Regular Spatial Separation for Exploratory Visualization

Jonathan C. Roberts

University of Kent at Canterbury, Computing Laboratory, Canterbury, England, UK.

ABSTRACT

There are many well-used techniques in exploratory visualization that select, filter or highlight particular aspects of the visualization to gain a better understanding of the structure and makeup of the underlying information. Indeed, distortion techniques have been developed that deform and move different spatial elements of the representation allowing the user to view and investigate internal aspects of the visualization. But this distortion may cause the user to misunderstand the spatial structure and context of surrounding information and works better when the user knows what feature they are looking for. We believe that regular separation techniques, that separate and generate space round features or objects of interest clarifies the visual representations, are underused and that their use should be encouraged. We describe related research and literature, present some new methods, and classify the realizations by what type of separation is used and what information is being separated.

Keywords: Visualization, Separation, Displacement, Distortion, Exploratory visualization, Multiform

1. INTRODUCTION & MOTIVATION

Layout, positioning and space are important facets of many applications including visualization. For example, space and silence in music make the phrases and motifs 'stand out' and be heard. Rest and sleep in our daily cycle enables us to recover from the day; in Macbeth, Shakespeare writes "[sleep is the] nourisher of life's feast".[1] Indeed, space is the natural delimiter in the written word, allowing the reader to scan and understand each individual word and phrase, we use short gaps to delimit words, and new lines or indentations to determine paragraphs; when reading our eyes make saccadic movements: visually searching the image, making eye scan movements from fixation to fixation[2] moving from one word to another.

A dictionary definition of *separate*[3] includes aspects of 'setting or keeping apart', disconnecting, dispersing in space or time, scattering; go in different directions, sever ties; block off and segregate; isolate and extract; dislocation and break. Thus, in essence separation techniques move aspects of the data and visualization apart, the operation may add intervening space round pertinent features or areas that may appear interesting, or completely move objects away.

The motivation behind this separation idea is to provide space, both spatially and temporally, to specifically look at, explore and examine in more depth particular aspects of the information. For example, internal isosurfaces may be obscured by external surfaces or other objects, by using some form of separation the internal objects may be able to be seen: whether partially via the generated space from a spatial separation or through a spatial extraction of those once occluded objects.

Moreover, in this 'information age' with computers and people generating, processing and exchanging vast amounts of data and information – with no apparent end in sight to this ever increasing data mountain – effective exploratory visualization can help users make important discoveries generate theories, generate models and develop an understanding of the underlying information. So, we need to design effective visualizations.

The use of white space is one of the tools that enables information to be displayed clearly. Separation techniques allow objects (or parts) of the three dimensional visualization to be distanced or displaced from each other. The newly generated space between the objects allow the viewer to explore more easily and better understand the makeup of the information. For example, Tufte[4] discusses generating appropriate graphics that are truthful, do not misguide the user and allow for comparisons; So chartjunk and elements that do not pertain to the variables and values of the data, that do not make up the data ink, should be removed. Table 2 on the right is a much improved version of that on table 1 on the left, this is achieved by removing the lines and replacing it with space. This highlights the importance of space.

E-mail: j.c.roberts@ukc.ac.uk http://www.cs.ukc.ac.uk/people/staff/jcr/

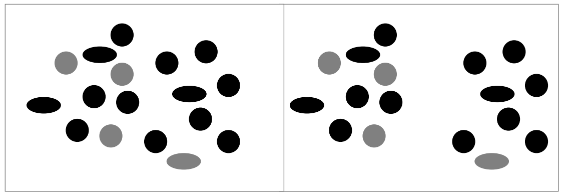

Figure 1. Spatial conjunction, after Ware.[2] The figure shows that separation may aid a pre-attentive conjunction search; when the user is asked to find (say) gray ellipses, they either have to search the grey things or the elliptical things. This process may be speeded up by spatial grouping, depicted to the right.

Monthly Temperatures for England 2000 ($^{\circ}C$)

	Maximum	Average Maximum	Average Minimum	Minimum
January	13.3	7.9	2.7	-3.6
February	14.7	9.6	3.6	-3.0
March	16.7	10.8	4.7	-0.7
April	17.5	12.0	5.9	-0.2
May	25.0	15.2	9.7	5.8
June	29.1	17.7	11.5	7.0
July	24.6	17.4	11.9	7.9
August	26.5	20.0	13.8	7.7
September	24.7	19.7	12.8	7.0
October	18.8	14.8	8.6	4.4
November	14.1	10.7	5.1	0.7
December	14.9	8.7	4.6	-4.2

Table 1. The table is depicted using many vertical and horizontal lines that are meant to demarcate each individual values, but, these lines represent chartjunk and thus distract the user from the reference information. The table itself shows monthly temperatures for England 2000 in $^{\circ}C$. Data courtesy of the UK Met office.

Monthly Temperatures for England 2000 ($^{\circ}C$)

	Maximum	Average Maximum	Average Minimum	Minimum
January	13.3	7.9	2.7	-3.6
February	14.7	9.6	3.6	-3.0
March	16.7	10.8	4.7	-0.7
April	17.5	12.0	5.9	-0.2
May	25.0	15.2	9.7	5.8
June	29.1	17.7	11.5	7.0
July	24.6	17.4	11.9	7.9
August	26.5	20.0	13.8	7.7
September	24.7	19.7	12.8	7.0
October	18.8	14.8	8.6	4.4
November	14.1	10.7	5.1	0.7
December	14.9	8.7	4.6	-4.2

Table 2. The table is depicted without the extra lines, which provide a better, clearer representation of the information. The data itself represents monthly temperatures for England in 2000. Data courtesy of the UK Met office.

Such a separation or grouping of subparts, may aid in perceptual operations such as conjunctive searches. For example, Ware[2] explains that pre-attentive conjunction search, to find (say) gray ellipses, either the grey things or the elliptical things must be searched. However, this may be speeded up by spatial grouping, such as in the right part of Figure 1.

Thus in this paper we propose:

1. that separation techniques are useful, easy to generate, and that they are underused,
2. that separation may occur at different stages of the visualization process and of different styles of data,
3. there are different separation operations appropriate for visualization exploration,
4. visualizations that contain separated information should maintain contextual information of those displaced objects.

In section 2 we categorize and discuss what kind of separation and where it may occur, and provide some visualization examples. Finally, we discuss the methods presented in this paper (section 3) and conclude in section 4.

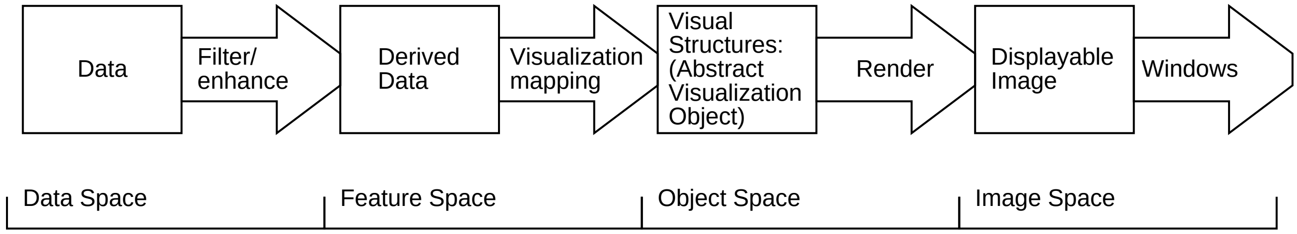

Figure 2: The visualization process, after Haber and McNabb.[5,6]

2. CATEGORIZATION & EXAMPLES

Space and layout are important tools for the visualizer. The visual forms – the symbols and marks of a visualization – are placed on a spatial 'workbench' to form the visual representation.

In particular the numerical, textual data is exchanged into some form of visual structure: a visual abstract form that consists of symbols, marks, graphical and perhaps temporal properties. This abstract form is then *mapped*, via view transformations, into a spatial representation which can be *displayed*,[5,6] see Figure 2. Such view transformations may include zoom, pan, clipping, distortion and changing visual effects from (say) a brushing command.[7] Indeed, Card et al in chapter 1 say "The most fundamental aspect of the visual structure is space ... spatial position is such a good visual coding of data that the first decision of visualization design is which variables get spatial encoding at the expense of others.".[7]

As we see from the above reference model there are different forms of separation. Indeed, we propose that there are different types of separation operation and that the separation may occur at different places of the dataflow. For example, a separation may provide space to demarcate boundaries and groups of objects; it may act as an extractor filtering (extracting) certain aspects of the information or visual representation; it could act as a hard buffer round sub-areas of data such that algorithms would operate differently on the boundaries of that data.

We have generated different various regular separations and experimented with separation on data at various stages of the dataflow paradigm. Indeed, we have also used a layering technique that re-joins part of the information back together. We have implemented these ideas in various visualization tools including IRIS Explorer,[8] the Waltz visualization system[9] and the Visualization toolkit[10] and in this paper show results from the Visualization Toolkit. In the next sections we discuss the types of separation operation and then where the separation occurs.

2.1. Separation Operations

There are many different separation operations; these we can see from the various transitive senses of separation. Including Disconnection (break), Scattering (explode, dislocate, disperse in space or time), Movement ('go in different directions'), Isolation (extract) and Distortion.

2.1.1. Disconnection

Many datasets are implicitly spatial, and hence are connected as one. A separation operation would allow once continuous objects to be treated as separate entities. This operation represents a barrier: whether non spatial or spatial. The elements are segregated and 'blocked off' from others. For example, continuous data from an MRI scan may be separated into octants, each of the octants are disconnected from each other such that a flood filling operation would only flood over one octant and would not be able to flood into neighbouring octants, see Figure 3.

2.1.2. Scattering

Scattering allows the objects to be displaced, translated and moved from their original position. This includes explosions and other dislocations, such exploded views are used in CAD drawings. Often it is desirable to have the displacement factor constrained such that the explosion occurs in one controlled direction rather than skewing out into space in multiple directions.[11] Figure 4 shows some pictorial variations of scattering.

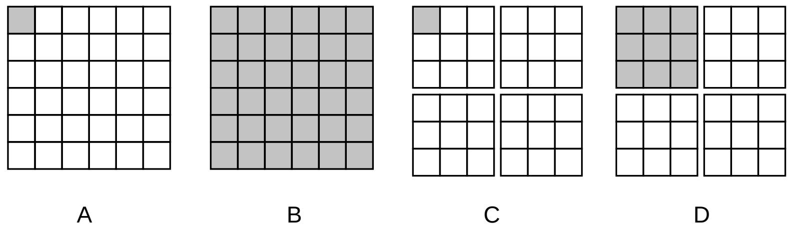

Figure 3. A separation operation may disconnect certain aspects of the information, such that elements that were connected, or adjacent to others before may be considered as separate entities, such that algorithms that consider neighbourhoods, for example, flood filling algorithms, would only flood throughout the appropriate separated parts. Part A is the original dataset, B shows the original flood result, C shows the separation and part D depicts the resulting flood.

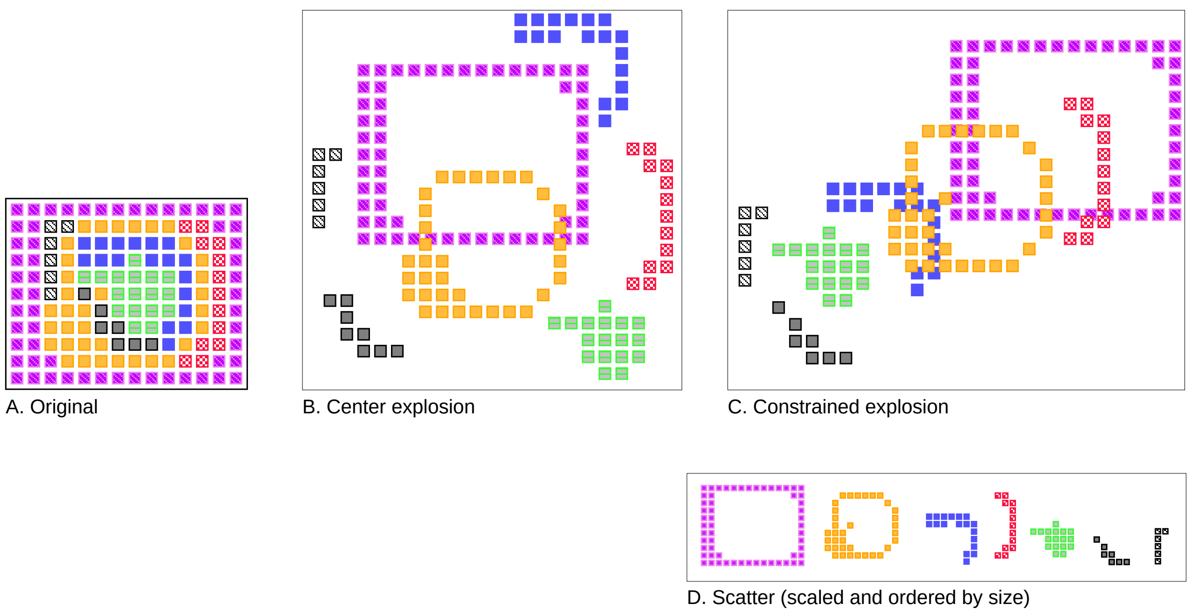

Figure 4. Figure showing different scattering or explosion methods. These are scatterings of derived data, such as created from a flood-fill threshold.

2.1.3. Movement

Dispersion may operate over time; motion may be used to separate the information. For example, a scatterplot of different human attributes may be displayed, if the men and women were displayed by the same symbol then they would not be able to be distinguished. But, the user could select all the information pertaining to women, pick them up and move them away. Such motion would be processed as a pre-attentive cue[2] and enable the information about the women to be viewed and seen as separate to the male information, however, the grouping information would be lost when the movement ceased.

Investigative visualization using movement to separate away objects of interest, especially internal objects that were obscured, was used by Roberts in the Waltz visualization system.[9,12]

2.1.4. Isolation

An isolation or extraction operation may occur visually, by arranging the appropriate pre-attentive marks (e.g. using techniques that elide, such as changing the color of some marks to the background color), or could occur as an extraction operation to subset, filter or specialize the data into a reduced subset of information.

2.1.5. Distortion

Although, we are not specifically advocating distortion or the magnification of parts here we include it as the operation is based on the same principle but the size, scale, orientation may be distorted during the separation operation.

Sheelagh et al[13,14] describe some methods that linearly stretch, warp, radially move or displace objects away from the 'line of sight', enabling the user to focus on a particular object or view the information better. Such non-linear magnification techniques are similar to the techniques used by map cartographers in the different projections used when, for example, mapping the surface of the earth to a 2D map. Such distortion techniques may be useful and understandable for certain datasets and mappings. Indeed, the user implicitly understands the connection of the graphs even using a non-linear mappings, as the adjacency information is kept by the explicit line connections between each nodes, but may not be so appropriate on every kind of representation, such as isosurface visualizations as the continuous nature of the visualization is represented by the adjacency with neighbouring objects. Ware[2] states "an obvious perceptual issue ... is whether the distortion makes it difficult to identify important parts of the structure". This problem can be especially acute when actual geographical maps are expanded.

The motivation behind their distortion techniques is to 'provide space for magnification of local detail by compressing the rest of the image'.[14] Additional distortion oriented presentations are described by Leung and Apperley.[15]

2.2. Where the separation occurs

We categorize 'where and what information may be separated' based on the dataflow model, Figure 2. The function that generates the *separation* may occur at different stages (or at different data spaces) in the dataflow model. Thus the separation command affects information *up stream* in the data flow: as the up-stream data is dependent on the processes down stream. Thus, it may be argued that the separation command only takes place at the last mapping-stage, however, by categorizing the information in the whole dataflow model, we provide a convenient method to evaluate and describe what information is being separated and the *scope* of the separation. The scope determines, for example, if the separation operation is taking place on the whole data-space or on a specific object.

We state that the information may be separated at each stage of the dataflow paradigm, indeed the separation occurs before the next stage operation. Separation operations may be applied to:

1. the original *Reference Data*,
2. the *Derived Data*, where the separation operation acts upon individual categories, sub-sets or any filtered data,
3. the *Abstract Visualization Objects*, where the displacement occurs on individual parts of the mapped Abstract Visualization Object,
4. the *Image and Screen Space*.

The separation applied at different stages of the dataflow paradigm generates a different method of exploration and, as we explain further in the full paper, the techniques at the various stages may be used together to generate interesting separation results.

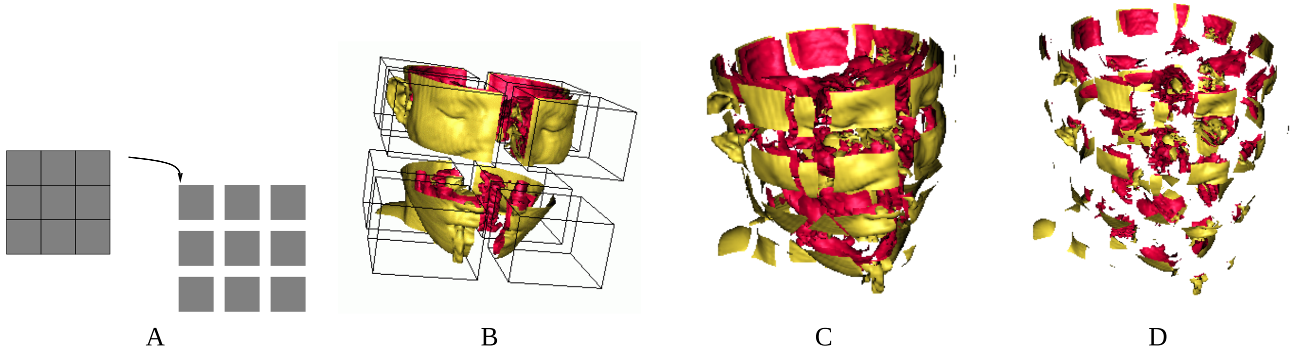

Figure 5. Part A depicts schematically that the data may be separated into sub-areas. Each area may be displaced to increase the inter-data spacing. Parts B,C and D show two different isosurface values being depicted in each sub-cube, with different numbers of separations and a variation of the separation spread.

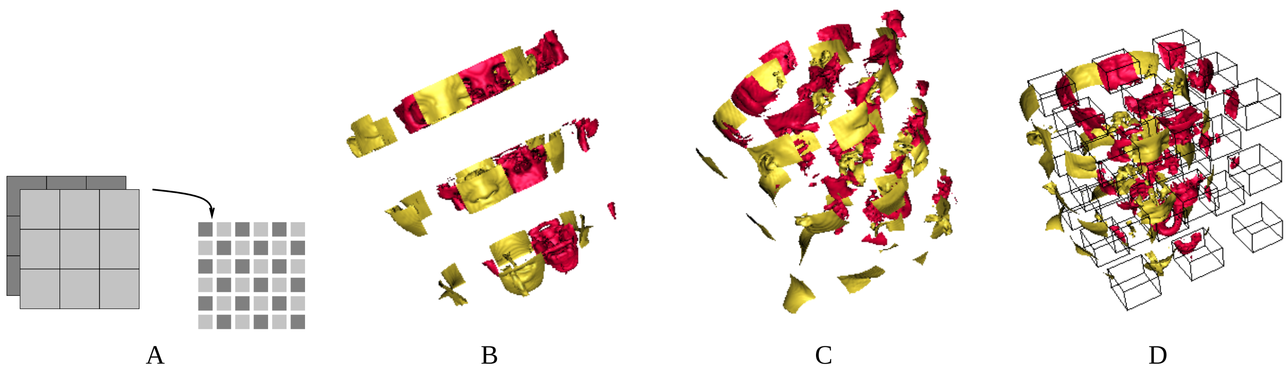

Figure 6. Part A depicts schematically that the data may be separated into sub-areas that interweave each other. This generates a checkerboard style pattern. Parts B,C and D show two different isosurface values being depicted in each sub-cube, with different numbers of separations and a variation of the separation spread.

2.2.1. Separation of the Reference Data

At the data level the information is in its reference un-processed state any separation at this level has the possibility of being abstract, especially as the information itself may, or may not be spatial. For example, if the information is in tabular form, a separation operation may occur on a row or column. Disconnection operations may be usefully applied here, such that spatial data may be subdivided into a number of parts. Individual classification of the subparts may enable the disconnection, such as shown in the skull images of the Voxel-man 3D navigator[16] that shows different parts of the human skull in various colors (red: frontal bone, blue left parietal bone, green lambdoid suture, etc).

Different separation operations may be applied to an individual portion of the data or to the whole dataset. For example, a subset of the information in the Original-Data Space may be separated, or, every part of the information may be moved away in a grid formation. This latter method is similar to the ‘tiny cubes method’ of,[17] who display the three dimensional data as a series of coloured cubes with open space between the cubes, their displacement value may be dynamically altered to increase the inter-data spacing. Such a grid formation is shown in Figure 5.

The individual sub-cubes may themselves be displaced or scattered, or may be overlayed with other sub-areas such that each alternate cube shows different visualization. In Figure 6 we display the data with two isosurfaces placed neighbourly such that one cube with a different isosurface value is depicted in an adjacent cube (a checkerboard style pattern).

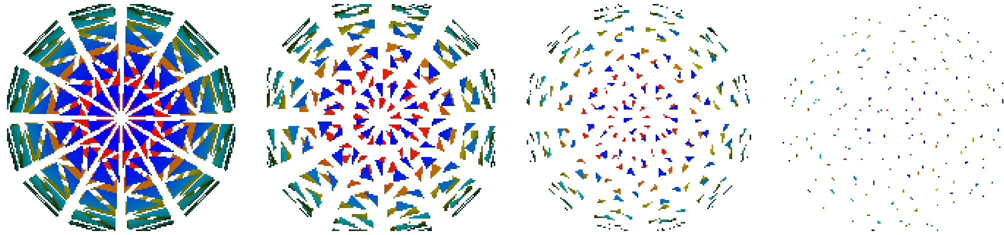

Figure 7. The LoopShrk.cxx example from the Visualization Toolkit.[10] The example shows that aspects of the mapped data, such as the position of individual polygons may be separated.

Figure 8. In part A we visually see that each symbol has the same width and that the result we see on the right is $1 + 1 = 2$. However, part B shows that the center gap, with the same width as the objects, may visually represent an object (albeit a negative description) thus three objects are counted.

2.2.2. Separation of the Derived Data

Separation of derived data allows features or subparts to be treated as one entity. For example, the examples in Figure 4 are explosions of data features. The features could be generated from a isosurface algorithm, where, each of the joined surfaces would make up the feature set. Indeed, the aforementioned Voxel-man 3D generates exploded views of the individual skull parts.[18]

2.2.3. Separation of the Abstract Visualization Objects

It may be useful to separate the individual aspects of the mapped data, such as the position of individual polygons. Indeed, Schroeder et al[10] in the Visualization Toolkit provide an example `LoopShrk.cxx` that shrinks the polygon size to create a gap or space between neighbours, Figure 7.

2.2.4. Separation of the Image and Screen Space

The separation operation could occur also at the image space, such an operation may be conceived as a clipping operation.

3. DISCUSSION

We have described many different ways that separation may be used in exploratory visualization. We state that this is regular separation as the information is not distorted or deformed in any respect. Indeed, most of our examples have used straight cutting planes to divide and distance the objects; however, like the Voxel-man[16] exploded view example, non planar cuts to separate the information are possible and useful.

One of the uses of such separation is to provide space and allow the information to be better seen. Indeed, separation operations do provide space between objects and features making exploration possible, but depending on the amount of increased space, the visualization may still have occlusion problems. The distortion techniques, that provide lines of sight to a particular feature, may be better when the user knows what to look for and how the information is organised; but implicit spatial adjacency information may be lost by using such techniques.

Another problem with separation techniques is that the middle gap may look like another object. Josef Albers, as quoted by Tufte[19] says "one plus one equals three or more...". This is shown in figure 8. This noise is directly proportional to the contrast in value between the light and dark areas, thus, Tufte says "a varying range of lighter colors will minimize incidental clutter".[19] Moreover, such a separation of continuous parts may be in conflict with perception theories such as the Gestalt laws[2] of grouping of parts: for example, proximity is a strong cue: things that are close together are perceptually grouped together. But the separation techniques mentioned in this paper may aid understanding or certain perceptual tasks such as in a conjunctive search (mentioned in section 1).

This paper suggests that space is useful. However, too much space without too much content may generate a useless visualization indeed taking this idea to the extreme may or may not be useful. For example, space in music is useful, however, taking the space to its furthest conclusion generates silence; as indeed John Cage did with his piece of music 4'33" that details a complete absence of sound.[20] In this case, it is argued that this silence allows the listener to relax, be at peace, hear the wind through the trees,[21] but such a philosophical extreme applied to visualization would mean nothing is displayed: a meaningless visualization would result.

4. CONCLUSION

Spatial Separation is a simple concept, yet we believe it is a method that is not widely used. We have described different separation techniques and provided a categorization of where the information may be separated. This grouping is based on the dataflow model and provides a convenient way to evaluate what information may be separated. We have also presented some example visualizations.

Further work and evaluation of the use of separation would be beneficial. Indeed, Sheelagh et al[14] mention the studies by Ware about the 'amount of usable space in a 3D graph display'.

Separation should be encouraged as a good method, but to gain a correct understanding of the information multiple visualization methods should be used to display the same information. In any visualization exploration – especially in separation – the task is to find objects of interest by highlighting and moving parts of the visualization, whether these are the objects of interest themselves or occluding (non-interesting) facets. By using regular separation techniques it is possible to explore the visualization and find features of interest, indeed, this is made easier by keeping the adjacency information of the parts of the visualization.

5. ACKNOWLEDGEMENTS

I acknowledge the Chapel Hill site for the three dimensional MRI Head scan and Magali Roberts for proof reading the document.

REFERENCES

1. W. Shakespeare, "Macbeth, Act II. Scene II.."
2. C. Ware, *Information Visualization: Perception for Design*, Morgan Kaufman, 1999.
3. "Merriam-webster onlin dictionarry." http://www.m-w.com.
4. E. R. Tufte, *The Visual Display of Quantitative Information*, Graphics Press, 1983.
5. C. Upson, T. Faulhaber, D. Kamins, D. Schlegel, D. Laidlaw, F. Vroom, R. Gurwitz, and A. van Dam, "The application visualization system: A computational environment for scientific visualization," *IEEE Computer Graphics and Applications* **9**(4), pp. 30–42, 1989.
6. R. B. Haber and D. A. McNabb, "Visualization idioms: A conceptual model for scientific visualization systems," in *Visualization in Scientific Computing*, B. Shriver, G. M. Nielson, and L. J. Rosenblum, eds., pp. 74–93, IEEE Computer Society Press, 1990.
7. S. Card, J. MacKinlay, and B. Shneiderman, *Readings in Information Visualization: Using Vision to Think*, Morgan Kaufman, 1999.
8. NAG, Numerical Algorithms Group, *IRIS Explorer Users' Guide*, October 1999. www.nag.co.uk/visual/ie/iecbb/doc/.
9. J. C. Roberts, "Waltz: an exploratory visualization tool for volume data using multiform abstract displays," *Visual Data Exploration and Analysis V, Proceedings of SPIE Vol. 3298* , pp. 112–122, January 1998.

10. W. Schroeder, K. Martin, and B. Lorensen, *The Visualization Toolkit: An Object-Oriented Approach to 3-D Graphics (2nd Edition)*, Prentice-Hall, 1997.
11. J. LoFaso, “An alternative method to creating exploded views,” April 2001. http://www.elementkjournals.com/iac/0104/iac0141.htm.
12. J. C. Roberts, “Multiple-View and Multiform Visualization,” in *Visual Data Exploration and Analysis VII, Proceedings of SPIE*, R. F. Erbacher, P. Chen, J. C. Roberts, and C. Wittenbrink, eds., **3960**, IS&T and SPIE, January 2000.
13. M. Sheelagh, R. Carpendale, D. J. Cowperthwaite, and F. D. Fracchia, “Distortion viewing techniques for 3-dimensional data,” in *Proceedings ’96 Information Visualization*, S. Card, S. Eick, and N. Gershon, eds., pp. 46–53, IEEE Computer Society Press, 1996.
14. M. Sheelagh, R. Carpendale, D. J. Cowperthwaite, and F. D. Fracchia, “Extending Distortion Viewing from 2D to 3D,” *IEEE Computer Graphics and Applications* **17**(4), pp. 42–51, 1997.
15. Y.K.Leung and M.D.Apperley, “A review and taxonomy of distrotion-oriented presentation techniques,” *ACM Transactions on Computer-Human Interaction* **1**(2), pp. 126–160, 1994.
16. K. H. Hhne, A. Petersik, B. Pflesser, A. Pommert, K. Priesmeyer, M. Riemer, T. S. R. Schubert, U. Tiede, M. Urban, H. Frederking, M. Lowndes, and J. Morris, *VOXEL-MAN 3D Navigator: Brain and Skull. Regional, Functional and Radiological Anatomy.* , Springer-Verlag Electronic Media, Heidelberg, 2001.
17. G. M. Neilson and B. Hamann, “Techniques for the interactive visualization of volumetric data,” in *Visualization ’90*, pp. 45–50, IEEE Conference on Visualization, 1990.
18. “Voxel-man 3d-navigator: Brain and skull – regional, functional and radiological anatomy; example scene: Exploded view of the skull.” www.uke.uni-hamburg.de/institute/imdm/idv/vm3dn/bs_exploded.html.
19. E. R. Tufte, *Envisioning Information*, Graphics Press, 1990.
20. J. Cage, “ 4’33” ,” 1952. (Composer, 1912–1992).
21. L. J. Solomon, “The sounds of silence: John cage and 4’33” .” www.azstarnet.com/s̃olo/4min33se.htm, 1998.