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A Compendium on Glyph/Icon Research Including MIL 2525B

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FOR THE DIRECTOR

//signed//

DANIEL G GODDARD
Chief, Warfighter Interface Division
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A Compendium on Glyph/Icon Research Including MIL2525B

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Abstract

An overview is conducted on the vast area of visualization when applied to icons and their application in map-type displays. The early history and motivation of the use of icons is examined. Displaying complex information is surveyed in multiple areas. The possible use of animation is both researched and hypothesized for application in military scenarios. The genesis of the military standard MIL2525B is discussed. Suggestions are made on means of improving and the rendering of the multiple dimensions of MIL2525B to maximize information transferred to a human operator.

I. Introduction

As visualization systems become more and more complex, they eventually lose their effectiveness to render information to operators in an efficient manner. The history of the display of visual information is provided in this report with a particular focus on a military application. In the US Air Force, MIL2525B is one icon examined herein. Before suggestions are made on the possible improvement of MIL2525B, a survey or compendium of visualization systems is conducted to provide a baseline of possible alternatives to the existing military system.

II. Literature Survey of Early Visualization Methods

Over 5,800 years ago, ancient Egyptian geographers used visualization to transform position information into spatial diagrams (Wainer (1997)). These early data maps were drawn on clay tablets. By 1100 AD, the Chinese had actually produced stone maps (Tufte, 2003, Needham, 1959) that presented an extremely accurate data map by today's standards. In the 1530s, as printing became more persuasive, the use of diagrams to explain concepts became more and more ubiquitous. In 1644 (see Tufte (2003)), one of the earliest visual representations of statistical data was drawn by Michael Florent van Langren, a Flemish astronomer to the Spanish court. The graph produced showed 12 diverse estimates of the same distance between Toledo and Rome, measured in degrees longitude. This one-dimensional map of data arranged each data point spatially and is considered as the first statistical graphic ever produced. Slightly later, by 1686, Edmond Halley had developed a data map showing trade winds and monsoons on a world rendering (Halley, 1686). By 1765, two dimensional visual renderings were constructed to show cause-effect relationships between two variables (see Lambert (1975)). By the 1800s, many complex renderings of text with drawings became common (compare Humphry (1808), Tufte (2003)) in the design of buildings. In 1854 one of the earliest and well-known successes of visualization to uncover cause-effect relationships in data was documented. Briefly (Richardson (1858), Wainer (1997), and Tufte (2003)): "Dr. John Snow in London was trying to understand the most terrible outbreak of cholera which had ever occurred in that city. There were 500 fatal attacks of cholera in 10 days (graphically and spatially annotated on a map) proximal to a point at the intersection of Broad and Cambridge Streets. Dr. Snow denoted on a map, with a bar graph, the frequency of deaths spatially where the deaths occurred. On the same map, Dr. Snow also plotted, with a circle icon, the spatial location of the water pumps in the city. The clustering and correlation was striking! This gave the physician a clue of some possible causality between the spatial location of the pumps and the deaths caused by cholera. By then removing the handle from the pump near the highest death rate point, the subsequent deaths then dropped dramatically. There may have been a placebo effect (the subsequent deaths would have dropped, anyway, without intervention), but the suspicion derived from this observation was that the common use of the city water pump spread the cholera through hand contact, which was true. This occurred prior to Louis Pasteur's discovery of germs (later that century) and the need for sanitation procedures including the boiling of water to mitigate the growth of bacteria." This one of the first uses of visualization or data mining and is considered as a landmark in epidemiology (Richardson (1858), Tufte (1983)). In modern times, there is great interest in all types of graphics, which now include iconic representations and animations.

By the early 1900s, statisticians became more sophisticated in dealing with data and the visual renderings became more and more complex. Diagrams were the first way Sir Ronald A. Fisher helped bring statistics into the forefront of the scientific and technical community over his long technical career (Fisher (1925), (1971), Cleveland (1993)). Fisher worked, early on, with crop barley data, and special visualizations (multiway dot plot graphs) which revealed anomalies in the data missed by prior researchers. By the 1970s, statisticians became more and more concerned with the display of complex information, since the data now were very multidimensional and needed to be portrayed to the user in a form that was understandable. Another key person, in this era was John W. Tukey at Princeton, who developed the first box and whisker plot (Tukey et al. (1977), (1981)) which emphasized the need to display several statistical components of a data set including such measures as its mean, median, range, outliers and quartile markers in a simple, easy to comprehend diagram. As discussed earlier, a contemporary statistician with J. Tukey is Edward R. Tufte (Tufte (1983), (1990), (2003)), who has numerous books and other publications comprising some of the most modern and respected works of the history and use of visualization techniques.

Improving graphics of any type as been of interest for thousands of years. To quote Tufte, 1983, "Graphical excellence is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space." In more recent times, Tversky et al. (1995, 2001a, 2001b) reports that graphics of all types benefit comprehension and learning and helps foster insight with many proponents in the field (compare Larkin & Simon, 1987; Levie & Lentz, 1982; Levin & Mayer, 1993; Schnotz & Kulhavy, 1994; Scaife & Rogers, 1996; Winn, 1987, 1989). Graphics provide multiple means of displaying information. Graphics may be aesthetically appealing or humorous, attracting attention and maintaining motivation. Dr. Tversky et al. (2001b) expounds on two main principals when composing graphical renderings:

(1) **Congruence Principle:** The structure and content of the external representation should correspond to the desired structure and content of the internal representation.

(2) **Apprehension Principle**: The structure and content of the external representation should be readily and accurately perceived and comprehended. These rules apply if the graphics rendered are static or animated.

Since brevity must be the style here, this terse historical perspective, of course, has left out many key contributions. The focus of this technical report, however, is to specialize on icons or more advanced representations such as glyphs (Whitaker & Thomas-Meyers (2006)), which also has a long history. In a simple sense, icons may be defined as augmented objects added to a map or other visual rendering that portrays meta data. This means that additional information may be gleaned from the iconic object related to a key asset in the original visual depiction. The icon adds information in the sense that without this object, less knowledge is provided to the user about the particular asset of interest on the map. It is worthy of note that the term "glyph" has its genesis traced to the Greek word *glyphe* (a carving) to the petroglyphs of early Europe (prior to 10,000 BC) involving the cave paintings in France as well as the hieroglyphics of early Egypt and South America. These types of visual rending were not text but generally depicted objects/animals to provide some message.

III. Literature Survey of Icon/Glyph Research

In the history of visualization, there is strong evidence of the use of icons over 500 years ago as discussed in (Wainer (1997)), in which a literal icon was portrayed to show wind direction from Juan de la Cosa's 1500 map of the New World. In this rendering, the land mass Cuba is depicted as an island and the pertinent information the icon would display would be the two dimensional wind direction. In modern times, the use of complex icons to represent multidimensional data was popularized by a statistical professor at Stanford University using faces, H. Chernoff (Chernoff (1973) and Crawford & Fall (1990). These "Chernoff" features could portray up to 14 dimensions of a variable by changing certain attributes of the face to illustrate a particular dimension. Complex icons can take many other forms, for example other renderings of complex data can be seen in the glyphs consisting of castles/houses (Kleiner & Hartigan (1981)) as a representation of multiple dimensions of information. Wilkinson (1982) evaluated several types of multidimensional icons including faces and castles. He found faces effective but users were easily overwhelmed by complicated representations and large data sets. Others (Spence & Parr (1990), (1991)) employed house representations in eight dimensions to help home buyers select a residence. They found task completion times to be significantly faster for icons versus text descriptions, but this advantage was lost as the number of icons or text descriptions increased from 28 to 56. Complexity can also include graphical movement, e.g. glyphs can be made to move independently, or have a dependency to produce continuous motion fields, Kerlick, 1990.

Clearly, there are a number of perceptual and cognitive issues which must be investigated to understand the utility of multidimensional icons. Many concepts have been discussed in the literature. However there has been little basic research to compare relative efficiency of design or the usability of icons.

While there has been little empirical evaluation of multidimensional icons, there has been discussion of what constitutes a usable icon. Levialdi, Mussio, Protti, & Tosoni (1993) state users of multidimensional data should obtain results they can properly understand, evaluate for reliability, use to pursue activity, and communicate to others. (Goodall (2003)) reduces usability issues to accuracy, efficiency and user perception. He elaborates that users need to find the data quickly without expending undue effort, find accurate information, and not find the experience onerous. First we discuss the genesis of the military standard MIL2525B as it is used today in the armed services.

IV. The Genesis of MIL2525B

Figure 1 shows a rendering of MIL2525B for a ten dimensional icon in two alternative states. The dimensions were derived from early military map scenarios going back to the Napoleonic era. The actual military standard, however is quite modern. In August, 1993, the Defense department asked both US and NATO organizations to help develop a standard in warfighting symbology. In September 1994 the original MIL-STD-2525 was published being drawn from three sources: (a) NATO Document, "Military Symbols for Land Based Systems," STANG 2019, (b) US Army, "Operational Terms and Graphics," FM 101-5-1, and (c) NATO, "Display Symbology and Colours for NATO Maritime Units," STANAG 4420.

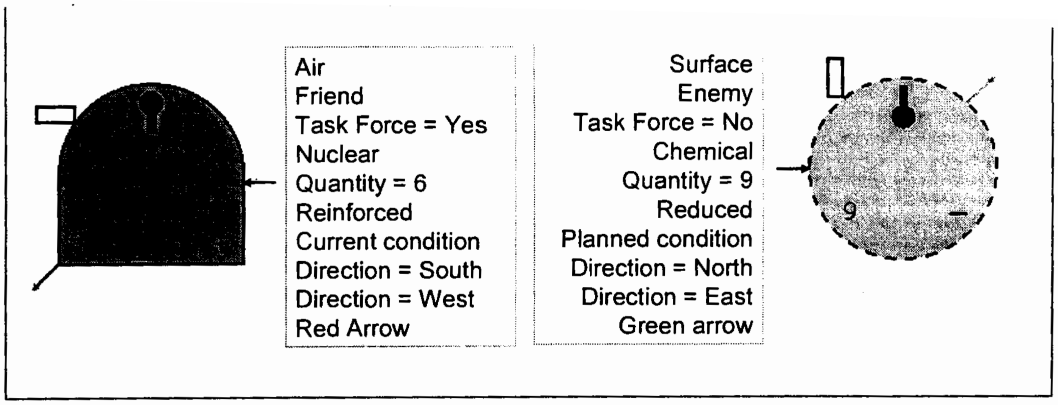

Figure 1 - Two Complex 10-dimensional Icons

In December, 1996, MIL-STD-2525A was first published and in January, 1999, and the later version MIL-STD-2525B was then published. On March, 2005, was the cutoff date for all changes in the established standard, which is in existence today.

V. Challenges with the existing MIL2525B

Recent investigations of MIL2525B have show some special challenges. Two such challenges are briefly discussed here.

Challenge 1: Perceptual Bias in the Respective Dimensions

First there appears to be a perceptual bias at which operators view the different dimensions of a complex iconic representation. In Figure 2, it shows that with equal presentations of the ten dimensions of the attributes of the symbology in Figure 1, certain dimensions are perceived more accurately by operators while other dimensions are not perceived with this level of correctness. It is clear that in order to maximize the information received by the operator, it is important to parse out information in various dimension, most likely with the most important dimensions having the highest saliency. The term "saliency" is used within this context to describe which dimensions are received by the operator with the highest accuracy.

Results of – Saliency Investigation of The Input Stimulus
(attention grabbing) (Study 2 – Dynamics of Perceptual Filter)

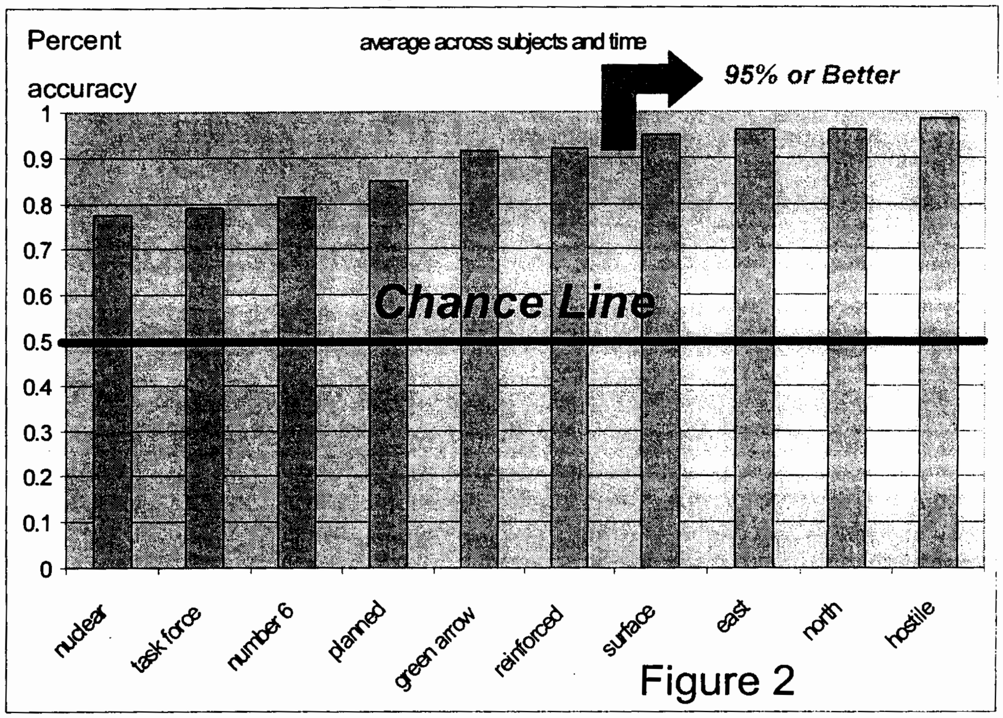

Figure 2

The second challenge with MIL2525B is the rate at which it provides information to the operator, who in this case is the decision maker or war fighter.

<u>Challenge 2: Limited Information Capacity Received by the Operator</u>

Figure 3 was obtained from the third study from Repperger et al. (2006a, 2006b, 2006c) in which actual information capacities (bits/sec) were obtained for subjects performing the recognition of the binary states of the dimension variables with limited time exposure to the symbology. It is clearly seen that the operator reaches limits at about 6 dimensions of complexity of an icon before he loses his efficacy. This is low by traditional standards (Miller, 1956) in which other sensory modalities can easily transmit 7 $\pm$ 2 dimensions effectively. This shows the present state of MIL2525B could be better optimized to provide information to an operator in a more efficient manner.

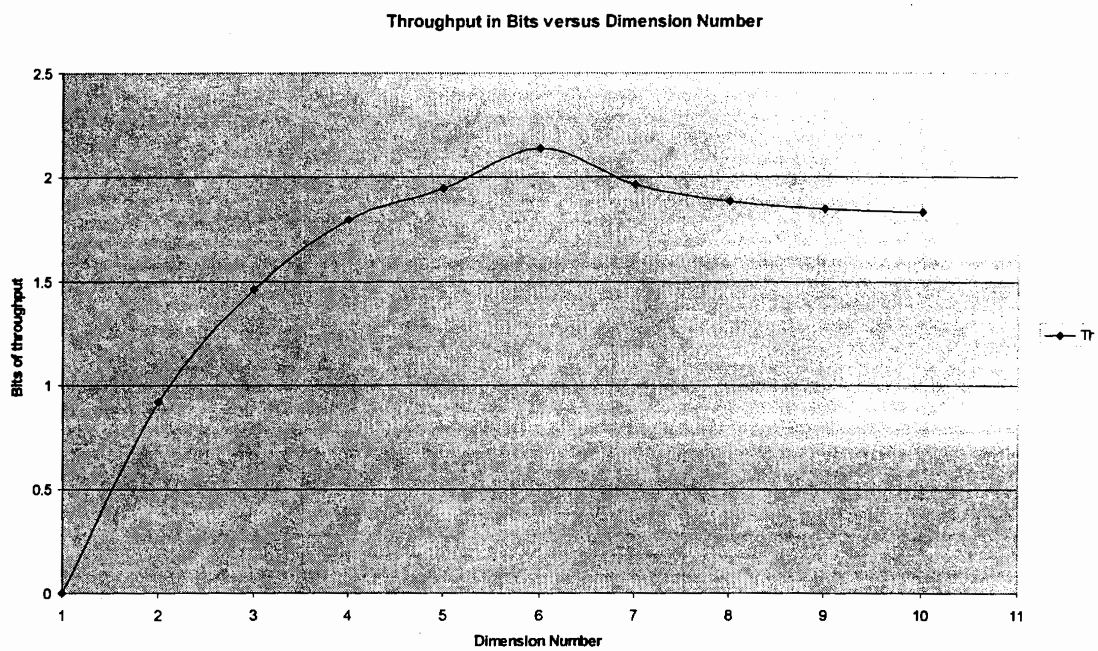

Figure 3 – Throughput of Operators on MIL2525B versus complexity Number

VI. Suggested Modifications in MIL2525B

It is seen in Figure 3 that efficient use of the present MIL2525B is hampered by the fact that effectively the first 6 dimensions produce information throughput and then throughput drops off. Comparing figures 2 and 3, one would suggest that present static renderings of the military symbol use as a maximum of 6 dimensions. For rendering additional information, it may be best to drill down to another level of possible dimensions and then to have six or fewer states in the next level of information rendering. Another way to increase how the icons could better deliver information would be to enhance the attention-grabbing attributes of a particular dimension via animating certain dimensions of the icon. This motivates the literature search to examine possible studies on the benefits and drawbacks on animation with respect to iconic representations.

The discussion is now turned to some prior research on dynamic icons which is analogous to the concept of animation. Animation may be defined as graphics that change with time. The question: Is animation, per se, facilitory for performance of a particular mission? Animation may be very compelling and is known to be effective for real time reorientation in time and space. The common example is on the Internet when a file is being downloaded and the fill symbol is animated (changing) to give the user some idea of how far along is the process before the task will be completed. As an initial introduction into animations there exist at least five accepted ways to induce a motion change in graphics (Horton, 1994) including (a) blinking (b) vibration, (c) change color, (d) movement or (e) morphing or changing shape.

VII. A Foothold Into Animation

One goal of this research is to consider using animation to modify an icon to better display information to decision makers in a military scenario. We presently note two possible uses of animation that may benefit the decision maker: (1) Animation may be productive in improving the attention grabbing (saliency) of a particular dimension of an icon, or (2) animation may portray the change of state of the data (uncertainty may adapt which may be reflected by a probability modification of the reliability of some sensor in the field, Bisantz, Marsiglio & Munch, 2005). In the first application, by having some control over the relative saliency (prominence to the user) of that dimension, this attribute can be manipulated when necessary. For example, if an icon attribute has a sudden change in the quality of its data (the data came from a new source (sensor), rather than from a database), then that particular attribute or dimension of the icon could be animated to grab more attention from the decision maker. As discussed earlier, some possible means to animate just one attribute of the icon may be to: (a) flicker the dimension on – off , (b) jitter that portion of the symbol related to this attribute, (c) change the color of the dimension attribute (compare, Bennett et al. (1993, 2000)), (d) translate or rotate the object, and (e) morph (change the shape dynamically), and possibly via other methods. Grabbing attention (improving saliency to the human operator) may also be viewed within a negative context as ***the disruption of information/attention*** (Ware, Bonner, Knight, & Cater, 1992. This disruption may be exactly what is desired in certain military situations with the decision maker, when he/she needs to be notified about the change of some aspect of the data being studied. We now examine the literature about animation to glean out the pros and cons of possibly employing dynamic icons in military scenarios. Some examples are then presented of cases in the literature where dynamic icons have documented advantages, disadvantages, and mixed results.

7.1 A Brief History of Animation in Visualization

Animation addresses some types of visualizations that are not possible via static renderings. For example (Tufte, 2003, Fitzkee, 1945) "Some 400 years of writings on magic make a very clear point about the design of information: *There is no magic in still-land*." In this report, the first step will be to examine situations where animation has provided some beneficial performance changes in the human-machine interaction when dealing with complex displays. After those references are explored, then the detrimental effects of animation are reviewed. Finally, where mixed results are reported in the literature about the utility of animation, these works are then summarized.

7.1a Literature Showing Some Benefits From Animation

Animation has been studied mainly within the context of education (Cunningham, Brown, & McGrath, 1990), and in particular for displaying flow data (Long, Lyons, & Lam, 1990). Some applications have developed videos for training, such in the field of semi conductors (Kluksdahl, Kriman, & Ferry, 1989). In early studies of animations (Baek & Layne, 1988), dashes moved proportional to speed. They presented experimental data to show students who learned from the animations outperformed those using only a static diagram. Thus animation may facilitate learning. For teaching about the circulatory system, the moving graphical diagrams of the heart included dynamic pathways (Large, Beheshti, Breuleux, & Renaud, 1996), which seemed to help students better understand the blood flow within the cardio vascular system. In physics, studying the basic dynamics of Newton's Laws via computer-based lessons, the findings supported the use of animated graphics to portray certain intrinsic properties, such as inertia (Rieber, et al. 1990a-b, 1991a-b). Zacks, et al. 2001 used animation effectively to portray visual renderings consisted of more intricacies and hence delivered additional information as compared to the static counterpart. The static rendering was coarse. The animated graphics portrayed both the coarse and fine segments, thus providing more diversity and complexity. For tasks such as students learning the operation and troubleshooting of an electronic circuit from either a static graphic or animated version (Park & Gittelman (1992, 1995)) report better performance in the animated graphic condition. Similarly, Thompson & Riding, 1990, concur that animation facilitates learning (via the fine-grained actions the static renderings are missing). Again, within the context of learning and with students, Kieras (1992) investigated the effects of animated and static graphics on a student's ability to understand the operation of an energy system, the "Star Trek Phaser Bank." Students who learned from the animated graphic performed significantly better on firing the phaser and diagnosing malfunction tasks. Nathan, Kintsch, & Young, 1992 developed an animated interactive program to help students comprehend algebra word problems. Performance in the animated condition was better than any of the three static conditions. Finally, Palmiter, Elkerton & Baggett, 1991; Palmiter & Elkerton, 1993) compared animated and still graphics for teaching students how to use an on-line help system for Hypercard™. The students using animation completed the training task more quickly. In developing a rule base regarding graphics with motion, a possible taxonomy of motion properties for display dimensions are provided in Bartram, 1997.

For military applications, one goal of introducing animation into icons is to redirect the attention of the decision maker to new situations caused by changes in the data. Both Ivry & Cohen (1992) and Rosenholtz (1999) demonstrated that attention can be directed to the fastest moving items on a display, thus improving the saliency of particular search targets. This provides a means of highlighting the search targets. In the same vein, with the goal of manipulating saliency, Freeman & Harris (1992) have shown that expanding and contracting motion patterns are more easily detected as compared to translating or random motion for graphical objects including other pattern actions. In finding objects more quickly, there is strong evidence of the benefits of non stationary graphics. For example Wiegmann, Essenberg, Overbye & Rich (2002) found, in studying trials with multiple faults, that the time to identification for multiple fault trials tended to be faster with a moving arrow display rather than with a digital display, perhaps, because the moving arrows helped the participants determine power flow direction faster. Essenberg, Wiegmann, Overbye, & Sun, 2003 suggested that the initial study may have failed to find an advantage for motion in the task because the motion did not adequately support search for faults. A new experiment then showed a clear advantage for the motion displays. These authors concluded that motion can be used successfully to aid understanding of the behavior and monitoring of systems if the display is configured such that motion provides new knowledge directly relevant to the user tasks and draws the user's attention to the most pertinent information. For computer-based instruction, Park et al. (1993,1995) have shown that animation reduces learning time. There is some possible confusion (Rensink (2002)) in accurately defining animation, since it has been noted that detecting image changes is more difficult than detecting motion, so how animation is constructed is not a trivial task.

Also, in terms of speed recognition, Bodner & MacKenzie (1997) found that subjects identified the correct tasks of animated buttons more often than for static buttons. Recognition accuracy was also higher for animated buttons. Analyses indicated that animated buttons are particularly useful for representing highly complex tasks. There were also semantic benefits derived from animation, for example, Bodner (1994) found that animation was beneficial in helping users identify the function of an icon. Thus, higher level information was gleaned from an animated icon that may not be easily measured in terms of simple mission performance measures.

7.1b – Literature to Indicate That Animation is Disruptive and Degrades Attention

There is far more literature found in a negative sense about animation, but our objective for the military application of graphical motion may be to welcome disruption, since it provides a method to manipulate the attention of the decision maker. As discussed previously, animation may violate the apprehension principle. Moving graphics must portray change over time. However, there may exist a lack of equivalence between the static and animated graphics. The animation may be too complex or moves too fast to be accurately perceived. Of course, in studying this effect, animation must be distinguished from interactivity. Thus "disruption is good" when employed in the proper situation. If performance is measured by the time to search for a target, Driver, McLeod & Dienes (1992) showed that incoherent non-target motion can distract attention and slow search for hidden objects. Hegarty, 1992 raised the issue that motion may be perceived as being non smooth and composed of discrete steps. This is reinforced by Kaiser, Proffitt, Whelan, & Hecht, 1992 where experimentation demonstrated that observers can select the correct path utilizing animation but when asked to reproduce the results, it is incorrect. As discussed previously in the study by Wiegmann et al. 2002 found that the total time required to identify the worst fault was reduced with moving arrows as compared to a one line diagram with digital values. This may possibly be due to distraction caused by non-relevant motion. Tversky et al. (1991, 2000, 2001a) failed to find benefits of animation for conveying complex processes. These authors argue that experimental studies reporting advantages of animation over static displays lacked equivalence between animated and static graphics in content or experimental procedures. When they are equivalent, animations show no apparent benefit; sometimes they even result in performance deficits. In studies of navigation paths, among objects or teaching permissible social paths among people, diagrams that animated the path provided no benefit beyond that of the individual static diagram (Schnotz & Grondziel, 1999; Morrison & Tversky, 2001). For teaching Newton's Law of motion, some negative effects of animation were reported in Rieber & Hannafin, 1988 and Rieber, 1989. They found no facilitation for animated graphics in teaching elementary school students. Schnotz & Grzondziel, 1999 confounded interactions with animation which is always a critique in comparing to a static rendering (Betrancourt & Tversky, 2000, 2001). Also, animation may provide prediction, which can further compromise a fair comparison to the non moving graphic (Hegarty, Quilici, Narayanan, Holmquist, & Moreno, 1999). In studying college students and teaching Newton's Laws, Rieber, et al., 1990b reported no performance benefit as a result of the animation. In studying growth hormones during biotechnology, ChanLin, 1998, used animation to demonstrate the production of growth hormones. He showed little benefit of the animation in the student's performance. For junior high school students, Pane, Corbett & John, 1996 employed a multimedia program in the Advanced Computing for Science Education program with no better performance achieved with moving simulations. For learning computer algorithms, Byrne, Catrambone, & Stasko, 1999, used animations for college students. They viewed the animation as giving additional predictive cues that the static renderings could not provide. In teaching students to use a Macintosh and Hypercard™ (Dyck, 1995; Payne, Chesworth & Hill, 1992; Harrison, 1995) students in the animated graphics group did not out perform those in the equivalent text group.

Lowe's (1999, 2003, 2004b) experiments on complex interactive weather map animations are often cited by critics of moving visual renderings as examples of where animation fails. Lowe (1999) found that participants tend to extract information based on perceptual salience rather than thematic relevance. Furthermore, Lowe (2004a) suggests that simply providing user control doesn't always result in the desired learning improvements. He found that participants neglected the animation's dynamic aspects, perhaps because of available user controls. Participants usually stopped the animation and investigated still frames, or the animation was viewed one frame at a time.

We also discuss a number of other eclectic studies involving animation with mixed results. They need to be mentioned to bring to the table a number of other points of view related to this controversial topic.

7.1c –Mixed Results with Animation in Visualizations and Pertinent Topics

There are mixed results in the literature about the use of animation. Animation may be used to acquire an observation or may possible represent an action initiated by the user. Iconic representation may be viewed as representing knowledge about objects on a map. Semiosis (the sign process) has been limited to representing only objects. The reasons may be two-fold. First, an icon has been considered to be a graphical symbol to represent objects in a computer system (Gittins, 1986). Secondly, icons have evolved from pictorial representations of objects. In recent times software developers have extrapolated the icon to go beyond object to represent actions (Blankenberger and Hahn, 1991) However, actions (verbs) manipulate objects in specific ways and are not easily represented compared to their counterparts, the objects (nouns). (Apple Computer, 1996).

Mullet and Sano (1995) have suggested three principles for simplicity of iconic representation: (1) Unified to produce a coherent whole, (2) Refined to focus on the viewer's attention on the essential aspects, and (3) Fitness or appropriateness of the solution to the problem.

An established way to design icons is based on unifying individual icons into a collective metaphor (Gittins, 1986). Icons are meant to correspond with real objects with which the users are familiar. Limitations arise due to lack of direct mapping between the real objects and the system objects. Even greater problems arise if icon designers use the same or similar metaphors in different contexts causing confusion for users.
From the perspective of iconic visualizations, Landsdal, Simpson and Stroud (1990) found that recall performance for icons is related to the semantic-fit of the representation. However, Horton (1994) suggests that icons alone are meaningless without a particular context and suggested: **Icon + context + viewer (interpreter) = meaning.** There are also issues of classification, for example, many different classification schemes exist for icons (Smith, Irby, Kimball and Verplank (1982), Lodding (1983), Jervell and Olsen (1985), Gittens (1986)). The use of text versus other symbols is still debatable. Apple Computer (1996) suggests that text should not be used in icons, as text is often confusing. However Horton (1994) says icons and words are not mutually exclusive. Paivio (1971) argued that multiple modalities enhance memorability, thus text and graphics combined may be more effective that pure graphics. Kacmar and Carey (1991) and Egido and Patterson (1988) have shown that text and graphics together improve performance. How icons are employed is important, for example, users of visualizations must be able to "point" at objects and get the numerical and textual data behind them. This technique, called "brushing," Gershon and Eick, 1998 is an important requirement for information visualization.

From Marchak, et al. (1990, 1991, 1992, 1994), the overall goal of a visualization is to identify patterns and understand any underlying relationships existing in the data. Whether the purpose of the visualization is for analysis or communication, the better the mapping between the data and the visual form takes into account the capabilities of the human visual system, the better the chance the information will be detected and understood. The visual system can decode information in several dimensions including spatial, chromatic and temporal. By designing visualizations with human strengths and weaknesses in mind, it is possible to exploit the visual systems' ability to recognize structure and patterns and circumvent human limitations in memory and attention.

A graphical method for visualizing data consists of two parts: a selection of quantitative information to be displayed and a selection of a visual display method to encode the information. Some other points include: Bederson & Scneiderman (2003), information visualizations can ameliorate the experience of people using computers, making the experience more effective and enjoyable. A visual user interface should be intuitive and efficient. Effectiveness can be defined via the accuracy and completeness with which users achieve specific goals. Efficiency refers to the resources expended in relation to effectiveness. The purpose of visualization is insight, not pictures. Information is data made accessible and usable to people. Scientific and information visualization can be distinguished by the data they depend upon. Scientific visualization is based on physical data. Information visualization is based on abstract data, resulting in information with no obvious spatial mapping. Thus information visualization is the more difficult of the two methods considered.

Burkhard (2004) describes this definition as limiting when it comes to information visualization. He claims that the definition results in the focus being on information exploration, overlooking the potential of using visualization as a medium for the transfer of knowledge. Burkhard introduces knowledge visualization which examines the use of visual representations to improve the transfer of knowledge. A neural architecture of visual system disproportionately represents the central visual field. Additionally, dynamic mechanisms of selective attention focus the processing resources of the visual system by functioning as an information gating mechanism. Together, attentional mechanisms and neural architecture determine what visual information is or is not fully processed.

Two major attentional mechanisms are known to control the selection process in describing information from glyphs. First, a bottoms-up attentional selection is a fast and often compulsory stimulus driven mechanism. There is now evidence indicating that attention can be captured under the correct stimulus conditions. For example, highly salient feature singletons (Bacon and Egeth, 1994; Treisman and Gelade, 1980) or abrupt onsets of new perceptual objects (Yantis and Jonides, 1984; Yantis and Hillstrom, 1994) automatically attract attention.

The other mechanism, top-down attentional selection, is a slower, goal-directed mechanism where the observer's expectation or intentions influence the allocation of attention. Observers can volitionally select regions of space (Posner, 1980) or individual objects (Rock and Gutman, 1981; Duncan, 1984; Tipper et al. 1994) to attend.

The degree to which these two mechanisms play a role in determining attentional selection under natural viewing conditions is under debate. Much of the research relevant to this question has been focused on the way in which people make eye movements while viewing complex natural scenes. The logic rests on the assumption that eye movements and attention are associated. Evidence indicates that focal attention at the location of a pending eye movement is a necessary precursor for that movement (Deubel and Schneider, 1996; Hoffman and Subramaniam, 1995; Kowler et. al.; 1995; McPeek et. al. 1999; Schneider and Deubel, 1995; Shepherd et. al., 1986).

Some evidence suggests that top-down semantic influences affect attention guidance, leading to longer and more frequent fixation on items that are inconsistent with scene context. From the perspective of animation, how animation, as an external, exogenous source, interacts with the internal human visualizations is of interest. For example, Barkowsky, Freska, Hegarty, & Lowe, 2005 studied how externalized visual representations such as statistical graphs, organizational charts, maps, animations, etc. interact with human internal visualization capabilities. Fabrikant & Goldsberry (2005) employed a bottoms-up, saliency-based visual attention model developed by Itti, Koch, & Niebur, 1998. This pre-attentive vision model is used as a baseline to compare human subject viewing behaviors collected with eye movement data. The Itti model is neural net based. The goal of the model is to identify the focus of attention of a visual system based on the "where" the salient features exist, not the "what" or semantic characteristics (Itti & Koch (2001)). The Itti model can be applied to dynamic scenes including map animations. Dynamic input parameters include temporal change (on/off flicker) and the four motion directions (up, down, left, right). Wittenberg, Forlines, Lanning, Esenther, Harada, & Miyachi, 2003 proposed a model for a class of rapid serial visual presentation (RSVP) interfaces in the context of consumer video devices. The basic spatial layout "explodes" a sequence of image frames into a three-dimensional trail in order to provide additional context for a spatial/temporal presentation. As the user plays forward or back, the trail advances or recedes while the image in the foreground focus position is replaced. They found that subjects were more accurate but not faster in browsing to the target of interest.

7.1d – Literature Related to Short Term Memory and Visualization

In order to measure the ability to perceive information in the icon experiment described in Repperger et al. 2006a, 2006b, 2006c short term memory may provide an important consideration. There are many issues associated with short-term memory that can affect experimentation to determine maximum information capacity of human operators. This is due to viewing the icons visual/retinal inputs as being converted into information that is stored in memory structures and processes. This has been discussed in Baddeley, 1974 as an interesting anecdote: "Early students of visual attention asked the question: 'How much information can be extracted in a single glimpse?' Sir William Hamilton (1859), using the technology of his time, cast marbles onto a horizontal surface, varying the number of marbles, and had observers estimate the number of marbles on the surface. Hamilton concluded: "If you throw a handful of marbles on the floor, you will find it difficult to view, at once, more than six, seven at most without confusion: but if you group them into twos, or threes, or fives, you can comprehend as many groups as you can units: because the mind considers these groups as only units." Thus short term memory is an important consideration.

<u>Iconic memory</u>

From Badelley & Hitch, 1974: "The Hamilton (1859) marble experiment is a good example of a memory concept called iconic memory. In a similar fashion, Mandler and Shebo (1982) also studied the accurate reporting of small numbers of briefly presented items. They concluded that it comprises three separate memory processes: 1) a response to arrays of one to three items which is fast and accurate, 2) response to arrays of four to seven items are assumed to be based on mental counting of arrays that are able to be kept in conscious attention for a limited period of time, and 3) a response to arrays greater than seven items tend to fade from conscious awareness before counting is complete, and hence must be estimated rather than counted, leading to a much lower level of accuracy.

Recently there has been less interest in the number of dots that can be perceived and more in the perception of more complex stimuli such as strings of letters and numbers. Sperling (1960) presented subjects with a stimulus comprised of 3 rows of 4 letters. When shown these stimuli for 50 ms, followed by a blank white field, subjects were able to report only 4 or 5 of the 12 letters. Was this because these were the only letters that had been seen, or could the subject have seen them all, but forgotten some of them in the brief period it takes to report 5 letters? Sperling tested this hypothesis by instructing the subject that he need only report one line of letters, but that he would not be told which line until just after the letters had been shown. When tested this way, Sperling's subjects were able to report about 3 of the 4 letters comprising the line requested. How should these results be interpreted? When asked for a specific line, subjects were able to repeat about 3 of the 4 letters. Since the subjects did not know in advance which line was to be probed, we must assume that they also had available about 3 items from each of the two rows that did not happen to be tested. This suggests that the total number of letters being held in memory was about 9. This is considerably better than one would expect from the score of about 4 letters reported in the uncued condition in which the subject was asked to report letters from all three lines.

Sperling interpreted his results as suggesting the letters were being read from a rapidly decaying visual memory trace. In support of this view, Sperling describes a study in which the interval between the offset of the letters and the presentation of the cue specifying which line to report is systematically varied. The result showed that the advantage from cueing a single line declines until at about 500 ms the advantage disappears, which is consistent with the idea of a visual trace that has a persistence of about one-half second under these conditions.

Sperling performed another experiment in which he varied the brightness of the blank field occurring before and after the letters. If instead of darkness, or a uniform dim field, the letters are followed by a brighter flash of light, then performance is substantially impaired as if the flash of light were wiping out the iconic memory. This phenomenon had been previously studied by Baxt (1871). His results showed two things. First he demonstrated that the brighter the light, the poorer the performance, an effect known as brightness masking. Secondly, when he systematically varied the interval between the presentation of the items and the presentation of the flash, Baxt obtained a linear increase in the number of letters reported. A flash that occurs immediately after viewing is extremely disruptive to performance while a flash that occurs a longer time after the viewing of the letters is less disruptive. Sperling suggests that these results indicate that the letters are being transferred from some fragile peripheral store into some more durable form. What is the nature of this second, more durable stage? Sperling (1963, 1967) suggested they are read into a buffer containing motor control codes for subsequent speech, a phonological speech based coding. One reason for drawing this conclusion was the tendency for errors to be similar to the correct item in sound than in visual characteristics. Subsequent research has shown that features such as color, shape and direction of movement presented under conditions that make verbalization unlikely can all be stored within the iconic memory system, suggesting that the peripheral iconic information is probably fed into a further visual store, rather than mapped directly onto a speech code.

Turvey (1973) showed that iconic memory should be considered as storage occurring at a series of stages in the process of visual perception, rather than being the output of a simple passive peripheral store. Turvey studied the difference between two forms of masking: brightness masking and pattern masking. Pattern masking involves the disruption of performance by presenting a patterned stimulus after the experimental stimulus turns off. One crucial feature of a brightness mask is the amount of energy it contains. The disruptive effect of the mask is a ***joint multiplicative function*** of its brightness and its duration. Hence a 2 ms flash at an intensity of 20 ftL is equivalent to an 8 ms flash at 5 ftL. A second important feature of brightness masking is that the icon is only disrupted if the mask is presented to the same eye as the letters: presenting the letters to the right eye and the flash of light to the left eye does not lead to brightness masking. This suggests that the masking effect is occurring at the retinal level, before information from the two eyes is combined. In the case of pattern masking, intensity is not important. The most crucial feature is the interval between the presentation of the letters and the onset of the mask. Furthermore, the effect is not dependent on presenting the mask to the same eye as the stimulus. Presenting letters to the right eye and the pattern to the left eye will cause just as much masking as presenting both the letters and spatial mask to the same eye. This suggests that pattern masking occurs at some point in the system after information from the two eyes has been combined. Coltheart (1983) suggests that the iconic memory system does not operate by maintaining a stimulus for a standard amount after its offset, but rather guarantees a given persistence from the onset of the stimulus, hence having its maximum effect with briefly presented stimuli. As such, it is likely that the iconic memory system serves the function of ensuring that the perceptual system has some minimum amount of time to process the incoming stimulus.

Short term Visual memory

Posner, Boies, Eichelman and Taylor (1969) presented subjects with the task of deciding whether two letters did or did not have the same name, hence if shown AA or Aa, the subject should respond "yes". If given AB or Ab the subject should respond "no". Posner observed that subjects were about 80 ms faster when the letters were visually identical as well as having the same name (AA and aa were faster than Aa or aA). The second part of the study involved presenting the letters one at a time, varying the delay between presentation of the first and second letter. As the delay increased, the advantage to having the letters physically identical declined, and was completely lost after a delay of 2 seconds.

Phillips and Baddeley (1971) used matrices of cells with each cell in the checkerboard having a 50% probability of being black or white. 4x4, 6x6 and 8x8 checkerboards were employed. A given checkerboard pattern was presented, and after an interval ranging from 0 – 9 seconds was presented either an identical form, or a form with one cell changed. The subject responded "same" or "different". Performance was inversely related to matrix size and above chance performance persisted for 9 seconds for the most 4x4 and 6x6 matrices and for a little more than 2 seconds for the complex 8x8 matrix.

Short term Memory

Capacity of short term memory

Jacobs (1887) devised the technique that has become known as the memory span procedure in which the subject is presented with a sequence of items, often numbers, and required to repeat them back verbatim. His sequences begin with one item and are gradually increased in length until the subject fails to repeat the sequence correctly. He found the point at which the subject is correct 50% of the time, which is designated as the memory span.

Miller (1956) showed that immediate memory span was determined by number of "chunks" rather than the number of items, averaging about seven chunks. A chunk is an integrated piece of information, where remembering part of it will help you remember the rest. Memory span as measured in terms of items can be increased by increasing the number of items in each chunk. Another issue is possible short term forgetting.

Short Term Forgetting

The Brown-Peterson Paradigm

Brown (1958) and Peterson and Peterson (1959) devised experimental procedures that showed extremely rapid forgetting of small amounts of information provided the subject is briefly distracted. The technique involved presenting the subject with a consonant trigram such as HLM, followed by a number such as 492. The subject was required to repeat the number and then proceed to count backwards from it in threes until given a recall signal, whereupon he attempted to repeat back the consonants. The results when combined with the results of Murdock (1961) in which subjects were presented with unrelated 3 letter words showed: (1) Chunking occurs, 3 words is as easy to remember as 3 letters; (2) The secondary task reduced performance, with percent correct recall decreasing as the retention interval was increased. Recall, the subjects are counting backwards by 3 during the retention interval. Interference may also influence forgetting.

Trace Decay or Interference

A trace decay theory assumes that forgetting occurs as a result of the automatic fading of the memory trace. An interference theory assumes that forgetting reflects the disruption of the memory trace by other traces, with the degree of interference depending on the similarity of the two mutually interfering memory traces.

Proactive interference occurs when new learning is disrupted by old habits. Retroactive interference occurs when new learning disrupts old habits.

Release from proactive interference

Since interference is dependent on similarity, it should be possible to get rid of the proactive interference by changing the nature of the target items after the first few trials. Wickens, Born and Allen (1963) had subjects remember consonants for the first few trials and then switched to remembering numbers. Immediately after the switch, performance reverted to being almost perfect, which Wickens et al. referred to as release from proactive interference. Loess (1968) presented triplets of words from a given semantic category such as animals requiring recall after 15 seconds of backward counting. After presenting 6 sequences of animal names without warning his subjects, he switched to another category, say vegetables, and after 6 further trials switched again to a different category. The pattern of results was very clear: The first word triplet in each new category was very well recalled, the second somewhat less well, with performance leveling off by about the third or fourth, recovering each time the category was changed. The release from proactive interference effect could be explained by a discrimination hypothesis, if we assume that subjects are able to use the nature of the target item to rule out dissimilar prior items. If the category has just switched from animals to vegetables then there is no problem in rejecting earlier items (animals) in favor of target items (vegetables). Gardiner, Craik and Birtwisle (1972) presented their subjects with sequences of flower names in a standard Peterson procedure. The names were in fact separated into clusters of wild flowers and clusters of cultivated flowers. After a number of clusters of cultivated flowers, the category was switched to wild flowers. Virtually none of the subjects noticed this, and left to their own devices showed no release from proactive interference. One group, however, was informed of the classification wild versus cultivated with this group showing release from proactive interference.

One or Two Memory Stores?

Melton (1963) investigated evidence for long term learning in short term memory. He chose the Peterson task and memory span as the two characteristic short term memory tasks and showed that presenting an item several times enhanced its overall level of retention in the Peterson task. Melton performed an additional experiment where he had subjects doing the simple task of immediate recall of sequences of random numbers. The sequences were always of fixed length, the length being just beyond the subject's memory span. Unknown to the subject, rather than having a different random sequence on each trial, a given number sequence is repeated every 3 presentations. Under these circumstances, the probability of recalling the repeated sequence gradually increases over successive presentations, showing evidence of long term learning for short-term memory. There also exists evidence against a unitary view of memory.

Two component tasks

One of the strongest arguments against a one mechanism unitary view of memory comes from experiments using a task called "free recall", in which subjects are presented with a list of unrelated words and asked to recall as many as possible in any order they wish. Using this technique Postman and Phillips (1965) and Glanzer and Cunitz (1966) showed that when recall is immediate there is a tendency for the last few items to be very well recalled, termed the "recency effect." After a brief filled delay, however, the recency effect disappears, while performance on earlier items in the curve are relatively unaffected by the delay. Glanzer (1972) showed that the recency part of the curve is unaffected by a wide range of variables such as the familiarity of the words, their rate of presentation, the age of the subject or the requirement to perform some other concurrent task.

Storage capacity

A second argument against a unitary memory interpretation comes from evidence suggesting that primary memory or the short term store has a limited storage capacity, but relatively rapid retrieval. Secondary memory or the long term store on the other hand, has an enormous capacity, but tends to be slower to register information and to retrieve it. Arguments for the limited capacity of the short term store come principally from tasks such as the digit span, in which the subject appears to be able to hold about seven chunks of information (Miller, 1956). Murdock (1965) studied the effect of combining a distracting card sorting task with free recall. Subjects were required to sort cards into one pile, two colors, four suits or eight categories based on number, at the same time as hearing a sequence of words for immediate recall. The attentional demand made by the sorting task increased with number of sorting alternatives causing a systematic decrement in performance on the earlier part of the free recall curve. In contrast, the recency effect was not influenced by concurrent load, suggesting that input into primary memory or short term store system may be less attention demanding than long term learning. Waugh (1970) found that responses from the recency part of the curve were consistently faster than responses from earlier serial positions, prompting her to suggest that retrieval from primary memory may be easier than from long term memory.

Acoustic and Semantic coding

Conrad (1964), as part of a series of experiments concerned with the retention of telephone codes, noted that when such codes comprised consonants the recall errors made by subjects were typically similar in sound to the correct item even when the letters had been presented visually. Hence P was more likely to be misrecalled a V, a letter similar in sound, than a visually similar letter such a R. Conrad showed that the pattern of errors made in remembering visually presented sequences of consonants was very similar to the pattern of listening errors made when the subject was discriminating individual auditorily presented letters presented against a background of noise. He suggested that the items were stored in some form of acoustic code. Conrad and Hull (1964) showed that sequences of items that were similar in sound were harder to recall than sequences of dissimilar sounding letters. Wickelgren (1965) showed that the effect stemmed principally from the difficulty in recalling the order of the items; if anything, similarity tended to help recall of the letters themselves.

Baddeley, (1966a) presented subjects with sequences of 5 words for immediate serial recall. The words were selected from either a phonologically similar set, which produced sequences such as man, mad, cap, can, map, or dissimilar sequences such as pen, rig, day, bar, sup. Similarity of meaning was manipulated using sequences of adjectives having either the same meaning such as big, huge, broad, long, tall, or different meanings as in old, late, thin, wet, hot. Subjects performed very poorly when the sequence contained phonologically similar words, indicating that subjects were remembering the items in terms of their sound or articulatory characteristics. Baddeley (1966b) opined the simple generalization that the short term store relies on a phonological code, while the long term store is primarily concerned with meaning.

Kintsch and Buschke (1969) used a probe technique in which a sequence of items is presented, and recall tested by presenting one of the items again and requiring the subject to say what followed. Hence, if the sequence were 1 5 3 9 2 and the probe was 5, then the correct response would be the following item, 3. Kintsch and Buschke presented sequences containing pairs of similar items. The similarity was either in terms of sound or in terms of meaning. They observed that both kinds of similarity tended to impair performance compared to lists containing only dissimilar words. However, the pattern of impairment was different for the two types of similarity, with the recency part of the curve suffering most from phonological similarity, while similarity of meaning tended to influence the long term store based part of the curve. Waugh and Norman (1965) have shown that this task also has a recency component, which they suggest is dependent on primary memory or on the short term store, while the performance on earlier items is assumed to reflect secondary memory or long term store. Sachs (1967) presented subjects with passages of prose. Occasionally a sentence would be repeated, and the subject's task was to decide whether the sentence was exactly as it had been previously, or whether some change had been made. When a change occurred, it could either involve a syntactic modification, or it could involve a change in meaning. The delay between presenting a target sentence and testing it ranged from an immediate test to several sentences later. Sachs found that if the sentence was tested immediately, subjects were good at detecting all changes, whether in meaning or syntax. After one or more intervening sentences the subject's capacity to remember the syntactic and surface features of the prose dropped dramatically, while retention of the meaning remained excellent.

Neuropsychological Evidence

Perhaps the strongest evidence for separate short and long term memory systems came from studies of brain damaged patients.

The Role of Memory in Cognition: Working Memory.

Testing the working memory hypothesis

A widely held assumption is that short term store acts as a temporary working memory that helps us perform a range of other cognitive tasks. (Atkinson and Shiffrin, 1968; Hunter, 1957; Newell and Simon, 1972) Badelley decided to test it by using a dual-task technique whereby the subject is required to perform one task that absorbs most of the capacity of working memory, while at the same time performing each of a range of tasks such as learning, reasoning and comprehending that are assumed to be crucially dependent upon working memory. If the assumption is correct, then performing a concurrent short term memory task should lead to a dramatic impairment in performance. Digit span was the concurrent memory task studied in this context, with digit loads of 3 or 6 items. Subjects rehearsed the digit out loud, ensuring that they were performing both tasks simultaneously. In one study, subjects were required to remember number sequences ranging from zero to eight digits in length, while at the same time performing a reasoning test. The reasoning test involved verifying a series of sentences each of which purports to describe the order in which two successive letters, A and B, were presented. The subject's task is to decide whether the sentence correctly describes the order or not. Examples ranged from simple active declarative sentences such as A follows B –BA (true) to more complex sentences involving passives and/or negatives such as B is not preceded by A – AB (false). The reasoning time increases clearly and systematically with concurrent memory load, just as a working memory hypothesis would predict. A broadly similar pattern of results was obtained across a range of other cognitive tasks. In one study, the free recall of lists of unrelated words was studied when they were accompanied by a concurrent digit span of zero, three or six items. Performance on the earlier part of the serial position curve, normally associated with long term learning was impaired by the concurrent load of 6 digits, while a 3 digit load had no effect on performance. In Baddeley and Hitch (1974), comprehension of prose passages was studied in subjects who were concurrently remembering sequences of zero, three or six unrelated digits. The level of comprehension was significantly impaired by the six digit, but not the 3 digit load. Baddeley, Lewis, Eldridge and Thomson (1984) found that despite a clear effect on learning, concurrent digit span during retrieval from long term memory was found to have no effect on accuracy of performance, although it did produce an increase in retrieval latency. The requirement to remember and recite a six digit number had no effect on the accuracy of recalling or recognizing lists of words, whether tested by free recall or paired associate learning. Working memory models have been proposed.

A Working Memory Model

Baddeley proposed a model of working memory in which a controlling attentional system supervises and coordinates a number of subsidiary slave systems. The attentional controller influences two subsystems, the articulatory or phonological loop which is assumed to be responsible for the manipulation of speech based information, and the visuo spatial sketchpad, which is assumed to be responsible for setting up and manipulating visual images.

The Phonological loop

The phonological loop is assumed to comprise two components, a phonological store that is capable of holding speech based information and an articulatory control process based on inner speech. Memory traces within the phonological store are assumed to fade and become irretrievable after about 1.5 to 2 seconds. The memory trace can however be refreshed by a process of reading off the trace into the articulatory control process which then feeds it back into the store, the process underlying subvocal rehearsal. The articulatory control process is also capable of taking written material, converting it into a phonological code and registering it in the phonological store. This simple model of a phonological store served by an articulatory control process elicits a coherent account of the following phenomena.

The Phonological Similarity Effect

The phonological similarity effect is assumed to occur because the store is based on a phonological code, hence similar items will have similar codes. Recall will require discriminating among the memory traces. Similar races will be harder to discriminate, leading to a lower level of recall. Another phenonoma is the unattended speech effect.

The Unattended Speech Effect

Colle and Welsh (1976) performed a study in which subjects attempted to repeat back sequences of visually presented numbers. In one condition, immediate serial recall was accompanied by the sound of someone reading a passage in German, a language the subjects did not understand. Nevertheless, performance on the immediate memory task showed a clear decrement.

Baddeley, 1966a discusses an experiment in which subjects attempted the immediate recall of nine visually presented digits which were presented either in silence, or accompanied by spoken words or spoken nonsense syllables, both of which the subject was instructed to ignore. Performance was disrupted to an equal extent by both words and nonsense syllables. They concluded that the unattended material was gaining access to the phonological store, a store that holds phonological but not semantic information. Baddeley's conclusion was reinforced by a subsequent experiment in which subjects again attempted to remember visually presented digit sequences, this time against a background either of other digits, or of other words made up from the same phonemes as digits (e.g. tun, woo instead of one, two). A third condition involved ignoring words that were phonologically dissimilar disyllables (e.g. happy, tipple), while a fourth comprised a silent control condition. The disyllables caused some disruption but not so much as the monosyllables having the same phonological characteristics as digits. These did not, however differ in their degree of disruptiveness from actual digits, suggesting the store contains phonemic information but does not represent items at a word level, otherwise the digits would have been expected to be more disruptive than the non digits made up from the same phonemes.

Salame and Baddeley, (1987; 1989) compared the effects of unattended speech with that of unattended noise on immediate serial recall of digits. Unattended speech produced a clear effect. But noise produced no performance decrement, even when the noise was pulsed so as to give the same intensity envelope as continuous speech. The effect is not influenced by the intensity of the unattended speech provided that it is clearly audible (Colle, 1980; Salame and Baddeley, 1987).

Salame and Baddeley (1989) studied the effect of music by having subjects recall sequences of visually presented digits against a background of either vocal or instrumental music. Whether the vocal music came from nineteenth century opera in an unfamiliar language or from a current pop star singing in the subject's native language, the disruption was the same and approximately equivalent to that produced by unattended speech. Instrumental music produced a reduced effect.

The Word Length Effect

Another powerful determinant of immediate memory span is the spoken duration of the words presented. Hence most subjects would relatively easily remember a sequence of 5 monosyllabic words such as wit, sum, harm, bag, top, but would have considerable difficulty in repeating back a sequence of polysyllables such as university, opportunity, aluminum, constitutional, auditorium. Baddeley, Thomson and Buchanan (1975) performed an experiment using this approach. The results indicate that memory span represents the number of items of whatever length that can be uttered in about 2 seconds. There is a correlation between the rate at which a subject speaks and his or her memory span. Is the crucial feature *spoken duration* or the *number of syllables*? Duration appears to be the critical variable since sequences of words that tend to have long vowels and be spoken slowly such as Friday and harpoon lead to somewhat shorter spans than words with the same number of syllables and phonemes that can be spoken more rapidly.

Hoosain and Salili (1988) reported a mean articulation rate of 265 ms per digit for Chinese speaking people as compared to 321 ms per digit for English speaking people and 385 ms per digit for Welsh speaking people (from Ellis and Hennelly (1980)). Mean digit spans for these groups was 9.9 for Chinese, 6.6 for English and 5.8 for Welsh. Hoosain and Salili also report a correlation between memory span and mathematics exam grades of 0.38. They also report that recitation of multiplication tables is much faster for Cantonese speaking Chinese undergraduates (mean time = 64.3 seconds) than for U.S. undergraduates using English (134.2 seconds.

How should the word length effect be interpreted? The simplest account might be to suggest that the process of overt or covert articulation involves setting up and running speech motor programs which operate in real time, with the result that the longer the word the longer it takes to run off. If we assume that this process of subvocal rehearsal has the function of maintaining items in the phonological store by refreshing their fading traces, then the faster it can run, them more items will be maintained and the longer the memory span. If we assume that the memory fades, then the memory span will be determined by the number of items that can be refreshed before they fade away. That number will depend both on how rapidly the trace fades and on how long it takes to articulate each item and hence refresh each memory trace. Data suggest that trace decay time is approximately 2 seconds.

Chunking and the Phonological Loop

The essence of the phonological loop hypothesis is that memory span will depend on rate of rehearsal, being approximately equal to the number of items that can be spoken in 2 seconds. Hence the number of items recalled will be a function of how long they take to articulate. Where does this leave Miller's magic number seven, which suggests that memory span will reflect a constant number of chunks, regardless of the characteristics of those chunks? Simon collaborating with a group of Chinese colleagues took advantage of some of the features of the Chinese language to explore the articulatory loop and chunking hypotheses, (Zhang and Simon, 1985; Yu, Zhang, Jing, Peng, Zhang and Simon 1985). Zhang and Simon directly pitted the chunking hypothesis against the phonological loop hypothesis. Using 3 types of material which were equivalent in that each comprising familiar chunks, but differed in ease and speed of pronunciation. One set comprised radicals, the complex components which go to make Chinese characters and words. There are about 200 radicals in the Chinese language, and they are likely to be highly familiar to their Chinese subjects since they are, for example, used for indexing dictionaries. They do not, however, have commonly used oral names. The second set of material used comprised Chinese characters, each of which was made up from two radicals, with each having definite single syllable pronunciation. The third set of material comprised Chinese words, each comprising two characters and having two syllables in their pronunciation. A simple chunking hypothesis would predict no difference between the three sets of material, since in each case the constituent items comprise familiar chunks. The phonological loop hypothesis on the other hand would predict very poor performance for the radicals which have no familiar name, with somewhat better performance for the disyllabic words, and the best performance for the monosyllabic characters. This is exactly what happened. Further evidence for the phonological loop came from intrusion errors, of which almost half were homophones, items that have the correct pronunciation but are written differently. Chinese has a large number of homophones, and since the pictographic script is not based on the sound of the items depicted, such homophones are typically written quite differently. Zhang and Simon, 1985 took advantage of this in order to explore further the role of phonological coding. They used nine distinct characters, all of which are pronounced "gong" with high tone in Chinese. Memory span for these items was tested together with memory span for the unpronounceable radicals. The span for the radicals was 3.00 and for the homophones 2.83, both very low levels of performance. In a third experiment, Zhang and Simon explored memory span for items varying in number of syllables, testing memory for characters, comprising one syllable, words with two syllables and idioms comprising four syllables. The data show that memory span does not represent a constant number of chunks, it does not either represent a constant number of syllables. Syllables within chunks tend to lead to faster articulation than do syllables that comprise separate chunks. Zhang and Simon, 1985 propose that memory span is determined by rehearsal rate, but that this in turn depends on three factors: (1) The interval of time required to bring each chunk into the articulatory mechanism, (a) (2) The interval of time required to articulate each syllable in the chunk beyond the first (b) and (3) The average size of a chunk in syllables (S). This yields an equation that can be used to express either T, the duration of the underlying storage parameter, or C, the STM capacity in chunks.

$$T = C[a+b(S-1)] \quad \text{or} \quad C=T/[a+b(S-1)] \qquad (1)$$

Zhang and Simon (1985) show that these equations fit a wide range of experimental results collected in Chinese and also the data on word length and memory in English reported by Baddeley, Thomson and Buchanan (1975).

How to Employ Animation?

As discussed in Fabrikant & Goldsberry (2005), much of the prior work has focused on geovisualization displays with an emphasis on thematic relevance and perceptual salience. Thus, the goal is to identify the focus of attention of a visual system based on the "where" the salient features exist, not the "what" or semantic characteristics.
Our goal, however, is not to use animation to increase the efficiency of a training process or to provide better understanding. Thematic relevance isn't really an issue, since we

assume battle planners and war fighters are well versed in the realities and concepts of offensive and defensive combat. We want to get the information to the war fighter in the most efficient manner possible. If animation can effectively increase the information uptake bandwidth, then it should be considered as part of the display process.

VIII. Summary and Conclusions

A compendium of glyph/icon studies has been summarized involving the early visualization renderings going back over 1000 years to present investigations that may include animations. Every type of visualization may contain certain strengths and weaknesses. For MIL-2525B, certain parsing of dimensions may lead to better use of the visual rendering in delivering information to the decision maker or war fighter by not overloading his ability to glean Meta information from such an object at the same time providing a sufficiently rich information environment to serve the operator's needs.

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