Exploring social structure using dynamic three-dimensional color images

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Abstract

Here we introduce a computer-based visual display program, called MAGE. MAGE was designed to display molecules but we will explore its potential for application to the study of social networks. To do so, we will use MAGE to examine the structural properties of two data sets, friendship choices in an Australian college residence and peer choices among teenagers in a Dublin suburb. © 1998 Elsevier Science B.V.

1. Introduction

In his recent book on microphysics, Galison (1997) discussed two kinds of 'instrument builders' in that field. There are those who build graphic devices that produce visual images of particular particle interactions, and there are those who build computational devices that are designed to analyze vast amounts of data on such interactions.

A similar division—between visual and computational instruments—can be found in social network analysis. We use tools like KrackPlot (Krackhardt et al., 1995), that produce pictures of the structure of a particular network, and we have programs like UCINET (Borgatti et al., 1992) that facilitate computations on social network data.

The present paper is focused on an instrument of the first kind. We will introduce MAGE (Richardson and Richardson, 1992), a computer graphic program, and evaluate its potential for applications in social network analysis. To conduct that evaluation, we will draw upon two data sets and see what we can uncover using this strictly graphic approach.

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2. The MAGE program

MAGE was developed as a device to be used in molecular modeling. It produces three-dimensional scientific illustrations that are presented as interactive computer displays. Transformations of these displays are immediate. Images can be rotated in real time, parts of displays can be turned on or off, points can be identified by picking them, and changes between different arrangements of objects can be animated.

MAGE has been compiled on, and will run on, PCs (under Windows 3.1, 3.11, '95, NT or Linux), MACs and on most common UNIX-based workstations. It displays images of files that have been prepared in a format called KIN. MAGE can either be run as a stand alone program to display downloaded KIN images or it can be attached to a web browser (Netscape or Microsoft Internet Explorer) in order to display images automatically whenever they are confronted on the web.

If you simply load MAGE on your MAC or PC, you can run it by clicking on its icon and loading a KIN file. MAGE then opens five windows: (1) a large main window that contains the pull down menus and image control sliders, (2) a text window, (3) a caption window, (4) an image window and (5) a banner window for starting the program. The banner window allows you to start in the regular mode or in a limited 'student' mode. The regular start is preferred.

Once MAGE is started you can move among these windows either by clicking on the desired window itself or by pulling down the 'Windows' menu and choosing 'Show text,' 'Show caption' or 'Show graphics.' You can load a KIN data file, or you can change files at any point, by using the 'Open File' command in the 'File' pull-down menu.

MAGE permits rotation of three-dimensional objects in order to help viewers explore the details of any structure that is displayed. If you place the cursor in the graphics window and hold down the primary mouse button, you can rotate the image by moving the mouse. Left/right motion in most of the window spins the image horizontally. Up/down motion spins it vertically. And left/right motion when the cursor is in the top sixth of the window spins the image in the plane of the screen—clockwise or counterclockwise.

Moving the cursor over it and clicking can pick any point in the image. The screen will then display any information the author stored regarding that point (name or attributes) and it will show the distance of the chosen point (in three-space) from the point previously chosen.

Sliders on the right edge of the main screen facilitate other user controls. Users can move into an image or away from it by using the 'ZOOM' slider. The 'ZSLAB' slider controls contrast and 'ZTRAN' controls brightness. Typically, users will not need to adjust the 'ZSLAB' or the 'ZTRAN' slider. Also on the right side of the main screen, but not clear out at the edge, are a series of switches defined by the author of each specific image and linked to that image. These switches can be used to turn particular features of the image off or on and thereby to call attention to its various structural properties.

Pull-down menus permit other adjustments and refinements. The most useful of these menus are labeled 'VIEWS' and 'KINEMAGE.' The user can always return to the

original view specified by the author by pulling down the 'VIEWS' window and choosing the 'View 1' option. If the author has specified more than one view, more than one option will be highlighted, and the reader can choose any one of them simply by pointing at it and clicking. If the author has specified multiple images, the user can move from image to image by pulling down the 'KINEMAGE' window and choosing 'Next' or by choosing 'Choose' and then specifying an image by number.

All this permits the author to pre-program some of the user's experience by including text and captions and by specifying particular views of particular objects. But at the same time users are completely free to interact with the pre-programmed objects and to modify the views to suit themselves. Such flexibility permits users to explore the data in their own ways and to arrive at their own conclusions.

The KIN input file for MAGE must contain a list of points as well as a location in a three-dimensional x by y by z space for each point. [3] Locations can be arbitrary, or they may be produced by some systematic procedure. Typically points are placed by using a gravitational model (Kamada and Kawai, 1989) or on the basis of the results of statistical computations, like multidimensional scaling (Kruskal and Wish, 1978), correspondence analysis (Weller and Romney, 1990) or some form of cluster analysis (Arabie et al., 1996). [4]

To see how all this works in the social networks context, we will first try using it to model a data set collected by Webster.

3. The Webster data set

Webster collected friendship data among the 217 residents living at a residence hall located on the Australian National University campus. Residents were interviewed individually at the start of the university's second semester. First, they were asked to recall all of their friends who currently lived in the residence hall. They then were provided with a list of all residents and were asked to add anyone whom they also considered a friend, but had forgotten to include. From the complete list of friends, they were asked to indicate the strength of each friendship tie. Most specified three levels of friendship, 'best friend,' 'close friend,' and 'friend.' The data were combined to form a valued, actor-by-actor matrix of reported friendship relations.

For the present illustrative application, we began with the square, non-symmetric data matrix described above. That matrix was first symmetrized by taking, for each pair of points i, j, the maximum of the strengths of the two ties, from i to j and from j to i. Then we used the correspondence analysis routine from UCINET (Borgatti et al., 1992) to uncover the basic structure of the data.

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[3] The structure of KIN files is specified in detail in a text file called KinFmt31.txt. This file is included in the MAGE package that can be downloaded from any of the sites listed in the Editorial on p. 107 of this issue.

[4] All of these computational techniques are designed, one way or another, to place points that are adjacent (or closely linked or similar in their pattern of connection to others) close together and points that are not adjacent (or not closely linked or dissimilar in their pattern of connection to others) at some distance from each other.
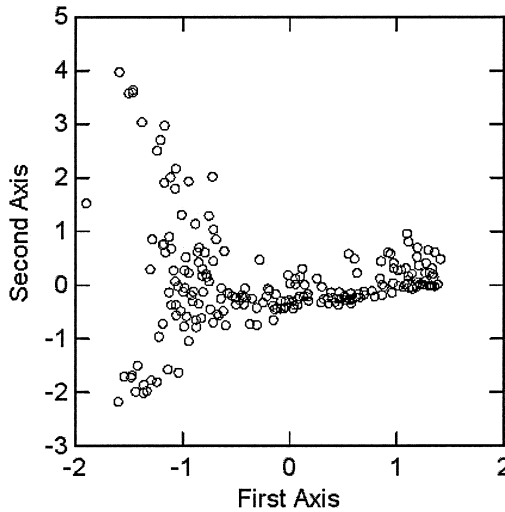
Fig. 1. Two-dimensional plot of the first two axes of the correspondence analysis on Webster's residence data.

If the transformed data lack interesting structural properties—if individuals are found to pair-up more or less at random—correspondence analysis will place the points in a roughly spherical arrangement in which those near the center will be more densely packed and those farther out will be relatively sparse. [5] But, if social differentiation is present, the image should display some non-spherical properties.

Normally, only two dimensions are retained from the output of correspondence analysis and they are used to generate a flat two-dimensional picture. The first two axes produced by the residence data are shown in Fig. 1. Fig. 1, typical of network graphics, was produced by SYGRAPH (Wilkinson, 1989). It shows that these friendship data do not display a simple spherical structural form. Since the data display a three-pointed, propeller-like form, some interesting structural differentiation does seem to be present.

Compare Fig. 1 with what the correspondence analysis output produces in the way of a MAGE image. [6] The first three axes of the correspondence analysis were used to provide three-dimensional locations for points. These locations were the inputs to the MAGE program.

To start to explore the structure presented in this image, try spinning the image along its horizontal axis. Place the cursor on the left edge of the screen halfway between the

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[5] Romney and Weller (1984) first described this phenomenon.

[6] You will have to download the self-extracting DATA package along with the self-extracting MAGE package from any of the sites listed in the Editorial on p. 107 of this issue. Then when you execute the MAGE package, you will end up with an executable MAGE program and a text file. When you execute the DATA package, it will produce a couple of data files, including one called webster.kin. You will need to run MAGE. Then click on 'Proceed'. Pull down the 'File' menu, hit 'Openfile' and open webster.kin. View the image by clicking your mouse button with the cursor over the black window.

top and the bottom, press the primary mouse key and move the mouse (and therefore the cursor) to the right. It is immediately clear that this image has a more complicated structural form than the one we could see in the static projection of Fig. 1. The residence data, it seems, contain more structural patterning than that displayed in the three 'arms' shown in Fig. 1.

Now the question is whether we can discover some of the bases for this patterning. Two established factors that typically influence social affiliation are spatial proximity and interpersonal similarity. Time and again, it has been shown that individuals who live closer to one another tend to interact more frequently with one another (Festinger et al., 1963; Priest and Sawyer, 1967; Coombs, 1973; Freeman, 1979). Studies conducted to identify relevant dimensions of interpersonal similarity consistently find sex and status to have an impact on behavior and perception. Pairs of individuals of the same sex tend to interact more often with one another and have closer ties than do cross-sex pairs (Caldwell and Peplau, 1982; Feiring and Coates, 1987; Ibarra, 1992, 1993). Similarly, pairs of individuals of similar status tend to interact more often with each other than do pairs who differ in status (Blau and Duncan, 1967; Nakao, 1987; Brewer, 1995; Webster, 1995).

Both proximity and similarity can be examined in relation to the residence data by coloring points corresponding to these features. To do this, it would be useful to return the image to its original x, y, z orientation in terms of the axes produced by the correspondence analysis. Pull down the 'VIEWS' menu and choose 'View 1.'

The residence hall is physically divided into two wings with a common ground floor connecting the wings. Residents' room locations can be revealed by hitting the 'Wing A' and 'Wing B' buttons on the right of the image. To see the differentiation due to physical proximity by wings, spin the image a bit to the left. Spatial proximity does seem to have some impact. More residents living in Wing A (in bluetint) appear to be on the left side of the horizontal x dimension while more residents in Wing B (in green) are on the right side. The vertical y dimension also shows some separation with Wing A residents towards the top and Wing B towards the bottom. The third z dimension is difficult to see because it goes in and out in the image. To make it clear, you could spin the image further, or better still, you can simply pull down the 'VIEWS' menu and choose 'View 2.' View 2 rotates the image 90° to the right and reveals the z dimension horizontally. The distinction between the wings is quite apparent from this perspective.

We also can look at whether the friendship structure of the residence hall is affected by interpersonal similarity. The residence hall contained 104 females and 113 males. In addition, 91 of the 217 were first year residents. All the floors on both wings housed females and males as well as some first year residents and some residents who had lived in the hall for a longer period of time. 'Sex' and 'Years' are the two pertinent categories since all but a few of the residents were white (93%), undergraduate students (95%) between the ages of 18 to 22 (93%).

To explore the effects of sex, turn off the 'WINGS' button and hit the 'Females' and 'Males' buttons. There does not appear to be much segregation by sex. In View 2 a cluster of females (in yellow) is apparent to the extreme left and an all male (in gold) cluster is at the top. The amount of time living in the residence has a much more dramatic impact. Both View 1 and View 2 show the first year residents to be much more

spread along the y dimension and first year residents are the only ones at the bottom. The residents who have lived in the hall for a longer period are more spread along the x dimension, with only a few located towards the top of the y dimension.

This MAGE image also allows the ties linking pairs of actors to be displayed. Hit the 'Best' button under 'TIES' to show ties (colored in pinktint) linking those residents who mutually named one another as best friends. The 'Close' friends button adds ties (in bluetint) for those who mutually named one another at least at the 'close' friend level. And the union of all of the mutual friendship-based ties is seen in yellow by hitting the 'Friends' button.

To this point we have not looked at the ties linking residents in any detail. We have provided two additional series of images that take advantage of the fact that the data are valued. Image 2 displays the information for mutual 'Best Friends' and Image 3 shows the 'Close Friends,' those individuals who named one another as at least a close friend but not as mutual best friends. Pull down the 'KINEMAGE' window and select 'Next' to explore the mutual 'Best Friends' ties or select 'Choose' and type in 3 to examine the 'Close Friends.'

Both images begin with the same initial orientation as in the first image. The simplest way to progress through the various options provided is to hit the 'ANIMATE' button on the right. The actors are shown in yellow with the 'Best Friend' ties in pinktint and the 'Close Friend' ties in bluetint. To continue, hit the 'ANIMATE' button again and the image will jump to reveal in which of the two wings these best (or close) friends are located. Hit the 'ANIMATE' button again and those best (or close) friends both living in Wing A (A–A Ties) are displayed. Since there are multiple floors on each wing, we can investigate which best or close friends live on the same floor (in bluetint) and which live on different floors (in darker blue), but also in Wing A. The B–B Ties show those living in Wing B, also shown are those on the same floor (in green) and those on different floors (in cyan), but still in Wing B. A–B Ties are those best or close friends who live in different wings.

Continue to hit the 'ANIMATE' button to reveal those best (or close) friends who are of the same sex (F–F Ties or M–M Ties) and those who are of the opposite sex (F–M Ties). Similarly, you can highlight those who are in the same year (1–1 Ties or 2–2 Ties) and those who are in different years (1–2 Ties).

As would be expected, the graphic presentations for 'Best Friends' and for 'Close Friends' call attention to details in the overall patterning of the friendship structure in the residence, details that might be less obvious without these images. In the 'Best Friends,' for example, two notable distinctions are evident. A comparison of the ties within Wing A with those within Wing B immediately reveals that many more residents in Wing B have best friends who live on different floors whereas in Wing A only two pairs of best friends do not live on the same floor. When examining the same-sex friendship ties, note that the male best friends are segregated into two tight clusters and one dyad, whereas the female and opposite sex best friends are much more spread along both the x and y dimensions. In the 'Close Friends' image the impact of proximity between Wing A and Wing B is prominent. All in all, then, this kind of visual display seems to capture a number of the essential details of the friendship structure of the residence hall.

Now we turn to the second data set. Here we will show the ability of MAGE to go beyond standard analysis and permit investigators to develop new insights about their structural data.

4. The Kirke data set

Kirke (1996) interviewed teenagers in suburban Dublin, Ireland and asked them to name their best friends, good friends, boy or girl friends, friends and pals. Then she took the union of all these relations and defined that as a 'peer' relation. She partitioned the data into weak components (distinct collections of teenagers who were linked together by chains of these relations but not linked to outsiders).

The largest of these components contained 26 teenagers. She illustrated the patterning of the peer relations linking these 26, along with sibling ties, in her Fig. 2 (reproduced as Fig. 2 here). [7]

A six-digit identification is given for each member of the network. The first two digits indicate the road on which the person lives. The next three digits are the family's number. These numbers are assigned consecutively along the road. The final digit is the identification number of a particular individual in that family.

When Fig. 2 was originally published, Freeman studied it but was unable to uncover much structural information from his inspection. So he coded the data from the figure as a symmetric matrix and calculated the graph theoretic distance between all pairs of individuals. He entered that distance matrix into the UCINET multidimensional scaling program (Borgatti et al., 1992) and solved in three-dimensions (where stress was less than 0.002). He then placed the points in three-dimensional space and redrew the graph. The three-dimensional image is presented as the opening image when the file kirke.kin is loaded into the MAGE program. [8]

The first image presented by MAGE is striking because it contains a very long (10-step) geodesic cycle. This cycle is shown alone in the second image. When examining the various images, readers should also examine the ID number for information on the road upon which the person lives and on pairs linked by sibling ties. [9]

Long cycles of this sort are practically never seen in networks of personal affiliation. Freeman then sent the first image to Kirke and asked if she had any ideas about how it happened to be found in her data.

She replied immediately and she came up with a number of ideas that were suggested to her by looking at the image. In the first place, Kirke indicated that, contrary to

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[7] It should be noted that there is a missing line in this diagram; the wavy line depicting a sibling tie between 014912 to 014914 at the upper right of the figure was omitted.

[8] Run MAGE. Click on 'Proceed'. Pull down the 'File' menu, hit 'Open file' and open the file kirke.kin. Open the image by clicking your cursor over the black window. You can move from image to image by clicking repeatedly on the 'ANIMATE' button on the right of the screen.

[9] To determine the identity of any individual, simply put the cursor over that individual and hit its primary key. Kirke's ID number for that person will appear at the lower left corner of the screen. The decimal number that appears above the label is the Euclidean distance of that point from the one previously chosen.
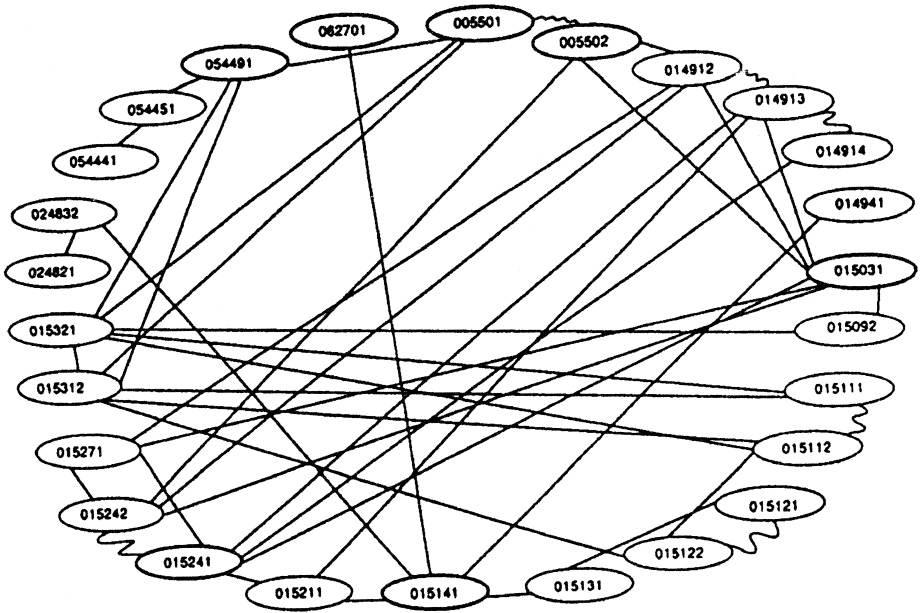
Fig. 2. Ties linking teenagers in Kirke's largest component (straight lines are peer ties, wavy lines link siblings).

Freeman's assumption, the sibling relation was distinct; it was not part of her defined peer relation.

So Freeman separated the sibling from the peer ties in the image. The third MAGE image shows only the sibling pairs. And in this image we can see two things: (1) there are relatively few sibling links compared to the number of peer links in this structure, and (2) these sibling links may have a key role in producing the cycle.

The fourth image shows only those ties that were based on the peer relation. And it is clear when we examine that image, that removal of the sibling link at the top of the page eliminates the cycle.

Kirke, went on to suggest that there is more to the story, however. She pointed out that the graph contains 17 males and nine females, and that the males were generally connected to males and the females generally connected to females. The exceptions, she said, were three in number. One 15-year old male, 015211, who mentioned an 18-year old female who lives on the same road, 015141, as a 'pal' but was not mentioned in return. One 18-year old male, 054491, mentioned an 18-year old female who lives on the same road, 054451, also as a 'pal' again without being mentioned in return. And the third male–female link is the sibling link between a female, 015121, and her brother, 015122.

This suggested that it would be useful to distinguish between males and females. In the fifth image, females are shown in red and males in green. Peer ties are gold and sibling ties are blue. And, as the image shows, it is the brother–sister tie between

015122 and 015121 that completes the cycle. So the tie that completes the cycle is not only a sibling tie, it is the only cross-sex sibling tie.

What the structure seems to indicate is that, in suburban Dublin, teenagers of this age —14 through 18 years—form their peer ties overwhelmingly with others of the same sex. Some 'pal' ties were formed between males and females living on the same road, but this was not a general pattern. It may be important to the formation of boy/girlfriend relationships in the near future. Moreover, cross-sex siblings may be crucial in linking their same sex friends to young people of the opposite sex.

It seemed reasonable, then, to re-analyze the data taking the peer relation alone. So we removed the sibling ties, recalculated graph theoretic distances and re-scaled the data. The result is shown in the sixth MAGE image.

By rotating this new image new insights are generated. It becomes clear that these boys and girls pattern their friendships in very different ways. The boys seem to get organized into two rather tight knit little clusters—in which each is tie to most of the others—and the clusters are linked by a 14-year old boy, 015092, who serves as a cutpoint linking the two. The girls, on the other hand, form far looser structures. Both female–female structures are, in fact, trees; they contain no cycles at all. And finally, all the males can reach one another without using girls as links, but the two subsets of females are connected only through male intermediaries.

This exchange between Freeman and Kirke certainly suggests the potential of MAGE as a tool for exploring network data. The new image produced by Freeman spurred Kirke to think about her data in new ways. And those thoughts led to still newer images that produced other new insights. This interchange clearly demonstrates the power of visual tools—and MAGE in particular—to provide new insights in the process of social network analysis.

5. Conclusions

We have shown how MAGE can play several roles in social network research. Its visual images use dynamic three-dimensional displays and color to help those engaged in network research to become aware of details of network structure that are not otherwise apparent. As a consequence, it becomes easy for research workers to 'see' their data in different ways and therefore to develop new insights about their data.

These images of networks can, moreover, be used to facilitate communication of the results of network research to others. And, perhaps most important, MAGE presents those results in a form that encourages viewers to try out their own perspectives in viewing the data and to come to their own conclusions.

The code that produces MAGE images is simple, straightforward and easy to produce and to modify. [10] It is coded in an ordinary ASCII file in plain English and it can be edited simply by loading it in the editor or word processor of your choice.

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[10] See the text file, KinFmt31.txt, that is included in the Mage package that can be downloaded from any of the sites listed in the Editorial on p. 107 of this issue.

The MAGE program does have one important limitation for use in social network research. It makes it difficult to display directed relations; two points are either connected or they are not, and there is no simple way to display a directional tie. Other than that, however, MAGE seems ideal for network applications.

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