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Actionable Knowledge Guided HTC Visualization

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ABSTRACT

A central concern with utilizing CIE to accelerate C2 is developing an encompassing knowledge centric holistic target characterization (HTC) that fully addresses the mission objective while utilizing second order and higher effects. This presents a problem as an HTC using multiple order effects can quickly become unmanageable. The manner in which the vast amounts of HTC information are visualized can be a multiplier of the overall CIE performance. Thus HTC visualization requires a methodology for approximating the hard problem of maintaining the highest degree of the commander's intent while minimizing the size of the HTC. The CIE HTC development process can be modeled as a set of conversations between HTC development staff and stakeholders building a knowledgebase of product from which an HTC can be synthesized with regards to the mission objective. Without providing mechanisms for representing the actionable knowledge contained in the mission objective there is no guaranteed visualization which will discover the highest value information. Decision support guided visualization improves this process by sorting the visualization options according to the mission objective. Developing a well-formed actionable knowledge representation that maintains commander's intent can improve the resultant HTC by using actionable knowledge guided visualization throughout the CIE process.

I. INTRODUCTION

The warfighters are increasingly asked to make decisions based on ever larger evidence sets and as a result the systems the warfighters use are asked to assist them more often and to a greater extent. Trust in these systems is inversely proportional to the size and quality of the evidence sets these systems must reason with as well as the complexity of the tasks involved, for both man and machine. The loss of trust is rightfully based on the apprehension that the systems are growing less capable of handling these demands and so their results grow more random and/or aberrant. As a result, these systems do not faithfully represent the original mission intent. The advances in our scientific knowledge and technical capability to simulate and analyze ever growing problem spaces may lead one to believe that trust in the system should actually be increasing. Unfortunately, the basic mathematical limitations of the computer have not changed and it could be said that, from a computability standpoint, the problem space is practically infinite.

Thus, it is then important to minimize and limit the number of intractable problem spaces included in the universe of discourse whenever and wherever possible. In order to do this the system must maximize the utilization of humans cognitive services in the decision process wherever the tractability of a particular problem is in question and/or to use heuristic to reduce the problem space to a more tractable problem. Heuristics can preference order the search space such that the paths most likely to satisfy the constraints are utilized first. The representation of these preferences and constraints are represented by the actionable knowledge content of the mission. Only those tasks that are likely to drive a hypothetical encountered world state towards the desired world state are considered when developing a holistic target characterization (HTC) which contains all of the sub-objectives, possible target sets, task trees to achieve the desired state of these sub-objectives, and sufficient supporting evidence. The amount and complexity of the data contained in an HTC can be very large and, if not structured through the human-computer interface (HCI) in the correct way, would likely be beyond the cognitive load capability of most of the personnel required to utilize an HTC. An overall measure of the quality of the resultant HTC is how well it maintained the actionable knowledge of the original mission objective. HTC development is a set of processes loosely aggregated in a collaborative information environment (CIE). According to [USJFCOM05] "A CIE is the aggregation of infrastructure, capabilities, people, procedures, and information to create and share the data, information, and knowledge used to plan, execute, and assess joint forces operations. It enables collaboration among a selected group of individuals or organizations and enables the joint commander to make decisions better and faster than the adversary."

As part of an overall strategy to maximize the quality of the resultant HTC we propose utilizing the actionable knowledge in the mission objective to guide the CIE processes for the formation of an HTC. There are many interpretations of what actionable knowledge means. In this paper we mean actionable knowledge as the explicit symbolic knowledge that forms the basis for evaluating the evidential support for some action [GL02]. The well-formed actionable knowledge content associated with the HTC provides the capability of the HCI system to dynamically formulate an appropriate preference ordering with regards to the ontology of the visualization task at hand. This innovative HCI methodology can help decision support systems (DSS) to deal with the vast quantities of information and varying ontology by allowing choosing the best visualization and ordering to minimize user cognitive load. The alternative is to attempt to show as much data as possible without regard to the value of that data to the task at hand, force the data into a preconceived visualization, or to have deeply nested navigational structures. 21st Century Systems, Inc. (21CSI) has utilized many of the HTC visualization approaches listed in this paper while developing a functional Joint Integrative Analysis and Planning Capability (JIAPC) prototype. The development and technical considerations of the JIAPC prototype is summarized in the last half of this paper. Although this paper concentrates on information operations (IO), the base assumptions and techniques do not change for a more kinetic world. Indeed, the JIAPC project was a joint integrative project that addresses the largest union possible.

II. HTC FORMATION AND ANALYSIS

The initial input to HTC formation process is a mission objective which may have already undergone some level of mission analysis and refinement. The combatant commander (COCOM) may assume the role of analyzing and refining the mission and perhaps rejecting the mission altogether. There is unfortunately no standard ontology (it is arguable that none can exist) so that the knowledge represented in the mission objective could be machine read in a formal manner. Actionable knowledge representation is an ideal ontological kernel to bootstrap the correlation and fusion of the knowledge in the mission objective in a fairly generic manner. It is likely that before a COCOM would adopt a set of ontology for at least a partial representation of the actionable knowledge contained in the mission objective, the COCOM would need to see a working example. At the JIAPC user/producer conference held in January 2005 at Offutt Air Force Base, many COCOMs were able to see first hand some of the techniques we propose here. Many acknowledged the need for a bootstrap ontology, but also saw the problem of multiple level security (MLS) in the integrative aspect. While formal semantic decoupling may help address the MLS issue, we do not address the security aspect here.

II.1 Actionable Knowledge Representation

Actionable knowledge has many different aspects and representations. An actionable knowledge ontology is a smaller problem space and could be developed for representing at least some of the actionable knowledge represented within the mission objective.

For example, the XML rule exchange format RuleML has a reaction rule (event-condition-action) representation [Rul05] that may be transformed with little loss in meaning into a SQL database trigger representation. In this database example, it is contextual implied but fairly clear that the event space will be an insert, update, delete, or stored procedure in a database process and conditions are mapped to the relational clause and/or the triggers stored procedure.

II.2 Mission Objective as a Utility Function

We propose that one of the most succinct interpretations for actionable knowledge is as the utility function representing the mission objective. While it is true that the computability of varying classes of utility functions is an open research problem [Fre99], utilizing the concept of utility accomplishes multiple benefits. The utility function can represent not only the explicit goals in the mission objective, but also the underlying mission intent, and perhaps also the COCOM stance (meaning various and numerous preferences associated with the COCOM not immediately associated with the mission). There is a vast domain of economics and game theoretics that could be leveraged in the CIE process by providing a formal mechanism for specifying a utility function representing the mission objective. Although there is a rich history of utilizing game theoretics, such as Nash's Equilibrium, there needs to be a more rigorous foundation for specifying the utility function if the concept has any chance of succeeding. One method of developing the utility function is to treat the function as a pattern matching or a variation on semantic distance from the current perceived world state and the desired world state. This mechanism is well known from the belief-desire-intention (BDI) rational agent design methodology. The actionable knowledge mechanism induces a graph characterization and preference ordering which can be utilized by heuristics. There do exists mechanisms for formally specifying actionable knowledge, such as through RuleML and OWL, and type and theorem provers are becoming more widely available, which will allow systems to formally verify the actionable knowledge content of these interchange formats. The belief mass assignment over the discernment frame created by base level mutually exclusive actionable knowledge provides and excellent mechanism for developing the utility function. While the mission objective may not be fully enumerated, one of the first HTC formation tasks is to discover the base mutually exclusive frames of discernments. A significant problem that often is not addressed is accounting for cost while developing the HTC. It may be assumed that given two actions, where all other things are equal, the action with the lesser cost would be selected. However, for various reasons that can't always be controlled, these cost functions are not always known at planning time. Indeed, when doing second or higher nodes and links analysis, dampening features such as cost and utility are important mechanisms for bounding the result set. Costing is also important in that each action may have an associated cost. This cost is obvious for resources like satellites that have fixed fuel onboard, but less obvious with resources like cameras. Also, not all of the costs involved are explicit hard dollar values, some of the costs may be opportunity costs.

III. JOINT INTEGRATIVE ANALYSIS AND PLANNING CAPABILITY (JIAPC) IMPLEMENTATION

Joint Integrative Analysis and Planning Capability (JIAPC) provides IO analysis and planning to combatant commanders to support holistic target characterization of kinetic and non-kinetic, lethal and non-lethal options for courses of action. Pattern matching and relationship binding tools, along with user interfaces, became imperative to support the analysis mission of the JIAPC Center (JIAPCC).

The JIAPC project of 21st Century System, Inc. incorporated tools to build relationships between hard targets, humans, and communications. These tools have the ability to show interdependencies and non-obvious relationships. The sum of these relationships shows a Holistic Target Characterization (HTC) of the battle space.

Associations between entities require a complex integration of diverse fields and the expertly guided analysis of alternatives whose variables and dependencies may number in the millions. Ontology analysis tools, created to tie entities from dissimilar data sets from a multitude of sources, were built to recognize and build relationships. These ontology tools are at the beginning phase of a long improvement process and will probably not reach its full capabilities for years.

Visualization of dependency relationships, particularly second and third order relationships, is a complex problem. An ontology and electronic dictionary, such as WordNet, is required to determine essential ties between entities, while hiding or avoiding non-imperative relationships. In addition, the system must be able to translate words used in disparate Subject Matter Expert (SME) domains into one common language in order to correctly analyze the patterns and relationships needed for the HTC.

The primary focus was to support the semiotics and collaborative visualization of JIAPC Integrative Support Process (JISP). In addition to the development of visualization and semiotics, knowledge representation and COTS integration will be addressed in the JISP collaborative visualization architecture. In developing the visualization and semiotics for JIAPC/JISP, 21st Century Systems, Inc. (21CSI) interacted with many different knowledge representations from at least four different knowledge producers (HFAC, E-Space, NEC, and JWAC) as well as the JISP internal knowledge representation. The software also explored additional functionalities that assist in analyzing IO effectiveness.

III.1 JIAPC Overview

The project's main objective was to visualize an HTC. During target planning, several different perspectives must be considered when determining the best course of action to accomplish the objectives. To view each perspective took serious time-consuming work and the work was performed by several different stakeholders. The products returned by each stakeholder were views from each stakeholder and needed to be integrated by the target planner. This was both time consuming and the characterization of the resulting plan were not always complete.

A coordination effort needed to take place in order come up with a way to display a holistic view of the target characterization. This holistic view needed to be created in order to show relationships easily. The relationships were classified in six different categories: Political, Military, Economical, Social, Intercommunications, Informational (PMESII).

III.2 JIAPC Goals

There were three primary goals to visualizing the HTC. The first goal was to provide a picture to the planner to show the underlining PMESII relationships. The second goal was to provide a JISP process tool to help facilitate the process of building the PMESII relationship. The final goal was to build automated tools to help recognize non-obvious and obvious relationships.

Building the final HTC view to show the PMESII relationships had never been successfully accomplished before. To view PMESII relationships required the user to navigate several different products. There needed to be an application to collaborate all the products into a single picture at the same time visualizing the relationships of data found in each product to show PMESII relationships using a solid Human Computer Interface (HCI) display.

In addition, the JISP process had to be developed to help facilitate the transition from disparate products to the final amalgamated HTC visualization. The JISP process is a collaboration and workflow process where JIAPC personnel can develop tasks to outline efforts and establish stakeholder requirements in order to build the HTC. The JISP tool had to initiate and guide the JISP process and assist the JIAPCC personnel in coordinating their efforts on developing different HTC products.

Automated tools for parsing stakeholder products and building relationships from data within each product range from simple, rudimentary to very complex. Parsing well-formed structured data required rule-based algorithms and is usually rudimentary. Parsing non-structured data could be very complex and difficult. Although techniques and technology is available to parse this data, it is not fully reliable.

Furthermore, once the data is parsed, a more difficult challenge is determining relationships automatically. Again well formed, rule-based data may explicitly show relationships among nodes. However, much of the products from stakeholders are in documents which are not well formed, such as Microsoft Word® documents. Correctly determining relationships requires a mature ontology.

III.3 JIAPC Software Application

As stated above, there are two complimenting software programs used in the JIAPC product: the hybrid display used to visualize the HTC and the web portal used to guide and facilitate the JISP. Both programs were designed according to the constraints and requirements of their problem space. The hybrid display requires a strong visualization and user interaction, while the portal requires distribution and collaboration between physically separated departments.

The two software programs heavily influenced the process of HTC visualization and JISP requirements. The hybrid display simulated discussions of what to include and how to display stakeholder products, obvious, and non-obvious relationships. The portal provided a storyboard for the JISP which allowed the JIAPCC to perform process walkthroughs in order to make adjustments.

III.4 Hybrid Visualization (2D GIS and Hyperbolic Graph)

To support the effort of an HTC, the need for a unique and capable visualization tool was identified. Whenever new technology and methods are introduced, there needs to be a step-wise introduction of these concepts into the community. Understanding that the intelligence community did not want another set of tools introduced, 21CSI decided to integrate pre-existing technologies in a new way to provide a holistic visualization of the problem space.

Using the established three domains of the battlespace environment - Physical, Cognitive, and Information - an HTC Visualization (HTCV) component was developed. The component takes a portion from each domain and integrates them so that any individual, regardless of their domain of expertise, can extrapolate useful information quickly. This type of approach aids in breaking down the barriers between the domains and providing a holistic understanding of the problem space.

The three major components of the HTCV, the Geographic Information System (GIS), the hyperbolic graph, and the supporting information area, are outlined below with an explanation and justification of each.

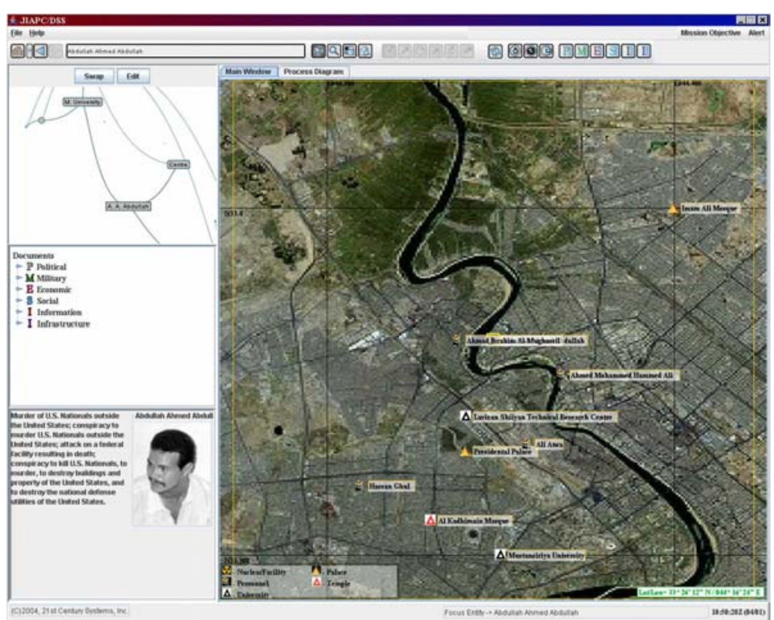
III.5 GIS

The GIS display is very critical to achieving a holistic understanding of the problem space. It provides spatial reference to physical objects and areas of effect of particular systems. All information contained within the HTC dataset with a corresponding geographical location can be displayed through the GIS display. This display is partial to the physical domain but delivered in such a way that the other domains can easily understand the information as well.

The GIS display is implemented using a 21CSI open-architecture software package known as AEDGE®. AEDGE® provides the functionality to render the physical entities on various two-dimensional image formats. This allows the use of multiple map overlays to better visualize the focus area. AEDGE® also contains additional features to include a three-dimensional display using Digital Terrain Elevation Data (DTED) that may be implemented in future iterations.

Because AEDGE® was built using an open-architecture design, the ability exists to "plug-in" other possible product solutions to depict the information in a two-dimensional display. This approach does not limit the user to one specific type of display. Versatility in visualization allows for better understanding of the problem space.

There exists a definite possibility that not all data contained in the HTC will have corresponding physical locations. This data may include ideas, belief systems, organizations, or military and political structures. For this type of information, two other displays have been implemented to better understand all of the data - the hyperbolic graph display and the information display (Figure 1).



There exist a number of GIS solutions through COTS and GOTS software today. The advantage of using the GIS provided by AEDGE is two fold. The first advantage being that there is one tool to address all of the HTC visualization needs and the other is the ability to communicate seamlessly with the other domain-specific components of the visualization tool. This is apparent through the ability to view the HTC data using different components and those components having the ability to communicate with each other to provide an unparalleled understanding of the data. If further information is requested through the GIS display, the other two domain-specific components dynamically retrieve any and all information relevant to the focus area. Not only does this provide an increased understanding of the data through multiple views but also helps to familiarize each individual domain expert with the visualization that other domain experts use to view the data.

III.6 Hyperbolic Graph Display

The hyperbolic graph display is a “links and nodes” approach to viewing the data using a dynamic graph capable of demonstrating interdependent relationships between data. This helps the user navigate quickly and effectively through large amounts of data and aids in the identification of critical links and nodes. The hyperbolic display has the unique advantage over the GIS of being able to display non-physical data and its relationships to other information.

The data used to populate the hyperbolic graph is currently drawn from a Knowledge Repository (KR) consisting of data provided by multiple stakeholders and Subject Matter Experts (SMEs). The information displayed in the GIS is from the same set of data contained in the KR. Much like the GIS display, when an area is selected within the hyperbolic graph, the corresponding information, if any, becomes the focus in the GIS and information displays. Again, this aids in further understanding the information.

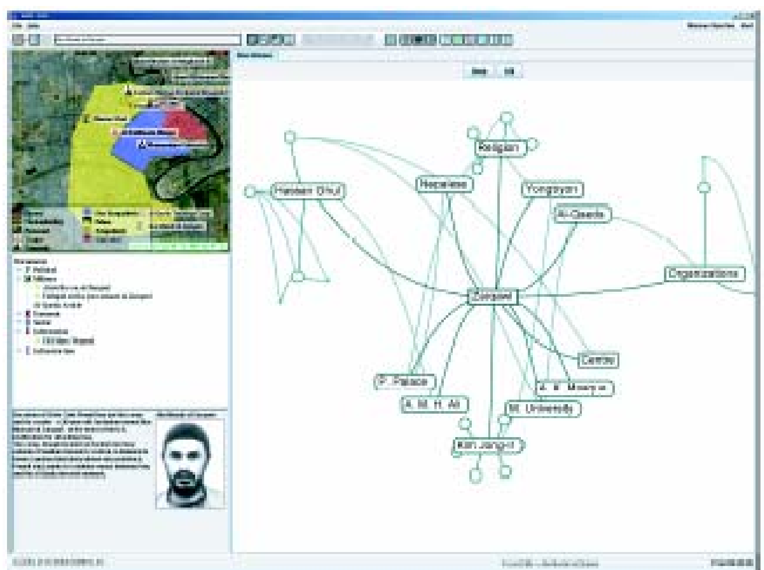


Figure 2. JIAPC Hyperbolic Graph

The hyperbolic graph is comprised of links, which are relationships between entities, and nodes, and the entities themselves (Figure 2). This depiction is very similar to the cognitive approach to understanding the data. Social networks are easily demonstrated using the hyperbolic graph as well as tying those networks into physical data. The amount of information displayed can be constrained using specific criteria to better focus on the current problem space.

The links in the hyperbolic graph demonstrate multiple aspects of the relationship to include strength, confidence, type, and amount of supporting data. The strength of the relationship demonstrates how close the two entities are related. The confidence in the relationship is drawn from the sources that provided them. The type of the relationship is based on a common definition of concepts or “ontology”. This enables the terms and ideas used to describe the relationships to have relevance regardless of source. The supporting data is also drawn from the ontology to provide non-obvious relationships between data.

III.7 Supporting Information Display

The GIS and hyperbolic graph are intended to provide a high-level depiction of the problem space identifying structures and relationships that are critical to the problem space. The supporting information display takes this a step further and provides low-level information pertaining to the focused area to include raw inputs from stakeholders and SMEs. This facilitates drill-down capability to pertinent data while providing data abstraction to outlying information. In short, the supporting information area supplies information the warfighter needs, when they need it.

III.8 JISP Portal

The JISP web portal was built to visualize the JISP. It has an aggregated view of the HTC products in the JISP and HTC products completed and archived. The combatant commanders can request an HTC for a mission objective through the portal and track the JISP status of each HTC being developed. In addition, the portal allows the collaboration and workflow to be developed for each HTC.

There were numerous reasons to display the JISP as a web portal design and not an application residing on a user's workstation. STRATCOM uses portals for many applications and encourages the use of web-based products. The advantages of web portals were very appealing to the JISP collaboration.

The front end of the portal is written using Java Server Pages (JSP). JSP produces Hyper-Text Markup Language (HTML) products capable of being displayed in a browser. Using a browser limits the need to download applications to machines and assists in ensuring software is up to date. This was very important in order to smooth the process associated with installing software on secure systems.

The JSP used both Java bean and j-tag technology. Both technologies allow reuse and easy modifications of web pages. This was important because the JISP had to be modified based on user feedback. Moving page windows and adjusting displays without changing the data is a simple process if the pages are designed correctly.

In addition, Cascading Style Sheets were designed early to establish a baseline look and feel that could be adjusted base on user's preference. The CSS separates style from content. Using CSS, the software team was able to modify the view quickly without modifying the underlining code.

III.9 Portal User's Page

The user's page is a personalized page used to show a snapshot of JISP statuses either associated with the user or in the user's watch list. A watch list is a list of HTC products in the JISP which are of interest to the user. The user's page also has alerts and notes sent to the user or a collection of users. These alerts could be a notification of work in the workflow, a general comment, or a system notification.

III.10 JISP Workflow

Combatant commanders have a web view showing management information and overviews of the JISP status. Commanders can insert mission objectives using a defined web template. Although the template does not have to be filled out completely, it does assist the JIAPCC in prioritizing the list of HTC products in development. Once the mission objective is inserted in the system, a JISP workflow process is started and status tracking begins.

The current JISP portal has a workflow engine for tracking the JISP stages. This workflow was designed and built as a placeholder to be replaced by a GOTS workflow engine. The GOTS workflow application was not released for this development cycle, therefore, a workflow placeholder had to be built to show the flow of the JISP. In future builds, the GOTS workflow engine will be integrated in the JISP portal. This should not cause many changes to the current architecture.

The workflow display was instrumental in visualizing the JISP process. The workflow display is not the same as the workflow engine. In future builds, it will almost certainly be a derivative of the current workflow display.

The workflow was designed to associate each workflow task with a role. Roles associated with each workflow task are assigned to users. Each user can have multiple roles. A work list for each user is displayed on the user's JISP home page. This work list is tailored to show only work assigned to the roles associated with the user. When the workflow is updated, the group assigned to the next step is notified.

III.11 HTC View

The workflow is part of the HTC view. The view shows the history and status of the HTC in the JISP. It also has a point of contact list associated with the particular HTC (Figure 3). In addition, each document supporting the JISP can be loaded for the HTC from this view. These documents are parsed and relationships are developed. Moreover, the documents are archived and displayed on the HTCV for reference and evidence of PMESII relationships.

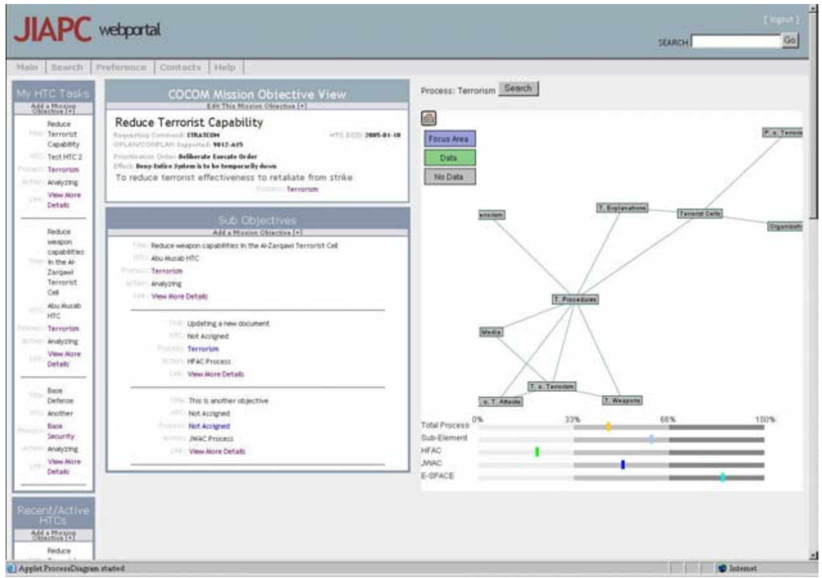


Figure 3. JIAPC HTC display

Each HTC view has a task template associated with it. A task template is used as a checklist to show relationships usually expected in mission objectives. The task template is assigned in the HTC view and used in the hybrid application to show where holes of PMESII relationships are located. In turn, the JIAPCC will formulate questions for a SME to answer in order to fill the holes.

Notes can be attached to the HTC view in order to clarify circumstances and decisions of each HTC. The notes can be sent to multiple users, a role, or to individuals. The notes can be made into alerts which are sent via email and prominently posted on the web portal.

By using data from the same database and using the same data access object to receive data, the web portal and hybrid application work in concert with each other to visualize the entire picture of the JISP and HTC of each mission objective.

IV. KNOWLEDGE REPRESENTATION AND ONTOLOGY

An HTC contains the targets with sufficient information about their relationships and effects (nodes and links) required for developing a set of Recommended Planning Considerations (RPC). The content of an HTC is an accumulation of products from many different sources that is correlated, fused, and filtered according to their contribution or relevance to the mission. An HTC may require second order or higher relationships and effects. The accuracy of the HTC is dependent on the accuracy of the description of the targets and their relationships. Maximizing the accuracy of the knowledge content is a complex task made harder by disparateness of the backing product and the complexity of the second order or higher relationships and effects.

The structure of an HTC (or the HTC knowledge representation) is a core concern to accurately representing the backing evidence for an HTC. For example, two different sources may have nearly synonymous usage of a word used in describing a target or relationship, yet the small difference in meaning may have a distinct relevance to the success of the mission. This can often be the case when dealing with psychological factors within the context of a foreign culture. The breadth and accuracy of the "electronic dictionary" (or ontology) used for the knowledge representation is then a key component to the structure of an HTC and so too, then, is the HCI or visualization of the knowledge representation of an HTC.

At 21CSI, we were able to leverage our experience with knowledge representation and visualization for intelligent agent decision support software in developing our JIAPC prototype user interface, schema, and ontology. The hybrid visualization approach allowed us to utilize the multiple concurrent visualization methods to maximize HCI effectiveness. While many of the JIAPC users may be more familiar with a 2D or 3D approach found in many GIS applications, it is not optimal for every ontological relationship. Trying to force a 2D or 3D GIS visualization may produce a malapropos visual cue to the user which could lead the user to a false sense of confidence with an inappropriate conclusion. As the visualization technologies get more advanced and the complexity of the information to be visualized grows exponentially, the problem of malapropos decisions caused by complex visualizations with poorly founded semiotics (ontology visualization) may become more pronounced.

The system-of-systems (SoS) architecture and the pressures for open architecture and COTS force many ontologically diverse applications to attempt to work together, yet it may not always be possible to cobble together an ontological visualization from diverse applications while maintaining a coherent semiotic basis. 21CSI was able to design the HTC visualization around a well-founded semiotic basis while providing flexible mechanisms to support the iterative development process and the integration of diverse knowledge representations. Our approach addressed the complex problem of visualizing massive amounts of data while accounting for the ongoing requirement of integrating disparate knowledge domains and the software systems that support them.

To ensure that the base electronic dictionary was sufficiently broad, current, and well investigated while also maintaining an open architecture approach, we leveraged a COTS electronic dictionary (WordNet) and augmented it specifically to support JIAPC requirements.

IV.1 Knowledge Representation Centric Visualization

Our approach addressed the complex problem of visualizing massive amounts of data and their relationships while accounting for the ongoing requirement of integrating disparate knowledge domains and the software systems that support them. We leveraged an open architecture electronic dictionary augmented specifically for the JIAPC integrative problem domain, and used this as a basis for knowledge representation. Knowledge representation addresses the higher order structure of the 'nodes and links'. This higher order structure data is 'metadata' or schemata which is data that describes data. A central concern to JIAPC is the correlation and integration of multiple schemas representing the multiple knowledge domains required to construct an HTC. Correlating multiple knowledge domains is more than simply assigning synonyms between product producers but often requires understanding and mapping the schema from multiple knowledge domains into a single cohesive holistic knowledge representation for integration into the HTC. Correlating multiple knowledge domains requires flexible and powerful ways of visualizing and manipulating metadata directly. The choice of the metadata representation impacts the architecture and deployment of the HCI that visualizes the underlying knowledge representation and so is an important factor in designing a HTC visualization HCI.

Merely choosing a metadata representation, such as SQL or XML, does not in and of itself introduce a meaning or knowledge representation to the data model. There are countless SQL and XML schemas which are functionally equivalent but still can't be leveraged by the underlying decision support or visualization software because the software is incapable of accurately mapping the schemas without human aid. Many schema mapping problems are actually intractable for computers no matter how many computers or how much processing time is allowed. While choosing a representation, such as SQL or XML, may ease the overhead in parsing and storing the intermediate data files (or serializations), they do not change the underlying mathematical limitation of the computers themselves. In order to fully address the problem of schema mapping the ontology and electronic dictionary of the knowledge representation must be expressive enough to represent many different schemas simultaneously. It is much better for the JIAPC KR to have, say, ten possible interpretations for one particular product and not lose accuracy, than to have one possible interpretation for ten particular products and guarantee introduction of inaccuracy and ignorance into the system by forcibly translating the product into a schema too simplistic for the product. Although it may be that the information was simplified on purpose because the information that was lost in the translation was not relevant, this simplification should be done with full knowledge of the integrator and not by fiat of the system and certainly not the HCI.

Knowledge representation-centric visualization addresses visualization and expressiveness of the underlying metadata representation and provides visualization modes and methodologies for choosing and manipulating the accuracy of the information as the integrator sees fit. 21CSI choose an open architecture ontology and electronic dictionary that is highly expressive and sufficiently broad to account a large bulk of possible product. 21CSI chose SQL as the underlying knowledge base due to its ability to deal with large amounts of data more efficiently than any XML based system, and its universal support of metadata and transactions. SQL databases provide an ideal mechanism for sharing data for both web centric visualizations as well as highly immersive 3D environments. Recent SQL technology and standards allows the SQL database to be sufficiently expressive to build a nodes and links knowledge representation capable of being viewed in multiple modes, such as hyperbolic and GIS. The transaction support of modern SQL databases is of higher performance and is easier to use than many vendor specific alternatives but important in support of "possibilistic" or speculative reasoning. This is very important to the future capability of reasoning and visualizing second order and higher effects.

IV.2 Open Architecture Ontology

To ensure that the base electronic dictionary was sufficiently broad, current, and well investigated while also maintaining an open architecture approach, we leveraged a COTS electronic dictionary (WordNet) and augmented it specifically to support JIAPC requirements. While there are many knowledge representation and natural language processing systems commercially available, they often are intrusive in their metadata representation and are specific to a few core XML schemas. A central concern with adopting an ontology and electronic dictionary is choosing one that has large consensus. This is often more important than choosing a system due to some supporting software tools or methodologies.

Open architecture ontologies and electronic dictionaries have several key advantages over closed source systems and yet do not preclude working with closed source systems. Ontology inter-operation is one of the key advantages of choosing an open architecture system. It is this openness that specifically benefits consensual knowledge exchange systems such as an ontology or electronic dictionary, probably more than many other open architecture systems. By choosing an open architecture that has widespread support, it is also more likely that a closed source system will work with or maybe even be based on the open architecture system. WordNet has been used for years and is the boot-strap for many other open and closed source systems. WordNet is well researched and used as a corpus for many natural language processing and machine translation research projects. Even though it is likely that the JIAPC ontology and electronic dictionary will continue to be augmented, maintaining an open architecture core ontological structure such as WordNet may allow JIAPC to leverage and integrate other ontologies and electronic dictionaries much more easily and cost effectively in the future.

WordNet is used in many "Semantic Web" or Web Ontology Language (OWL)-based open and closed source systems. Protégé, from Stanford University, is one of the most popular ontology editors in the world and has many WordNet specific or WordNet-based plug-ins. As OWL and ontology tools, like Protégé, progress and proliferate, it is highly likely that WordNet and WordNet-based tools will progress and proliferate with them. OWL, although a good standard for representing and interchanging ontologies, does not address specifically the problem of visualizing massive amounts of nodes and links. There needs to be an intermediate representation that is flexible enough to represent the knowledge within the OWL file, but allow for real-world applications to utilize the information. A WordNet-based SQL schema can represent not only the noun like descriptions, but through stored procedures and triggers and other SQL technologies, represent the rules, transformations, and procedures encapsulated in the OWL and actionable knowledge contained in the OWL.

IV.3 Ontology based Schema

21CSI ported and augmented the WordNet electronic dictionary and ontology structure within and SQL database. The ontology was utilized in an SQL schema that allowed fine level of detail in the specificity of node and link description while limiting the cultural bias introduced by English language specific descriptions. Instead of using English keywords that may have many different interpretations, the JIAPC prototype utilized the electronic dictionary's language-neutral synonym set identifiers as part of the SQL schema. Utilizing an SQL database allowed for significant separation of data model from presentation, which is more important to multi-modal visualization due to the many different visual interpretations for the same data sets.

IV.4 PMESII-Tagged Ontology

While there are many different interpretations of what PMESII means, allowing for PMESII-tagged clustering and filtering is important for dealing with PMESII-tagged knowledge. 21CSI and SAIC worked together to provide an augmented WordNet that allowed PMESII weighted values to tag electronic dictionary entries within the knowledge representation. Leveraging the nodes and links relationships within the knowledge representation allows for second order and higher effects of the entire knowledge representation to be tagged and filtered according their PMESII weights. Utilizing the relationships within the knowledge representation allows propagation of PMESII weights to second order and higher relationships according to their relationships. This is a key methodology to actually implementing a system to analyze higher order effects. For example, if radar ground facilities (RGF) have a Military and Infrastructure tag, and a particular RGF was added to the knowledge base from a product (say RGF X), that RGF X could "inherit" the PMESII weights simply by classifying it appropriately. Additionally, if RGF X has a component, that component can have a PMESII weight according to the propagation rules. This shows how second order relationships and effects can be effectively tagged by PMESII weights.

V. CONCLUSION

Adopting a bootstrap ontology for mission objective knowledge representation would have benefits far beyond HTC visualization. Actionable knowledge representations are becoming more widespread, although not generally in a cohesive and concurrent manner. The IO Roadmap has caused actionable knowledge as a technology to proliferate due to its use in effects based operations and planning. While each of the armed forces and COCOMs are different and have different requirements, the unique requirements of joint and coalition operations will highlight the need for a standard, cohesive, and formally specified actionable knowledge representation. Utilizing a actionable knowledge guided visualization is a manpower multiplier in that it allows the CIE staff to make more and better decisions while not sacrificing the trust in the system overall, despite the growing flood of data.

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