Aggregate Towers: Scale Sensitive Visualization and Decluttering of Geospatial Data

James K. Rayson
The MITRE Corporation
202 Burlington Road
Bedford, MA 01730
jrayson@mitre.org

Abstract

We have developed a technique, Aggregate Towers, that allows geospatial data to be visualized across a range of map scales. We use a combination of data aggregation algorithms and dynamically aggregating data markers (e.g., icons or symbols) to accommodate interactive zooming by a user while maintaining a representation that remains intuitive, consistent across multiple scales, and uncluttered. This approach implicitly generates multiple levels of overview displays from a single set of underlying data.

CR Categories and Subject Descriptors: H.5.2 [Information Interfaces and Presentation]: User Interfaces; I.3.6 [Computer Graphics]: Methodology and Techniques; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

Additional Keywords: data visualization, information visualization, aggregation, zoom, cartography

1. Background

The modern battlespace contains enormous volumes of data. It can be static or dynamic, incorporating maps, imagery, live radar views of the air or ground traffic, fuel depot status, and many other categories of information. Subsets of this data are needed by thousands of users in hundreds of different job categories. One of the challenges is developing ways to visualize this data in a comprehensible uncluttered fashion, while accommodating users whose tasks and geographic scopes may be profoundly different.

The initial subset of battlespace data we chose for our research was a target list. Selecting a data set also served to constrain our universe of potential users to the comparatively homogeneous subset who care about this kind of data. A target list is point data that provides the locations and attributes of potential ground targets. It is typically presented as markers (e.g., an icon or symbol) on a map. Some users of this data are responsible for an entire theater of operations and will chose a map scale that will let them see the target distribution over a 1000km by 1000km region. They may periodically zoom in on an area of interest. Conversely, other classes of users will select a map scale that will allow them to focus on the locations of targets within a specific 10km x 10km region. While preferring to work at this more detailed scale, they may occasionally zoom out to get the big picture . The techniques we have developed apply not only to targets, but to a wide variety of cartographic point data sets. These could include the locations of cases of infectious diseases, factories with high emissions, fast-food restaurants, or clothing stores.

2. Problem

What issues are associated with viewing the point data at multiple scales? Foremost is clutter. As we zoom out, the amount of data to be displayed per square inch of display space increases dramatically (in fact, quadratically with respect to the zoom factor [1]). Given the typical density of our data sets, clutter is a frequent problem. It not only makes it difficult to understand the visualization, but an even more dangerous effect is data masking. As we zoom out the positions of markers on the maps converge more and more until they are obscuring each other partially or entirely. This hidden data makes any attempts at overviews very misleading. In regions with a high point density, this effect will degrade the effectiveness of even a close-up view.

In Figure 1 we see a conventional 2D display of cartographic point data for the entire theater. We annotated just a few representative areas, indicating the number of points each contains. In the lower left we see that a group of 1 point is indistinguishable from a group of group of 8 points. Elsewhere we see groups of 11 points that appears to be just 2, and of 13 points that appears to be just 4. These are a few examples of data masking in this view. Many more can be found by comparing Figure 1. to Figure 4.

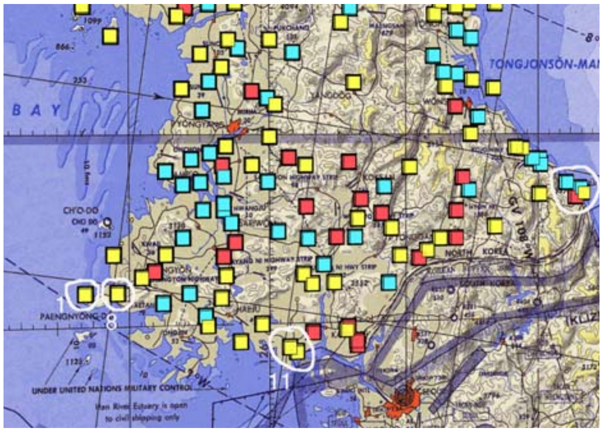


Figure 1. Data masking in conventional display

Another issue is the need to support user intent. Users will select a map scale based on the task they are trying to perform and the geographic scope it demands. The zoom can serve as a mechanism for specifying the amount of detail desired. When zoomed out, the user is interested in getting an overview of locations and distribution. However, that is problematic because information of that coarser granularity is not directly available. Something must convert the fully detailed data set into an overview.

In summary, the issues we must address are:

- How to visualize the data at a single scale
- How to visualize the data at multiple scales
- How to automatically generate an overview
- How to automatically declutter
- How to use a zoom function to range between the multiple data scales

3. Related work

There has been a lot of research in related areas, but while it provides conceptual insight it does not provide solutions to our specific problems. Sources such as Bertin[2] and MacInlay[3] provide basic tenets to apply to the design of a visualization, while Keller & Keller[4] provides a broad range of interesting examples. Perlin and Fox [5] provide relevant insight from the perspective of a zoom-based user interface. Frank and Timpf[1] explore cartographic zoom with an emphasis on the requisite data structures. However, they restrict themselves to manually generated discrete levels of detail and note that cartographic generalization, which includes the process of generating overview information from detailed data sets, is predominantly a manual activity because efforts at automation have been largely unsuccessful. Woodruff, et al, [6] have addressed clutter resulting from multiple zoom levels, but from the perspective of providing general tools to a designer rather than automatic generation of decluttered data levels or the inclusion of multiple zoom level support into the visualization primitives. Goldstein and Roth[7] explicitly deal with aggregates from the context of another user controlled tool that uses aggregations of the output of various database queries in interactive data exploration. The aggregation is not a part of the visualization technique. There has been some interesting work done on techniques for minimizing occlusion. Gridfit[8] addresses it through constrained spatial redistribution of 2D points. Distortion-oriented displays provide details within context, which is related to our interests in providing detail as a component of an overview. Carpendale, et al,[9] provide a summary of the research and extend the concept from 2D into 3D, with an additional emphasis on occlusion. The cityscape metaphor has been described as "a generalization of bar charts in 3D" by Keskin and Vogelmann[10], and bears some visual resemblance to our work. It has been implemented in several systems including MineSet[11] (which incorporates FSN), and SDM[12] which uses vertical displacement of towers to address occlusion. We diverge from those cityscape implementations through our notions of composition of visual primitives and dynamic aggregation. The use of multiple levels of detail (LOD) to support different viewing distances (or zoom levels) has been widely discussed in the computer graphics literature such as in Foley, vanDam, Feiner, and Hughes[13] but it is a fundamentally different issue. It provides for the simplification of a coherent visual object rather than our need, which is the formation or decomposition of a coherent object.

4. Testbed

Our work was performed in the MITRE Visualization Laboratory which contains a range of computing platforms, input devices, and display devices. Our configuration for this research activity is shown in Figure 2. At the top of the figure is a Sun workstation containing an Oracle relational database. It stores all the data we wish to visualize, and is connected via Ethernet to the visualization systems. The visualization platforms range from a high end Silicon Graphics system (Onyx2 InfiniteReality), to a 300 MHz personal computer. The display devices include a CRT, a stereoscopic rear projector, and a stereoscopic table. The stereoscopic devices have the option of being operated in non-stereoscopic (monoscopic) mode, as well as operating with or without eyepoint tracking. All the visualization software was developed in house. Our goal was to develop visualization techniques that would be effective across a range of computers and display devices. The diversity in our testbed allowed us to explore our visualization in a variety of display and compute environments. Initial development was performed on a Silicon graphics system and displayed on the table with both head tracking and stereo enabled. It was subsequently tested using the rear-projection system with tracking disabled and stereo both enabled and disabled. It was also tested on a monoscopic CRT driven by the PC. The visualization remained effective across all these environments.

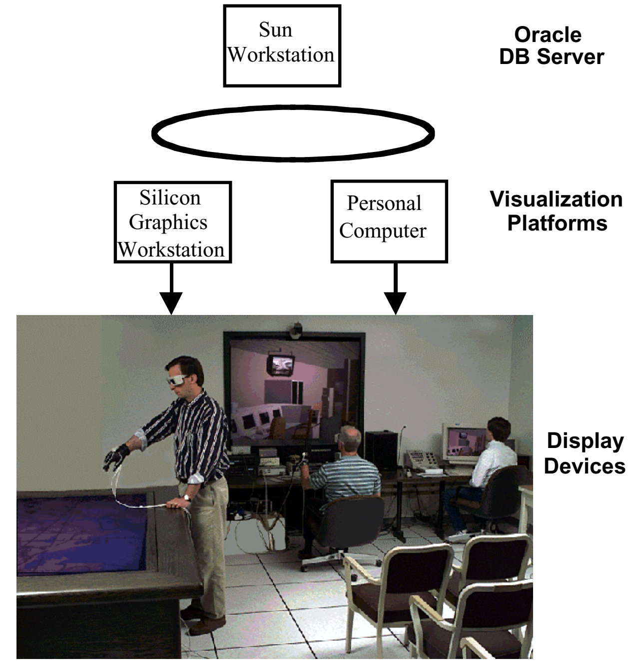


Figure 2. Testbed configuration

5. Approach

We need to provide continuous zoom display of point data across a geographic scope ranging from 10km x10km to 1000km x 1000km. As a user zooms out, the display should remain uncluttered and all the critical data presented within the visualization should remain visible and comprehensible. There should be a seamless transition from a detailed view to an overview, and vice-versa. Our basic approach is to apply an aggregation algorithm to the point data, and couple it with markers designed to function as both individuals and aggregates. The aggregation algorithm serves two purposes. First, it declutters the data by reducing the total quantity of markers that need to be displayed. Second, when coupled with a properly designed visualization technique, it can generate overview information from a source that originally contains only detailed information. Visualizations such as ours, which use depictions of the detail as components of the overview, have been dubbed micro/macro designs by Tufte[14].

5.1. Data Set

The targets (data points) are typically distributed throughout the theater of operations although each set contains at least a few clusters. In particular, there may be target complexes (e.g., multiple structures within a single military base) that are all identified with the same latitude and longitude. Each target has up to 14 text or numeric parameters associated with it. The most important are location (in latitude/longitude) and mission type. The latter is a nominal data set with 6 elements that categorizes the target as a threat to friendly aircraft, friendly troops, etcetera.

5.2. Marker Design

There are several considerations in the design of the markers:

- They must support multiple levels of aggregation
- They must immediately convey the critical information, and provide access to secondary data
- They must be visible

The varying geographic scope of the users drives the need to display both individual points and aggregated points. A marker design that maintains visual continuity as it transitions from its individual to its aggregate state is more intuitive to the user than a set of discrete marker designs that are distinct for each map scale. The need to immediately convey the critical information means that this information must be visually encoded in a fashion that makes it readily comprehensible and, again, this encoding must remain effective whenever the markers are in their aggregated or disaggregated state. Providing access to secondary data implies some mechanism for interacting with the markers to display information beyond what is currently depicted. Finally, the need to be visible (which seems obvious but in practice is sometimes overlooked) forces us to deal with color and size issues for the markers, especially in the context of the map on which they are overlaid.

5.2.1. Individual Markers. The basic point marker primitive is a cube, as shown in Figure 3a. A map serves as the reference plane, allowing the placement of the cube on the map to serve as one means of identifying point position. A single cube represents a single point. The tower of cubes is an aggregate marker and will be described in the next section. The color of each cube represents its mission type: yellow for Offensive Counter Air, blue for Interdiction, and red for Battle Area Interdiction. Bold solid colors were chosen to maintain contrast with the multicolored high frequency content of the map underlay. All edges of the cube are rendered with thick black lines. These help distinguish them from the background and each other. There is also a black footprint underneath each marker, slightly larger than the marker itself. The utility of the edge outlines and black footprints will be further addressed in the aggregate marker section.

5.2.2. Aggregate Markers. An aggregate marker is constructed as a stack of individual markers, the Aggregate Towers, as shown in Figure 3a. The blue tower represents 10 Interdiction targets within a single target complex. It is a uniform color because all of the targets at the complex are of the same type. Each aggregate marker serves as a stacked bar graph. This is done by sorting all the targets in an aggregate by color prior to rendering the aggregate marker, and outlining the individual cubes in black to allow the user to distinguish the quantity of cubes of each color within the aggregate. It allows us to easily understand the distribution of types within each aggregate. An alternative approach, not yet implemented, would use the stacking order to represent temporal information.

In Figures 3b, 3c, 3d, and 4 we see multi-colored towers representing aggregates of non-homogeneous mission types. One motivation for selecting single sized cubes as the individual markers is that, unlike spheres for example, when abutted they form a single visually coherent object. This composition of primitives approach to the creation of the aggregate markers allows us to automatically aggregate to any level to accommodate a continuum of viewing scales while maintaining

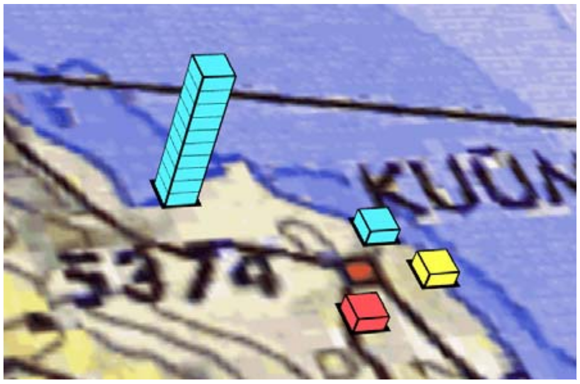
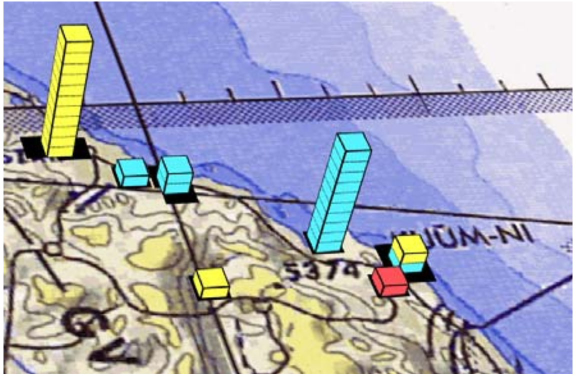
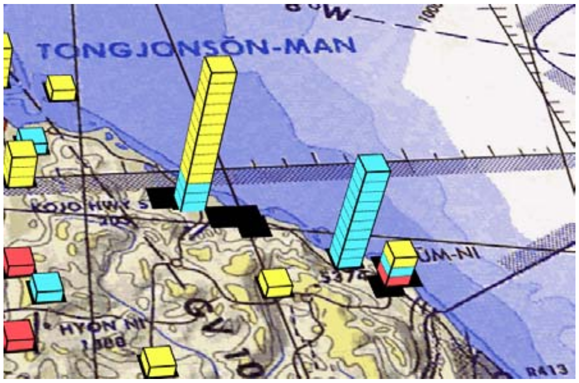


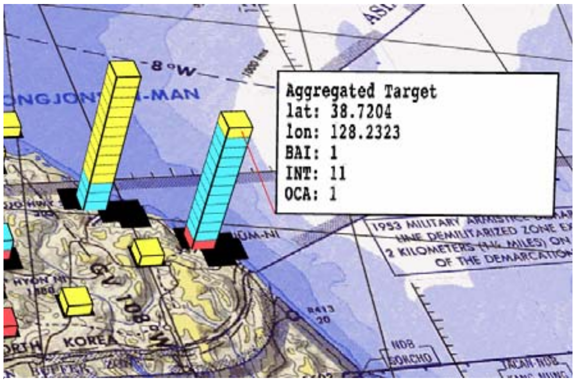
Figure 3a. Zooming out – Initial view
[See also color plates]



3b. Zoom out by 1 increment



3c. Zoom out by 2 increments



Aggregated Target
lat: 38.7204
lon: 128.2323
BAI: 1
INT: 11
OCA: 1

3d. Zoom out by 3 increments

consistency in the appearance of the markers. A key benefit of this aggregate marker design is that the aggregates implicitly generate an overview of the data while maintaining the detail in an uncluttered and non-distracting fashion. The overall height, color distribution, and edge outlines in the aggregates provide the user with an immediate qualitative perception of the distribution of point densities and types. This is our desired overview. To obtain more detailed quantitative information the user then has the option of counting the number of cubes in the aggregate, selecting the aggregate to access the secondary data, or zooming. Zooming in on an aggregate causes it to disaggregate into smaller stacks in a very intuitive fashion until it eventually degenerates into a set of disconnected individual point markers.

Each aggregate marker represents a set of points that are close to each other but dispersed over a geographic region of unknown shape and size. As Bracken[15] and others have warned, the grouping of geospatial data can be misleading. Does the aggregate represent a set of tightly clustered points within a 1km radius, or a long thin crescent of points spread out over many kilometers? We compensate for the potentially misleading portrayal of the point distribution through the use of the footprints. Each point s footprint is always rendered regardless of the level of aggregation. Since all the footprints are the same color, when they overlap or abut they blend together and appear to form a single contiguous object. This virtually aggregated footprint represents the entire region over which the point aggregate has been formed. The aggregate marker is always placed within its corresponding footprint.

We considered rendering the footprints using transparent rather than black overlays. This would have the benefit of not occluding details on the base map. The problem is that different areas of the aggregate footprint will be formed from different quantities of overlapping constituent footprints. The result would be variable opacity within the footprint of a single aggregate. We would lose the homogeneity and visual cohesiveness that fools us into perceiving the aggregated footprint as a single object. While it would be possible to correct these shortfalls algorithmically, and the variable opacity might in itself be informative, we did not think the benefits outweighed the increase in computational complexity.

5.3. Secondary Data

When visualizing data, sometimes not all parameters can or should be visualized simultaneously. However, a mechanism should be provided to display all available data, even that which is not immediately visible. We have chosen to display this secondary data using a text popup box that is invoked by selecting the marker with either a glove or a mouse click . This box is visually linked to the marker by a line. Figure 3d shows a small subset of the information from the database being displayed in text form. The secondary data display can also provide valuable redundancy by displaying the critical data parameters in an alternative way. An example is position. The map provides a good visual display for point position, but requires significant effort by the user should he need to determine more than an approximate latitude and longitude. Precise position information can be obtained by selecting the marker, resulting in a popup box that contains supplementary information including the latitude and longitude. Having this data available in text form facilitates its use in certain kinds of tasks. The secondary data display is adaptive. When invoked for an individual point, it provides the point name, location, and type. When invoked for an aggregate it provides a generic label for the target name (since there is no meaningful way to define a name), an average location for its constituent targets, and a list of target types and quantities within the aggregate. In order to select (query) an individual marker within the aggregate, it is currently necessary to zoom in until it is fully disaggregated. We are currently exploring techniques to support queries of individual markers within an Aggregate Tower, while still allowing the aggregate as a whole to be queried.

5.4. Perspective and Sizing

As seen in Figures 3 and 4, our visualization approach is inherently three-dimensional (3D) and requires that the viewer s eyepoint be off-axis to the normal of the map surface. If the viewer were looking straight down at the map along its normal he would be unable to ascertain the height or components of the aggregate marker. We use a perspective projection to convert from 3D to 2D for rendering. We chose a perspective rather than an orthographic projection to maintain a sense of natural behavior in the view, especially when using stereoscopic displays, and provide an additional depth cue for identifying the position of the markers relative to each other and the map. The disadvantage is that the foreshortening effect of the perspective projection leads to displays that have non-uniform scale from foreground to background. However, this is ameliorated by the equivalent foreshortening in the map reference plane, which leads to proper positioning of objects on the map.

The variable scale within the perspective view does enter in to our considerations for marker sizing. When zooming in or out, should the markers resize to maintain a constant size relative to the map scale (e.g., always 1km in width based on the current map scale) or instead maintain a constant size as perceived by the user (e.g., always 10 pixels wide)? Our scaling solution is a hybrid. We define a relatively small fixed geographic size for the markers in kilometers, but when it comes time to render them they are subjected to a minimum size constraint also specified in kilometers. As a user zooms in, the markers increase in size in a natural fashion, mimicking the user s expectations and matching the behavior of the underlying map. Markers in the foreground are also larger than those in the background as we would expect in a perspective view. As a user zooms out, the markers diminish in size, until they eventually reach a minimum and then maintain a constant size. The size changes during zoom also provide feedback to the user that a zoom in happening. The fixed and minimum sizes were determined empirically for our standard map series (1:1,000,000 Operational Navigational Chart) viewed at a wide range of zoom levels. The only constraint was that when fully zoomed out the minimum size markers still allow their colors and constitution to be discerned, and be consistent with ergonomic standards[16]

5.4.1. Zoom Behavior. The series of Figures from 3a through 3d illustrate how point markers aggregate as we zoom out. Each zoom increment is a cumulative rescaling (division) by a factor of 1.5. Going from 3a to 3b we see how a blue and a yellow marker have aggregated. As we get to 3c we see that their neighboring red marker has also joined the aggregate. Finally in 3d we see that aggregate has now been joined with the neighboring tall blue aggregate. Similar aggregation behavior can be observed in the yellow tower that first appears in 3b. Also note what happens to the footprints of the point markers. They are barely visible in 3a since they are coincident with the markers and start to join in 3b. They grow in coverage in 3c and 3d as the geographic spread of the points used to form the aggregates increases.

The background map scales appropriately as we zoom out from Figure 3a through 3d. The marker sizes also scale appropriately from 3a to 3b, but careful examination will show that they remain constant through 3c and 3d. The markers reached their minimum visible size and stopped rescaling with subsequent zooms.

There is no inherent necessity for the zooming to happen in discrete increments rather than continuously. Our algorithm supports continuous zoom. The incremental zooming was implemented to allow zoom control through discrete button pushes on some of our input devices.

5.5. Aggregation Algorithm

The aggregation algorithm is invoked every time the user requests a display of target information. It queries the database for target locations within that geographic area and determines, on a point by point basis, where aggregation is appropriate. The aggregations are <u>not</u> precomputed for a discrete set of map scales.

Aggregates are derived primarily from display space considerations (e.g., will the markers overlap when rendered on the display?) rather than data space considerations (e.g., what is the geographic distance between the points?) because clutter and occlusion are ultimately user experiences in display space. The software compares the marker size in kilometers at the current zoom level to the distance between points to identify overlap between markers. Any amount of overlap will force them to aggregate. Subsequent points may accrete to existing aggregates or form new ones. More sophisticated clustering algorithms could have been applied (e.g., using distances derived from similarity metrics), but these typically operate in data space and we were particularly interested in the efficacy of operating in display space with 2D occlusion as the primary clustering metric.

Our first approach to clustering was useable but imperfect:

```
For each point A not in a cluster
    For each point B not in a cluster
        If distance A to B is less than marker width,
        then accrete B into a cluster with A
```

This approach was relatively quick but imperfect because it did not maximize the cluster sizes and clusters that overlapped each other did not merge. Our next attempt was more computationally intensive but eliminated those problems by ensuring that all overlapping markers were placed into the same cluster:

```
For each point A not in a cluster
    For each point B
        If distance A to B is less than marker width,
        then accrete B into a cluster with A
            Recurse on B to check distance to all
            points not currently in a cluster
```

It should be noted that our algorithms for aggregation appear to be simple degenerate cases of algorithms from the field of cluster analysis[17]. That area may provide insight for increasing computational efficiency when faced with larger quantities of points than we typically need to address. An important point about the distance calculation in our aggregation algorithms is that it has to be consistent with the marker design. If we computed the distance between markers in a Euclidean fashion, the aggregation calculations would be incorrect unless the markers had a circular footprint. To ensure that our intersection calculations are consistent with the square shape of our markers (as illustrated in Figure 3) we calculate the Manhattan distance (delta x + delta y) between the points.

An additional issue is the placement of the aggregate marker relative to the visually aggregated footprint. The most effective and intuitive way to show the correspondence between markers and footprints is to place the aggregate marker within its corresponding aggregate footprint. If we computed the location for the marker as the geographic center of gravity of all points in the aggregate, then the aggregate marker might be placed outside its corresponding footprint. Instead, we compute the geographic center of all the points in the aggregate, and then place the aggregate marker at the location of the point that is nearest that center. This ensures that the aggregate marker will always be placed on top of the aggregate footprint. This behavior is illustrated in Figures 3b, 3c, and 3d.

Our aggregation approach results in a drastic reduction of data masking through formation of the Aggregate Towers. However, since it only operates in the 2D map plane, it does not address the issue of occlusion amongst the aggregate towers. This could be resolved with a 3D extension to the clustering approach. However, there are two reasons it has not been a significant focus of our research:

- For our current data sets, the problem occurs relatively infrequently, especially in contrast to the amount of data masking in the conventional 2D approach
- Our system is highly interactive, and users just instinctively fly their eyepoints around the scene giving each instance of occlusion a very limited (e.g., a fraction of a second) lifespan.

6. Conclusions

The primary contribution of this work has been to develop techniques for the presentation of geospatial point data at multiple scales in an uncluttered fashion. In the process we have developed a new visualization technique, Aggregate Towers, which incorporates dynamic aggregation of both data and markers to produce a continuum of overview displays from a single detailed data set. This provides both intuitive zooming behavior and uncluttered displays. Figure 3 provides a good illustration of the intuitiveness of the zoom behavior. A comparison of Figures 1 and 4 shows how effectively our visualization addresses data masking issues to generate an overview that is accurate, uncluttered, and easily comprehensible. In the future we will be extending this

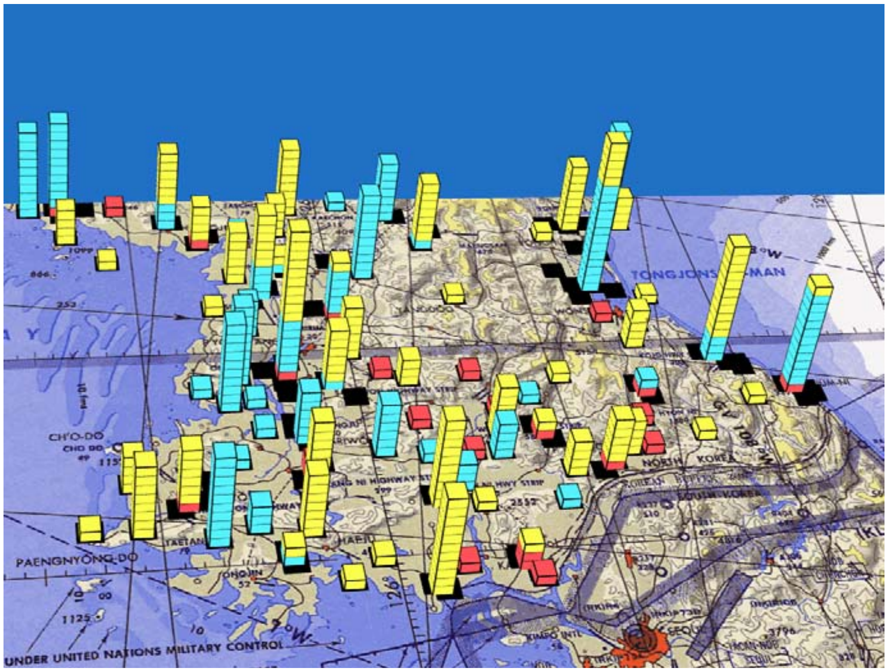


Figure 4. Overview of entire theater using aggregation [See also color plates]

work into representing lineal data at multiple scales and accommodating aggregation based on ordinal parameters.

7. Acknowledgements

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8. References

[1] A. Frank and S. Timpf, "Multiple Representations for Cartographic Objects in a Multi-scale Tree — An Intelligent Graphical Zoom," *Computers & Graphics*, Nov.-Dec. 1994, 18(6):823-829.

[2] J. Bertin, *Semiology of graphics.* The University of Wisconsin Press, Madison WI, 1983.

[3] Jock D. Mackinlay. Automating the Design of Graphical Presentations of Relational Information. *Association for Computing Machinery Transactions on Graphics*, 5(2):110-141, April 1986.

[4]Peter Keller and Mary Keller. *Visual Cues,* IEEE Computer Society Press, Los Alamitos CA, 1993.

[5] K. Perlin and D. Fox. Pad: An Alternative Approach to the Computer Interface, *Proceedings of SIGGRAPH 93* (Anaheim,CA), 1993, pp. 57-64.

[6] A. Woodruff, J. Landay, M. Stonebraker. Constant Information Density in Zoomable Interfaces. *Proceedings of. International Working Conference. on Advanced Visual Interfaces*, L'Aquila, Italy, May 1998.

[7] J. Goldstein and S. F. Roth. Using Aggregation and Dynamic Queries for Exploring Large Data Sets. In *Proceedings. of CHI-94*, pp.23-29, Boston, MA, 1994

[8] Daniel A. Keim and Annemarie Herrmann. The *Gridfit* Algorithm: An Efficient and Effective Approach to Visualizing Large Amounts of Spatial Data. *Proceedings Visualization 98*, pp. 181-188, Research Triangle Park, NC, 1998

[9] M. Sheelagh T. Carpendale, David J. Cowperthwaite, and F. David Fracchia. Extending distortion viewing from 2D to 3D. *Computer Graphics and Applications*, 17(4):42-51, July 1997.

[10] Can Keskin and Volker Vogelmann. Effective Visualization of Hierarchical Graphs with the Cityscape Metaphor. *Proceedings of NPIV 97 (Workshop on New Paradigms in Information Visualization and Manipulation)*, pp. 52-57, Las Vegas, NV, 1997.

[11] Barry G. Becker. Using MineSet for Knowledge Discovery. *Computer Graphics and Applications*, 17(4):75-78, July 1997.

[12] Mei C. Chuah, Steven F. Roth, Joe Mattis, and John Kolojejchick. SDM: Malleable Information Graphics. *Proceedings IEEE Visualization '95*, pp. 36-42, Atlanta, GA, October 1995.

[13]James D. Foley, Andries van Dam, Steven K. Feiner, John F. Hughes. *Computer Graphics: Principles and Practice, Second Edition,*: Addison-Wesley, Reading, MA, 1993, pp. 340-341

[14] E. R. Tufte, *Envisioning Information*, Chesire, Conn.: Graphics Press, 1990, pp37-51

[15] I. Bracken, 1994, Towards Improved Visualization of Socio-Economic Data: in H. M. Hearnshaw and D. J. Unwin., editors., *Visualization In Geographical Information Systems*, John Wiley and Sons, Chichester, pp. 76-84

[16] *MIL-STD-1472 Human Engineering Design Criteria for Military Systems, Equipment and Facilities* (available from the Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094)

[17] John A. Hartigan: *Clustering Algorithms*, Wiley & Sons, New York, 1975