
<td>- organizational subunits</td>
</tr>
<tr>
<td>structurally equivalent actors</td>
<td>- legal form of a policy actor</td>
</tr>
<tr>
<td>role equivalent actors</td>
<td>- attitudes towards policy issues</td>
</tr>
<tr>
<td><strong>Derived Network Attributes</strong></td>
<td><strong>Network Attributes, e.g.</strong></td>
</tr>
<tr>
<td>size</td>
<td>- period of data gathering</td>
</tr>
<tr>
<td>density</td>
<td>- reliability</td>
</tr>
<tr>
<td>centralization</td>
<td>- differentiation</td>
</tr>
<tr>
<td>inclusiveness</td>
<td></td>
</tr>
<tr>
<td>cohesiveness</td>
<td></td>
</tr>
<tr>
<td><strong>Selected Structural Roles</strong></td>
<td><strong>Selected Attributes, e.g.</strong></td>
</tr>
<tr>
<td>bridge</td>
<td>- distinct institutional role</td>
</tr>
<tr>
<td>broker</td>
<td>- such as political leader</td>
</tr>
</tbody>
</table>

Table 1: Principal substance of a network.

scoring optimally on the objective function. See Section 4.3 for more details on the algorithmic problem.

The formal model of a policy network is the mathematical notion of a graph. A finite set of vertices represents the actors, while relations between actors are modelled by edges. Each edge corresponds to a tie between two actors. Semantic attributes as defined in Section 4.1 correspond to labels assigned to vertices, edges, or subsets of either, respectively.

A graphical design maps the formal network model to a formal description of its graphical presentation. According to graphic designer Jacques Bertin (1983, see also MacKinley 1986), a graphical presentation consists of marks (points, lines, areas, and, possibly, volume objects), i.e. zero- to three-dimensional objects, for which positional (x-, y-, and, possibly, z-coordinates), retinal (size, shape, orientation, texture, color, brightness, and transparency), and temporal\(^20\) (in animation) properties are varied. Krampen (1990) advises to restrict the grade of variation to perceivable differences.

The fundamental decision in a graphical design specification is the choice of a representation format. That is, one has to choose what kind of marks is to represent which elements of the network model. From the many conceivable representations of graphs, the arguably most familiar consists of points depicting vertices (actors), and lines depicting edges (links).\(^21\)

\(^{20}\)Since we are in this paper, concerned with the classical case of static networks only, we do not go into detail about temporal properties.

\(^{21}\)Other types of representations are in use, too. Consider, for instance, a hierarchy in which each element has exactly one superordinate element. Each element of such hierarchy can be represented by an area containing the areas corresponding to subordinate elements. As is the case with many other representations, only graphs of certain structure can be visualized in this way. This representation is called inclusion drawing and closely
Sociograms and scattergrams (where edges are typically omitted) are members of the corresponding class of diagrams. Subclasses of this representation are obtained by globally fixing selected properties. For instance, the shape property of lines representing edges could be fixed to “straight” (straight-line representation) or “axis-parallel segments” (orthogonal representation). If the actor positions are fixed to lie equally spaced on a circle, the obtained representation is a circle diagram.

Positional, retinal, and temporal properties of marks need to be specified in accordance to the network's substance. Additionally, ergonomic aspects have to be considered to ease perception of the substance. According to the respective classes of properties, we subdivide the design specification into layout specification (positional properties), rendering specification (retinal properties), and animation (temporal properties). The structure of a design specification is summarized in Figure 6.

Layout. Consider a straight-line representation of a graph. Since all edges are represented by straight lines connecting their endvertices, it is sufficient to have coordinates for these. A layout specification does not fix these coordinates, but states desirable features of these coordinates. For example, the design might state that two actors connected by a link should be placed at some particular distance, that is, their coordinates are not set to a certain value, but they are constrained to fulfill a certain relation.

In general, a graphical design specifies desirable features of coordinates for a number of marks representing elements like vertices, edge bends, or labels. Given a certain form of representation, it must be possible to determine positional properties of marks representing other elements in the network model from those for which a design is specified. Blythe et al. (1995) observed that the layout of a network has considerable effect on the perception of network substance.

We distinguish two ways of specifying desirable positional properties. The first is to restrict the set of admissible layouts by imposing design constraints. Every assignment of coordinates then has to satisfy properties expressed in terms of constraints. A straightforward example are ego-centered networks, where it is reasonable to fix the position of ego to lie in the center of the drawing. Another example is a hierarchy, where subordinates be placed beneath their superordinates. It is not always possible to clearly separate representational from design constraints.

However, some desirable features may result in constraints that are not satisfiable. For instance, most networks do not admit a layout with equal distance between any pair of linked actors. A design criterion is a function that assigns, to a given layout, a value reflecting the layout’s conformance to some design goal. Criteria can be viewed as relaxed constraints that are to be satisfied in the best possible way, but not necessarily fully. A layout is considered better than another, if it has a higher conformance score than the other. In general, there is more than one criterion for effective display of substance (like uniform edge length, subgroups being visually separable, central actors being close to the center of the drawing, etc.) and ergonomic readability (like uniform vertex distribution, small total area, small number of edge crossings, etc.). Most of the time imposed criteria are conflicting, such that a perfect layout would not optimize each criterion in isolation, but their combination. In this combination, criteria might be weighted according to their relative importance. A generic mathematical model for layout design and generation is given by Brandes and Wagner (1997).

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related to the Venn diagram.
Figure 6: Specification of a graphical design.

**Rendering.** In a sociogram, instead of points or circles, one might want to have names or logos for actors constituting the nodes, line thickness might be varied as to indicate different strength of ties, or polygons separating subgraphs might be desired in order to distinguish structural subgroups. Such rendering rules do not alter a representation, or positional properties of its marks, but only its visual appearance, i.e. retinal properties. We do not go into further detail here, since it seems to us that the issue of rendering a presentation of relational data does not differ as much from the rendering of other data as does its layout. Therefore, most research in visualization of categorical data also applies to the rendering of relational data (see e.g. Tufte 1983).

It seems to be a reasonable rule of thumb that syntactical attributes should be displayed mostly by positional properties of graphical marks, while semantic attributes should determine the retinal properties. Such distinction also supports the development of a general tool for network visualization, since, in general, it is easier to customize a program’s rendering capabilities than its layout features.

### 4.3 Algorithmic Realization

Given a network model and a graphical design specification, a drawing has to be generated according to the requirements manifested in the design. The procedure used to generate the drawing is called *algorithmic realization* of the design. Since the representation is fixed in the design, the algorithm has to compute a layout, render, and possibly animate it.

Typically, the rules contained in a rendering specification do not result in conflicting requirements. A reasonable rendering specification should thus not pose problems in terms of its algorithmic realization.

Quite conversely, almost every layout specification leads to a difficult optimization problem. A layout generated by the algorithm has to satisfy every constraint, as well as to optimize the weighted sum of all criteria. Such requirements are often intractable, if the algorithm is to generate an output in reasonable time. In this case, approximate solutions are sought. A well known and fairly successful procedure for mostly unconstrained designs is *Simulated Annealing* (Metropolis *et al.* 1953). A prominent software using this type of algorithm is KRACKPLOT (Krackhardt *et al.* 1994). When applying Simulated Annealing, the objective function of a design is considered to be the energy of a physical system. A probabilistic sequence of layouts that change moderately from one layout to the other is produced according to some generation scheme that simulates the behaviour of the physical system in a slowly annealed heat bath. Note that different results may be produced in different runs of an algo-
rithm. This is obvious for probabilistic methods like Simulated Annealing, but it also holds for many deterministic methods that depend on the initial configuration.

We stress again the importance of clearly identifying and distinguishing a design and its algorithmic realization. For example, Freeman (1996) compares a layout algorithm from the graph drawing community (Kamada/Kawai 1989) with an algorithm implemented in KRACKPLOT. He states that the Spring Embedder variant of Kamada and Kawai “is based on an assumed ‘attraction’ between adjacent points and a ‘repulsion’ between non-adjacent points” (Freeman 1996), while the algorithm in KRACKPLOT “employs synthetic annealing to minimize the distance of each point from all the others to which it is adjacent” (Freeman 1996). These seem to be quite different approaches because, in the first the case, a physical analogy is used to describe the design, while in the second case, a different physical analogy is used to describe the applied algorithm. However, both designs are strongly related. And even though different algorithms are employed, both do sufficiently realize the design. It hence comes as no surprise at all that “...the arrangement produced (...) is quite similar” (Freeman 1996).

5 Example

In this section, we use a network analyzed by Doreian and Albert (1989) to exemplify some of the issues we raised in the previous sections (cf. Fig. 1 and 3). We therefore point out what is chosen be the network’s substance, devise a design, indicate some algorithmic aspects, and discuss the result shown in Fig. 7. Note that the example is set up such that it gives a visualization which is illustrative, but far from excellent.

Doreian and Albert hypothesized that the actors can be partitioned into two camps, based on their strong political ties. To visualize their findings, they used an MDS scattergram based on path distances. Hence, for the purpose of this example, we define the substance of the network to be, on the first level of aggregation (actor level), the degree of closeness centrality, and on the second level of aggregation (sub-network level), a partitioning into cohesive subgroups. Note that we do not employ a formal measure of cohesiveness, but incorporate an interpretation of cohesiveness into the design specification. Any other substance is considered to be of minor interest.

To specify the design formally, some more terminology is needed. Let $G = (V, E)$ be the graph associated with the (informal) network, where $V$ is the set of actors, and $E$ the set of pairs of actors indicating who has strong political ties to whom. Let’s say we want to visualize the network using a 2D straight-line representation. Then, actors are represented by point-marks, links by line-marks with property shape fixed to “straight”, and labels by point-marks. We now need to specify the objective function of the layout, and give a set of rendering rules.

Assuming that actor labels are shown at the center of each node, the positional properties of all marks are completely determined by an assignment of coordinates $x_v$ to all actors $v \in V$. Here, we do not restrict the set of possible assignments, so every vector $x = (x_v)_{v \in V}$ of actor positions constitutes a feasible layout. An objective function $U(x) = U_1(x) + U_2(x) + U_3(x)$ is used to determine layout quality. It incorporates the following design rules:

- spread actors evenly in the plane: $U_1(x) = \sum_{u \neq v \in V} \frac{c_{uv}}{d(x_u, x_v)^2}$

\footnote{Regarding this interpretation see also Krempel (1993:10).}
• place adjacent actors close to each other: $U_2(x) = \sum_{\{u,v\} \in E} c_2 \cdot d(x_u, x_v)^2$

• place actor $v$ with centrality score $C_v$ at distance proportional to $C_v + 1 - \max_{u \in V} C_u$ from the center $\zeta$ of the drawing: $U_3(x) = \sum_{v \in V} c_3 \cdot \left( d(x_v, \zeta) - c_1 \cdot (C_v + 1 - \max_{u \in V} C_u)^2 \right)$

where $c_1$ and $c_2$ are constants controlling the scale of distances, $c_3$ is a constant controlling the relative influence of $U_3(x)$, and $d(x_u, x_v)$ denotes the Euclidean distance between positions $x_u$ and $x_v$. Since $U(x)$ attains higher values for worse layouts, $U(x)$ should be minimized to obtain a layout that conforms to our design specification. Note that we also assigned point-marks to centrality levels. They are positioned in the center of the drawing, while their shape is set to “circle”, and their size is to reflect the level of centrality. In a similar way, a stem-and-leaf diagram of centrality scores was integrated to the right. The rendering rules used in this example are readily observed from Fig. 7.

We used an annealing type algorithm to (approximately) minimize $U(x)$, and the built-in rendering capabilities of GRAPHWIN, a graph editor included in LEDA\textsuperscript{23} (Mehlhorn/Näher 1997).

**Discussion.** In the above example, a number of important aspects are made obvious. Most important, one readily observes that the assignment of positions in the layout is a compromise of conflicting design goals. The constants have been chosen such that lying close to the correct radius is six times as important as lying close to an adjacent actor. Actor positions could be restricted to lie exactly at the correct radius, but in this case the goal of uniform edge length

\textsuperscript{23}Library of Efficient Datatypes and Algorithms. See \url{http://www.mpi-sb.mpg.de/LEDA/leda.html}
(the truth to the data principle) would be violated even more (e.g. actors K and L).\textsuperscript{24} Due to the number of accumulated conflicts, the deviation from their radius is larger for central actors than for peripheral.

Next, we did not include more sophisticated ergonomic criteria like sufficient edge-to-vertex distance or small number of crossings. In the above example there are two links unnecessarily close to actors F and H, respectively. Furthermore, the graph can be drawn with a minimum of one pair of crossing lines (see Fig. 1). It has been shown that crossings might hamper structural understanding (Purchase et al. 1995). On the other hand, a straight-line representation of a clique of four actors must place one of them in the middle in order to avoid crossing lines, wrongly suggesting a higher degree of centrality (compare actors A, C, D, and G in Figs. 1 and 7).

More elaborate rendering could improve on clarity and the amount of information displayed. For example, seven actors are County Council members, which is, in the analytical context of this network, a relevant information that is easily indicated by altering the color property of their marks.

Despite these drawbacks, there are two easily identified camps visible, which have not been preassigned in the design. Note that it would be easy to suggest arbitrary grouping by simply moving members of different groups apart (McGrath et al. 1997). Moreover, the most central actor (L) is clearly visible. The fact that one of the most peripheral actors (K) is directly linked to L results in a very long edge, suggesting that closeness centrality might not reflect the intuitive notion of an actor being influential in a political network.

6 Conclusion

There is a remarkable discrepancy between, on the one hand the potential of visualization techniques in the description, presentation and exploration of policy networks and on the other hand the interest, experience and techniques available for producing effective visualizations. Consequently, the paper aims at starting to bridge this discrepancy by arguing that it is worthwhile to invest in reflecting about the effective visualization of policy networks. It has been illustrated in the paper that a number of procedures and associated computer programs exist which allow for the visualization of policy networks, but that neither a discussion exists nor hints are given by their users and producers on the effectiveness of the visualizations these procedures and programs produce.

Consequently, the paper names three dimensions which help to evaluate the effectiveness of visualization of policy networks: substance, design and algorithm. Hence, it was concluded that an effective visualization is a combination of providing an algorithmic solution to a substantive problem in such a way that basic design principles are respected. In other words each of the dimensions should consider as far as possible the principles set by the other two dimensions. In a time that displays rapid increase in the availability of computing power and quality graphic equipment, one can expect a likewise increase in the usage of graphical output in both research and communication. It is hence important to be able to assess the quality of graphical presentations.

A short review of available visualization tools reveals, however, that it is almost never the case that all three dimensions are considered sufficiently. Visualization tools tend to almost

\textsuperscript{24}Observe that the optimal edge length implied by the expressions contributing to $U_1(x)$ and $U_2(x)$ is $\sqrt{c_1/c_2}$, i.e. constant over all edges.
exclusively concentrate on one of these, leading to an uncontrolled determination of the other two. It seems that most of the visualizations of policy networks are in the first place the result of applying an algorithm which was developed for a very different type of information to be communicated. As spelled out in the paper, policy networks are, however, phenomena which have to be described in very specific terms in order to discover significant and useful information about them.

Since the formal concepts of policy network analysis are well established, the next task would be, in order to routinely produce effective visualizations, to devise principles for an effective design on the basis of this substance. The major problem here seems to be the positioning of actors, i.e. the layout of the network. It can be expected that most design goals will be contradicting (as in the centrality/edge length trade-off in Section 5). A possible approach might be the combination of different forms of visualization in order to “triangulate” different analytical perspectives. Each of them should provide greater accuracy in the description of selected aspects, while their combination diminishes the risk of being taken by a methodological artifact.  

To come up with specific design principles for the visualization of policy networks, much research is needed, drawing on general insights in the visualization of quantitative information, general semiotic principles, and experimental validations. It is our hope that algorithms for the resulting designs will be able to produce pictures which tell us more than just how complicated this world is.

References


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25 *Triangulation* is generally defined as the combination of methodologies in the study of the same phenomenon. It stems from a military metaphor pointing to the use of multiple reference points to locate an object’s exact position (Jick 1979: 602). For an implicit use of triangulation in network analysis see Doreian (1988).

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23

Manigart, Ph. (1986) Les Relations Inter-Organisationelles dans le Domaine de la Défense Nationale, Centre de Recherche et d’Information Socio-Politiques, Bruxelles.


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