SANDIA REPORT

SAND2016-6658
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Printed July 2016

PANTHER Grand Challenge LDRD: Human Analytics Research Summary

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PANTHER Grand Challenge
Human Analytics Team - End of Project Summary

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Abstract

This summary of PANTHER Human Analytics work describes three of the team's major work activities: research with teams to elicit and document work practices; experimental studies of visual search performance and visual attention; and the application of spatio-temporal algorithms to the analysis of eye tracking data. Our intent is to provide basic introduction to the work area and a selected set of representative HA team publications as a starting point for readers interested our team's work.

ACKNOWLEDGEMENTS

We thank our fabulous undergraduate student interns, Stephanie McMichael and Mika Armenta, for their excellent work and ideas on PANTHER.

PANTHER was a large LDRD project with many areas of activity, most of which engaged members of the Human Analytics team at one time or another. Cross-disciplinary collaboration was a hallmark of the PANTHER initiative and our team benefitted greatly from the experience. Our fellow PANTHER researchers, along with the Sandia management and the business support staff, were some of the most professional, helpful and creative people we've known at Sandia. We are sincerely grateful for your assistance and input on our technical work and look forward to future interdisciplinary adventures.

We'd also like to thank the Sandia LDRD program and the PANTHER External Advisory Board, and particularly Dr. Christopher Nemeth, for consistently supporting the PANTHER Human Analytics team's research activities and ideas.

Finally, the HA team is very grateful to our PI, Kristina Czuchlewski, for so gracefully shepherding PANTHER through three years of intense exploratory research and development.

CONTENTS

1. INTRODUCTION

In the past four years (three years of the PANTHER Grand Challenge, plus a year of research on the FY2012 "Activity Based Intelligence, Data to Decisions LDRD"), PANTHER has demonstrated the scientific and engineering value of integrating human cognitive science with math, algorithms, software and visualization research. This report provides a summary of major research activities performed by the Human Analytics (HA) research and development work under the PANTHER Grand Challenge LDRD.

The PANTHER HA team was established as part of the PANTHER Grand Challenge with two complementary goals: first, PANTHER research team leads wanted to ensure that the mathematics, algorithms and associated software technologies were developed to facilitate eventual transition to intelligence community environments. Second, the interaction with skilled imagery analysts afforded Sandia's cognitive science/psychology research community an opportunity to study how experiential knowledge evolves and is deployed in high-demand, high-throughput visual search workflows such as the ones engaged by PANTHER.

To achieve this work, team members performed a series of qualitative and quantitative research activities with analytic work groups in the Airborne Synthetic Aperture Radar (SAR) and space-based remote sensing communities. Over the past four years, in the context of PANTHER and the earlier FY2012 Activity Based Intelligence LDRD, PANTHER project, our team has conducted extensive qualitative research with imagery analysts and other domain professionals. We have interacted with over fifty professionals performing various roles in the SAR imagery analysis domain under study. Our data have come from observing imagery analysts reviewing analysis products for completeness and correctness; open-ended interviews with system designers, users, and imagery analysts; and teach-aloud interviews with imagery analysts in both domains. We have conducted several experimental studies examining issues in visual perception, visual search and signature detectability in synthetic aperture radar image products.

This summary of PANTHER HA work describes three of the team's major work activities: research with teams to elicit and document work practices; experimental studies of visual search performance and visual attention; and the application of spatio-temporal algorithms to the analysis of eye tracking data. Our intent is to provide basic introduction to the work area and a selected set of representative HA team publications as a starting point for readers interested our team's work.

2. ANALYTIC WORK DOMAIN AND TASK STUDIES

When the PANTHER Grand Challenge was funded in FY2013, HA team members began engaging analytic working groups in eliciting and documenting imagery analysis workflows to build a foundation of empirical user data. The primary purpose of this activity was providing PANTHER Sensor Exploitation (SE) and GeoGraphy teams with analyst-aware data and evaluation frameworks for prototype pattern analytic systems. We also expected these data to inform the Human Analytics team's experimental studies of gaze patterns in imagery analysis workflows.

Our approach drew on Cognitive Work Analysis (CWA) and Cognitive Task Analysis (CTA). These are two related methodological frameworks for eliciting and documenting how people use available resources to accomplish work goals. The CWA and CTA are complementary frameworks for studying, respectively, a *domain* of work activity, as well as individual workers' *strategies for accomplishing key tasks* within that domain. CWA has its origins in the ecological approaches to work first articulated by Jens Rasmussen and colleagues in Denmark in the late 1980s, and later elaborated by design researchers in Canada, the United States and Australia.

What these practitioners share is an emphasis on holistic study of human problem-solving activities within the constraints of a work domain. These constraints span the material, ideational, purposive, communicative, organizational, and skill/knowledge elements that collectively constitute meaningful activity within the domain. Cognitive Task Analysis, in contrast, aims at detailing how an individual or team of individuals access and deploy knowledge, skill, and external resources and artifacts to accomplish critical elements of work within the domain under study. The methodological frameworks are complementary, however. Used together, they effectively guide the collection of behavioral data to document individual, team, and organizational approaches to problem-solving in the context under study.

2.1 Work Domain Analysis

Despite the richness of domain representations that CWA and CTA can provide, implementing these methodological frameworks can be a time-consuming and expensive project. To facilitate our tight schedule, our team decided to focus on Work Domain Analysis (WDA) one of the five major modules comprising a full CWA study; and to invest some time in representing key analytic decision processes in the CWA Decision Ladder framework. Specifically, HA members pursued WDA inquiries with forensic project analysts in the Sandia Copperhead Synthetic Aperture Radar program, as well as Measures and Signals Intelligence (MASINT) system operators in a space-based radiometric team environment. A selection of publications and reports generated from our WDA research is provided below.

WDA: Selected Papers

J. Ganter, "Cognitive Systems Engineering: Work Domain Analysis for an Evolving Space Sensor Operation," SAND 2013-9017, October, 2013.

K.S. Cole, S.M. Stevens-Adams, L. McNamara and J. Ganter, "Applying cognitive work analysis to a synthetic aperture radar system," *16th International Conference on Human-Computer Interactio*n, Crete, Greece, 2014.

L.A. McNamara, K.S. Cole, S.M. Stevens-Adams et al. "Ethnographic Methods for Experimental Design: Case Studies in Visual Search," *17th International Conference on Human-Computer Interaction*, Los Angeles, CA, 2015.

2.2 Cognitive Task Analysis

Team members used information gained in the WDA studies to inform the development of cognitive task analysis protocols; specifically, in picking out key tasks from the overall analytic workflow, as well as the data, artifacts and processes associated with those. For example, our WDA representations informed a CTA protocol that we used with Copperhead SAR Imagery analyst. In that activity, we recruited imagery analysts to review Copperhead mission data for

theater-relevant classes of objects and signatures. We used screen capture software to record their interactions with the imagery and developed a logging suite that captured which images the analyst was using and some of their interactions with those images (panning, zooming, switching between scenes). Once the analyst had completed the task, we immediately performed a cognitive walk through with the analyst using the video to guide the discussion, using both voice and video capture to record their subjective description of their strategy as they explained it to us.

Findings from the team's CTA analyses not only informed our recommendations for prototype graph analytic workflows in the PANTHER project, but fed into the design of the team's experimental studies of visual search. A selection of relevant research reports is provided below.

CTA: Selected Papers

L. A. McNamara, K.M. Simonson, et al. "Characterizing Patterns of Life via Synthetic Aperture Radar – II: Cognitive Task Analysis for Information Foraging," SAND 2013-10634, December, 2013.

S.M. Stevens-Adams, K.S. Cole and L. McNamara, "Hierarchical task analysis of a synthetic aperture radar analysis process," *16th International Conference on Human-Computer Interaction*, Crete, Greece, 2014.

M.H. Haas, L.E. Matzen, T. Bauer and L. McNamara, "Assessing user interactions with information: Applying the normalized compression distance metric to log file analysis," *17th International Conference on Human-Computer Interaction*, Los Angeles, CA, 2015.

L.A. McNamara, K.S. Cole, S.M. Stevens-Adams et al. "Ethnographic Methods for Experimental Design: Case Studies in Visual Search," *17th International Conference on Human-Computer Interaction*, Los Angeles, CA, 2015.

3. VISUAL SEARCH AND VISUAL ATTENTION

As team members were developing the CWA and CTA findings for PANTHER's analytic domains, we were also preparing for experimental studies of visual search performance in imagery analysis communities. SAR analysis is one of many professional domains that require professionals to deploy their visual attention skills to detecting and characterizing signatures in electronic image products. Studies of visual cognition in such domains have demonstrated that tacit, experientially acquired knowledge influences search strategies. In particular, novices search strategies tend to be exhaustive, since they have not developed the heuristics for differentiating between significant and insignificant visual cues. In contrast, experienced personnel tend to identify and focus on task-relevant information very rapidly.

The PANTHER team's organizational proximity to a community of professional imagery analysts gave us a rare opportunity to study visual search strategies in the SAR image domain. Sandia management provided space for us to set up a small eye tracking laboratory in Building 891, which we outfitted with a Seeing Machines FaceLab 4 eye tracking system and Eyetracking, Inc.'s Eyeworks study design, collection and analysis software.

This laboratory was a key factor in our team's research productivity, since it enabled us to spend most of FY2014 and 2015 running a comparative study of visual search strategy and performance among groups of people with different levels of experience using SAR image products. In addition, we performed a smaller study examining the impact of visual clutter on the detectability of individual signatures in SAR change detection products. As we discuss below, this eye tracking research has contributed significantly to a broader collection of Sandia research activities examining visual search performance among imagery analysts in several different national security communities.

Visual Search/Visual Attention: Selected Papers

M. Carroll et al. "Expert Knowledge Evaluation of Coherent Change Detection (CCD) Imagery: Developing a CCD Interpretability Metric," *MSS Tri-Services Radar Symposium*, Baltimore, MD, July 2014.

L.E. Matzen, M.J. Haas and L.A. McNamara, "Using eye tracking to assess cognitive biases: A position paper," *IEEE VIS Workshop: Dealing with Cognitive Biases in Visualizations*, Paris, France, 2014.

L.E. Matzen, "Effects of professional visual search experience on domain-general and domain-specific cognition," *17th International Conference on Human-Computer Interaction*, Los Angeles, CA, 2015.

S. McMichael and L. Matzen, "Professional and novice differences in domain general and domain specific tasks: When expertise impacts cognitive and visual processes," Poster presented at the *International Conference on Applied Human Factors and Ergonomic*s, Las Vegas, Nevada, July 2015.

L.A. McNamara, K.S. Cole, S.M. Stevens-Adams et al. "Ethnographic Methods for Experimental Design: Case Studies in Visual Search," *17th International Conference on Human-Computer Interaction*, Los Angeles, CA, 2015.

4. NOVEL GAZE ANALYTICS IN PANTHER

Eye tracking sensors, collection systems and data analysis techniques were developed for use in laboratory settings, but have emerged "in the wild" as commercial and academic researchers have recognized the value of gaze data for a wide range of applied and basic research challenges. As the eye tracking research community diversifies, there is greater interest in new analysis techniques for extracting patterns in gaze data.

One of the great advantages of working on an interdisciplinary research project is the chance to learn about technical achievements in other teams and the freedom to explore their extension to other problems. Interacting with our team members in the Trajectory Analytics and Graph Analytics teams afforded us exposure to the computational geometry algorithms and visualization toolkit in PANTHER's TrackTable effort. With minor adjustment, we were able to use TrackTable to make shape-based comparison of trajectories across individual visual search study participants. In addition, our team applied several of the image segmentation and feature classification algorithms to the image products used in our experimental studies, to support exploratory research on the "top down" deployment of visual attention between experts and

novices in the SAR domain. Selected publications discussing these analytic advances are listed below.

Eye Tracking Data Analysis: Selected Publications

D.J. Stracuzzi, A. Speed; A.R. Silva; M.J. Haass; D.Trumbo. "Exploratory Analysis of Visual Search Data." *17th International Conference on Human-Computer Interaction*, Los Angeles, CA, 2015.

M.J. Haass, L.E. Matzen, L.A. McNamara, K.R. Czuchlewski. Top-down Saliency Estimation for Advanced Imaging Scenes Using Pixel Statistics. Presentation to the *European Conference on Eye Movements* (ECEM'15), Vienna, Austria, 2015.

L.A. McNamara, D.J. Stracuzzi, K.R. Czuchlewski. Challenges in Eye Tracking Data Analysis: From the Laboratory to the Wild World of Information. Presentation to the *European Conference on Eye Movements* (ECEM'15), Vienna, Austria, 2015.

Eye Tracking Data Analysis: Technical Advances

M.J. Haass, L.E. Matzen, L.A. McNamara. Top-Down Visual Saliency Model. Sandia Technical Advance SD 13407. January 2015.

M.J. Haass. Automated Geometric Feature Method for Identifying Gaze Patterns. Sandia Technical Advance SD 13547. January 2015.

5. LIFE AFTER PANTHER: VISUAL COGNITION R&D AT SANDIA

PANTHER's Human Analytics team will continue to build on the research and application foundations established under the Grand Challenge LDRD funding. Of particular importance is the establishment of several eye tracking/gaze research initiatives that make use of the data analysis advances described above. In FY2015, Sandia Corporation finalized a Cooperative Research and Development Agreement (CRADA) that our team developed with Eyetracking, Inc., a small eye tracking technology company located in San Diego, CA. We are continuing to engage Eyetracking in identifying emerging challenges in gaze data collection and developing new solutions for making eye tracking systems more suitable for real-world work environments (as opposed to the controlled laboratory studies for which most eye tracking systems were designed). Such creative outcomes are a great benefit of Sandia's Grand Challenge LDRD program: three years of PANTHER funding afforded the interdisciplinary exchanges through which our team established entirely novel approaches for analyzing eye tracking data and modeling human gaze behaviors.

Finally, PANTHER's Human Analytics research is one of several areas in which Sandia researchers have been using eye tracking to study factors that influence visual search performance in national security analytic communities. In 2014, Laura McNamara and Ann Speed (ORG-01463) established the Sandia Visual Cognition Working Group (VCWG) as an informal venue for researchers to exchange ideas and share experiences in eye tracking research design, data collection and analysis. As of this writing, in September 2015, the VCWG has grown to include 25 Sandia staff and year-round student interns in five Centers. Members are

collaboratively developing a roadmap to build Sandia's eye tracking/visual cognition research activities into a comprehensive, cross-Center R&D program. Our collective goal is establishing Sandia as a United States Government center of excellence in applied visual cognitive research for national security analysis challenges.

6. PANTHER HUMAN ANALYTICS STAFF MEMBERS

Kerstan Cole received her PhD in Human Factors Psychology from Texas Tech University in 2010. Kerstan's primary area of expertise is the application of human factors methodologies for the design and evaluation of human-machine systems. She has studied the human element in a variety of domains including driving, intelligence analysis, synthetic aperture radar, power grid operations, aviation, and nuclear weapons operations. Kerstan enjoys teaching and has developed and lead classes in Human Factors, Research Methods, and Introduction to Psychology; as well as DOE professional courses engineers and practitioners employed by national labs across the U.S.

Kristina Czuchlewski was the the Principal Investigator of PANTHER and the Acting Manager of ISR Systems Engineering and Decision Support (ORG-05346). She holds a BSE in Civil Engineering from Princeton University and a Ph.D. in Earth and Environmental Sciences from Columbia University. Kristina has been at Sandia Labs for over seven years and during her time here has led high performing teams on SAR systems, space-based radiometric sensing and advanced geospatial analysis R&D. She loves working with diverse teams of creative people and, thankfully, the "Big Bang Theory" only occasionally hits close to home.

John Ganter is Principal Member of Technical Staff in Center 5500's Systems Engineering group (ORG-05537). John is a software developer who studies team cognition and situational awareness of sensor operators, and the use of social media and crowdsourcing in the intelligence community. His many years of working with operational teams make John one of the most articulate advocates for user-oriented system design at Sandia. John has a BS and MS in Geographic Information Systems from Penn State.

Michael Haass ('Haass') is Senior Member of Technical Staff for Scalable Analysis and Visualization (ORG- 01461). He has extensive experience with measuring, modeling, and assessing human performance for DOE and DoD customers. Haass completed his master's degree in physics at the University of Tennessee, Knoxville. His research interests include visual cognition, automated human performance assessment and brain-computer interfaces. Haass is also an avid mountain biker and photographer and is particularly skilled at getting his colleagues to "act naturally" when he is taking pictures of them at conferences. Prior to Sandia, he worked in private industry for over twelve years developing noninvasive quantitative measurement devices for applications in the life sciences. He has been awarded three US patents for inventions in this field.

Laura Matzen is a Principal Member of the Technical Staff in the Cognitive Science and Systems Department (ORG 01463) at Sandia National Laboratories in Albuquerque, NM. She received a Ph.D. in Cognitive Psychology with a concentration in Cognitive Neuroscience from the University of Illinois at Urbana-Champaign in 2008. Her primary research interests lie in using cognitive neuroscience methods to understand how humans process and remember information while performing complex reasoning tasks. As of this writing, Laura, her husband Drake, and their toddler daughter are getting ready to welcome twin girls into their family.

Laura A. McNamara is Principal Member of Technical staff in ISR Systems Engineering (ORG-05346). She holds a BS in International Affairs from Georgetown University's School of Foreign Service and an MA/PhD in Cultural Anthropology from the University of New Mexico. Laura's primary skill set is developing and applying qualitative research methods in organizational studies. She enjoys collaborating on experimental protocols for workplace studies and engaging users to elicit design guidance for visually-oriented human-information interaction systems. Since 2011, Laura's topical interests have converged on sensor data interaction problems for the United States intelligence community. Because being an anthropologist in an engineering laboratory is not odd enough, Laura also owns three llamas, none of whom have participated in any eye tracking studies. Yet.

J. Daniel Morrow (Dan) is Principal Member of Technical staff in ISR Systems Engineering (ORG-05346). He holds a BS, MS in Mechanical Engineering from UT Austin and a PhD in Robotics from Carnegie Mellon. Dan is a skilled software developer whose expertise in machine learning informed much of PANTHER's approach to integrated data analytics. Dan may never have intended to become a key technical contributor to eye tracking data analysis at Sandia. However, under PANTHER, he became the resident expert on eye tracking data collection, because of his uncanny ability to figure out solutions for the tricky timing problems that crop up when one is gathering gaze data in user-controlled imagery analysis tasks.

Susan Stevens-Adams is a Senior Member of Technical Staff in Sandia's Human Factors Department (ORG-00431). Susan holds a Ph.D., M.S. and B.A. in Cognitive Psychology. Her technical skills include experimental design, human factors assessment and statistics. In terms of research, Susan is interested in knowledge elicitation, human and team performance, and false memory. When not in the laboratory pursuing such topics, Susan can be found on a soccer pitch, playing with one of several Albuquerque teams.

David Stracuzzi is Principal Member of Technical Staff in the Cognitive Systems Department (ORG 01462) at Sandia. Before joining Sandia in 2010, David was research faculty at Arizona State University and a postdoctoral scientist at Stanford University. He received his PhD and MS from the University of Massachusetts at Amherst and a BS from Clarkson University in New York. David's technical skills include artificial intelligence, machine learning, and statistical modeling. In terms of academic research and publication, he is pursuing work in data science, human-in-the-loop intelligent systems, and computational cognitive architectures. David is also the busy father of three clever children. This means he spends much of his time wondering what could possibly happen next, as prior data has not proven to be predictive of future events.

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