"Space Frames": Using space, color and animation in the visualization of complex graph systems

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Abstract

This paper presents some of the findings of an ongoing study conducted by an interdisciplinary team of computer scientists, artists and designers. It concerns the development of 3D user interfaces that aid the navigation and representation of large data structures through the usage of the HSV color space, and the ensuing "spatial frames". While data objects that have been colorized in various hues that carry equal saturation and brightness/transparency value seem to be equally foregrounded; varying saturation, brightness and transparency values add depth and hierarchy: Less saturated and/or darker, more transparent values recede into the background, while brighter, more highly saturated objects tend to become foregrounded. During our experiments we noticed that, when thus colorized, the edges connecting the nodes form visual spatial frames, which can result in the meaningful partitioning of 3D space. This property can be exploited to facilitate the display of overall trends within data sets, as well as to ease navigation, presenting overviews of the structure, and navigational help.

Key words: Information visualization, 3D, color space, foregrounding, hierarchy.

1. Introduction

In some cases the analyses of large data hierarchies involve selecting a node of the graph and studying its first and secondary order connections to other nodes. In large graphs this can lead to problems such as occlusion and legibility. To address these issues we are proposing solutions related to color and space, the combined usage of which will go to some distance towards the resolution of these issues.

We have implemented a three-layered graph layout, generated from spherical coordinates, using two different data sets: One real data set with 180 nodes [BM96] and a synthetic data set with 1000 nodes, both implemented in a 3D space. The position of each node in the layout is computed according to the number of links it has with other nodes. The nodes that have a significantly higher number of connections than the average number of links are identified as cluster centers. Amongst these the node with the highest number of connections is positioned at the origin. The remaining central nodes are positioned around the origin by partitioning a half sphere around it. The system also allows users to modify three parameters of the positioning algorithm depending on the data: *global radius*, which scales the complete layout, *cluster radius*, which defines how detailed a cluster is represented and *layer distance*, which partitions the space between different layers, and finds the most suitable representation to accomplish tasks such as searching for a critical path between clusters.

In our experiments these two techniques performed well for nodes with few hundreds of nodes. However, for graphs with thousands of nodes, we had to develop an additional tool, which displaces the remaining nodes out of the view volume, so that the user can examine the structure of selected nodes clearly.

2.1 The usage of the Third Dimension

In a three dimensional graph, the design space is enlarged considerably and factors such as form, lighting and viewing angles become critical considerations. Furthermore in 3D, objects take on an immediate quality of concreteness that facilitates remembrance and recognition as well as placement in the context of other objects. [FW94]

The fact that the limited size of the display screen makes creating effective global views difficult has been acknowledged by Jerding and Stasko [JS95], indeed this conundrum led them to design the "Information Mural", a two-dimensional reduced representation of an entire information space that fits completely within a display window or screen, through the implementation of a multiple view system. 3D visualization systems hold certain advantages over their 2D counterparts, in addressing the limitations of screen size, since the utilization of the third dimension allows for an exponential increase in display area, adding depth to the already existent width and height parameters.

Einsfeld, et al. [EAD06] state that humans can intuitively interact with 3D environments and that these environments facilitate the perception of irregularities within large scale systems. This too is a persuasive argument to further investigate the possibilities of working with 3D spaces in information visualization, where the detection of abrupt changes and emerging trends is one of driving tasks at hand. A third, compelling argument is the presence of data which inherently carries more than two informational parameters.

Franck and Ware [FW94] in their study on representing nodes and arcs in 3D networks have also commented that approximately one thousand nodes are representable using a 3D tree structure, considerably more than can be understood in 2D. Their experiments involving a 3D graph tracing task showed that test subjects were able to comprehend about three times as much information in an interactive, 3D environment as in a comparable 2D one, if both stereo viewing and motion parallax information was available.

2.2. The HSV Color Space

While there is certainly no lack in the usage of color in many information visualization systems, the prevalent practice seems to be limited to the usage of “hue” only; although experts in the field have been urging developers to take on a different approach: In their above quoted study [FW94] Franck and Ware have stated that color has three dimensions and one may choose to render different objects of the same family with the same hue (for identity) but different saturations (for state). In a separate study Ware [War00] also states that it is useful to think of color as the attribute of an object rather than as one of its primary characteristics. Color, according to Ware, provides excellent clues where categorization and differentiation are concerned, however it is of little use for displaying shape, detail or space.

As far as two dimensional graph visualization systems are concerned, applications that take into account an extended color space for visualization can be frequently encountered: Pretorius and van Wijk’s recent research [PW06] is on such application, using grayscale shading and color along with anti-aliasing techniques to create a miniature version of the entire data set. The creators of the interactive visualization tool “Viz” [HYL06] also propose that given their visual complexity, it is important to make good use of color/grey scale level in large scale data systems. Finally, Queli, et al, make good use of HSV color space values in their 2D graphs [QWF05] of time-varying matrices.

The present study wishes to further expound upon the benefits of using the full color space of the HSV system for these highly complex charts; whereby a much higher degree of visual differentiation between the data objects – i.e. the nodes and paths can be attained. While data objects that have been colorized in various hues that carry equal saturation and brightness value seem to be equally foregrounded; varying saturation and brightness values add depth and hierarchy: Less saturated and/or darker values recede into the background, while brighter, more highly saturated objects tend to become foregrounded. Yet another benefit of using the full HSV space is the utilization of color in the creation of “meaningful landmarks” [Che04]: Brighter, more saturated nodes and connecting paths, in juxtaposition to their darker, less saturated counterparts tend to attain landmark attributes with much greater facility than those in systems where these values are ignored.

Yet another concept we are taking into account is aerial/atmospheric perspective, which the The Columbia Encyclopedia defines as being “...based on the perception that contrasts of color and of light and dark appear greater, and contours more defined, in near objects than in far. Aerial perspective takes note of the recessive character of cool colors and the prominence of warm colors...”. Thus, foregrounding and backgrounding in visualization can also be accomplished by the usage of saturation and lightness value in imitation of a natural occurrence; a technique which the renaissance painters put to excellent use. Although here we use the concepts of foregrounding and backgrounding, not so much in their spatial sense as in a sense which can be contextualized with informational relationships and hierarchies; we, nonetheless, think that attributing bright, pure hues to hubs, i.e. well connected nodes and connecting paths and less saturated, cooler and darker color values to less connected, second and third order nodes and paths is a viable usage of using the full HSV space to establish visual hierarchies that will facilitate the detection of emerging trends and abrupt changes within complex data structures.

2.2.1 Color

Both during the initial design research and also during subsequent implementation phases the visibility of the construct was initially tested against pure black and white backgrounds. It was found that the level contrast that these provided caused visual exhaustion in

prolonged viewings, almost causing a strobe light effect upon the eye. Thus all color schemata were implemented within a soft, dark, charcoal grey environment.
Both paths and nodes, present a dual state: active and inactive: In their inactive, i.e. deselected state, all nodes are represented in shades of grey, which are light enough to be clearly distinguished form the charcoal grey background and have differentiated lightness values, depending upon their weight, i.e. their rate of connectivity. Nodes with low connectivity are in darker tones, thus receding further into the background, whereas hubs, i.e. nodes with high rates of connectivity, are in lighter values. In their inactive state all connecting paths are also grey.

The merits of the construct become apparent when data is actually accessed. While in its inactive state all nodes and their interconnections can be viewed at the same time, in a neutral grey, when hubs are selected they, and their first and second order connections, become colorized; according to the particular color scheme with which the diagram is viewed. While hubs manifest themselves in pure hues, first and second order nodes that are connected to them are colorized in progressively darker and less saturated values. In comparison to their inactive state, the connecting paths are also emphasized by significantly lighter tones of grey, which, however, also progressively darken the further apart from the hub the connection occurs. While the examined hub and its connections are foregrounded the overall diagram is still visible, but backgrounded, remaining in its original grey value. Hubs can be shift selected for comparison purposes, in which case, one hue, and its color space, is assigned to the first and a second hue, and its color space, is assigned to the second selected, depending upon the color scheme implemented.

We colorized the data structure using 4 separate color schemes: (a) monochromatic; (b) analogous, i.e. using 3 hues adjacent to one another on the color wheel within a a segment of 120 degrees; (c) complementary/split complementary contrast, i.e. using two hues opposed to one another by 180 degrees on the color wheel, with a divergence of 45 degrees in either direction from the original axis and (d) triadic, i.e. using three hues, from the three corners of equilateral triangle on the color wheel, with a divergence of 30 degrees in either direction. The first three of these are more in accordance with the propositions of Edward Tufte [Tuf90], who leans towards the usage of color harmonies, i.e. few colors with subtle tonal distinctions; while the latter two follow the powerful assertions of Johannes Itten [Itt02] on the usage of color schemes which point at the usage of color contrasts, particularly the complementary contrast. Thus, in a complementary contrast scheme, the selected hubs manifest as hues, and appended color space, from opposite ends of the color wheel, further selections veering to adjacent hues, within a 45 degree angle; whereas in an analogous color scheme selected hubs manifest as hues, and appended color spaces, from the same end of the color wheel, within a 120 degree angle.

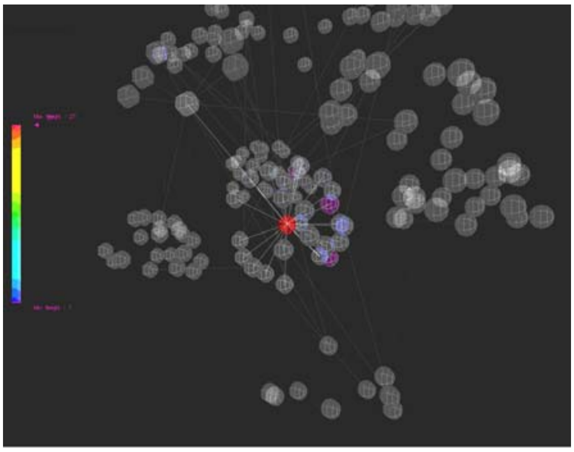


Figure 1: A node and its first and second order connections are highlighted using the full spectrum.

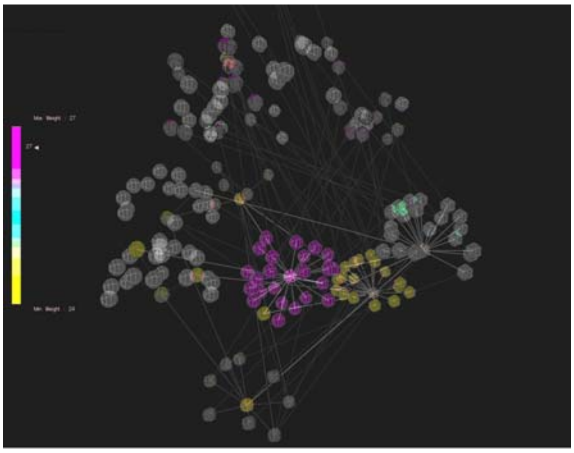


Figure 2: Triadic color scheme.

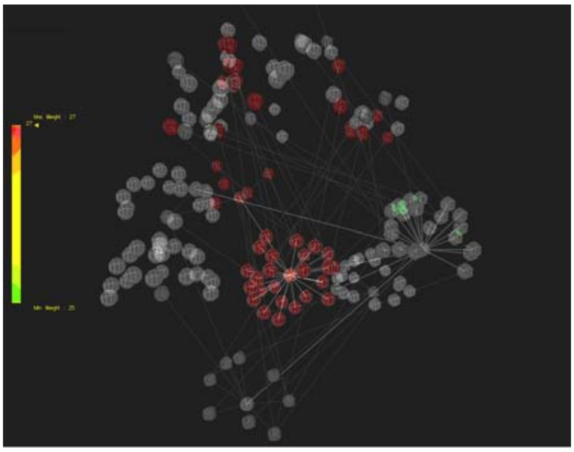


Figure 3: Complementary color scheme.

To compute the hue color of a node we first normalized its weight and multiplied the normalized value with the spectral range. Spectral range was defined by current spectral scale. Spectral range is the visible lights in wave length mapped to the 360^0 degrees of circular plate.

Spectral scale is a portion of Spectral range depending on the spectral domain.

$$Item_{HueColour} = (W_i - W_{min})/(W_{max} - W_{min})*(spectralRange)$$

W_i is the weight of current node. W_{min} and W_{max} are the maximum and the minimum weights of the available nodes

After the system assigns the color of a node, we then apply our saturation algorithm. According to the node's depth value, descendent nodes of a hub will be rendered as saturated. Moreover, edges that define path between nodes are also rendered in same manner. The developed saturation algorithm alters the saturation and darkness value of a node depending on its depth value, which is given by data it self. Thus, first order descendents of a selected hub will be brighter than the second order descendents but darker then the selected hub.

$$Item_{SatColour} = (H_i - 1)/1$$
$$Item_{ValColour} = (H_i - 1)/1$$

H_i is the height of the current node depending on the selected hub.

2.2.2 Space Frames

During our experiments with color, discussed above, we noticed that the edges connecting the nodes form spatial frames which define and shape the 3D space, when a variegated color scheme, emphasizing foreground and background values, is implemented. Realizing that this property can be exploited to display overall trends or indeed create meaningful space partitioning, easing user orientation and navigation we focused exclusively on the connecting paths in the second phase of investigations. We also substituted transparency for lightness value as a means for achieving illumination in accordance with Colin Ware's finding that that lightness is a poor choice for displaying attributes since in a rendered 3D environment it is important that the surface color be orthogonal to the effects of shading [FW94].

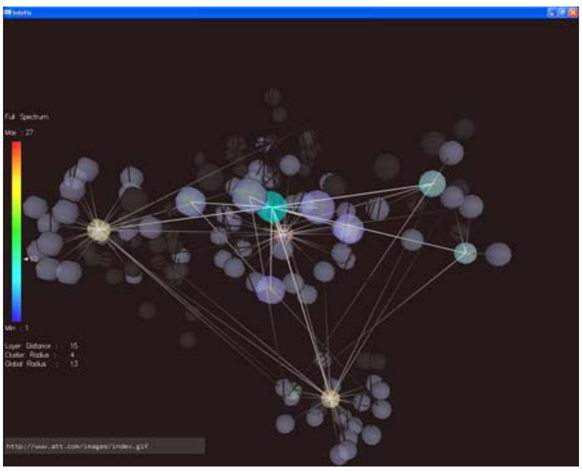
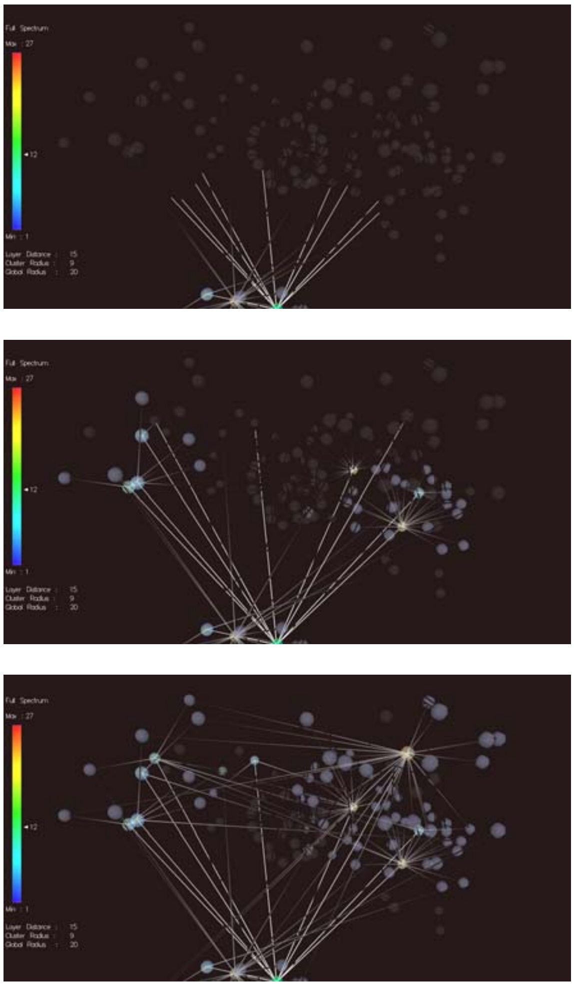


Figure 4: Spatial frames created from selected, i.e. highlighted/foregrounded paths

When color is applied adroitly to the connecting paths, these paths do indeed create "spatial frames", which subdivide the homogenous 3D space into spatial partitions, very much like architectural elements, provided that they are foregrounded sufficiently from the rest of the construct. We painted the edges between the selected node and its first and second order connections starting from near opaque white and progressing to light to midtone grays, derived from increased transparency values of the initial white, perceived as tones of grey against the charcoal grey background of the background. Since the system increases the transparency of the unselected nodes and edges, darkening and backgrounding them in the process, the illumination of the selected paths re-defined the concept of linkage and connection, creating dramatic virtual architecture: Defined and separate structures composed of illuminated links and hierarchies within the overall, albeit backgrounded, data set.



Figures 5-7: Progressive path animation.

Performing this operation as an animation where these connections and hierarchies manifest themselves as progressively transparent paths starting from the selected node was also found to facilitate the display of overall trends, enabling clearer overviews of the structure.

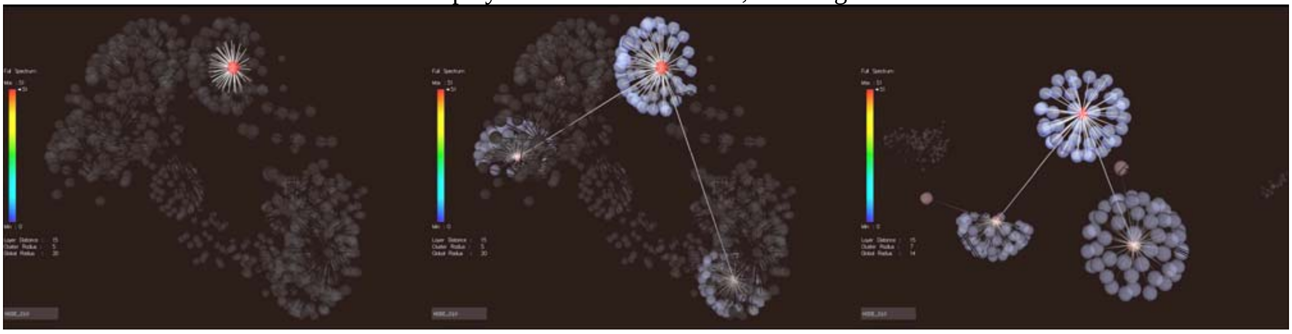


Figure 8: Animated depiction of critical paths in a 1000 node graph from left to right. We have used a full spectrum coloring schema where node loads represent the number of connections of each node. Edges from first and second order connections to the selected node (red) are illuminated over 3 seconds time to improve spatial perception (left and middle images). At the right frame the system places remaining nodes out of view volume automatically to reveal the structure clearly.

3. Results and Discussions:

While usage of the full HSV color space does indeed aid the detection of connections and hierarchies between data, that are not as easily discerned in less variegated color schemata, not all data sets can be examined under the same color scheme. While data with few clearly defined well connected hubs will certainly benefit from the implementation of a complementary or analogous scheme, data that is comprised of numerous nodes, such as was the case with our sample data set, will benefit from the implementation of a fuller spectrum. We experienced that positioning techniques depended heavily on the number of nodes. A technique which will work well for a couple of hundred nodes will not perform well for thousands of nodes or more, compelling us to develop an additional tool, which displaces nodes that are at very low levels of and/or no connectivity out of the view volume entirely, so that the user can examine the structure of selected nodes more clearly.

New hardware and user interfaces, such as the Multi-Touch Interaction Research conducted by Han and Davidson [HD06] will certainly provide a framework for the emergence of salient, novel display and interaction methodologies in information visualization. While this particular segment of our research focuses on the usage of color in information visualization, as a team, our ultimate aim is the integration of information visualization with intuitive interfaces and display systems, by means of which data search can be indeed conducted in a gestural, intuitive manner, very much akin to what is proposed by Han and Davidson. Thus, as part of ongoing research, we are in the process of evaluating large sized, high-resolution displays and Cave like immersive systems within the context of data visualization, the ultimate motivation for which is the building of a cost-effective display system that can be used to increase perceptive and interactive ability on a large display surface and can be used for small user groups.

The importance of meaningful landmarks for the decipherment as well as the navigation of data structures and the problematic surrounding their implementation is covered extensively by Chaomei Chen [Che04]: In most visual/spatial systems, from maps to paintings and architecture these landmark attributes are present and can be readily discerned by users and viewers, either as geographic, ornamental or indeed focal elements. The homogeneous and abstract nature of graphs, however, makes the differentiation of data objects, to the extent where they might indeed acquire landmark attributes a considerable challenge, since this differentiation would need to serve the inherent attributes of the data object, i.e. hub qualities, data weight, connectivity, etc; as well as provide visual landmark clues that facilitate orientation.

One ready solution would be the insertion of structural elements into info-vis systems, which are separate from the data structure itself and serve only orientation and navigation, somewhat akin to the usage of spatial/ornamental elements in art, design and architecture. Although we feel this line enquiry to be valid, and we may indeed be exploring this in the future, an investigation into the possible usage of the inherent structural elements of the graph system itself for meaningful landmark creation constitutes our initial phase of design research. Our present study in the usage of the HSV color space in 3D graphs has, however, provided us with valuable clues in how to proceed with the task at hand, and we shall be pursuing this diligently in work to come.

4. Conclusion

Visual representation can have a profound effect on the success of a visual analytics system. We selected a medium sized dataset of 180 nodes that had already previously been visualized as a node/link diagram in 2D. We colorized the data structure in 4 separate color schemata: monochromatic, analogous, complementary/ split complementary contrast and triadic. This enabled us to see clearly whether there were indeed tangible benefits in visualizing this particular dataset as a three dimensional node/link diagram that used the HSV color space over a two dimensional one, with uniformly colored nodes and paths. This system achieves lightness/darkness value by increasing the transparency of the unselected nodes and edges to improve visual perception.

We found that the usage of color space, particularly in the variegation of the transparencies of the path connections, both animate and inanimate, does indeed create visual disturbances in the homogeneity of the data structure, forming spatial frames and partitions, which can aid both in orientation tasks as well as the detection of data trends. Thus part of immediate future work will be the exploration of the design possibilities that the colorization of the path connections can reveal. Furthermore, these partitions can be enhanced by ascribing different shape attributes to these paths, which may also enhance their landmark value.

In our experiments these two techniques performed well for nodes with few hundreds of nodes. However for graphs with thousands nodes, we had to develop an additional tool, which displaces nodes that are at very low levels of and/or no connectivity out of the view volume entirely, so that the user can examine the structure of selected nodes more clearly.

References

[BM96] Batagelj, V., Mrvar, A., Graph Drawing Contest 1996. Berkeley, CA. http://vlado.fmf.uni-lj.si/pub/gd/gd96.htm Retrieved on: 12/02/2007

[Che04] Chen, C. Information Visualization: Beyond the Horizon. Springer, London. 2004. P: 22, 287.

[EAD06] Einsfeld, K,, Agne, S., Deller, M., Ebert, A., Klein, B., Reuschling, C. Dynamic Visualization and Navigation of Semantic Virtual Environments. Proceedings of the Information Visualization (IV'06), IEEE. 2006

[FW94] Franck, G., Ware, C., Visualizing Information Nets in Three Dimensions, University of New Brunswick technical report TR94-082, February, 1994.

[FW94] Franck, G., Ware, C., Representing Nodes and Arcs in 3D Networks Proceedinggs. IEEE Conference on Visual Languages. St. Louis, 1994. 189-190.

[HYL06] Halim, S., Yap, R. H.C., Lau, H. C., Viz: A Visual Analysis Suite for Explaining Local Search Behavior. UIST'06, 2006.

[HD06] Han, J., Davidson, P., Perceptive Pixel. http://cs.nyu.edu/~jhan/ftirtouch/index.html Retrieved on 01/03/2007

[Itt02] Itten, J. The Art of Color. John Wiley and Sons, Inc., 2002.

[JS95] Jerding, D.F., Stasko, J.T. The Information Mural: A Technique for Displaying and Navigating Large Information SpacesIn Proceedings of the IEEE Visualization `95 Symposium on Information Visualization, pages 43-50, Atlanta, GA, October 1995..

[QWF05] Qeli, E., Wiechert, W., Freisleben, B., Visual Exploration of Time-Varying Matrices. Proceedings of the Ninth International Conference on Information Visualization (IV'05). IEEE. 2005

[PW06] Pretorius, A. J., van Wijk J. J. Visual Analysis of Multivariate State Transition Graphs, IEEE Transactions on Visualization and Computer Graphics, Vol. 12, No. 5, September/October 2006.

[Tuf90] Tufte, E. R. Envisioning information. Graphic Press, Connecticut,1990.

[War00] Ware, C. Information Visualization: Perception for Design. Morgan Kaufman. San Francisco. 2000. Pp: 105-148.