LAYING THE FOUNDATION FOR AUTOMATED SITUATION ANALYSIS

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ABSTRACT

During the relief efforts following hurricanes Katrina and Rita, there was no lack of remotely sensed data available for analysis as remote sensing companies rushed to help. Through a combination of automated feature extraction, human analysis and field reports, analysts cataloged structures destroyed, buildings searched and victims needing rescue. Despite all of the data cataloged, complete situational awareness remained elusive.

In any environment, complete understanding of a situation is difficult. Teams of people must have the ability to collaborate and understand what conclusions have been drawn, the degree of confidence behind each conclusion and what information is available to back up those conclusions. Particularly in a crisis situation, the ability to both automate the process of feature extraction from remotely sensed data and automatically assess the situation could produce dramatic benefits.

Current analysis capabilities will be enhanced by developing a prototype image analysis tool (“System”) to track the confidence levels and cognitive relationships among features. Understanding the confidence that other analysts have in their data and the process by which they came to specific conclusions enables analysts to more effectively collaborate and understand complex situations. Maintaining detailed records of these complex situations together with their component features will provide the foundation for the development of models for automated situation analysis.

INTRODUCTION

During recent major disaster response efforts analysts were overwhelmed with imagery. As they struggled to provide actionable geospatial intelligence it became apparent that, with current systems, it is extremely difficult to provide the first responders with a near real-time common operating picture of the disaster zone. Due to many limitations, available analysis was not always shared among the many responders. Compounding this problem was the fact that the shared information is often a product in its final form – features on a map – rather than intermediary results, which further delays the availability of the geospatial intelligence. In the end, situation awareness during the disaster response was incomplete, in part, due to the lack of sharing of data that could lead to relevant, actionable intelligence.

“We are also going to take a look at what we can do within DHS to ensure that our agencies have a common operating picture of events. For example, during Katrina, we often lacked situational awareness because our Homeland Security Operations Center and the FEMA National Response Coordinating Center were located in different places and information did not always flow smoothly between them. I have mandated that we integrate these kinds of incident management functions, including a virtually – if not physically – unified operations center, so that we have a better integration of information within DHS and across the Federal government.”

The need for collaboration is clear. The creation of shared situational awareness or a common operating picture provides the means for large teams to be mobilized in a consistent and coordinated fashion. The development of this common operating picture relies on input from many different sources including field reports, historical information, current imagery and automated asset tracking systems.

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Image analysts can benefit from their own common operating picture as they perform their tasks. When analyzing remote sensing data, additional information available from alternate sources can provide useful clues in identifying potential features identified in the imagery. By developing an environment allowing image analysts to share intermediate results, view alternate sources of information and discover potentially related final data products, image analysts can more quickly and easily develop new data products and improve their confidence in the quality of those products.

In addition to the immediate improvement in collaboration among analysts, this System can provide many potential long term benefits. By reviewing the history of analysis results associated with particular events and data products produced, case studies may be developed to be used as training aids for new analysts learning the trade. Further research may also lead to the use of these case studies as definitions for specific situations in automated situation analysis systems.

**SITUATIONAL AWARENESS**

A flood ravages the streets of a major city. A nursing home has begun to flood and rescuers have been called to evacuate the residents. A helicopter has been dispatched to the location ahead of the boats to assess the situation. Images transmitted back to the emergency operations center show a fire burning in the building next door to the nursing home. What are the risks to the rescuers and residents? What should the rescuers be looking for to help them maintain safety during their operation? Are any known spills of flammable materials an immediate threat? Are there any dry extraction points available with viable ground escape routes?

The answers to these questions do not completely define the situation related to the rescue effort. The complete definition of the situation might also include pieces of information like: ingress/egress points for the nursing home, number of patients/staff to be extracted, the precise location of the building (preferably latitude/longitude), capacities of available rescue craft, and availability of rescue personnel. Even without the complete definition of the situation, an environment combining all of the information that is available may provide the details necessary to maintain everyone’s safety.

Perfect situational awareness is nearly impossible to achieve. In everyday life, we rarely have all of the information required to make decisions. We analyze our current situation based on the information available whether it is incomplete, flawed, or even deceptive. Try as we might, we can never quite know everything that we would like before making a decision. This lack of information can be innocuous: missing the lowest price on that new home appliance, or it may be dangerous: not being aware of the frailty of the levee protecting your house. Every day the world around us changes. We must continually analyze the situation in order to achieve the level of awareness that we need in order to get things done.

When working with a team of people, communication is critical to maintaining situational awareness. Different team members contribute different views of the environment. By combining these different views in an intelligent fashion, a more complete vision of the situation may emerge. Unfortunately, if communication is hampered, each member of the team must operate within his own limited view. This can lead to unnecessary time wasted on duplicated effort, conflict among teams in the field working at cross purposes, and many other common operational issues.

**IMAGE ANALYSIS**

Satellite and aerial imagery provide a very useful tool in understanding situations that extend “over the horizon.” Imagery provides direct information describing a situation. Analysts can use imagery to provide a general spatial context for a situation that might not be available from a ground level view. In the aftermath of Hurricane Katrina, the US government worked with commercial imagery providers to acquire imagery in support of the search, rescue, and recovery operations. (NGA 2005) The volume of imagery collected over the Mississippi and Louisiana Gulf Coast regions around Hurricane Katrina is significant. Currently, the Louisiana State University GIS Clearinghouse contains approximately 3.8 Terabytes of imagery data collected in the aftermath of the hurricane. Some of this

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Personal communication with Ramesh Ramani of The Computer Aided Design & Geographic Information Systems (CADGIS) Research Laboratory at Louisiana State University.
imagery was used extensively during the immediate aftermath of the storm to produce maps, direct rescue efforts, and identify risk areas.

During the immediate relief effort, a number of deficiencies were identified in the ability of analysts to work with the data available. The volume of imagery created problems for networks that had been damaged during the hurricane. Analysts were limited in their ability to share intermediate information amongst themselves in different forward deployment areas. Communication of data between the federal and local networks was hampered by security and network protocol issues.

Despite the problems encountered, the analysis of the available imagery and the products generated were valuable tools for everyone involved. On major news networks, the imagery allowed the rest of the country to visualize and understand the massive extent of the damage. In the field, analysts provided maps and imagery for first responders.

In the field, image analysts usually perform their tasks with a combination of geographic information systems (GIS) and specialized image tools. Most of these tools are designed to allow the analyst to use the imagery as the basis for creating new elements in the GIS to enhance and annotate existing maps. The GIS tools are then used to create the final products that depict a map of the information gleaned from one or more remotely sensed images. In some cases, the analyst may choose to simply draw annotations directly on a source image to convey expert analysis in the context of the original source material.

**IMPROVING IMAGERY ANALYSIS**

Like most individuals in a team environment, image analysts never work in a complete vacuum. They discuss bits of information among themselves, they may ask for second opinions during their analysis, and they have access to final products developed by themselves and other analysts. All of these interactions strengthen the ability for high-quality data products to be developed. Are these interactions effectively promoted, or even supported, by the existing software tools employed?

Beyond the daily interactions, how are new analysts trained? In most cases, the answer is that they serve something of an apprenticeship. They help with analysis and watch other analysts to learn strategies and techniques for analyzing imagery and identifying real world situations through the use of different types of imagery. Could the duration of the apprenticeship be reduced by producing case studies of analysis? What are the best ways to develop those case studies?

The imagery analysis process can be improved by creating new software tools designed to deal with some of these existing limitations. The development of a system to enhance and promote analyst collaboration and record analysis processes for case studies and training aids will go a long way in overcoming existing deficiencies and may, eventually, play a role in automating situation analysis.

**ANALYST COLLABORATION**

The emergency operations center employs a variety of experts with many different areas of expertise. Through collaborative action, these experts can combine their knowledge to define a clear picture of the problems on the ground. Given the right tools, these experts can collaborate to answer the questions of the first responders. Hazardous materials experts may track reported spills and the locations of significant stores of flammable materials. Image analysts may work with aerial imagery to determine if any of the buildings containing hazardous materials have been damaged. Fluid dynamics may be able to track the movement of hazardous material spills and predict where they might be headed. Combining all of this information into one place can be invaluable in supporting first responders.

The need for this type of common operating picture has long been understood in the operational world. In the military, the most emphasis has been placed on developing a common operating picture for command and control of operations. In emergency operations centers, there have been a number of different efforts to provide software for tracking information pertinent to understanding the scope of emergency situations. In the same manner, these common pictures of the environment can be used to enhance the ability of image analysts to work together even when separated by dramatic distances.

Collaboration among analysts and first responders is similar to the military tenet of Network Centric Warfare – pushing Power to the Edge. The key principle of pushing power to the edge is a move from the intelligence cycle of
Task, Process, Exploit, and Disseminate (TPED) to one of Task, Post, Process, and Use (TPPU). In the new cycle, intelligence is gathered, posted to a common data store, processed by many nodes and the results of the intelligence are used by many other nodes.

One of the benefits of TPPU is greater opportunities for collaboration; however, this also increases the risk of being publicly wrong about the presumed nature of a feature. One of the challenges facing any system in this environment will be to allow an analyst to post his findings (i.e. his impressions) with his rationale: "I think there is a strong possibility of an accelerant located in the building next to the nursing home because, after analyzing the available hyperspectral imagery, I believe I have detected the spectral signature for Carbon Disulfide. Be prepared for fire/explosions if entering the nursing home."

Developing a system designed to provide image analysts with a common operating picture, by its very nature, promotes collaboration. By publishing features and impressions (essentially the product of analyzing intelligence) to a common, shared data store, the system allows intelligence analysts to collaborate. In many ways, this is similar to the far more unstructured way that US Embassies convey information – using web-logs (or more commonly, “blogging”). Additionally, by sharing features and impressions, analysts can promote constructive criticism of their analysis results.

In its initial form, the system under development provides image analysts with a shared view of the current situation that will enhance their ability to analyze imagery. As the system develops, the ability to push information forward into integrated operational systems designed for the first responders and incident commanders will allow analysts to directly share a common operating picture for users truly “on the edge.”

**HANDLING UNCERTAINTY**

As image analysts are encouraged to share information representing incomplete or intermediate analyses, the system under development must find ways to handle uncertainty. The analysts must be encouraged to provide consistent measures of their uncertainty allowing the system to filter posted analysis results based on the degree of confidence expressed. In addition, other analysts can use the uncertainty as a tool when using preliminary analysis results as support for their own analysis.

The misuse of intermediate analysis results can create problems for everyone involved, but the availability of information that may not be absolutely certain can also be incredibly useful. In planning an extraction in a disaster situation, unconfirmed reports of bridges washed out or debris blocking an escape route are very valuable to people on the ground. They need to know that alternative routes should be identified in case those unconfirmed reports are true. Withholding that information simply because it can’t be confirmed may not always be the best course of action.

Similarly, image analysts should be able to take advantage of information that has not been absolutely confirmed. While the introduction of this additional information requires additional judgment from the analyst regarding the validity of the claims, the additional information generated by their own prior analyses or the analysis of other people may be useful in deciphering the contents of a new image. In addition, previously unconfirmed information may easily be confirmed by an image as a secondary analysis task. For example, an analyst has been tasked with identifying damaged petroleum storage tanks in a flooded region. In the imagery currently available, she is able to see a heavily damaged structure in the general vicinity of a known storage vessel; however, the image does not allow her to actually verify that the structure is the storage vessel in question. The following day, a different analyst has been tasked with identifying routes through the flooded portion of the city that have become blocked by debris. During his analysis he loads all available features to help provide additional context during his search. In reviewing his imagery, he notices that a feature had been previously created with a high degree of uncertainty with respect to a damaged petroleum storage tank. In the new imagery, it is quite apparent that the damaged structure is definitely the storage vessel. Before continuing his search for debris, he makes a note in the system referencing the new imagery and increases the certainty of the feature marking the site of the damaged facility.

This type of scenario starts to show some of the potential benefits of sharing intermediate and uncertain results. The most difficult task in handling this uncertainty will be providing analysts with enough guidance to allow their report of uncertainty to be consistent. Without consistency in reporting, it becomes impossible for different analysts to make intelligent use of the additional information.

As the System develops and automated tools to interpret potential situations are developed, uncertainty will continue to play a significant role. Sophisticated reasoning tools will develop a number of different hypotheses that
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may potentially be supported by the information provided by different analysts. The uncertainty of different claims will lend additional information to the engine as it attempts to reason over the different plausible alternatives. As uncertainty in specific features decreases, hypotheses relying on those identified features may be given more weight than alternatives that still rely on more uncertain claims.

CASE STUDIES AS SITUATION DEFINITIONS

In the System, analysis for a geospatial coverage area and set of requirements is grouped into projects. After the analysis is complete, the analysis products, the analyst’s impressions and judgments, indeed, the analysis process – essentially the analyst’s mental model – is available for future reference. In fact, this data set is available to be used as a case study for training.

The first evolution of the prototype System would include the ability for a user to essentially search the set of past cases (historical records of analysis requirements, the analysis products and results as well as the “mental model” of the analysis process used by that analyst) with some similarity to the problem currently facing the analyst. The prototype System would provide a set of search results that the analyst could use as a case study for determining what analysis process would be potentially employed to address the current requirements. This could be presented in the form of a checklist with underlying detail that would allow the current analyst to understand the processes used by previous analysts. A key concern in this stage in the lifecycle of the prototype system will be to capture as much of the analyst’s thought process as possible. Why did the analyst choose to conduct a specific type of analysis? What did the analysis yield? Capturing this data without impacting the usability of the system will be critical.

In the proposed System, a case study would contain project information (e.g. geospatial locations, project goals) as well as the imagery that was analyzed for the projects, features discovered within the imagery, attributes of the features (e.g. time discovered, geospatial location, certainty, relevance to overall project goals, linked features and their relationships, etc.) and the impressions of the analyst about the features. The system would track imagery and allow imagery to be associated with one or more projects. The features themselves are stored and accessed using a Web Feature Service and would be linked to the source imagery in the feature metadata. The analyst observations are likewise linked to the project and features. A client application can access project information, imagery, the features associated with imagery and all feature metadata. Since a feature has a geospatial location, it will be possible to display features on related but different imagery allowing the analyst to form additional conclusions based upon feature relationships when analyzing new imagery.

Over time, as more case studies are recorded and reasoning engines become more capable, the case studies recorded may serve as the basis for defining specific situations. Essentially, the critical elements of a particular case study can be used to define a specific set of factors that define the components necessary for identifying the existence of a particular situation. These situation definitions can be used by case-based reasoning engines to
determine hypotheses regarding the situation described by a new set of features. The individual cases defined would then act as templates for generic situations. (Jackobson 2004)

**AUTOMATED SITUATION ANALYSIS**

When performed manually, situation analysis involves combining tacit knowledge with external sources of information to form a mental model. This model may then be used as a framework for understanding any new information that becomes available. The skill of the individual analyzing the situation is controlled by three primary factors: the tacit knowledge available to them, their ability to access and assimilate external information, and their ability to develop a model that fits all of the available information.

In order to automate the process of situation analysis, systems must be developed to mimic the existing manual processes and duplicate or improve upon the three primary skill areas. In general, computers are considered to be quite adept at retrieving and assimilating information from a variety of sources. Knowledge management systems, web portals, and other systems bring together vast collections of information in a structured manner that can be conducive to further analysis. Automated situation analysis requires continued development of computerized forms of tacit knowledge and methods for hypothesis testing that allow for missing or imperfect information.

Many different fields of study investigate the need for situational awareness and the process of situation analysis. Psychology and philosophy have long investigated the process by which humans study, identify, and mentally model the world around them. These studies describe a number of deficiencies in human understanding that we would like to overcome through automated analysis. Typically, humans are very dependent on past experiences in order to understand current situations. This fact makes it quite difficult for people to deal with situations that are truly foreign to them. To exacerbate this problem even more, mental indexes are imperfect. Individuals are rarely capable of perfect recall for situations that do not occur often. In addition, people prefer to hold on to beliefs even when faced with conflicting information. When analyzing a situation, this tendency will tend to cause an individual to ignore conflicting evidence in favor of information that supports their original mental model.

If we are able to automate the process of situation analysis, we would like to improve upon these human failings. Automated systems should be capable of more precise indexing of potential models and may be developed allowing them to dispassionately consider alternative explanations rather than sticking by an original conclusion. Questions still remain as to the ability of automated systems to develop models for and handle unexpected situations appropriately. In robotics, where situational awareness for automated machines has been developing for years, most systems are designed to simply stop all activity if a state is reached that the system has not been programmed for. As long as designers and developers are able to provide an appropriate response to all situations, the system will continue to function properly. Unfortunately, there will always be truly unexpected situations in all but the most controlled environments. This poses a problem both for humans and automated systems.

**LIMITATIONS**

To support future improvements, the System will need to track a significant amount of data about the situation. To track this data, the System will require the analyst to provide as much detail about the situation as possible, including detail about the analyst’s mental model as he conducts the analysis. The design of the System will have to trade off some of the desired data tracking for usability.

The first prototype of the system will focus on the imagery analyst. Successive incarnations will extend the system to utilize additional intelligence sources.

**FUTURE IMPROVEMENTS**

The initial prototype System will enable sharing of features and analysis results, e.g., the features an analyst has found and the analyst’s conclusions and impressions. By tracking as much of the analysis process as possible, the first future improvement would be to provide the capability for the user to retrieve a set of data about a similar situation which would, potentially, allow the user to determine a course of action, e.g., a set of analyses to execute for his current situation. This is much the same as humans, when confronted with a situation, will access prior

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situations from memory and determine a course of action. Another future improvement would have the system automatically provide a set of data from similar situations and recommend a course of action using Case-Based Reasoning techniques.

APPLICATION AREAS

Disaster Response
Throughout the paper, examples of the applicability of situation awareness and analysis have been highlighted for the disaster response community. The public outcry in the aftermath of Hurricane Katrina clearly cited a lack of situation awareness in the days immediately following the arrival of the storm clouds. Better tools for enhancing situation awareness are needed. The prototype system would allow imagery analysts to quickly post their preliminary results and immediately provide enhanced situation awareness to the first responders. The common operating picture that was missing in the response to the disaster would have been far clearer.

Intelligence Gathering
The 9/11 Commission Report cites a failure in the Intelligence Community in the runup to September 11, 2001, to “connect the dots” which, in essence, says that the intelligence failure resulted, at least in part, from lack of collaboration between different parts of the Intelligence Community. Section 13.3 of the report discusses the issues of sharing information and says, “The biggest impediment to all-source analysis -- to a greater likelihood of connecting the dots -- is the human or systemic resistance to sharing information.” (Kean 2004) The prototype system is a step towards solving this problem in that it promotes sharing information thus increasing the overall situation awareness of the Intelligence Community.

Criminal Investigation
Criminal Investigation seeks to build a case against the criminal in much the same way as National Intelligence does by collecting evidence about unlawful acts perpetrated by one or more individuals. Such acts take place in a particular geospatial location at a particular time. The perpetrators typically leave behind forensic or other evidence that can be considered features. The criminals may operate in multiple jurisdictions making it difficult for one investigative group to have access to all of the evidence. A system that promotes the sharing of the analysis results of geospatially and temporally tagged forensic and investigative evidentiary features could allow investigators in multiple jurisdictions to build a cohesive case against the criminals where otherwise it would be extremely difficult to share the evidence and intelligence.

CONCLUSIONS
Complete situation awareness is unrealistic and automated situation analysis is not currently practical. There are many restrictions, both cultural and technological that limit the potential for enhanced situation awareness by the consumers of intelligence, be they analysts at a National Intelligence Agency or first responders to a natural disaster. The prototype system discussed in this paper will provide, in its first evolution a method for sharing intelligence results quickly with others that can make the best use of them. It will immediately improve the situational awareness of the users and consumers of geospatial intelligence products. As the system is used and data is collected about the intelligence process, case studies will be built as training aids for future analysis work. Finally, the System could evolve, with the advent of practical case-based reasoning engines, into a platform for automated situation analysis, eventually cuing the user to possible solutions to a similar unresolved case.
REFERENCES
