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**[INTERACTIVE PLANNING FOR CAPABILITY DRIVEN AIR &
SPACE]**

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System Architectures Laboratory

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Final Report

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14. ABSTRACT The report describes the progress made, during the reporting period (March 01, 2005 to Aug. 31, 2006), on research conducted to develop approaches for capability driven planning, and to identify/develop methodologies and tools to implement the approach. The report presents work on a temporal representational and reasoning formalism and its software implementation. It also presents findings on an examination of the need and nature of campaign of experimentation to explore approaches to planning in the context of network centric operations.				
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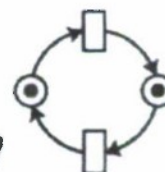


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1. STATEMENT OF WORK

The following tasks were identified in the grant proposal with some minor terminology changes, mentioned in the productivity report for the year 2005.

Task 1: Extend PIL for Interactive Programming

The present implementation of Point-Interval Logic (PIL) is equipped with a verification mechanism. A fast revision algorithm incorporates the change in an existing system of PIL statements by first identifying the extent of change and then applying the change to the effected part of the system only. In this task, we will integrate these two mechanisms. The two mechanisms, collaborating with each other, are expected to yield more efficient algorithms for handling change in the plans. Further research will be conducted to exploit the advantages of the two approaches to facilitate a dynamic, collaborative, and interactive environment in which several users can input their specifications, in a real-time manner, based on their incomplete picture of the domain at hand.

Task 2: Integrate Space-Time using PIL

The PIL formalism has been shown to incorporate temporal and spatial information separately from each other. The objective of this task is to integrate the two formalisms, temporal and spatial, in such a manner that a causal relationship between temporal and spatial objects can also be captured by the approach, and supported by a fast revision capability. The insistence on fast revision capability is kept to avoid restarting the planning process with every change in the temporal and spatial parameters.

Task 3: Extend the Capabilities of PIL for Space-Time-Capability Integration

The capability-driven interactive planning is presented as a constraint satisfaction problem, with constraints representing temporal, spatial, and capability attributes' requirements for the mission under consideration. The objective of this task is to capitalize on the temporal and spatial constraint-handling capabilities of the PIL formalism for possible use in a first-order algebra, or an applications suite, that captures all three aspects, with an arbitrary degree of abstraction, within a single framework. The analysis tools developed for the present implementation of PIL inference engine will be extended to validate the input specifications and to generate robust feasible plans satisfying all spatial, temporal, and capability-attribute constraints. The graph-theoretic Point Graph (PG) approach used in the knowledge representation and reasoning of spatiotemporal systems, will be extended to incorporate capability attribute features and the causal relationship among all the three aspects of information.

Task 4: Develop Tools for Capability-Driven Interactive Planning

This task consolidates the results of the earlier tasks. The objective is to implement the formalisms for capability-driven interactive planning in a suite of software applications.

Task 5: Planning and Execution in a Network-Centric Environment

This task involves an examination of the need for and the nature of a campaign of experimentation, and an associated program of research, to explore approaches to planning in the context of network centric operations in support of complex, coalition, civil-military missions.

2. STATUS OF EFFORT

Task 1

The inference and revision algorithms of PIL have been updated and incorporated in the application TEMPER. The current inference mechanism has been shown to be complete for a class of temporal queries. The two algorithms, inference and revision, have been combined in a bounding function based solution approach to solving the general temporal problem. The solution uses a combination of the inference and revision algorithms together with a heuristic to implement a fast search in the solution space. The worst-case complexity of the algorithm is exponential as is to be expected for any exact algorithm for an NP Complete problem. An empirical study of the performance of general temporal problem solver using different heuristics has been conducted and the results are presented in a recent conference paper (see Section 9.3).

The scheduling algorithms of TEMPER have also been extended to incorporate stretch float, lead/lag times, milestones for start and finish of activities, and to solve the management problem at the graph representation without a need for the mathematical program required by the earlier approach. The proofs of correctness for the scheduling algorithms are also provided. A new representation of Point Graphs (PG) called Hierarchical PGs has been introduced and implemented in the application that supports both *top-down* and *bottom-up* approaches to project management/planning. The final implementation of TEMPER supports both approaches with some manual steps required to carry out the two. A detailed description of the features, mentioned above, is provided in the two journal papers in Section 9.1 and Section 9.2. A technical report based on the unaltered MS thesis of Mr. Mashhood Ishaque, submitted to the Volgenau School of Information Technology and Engineering in partial fulfillment of the requirements for the degree of Master of Science in Computer Science, has been submitted with an earlier progress report. The thesis was submitted in May 2006.

The PIL formalism has been shown to have applications in mission planning, project management, temporal assessment of situational influence models, and criminal forensics. Some of these applications are presented in attached papers in Section 9.4 and 9.5.

Task 2

A framework for integrating the space and time information into a single formalism was developed. The framework uses the WebTAS¹ suite of application as the underlying platform for storing and visualizing temporal and spatial information. It employs temporal and spatial reasoning tools, together with WebTAS, to store and reason with both qualitative and quantitative information. The inference made by the spatiotemporal tools is fed to the WebTAS database where it can be visualized together with the existing information using WebTAS' extensive suite of interfac-

¹ http://www.issinc.com/webtas/webtas_overview.php

es. The framework is still under investigation and a prototype application is being implemented for an expected release in fall 2008.

Task 3

An attempt has been made to analytically formulate the problem of capability driven planning by identifying the type and nature of constraints/knowledge representation required to handle capability requirements together with temporal and spatial constraints. Some exploratory work was conducted in the use of *ontologies* for mapping capabilities to requirements.

On a parallel track, an attempt is made to develop analytical models that relate strategic objectives/goals, and components of an environment (i.e., political, military, economic, social, infrastructure, and information), to tactical actions for planning and assessment of Effects Based Operations (EBO). A major accomplishment in this regard was a comprehensive expansion and improvement of an existing effects based analytic approach, called Timed Influence Net (TIN) modeling, which allows the adoption of task-sensitive and time-varying flexible influence relationships and functions to derive consistently probabilities of occurrence of sequential events. The theory also provides the means for the utilization of data pertinent to one variable towards the assessment of another dependent variable, and encompasses specific algorithmic steps for the representations and effects of time delays. A variant of this approach, called Activation Timed Influence Networks (ATIN), was developed to capture the explicit mechanisms and/or tactical actions responsible for change in the state of an environment as a result of occurrence of events. An ATIN represents a progressively evolving sequence of actions, where the effects of an action become the preconditions of the action that follows. An ATIN integrates the notions of time and uncertainty in a network model, where nodes explicitly represent mechanisms and/or tactical actions that are responsible for changes in the state of a domain.

The theoretical developments were followed by experimental design and implementation of the algorithms for both enhanced TIN and ATIN models in the application suite called *Pythia*. Sections 9.6 and 9.7 provide detailed technical accounts in presented or published research papers.

We expect that this research results will have a significant impact on the understanding of inter-effects between tactical actions and components of their environment. We also expect that the approaches will facilitate the decision making and planning processes, as related to tactical actions which are dynamically affected by unraveling events in the environment of their operation.

Task 4

The work carried out under tasks described above has resulted in additions and modifications to the tool suite developed for the research. The following are some of the features added to TEMPER reflecting either the implementations of new algorithms or fixes done to old ones to enhance computational performance.

1. A new set of inference algorithms.
2. A heuristic based branch-and-bound algorithm for the solution of General Temporal Problem.
3. The hierarchical temporal planning module.
4. A new interface for the application. This adds Gantt chart and other graphical I/O support to the application.

5. A new set of influence and temporal models/algorithms for Influence Networks and Activation Influence Networks in *Pythia*.

An application TEMPER on criminal forensics was carried out during the reporting period. The information regarding events surrounding some criminal activity or an act of terrorism unfolds in no specific order. The information gathered, in turn, may be incomplete, partially specified, and possibly inaccurate, or inconsistent, making it difficult for investigators and counter-terrorism experts to piece together the events that can help resolve some of the investigative questions. The time-sensitive information, the information about the timing of events surrounding a criminal/terrorist act, may contain hidden patterns or temporal relations that can help identify missing links in an investigation. This calls for a formal, computer-aided approach to such an analysis. The study found TEMPER to be a promising approach/tool for such a forensic analysis. In the study, a set of temporal facts was taken from the London bombing incident that took place on July 7, 2005, to illustrate the application. The information used in the illustration was gathered through the online news sites. A hypothetical investigation on the information was carried out to identify certain time intervals of potential interest to crime investigators. A paper written on the application was nominated for the "Best Student Paper" award in the 2006 Command and Control Research and Technology Symposium (CCRTS). A published version of the paper is provided in Section 9.4.

Task 5

This was a six month effort that concluded in September 2005. A detailed report on this task is given in Section 9.3 of this report. A brief description of the results is given as follows:

The development and maturation of Network Centric Operations is one of the two major dimensions of an Information Age Transformation of the DoD. The other dimension, the mission space, a space that represents the full range of the operations a force must be able to successfully undertaken, is being transformed as well. The 21st century mission space encompasses a wide range of operations including civil-military operations that require (1) an effects-based approach to operations and (2) the ability to work effectively in coalition environments that include not only other militaries but also other government entities, international organizations, and a variety of non-governmental and private voluntary organizations (NGOs and PVOs). Network Centric Operations require the coevolution of concepts of operation, approaches to command and control (including organization, doctrine, and C2 and information processes) with a robustly networked force, and their materiel and systems. Planning is an integral part of command and control processes, and thus needs to be "reinvented" in order to leverage the capabilities of a robustly networked force and be compatible with network-centric concepts of operation. Thus, moving to Network Centric Operations involves a redefinition of command arrangements and processes, including the adoption of effects-based planning, better integration of planning and execution, and a redefinition of the nature of mission participants and their respective roles, responsibilities, and interactions.

Transformation is by definition more than incremental improvements or sustaining innovations. Transformation requires venturing beyond one's comfort zones to explore new concepts of operation, new approaches to command and control, and new processes.

As such, it would be unreasonable to expect the answers to be apparent or the data for analysis to be available. The way ahead involves the formulation, design, and implementation of a campaign of experimentation and an associated program of research focused on the development and assessment of interactive and dynamic effects-based planning in the context of 21st century Network Centric Operations.

This research effort found that there was an urgent need for a campaign of research and experimentation focused on developing a network-centric approach to air and space command and control, specifically the development and assessment of approaches to mission planning in a network-centric environment. Having concluded that such a campaign of experimentation is necessary, this document provides the intellectual foundation for such a campaign. It provides appropriate definitions for key concepts, a conceptual reference model for network-centric, effects-based planning and execution, identifies a set of research issues, and identifies key activities that are on the critical path to transforming the planning and execution of air and space operations.

3. ACCOMPLISHMENTS/NEW FINDINGS

The progress made during the period includes: a) Enhancements to the PIL approach and implementation of new algorithms in TEMPER together with rigorous testing and debugging of the software; b) Redesigning of the TEMPER application for Gantt chart and other graphical I/O interfaces; c) An introductory framework for integrating qualitative and quantitative spatial and temporal information; d) An exploratory study of the structure and contents involved in a capability package and a possible use of ontologies to map the two notions of capability and requirements; e) A promising application of the tool, TEMPER, for criminal forensics and for analyzing acts of terrorism; f) Reformulation and expansion of Influence Network modeling approach; g) A new modeling approach called Activation Timed Influence Nets, and h) Providing an intellectual foundation for a campaign of experimentation focused on developing a network-centric approach to air and space command and control.

4. PERSONNEL SUPPORTED

Faculty:

Dr. Abbas K. Zaidi
Dr. David Alberts
Prof. Alexander H. Levis
Dr. Lee W. Wagenhals

Graduate Student(s) (PhD)

Mr. Abdul Qadar Kara
Mr. Sajjad Haider

Graduate Student(s) (MS)

Mr. Mashhood Ishaque
Ms. Shanthi Ramaswami
Ms. Juan Luo

5. PUBLICATIONS (Entire period)

- ‡ Published Paper in Research Journal/Special Issue
- † Published Paper in Conference Proceedings
- Thesis / Dissertation / Technical Report

- ‡ Mashhood Ishaque, Abbas K. Zaidi, "Project Management Using Point Graphs," *Journal of Systems Engineering*, 12 (1), To appear in 2009. [See Section 9.2]
- † Titsa Papantoni-Kazakos, Abbas K. Zaidi, Muhammad F. Rafi, "An Algorithm for Activation Timed Influence Nets," The 2008 IEEE International Conference on Information Reuse and Integration, IEEE SMC, Las Vegas, 8, Submitted, July 2008. [See Section 9.7]
- ‡ Abbas K. Zaidi, Faisal Mansoor, P. Papantoni-Kazakos, "Theory of Influence Networks," *IEEE Transactions on SMC, Part A: Systems and Humans*, Revision Submitted, 2008. [See Section 9.6]
- † Mashhood Ishaque, Faisal Mansoor, Abbas K. Zaidi, "An Inference Mechanism for Point-Interval Logic," The 21st International FLAIRS Conference, Association for the Advancement of Artificial Intelligence, Coconut Grove, FL, May 2008. [See Section 9.3]
- † Abbas K. Zaidi, Faisal Mansoor, P. Papantoni-Kazakos, "Modeling with Influence Networks Using Influence Constants: A New Approach," 2007 IEEE International Conference on Systems, Man, and Cybernetics, IEEE Systems, Man, and Cybernetics, Montreal, Canada, 6, 2007. [An extended version sent for publication (Section 9.6)]
- † Abbas K. Zaidi, Mashhood Ishaque and Alexander H. Levis, "Project Management Using Point Graphs," *Conference on Systems Engineering Research (CSER)*, INCOSE, 2007. [An extended version accepted for publication (Sections 9.1 and 9.2)]

Abbas K. Zaidi and Alexander H. Levis, "Using Temporal Reasoning for Criminal Forensics against Terrorists," *Descartes Conference on Mathematical Models in Counterterrorism*, Center for Advanced Defense Studies, Unpublished, 2006.

- ‡† Abbas K. Zaidi, Mashhood Ishaque and Alexander H. Levis, "Using Temporal Reasoning for Criminal Forensics against Terrorists," In Newton Howard and Ammar Qusaibaty (Eds.), *Mathematical Models for Counterterrorism, Springer Series*, 2007. [See Section 9.4]
- † Abbas K. Zaidi, Mashhood Ishaque and Alexander H. Levis, "On Applying Point-Interval Logic to Criminal Forensics," 2006 Command and Control Research and Technology Symposium (CCRTS), 2006. [An extended version was later published (Section 9.4)]
- ‡ Abbas K. Zaidi and Lee Wagenhals, "Planning Temporal Events using Point Interval Logic," Special Issue, *Mathematical and Computer Modeling*, (43), 1229-1253, 2006. [See Section 9.1]
- † Abbas K. Zaidi, Lee Wagenhals and Sajjad Haider, "Assessment of Effects Based Operations Using Temporal Logic," in Proc. of The 10th International Command and Control Research and Technology Symposium, McLean VA. June 2005. [See Section 9.5]

- † Abbas K. Zaidi and Mashhood Ishaque "Time Sensitive Planning Using Point-interval Logic," in Proc. of The 10th International Command and Control Research and Technology Symposium, McLean VA. June 2005. [An extended version accepted for publication (Section 9.2)]
- † Abbas K. Zaidi, Sajjad Haider and Alexander H. Levis, "On Temporal Analysis of Timed Influence Nets using Point Graphs," in Proceedings of The 18th International FLAIRS Conference, FL. 16 May 2005. [A revised version appeared in another conference proceeding (Section 9.5)]
- Mashhood Ishaque, "On Temporal Planning and Reasoning with Point-Interval Logic," MS Thesis, Department of Compute Science, George Mason University. [Submitted with 2006 Progress Report]
- David S. Alberts, "Planning for Network Centric Operations." September 2005. [See Section 9.8]

6. INTERACTIONS/TRANSITIONS

a. Participation in Conferences, Meetings:

- Participation and presentation at the International IEEE Conference on SMC, 2007, Montreal, Canada.
- Participation and presentation at the annual program review, Optimization and Discrete Mathematics, AFOSR, 2007.
- Participation and presentation of a paper at the 'Conference on Systems Engineering Research,' March 2007, NJ
- Participation and presentation of a paper at the 'Conference on Systems Engineering Research,' April 2006, CA
- Participation and presentations in the meetings of the research personnel for AFOSR multi-university research initiative titled: Model and Systems Integration Technology for the C2 Wind-tunnel (WIN), March 27, 2006 (Kickoff) and May 11, 2006 (Group Planning Meeting.)
- Participation (by invitation) in the 'AFOSR Workshop on Methods for Designing, Planning, and Operating Systems of Systems,' Indianapolis, IN, May 17-18, 2006.
- Participation and presentation at the annual program review, Optimization and Discrete Mathematics, AFOSR, May 22-24, 2006
- Participation and presentation of a paper at the '2006 Command and Control Research and Technology Symposium (CCRTS),' June 19-20, 2006.
- 18th International FLAIRS Conference, Florida, May 2005.
- 10th International Command and Control Research and Technology Symposium, McLean Virginia, June 2005.
- Program Review, Optimization and Discrete Mathematics, AFOSR, August 22-24, 2005.

b. Consultative and Advisory Functions

None at this time.

d. Transitions:

The API of TEMPER has been successfully embedded in *Pythia* for temporal assessment of COAs. The Pythia application is being tested by an Air Force Intelligence organization (NASIC) and is also used by NPS and JIEDDO.

The standalone application TEMPER is being tested/explored by Dr. Susan Numrich at the Institute for Defense Analyses (IDA), Alexandria, VA, for research projects/grants management and planning purposes.

The Pythia application is being extended by the inclusion of new influence and temporal models developed in the last year of the effort. The version with new models and algorithms is due for release in Fall 2008.

7. NEW DISCOVERIES, INVENTIONS, PATENT DISCLOSURES:

None

8. HONORS/AWARDS

Prof Alexander H. Levis: AFCEA Special Merit Award, 2006.

Prof. Alexander H. Levis: Lifetime Achievement Award at 10th International Command and Control Research and Technology Symposium, McLean Virginia, June 2005.

9. ATTACHMENTS

9.1 Planning Temporal Events using Point Interval Logic

9.2 Project Management Using Point Graphs

9.3 An Inference Mechanism for Point-Interval Logic

9.4 Using Temporal Reasoning for Criminal Forensics against Terrorists

9.5 Assessment of Effects Based Operations Using Temporal Logic

9.6 Theory of Influence Networks

9.7 An Algorithm for Activation Timed Influence Nets

9.8 Planning for Network Centric Operations