Technical Evaluation Report

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INTRODUCTION AND BACKGROUND

Background

The NATO R&T Organization Task Group, IST-085/RTG-041 ("Visualization of Network Dynamics") has been tasked with advancing solutions for visualizing networks coping with change and uncertainty in various problem domains, determining the role and value of the underlying technology, and identifying promising technologies for visualizing network information to support effective analysis. In support of its mandate, the RTG initiated this latest in a series of workshops addressing various aspects of dynamic network visualization. In each of the previous three workshops – September 2002, "Massive Military Data Fusion and Visualization: Users Talk with Developers" (IST-036/RWS-005), September 2004, "Visualization and the Common Operating Picture (COP)" (IST-043/RWS-006), and October 2006, "Visualizing Network Information" – military officers and operators conducted problem-oriented discussions with visualization researchers and system developers, both in plenary sessions and in small focused working groups to identify issues and recommend future areas for research.

A key development of the early work by the previous visualization activities was the development of the VisTG (Visualization Task Group) Model to describe the linkages between the various parts of the visualization process. A key point of the model is that visualization is in the head of the user not in a display on a screen. The model was further developed as part of a framework for static visualization under IST-059/RTG-025 ("Visualizing Technology for Network Analysis"). Given the large number of network presentation techniques available, both designers and users need assistance to discover the most effective technique for a given task at hand. A framework was needed within which both the users' requirements and the properties of the available visualization tools and methods could be matched. A conceptual framework has been developed and was used to 'walk through' scenarios from different domains. Work remains to further refine the framework and to test it in realistic cases. So far, the framework has not yet been extended to dynamically changing networks.

Theme

Military operations are dependent in many ways on the ability of commanders to grasp and understand what is happening in the various types of networks, physical and social, that affect and support their operations. Visualization is an important activity in understanding these networks, but so far tools provide little support for understanding the implications of the networks' dynamics and uncertainties. Indeed, it can be argued that visualization tools are inadequate still to support even the static network visualization case. This workshop was intended to provoke thought and discussion on the topic of tools to support visualization in the face of change and uncertainty, as well as to provide recommendations as to future key research and technology activities.

PURPOSE AND SCOPE

The goal of the workshop was to bring together operational users, developers and researchers to explore how visual technologies can support network analysis for military and civil applications in the face of change and uncertainty in the networks. Application domains covered were varied and included geospatial, cyber-defence, network-enabled activities and homeland security applications. The aim was to be multidisciplinary since the ultimate solution will depend on collaboration among operators, human factors specialists and technological innovators. The workshop was to identify problems to which there are yet no solutions, but solutions seem possible; as well as to suggest future fruitful directions for research.

The workshop agenda had several sessions of papers meant to provoke discussion on specific topics: Geospatial Network Visualization, Network Models and Frameworks, Situation Awareness Visualization, Visualization of Changes in Networks, Inferential and Evidential Visualization and Network Abstraction. In addition to the papers and discussion, several breakout sessions in small groups were used to discuss in more depth topics deemed of importance. These breakout topics covered Information Probability and Uncertainty, Embedding Fields and Dynamics, Network Attributes, Decision Making by GUI (Graphical User Interface), and Dynamics from User Interaction.

EVALUATION

Overall the combination of presentations did a good job of exposing the current state of the art and the research challenges. Initially, the call for papers envisaged a division of papers by military and civil protection applications, human factors, and technology. At the event, the workshop used a division into six sessions: Geospatial Network Visualization, Network Models and Frameworks, Situation Awareness Visualization, Visualization of Changes in Networks, Inferential and Evidential Visualization, and Network Abstraction. This division was based on the papers received, but it served to provoke the discussion well. One weakness was the lack of any papers from military users or analysts that provided their perspective on what they need. That being said, the workshop did succeed in attracting several military officers – one at the Colonel level. The AFRL location made it possible to involve military from their staff, which was a positive aspect of the venue.

The workshop began with a keynote from the former chairman of the previous series of NATO visualization activities. This keynote served to provide the background to the audience on what had gone before and it briefly introduced the Visualization Model developed by the group several years ago, as well as the more recent work on the overarching framework for visualization. It was not as clear from the keynote how the previous work of the various RTO activities had been exploited. That would be a useful contribution to add. It is clear from the discussion that there have been very positive spin-offs to the participants both in industry and government, but there is no compendium of these.

The current chair of IST-085/RTG-041 (“Visualization of Network Dynamics”) described the goals of the RTG: to understand the interactive visualization methods that facilitate and make more effective the analysis of network dynamics, and to understand the networks of relationships that include causal or probabilistic networks that affect planning. The relationships among the layers in the networks are not often made evident in current planning. As a stretch objective, the group has started to explore what would be required to arrive at a unified network theory, if such a goal is possible. The objective is to apply information theory to the modeling of network behaviour. It is unlikely that the current RTG will accomplish this stretch goal in the time remaining, but they have made an interesting start on identifying the issues.

The first session addressed the issue of **visualizing geospatial and other networks as a function of time**. One paper showed the challenges in combining disparate types of networks (air, space and cyber) in a

single visualization. Different types of displays were explored to provide an understanding of the very different types of data. Two key issues raised in the discussion were how to discover and portray the links among the disparate domains which support each other and their interdependencies, and how to do effective experimentation to actually prove the effectiveness of a given presentation in accomplishing the mission tasks. So far, the work had been more qualitative in nature.

The second paper described an existing COTS tool for Combining Space-Time and Network Analysis. It has been effectively used to handle logistics and cyber network analysis. Discussion ensued around various display abilities and the number of entities that can be viewed. It was pointed out that in some cases aggregation would be required to allow effective visualization. A suggestion was made that a positive future direction would be to allow a user to define a pattern in the data and ask the system to find all patterns like this from now on.

The papers in this session were an effective stimulus to realizing the issues involved in practically trying to portray relationships among disparate interrelated networks varying with time and how to handle conflicts between large areas of view and finding specific patterns of interest.

The second session examined **Network Models and Frameworks**. The first paper described an approach to quickly generate massive (> GByte) datasets with a compact set of software. The proposed approach addresses a key need to be able to have very large statistically repeatable datasets to test the effectiveness of a given visualization approach. The work was at the stage of writing the data generators and doing initial testing. Some concerns were expressed that the data would be of low dimensionality, given how it was generated and may not be representative of real data. Although complicated shapes can be created (a bush example was given), the created data might have many similar pieces such as fractal generated scenes do. It is an interesting approach, but it still remains to show how truthful the generated product is as a synthetic environment.

The second paper in the second session provided a set of challenges in the measurement and characterization of dynamic layered networks. These challenges are summarized below. Each challenge was accompanied by a set of key research questions. These questions provided fertile ground for research to move towards a unified approach to understanding of all network types. The challenges are as follows:

- Node connectedness among layers – how to measure attributes when the information is spread across network layers?
- Probability propagation between layers – how to measure uncertainty as it propagates through network layers?
- Embedding fields on which the network is dependent for existence or relevance
- Temporal Dynamics – how node and link attributes change over time
- Aggregation into collections of hypernodes and hyperlinks.

The final paper in the session described the VisTG Framework for Dynamic Network Visualization that was developed under IST-059/RTG-025 (“Visualizing Technology for Network Analysis”). Given the large number of network presentation techniques available, both designers and users need assistance to discover the most effective technique for a given task at hand. A framework was needed within which both the users’ requirements and the properties of the available visualization tools and methods could be matched. A conceptual framework was developed and was used to ‘walk through’ scenarios from different domains. There is an excellent detailed description of the framework in the final report of the RTG available on the NATO RTA website. The current RTG (IST-085) is refining the framework and adding the dynamic questions to the model. Several novel concepts were introduced: negative fuzzy membership values, relativistic networks, relativistic observable networks and Boltzmannian macrostates in information theory. There was insufficient time allocated to go into these concepts in any depth, but

they are the subject of the current program of work of IST-085 and will be explored in their final report. A key concept noted was the issue of bandwidth and time delays in the network and how they affect the propagation of events in the network and their observability.

The third session described two approaches to **Situation Awareness Visualization**: one for Tactical MANETs (Mobile Adhoc Networks) and the second for Cyber Defence. The first presentation provided some insights into MANET visualization challenges and gave a few examples of possible solutions. Significant difficulties exist in finding appropriate ways to display the MANET SA (Situation Awareness) relative to the main mission SA picture. The dispersed aspect and dynamic nature of the problem are particular challenges. As yet, there is no agreed symbology for displaying the MANET SA and there are concerns about how much overhead information has to be passed on the network to provide the network SA. A suggestion was made about trading off remote rendering versus local rendering to preserve bandwidth. Work still remains to validate data requirements with users and test the effectiveness of the suggested approaches, so this work is still in the early stages.

The second presentation described the initial work on a model-based approach for cyber-defence SA visualization. A model was used to not only allow the formation of the overview of the security situation but also to permit prediction of future behaviour and suggestion of courses of action to respond to events. Ideas were presented for the creation of role-based user displays and focusing of user attention on salient events. The visualization example showed the status of the network and the resulting accessibility to resources on the network. The work is still in the early stages and much of the implementation is yet to be done. The approach seemed to have promise, but a question was raised as to the scalability of the approach and how clustering of nodes would likely be required in actual practice in a network operations centre with thousands of nodes.

Session Four on **Visualization of Changes in Networks** started with an interesting paper on work being done to try to find new breakthrough directions of research based on the analysis of citation indices. The results are of interest to funding agencies such as the National Science Foundation who are interested in prioritizing their grant funding on key directions of promising research. The techniques examined clusters of paper citations to look for new bridges between large clusters of citations that bridge the previous clusters of research and potentially set off in new directions. Time analysis of how the new bridges evolve may show something new is brewing that may be worthy of funding priority. The metrics developed to measure the “bridge” formation and evolution seem to be promising tools for drawing attention to new research directions, but also could provide valuable tools for the analysis of the dynamics of networks and for dealing with change in other applications. Examples of application of the tool to other situations were also given. These examples brought out discussion on the need for an understanding of the underpinning theory of the phenomenon being visualized, so that the metrics truly bring out the aspects or behaviours being sought in the data set being examined – for example, is the bridge formation between clusters a significant indicator of what the user is looking for. There was also discussion of semantic versus syntactic analysis of the data sources and how this might change the clusters in the visualization. In this case, syntactic meant the citation and semantic the actual text contents. Another question was how the conclusion might be skewed by initial erroneous, but oft-quoted reports. Overall, this paper stimulated a great deal of useful discussion.

The second paper in this session “Modifying Network Topology by Removing a Node” was a simpler provocation on the effects on the network entropy for a network embedded in a geographical space. Discussion ensued on the importance of assigning weights to the nodes when calculating the entropy change. The concept of semantic versus syntactic was raised again to bring out the issue of the importance of the loss of a given link or node. The fundamental question of what vulnerability really meant was also raised. Is the weakest link most vulnerable if the data contained there is less important?

Session Five consisted of three papers that discussed **Inferential and Evidential Visualization**. The first paper on Dynamic Hypothesis Visualization presented a tool for evidence analysis and hypothesis testing based on the Wigmore Chart concept. The Wigmore Chart was originally developed approximately 80 years ago to aid jurists in examining the evidence in court cases. The resulting modern tool called PAGAN was used in an example to illustrate how an analyst might use the technique to examine hypotheses of where a convoy might be attacked. There was considerable discussion of the effects of multiple hypotheses and the effect of adding more evidence – did it strengthen or weaken the hypothesis? This tool was still in the early testing stages and will need to be evaluated with users.

The second paper in the session entitled "Crack in the Heart of Everything" was a theoretical piece aimed at the goal of finding a unifying theory of networks. Could information, as defined by Shannon, be the grand unifying property? Parallels were drawn with between quantum theory and information theory. In particular, the Shannon definition of information entropy and the link to the 2nd law of thermodynamics was discussed and the whether thinking about information in this sense might be useful in the creation of a unified theory of networks and the flow of information on them. There was discussion about the accuracy of the parallel drawn between the definition of information flowing on networks and the Shannon definition of information. Could information be lost in the quantum mechanical sense? Did it fall into a conceptual "black hole" where it was spit out again when the black hole extinguishes? The higher organization of the Shannon information (names, places, data etc), like the organization of matter falling into a black hole does appear to be lost. It remains an item of discussion where this idea might lead.

The final paper in the session: the "Visual Data Collection for Social Networks: IKNOW" discussed a practical application of using a survey type tool with user friendly prompts to discover connections in a social network. Questions on this paper centred on how much the interface for collecting the data matters and how one validates the data collected in this way. Some work has been done on validation using video interaction and tracking of movements. Also, it was indicated that the way the data analysis tends to triangulate nodes in the network provides a measure of self-validation of the true frequency of social interaction at that node.

Session Six on **Network Abstraction** consisted of three presentations on Visual Analytic approaches to understanding various types of data normally used by intelligence analysts or historians. The first paper looked at the combination of two networks: world-wide weapons incidents and international alliances. The networks were shown on a geographical underlay. Attempts were made to draw inferences from hypernode clusters of alliances related to weapons incidents. The work was still in the early stages and initial reactions were that care needs to be taken to weight the data appropriately by importance. Other conclusions in the paper were that work is required to be able to visualize both the nodes created between different network layers and the links between hypernodes from different layers, as well as, the hypernodes generated from time series. It remains a research question of how to make uncertainties in the data understandable for the users.

The second presentation was entitled "Interactive Visual Analytics of Alliance Networks". It examined changing alliances in the period between the two world wars. Hypernodes were used to declutter the complicated network graphs. The objective was to determine how world-wide alliances changed over this period. Discussion ensued on a couple of snapshots of hypernode networks from 1914 and 1918. This example served to bring out a couple of key points: the role of the understanding model employed by the user – e.g. does this make sense to an historian and help them?; and the evolution of the network with time is quite important, since many changes in alliances occurred in the year or two just after 1918 – the breakup of the Austro-Hungarian and Ottoman Empires, the formation of several new nations and the formation of the Soviet Union. These changes might be missed in a given time snapshot.

The final presentation, "Ideal Case Study for Networked Visualization Research", looked at the development of tools for historians to analyze the enormous compendium of unpublished writings by Isaac

Newton. Again, the importance of the understanding model of the user was brought out as a key element. Sense Making and "Retroduction" were found to be two important components of any eventual solution. Sense Making is the study of how people orient themselves in new environments and "retroduction" is how people develop novel hypotheses from surprising developments. So far, the tools have been tested with historical researchers to see if the relationships shown with the tools make sense for already known situations. The work has not yet progressed to the stage where new relationships have been uncovered.

Overall, the work in this session was in the early stages of development. Cautions are important, as mentioned above, to avoid erroneous conclusions and the close involvement of subject matter expert users will be the key to taking the work to a validated set of useful tools, but there are some interesting possibilities here.

The formal paper sessions were augmented with breakout sessions which were a valuable means of getting work done and allowing more in-depth discussion on the various topics chosen. Although, the bottom-up approach to choosing topics was a practical one and the results of the process were useful, a suggestion in future workshops might be for the RTG to provide an element of top-down guidance for the breakout sessions to ensure that the discussions focused on topics specifically tied to the key objectives of the group. The break-out group topics were as follows: Decision Making by Graphical User Interfaces, Information Probability and Uncertainty, Embedding Fields and Dynamics, Network Attributes, and Dynamics from User Interaction. In hindsight, a metrics group may have been useful; given that there are many questions about how one knows a given visualization approach helps or hinders users in accomplishing their mission.

The breakout session key discussion points are reflected below.

Decision Making by GUI (Graphical User Interface) Group 1

- It is critical that the developer and user/operator maintain a close working relationship during the tools development and afterwards
- As far as the end user is concerned, too much flexibility can add complexity to the tool and make it more difficult to learn how to use – implying higher training costs - and less robustness.

Decision Making by GUI (Graphical User Interface) Group 1

- The question addressed by this group was: can a GUI improve decision making for Time-Critical Targeting?
- Suggested impediments to good decision making were as follows:
    - Difficulty in accessing the right data
    - Insufficient time/too much data
    - Not aware of alternatives for courses of action and the consequences of decisions
    - Bad data – inaccurate, unreliable
    - Human Foibles
    - Communication Overhead

Note that the first two groups did not address change and uncertainty explicitly. This might have been avoided by a bit more top-down direction on the working group goals

Network Dynamics and Layered Networks Group

- Connections among layers – how arbitrary are the layers if they are interdependent?

- Existing representations of dynamic data are not good. It is not easy to detect change and distinguish it in some cases from absence of change.
- Changing graph layouts inhibits comprehension
- Need to be cautious using animation – distracting
- Need a fundamental mathematical model for network dynamics
- Look at existing formalisms for working with dynamics
- For layered networks there are issues of their relative ranking and the links among them – how to avoid clutter and show the different temporal properties in each layer?

Network Attributes

- Some ideas were explored for displaying dynamic network attributes using the concept of Stigmergy – evidence left behind by changes
    - Highlight areas that have changed – leave a trail on display
    - Could leave small histograms beside nodes
    - Node merging and splitting – like cell division, show stretching
    - Alert user to changes with warning indicator
- Some simple examples were illustrated.

Dynamics from User Interaction

- Used example of fuel transport ambushes to present a visualization exercise using cell phone traffic on 5 towers between Pak border and Spin Bolduk in Afghanistan.
    - Used towers location to represent road corridor roughly
    - Tracked traffic on towers and looked for call patterns before an event
    - Alert analyst using previously observed cell phone traffic patterns that happened before previous events
- This was essentially a multisource fusion problem that was presented as an example of how pattern visualization on a dynamic network could be used to provide threat warning

Information Working Group

- The group looked at the challenges and associated research questions posed earlier in connection with the work of IST 085 and the network visualization framework.
    - They found that some of the questions were answered already and some have clues in the previous work of the (RTG) group and in papers presented in the workshop, but others remain unanswered and are still valid questions to pursue. See the detailed summary of the workshop for the specifics.
- A few important questions posed by the group were as follows:
    - What do information theoretic measures do for us?
    - Could measure a lot of things, but why?
    - We should only measure what is useful in accomplishing the goals of better visualization
- The concept was also presented of how bandwidth and propagation time delays can affect uncertainty in a dynamically changing network.

WRAP-UP OF WORKSHOP

The main conclusions for the wrap-up session were collected by soliciting ideas from the workshop participants. This appeared to work well and the list is probably quite similar to what would have been obtained by the chairpersons doing their own wrap-up. The main recommendations were the following:

- There is a pressing need for a common, representative data set that could be used by researchers in validating the pros and cons of various visualization techniques.
- There is still room to include human factors in this work. Need to compare how the proposed tools help or hinder a human user.
- Clearer definition of the goals of the breakout sessions and possible circulation of the topics in advance would have made the discussions more valuable.
- Layered networks need to be thought about more. Metrics based on mathematical measures between layers are needed and further development should be done of the theory of multi-layered networks.
- When examining various types of networks, not all nodes should be weighted the same. Some nodes and links are more critical than others and their loss has a greater impact on the remaining network.
- Need to keep in mind the pragmatic relevance of the network and not get too seduced by a ideal network described by a theoretical model.
- In attempting to create a unified network theory, need to still balance the effort spent on the theory and that solving users' operational problems.
- Is there a format available from RTO for a short summary in users language that could be used to summarize the work thus far?

CONCLUSIONS

Overall, the workshop was well run, the level of discussion very good, and the mix of attendees generally good with scientists, industry developers and military users. One small proviso is it is always useful to get more military participation to help guide the requirements for the work. The mix of papers, working groups and demonstrations was a useful way to expose various points of view. The key challenges yet to be solved were exposed and examples of current visualization approaches were demonstrated by industry and researchers. Many valuable suggestions for future work resulted from the discussions and the breakout sessions.

5. RECOMMENDATIONS

It is clear that there is much work to be done to come up with a unified theory of network visualization, if such a theory can be developed. The framework developed thus far is a very interesting start and is a key piece of work. Much work is required to extend this framework to support a unified theory, particularly in the face of change and uncertainty. Dr. Vanderbilt, the chair of IST-085 suggested six challenges for the measurement and characterization of Dynamic Layered Networks. These challenges repeated below are a good start for choosing the future work that needs to be done to evolve the framework. It is suggested that the future work of the group be less broad, and focus on a few key challenges that would significantly move the understanding of the visualization problem forward. The challenges are the following:

- Node connectedness among layers – how to measure attributes when the information is spread across network layers?

- Probability propagation between layers – how to measure uncertainty as it propagates through network layers?
- Embedding fields on which the network is dependent for existence or relevance
- Temporal Dynamics – how node and link attributes change over time
- Aggregation into collections of hypernodes and hyperlinks.

The specific research questions associated with these challenges are contained in the detailed presentation. These should be read in conjunction with the detailed notes from the Information Breakout Group.

There are many remaining questions about how one knows a given visualization approach helps or hinders users in accomplishing their mission. The development of metrics or measures of performance, and the creation or provision of a common data set for experimentation would be important contributions to the effort. There is a need to work with human factors researchers to develop an approach. Can conclusions from smaller controlled experiments scale up to the large network problems? Close relationships with clients can also help, especially if there are opportunities to be embedded with analysts to develop a technique, test it and quickly change it based on feedback.

Another key direction for future work is visual analytics. Tools for visual analytics would provide concrete products or ideas for tools that could be spun off to the user community and show the relevance of the work. It is critical though that the analyst community be involved in the development and testing of these tools so that they remain focused on problems that need solving and produce user friendly approaches to automating the analysis process.

A common representative data set that could be used by researchers to quantitatively compare one technique to another would be very useful. Possibly, the paper presented on creating large synthetic data sets may help in this regard, although synthetic data sets always need grounding against real data, since the unexpected happens in real data sets.

The workshop worked hard at bringing military staff together with the R&T community and industry. They did succeed in this goal to a reasonable extent, given the challenges involved in attracting military members to such events. Tapping into the military staff at AFRL was a good way to help satisfy this goal.

The breakout sessions were a valuable means of getting work done and allowing more in-depth discussion on the various topics chosen. The bottom-up approach to choosing topics was a practical one and the results of the process were quite useful, however in future workshops it might be useful for the RTG to provide an element of top-down guidance for the breakout sessions to ensure that the discussions focused on topics specifically tied to the key objectives of the group.

Considerable effort has been expended during the series of RTO activities leading up to and including this workshop and much well considered thought has gone into the R&T outputs such as the extensive report from IST-059/RTG-025. Unfortunately, this work is not well known outside the members of the RTG. To address this issue, the following recommendations are made:

- It is recommended that some thought be given as to how the work of the group could be made more accessible to military capability requirement and development teams. A suggestion is to produce short summaries that are more easily digested by non-SMEs (Subject Matter Experts) and to consult with the ACT (Allied Command Transformation) representative on the IST panel as to ways to communicate the work that would be useful to them, as a representative military requirements staff.

- If possible a summary of the visualization framework should be published in the open literature to publicize the results more widely to the R&T community and also to provide useful external peer comment.

The work of the series of RTO activities is too valuable to be not made more accessible for potential exploitation.