# Hierarchical Task Analysis of a Synthetic Aperture Radar Analysis Process

Susan Stevens-Adams, Kerstan Cole, and Laura McNamara

Sandia National Laboratories, P.O. Box 5800, Albuquerque, NM 87185, USA
{smsteve,kscole,lamcnam}@sandia.gov

**Abstract.** Imagery analysts are given the difficult task of determining, post-hoc, if particular events of importance had occurred, employing Synthetic Aperture Radar (SAR) images, written reports and PowerPoint presentations to make their decision. We were asked to evaluate the current system analysis process and make recommendations for a future temporal geospatial analysis prototype that is envisioned to allow analysts to quickly search for temporal and spatial relationships between image-derived features. As such, we conducted a Hierarchical task analysis (HTA; [3], [6]) to understand the analysts' tasks and subtasks. We also implemented a timeline analysis and workload assessment [4] to better understand which tasks were the most time-consuming and perceived as the most effortful. Our results gave the team clear recommendations and requirements for a prototype.

**Keywords:** Hierarchical Task Analysis, Synthetic Aperture Radar, timeline analysis, workload assessment.

## 1 Introduction

Imagery Analysis refers to the perceptual and cognitive work of detecting and identifying features of interest in two-dimensional renderings of remotely sensed data. Analysis of imagery is a core activity in many fields, from radiology to military operations planning to civilian intelligence production. Over the past two decades, computers have emerged as the primary vehicle for rendering and displaying imagery, but its review and interpretation remains primarily a human activity. Indeed, in government military and intelligence activities, imagery analysts typically undergo months of rigorous training to acquire the skills that enable reliable, accurate identification of features in products derived from a broad spectrum of sensing systems [5].

Yet the human 'eyes-on-imagery' analysis paradigm is increasingly strained by the sheer scale of digital image datasets in commercial, government and academic domains. For example, over the past decade, the United States' military and intelligence communities have invested significantly in remote sensing technologies with the goal of increasing the quality and quantity of information to support both tactical and strategic decision-making. The investments have been wildly successful, providing military and intelligence functions with impressive remote sensing capabilities that have, in turn, swamped those same functions with unprecedented

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amounts of sensor data. In response, government agencies are seeking capabilities that will enable management of the so-called 'data deluge'; i.e., technologies to automate the processing and analysis of sensor datasets, so that military and intelligence personnel are able to realize the expected information value of the terabytes of sensor data that systems are generating.

Importantly, government agencies are not the only entities dealing with a data deluge. Commercial and academic organizations are also seeking technology that will facilitate human processing and evaluation of imagery; e.g., search systems that can retrieve image content without reliance on text tags. Such systems present considerable design challenges: the human visual system is exquisitely capable of recognizing and classifying patterns into contextually-relevant information, an interpretive task that is quite challenging for even the most sophisticated algorithms running on the fastest processors.

Rather than automating the interpretive work of imagery analysis, a better design goal is to identify and address elements of image-related work that are laborious to humans but well-suited for automation. For example, most digital cameras include image processing software that reduces visual noise by minimizing glare or enhancing contrast in an image, making key features more detectable and recognizable to human viewers. In the context of very large image sets – for example, giga- or tera-sized image datasets – one might imagine algorithms that enhance pixel-based temporal or geospatial patterns over multiple sensor datasets, in ways that enable people to engage larger, more detailed, even heterogeneous data resources, without introducing extraneous cognitive, motor, and/or perceptual load.

In this paper, we discuss the use of Hierarchical Task Analysis (HTA) to support just such a set of algorithmic design goals [4], [6]. We used HTA and associated methods, described below, to understand how offline analysts work with a particular type of imagery, namely the pixel-based renderings generated by of Synthetic Aperture Radar (SAR) systems. This work is part of a larger informatics effort entitled PANTHER - **P**attern **AN**alytics **T**o support **H**igh-performance **E**xploitation and **R**easoning. PANTHER is a three-year research and development project that that brings together statistics, graph algorithms, software engineering, visualization and human factors to automate the extraction and aggregation of key features captured in remotely sensed datasets, with the goal of enabling humans to perform the interpretive work of pattern recognition, classification and contextualization over temporally and geospatially distributed image sets.

First developed over fifty years ago, SAR systems typically comprise a radar and antenna side-mounted on a small aircraft. As the aircraft flies, the radar pulses the ground with millimeter-scale radio waves. Echoes or 'returns' are captured by the antenna, then stored, processed, and rendered for visual inspection as pixelated imagery (see Figure 1 for an example). Because SAR systems can acquire high-resolution imagery in day or night, even in inclement weather, these systems have found use in a wide range of applications including reconnaissance, environmental monitoring and activity detection. Importantly, SAR systems can be used to repeatedly image the same scene over extended time periods. By analyzing differences in the coherence and magnitude of returned signals, it is possible to create imagery that indicates scene changes occurring between radar passes.

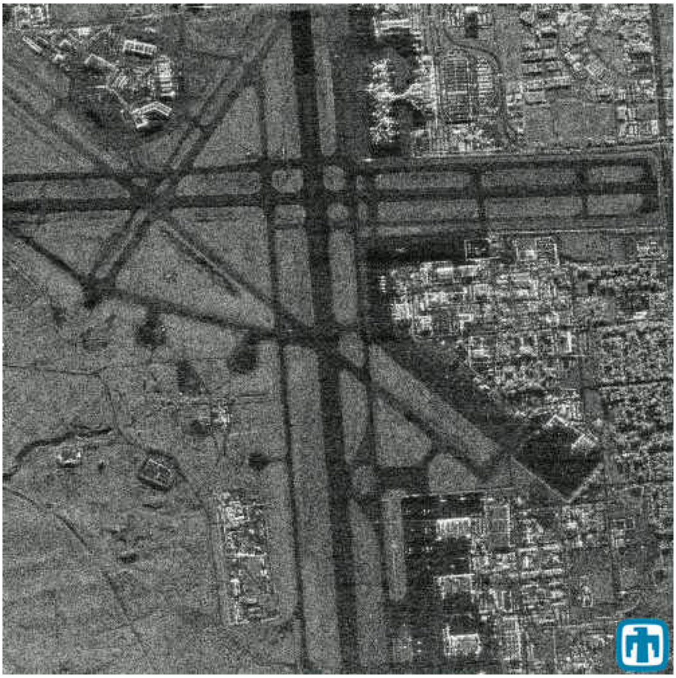

**Fig. 1.** SAR imagery of the Albuquerque Airport

## 2 Imagery Analysis in Mongoose

Our design research has focused on SAR imagery analysts associated with "Mongoose," an imaging system used to support both military and civilian field operations. PANTHER computer scientists are partnering with Mongoose stakeholders to develop algorithms that take advantage of the rich coherence and magnitude change information in SAR datasets, to reveal temporal and spatial patterns captured in Mongoose imagery. Studies of Mongoose imagery analysts are providing key information not just about the patterns that imagery analysts are seeking to characterize, but elements of the workflow that offer opportunities to reduce extraneous workload: e.g., manual cut-and-paste actions to associate reporting content from one database with images in another database.

Over the past year, we have studied how imagery analysts at different points of the Mongoose workflow interact with SAR image products to identify and characterize changes in scene content over periods ranging from several hours to multiple days. Mongoose employs imagery analysts at two points in the system workflow: "near-real time" imagery analysts work with the fielded sensor, reviewing and evaluating imagery as it comes from the aircraft. A complementary "offline" process involves reviewing imagery and reports to determine, post-hoc, whether Mongoose teams in the field have accurately characterized trends and events of interest. Despite the fact that this analysis takes place "offline," it is still done under time pressure and with the knowledge that the feedback may influence the judgments of the field imagery analysts who work in "near-real time"; that is, making rapid trend and event assessments using Mongoose imagery as it comes off the radar.

The HTA described in this paper focuses the work of "offline" imagery analysts. Not only do they review reported events to evaluate the correctness and completeness of field reports, but they frequently augment field reports with additional information that may not be available to the fielded teams. Offline analysts use a variety of forms and presentation templates to capture their analysis, with products populating a Mongoose database for all field events reported during the Mongoose system's lifetime. As we discuss below, the current workflow involves a number of onerous, time-consuming tasks that do not contribute significant content to the analysis products, but which do consume significant attention and energy. By studying the current workflow, our team has made recommendations for a future temporal geospatial analysis prototype that is envisioned to allow analysts to quickly search for temporal and spatial relationships between image-derived features.

### 2.1 Methodology

Our approach to HTA begins with analysis of the broader work domain methods from Cognitive Work Analysis (CWA). Previous research has suggested that the CWA and HTA methods are complimentary, with CWA being useful to inform the design and implementation of HTA focused on specific tasks in the workspace [3]. Of particular importance was the development of a CWA Abstraction Hierarchy and Decision Ladder, both of which we found very useful in identifying key activities suitable for focused inquiry of HTA. By developing these representations of the work domain and key decision processes, we were able to put the offline analysis process into the context of the broader Mongoose workflow. This workflow begins with imagery analysis tasks at the fielded sensor and ends with population of the offline Mongoose event database mentioned above (see [1] for a description of the work and findings).

In addition to the HTA, we also conducted a Timeline Analysis and Workload Assessment on the tasks derived from the HTA to shed light on which tasks were taking the most amount of time and were most effortful. PANTHER algorithm and software developers have been using our analysis products to identify areas where automation of tasks is most likely to have significant benefits for the analytic community, in terms of reducing time and effort spent on processes that do not contribute to event and trend analysis.

## 3 Hierarchical Task Analysis (HTA)

Hierarchical Task Analysis involves the study of what an operator is required to do, in terms of actions and/or cognitive processes to achieve a system goal [4]. Three principles govern HTA approaches [6]: a system is described first in terms of its goals; then, the operation can be broken down into sub-operations, each of which is defined by a measured sub-goal. The analysis posits a hierarchical relationship between operations, sub-operations and, by extension, between goals and sub-goals.

We took the framework from Stanton [6] for conducting a HTA and summarize the authors' recommendations for conducting an effective HTA:

1. **Define the purpose of the analysis**. Stanton [6] (hereafter referred to as 'the author') emphasizes the importance of identifying the expected outcomes of an HTA analysis prior to starting data collection. In our case, the purpose of the analysis was to obtain an understanding of the analysts' workflow, the tasks performed and the task resources, with the goal of identifying high-effort, low-learning-payoff tasks and provide recommendations and requirements for analytic software that automated such tasks.
2. **Define the boundaries of the system description.** The author emphasizes that the boundaries of the system will depend upon the purpose. We were interested in the offline analysts' tasks and workflow as a subset of the larger Mongoose workflow. The analysts were required to access multiple databases (some of which were not in-house) and use several in-house computers in order to perform and complete their analysis. We did not address the SAR sensor system nor examined other areas of the larger Mongoose workflow, which is quite extensive.
3. **Try to access a variety of sources of information about the system to be analyzed**. We used multiple sources to gain an understanding of the system. We observed and interviewed two offline imagery analysts (subject matter experts) for 50+ hours. The analysts performed and talked through their daily tasks, which included transferring data from a server, consolidating and reading relevant reports and PowerPoint presentations, looking through SAR imagery and determining what transpired for all events. We also observed, documented and participated in weekly team meetings at which the offline analysts discussed updates and current issues.
4. **Describe the system goals and sub-goals.** The overall aim of the analysis was to derive a sub-goal hierarchy for the tasks. Based on our observations and interviews, we were able to describe the goals and sub-goals and relate these to specific operations and sub-operations.
5. **Try to keep the number of immediate sub-goals under any super-ordinate goal to a small number.** The author suggests keeping the number of immediate sub-goals to between 3 and 10; we kept to this recommendation.
6. **Stop re-describing the sub-goals when you judge the analysis is fit-for-purpose.** Once we obtained an understanding of the offline analysts' tasks and resources, we judged the analysis fit-for-purpose. In this case, our purpose was to identify onerous tasks that could be automated to reduce extraneous workload for Mongoose's offline imagery analysts.
7. **Try to verify the analysis with the subject-matter experts**. The author states that it is important to check the HTA with subject matter experts to verify the completeness of the analysis and help the experts develop a sense of ownership of the analysis. We met with our offline imagery analyst participants throughout our analysis. We engaged them in discussions about the completeness and correctness of our research and representations as iterated to our fit-for-purpose. We used the offline analysts' feedback to refine our representations and recommendations for the PANTHER development team.

8. **Be prepared to revise the analysis**. Based on our evaluation discussions with the offline analysts we revised our analysis multiple times. Only after the experts were in agreement that our representations were complete and correct did we stop iterating and provide our analysis to the PANTHER development team.

# 4 HTA Analysis

Our HTA revealed that Mongoose's offline analysts performed six distinct tasks under the larger goal of "Analyze and Evaluate Reported Trends and Events" (abbreviated as "Analyze Event" in the hierarchy example in Figure 2). All tasks consisted of multiple subtasks. We also identified offline analysts' decision points, as well as potential errors and sources of bias that we believed to influence their evaluation of field team performance. The six tasks and associated sub-tasks are represented in Figure 2.

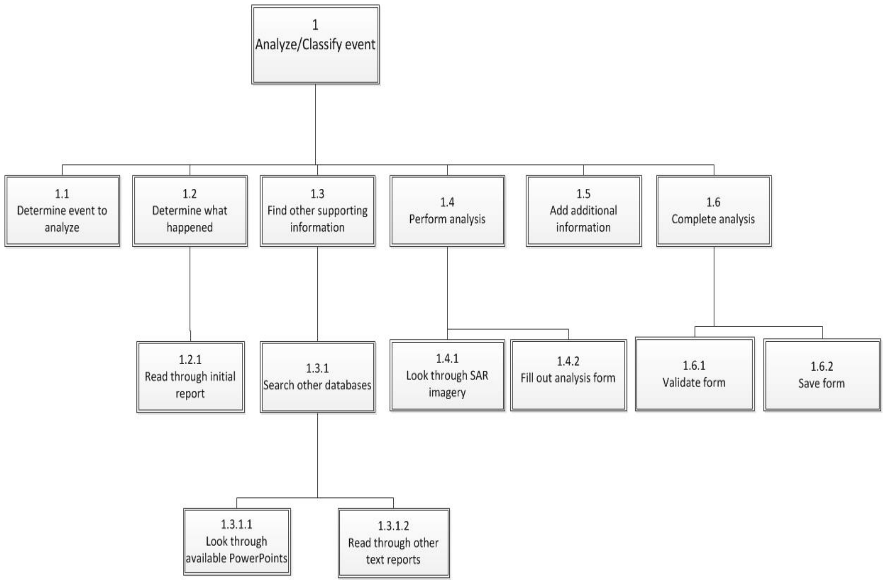


**Fig. 2.** Hierarchical diagram of the goal of "Analyze Event"

In breaking down the offline analysis process hierarchically, we learned that the offline analysis process draws heavily on the written (text) reports. To our surprise, our study participants spent minimal time visually inspecting the SAR imagery. In fact, analysts tended to make a decision about the correctness and completeness of possible events and trends of interest *prior* to any visual inspection of the imagery data.

Given this task sequence, we wondered if the offline analysts' evaluation might be prone to confirmation bias. Despite the fact that the SAR image data contains significant information about events and trends on the ground, our participants spent minimal time with the imagery, and a significant amount of time reviewing text datasets, such as event reports. This was a surprise to the algorithm developers on the PANTHER team, whose members had assumed that all SAR analysts would rely first on image products, using auxiliary non-image data as a secondary information source. However, the offline analysts pointed out that text datasets contained important contextual metadata that was not easy to extract from the SAR image sets, and which were critical for their analytic work. As a result, the offline analysts had learned to read and select information items from non-imagery sources that contained meta-information about the trends and events under study; the imagery associated with these events and trends was primarily useful in understanding how the field analysts had assembled their reporting, and to illustrate details of the region in which such events and trends had taken place.

## 5 Additional Analysis

### 5.1 Timeline Analysis

In order to more quantitatively assess which of the tasks was most time consuming, we implemented a timeline analysis. A timeline analysis is a method of identifying the density of tasks to be performed [4]. We were interested in how long it took the analysts to perform each of the tasks identified in the HTA. As such, we asked three analysts to record how long it took them to perform each of the HTA tasks. We compiled the results and found that, on average, the analysts spent the most amount of time searching other databases for information, reading relevant reports and completing their analysis (see Figure 3). The analysts informed us that, in terms of finding other supporting information (Task 3), they spent roughly the same amount of time on the sub-tasks of reading through other text reports and looking through available PowerPoint slide decks. In terms of performing their analysis (Task 4), the analysts noted that the sub-task of filling out the analyst form was much more time consuming than the sub-task of looking through the SAR imagery.

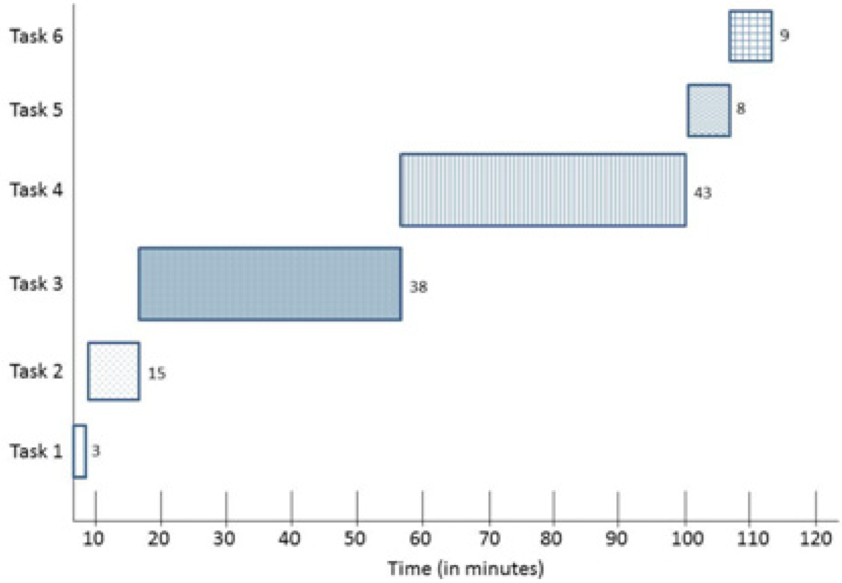


**Fig. 3.** Timeline assessment of tasks

### 5.2 Workload Assessment

In order to assess which of the tasks were perceived as the most effortful, we performed a workload assessment via the NASA Task Load Questionnaire (NASA TLX; [2]). After completing each task, the analysts were asked to rate their perceived workload (or effort) on a scale of 1 (very low) to 7 (very high) for five different areas; mental demand, physical demand, temporal demand, effort and frustration and on a scale of 1 (perfect) to 7 (failure) for the area of performance. Three analysts completed the workload assessment and their scores were averaged (see Table 1). None of the tasks were rated as particularly physical or temporal demanding, which is aligned with the fact that the analysts use a simple computer and keyboard to perform their work and are generally given sufficient time to complete their analysis. We found that those tasks that were more rote (Tasks 1 and 6) were rated as the least mentally demanding, the least effortful and the least frustrating. However, those tasks that required more cognitive resources, reasoning and decision making (Tasks 2-5) were considered more mentally demanding, more effortful and the most frustrating.

**Table 1.** Average NASA TLX ratings for each analysis task

| | Mental demand | Physical demand | Temporal demand | Performance | Effort | Frustration |
|---|---|---|---|---|---|---|
| Task 1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 2.0 |
| Task 2 | 3.3 | 1.3 | 1.3 | 1.7 | 2.8 | 1.7 |
| Task 3 | 3.3 | 1.7 | 1.3 | 2.0 | 2.7 | 2.5 |
| Task 4 | 3.7 | 1.7 | 1.3 | 1.7 | 3.0 | 2.3 |
| Task 5 | 2.7 | 1.7 | 1.3 | 2.0 | 2.2 | 1.7 |
| Task 6 | 1.3 | 1.0 | 1.0 | 2.0 | 1.3 | 1.3 |

## 6 Recommendations for Prototype

Based on the results from our analysis, we were able to propose requirements and recommendations for a future system in which the analysts could better utilize SAR imagery. We proposed that a future system be designed intentionally to support a workflow that relies primarily on imagery analysis with auxiliary text descriptions as a secondary or supporting contextual element. The imagery needs to include metadata, as this was very important to the analysts and their analysis. In addition, the system should allow the imagery and metadata to be searchable, through querying. The analysts could benefit from an interactive search capability that would allow them to determine any sort of trend behavior or to pull up any similar events from the past. Finally, it was recommended that the future system auto-populate some of the routine information currently captured in spreadsheet-based forms, since the analysts found the task of filling out the form particularly mundane and tedious. We emphasize that selection of auto-populated information would have to be carefully determined with the analysts' input.

## 7 Discussion

The imagery analysts in our project were tasked with evaluating the completeness and correctness of reported events and trends of interest, using radar imagery, written reports and PowerPoint presentations. In support of the PANTHER informatics project, our team was asked to evaluate the current system analysis process and make recommendations for a future temporal geospatial analysis prototype that is envisioned to allow analysts to quickly search for temporal and spatial relationships between image-derived features. We used HTA, Timeline Analysis and Workload Assessment to better understand offline analysts' workflow. In regards to the current workflow, the offline analysts focused most of their attention on the written reports and PowerPoint presentations, and spent little time looking at the SAR imagery. This was news to the team leads, as they assumed that the analysts were primarily using the SAR imagery to make their decisions. The analysts informed us, however, that they were not able to easily access the information they needed from the imagery. Thus, they relied on the written reports and PowerPoint presentations for the pertinent information and only used the imagery to confirm their decision, which could lead to confirmation bias.

Based on our analysis, we were able to make recommendations and requirements for the design of a future system aimed at minimizing the amount of effort required to complete low-value routine operations, such as cutting and pasting text information into spreadsheet forms. In addition, our recommendations identified barriers to the effective offline exploitation of SAR imagery in this particular analytic workflow. As we go forward, we expect to continue interacting with the analytic teams, the PANTHER developers and other stakeholders in an iterative prototyping-and-evaluation process.

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