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GRAPHICAL TECHNIQUES FOR FORCE LEVEL PLANNING

General Electric Company

Dipen Moitra, George D. Montanaro, Catherine Chalek

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Rome Laboratory
Air Force Systems Command
Griffiss Air Force Base, NY 13441-5700

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APPROVED:

EARL C. LABATT, JR.
Project Manager

FOR THE COMMANDER:

RAYMOND P. URTZ, JR.
Technical Director
Command, Control, & Communications Directorate

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6. AUTHOR(S)
Dipen Moitra, George D. Montanaro, Catherine Chalek

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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P.O. Box 8
Schenectady NY 12301

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13. ABSTRACT *(Maximum 200 words)*

This report presents novel interactive graphical techniques for performing Air Force planning tasks such as deploying aircraft and weapons against desired targets, determining the availability of resources, performing a cost benefit analysis to improve resource use, coordinating interdependent missions, and assessing the strategic value of a set of mission plans in a theater of operations. The most fundamental aspect of force-level planning is that it is an iterative process, during each cycle of which it is important to be able to visualize the interdependence among the decision variables, and to be able to gauge the impact of modifying specific decisions. Traditional text-based techiques deny the planner the power of the interactive graphical medium for visualizing these dependencies, and for guaging the impact of proposed changes. In contrast, our techniques help the planner to understand arbitrary fragments of the current state of the mission's plans, and incrementally improve them to achieve tactical objectives.

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1 Introduction

The Air Force contract on Graphic Systems Representation has three major phases: Analysis, Recommendation, and Final Demonstration. Figure 1-1 depicts the major tasks to accomplish each of these phases.

The Analysis phase consists of:

1. The investigation and analysis of the latest computer graphics technology which can potentially have a significant benefit in the display of Air Force tactical information. This technology review includes graphics algorithms, computer hardware, computer software, and design methodologies. The technology can either exist today or be available within the time frame of about five years.

2. The investigation of Air Force tactical planning applications with particular emphasis on the analysis of existing graphical techniques used in these applications. The primary source of application knowledge has been a combination of consultants (e.g, former Air Force pilots), demonstrations of existing computerized technical planning systems at Rome Air Development Center, video tapes of tactical planning systems, and reports/manuals describing existing tactical planning systems.

A major output of this Analysis phase is this document, *Graphical Requirements for Air Force Tactical Decision Aids*. The purposes of this report are to describe the graphical needs or requirements associated with Air Force tactical planning, and to describe 2D and 3D graphical techniques that address these requirements. The description of requirements and potential graphical techniques are divided into six major categories:

Section 2 Planning

Section 3 Maps

Section 4 Threat Zones

Section 5 Weather

Section 6 Route Planning

Section 7 User Interaction

In Section 2, the high-level graphics requirements of the planning process are investigated. The next four sections - Maps, Threat Zones, Weather, and Route Planning - were found to be pervasive throughout all the planning phases, and are addressed separately. In Section 7, user

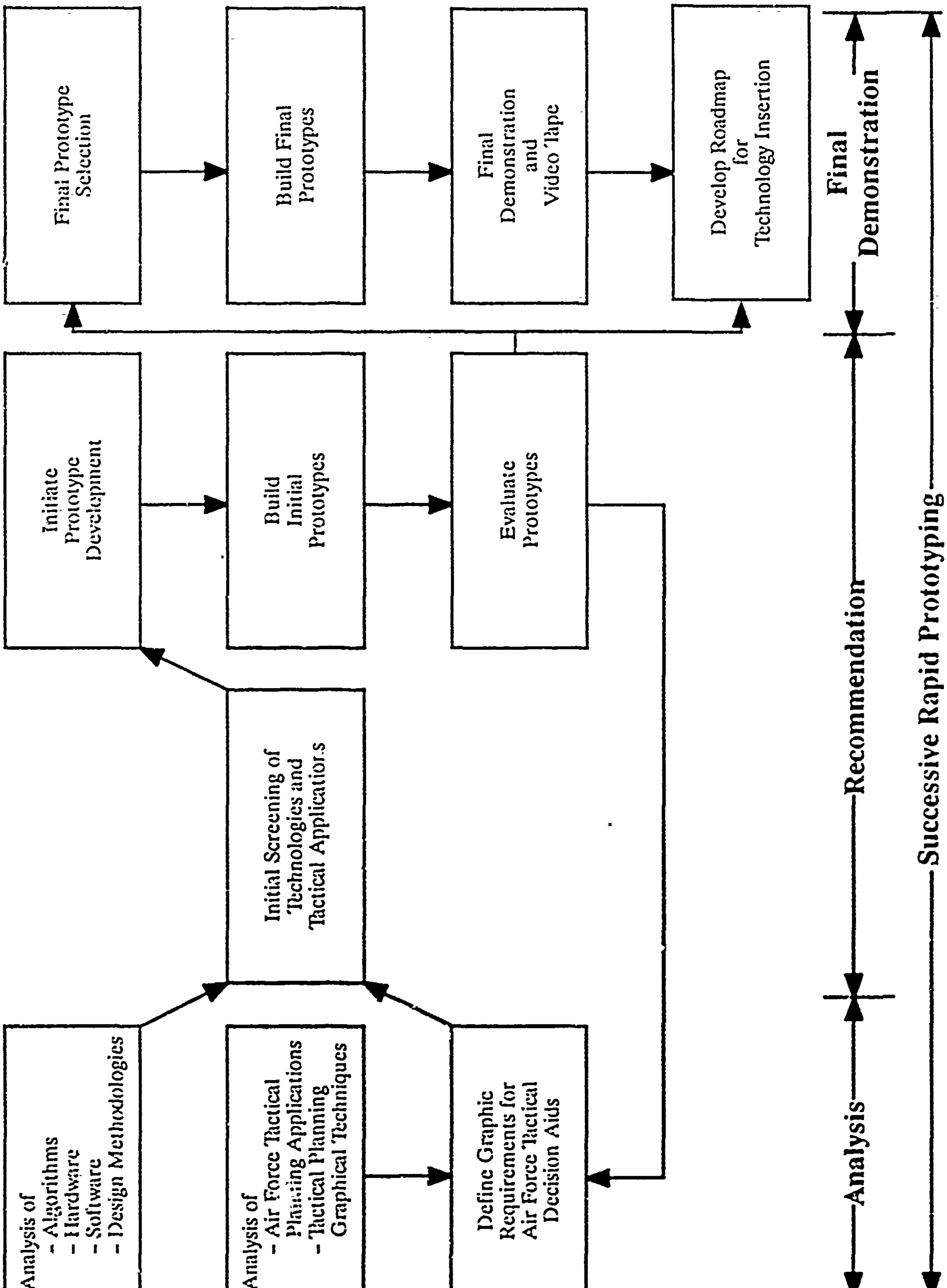

Figure 1 Overview of Major Tasks

interaction is singled out because it is a critical element in the acceptance and implementation of any new ideas, including new approaches in graphic systems representation. A summary of the graphical requirements and potential graphics solutions is contained at the end of each section.

A second major reason for this report is to focus attention on the next part of this contract, the Recommendation phase. This document identifies many graphics needs and new techniques that can be of potential benefit. One of the first steps in the Recommendation phase is to begin to "screen" the large set of applications, graphics needs, and potential technologies and to select "graphics ideas" for rapid prototype development. The feedback from the Air Force is essential in selecting and prioritizing the most important graphics requirements. At the end of the rapid prototyping phase, we will jointly with the Air Force select the final demonstration(s) and video tape to be developed and delivered.

2 Planning

2.1 Introduction

Mission planning is the fundamental process of the tactical Air Force environment. Efficient planning requires the assimilation of large amounts of information, along with the capability to evaluate the plan at any time. In addition, since deviation from plan is a likely occurrence in the tactical Air Force environment, it is important to provide methods for monitoring and reacting to such a situation. Indeed, the planning process is inherently dynamic, and the single most important aspect to successful planning is the ability to rapidly interact with the process.

Computers provide a natural tool for the planning process. Their basic function has been to manage data, assisting decision makers as they assimilate mission information. Computers also provide an evaluation mechanism, using rapid calculation to provide feedback to the planner. Unfortunately, computers often generate so much information, so quickly, that the planning process is swamped with detail. The results are then that much of the information is either lost or ignored, or the relative importance of information is lost to the planner. Therefore, computer graphics are useful in the planning process for a number of reasons:

- **Data Simplification** Reduce large amounts of data, or complex data inter–relationships to simpler, easier to understand representations. For example, a table of numbers can be represented as a bar chart or 2D plot.

- **Data Access** Provide access to data through straightforward, intuitive interactions. For example, clicking on an icon with a mouse to display characteristics.

- **Enhanced Cognition** Design displays to increase the transfer of important information to the planner. For example, use color contour shading to indicate threat representation at different locations on a map.

- **Focus** Computer graphics can provide focus to an activity. For example, the use of sound or color is often used to draw attention to a particular area.

In this section high-level graphics requirements for the planning process are developed. Many of the details of the planning process (such as threat representation) are covered in later sections. To develop these requirements we will consider the planning process of consisting of four parts: mission preparation, simulation, execution, and review.

2.2 Mission Preparation

In mission preparation the task is to understand the goal(s) of the mission, as well as to develop initial approaches to achieving the goal. This process primarily involves data acquisition; the data being current resources, constraints, target, intelligence, and prior history. In general, because of the scale of the problem, most of the graphics for mission preparation involve 2D graphics. It is only when needing detailed knowledge of terrain or target that 3D graphics are required.

The graphical requirements for mission preparation include:

- **Maps** serve as the foundation for understanding a tactical situation, especially when augmented with supplemental information such as threats, transit routes, tanker routes, front line of troops, political and geographic boundaries and so on. However, to be useful and avoid information overload, the map representations must be quite flexible so that inquiries into any data on the map provide rapid and effective information transfer. For example, pointing at an iconic representation of a threat on the map yields pertinent information about that threat.

- **Map Overlays** prevent information overload by logically grouping data, allowing the planner to interact with only selected information. One example is to group roads, thereby allowing the user to manipulate all roads simultaneously. Typically this would be useful to turn the visibility of the roads either on or off, to avoid cluttering a display. The grouping mechanism needs to be general, so that the planner can decide what is appropriate for his application.

- **Spreadsheets & Forms** are useful tools for summerizing numerical data, as well as entering or operating on numerical data. It is also possible to create graphical spreadsheets and forms, so that spreadsheets cells can contain graphical images. Resources can also be depicted on graphical forms, as for example allocating ordnance to aircraft. In this case, the aircraft of choice could be shown along with possible ordnance combinations, and by interacting with the display the planner could assign it.

- **2D Graphics** capability such as standard business graphics is required. These representations include pie charts, bar charts, x-y plots, multi-dimensional plots, statistical plots, and so forth. These provide a simple and familiar method for resource and information management. These displays must be used quite carefully to avoid information overload.

- **2D Pictorials** such as iconic representations are one of the most useful graphic representations available. Carefully crafted pictorials can represent an enormous amount of information in an succinct and readily understandable manner. The key to useful pictorials is to associate data directly to its various components, and to clearly represent each piece of data. For example, the sensitivity and allowable range of a parameter can be displayed by color coding a slider: the slider indicates maximum and minimum range information, the color of the slider represents the sensitivity at the current value of parameter.

- Multiple Displays are mandatory for assisting planners in assimilating information. Usually planning aids are written to address just a small set of needs, but often other information is pertinent to the planning process. The planner needs to look at multiple sources of information simultaneously; in addition, data in each display needs to be transferable from one into another. Simple cut and paste paradigms are possibilities, but future data requirements demand that the context of the data is provided as well.

- Interactive Displays are vital to encourage the free thinking and exploration required in the planning process. Users of the system must feel their creative abilities empowered by the system rather than stifled by it. Besides providing quick feedback, displays must be predictable to use, robust, provide guidance, and allow easy tailoring so that users have control over the information portrayal.

- Customizing the layout and informational content of a planning aide is helpful to users of computer systems because each individual has their own idea of what information is important. By customizing a graphic interface, a planner can improve the effective knowledge transfer rate. Of course, some users can create interfaces that are detrimental to effective use, or can develop interfaces that no one else can use.

- 3D Graphics are generally useful only in those cases where the vertical dimension is significant as compared to the horizontal dimension. In most planning operations this is not the case. (The following sections discuss some applications of 3D graphics). 3D graphics are also useful for representing certain forms of data, such as multi-variate statistical information, or complex icons or pictorials. However, the difficulty and ambiguity of interacting with 3D images means that it should be used in a limited way in the higher levels of the planning process.

- Sound is generally used as a supplemental channel for information transfer, especially when communicating vital information. Since sound provides another channel for information transfer, input or output is available to a planner who has his other senses are engaged with additional tasks.

- **Animation** is often necessary because the information is of a temporal nature. In these cases, developing an understanding of the data can only be developed by viewing it in all its dimensions, including time. However, since animation processes are often difficult to develop, they have to be generated automatically, or with a small amount of user interaction.

2.3 Mission Simulation

In mission simulation the task is to evaluate potential plans, improving them as necessary to meet mission constraints and goals. Here the process is considered to be iterative; that is, mission simulation and preparation proceed hand in hand until an acceptable solution is determined. Therefore, the graphic requirements in this phase are a superset of those required by mission preparation, with the added requirement of simulation.

Mission simulation is most effective when it is as realistic, i.e., meaning as much like an actual mission as possible. In this sense, mission simulation is identical to mission execution; the only difference being that system is being driven by underlying gaming or simulation algorithms. Therefore, the graphics requirements for mission simulation include the requirements for mission execution as well. This are discussed in the next section.

2.4 Mission Execution

As a mission unfolds, it is necessary to provide and update a detailed description of the current mission or battle status. This description must be as accurate as possible and cover your own force, other friendly forces, and enemy forces. A wide variety of information is used to present and evaluate the current status of a mission or battle:

- Intelligence reports on the location, damage, destruction, and movement of your own resources and enemy targets and resources
- Weather processes which can affect original mission plans (e.g., plane routings), target visibility, intelligence gathering (e.g., satellite photos), movement of enemy threats, and resupply of your own or enemy resources
- Communication links for receiving intelligence and weather information and for directing actions of your own resources
- Historical knowledge of enemy strategies and tactics when faced with certain scenarios
- Logistics and resupply processes for your own and enemy resources

- Alternate sources of sensor data (radar, IR, visual) from which a situation assessment must be fused or derived

The graphical requirements for describing and assessing a mission or battle situation as it is executed and unfolds are:

- **Maps** should be available to display the geographical area over which the mission or battle is taking place. The maps are ideally in digital format residing on a disc or must be scanned and converted into digital format. The maps typically have to cover a variety of scales from thousands of miles to miles/thousands of feet. Elevation and feature data (rivers, roads, mountains) are essential MAP elements.

- **Map overlays** can show spatial and logical relationships among relevant objects. One such overlay is the depiction of threats (see Section 4). This overlay could show location, range of lethality, and probability of lethality contours for a single type of threat or multiple threats. Transparency or choice of color can be used to emphasize a specific target type.

- **Multiple Displays** can be used to maintain a simultaneous perspective of different but important mission or battle information. Windowing environments are typical solution for this requirement. For example, one window can depict a large geographical scale showing a 2D representation of all known targets/threats, while other windows can show a 3D representation of threats (lethality zones) for more detailed geographical areas.

- **Weather patterns** can be critical in affecting your own or enemy tactics and resource allocation. A hierarchy of detail from 2D to 3D displays are required. A large scale map overlay covering hundreds to thousands of miles can show a 2D representation of weather patterns, with symbols and/or moving arrows showing such weather patterns as snow, rain, and wind. The symbol or pattern can be depicted over a 2D geographical area. More sophisticated 3D displays can be shown to depict and understand weather patterns over a smaller geographical area. For example, pilot visibility can be shown as a function of elevation. 3D shaded images, isometric surfaces, and transparency will be important requirements for such displays.

- **Communication links** are important for gathering intelligence, finding out resources status, and issuing orders. A 2D display of the available (and damaged) communication paths for own or enemy forces can provide a quick assessment of available communication options. Different colors, line patterns, or overlays can show different types of communication links.

- **Organization charts** showing the relationships among your own forces (force, squadron, wing, unit) can be helpful in identifying available resources. Such charts may also be helpful in reviewing enemy forces. 2D geometry (lines, boxes, circles) would suffice for this requirement.

- For computer-based tracking of mission execution, it is essential to review current battle status and evaluate alternative tactics during the battle with **interactive displays**. Large screen displays (a few feet in width and height) would be extremely useful in depicting an entire region or sub-region of battle. User-friendly interaction with a small or large screen is important. The use of a device such as a Telestrator would be valuable. For example, in football sports coverage, the announcer draws the explanation of a football play (plan or execution) on a tablet and it is superimposed on a TV display screen in real-time. The same concept can be used in AF applications. Simple 2D hand-drawn graphics representing flight paths, communication links, logistic routes, etc., can be immediately shown on the large screen display. Large screen flat displays would permit a picture of the battle scene more compactly and conveniently (on a table versus wall screen).

- There is a requirement to show and evaluate alternate tactical plans during a battle situation. **Computer animation** can show important logistical and spatial relationships and must be in real-time. Contingency plans can be demonstrated using animation, such as alternate flight plans if a friendly base(s) is destroyed. 2D animation can show line paths of objects over time. 3D animation can show realistic color-shaded objects and their movement over time. The animation can show the expected (or other) enemy tactical responses to your own tactical plan and your planned response.

- **Storage** of historical knowledge of enemy tactics and strategies is a requirement for mission execution, tracking, and resource allocation. Graphics requirements are the ability to display these tactics and strategies, using 2D geometry and 2D/3D animation. 2D graphics icons could be used as a symbology to represent an overall enemy tactic, e.g., for user interface access to a specific tactic. Optical discs can be a cost effective method for storing these tactics.

- There are many sources of sensor data, intelligence and other battle information which are not known with certainty. Graphics techniques are required to represent the confidence level or **uncertainty** of this information. For example, artificial intelligence techniques can determine the certainty of drawing a conclusion from a known set of information inputs (each having their own certainty). 2D graphical methods can be used to comprehend the certainty or confidence of a set of sensor data or a conclusion derived from the application of AI techniques. For example, a bar graph or the degree of color shading can show increasing (or decreasing) certainty.

- Automated **warnings** can be helpful in representing an actual or planned tactical action. Intelligence can be built into the battle tracking process such that when, for example, a communication link fails or a certain level or resources are damaged or destroyed, a warning occurs. Warning representations can include sound and computerized voice output. **Graphic warning representations** can include blinking, color change, or combinations of these. For example, when a specific route had been flown a certain number of times to reach targets in a certain geographical area, the route path would blink to warn the planner of this fact.

2.5 Mission Review

Mission review is the analysis and understanding of the actions and events that took place in a mission, in order to learn and apply information and techniques that can be used to improve future mission plans and execution. Relevant mission information that is useful to review includes:

- Enemy tactics and movement to evade own forces
- Location and type of enemy weapons and sensors
- Terrain features that can help in terrain masking, navigation, and avoidance of trouble areas
- Enemy counter-communication and sensor-interference tactics

Graphical requirements for mission review include:

- **Speed** of data input and output display is needed to convey and understand a large amount of information in s short time period. The time between missions for review of a previous mission can be short (hours). Methods for quickly inputing relevant data that can be shown on a display include: on-line forms or tables that can be quickly accessed via menus or graphical icons for keyboard entry or item selection; voice recognition, hand-drawn graphics that can be digitally scanned or electronically captured (See section 2.4, Telestrator) for display; touch screens for indicating approximate geographical locations of important features or known targets and threats, and the ability to input or select 2D geometry for indicating flight routes, turn points, and so forth. The most critical requirements are that data entry is fast and convenient.
- As in Mission Execution (Section 1.4) there is the requirement to interact with the review of the mission. Hence, the Mission Review graphical requirements for map overlays,

windows, weather patterns, organization charts, interactive displays, animation, storage of enemy tactics, and warnings are fundamentally the same as Mission Execution.

- Another important requirement is the ability to compare the actual mission with the original mission plan. **Animation** and multiple window displays can be used to satisfy this requirement. For example, one can animate the original plan in one window and simultaneously animate the actual execution in a second window - and stop the animation at specific times to analyze and understand the reasons for the differences. Or one can overlay the animations (such as a plane routing) of the original plan and actual execution simultaneously in a single display to see and understand the deviations.

- **Storage** of previous tactical plans (your own or enemy) is a critical requirement for Mission Review. Important review questions are always *What mistakes did I make?* and *How can I do better?* Graphics can permit ready access to these plans via graphical icons, table lookup and multiple windows. Using **animation**, one can compare the actual battle tactic with other stored alternate tactics.

2.6 Summary

The following is a brief summary of the graphics requirements for the planning process.

- Interactive Displays
  - Encourage exploration of alternatives
  - One of the most important features of a useful system
  - Large screen displays for briefing and monitoring
  - Use Telestrator to interact with video displays
- Multiple Displays

Provide multiple, simultaneous views of information Allow transfer of data from one display to another

- Customization

Allow the user to adjust displays according to the needs of the particular situation Can enhance cognition process

- 2D/3D Pictorials (Other sections contain additional information)

- Simplify data
- Provide access to underlying data by selecting icon
- Enhance cognition process
- Need to be tailored to specific need, for example;

  Showing sensitivity by using a slider to set decision values, with color of slider varying depending on sensitivity of plan to variable.

  Weather patterns including standard meteorological symbols

  Communication links and status (using color, varying line widths, etc.)

  Organizational charts depicting chain of command; resource responsibility

  Representing uncertainty
- Data Association

  Assign data to features of display. Modify display as a function of data.

  Provide ability to correlate data interactively
- Overlays/Grouping

  Mechanism for logically grouping data

  Used to interactively display data of interest

  Simplify displays by removing unnecessary detail
- Spreadsheets & Forms

  Simple method of presenting and entering numerical data

  Spreadsheets should be capable of representing graphical images

  Forms may be graphical in nature; i.e., data can be entered through selection of graphical images
- Sound

  Supplemental data manipulation channel. Speech input/output a possibility.

  Provide focus as important information becomes available.

  Convey qualitative information using attributes such as tone, volume, and repeat rate.

- Animation

  Provide an understanding of time-dependent data

  Useful for providing overview of a plan, including contingencies

  Display potential enemy responses to plan, with possible counter measures

- 3D Graphics

  Needed when altitude effects important

  Provide added dimension for displaying multi-variate data or pictorials

  Difficult to manipulate 3D objects on 2D displays

- Storage/Data Access

  Need to efficiently and reliably access data

  Use visual sign-posts such as icons to provide access to data

  Need to interactively associate data with displays

  Need to store intermediate plans

  Obtain pertinent tactical strategy

  Obtain past plans and results, both friendly and enemy

3 Maps

3.1 Introduction

The previous section examined the planning process from a high level. In this and the following sections, we begin to look at the details of the planning process. One of the fundamental requirements is the ability to display maps.

Almost all planning, decision making, and situation assessment tasks in the Air Force involve:

- A knowledge of the location of objects, and
- Relating objects to their spatial environment.

One can easily see the central importance of maps to almost every task in the Air Force. The primary features displayed on most maps consist of:

- Elevation of the underlying terrain,
- Nature of ground cover - desert, shrubs, forest etc.,
- Position and extent of natural features - lakes, rivers, oceans etc.,
- Position and extent of man-made features - roads, railway tracks, bridges, runways, towns etc., and
- Location and nature of strategic / tactical resources and threats - airbases, radar, SAM sites etc.

3.2 Display Criteria

The use of advanced *color graphics* techniques is essential for presenting this diverse range of information. First, we must set some general guidelines for the display of maps, so that the presented information can be easily assimilated by the user.

1. **Visual Codes** - We should make the best use of visual cues such as color, texture and icons, so that the user needs minimal conscious thought for locating and assimilating geographic information.
2. **Information Masking** - We must avoid the risk of visual and information overload of the user, by selectively presenting only information which is relevant to the current user task.

3. **Zoom and Pan** - The user should be able to rapidly obtain a display of the required region of the map, at the desired level of detail. This task should require as little interaction with the user as possible. Access to the stored map data should also be accelerated by the use of appropriate algorithmic and data structuring techniques.

4. **Derived Information** - We must provide means for the user to query the map application for any information which can be reasonably deduced from the underlying map information. Examples include [illegible], distance, geographically weighted measures such as time of flight etc.

5. **Display Customization** - The user should be able to dynamically change the visual representation of the mapped information, with minimal effort. Examples include color and texture coding, icon classification etc. A significant advantage can be gained by being able to dynamically link secondary visual properties of the displayed icons (such as size, orientation, blink rate etc.) to user selectable attributes of the underlying object (such as altitude, velocity, remaining fuel, weapons cargo etc.). For example, on the outward leg of a bombing run, the size of the displayed aircraft icon could represent the quantity of munitions, whereas on the return it could denote the quantity of remaining fuel.

6. **Dynamic Status Display** - We must provide the means to represent dynamically changing attributes of the displayed objects. We must also adapt suitable display techniques so that the user can easily perceive the nature and magnitude of changes in those attributes. Some of these attributes could be tracked by information received from outside the system, and yet others could be updated from a script which may for example replay a planned mission.

3.3 Displaying Topography

Topography is a description of the elevation at each position of the earth's surface. A knowledge of the topography along mission routes and surrounding locations of possible enemy encounters is crucial for planning successful missions, as well as for selecting basic strategies for attack and defense. For example, narrow valleys provide excellent opportunities for evading radar, but also create a hazard for flying. Also, being on the leeward side of a mountain with respect to the location of a radar or SAM site is clearly advantageous. While flying *Close Air Support* missions, a knowledge of the slope and texture of the underlying terrain is important, since it affects the nature of the land battle, and hence impacts the type of required support.

Topography can be displayed in a two dimensional or a three dimensional form. A 2D display is obtained by dividing up the land / water surface into regions which lie within selected bands of elevations. It should be possible for the user to select the number of displayed ranges, as well as the bounds for each range of elevation. This is not possible in most current systems, since the display form of the map is usually pre-computed using pre-selected and uniformly spaced elevation ranges. A two dimensional display of the elevation ranges is possible in the following ways:

1. **Filled Map** – by color coding each range distinctly, or as a
2. **Contour Map** – by drawing the contours which demarcate each range, and labelling each contour with its elevation.

A three dimensional topographic display is possible in one of the three following ways:

1. **Wireframe model** – a uniformly spaced wire grid is assumed to be moulded to the three dimensional terrain surface, and the resulting curved lines constituting the deformed grid are projected onto the display plane.
2. **Illuminated Polyhedral model** – the three dimensional terrain is approximated by 3D polyhedra, which are then illuminated suitably, and the resulting shaded polygonal faces of the polyhedra are projected onto the display plane.
3. **Texture Mapped model** – photographs of several perspective views of the actual terrain are image compressed, and mapped onto the polygonal faces of the modelled terrain. This results in a more realistic display of the colors and texture of the target terrain. With texture mapping, it is also possible to account for seasonal variations, as well as variations due to time of day or weather effects on illumination and visibility, in order to generate a very realistic display. Such techniques permit the user to assimilate these related items of information effortlessly, and thus account for these factors during planning and situation assessment.

While displaying either a filled map or a contour map, one has to be careful not to obscure the display of other desired features such as roads, lakes, political boundaries etc. It is important to permit the user to customize the display, so that he can highlight the desired information. At the same time, it is important to adhere to some relatively uniform standards for display, so that different personnel can interact during decision making, and can simultaneously refer to common points of interest on the display. The use of customizable and default display profiles, as well as convenient temporary highlight modes, can significantly enhance the planning and decision making environment.

3.4 Displaying Terrain and Cultural Features

Features of the terrain which are of interest include both natural and man-made objects. Natural area features such as soil type and ground cover can be depicted: (i) by color coding the area, (ii) by filling the area with a selected textural pattern, or (iii) by randomly distributing icons of the selected type across the area. The last method can also be used to depict the density of the displayed object in that area by a corresponding density of its icons in the display. Other area features correspond to bodies of water such as lakes, rivers and oceans. Such areas are almost always color coded, with the color also depicting depths within different regions in the case of lakes and oceans. In the case of rivers, we also need to depict its width. Since its width is typically very small compared to the scale of the map, the width needs to be coded by some symbolic means such as line type or line width.

Man made objects are often the most interesting features on a map, and include such objects as roads, railroads, bridges, airfields, towns, factories, depots, SAM sites, radar etc. There are well accepted icons for depicting such objects. It is useful to provide means for the user to add icons to the display library, as well as enable him to modify the icons associated with a selected category of objects. A significant benefit can be obtained by permitting the user to dynamically link secondary visual properties of the displayed icons (such as size, orientation, color, blink rate etc.) to desired attributes of the underlying object (such as altitude, velocity, remaining fuel, weapons complement, population, traffic rates, load bearing capacity etc.).

3.5 Coordinate Systems and Projections

The representation and display of geographic information is often based on a flat earth or rectangular (LAT, LONG) coordinate system, when the user is viewing relatively small areas. This permits rapid assimilation of the relative distances and orientations between points of interest. However, as the viewing area increases, or as we approach regions farther from the Equator, the distortions become unacceptably large if we ignore the curvature of the earth's surface.

Using current technology, it is possible to render a map on a spherical surface, which is then displayed on a flat screen as it would appear to a camera at the location of the user, and with his perspective. The underlying map information would naturally be stored in a geocentric coordinate system. However, over the years many standard projections have been devised by cartographers in order to render maps on paper. The following projections are some of the more familiar ones:

1. **Mercator** – the globe is *conformally* mapped onto a cylinder. Land shapes are displayed correctly, but the areas of landmasses are greatly exaggerated towards the poles.
2. **Lambert Equal Area** – the globe is projected onto a plane tangential to it. It shows true distances close to the point of tangency, but compresses them greatly as we move farther away from the center.

3. **Goode** - it is an equal area projection. The parallels of latitude are all depicted with the same scale, with breaks in them to separate the major land masses. Each land mass is depicted about a separate central meridian, which permits minimal distortion for each.

4. **Robinson** - this recently devised projection attempts to simultaneously minimize distortions in shape, relative sizes, orientations, and relative distances.

3.6 Displaying and Scanning Large Areas

A theater of air operations typically spans an extremely large area, and viewing a map of the entire theater with complete detail would often be neither practical nor even useful. Hence, the user needs to be able to selectively display just the region of interest. If the selected region is large, then the user needs to be able to disable the display of selected categories of objects. Also, as the focus of attention moves, or changes in scope, it becomes necessary to zoom and / or pan across the map.

The speed and convenience of effecting these display changes are influenced by two factors:

1. User Interaction - The fastest scheme that is possible with available technology is for the user to be able to zoom out / in with fixed magnification / demagnification factors, using a pop-up menu attached to a mouse button. The user could also lasso an arbitrary rectangular region of the displayed map using a mouse, and have that portion fill the entire field of view. Additionally, the user could selectively enable / disable desired categories of map objects, by using a programmable pop-up menu attached to a mouse button, or by selecting or deselecting specific objects. This could be aided by associating attributes and classes with each instance of a displayable object. Additional speedup can be achieved by permitting the user to set named tags with map locations, and enabling the user to directly change the focus of the displayed map to a tagged location, or to a specified latitude and longitude. During operations in which the user wishes to pan across large areas of the map, we can obtain a significant speedup in displaying the map by suppressing the display of many unnecessary details and features. Unfortunately, very few of these desirable features are supported by existing map display applications.

2. Storage Retrieval - Map databases are inherently very large, and the time required for retrieving desired portions of the map for display can be speeded up significantly by using innovative data structuring techniques, as well as by using innovative algorithms for locating desired fragments of the map within the storage medium. This would provide speedups above and beyond that provided by faster hardware alone, and is also

necessary since a user's expectations about the level of detail in the map go up as soon as hardware becomes faster.

3.7 Level of Detail

As discussed earlier, it is not desirable to display all the available information on a map, in order to avoid an information overload of the user. Some of the detail can be suppressed by the user, by selectively disabling individual items or entire categories of objects. Additionally, there are two automatic methods which can be used for suppressing detail.

1. Boundary Detail Scaling – It is possible to display linear features, and the boundaries of area features, with a number of segments which is appropriate to the scale of the display. It is possible to approximate area features with a series of bounding polygons, progressively having a greater number of segments, and approximating the feature with a smaller maximum deviation. When the scale of the display is very small, it may be necessary to generate additional jagged edges using fractal interpolation, for displaying realistic boundaries for area features such as lakes etc.

2. Context Sensitive Filters – We can expect that the map display application is invoked in conjunction with a user task menu system, which enables the user to undertake predefined categories of command, planning, or decision type tasks. It would be fairly straightforward to custom design display profiles for each task category, which would specify what should be displayed for such a task. It is also important to provide mechanisms for end users to easily modify the task categories, as well as the display profile for each category.

3.8 Secondary and Inferred Attributes

Using object oriented techniques, it is possible to generate smart maps which can be queried for information related to the underlying map, as the following examples illustrate.

1. The user could select two locations on the map, and inquire as to whether they are connected by road / rail, or what the estimated travel time or fuel requirement between those destinations is by road / rail / air. The answers to such questions could take into account current status of road conditions, weather, known enemy activity, type of transport vehicle, mission directives, policy etc.

2. The user could enter the details of a mission plan, such as flying routes, waypoints, start and synchronization times, and other supporting troop activity. Then he could use the map and mission plan information as a base to animate the probable sequence of events,

as well as to display dynamic status information such as remaining fuel, cumulative survival probability, instantaneous threat level, weapons complement etc.

3.9 Data Accuracy and Automated Map Generation

The primary sources of map information are: (i) Digital Terrain Elevation Data (DTED), and (ii) Digital Feature Analysis Data (DFAD), both provided by the Defense Mapping Agency (DMA), as well as data provided by the US Geological Survey (USGS). These data often contain inaccuracies due either to the poorer resolution obtainable in older surveys, or as a result of man made or natural changes to the area. Sometimes, these inaccuracies can result in annoying errors in the displayed map, such as lakes without closed boundaries, or bridges not aligned with the roads they are on. There are two major remedies to these errors, and both involve automating the map making process to a greater degree than at present. The first is to develop new image processing algorithms which will enable much of the map data to be corrected by reconciliation with high resolution satellite images of the terrain obtained using different bands such as visible light, ultraviolet, and infrared. The second method involves incorporating semantic constraints with various object categories, such as: (i) bodies of water must have a closed boundary, and (ii) a bridge must align with an associated road or railway track etc. Algorithms can be devised to check these constraints, as well as to correct any detected violations of these rules.

3.10 Storage Representation

The internal form in which the map is stored has a significant impact on: (i) the speed with which the map can be accessed and displayed, (ii) the hardware requirements (size and speed) for storage, (iii) the flexibility with which the map data can be modified, and (iv) the ease with which other applications can make use of the map data. In Section 3.8 we showed examples of applications which rely on querying and / or updating the map database.

The simplest form in which map data can be stored is as a raster of points obtained by digitizing desired maps at fixed scales. This is the least useful representation: since it uses most storage, produces unsatisfactory results for changing scales (with large computational cost), and cannot be used as a basis for computing secondary inferred attributes.

The most preferable scheme would have the following features.

- Displayable features on the map should be stored in an *object–oriented* form, with size and placement specified in a manner which is independent of the viewing scale or resolution.

- The perimeter of area features, as well as the skeleton of linear features should be specified as a hierarchy of successively closer polygonal (segmented) approximations, and independently of the resolution of the display device.
- Displayable objects should have tags associated with them, which specify the type of each object. These tags could be used to selectively enable the display of desired classes of objects, as well as for customizing the color, linewidth, line style, texture and other display attributes.
- Displayable objects can have other items of information associated with them, as well as links to related objects: which can be used for computing secondary inferred attributes.
- The data structures for storing the map should be organized to permit very rapid access to desired coordinates, for panning across areas of the map, and also for rapidly changing scales. Some techniques which are known for this task include *Indexed Search Trees* and *Hashing*.

3.11 Three Dimensional Information

Topographic information about a map is most naturally available in a three dimensional form. In section 3.3 we discussed various techniques for displaying topography. In most planning related tasks, the map is viewed at such a scale that just a symbolic display of the altitudes (using contours or color coding) is adequate. The scale of perception for such tasks focuses on the two dimensional attributes almost exclusively.

Occasionally, it becomes important to visualize the effects of *Terrain Masking*, when for example high mountains make aircraft in some area invisible to radar. Also, when planning a flight route through a narrow valley, it becomes important to visualize the detailed three dimensional features of the terrain, in order to determine the feasibility of certain flight patterns, or of flying certain types of aircraft. Sometimes, weather related phenomena such as storms or wind shear are also greatly influenced by the topography of the terrain, whence it can be important to view the terrain in 3D for such applications as well.

3.12 Summary

The following is a brief summary of the graphics requirements for maps.

- 2D/3D Pictorials
  - A 2D display of topography, showing elevation ranges, can be achieved by:

color coding each range of elevations

using contours to demarcate each range and labelling each contour with its elevation

- A 3D terrain display can be important for such applications as terrain masking, mission rehearsal, and weather patterns. A 3D display of topography can be achieved by:

  projecting a wireframe model of the 3D terrain surface on to the display plane

  projecting a 3D shaded polygon model of the terrain surface on to the display plane

  photographs of the actual terrain or terrain features (roads, buildings) are "texture mapped" on to the polygons of the modelled terrain

- Display Customization
  - Change visual information associated with map quickly (icon types, icon classifications, color, line widths)
- Coordinate Systems
  - Rapid and accurate conversions of different coordinate representations
- User interactions
  - Zoom out/in with fixed magnification/demagnification factors (popup menu, lasso)
  - Selectively enable/disable individual objects or categories of objects (popup menu, pointing to objects)
  - Select a specific latitude and longitude
  - Associate name tags to map locations and select name tag to "focus" display
  - Query map for data(attributes) related to objects on map.
  - Display elevation as you move along terrain surface
- Storage/Data Access
  - Innovative data structures and/or hardware for compressing map-related data and rapidly accessing portions of a map

- Cost–effective data storage

- Level of Detail
  - Ability to display large area maps and then rapidly display smaller area maps, with display automatically accounting for difference in scale
  - Selectively disable/enable individual objects or categories of objects (overlays)
  - Display linear features and boundaries of area features, with the number of segments appropriate for the display scale

- Modelling
  - Automation techniques for map generation process and map accuracy
  - Image processing algorithms for photographic data
  - Heuristic rules/constraints for categories of objects, e.g., bridge must align with road or railroad track

- Geometric Representation
  - Displayable features stored in object–oriented form
  - Objects have wide variety of attributes associated with them(color, linewidth, line style) which can be quickly accessed, displayed, or modified
  - Efficient geometric data structures for changing scales rapidly, panning across areas, and accessing desired coordinates.

- Data Association
  - Objects can have links to other objects. For example, link the visual property of an icon(size, blink rate) with a selectable attribute of an object(remaining fuel, amount of weapons).

- Special Algorithms
  - Calculate information which can be deduced from underlying map data, such as distances and connectivity.

4 Threat Zones

4.1 Introduction

All enemy threats, from the largest to the smallest, can potentially have a negative impact on a mission. The volume in which a threat is effective is termed its threat zone. The relevant properties of a threat depend on several factors, including

- its firepower,
- its sensing capabilities,
- its mobility,
- the impact of geographic and meteorologic factors on the above items,
- potential for cooperation between multiple threats, and
- the nature of the forces it threatens.

Accurate display and interpretation of threat zone properties is critical to ensure effective mission planning and execution. What to display is a compromise between the magnitude of the threat to the mission, how accurately the threat's properties are known, how threat display enhances (or detracts from) other objects being displayed (e.g., weather, geography, front line of troops, low-level transit routes, and targets), and the overall complexity of the display. This section describes several techniques for displaying threats effectively.

4.2 Current Techniques

Most threat displays use a constant intensity image to represent a threat, displaying just the threat boundary (outline mode) or a series of spokes radiating from the threat itself. These display techniques suffer from several problems:

- They do not account for different threat magnitudes in different parts of the overall threat zone. For example, we have not seen any displays of radars that visually account for the $1/r^2$ nature of the radar signal.
- They do not account for threats of different strengths. A SAM site has a larger threat zone than a soldier with a rifle, but if both are displayed, they will be displayed with much the same properties.
- They do not consider constructive or destructive interactions between overlapping threats.

- There is no ability to synthesize higher level images from the sum of the individual threats.
- No systems we have seen allow the user to reduce the visibility of threats, other than to totally eliminate them from the display.
- No systems we have seen can display threat zones in three dimensions.
- No systems we have seen account for threat movement.
- No systems we have seen account for uncertainty in the information about threat properties.
- Few display distinctions are made between different types of threats, say a SAM site vs. a radar site.
- They do not display ownship vulnerability to threats.
- No systems we have seen (or heard) use sound to represent threat information.

4.3 Threat Magnitudes

A threat does not have the same effectiveness over its entire range. For instance, radar power is proportional to the inverse of the square of the distance from the source. Guns and missiles are not as accurate near the limits of their range. Also, different threats have different maximum potential for lethality. Threat display should reflect these differences and gradients.

4.4 Higher Level Display of Threat Information

Threat zones often overlap, and the danger within that overlapping area is probably not the danger associated with just one of the overlapping threats. Two or more overlapping missile threat zones might increase the danger, since more missiles might be fired at your planes. On the other hand, overlapping radar threats might interfere with each other reducing their effectiveness in the area of overlap.

The potential for constructive or destructive interaction implies that threats should not be considered in isolation, but should be treated as a single, larger entity. This is especially important during higher level planning, where the details of individual threats may be less important than the overall danger of a situation. Several combination rules for multiple overlapping threats exist. Three simple ones are $\Sigma_i^n T_i$, max $T_1 \ldots T_n$, and $T_1 \ldots T_n$, where T_i is the ith displayed threat.

4.5 Threat Visibility

In extremely congested theaters, such as Europe, the number of threats may be so great that display of all threats, or even a substantial fraction of the total threats in an area, clutters the display, and may cause the planner to lose focus of other important features. Some way to selectively subdue threat display is necessary. Some techniques to consider are

- displaying only those threats to which mission resources are vulnerable,
- partitioning threats into types (e.g., SAMs vs. radars vs. anti-aircraft),
- accounting for the three-dimensional nature of the threat envelope, altitude of friendly resources and interaction with geography (terrain masking).
- suppressing display of threats that do not overlap planned routes,
- reducing the displayed intensity of selected threats, and
- displaying a hierarchy of threats, and only displaying those matching some user-specified display criteria.

Techniques that cycle between different overlays may be beneficial as well. For instance, enemy threats may be displayed in one overlay, weather in another, and geography in yet another. The three overlays might be cycled every second or two to present the planner with all the information, but prevent the display from being too cluttered. The planner should be able to select how many overlays are displayed, what their contents are, in what order they will be displayed, whether they will be statically displayed, and if dynamic, what their cycle frequency will be.

4.6 Three-dimensional Threat Display

Threat zones are typically displayed in just two dimensions, yet they have properties that make it important to view them in three dimensions, especially during lower levels (e.g., unit-level) of the planning process. Elevation effects, such as terrain masking, cannot be understood properly in just two dimensions. The threat zone may not be hemispherical (even neglecting terrain and weather effects), especially for aerial threats. Also, weather and terrain effects typically manifest themselves at different altitudes, making a two-dimensional display an over-simplification. Viewing threats in three dimensions from different perspectives can be of high value during mission rehearsal.

4.7 Representing Uncertainty in Threat Properties

Information regarding enemy threats is not absolute. Threats move, their firepower increases and decreases, and sometimes intelligence does not have enough information to say for certain just what the properties of the threat are. These factors contribute to uncertainty about threat capabilities. Planners should have some way of determining the uncertainty of various threat capabilities.

Bonissone and Dutta [7] view uncertain information in their reasoning system by plotting both the evidence supporting and refuting a conjecture as a small bar chart. The supporting value is plotted from the left edge of the interval, while the refuting value is plotted from the right edge, both in white. The region between the bars represents the amount of uncertainty and is colored black[1]. Overlap of the supporting and refuting values represents an error in the rule base of the reasoning system. The viewer can tell quickly whether the evidence available generally supports or refutes the conjecture it represents, and how uncertain that evidence is by the position and size of the black bar. The larger the black bar, the more uncertain the information is. The more to the right it is, the more the evidence is positive, to the left, negative. In LOTTA [5], threat intent is represented by five different variables, *engage-now*, *engage-later*, *influence*, *evade*, and *non-reactive*. For each enemy airplane, all five variables are plotted as described above in a small window.

4.8 Distinguishing Threat Types Using Animation

Different types of threats have different properties. The planner should be able to display those differences if he chooses. Radar sites might be displayed with a sweeping line from the center to the edge of the threat, similar to the radar displays popular in Hollywood movies. Anti-aircraft guns might be displayed with random flashing dots throughout the displayed threat zone. SAM sites might be displayed with dots that trace a line from the center to the edge of the threat zone, with the dot fading out as the edge of the threat zone is reached.

4.9 Displaying Resource Vulnerability

If multiple types of aircraft are being deployed on a mission, they are likely to have different vulnerability to enemy threats. It is important to understand the relationship between the different types of threats and the different types of aircraft. Some possibilities for displaying these relationships are

- Color each aircraft's route to indicate its vulnerability to threats at each point along the route. Threat display becomes potentially easier, since there is no strict requirement to represent the lethality of each individual threat. Aircraft display for different types of aircraft can be shown simultaneously in multiple windows. This has the potential

1. Overlap of the supporting and refuting values represents an error in the rule base of the reasoning system.

disadvantage, however, of spatially separating different pieces of information that should be registered to the map section being viewed and to each other.

- Select the display of different types of aircraft, and display the threats based upon the vulnerability of the aircraft being displayed. This has the advantage of leaving the route display for other factors, such as fuel load, although it sacrifices the ability to view all aircraft and their vulnerability to threats at the same time.

4.10 Sound

The purpose of sophisticated threat display is to transfer a large amount of information to the planner in a form he or she can utilize. Very few systems (even outside the planning realm) make use of sound to represent information, however. Humans are good at recognizing and acting upon two inputs from different senses (e.g., visual and sound). They are less good at recognizing and acting upon two inputs from the same sense (e.g., color and animation). It makes sense to take advantage of humans' natural signal processing capabilities where possible.

Bly [4] has shown that people can cluster multivariate data accurately based upon several sound properties, such as amplitude and frequency. Audible information can be quite useful in situations where the user can't shift his or her visual focus from specific displayed information (either the primary window or a specific object).

Listed below are some possible uses for sound in threat display activities.

- If a planner wants detailed information about a threat, rather than selecting it and having to shift focus to a secondary window, much of the data can be presented aurally, using speech synthesis techniques.
- Overall threat level during mission rehearsal can be presented aurally, rather than adding clutter to the display.
- The user might attach a spatially dependent parameter to a sound variable. As the pointer is moved about the screen, the value of that variable could be heard, rather than seen.

4.11 Summary

In this section we considered several criteria for effective display of enemy threats. Those criteria can help planners distinguish threat types, suppress unnecessary information, tailor the display to their needs, and focus on information in the display that is critical to effective planning and execution of Air Force missions.

The following is a brief summary of the graphics requirements for representing threats.

- 2D/3D Pictorials
  - Uncertainty graphs to represent inaccurate information
  - Color routes according to threat level
- Color
  - Color contours to display threat levels over area of interest
  - Use color gradients to represent overall threat level at any given point,
  - Adjust color saturation and intensity according to threat level
- Special Algorithms
  - Represent threat levels based on interaction of threats with each other
  - Represent threat levels based on interaction of threats with friendly forces
- Multiple Displays
  - Use to represent threat levels for different aircraft/threat combinations
- Sound
  - Provides another channel for information transfer
  - Present level aurally; using spoken words or by assigning to sound attribute such as tone or volume.
- Animation
  - Radar site displayed as revolving line
  - Anti-aircraft displayed as flashing dots in effective range
  - SAM sites displayed with points tracing lines radially from center of site. Lines fade as threat level varies.
- 3D Graphics
  - Use to display threat envelopes
  - Use to represent terrain masking
- Overlays/Grouping

- Associate threats of a particular type
- Associate threats of a given lethality
- Group according to threat to particular aircraft

5 Weather

5.1 Introduction

Weather has a major impact on visibility, as well as on the maneuverability of aircraft. Weather conditions can provide immunity to being seen by the enemy, winds can speed or delay flying aircraft, and storms can present a flying hazard. Hence, flight crew as well as planners need to account for the effects of weather while planning missions and flying routes.

5.2 Icons

There are many icons which are fairly standard and widely used for representing weather related information. Examples include: (i) cloud shapes for clouds, (ii) slanting broken lines for rain, (iii) snow flakes for snow, (iv) circle with outgoing rays for sunshine etc.

In addition to displaying the presence and location of weather phenomena such as snow, the icons could also be used for displaying auxiliary information.

- The density of the displayed icons could represent the magnitude of the represented phenomena, e.g. the number of snow icons per unit area could represent the amount of snow fall.
- The color or texture of the icon could display the predicted probability of the given phenomenon (e.g. rainfall).
- A vector attached to the icon could display the rate and direction of movement of the given phenomenon (e.g. storm).
- A bar chart attached to the icon could display the minimum, maximum, and average for the given phenomenon such as rainfall, at the given time of year.

5.3 Altitude Variations

Many weather phenomena such as clouds, temperature, and winds vary with altitude. These can be displayed as a cross sectional average in the altitude band of interest, by using colored overlay areas. Alternatively, they can be viewed as three dimensional surfaces which can be used for the detailed planning of flight corridors. In particular, when weather phenomena interact with mountainous terrain having narrow and steep passes or valleys, it is very necessary to visualize the detailed three dimensional flight corridors.

5.4 Distributed Area Displays

For some weather phenomena such as wind, temperature, and fog, we need to display the spatial variation of the desired phenomenon over a relatively large area, in order to provide information needed for flight planning or combat. It is important to provide this display as a user selectable overlay, and also to ensure that displaying weather phenomena does not obscure the underlying display of maps, flight plans, threats, or mission status. This constraint can be satisfied by a careful choice of the colors for displaying the overlays, and by associating transparency with the selected icons. Another way is to represent some of these phenomena by additively modifying the *texture* of the underlying display.

- **Wind Patterns** can be displayed by using *streamlines*.
- **Temperature Effects** can be displayed by using contours of constant temperature, by color coding, or by texturing.
- **Fog** can be displayed by using contours of constant fog density, by color coding, or by texturing.
- **Daylight** can be displayed by using contours of constant light level, by varying color intensity as a function of lighting level, or by texturing.

5.5 Terrain Effects

Many weather phenomena such as rainfall, snowfall, or storms are modified locally by the terrain. Examples include shielding by a mountain, runoff along a slope, and accumulation or channelling in valleys. Using available technology in conjunction with *smart maps*, it is possible to compute the effect of terrain on weather patterns; and to incorporate it into an integrated display, with suitable color coding, intensity modulation, transparency / opacity effects, luminosity and illumination effects, and texturing.

5.6 Flight Path Attributes

It should be possible to augment the display of flight paths with selected attributes of the weather such as visibility, ceiling, snow, rain, and fog. This can be achieved by varying the color, width, or line pattern of the lines representing flight paths. It is important that the displayed attributes do not obscure the main objective of displaying a flight path: viz. showing a path between the origin and the destination, as well as showing *way points*.

5.7 Animation

Animation could be used to display either the local variation of weather phenomena over time, or to chart out the anticipated movement of storms. Such animations, when coupled to an animation of mission plans, can provide very useful inputs to planners, and enable them to readily detect possible conflicts with respect to predicted weather patterns.

5.8 Summary

The following is a brief summary of the graphics requirements for weather representation.

- 2D/3D Pictorials
  - Icons to represent different types of weather (clouds, rain, snow)
  - Density of icons to represent magnitude of weather phenomena
  - Color or texture of icon to display predicted probability
  - Vector attached to icon to represent direction and magnitude or rate of movement
  - Bar charts to show ranges of weather phenomena(currently, past history, and predicted)
  - Showing 2D weather patterns over an area

    Streamlines to display wind patterns

    Color coding or texturing to show contours of temperature or fog density

    Use of overlays with careful selection of colors and transparency to show combinations of weather phenomena (wind, snow)
  - Weather phenomena such as winds and clouds vary with altitude. This can be displayed either as cross-sectional averages in a band of altitudes or as a 3D shaded surface, where the surface represents a constant weather parameter.
  - Weather data can be directly related to the individual legs of flight routes. Visibility, snow, rain, and wind can be directly associated with a route leg by varying line color, width, or line pattern. Specific data values can be accessible via icons or pop-up menu related to a route.
- Modelling

Terrain(e.g., mountains) affects weather patterns. It is possible to model the effect of terrain on weather.

- Animation
  - Display the projected pattern of weather movement over a geographical area for a mission. The time period for the weather projection must correspond to the time

period prior and during the mission. Overlay weather animation and flight routing animation to show potential impact of weather.

6 Route Planning

6.1 Introduction

Route planning is a component of both force level and unit (or squadron) level planning although each aspect requires different levels of detail and information. Routes are the paths of aircraft as they travel to and from targets. Routes consist of two parts: legs and turnpoints. Turnpoints are locations in a path where headings change while legs connect two turnpoints and are normally depicted as straight lines.

The goals of each planning level differ and consequently, their requirements for route representation differ. Routes are used to:

- Show the coordination of aircraft dispatched from numerous staging bases. This may include multiple sorties of aircraft over a period of time.
- Show the overall flow of aircraft in relation to political and geographic boundaries.
- Show alternative routes.
- Show the distances and fuel consumption between turnpoints.
- Show the location of flight paths with respect to known threats, targets, front lines, friendly bases, ground features and terrain contours.
- Show time constraints of the aircraft with respect to dictated times on target (TOT).
- Show both attack and egress routes.
- Show the survivability of routes.
- Show the effects of weather ceilings on flight paths.
- Show those portions of a route that are under threat.
- Show the feasibility of completing a mission given the available aircraft, ordinance, and squadron combat radius.

This section assumes that software exists to calculate headings, fuel consumption, speeds and distance. Also, software may exist that can automatically generate routes. Here, we concentrate on the requirements for route representations as they apply to both force and unit level planning.

6.2 Force Level Planning

Force level planning produces an air tasking order (ATO) that is used as a basis for the flight plans generated during unit level planning. At the force level, concerns are at a broad level, involving coordination of multiple resources from, possibly, multiple staging bases. Hence, the force level planner needs to visualize the many relationships between many active participants. Routes created during this step need not take into account details such as ground features or details of threats or weather. Here the graphics requirements are two dimensional, because of the high level view required.

Force level concerns are:

- Geographic features on maps can overwhelm a graphics screen with information. What graphical techniques will highlight routes on a busy screen covered with map data?
  - **highlight by color** - reserve fully saturated colors for routes.
  - **highlight by thickness** - draw legs as thick lines.
  - **highlight by blinking** - under user control, blink routes. If something changes (like the location of a turnpoint) about a route, blink it.
  - **highlight by animation** - move icons along routes. Direction and speed of movement can be controlled by the user.
  - **suppress map background** - increase the white level of the map background. This causes the maps colors to appear more pastel. The more saturated route colors will be more visible.
- Routes are paths that evolve over time. What graphical techniques show temporal relationships?
  - shape animation - change the width of the route, making it wider as it approaches the target.
  - lookup table animation - a technique used in TV weather broadcasts, change the texture or color of a route as a function of time.
  - color coding of time - map time onto the color hue circle, going from blue, cyan, green, yellow, to red. As the route approaches its endpoint, the color becomes red.
- Routes may intersect or overlap each other on a graphics display. How do we show the entrance and exit of an intersection? How do we show if two or more routes overlap?
  - **alternate display** - alternate the display of each route.

- **change shape** - use different shapes for each route with a legend displayed on the screen.
- **change color** - use different color for each route, perhaps tying the color codes to the colors of the originating staging base or target.
- **logical combinations** - when routes overlap, use logical operations to create a new combined color.

- Parameters such as fuel consumption vary over the course of a route. How can we show such data on a route?
  - **map data to shape** - map a scaled fuel level to the width of the route.
  - **map scalar to color** - map a scaled fuel level to the color of the turnpoint symbol.
  - **tie gauges to turnpoints** - fuel gauge can be attached to turnpoints.
- Paths may violate some political or practical concerns. How do we show these violations?
  - **highlight via sound** - let user move icon along route. Voice can explain any violations as icon moves.
  - **highlight by flashing** - those portions of the route that cause violation can be flashed.
  - **highlight by shape change** - thicken routes where they violate constraints. Superimpose a special icon over those parts of the route that are in violation. The icon indicates the nature of the violation.
  - **highlight by color change** - use a reserved color to show violations.
- Alternative routes may be generated by analysis programs. How can we show the differences between the routes?
  - **simultaneous animation** - show an icon moving along all active routes to see how the routes relate versus time.
  - **sequential animation** - show an icon moving along one route.
- Routes include a direction, either attack or egress. How can we show the differences between the routes?
  - **color for direction** - show attack routes in one color and egress routes in a complementary color.

- **arrows for direction** – use arrows to show direction of movement.

6.3 Unit Level Planning

Unit level planning takes the air tasking order generated at the force level, analyses it for feasibility, creates flight plans and avionics computer input. Since a route created during force level planning is not necessarily one that can be flown, unit level planning must address a route's feasibility considering current aircraft, personnel and ordinance inventories. At this level, a planner needs to visualize routes with respect to more detailed topographic, threat and weather representations, but three-dimensional representations are not required. Contours of elevations and weather patterns are sufficient for the unit level planning, and the routes can be shown superimposed over these two-dimensional representations of three-dimensional data.

Unit level issues are:

- The ATO flight plans may not be feasible. How do we highlight the bad ones and which constraints do they violate?
  - **highlight by blinking** – blink those legs of a route that are in violation.
  - **highlight by color coding** – color violating legs with a specified color.
- Weather ceilings may change flight corridor. How do we show ceilings affect on flight path?
  - **side view of weather ceiling** – show a vertical cross section of the weather pattern and the route projected onto the cross section.
  - **color coding by route altitude** – vary the color of the route according to its altitude.
  - **color coding by weather parameters** – color the route using weather parameters such as pressure and wind velocity.

6.4 Mission Rehearsal

Pilots use route plans to study the details of the mission including the topography and geography to be encountered as well as details of the threats that can be expected during the mission. From the pilot's point of view, three-dimensional representations of topography, threats and weather are critical to his understanding of the mission.

Mission Rehearsal issues are:

- The flight path of an airplane is three-dimensional. What techniques are available to visualize three-dimensional paths?
  - **parametric cubic splines** – represent the 3D path using parametric cubic splines, i.e. one spline per dimension parameterized by chord length.
  - **polygons** – show the path as a series of polygons, coloring the top and bottom sides of the polygons differently to highlight complex maneuvers.
  - **other primitives** – use cylinders with regular polygon cross sections to show twisting of the path.
  - **train tracks** – show two parallel tracks with cross polygons as is done in the Pilot's Associates video.
- A target protected by many threats may have limited approach paths. These paths are inherently three-dimensional. How can we represent the acceptable flight paths?
  - **volume modeling** – model the complement of the threat zones using volume modeling techniques. The resulting path will appear as geometric volume that can be interactively navigated.
  - **multiple views** – show top and side two dimensional views simultaneously.
- Alternative legs may exits at a turnpoint. How do we show these alternatives and their relative effectiveness?
  - **legs as spokes from a turnpoint** – at each turnpoint show the splitting as spokes of a wheel. Let the user highlight a selected spoke to see its relation to alternatives.
  - **map effectiveness to color** – change the color of the alternates, mapping probability of success, fuel consumption, deviation from time on target, etc.
- Resources such as fuel and ordinance are consumed during a flight. How do we show the status of these resources as a mission unfolds?
  - **vary width of path** – change the width of the path according to fuel and ordinance reserves.
  - **vary color of path** – map resources to the color of the path.
- Turnpoint correlation with topographic features is critical during the flight. How do we relate recognizable features to the flight path?
  - **panoramic views using recon data** – using optical video disk, display images of recon data tied to individual turnpoints or locations on a leg.

- **3D typography tied to turnpoints** - display 3D topography when the user clicks on a turnpoint. This technique uses the actual path as an active icon.

6.5 Summary

Route representation plays a role in all aspects of planning: force level, unit level and mission rehearsal. As planning proceeds from the big picture to the pilot's mission, the graphical requirements move from two–dimensions to three–dimensions. Color and animation play key roles in all areas of route planning.

- Overlays - to make routes visible on maps, make the map colors pastel. When routes overlap, use logical "and" and "or" to show the combination of two or more routes.
- Geometric Representations - change the shape of routes when they intersect or overlap. Map scalar data such as fuel reserves to the shape of a route. Show route direction with arrows. Change a route's thickness (make it bulge) when a constraint is violated. Represent 3D paths with parametric cubic splines. Use higher order primitives such as cylinders and train tracks to show twisting 3D flight paths.
- Modeling - create geometric models of flight paths using volume modeling techniques. The complement of threat zone volumes will show a safe path.
- Color - use fully saturated colors for routes to emphasis them on maps. Map scalar values such as time to target, fuel level, and probability of success to the color of a route. Use color to distinguish route direction (attack or egress). Highlight constraint violations with color.
- Animation - highlight routes on a busy screen by moving icons along the route. When routes overlay, alternate the display of each route. Compare the relationships between multiple paths by moving icons along multiple paths, synchronizing the motion with time.
- Data Association - associate fuel gauges with turnpoints. Associate 3D topography to turnpoints. Associate video clips of recon data to turnpoints.
- Multiple Views - Show top and side views of topography and weather.

7 User Interaction

7.1 Introduction

All planning activities that use computers require special attention to the human–computer interaction. This interaction includes:

- introducing input data to the system (constraints, targets, threats, etc.),
- observing the results of intermediate and final calculations,
- evaluating alternate solutions,
- storing data into data base,
- retrieving data from data base,
- receiving update information relevant to planned mission

In this section we present the general characteristics and requirements of a good user interface. At the end of the section we present an overview of windowing environments and user interface management systems.

7.2 User Interface Characteristics

The characteristics of a good user interface have been studied in many papers and books dedicated to this subject [1]. Some authors provide lengthy lists of do's and don'ts in user interface design[18, 21]. These suggestions are based on extensive research of user psychology and statistics gathered from various case studies. A good user interface:

- is invisible, e.g. it does not create breaks in user concentration on the performed tasks,
- provides closure, e.g. user is aware of the operation performed and is notified when operation is done,
- requires minimum training (simplicity),
- has high transfer–of–training,
- is predictable (consistency),
- is easy to recover from errors,
- is flexible,

- is intelligent,
- is fast

Users know right away if they are happy with a user interface. If unhappy, there is real danger that the software won't get used. This is a very condensed list and each of its entries can be elaborated into pages of specifications; for example, the menu and button selections have to be structured to provide convenient and fast retrieval of information. This involves many issues of choosing the right color, fonts, and selecting an appropriate layout for control buttons and display areas. A great deal of experience is required to avoid common pitfalls in creating a good user interface. The following list identifies important user interface requirements:

- **Map and photograph manipulation** This includes techniques for accessing map data or data base. Selected maps should be displayed and user should be able to zoom, pan, or select different layers of the map. Possible selection devices include pointers (mouse, touch–screen, digitizing tablet, and light pen) or menus and buttons.

- **Manipulation of 2D graphics data** Selection and dragging of 2D graphics on the screen should be provided. Some 2D graphics images may have different representation modes that should be selectable by the user from menus or user interface buttons. For example, putting a lasso around a threat representation and moving it to another location, or selecting a threat via a mouse pointer or a pop–up menu and removing it entirely from map.

- **Manipulation of 3D graphics data** This includes techniques for manipulating 2D graphics data and should support intuitive techniques to do translations and rotation in 3D space. Since most current pointing devices only support 2D input, special processing is required to do 3D manipulation. New devices, like data gloves, are true 3D input devices. Entertainment games, such as Nintendo, use data gloves to remotely transmit the intention of the user to participants on the display screen. For example, in a boxing match, a movement of the user's right arm in a certain direction and speed will be directly transmitted and used by one of the boxers on the screen. In an Air Force planning application, the user can remotely transmit his intent, such as send a signal to start the animation of a plane(s) route(s).

- **Timely notification of important events** The user can be alerted to high–priority changes in the display using a number of techniques, such as icon changes, changes in color or patterns, pop–up windows, audio signals, and speech synthesis. Some application-specific uses for alerts are changes in weather, threat or target movements, or changes in mission requirements or resources.

- **Concurrent Viewing of Information Sources** Because of the large amount and variety of tactical planning information, and the need to understand relationships between the types of information, a specific requirement is to be able to view different data sources or alternate plans concurrently. A graphical technique for satisfying this need is a windowing system such as X. Since this is an important graphics requirement, a subsequent section provides more detail on Windowing Environments.

- **Switching between alternate sources of sensor data** Different data sources (e.g., radar, infrared, or visual data) can be represented as overlays to the map data. Overlays can be selected individually or in combinations, or animated by cycling.

- **Switching between different representations** For example, ordnance can be presented visually as bitmaps, text, or small icons.

- **Animating objects in the display** Animation is extremely useful to represent changes in space and time. The user must be able to easily interact with the animation. This interaction involves the creation, manipulation, movement, and storage of animation objects. Many of the VCR-type functions must be available, such as pause and rewind. Editing of the animation must be interactive, e.g., changing the route way points and reinitiating the animation. A remote 3D device such as a data glove could allow a pilot or planner to control a flight path and change its direction as he reacted to threats or weather patterns (similar to a video game).

- **Customizing the user interface** A major portion of application software development is devoted to the creation of user interfaces. Graphics tools should be provided for easy change of layout and functionality of user interface objects. A subsequent section discusses User Interface Design Tools. Since there are so many combinations of overlays possible (how many to use, whether to display them statically or cycle through them dynamically, and what each one should contain), it is imperative that the planner be able to design them to suit his needs.

- **Simulation of virtual environments** A virtual environment is a computer simulation of some physical processes. In mission rehearsal, for example, the computer can simulate a fly-by of the aircraft through a 3D environment along the planned route, and the pilot can observe the scenery on the computer screen or with a head mounted display.

7.3 Windowing Environments

The large amount of screen real estate available on workstations requires software to manage it. In the early 1970s, researchers at Xerox PARC began experimenting with systems that allowed the user to partition computer displays into multiple regions, or windows. Coupled with the invention of the mouse at PARC in the 1960s, this made possible much of the user interface display technology available on today's workstations. In this section we discuss the basic terminology of window systems and the two most likely window systems that will be in use under UNIX for the next five years, X11 and NeWS.

7.3.1 Window System Terminology

A *window system* divides the display into multiple regions, usually called windows. (They are sometimes called canvases or layers.) Windows are organized into *trees*, with each window having a single parent. A window is clipped to the boundaries of its parent window. The root window provides the background for all other windows displayed. *Top-level windows* are windows whose parent is the root window. The window system user interface (its *look and feel*) is governed by a *window manager*. It is responsible for screen management of all top-level windows, such as:

- whether or not windows can overlap,
- how the initial location of a new window is set,
- how menus are displayed,
- which window receives characters when the user types on the keyboard (the *keyboard focus*), and
- how the keyboard focus is moved between windows.

Window management functionality has traditionally been part of the window system itself. With the release of X and NeWS, a trend has emerged to have window managers as separate programs.

7.3.2 X11

Most early window systems were tied to the hardware and operating system software on which they ran, so it was virtually impossible to write portable applications that made use of window system functionality. The X Window System, developed by MIT's Project Athena, changed that. Development progressed internal to MIT until X, Version 10 was made generally available to the public. The current version, X11, is now widely available from many computer vendors, as well as from MIT over the Internet. X11 is a network-based window system consisting of a server that manages display resources (frame buffer, mouse, and keyboard) for client applications and a protocol that the server uses to communicate with its clients. The two major contributions made by X11 are:

- Standardization – Many computer vendors now offer X as the only, or predominant, window system running on their machines. Coupled with graphics standards, such as PHIGS, and with standardized user interfaces, such as MOTIF or Open Look, X11 holds the promise of portable graphics and window-based applications.
- X protocol – The server and its clients communicate using the *X protocol.* This allows applications running on (say) a supercomputer to display results on the workstation on the user's desk. Better use is made of both resources, the supercomputer and the workstation.

In some respects, however, X11 is like older window systems. For instance, it is pixel-based, so an image displayed on two different monitors will look different if their resolutions are different. Device resolution independence must be programmed into each application.

X11 is currently the standard window system for much of the computer industry, and will be for several years to come. Currently the easiest way to develop portable applications is probably to develop them to run under X11 using a publicly available toolkit, such as the HP Widgets.

7.3.3 NeWS

NeWS, from Sun Microsystems, is another window system, similar in some respects to X. It is network-based, like X, so server and client can reside on different computers, and it is inherently policy-free; window management functions are performed by a separate client program.

However, NeWS is strikingly different than X in one major respect. Instead of using a special-purpose protocol to communicate between server and client, NeWS uses a superset of PostScript, the graphics page description language developed by Adobe. This makes NeWS display resolution-independent, and gives the software developer very significant gains in expressive power, because PostScript was designed as a high-level graphics language.

7.4 User Interface Design Tools

As user interfaces have become more sophisticated, they have become harder to develop. X11 application developers who program using one of the toolkits available, such as the HP widgets, have three subroutine libraries to choose from, containing 700 or more functions. Of those 700-plus functions, typically between 50 and 150 will be needed by most applications. Other window systems have programming interfaces of similar complexity.

This complexity leads to low quality user interfaces. While some initial design of the user interface may be done, the difficulty inherent in modifying the interface means that for all practical purposes, the first interface that is functionally correct (the one with the correct number of buttons and windows) is the final one. Even simple tasks, such as lining up a row of buttons or changing object colors, is often not performed, because it is too tedious a task. Little or no user interface design modification is attempted for most window-based applications.

Graphical user interface editors are now available from a number of sources. They promise to revolutionize the way graphical user interfaces are designed and to dramatically reduce the time necessary to develop a mature user interface. Some tools, such as VAPS and DataViews, are quite mature, and are geared toward specific application domains. Others, such as UIMX, GUIDE, and TAE Plus, are more general, but less mature.

User interface layout tools are important because the user interface, as discussed above, must be flexible. The planner should be able to modify many properties of the user interface without resorting to traditional programming methods. Much of the flexibility necessary can be achieved using layout tools. For other tasks, special tools must be developed, however, many of the properties they must exhibit are those of good layout tools.

7.5 3D Input

Three-dimensional input is a cumbersome task, because most displays and input devices are two-dimensional. No single solution allows the user to manipulate objects in the dimension perpendicular to the display device. Moreover, in the context of the tactical Air Force environment, 3D input is not generally required except in those instances where the third dimension of altitude is important. This is often the case for pilots who plan the details of their route. However, it would be best to use the usual aircraft controls in order to navigate this space, since this is what the pilot is familiar with.

When 3D input is needed by planners, some echniques have been developed to cope with this problem. Chen [14] discusses several schemes for rotation of 3D objects using a mouse. In particular, one technique he calls *virtual spheres* works quite well. In this paradigm, the object to be manipulated is located in the center of an imaginary sphere, and the user clicks on the sphere with a mouse, rotating the sphere (and thus the object inside into a new position). Nielson and Olsen [28] describe a technique for 3D manipulation (rotation, scaling and translation) that assigns motion along or about the three Cartesian axes based upon the relationship between their projection on the display and the movement vector of the mouse. Additional possibilities for 3D input include the space ball and the data glove.

7.6 Summary

The following is a brief summary of graphical requirements for user interaction.

- 2D Input
    - Selection and dragging of 2D graphic representations: mouse, touch-screen, digitizing tablet, menus, buttons. Ability to pan and zoom.
- 3D Input
    - Ability to perform translations and rotations in space.
    - 3D input devices such as data gloves to interact with objects on the display
- 2D/3D Pictorials
    - User notification of important events: icon changes, pop-up windows, changes in color or pattern, audio, speech synthesis
- Multiple Displays
    - Viewing of concurrent sources of information, such as weather, threat, and animations: windowing systems and techniques such as Hypermedia
- Overlays/Groupings
    - Ease of interaction with overlays of different data sources, e.g., sensors
    - Switch between different representations: 2D map with icons, 3D shaded polygons, photographs, text
- Animation
    - Ease of interaction in creating, manipulating, moving, and storing animation objects
    - Editing animation
    - 3D remote interaction with animation, such as data glove
- Interactive Displays
    - Customizing user interface: design tools for user interface
- Virtual Environment
    - Immerse user in a realistic simulation of his environment, e.g., mission rehearsal. Graphic methods: animation, head-mounted displays, 3D input devices

1 Ronald M. Baecker and William A. S. Buxton. *Readings in Human–Computer Interaction.* Morgan Kaufman, Los Altos, CA, 1987.

2 Stephen Bate and Kevin Stanley. Heuristic Route Planning: An Application to Fighter Aircraft. *Proceedings of the National Aerospace Electronics Conference*, pages 1114–1120, 1988.

3 Richard A. Becker and William S. Cleveland. Brushing Scatterplots . In *Dynamic Graphics for Statistics*, chapter 8, pages 201–224.

4 Sara Bly. *Sound and Computer Information Presentation.* PhD thesis, University of California, Davis, 1982.

5 Piero P. Bonissone and James K. Aragones. LOTTA: An Object Based Simulator for Reasoning in Antagonistic Situations. In *Proceedings of the Summer Simulation Conference*, 1988.

6 P. P. Bonissone and K. S. Decker. Selecting Uncertainty Calculi and Granularity: An Experiment in Trading-off Precision and Complexity . Technical Report 85CRD171, GE Corporate Research and Development, Schenectady, NY, December 1985.

7 Piero P. Bonissone and Soumitra Dutta. MARS: A Mergers and Acquisitions Reasoning System. Technical report, GE Corporate Research and Development, Schenectady, NY, 1989?

8 Jeffrey S. Bradshaw. A Pilot's Planning Aid for Route Selection and Threat Analysis in a Tactical Environment. Master's thesis, Air Force Institute of Technology, 1986.

9 Marty Broadwell, James Smith, Jack Barnette, and Chris Staros. Decision Aiding for Tactical Aircraft. *SPIE Applications of Artificial Intelligence II*, 548:153–160, 1985.

10 D. B. Carr and W. L. Nicholson. EXPLOR4: A Program for Exploring Four-Dimensional Data using Stereo-Ray Glyphs, Dimensional Constraints, Rotation, and Masking. In *Dynamic Graphics for Statistics*, chapter 12, pages 309–329.

11 John M. Chambers, William S. Cleveland, Beat Kleiner, and Paul A. Tukey. *Graphical Methods for Data Analysis*. Statistics/Probability Series. Wadsworth, 1983.

12 Leonid Charny, Mary E. Hornsby. and Thomas B. Sheridan. An Interactive Multi-Objective Decision-Aiding System for Tactical Mission Planning. In *Proceedings of the Human Factors Society–31st Annual Meeting*, pages 432–436, 1987.

13 Derek B. Chamberlain and Charles R. Kirklen. Advanced Mission Planning System (AMPS) Employing Terrain and Intelligence Database Support. *Proceedings of the National Aerospace Electronics Conference*, pages 1145–1151, 1988.

14 Michael Chen, S. Joy Mountford, and Abigail Sellen. A Study in Interactive 3-D Rotation Using 2-D Control Devices. In *Computer Graphics*, pages 121–129.

15 Herman Chernoff. The Use of Faces to Represent Points in k-Dimensional Space Graphically. *Journal of the American Statistical Association*, 68(342):361–368, June 1973.

16 William S. Cleveland and Marylyn E. McGill, editors. *Dynamic Graphics for Statistics*. Statistics/Probability Series. Wadsworth and Brooks/Cole, 1988.

17 Frank Crow and Setphen M. Pizer, editors. *Proceedings 1986 Workshop on Interactive 3D Graphics*, October 1986.

18 J. S. Dumas. *Designing User Interface Software*. Prentice-Hall, 1986.

19 Bernhard Flury and Hans Riedwyl. Graphical representation of multivariate data by means of asymmetrical faces. *Journal of the American Statistical Association*, 76(376):757–765, December 1981.

20 Lambertina W. J. Freni-Titulaer and William C. Louv. Comparisons of some graphical methods for exploratory multivariate data analysis. *The American Statistician*, 38(3):184–188, August 1984.

21 M. Gardiner and B. Christie. *Applying Cognitive Psychology to User Interface Design*. John Wiley and Sons, 1985.

22 Greg D. Gibbons, Jonathan S. Abel, and Jill V. Josselyn. ASAP: AI-Based Situation Assessment and Planning. *Proceedings of the National Aerospace Electronics Conference*, pages 932–939, 1988.

23 Gerald J. Hahn, Carolyn B. Morgan, and William E. Lorensen. Color Face Plots for Product Quality Assessment. *Proceedings of the Statistical Computing Section of the American Statistical Association*, pages 252–255, 1981.

24 Jeffrey D. Hoffman. Terrain Following/Terrain Avoidance/Threat Avoidance for Helicopter Applications. Technical report, Texas Instruments, 1988.

25 David W. Hussey. The Digital Colour Map Simplifies Ground Attack Operations. Technical report, GEC Avionics Limited, 1987.

26 B. Kleiner and J. A. Hartigan. Representing points in many dimensions by trees and castles. *Journal of the American Statistical Association*, 76(374):260–276, June 1981.

27 J. J. Mezrich, S. Frysinger, and R. Slivjanovski. Dynamic Representation of Multivariate Time Series Data. *Journal of the American Statistical Association*, 79(385):34–40, March 1984.

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