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Visualization of Uncertainty

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With the changing character of warfare, information superiority is a high priority. Our decision makers must be able to accurately assess the situation, decide upon a course of action, and set that course of action in motion before the adversary can react. It's always a challenge to provide decision makers with the right information in an easily understandable format. This is particularly true as more and more information can be made available. It becomes very important to display the right information at the right time and to make it easy to find and understand. Today's new computer and display technologies afford us a broad array of options for information presentation. Our challenges is to develop display interfaces that deliver decision-quality information culled from various sensors/systems directly to decision-makers.

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Visualization of Uncertainty

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Summary

With the changing character of warfare, information superiority is a high priority. Our decision makers must be able to accurately assess the situation, decide upon a course of action, and set that course of action in motion before the adversary can react. It's always a challenge to provide decision makers with the right information in an easily understandable format. This is particularly true as more and more information can be made available. It becomes very important to display the right information at the right time and to make it easy to find and understand. Today's new computer and display technologies afford us a broad array of options for information presentation. Our challenge is to develop display interfaces that deliver decision-quality information culled from various sensors/systems directly to decision-makers.

Decision makers want to understand the uncertainties associated with the information provided to them. New display techniques are needed to enable the decision maker to understand the meta-data associated with information. Some examples of meta-data include:

- Where did the information come from?
- What types of uncertainty are associated with the data?
    - Sensor precision & range limits
    - False variation due to noise
    - Human observers' limits of perception or trust/reliability
- How old is the data?
- Has the data been filtered by models? What might have been lost in the filtering process?

Air Force Research Laboratory Human Effectiveness Directorate researchers are working to develop and validate a new generation of icons for battlespace visualization. These "knowledge glyphs" will portray multiple dimensions of information as well as the uncertainty associated with each. There are a number of research issues to be addressed:

- How many dimensions can be displayed in one glyph and be readily understandable by the user?
- How can the uncertainties associated with information be displayed?
- Should glyphs be 2D, 3D, or 4D?
- Should all information associated with a dimension be displayed at once, or should there be drill down?
- Should glyphs be temporally dynamic?
- How will the perception of information change as a function of screen resolution?
- Can glyphs be created that counter information bias?

Decision-makers must be able to visualize the battlespace in order to assess current and future situations. Information portrayal must support this process and promote more rapid assimilation of data. This requires a systems engineering approach, in which the decision-maker is treated as part of the system along with computer and display technologies. There are many new and creative concepts for display of information. However, very few have been tested. Laboratory experimentation is needed to optimize and validate new display concepts for specific applications.

Visualization of Uncertainty

November 2005

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I'm from the Battlespace Visualization Branch of HECV. Our branch conducts research in the two broad areas of Visualization and Vision Enhancement for a variety of Air Force applications, including cockpits and command and control centers.

Visualization of Uncertainty
Problem Statement

- **Current military displays do not provide decision-makers with all the information they need**
- **Displayed information is not always intuitive**
- **Decision-makers would also like to understand the uncertainties associated with the information that is provided to them**
  - **Age of information**
  - **Reliability of source**
  - **Conflicting data**
  - **Etc.**

2

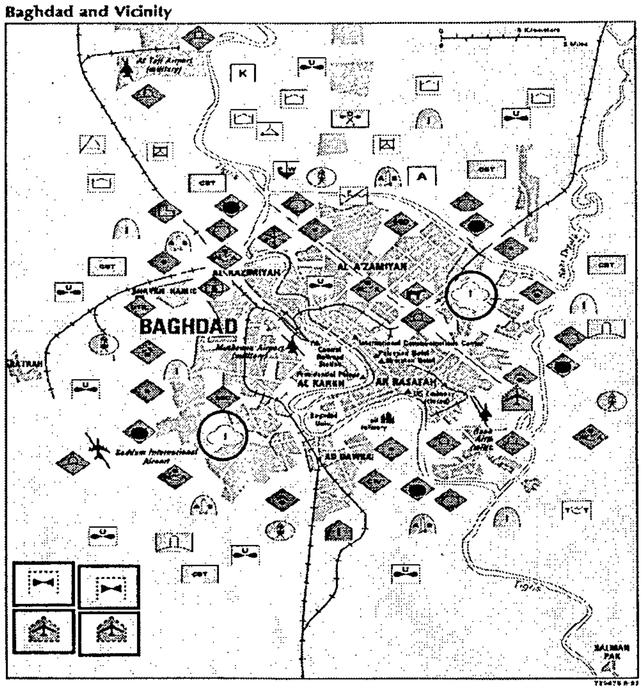
It's always a challenge to provide decision makers with the right information in an easily understandable format. This is particularly true as more and more information can be made available. It becomes very important to display the right information at the right time and to make it easy to find and understand.

Particularly in the area of command and control, decision makers want to know the uncertainties associated with the information they are using. A few types of uncertainty are listed here.

Current

Mil-Std-2525

Symbology



Here is a map with some examples of current military symbology. These symbols can show as many as 10 different dimensions of information about an entity. However, they do very little to address uncertainty. For example the circled icons represent air tracks. The yellow color and irregular shape indicate that they are unknowns. The icons in the square boxes on the lower left represent aircraft (the green symbols are neutral rotary wing and the red are hostile fixed wing. The dotted line surrounding the symbol indicated that it is expected or planned as opposed to actual. These are the only instances in which this symbology set addresses uncertainty.

Visualization of Uncertainty
Challenges and Opportunities

Challenge:

"Stop concentrating on individual systems and start focusing on the information they provide . . . Automate processing so that information can be displayed intuitively. In doing that, operators can make better decisions more quickly . . . The sum of the wisdom is a cursor over the target . . . Want to see interfaces that deliver decision-quality information culled from various sensors/systems directly to decision-makers"

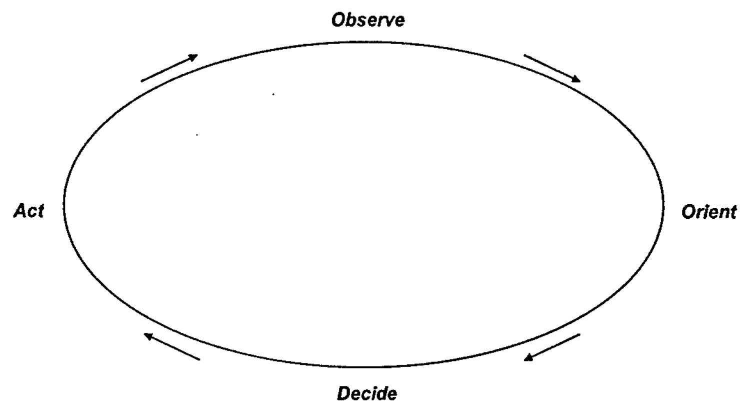
- *Source: General John Jumper, CSAF at C2ISR Summit, AF Magazine, June 02*

4

As stated here by Gen Jumper, our challenge is to deliver decision quality information to decision makers.

Visualization of Uncertainty
Better Decisions = Speed and Accuracy

OODA Loop



5

All of you are probably familiar with the OODA-loop. The goal is to cycle through the process of Observe-Orient-Deciding-Acting faster than the adversary. Better visualization will help decision-makers to make the right decision faster.

Visualization of Uncertainty
Challenges and Opportunities

Opportunities:

- **More Computer Processing Power**
- **Increasing Bandwidth**
- **Greater Graphics Capabilities**
- **New Display Technologies**

Not so many years ago, our options for displaying information were text or tabular displays or analog instruments. Today's new and improved technologies afford us a broad array of options for information presentation. But, more is not always better. We must be sure to design our displays with human perceptual and cognitive capabilities and limitations in mind.

Visualization of Uncertainty
Goal

Develop visualization concepts to provide decision makers the information they need in a format that is quickly and easily understandable

- **Approach:**
  - **Explore information portrayal capabilities of multidimensional icons**
  - **Explore information portrayal capabilities of dynamic icons**
  - **Explore other methods for portraying uncertainty**

7

Other methods might include drill down to secondary icons or textual information.

Visualization of Uncertainty Approach

- **Focus – Common Operating Picture**
- **Multiple map layers**
- **ID important entities for each layer**
- **ID information requirements for each**
- **ID associated uncertainties**
- **Evaluate adaptation potential of current symbology as well as other visualization techniques**
- **Evaluate applicability of new display technologies**
- **Develop visualization concepts**
- **Test experimentally**

8

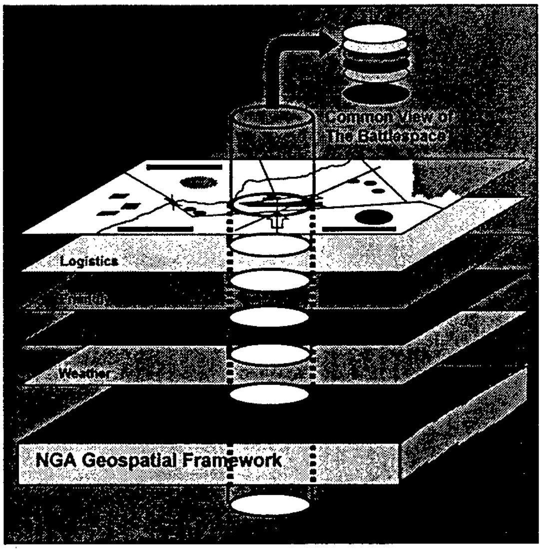
We're focusing on a common operating picture (COP), because everyone seems to agree that one is needed. However, there is not a lot of agreement as to what exactly should be included in the COP. First, we need to look at the user. What is his function. What tasks does he need to perform. What information does he need to perform each task. We start with a map, because a geospatial foundation is needed on which to overlay other information. A layered map is just one concept – others include various declutter mechanisms or a lens for getting greater detail in a given area.

After we've identified all the dimensions of information required, we can then identify the uncertainties associated with each information dimension.

New display technologies, such as depth displays and 3D displays may offer potential for information display.

Experimental testing of new visualization concepts. There are many new ideas for display of information. However, very few have been tested and validated for specific applications.

Visualization of Uncertainty
Global Common Operating Picture?

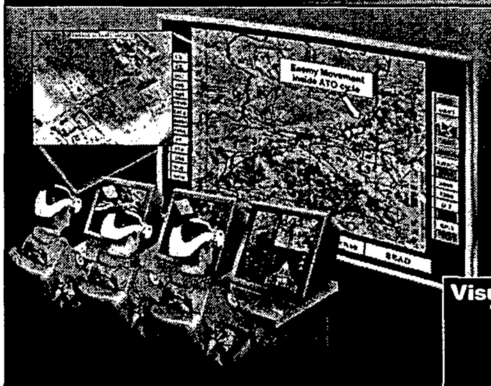


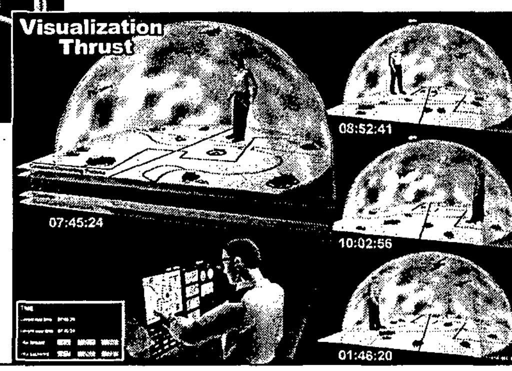
9

Here's just one display concept for the common operating picture. All layers of the map are georeferenced. Any layer, with it's appropriate detailed information can be accessed.

Visualization of Uncertainty
Information Visualization

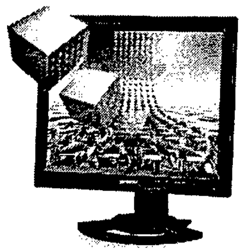
Future Concepts

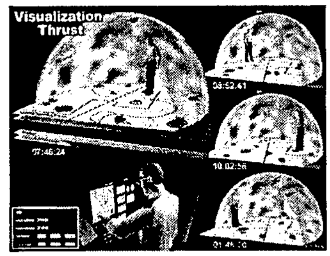




Here are just two display concepts for future command centers.

Visualization of Uncertainty
Display Technology Evaluations





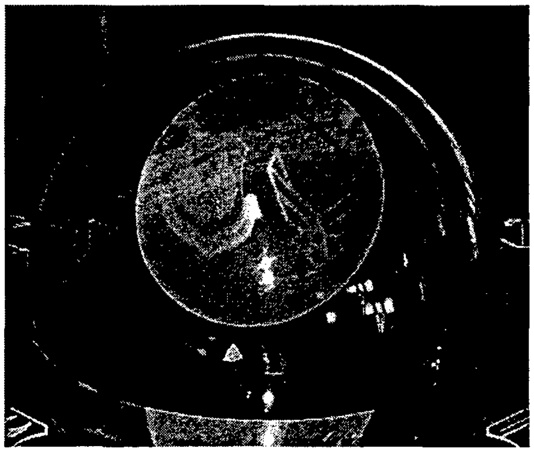
- Sharp 3D display
  - Software and special screen = 3D
  - But...not without problems
    - Can be hard on the eyes
    - The "eye box" is quite small
    - No one has really shown the benefit of 3D especially as compared to 2D for complex scenes

- Immersive/VR is still in a very embryonic stage
  - More concerned with "fun" than functionality
  - How do you interact with information that is all around?
    - 3D audio?
    - Visual cues?
    - Tactile cues?
    - All of the above?

11

There are a number of new display technologies coming on the market. These look exciting and may have potential for military applications. However, there are a number of issues to be resolved. Laboratory testing is needed to assess the potential usefulness of these displays for particular applications.

Visualization of Uncertainty
Display Technology Evaluations



Perspecta Volumetric 3D
360-degree viewing
- **Problems**
  - **See thru**
  - **Poor contrast**
  - **Size limitations**

12

Another exciting display technology, but how do we interact with it?

Visualization of Uncertainty
Beyond Mil-Std-2525 Symbology

- **New display techniques are needed to enable the decision maker to understand the meta-data associated with information**
  - **Where did the information come from?**
  - **What types of uncertainty are associated with the data?**
    - **Sensor precision & range limits**
    - **False variation due to noise**
    - **Human observers' limits of perception or trust/reliability**
  - **How old is the data?**
  - **Has the data been filtered by models? What might have been lost in the filtering process?**

13

We need a single symbol/icon which portrays multiple dimensions of information as well as the uncertainty associated with each

Applicable Joint Forces Command S&T Focus Areas include:

Effects Based Operations Visualization Tools

3D Sensor Fusion

Persistent and Pervasive Intelligence Surveillance and Reconnaissance

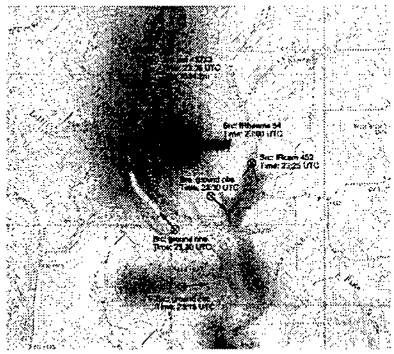
Predictive Battlespace Analysis

Joint Urban Warfare

Visualization of Uncertainty
Knowledge Glyphs

Develop next generation of icons

- **Temporally dynamic graphic objects that integrate and encode multiple types of information**
- **Temporal variability and graphic representation enable the glyph to express various types of uncertainty**
- **Readily understandable by the user**



ATC-NY

14

Some concepts for Knowledge Glyphs

Visualization of Uncertainty
Knowledge Glyph Research Issues

- 2D, 3D, or 4D?
- How can the uncertainties associated with information be displayed?
- How many dimensions can be displayed in one glyph?
- How many dimensions can a human perceive at one time?
- Should all information associated with a dimension be displayed at once, or should there be drill down?
- How will the perception of information change as a function of screen resolution?
- Can glyphs be created that counter information bias?

15

There are a number of research issues that must be addressed in the creation of Knowledge Glyphs.

Visualization of Uncertainty
Improved Decision-Making Using Complex Icons

AFOSR-funded basic research

Objectives: To Answer the Following Basic Research Questions

(1) How many elements of information can effectively be conveyed by a single icon?

(2) How can associated information uncertainty be effectively conveyed?

(3) Utility of dynamic icons?

Issues:

(a) Icon selection or design

(b) What kind of information should be portrayed with an icon

16

HEC has received funding from the Air Force Office of Scientific Research to look at some basic research issues related to complex icons.

Elements of information that might be portrayed on an icon include:

Location

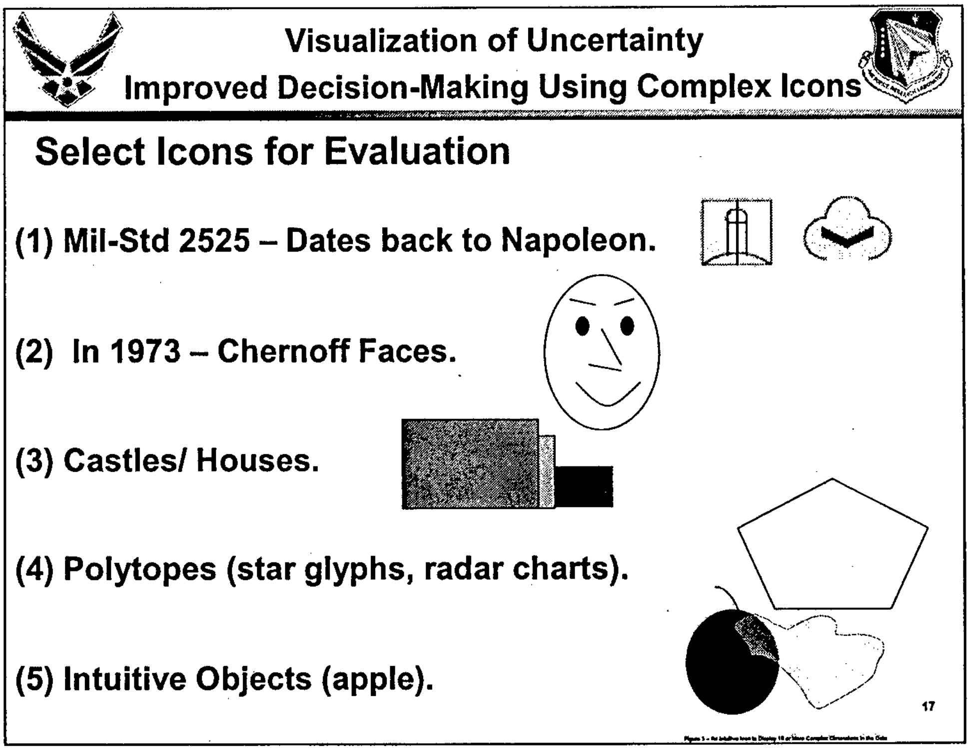
Size

Identity

Friend vs foe

Association

capability



Some examples of multidimensional icons.

Visualization of Uncertainty
Improved Decision-Making Using Complex Icons

Dimensions for Coding Information

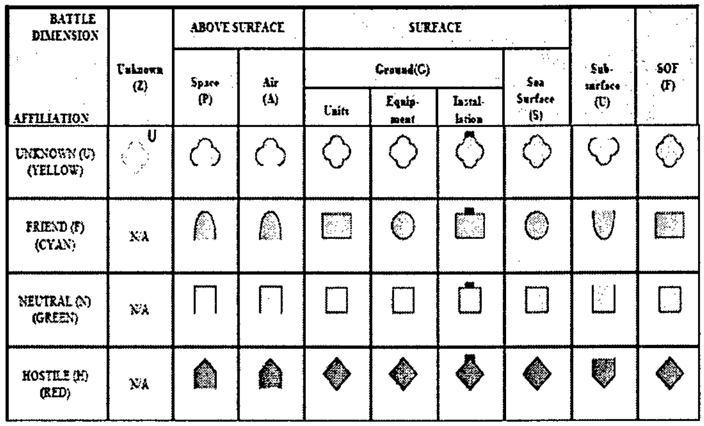
- **Shape**
- **Color**
- **Size**
- **Texture**
- **Transparency**
- **Orientation**
- **Position**
- **Movement**

18

Here are just some of the characteristics of icons that might be applied to coding various dimensions of information. Some may be more salient than others.

Visualization of Uncertainty
Improved Decision-Making Using Complex Icons

Mil-Std-2525 Symbology: 2 – 2.5 D of Information

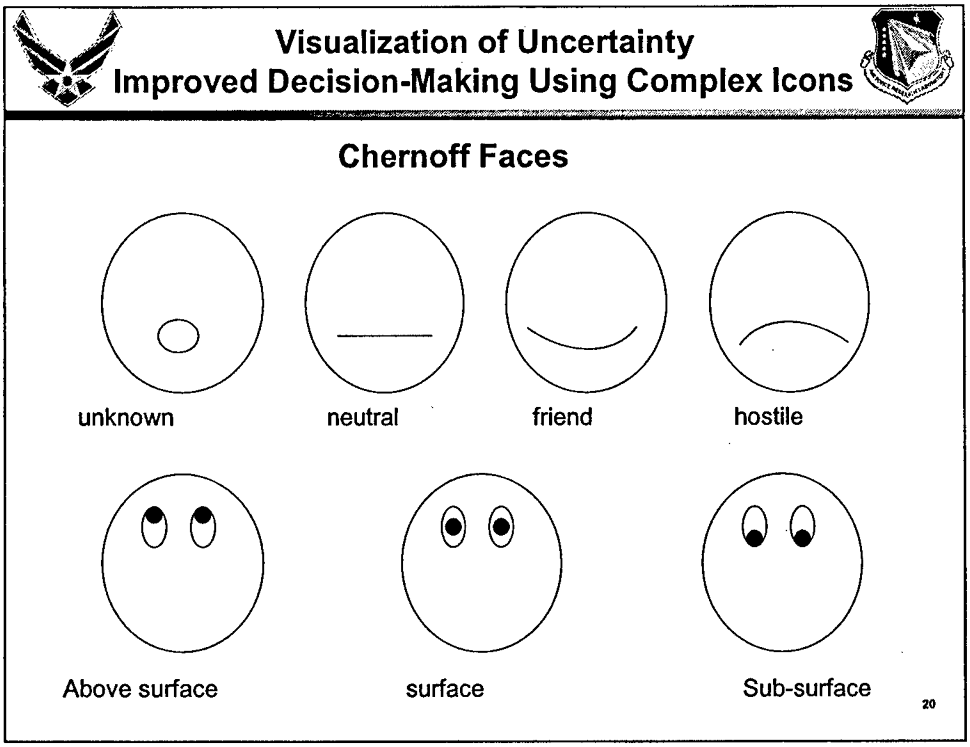


19

Color is used to code affiliation.

Shape is used to depict battle dimension - surface vs space or air vs sub surface.

Installation is depicted by adding another shape.



We might depict affiliation and battle dimension intuitively using chernoff faces. Adding more dimensions of information would be more difficult.

Visualization of Uncertainty
Improved Decision-Making Using Complex Icons

Intuitive Apple Coding Dimensions

- **Color – age of data**
- **Shiny – sensors vs rough – database**
- **Stem length - fuel**
- **Stem width - armed**
- **Movement**
- **Cloud – conflicting data**

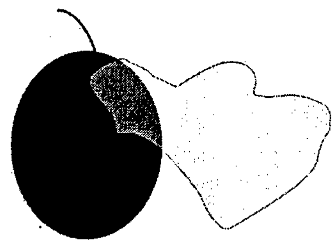


Figure 3 – An Intuitive Icon to Display 10 or More Complex Dimensions in the Data

21

Here’s another attempt at encoding information dimensions intuitively. This representation was developed by Dr. Dan Repperger at AFRL.

Visualization of Uncertainty
Improved Decision-Making Using Complex Icons

Information Theory Analysis

We model the human as an information channel. We calculate the effective information throughput as a function of icon complexity.

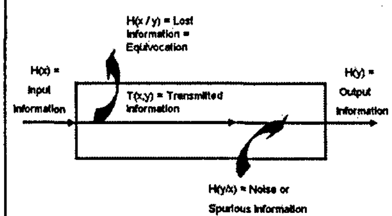


Figure 1 – Basic Elements of the Information Channel

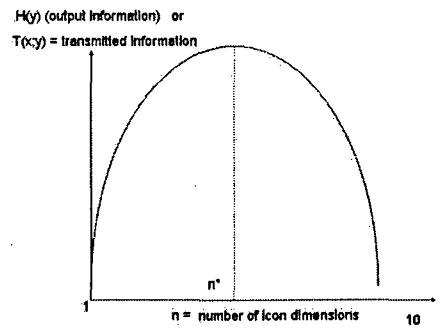


Figure 2 – Hypothesized Shape of T(x;y) or H(y) versus n = number of icon dimensions

(cf. Hick, Hyman Law the precursor to Fitts' Law).

22

The studies in information theory involving humans can be traced to one of the first published works in this area by Merkel (1885). Using strip chart recorders and other crude time measurement devices, in his early experiments, he noted that the time to complete a task with a number of alternatives or choices was always longer if the number of choices increased. In particular, he distinguished between the time to perform a pure reaction task (no choices) and the time to make a decision on a complex task and then to react. The distinction was made between reaction time and decision time. The decision time was defined as the difference between the total time to complete the complex task and the pure reaction time.

C. E. Shannon's seminal book (Shannon (1949)) is sometimes viewed as the birth of information theory when he documented 8 axioms that define what makes up an information channel. Shannon emphasized using the unit of a bit or log base 2 of the number of choices, which eventually became the standard to measure information. Work then began in studying how humans process information. At Cambridge, England, W. E. Hick publicized (Hick (1952)) a linear relationship between human reaction time to the logarithm of the number of alternatives (equally likely alternatives). In the next year, R. Hyman, from the Johns Hopkins University in the USA documented a similar result (Hyman (1953)). This became known as the Hick-Hyman Law and deal with the "perceptual loop" aspects of human information processing. Again, the time for a human to reaction to a complex perceptual stimulus was proportional to the logarithm of the number of alternatives of the complex stimuli..

Visualization of Uncertainty
Improved Decision-Making Using Complex Icons

Calculation of the Information Overload Point

Part a – Response Matrix

inputs ↓ / outputs →

inputs \ outputs	1	2	3	4
1	27	2	1	0
2	2	19	1	1
3	1	2	22	1
4	0	1	3	24

Part b – Calculate Contingency Matrix.

				H(x)
27/107	2/107	1/107	0	30/107
2/107	19/107	1/107	1/107	23/107
1/107	2/107	22/107	1/107	26/107
0	1/107	3/107	24/107	28/107
30/107	24/107	27/107	26/107	

H(y)

Part c – Calculate T(x;y)

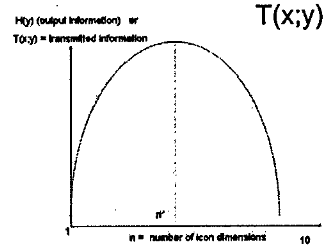
$H(x) = \Sigma p(x_i)\log_2(1/p(x_i))$

$H(y) = \Sigma p(x_j)\log_2(1/p(x_j))$

$H(x,y) = \Sigma p(x_i,y_j)\log_2(1/p(x_i,y_j))$

$T(x;y) = H(x)+H(y)-H(x,y)$

T(x;y)



Number of icon dimensions

Figure 2 – Hypothesized Shape of T(x;y) or H(y) versus n = number of icon dimensions

The information overload point is calculated as shown here. As the graph in the lower right shows, we can determine the number of information dimensions that will result in information overload. Information overload is said to occur when information begins to be lost in the transfer process.

Visualization of Uncertainty
Improved Decision-Making Using Complex Icons

Accomplishments to Date:

- **Pilot study using Mil-Std 2525 symbology – 10 dimensions**
- **Preliminary findings – information overload occurs beyond 4-5 dimensions of information**

The way ahead:

- **Explore saliency of various coding dimensions**
- **Explore other symbol sets**
- **Explore effects of dynamics**

24

We've just completed a pilot study using Mil-Std 2525 symbology with up to 10 dimensions of information. We found that for this particular symbol set and coding, information transfer tended to deteriorate if more than 4 or 5 dimensions of information were displayed at once.

We've seen that some coding techniques, such as color and shape, facilitate information transfer better than others. This will be explored further. We'll also look at other symbol sets to see if the same rules apply.

Then we'll explore the effects of dynamic coding dimensions.

Visualization of Uncertainty
Collaborations

- ***Participation with NGA and NSA Technology Futures Collaboratory***
  - ***Visualization of Intelligence Information***
- ***Participation in Visualization of Uncertainty Workshop***
  - ***National Academy of Sciences***
  - ***National Security Agency***
  - ***Academia***
- ***Collaboration with AFRL/IF – C^2 Concepts for a New Generation***
- ***Collaboration within AFRL Human Effectiveness Directorate***
  - ***Cognitive Systems (HECS) / Battlespace Visualization (HECV) / Collaborative Systems (HECP)***
    - ***Knowledge Glyphs for CPE***
    - ***Complex Icons and Information Theory***

25

Visualization of uncertainty is receiving a good deal of attention. These are just some of our collaborations.

Visualization of Uncertainty
Summary

- Decision-makers must mentally *Visualize* to assess current and future situations
- Information portrayal must support this process and promote more rapid assimilation of data
- Requires a systems engineering approach
  - Computer and display technologies
  - Decision-maker as part of system
    - Perceptual capabilities / limitations
    - Cognition / Decision Theory
  - Mission Requirements – Measures of Effectiveness

26

In dealing with complex information transfer, we need visualization techniques that help the decision maker to quickly assess and understand the situation.

We emphasize a systems engineering approach where the decision maker is part of the system, as well as the computer and display technologies. We need to design the system with the human's perceptual capabilities and limitations in mind as well as understand how humans assimilate and use information to make decisions. And, of course, we must always stay focused on the mission requirements and how we can quantify the effectiveness of any visualization technique.