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Using Work-Centered Support System Technology to Enhance Command and Control

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Abstract

As information systems technology continues to evolve, new opportunities arise to more fully harness its power to enhance user and organizational performance. Concepts such as Network Centric Warfare envision unprecedented access to types and amounts of information and data. User interface technologies and system design methodologies must also evolve in order to fulfill the Network Centric Warfare vision and allow us to build human-centered systems which leverage these advances without overloading or confusing the end user - systems that work together with the user to enable efficient work. We are developing Work-Centered Support System technology, which focuses on supporting all user work activities, including decisions, through a single interface client designed to capitalize on universally available data as afforded by the Network Centric Warfare and similar concepts. The WCSS technology is an analysis and design methodology for building interface clients which enable a tight coupling of the human and computer with a goal of maximizing work effectiveness and efficiency. This paper describes an demonstration prototype of the WCSS technology called the Work-Centered Support System for Global Weather Management. The WCSS-GWM uses intelligent agent technology, cognitive analysis and new user interface design techniques to enable command and control users in an airlift services firm to proactively manage and mitigate mission impacts due to changing weather events. It has also begun to provide insight into ways interface agents can be efficiently incorporated into user interface clients.

Introduction

In the Information Age, information technology has emerged as a key leverage point which presents both opportunities and challenges. Concepts such as Network Centric Warfare envision unprecedented access to more types and larger amounts of data and information. This provides an opportunity to build more powerful information technology that leverages this access to increase the efficiency and effectiveness of its users. A key challenge is enabling the system to leverage this increased information access while presenting it to the user and allowing manipulation in a manner that increases their ability to effectively and efficiently perform work. Simply increasing the amount of data and functionality access may have the unintended consequence of degrading user performance and result in longer work cycles and larger numbers of errors. We believe systems analysis and development techniques must continue to transform to provide solutions that leverage these opportunities while minimizing unintended consequences such as data and "information overload".

C2 Environment Support Requirements

Command and control (C2) environments are typically highly dynamic and time critical. As the world becomes more complex, C2 users need the ability to manage and leverage increasing amounts of information. Users are typically asked to fuse and assimilate large amounts of information from many sources, including information technology, normally in a short period of time. Users are asked to perform routine, repetitive activities as well as problem solving and decision-making for dynamic, situation dependent events where human judgment plays a key role. As technology has the effect of increasing the interactions between people, organizations and countries, decisions become more complex and users must rapidly adapt and attempt to understand the problems and constraints, often in the context of larger and dynamic sociopolitical realities.

In addition, differing levels of user training and expertise suggest "one-size-fits-all" technology solutions may not very effectively aid the very novice user. A normative approach to design or may force all users to follow the steps coded to support the novice, thus hindering the expert user from gaining significant work efficiencies based on his/her expertise. New information technology has the potential to speed the "learning curve" and enable users to work at high levels of expertise more quickly than they have in the past. There are also significant benefits in being able to identify potential problems as early as possible to minimize the amount of C2 conducted through "crisis management". We are developing and have demonstrated a technology called Work-Centered Support System technology provides an approach to dealing with these issues.

Work-Centered Support System Technology

WCSS technology is both a software interface client technology and a design technology (Eggleston, et al, 2000). The goal is to provide an integrated and tailored support system that is sensitive to the current context state and offers support in a flexible and adaptable manner. (Eggleston, et al, 2000).

These clients provide a single user unified interface which frame the workspace and provide both direct and indirect aiding to support efficient work performance (Eggleston and Whitaker, 2002). One goal is to enhance user productivity by enabling work in context and maximizing the time users spend performing core work activities. Core work activities are contrasted with non-core or overhead work activities that may be necessary to obtain and transform data into "actionable" information but are not an intrinsic property of the work that the user must perform. The user normally performs these tasks simply as an enabler to perform higher-level core work activities such as decision-making or production of reports or other documents.

Providing proper context is important in helping maximize the speed of work performance and minimizing potential errors. While the WCSS methodology is widely applicable, it is especially well suited to support dynamic environments such as C2 because it explicitly supports both routine and non-routine, situation dependent work activities. It utilizes design techniques that frame the work in a user-centered manner and provides direct and indirect aiding to enable rapid user adaptation to the dynamics of the work environment, which is especially valuable in time critical environments such as C2.

WCSS user interface clients are envisioned as network-centric applications which "plug in" to middleware to access required data (Eggleston, et al., 2000). Applications have utilized software agents to perform tasks for the client and user such as automatically obtaining, monitoring and fusing information for the client (Young, et al., 2000). While not demonstrated to date, WCSS clients have the potential to publish fused or other information to the information network for use by other activities.

Work-centered analysis involves obtaining a deep understanding of both the cognitive and process requirements of the work. It provides specific techniques for ensuring all aspects of the chosen subset of work and potential for corresponding support and aiding requirements are addressed (Eggleston, et al., 2000). It includes analysis of mental work and flexible problem solving as well as the dynamics of work behavior.

Work-centered design techniques build on ecological design principles to design interface clients that allows experts to work more efficiently than novices by allowing multiple navigation paths through the interface (Rasmussen and Vicente, 1990). In addition, the design aims to "speed the learning curve" of novice users by framing and portraying the core work elements in a cognitively compatible manner, including framing using a first-person perspective work ontology (Eggleston and Whitaker, 2002).

A WCSS prototype to minimize weather impacts on airlift missions

A WCSS prototype has been developed to support military airlift command and control personnel with minimizing and managing potential impacts on planned and on-going missions due to weather conditions. The prototype is called the Work-Centered Support System for Global Weather Management (WCSS-GWM).

Work support requirements
During operational planning, weather forecasters prepare and tailor forecast and other weather products for each mission prior to departure. Flight managers add these products to other products including routes of flight, diplomatic clearance and Notices to Airmen information to provide aircrews and flight managers a package of information to enable successful mission launch and execution. After mission launch flight managers monitor the aircraft en route and provide support necessary to enable successful mission completion. This support includes assessment and advice to the aircrew when unexpected weather conditions are encountered. Flight managers work collaboratively with the weather forecasters to understand the problem and determine a course of action. Any of several options may be exercised when unanticipated weather conditions are encountered. The options depend on an analysis of information such as an assessment of duration of weather severity, type of aircraft, aircrew qualifications, fuel levels, type of cargo, and importance of mission and a variety of other factors. Possible courses of action include actions such as aborting the mission, rerouting the path of flight, diverting to an alternate destination, or adhering to the current mission plan and flight path – i.e. fly "through" the weather.

The work-centered analysis indicated that support for three key high level work requirements was desirable to enable minimization and rapid management of potential impacts on missions due to weather. They were:

- Enabling the weather forecasters and flight managers to achieve and maintain weather and mission related situation awareness

- Enabling them to proactively identify potential mission impacts due to weather as soon as they occurred as well as various geographic regions for significant weather events. Early identification and notification typically provides a greater range of possible actions and helps decrease the number of "crisis" situations the users must deal with.

- Support for rapid problem solving when potential problems occur.

The functionality of the WCSS-GWM focused on supporting these general requirements in a work-centered context.

WCSS-GWM functionality
Analysis of the work activities, work requirements and associated cognitive processing determined that the following functionality and data sources were required:
- Acquisition of real-time weather observations - such as PIREPS (pilot reports) and automated observations of wind and turbulence information sent through the Aircraft Communication and Reporting System (ACARS).

- Acquisition of worldwide airfield and upper air forecasts - produced both locally and remotely. These include SIGMET (SIGnificant METeorological Information) bulletins, which describe areas of weather that are potentially hazardous to aviation; METARs which describe current surface weather observations at worldwide reporting stations; and Terminal Area Forecasts (TAFs), which provide surface weather forecasts for worldwide reporting stations.

- Graphical integration of multiple data sources – map, flight plans, forecasts, point observations, satellite imagery. Analysis revealed a key design requirement was the ability to easily overlay any subset of data types on a single geo-referenced map for purposes of comparison.

- Automated and directed monitoring of individual missions and geographical areas of interest and alerting - to focus user attention on changes in weather conditions that may impact planned or en route flights.

- Automated comparison of real-time weather observations with user-defined "watch areas" and alerting - to focus forecaster attention on operationally relevant changes in weather conditions. While achieving a general capability for an automated alerting process would be quite difficult, we limited this to very specific critical capabilities determined in our analysis – generate alerts for any report (from PIREPS or ACARS) of turbulence or icing of at least a defined severity level in the defined region of interest (latitude, longitude, altitude, time).

Because the context in which users frame, understand and manage the work for these particular activities is geo-spatial, a global map-based display was selected as the central display for the WCSS-GWM. It is a map showing the geographical area of interest, with a number of controls arranged around the map. The map controls allow the user pan and zoom and change projections to view any desired geographic region. Fusion controls are implemented as multiple layers of flight, weather and context related information superimposed on the map. They enable flight plans, PIREPS, ACARS, weather observations, SIGMETs, satellite images and related information to be placed on and removed from the map in any combinations desired. An altitude slider control allows the user to filter weather observations by specifying an altitude area of interest. Additional details can be accessed by hovering the cursor over individual icons. For example, the text of a PIREP can be obtained by placing the mouse over the PIREP symbol displayed on the map. The weather information that is included as layers and the labels that are used to index them reflect the first person, work-centered. The fusion controls and navigation techniques are designed to enable rapid tailoring of the display such that proper context is maintained and rapid problem solving is supported. Affordances and context are integrated to enable rapid understanding of the problem, constraints and possible solutions. Figure 1 shows a screen shot from the WCSS-GWM that illustrates its basic features.

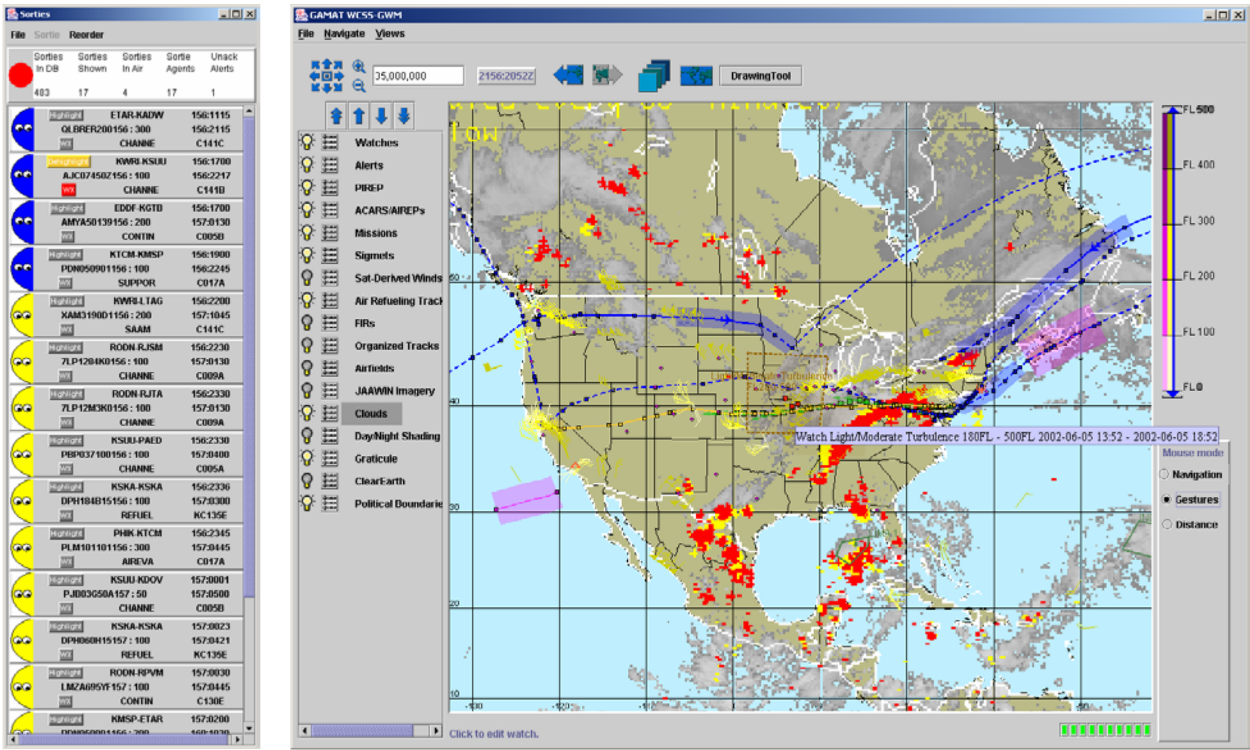

Figure 1. A screen shot of the WCSS-GWM that illustrates its basic features.

The WCSS-GWM also contains a floating Sortie Palette that provides a summary view of all missions of interest, status of individual missions, the ability to highlight and locate specific missions, and the ability to sort and organize them to suit the work context. It also enables users to maintain awareness of weather-related alerts and keep track of which have already been viewed and which remain to be dealt with. Further, it is integrated with the map display in that problem notifications can be directly highlighted on the map with a simple button click on the palette. The Sortie Palette aids the user in organizing and managing his work both for work on a given mission and for a set of missions. It enables rapid high level situation awareness at an individual user level and can also be used to provide a summary view of all or selected missions to a group or other users, such as collaborators or supervisors.

To provide additional flexibility to the interface, users can create and manage intelligent agents directly by directing them to perform custom tasks. For example, if a mission is known to be planned to cross a geographic region with the potential for significant and possibly detrimental weather conditions, the user can spawn an agent or set of agents to watch a user definable area for specific types of weather conditions and notify the user when operationally significant changes in weather occur. The ability to tailor the workspace increases the range and flexibility of support the WCSS-GWM provides. A key design element of the WCSS-GWM is that these agents can be created, monitored, and modified by the forecaster. For example, the forecaster can create an agent by drawing a polygon around a geographic region of interest (a watch area) on the map and specifying the agent behavior (desired altitude, start and stop time, hazard type and severity to watch for). At a later time, the forecaster can modify the agent behavior by changing these parameters, as well as modify the shape and position of the polygon. Forecasters can also create and modify the agents that monitor for changes in weather around a flight path.

Figure 2 shows a screen shot from the WCSS-GWM that illustrates the ability to create and modify agents. The wide blue shading along a flight path indicates the geographic area along a flight path that is being monitored by an agent. Similarly, the transparent geometric shapes (off the Eastern US coastline) provide visual indication of the watch areas being monitored by agents. The 'create watch area' pop-up window and 'edit agent parameters' pop-up window illustrate the ability to create new agents, and to view and modify parameters that control agent behavior.

It is also important to note that the watch area agent shown in Figure 2 is expressed in work terms (a physical area to be watched- indicated by the shaped polygon). This means the user does not have to translate from an agent icon to the weather-based semantic intent of what assistance the agent is providing. The agent is observed directly in the ontology and context of work, thereby reducing cognitive complexity and demand.

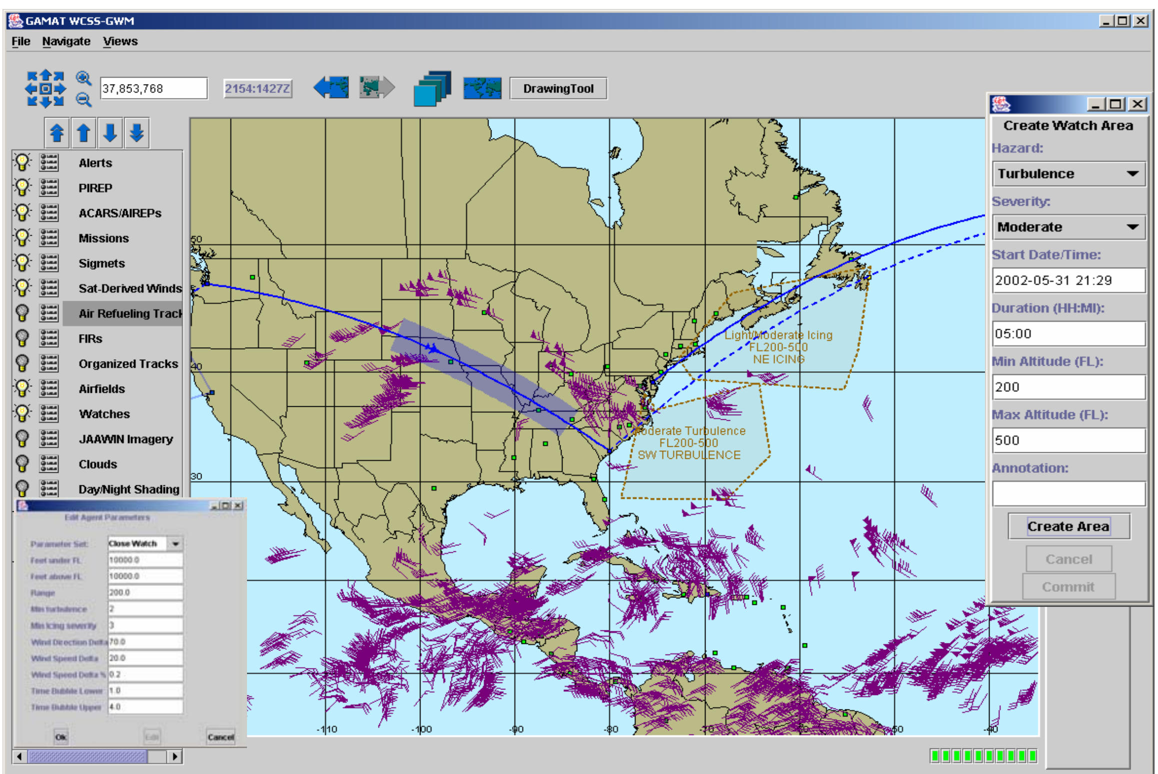

Figure 2. A screen shot from the WCSS-GWM that illustrates the ability to create and modify software agents.

Interface Agents in the WCSS

As stated earlier, one of the central goals of a Work-Centered Support System is to allow the user to work in context and maximize the time spent performing core work activities. This objective has led us to the use of interface agents as a key component of Work-Centered Support System design.

There are many definitions of software agents – possibly as many definitions as systems which claim to use them. For our purposes, though, we take a fairly modest definition of agents. We define an agent is an independent piece of software which encapsulates a desired functionality. In the WCSS-GWM, we believe, the function of an agent should be able to be understood by the user in terms of his own work domain. Agents should be able to be directed by the user – initiated or terminated. The behavior of an agent may be directly altered by the user, by changing parameters, or otherwise indicating the desired behavior.

The WCSS-GWM agent system is built on top of the D-OMAR (Distributed Object Model Architecture) system. It is a full-featured distributed software infrastructure that provides a broad range of services essential to agent-based system development, in this case agent-based interface client development. In the WCSS-GWM, agents are created, have the ability to launch procedures that implement their services, and retire or be removed when no longer needed. A publish-subscribe protocol supports communication among agents. In addition to the basic function of moving data between agents, the publish-subscribe capability plays an essential role in coordinating the activities of pairs or groups of agents. Furthermore, the publish-subscribe protocol used for inter-agent communication can also be used by an agent to coordinate the execution of its multiple proactive and reactive behaviors. We have found these language features to be essential to the rapid development of sophisticated agent behaviors. In the previous section, we gave examples of some of the agents in the WCSS-GWM.

We believe agent-based systems are a natural fit for implementing Work-Centered Support System technology. We believe agent-based systems enhance the power of application of Work-Centered Support Systems to most domains and especially to complex domains, such as command and control, with data and information normally being received from multiple sources (often multiple conflicting sources), in an environment where workload is heavy and often getting heavier. This characterization is also likely to fit practitioners of Network Centric Warfare. Among the challenges faced by the user are prioritization of workload and fragmentation of attention.

Our solution to this set of problems, as part of the Work-Centered Support System design philosophy, is to offer the user a range of agent behaviors and range of accessibility to these behaviors, through a set of individually controllable and observable, software assistants. Each of these assistants can perform a small job to break off a piece of work the user should no longer have to worry about – “keep me updated with the latest satellite images”, “watch this area of airspace for reports of turbulence”, or “let me know if any flights are intending to pass through this area of airspace”.

If we can allow the user to control these software assistants or agents without distracting him from his main work goals, we have gone a long way toward building an appropriate Work-Centered Support System. The techniques we use to allow the user to task and observe these agents are central to the philosophy of Work-Centered Support System design. Some of these techniques include:

- Framing the action of an agent in terms of the user's own domain terms. (Achieving an understanding of the domain ontology is one of the early steps in designing a WCSS.)

- Giving the agent an appropriate way to display both itself and its products, again in terms of the user's own domain ontology and in a work-centered, context appropriate and framed representation. A basic tenet is that the user needs to be able to understand what agents have been tasked to perform what work, and needs to be able to view and evaluate the results of the agent activities.

- Finding ways to minimize the outputs of the agents – clustering alerts together, for example, if multiple agent alerts appear in close proximity in a specific geographic region.

- Enabling management by exception - It is often desirable for the user to manage his work space on an exception basis, and only having his attention diverted to his agent assistants when necessary to enable efficient work activities and work goal achievement. This is consistent with the work-centered philosophy of minimizing cognitive and procedural burden associated with performance of work.

The WCSS-GWM contains three broad classes of agents:

- Acquisition Agents acquire data from outside sources (e.g., weather bulletins, ACARS, SIGMETs, satellite imagery, mission details, flight plans). Each acquisition agent is responsible for a particular data type/source, and will periodically retrieve the latest data from that source (anywhere from once a minute to once every few hours, depending on how often new data is available from the source). Furthermore, each acquisition agent signals other interested agents when new data have been retrieved. Acquisition agents could also be used to display simple information in the interface.

- Analysis Agents analyze data retrieved by acquisition agents to produce initial problem indications (individual turbulence reports, lightning strike reports, intersections of flight plans with SIGMETs, etc.) Types of analysis agents include: *Region analysis agents* that are triggered by the weather forecasters when they decide to monitor a geographic region for critical conditions (i.e., create a watch area), and then watch for observations matching given criteria; and *Mission analysis agents* that are automatically generated by the presence of a current or upcoming flight mission. This agent watches for reports (e.g., PIREPS or ACARS) close to the flight plan (in latitude, longitude, altitude, time space) that significantly affect the mission.

- Presentation Agents are based on the results of the analysis agents, and decide what information is presented to the user. These agents work on initial problem indications, clustering and prioritizing, to present high-level presentation of problems. For example, there may be many related notifications generated by the analysis agents that need to be aggregated together into a single notification message to avoid an 'alarm avalanche' problem (Woods, 1995). Presentation agents are also responsible for staging displays, that is, retrieving enough data, and the right kind of data, so that the information needed by the user can be quickly rendered on the screen. We have implemented only a limited presentation agent capability (as shown in Figure 2), but in a full-scale implementation of a WCSS-GWM these agents would have two additional responsibilities:

  - Displaying data at different levels of aggregation, depending on the user's role. For example, a supervisor may get only a top-level summary view of areas of turbulence, while the user responsible for a particular mission might see individual reports of turbulence close to that mission path. It would be the job of the presentation agent to aggregate the same underlying data to different levels for the different users.

  - Displaying different data, depending on the user's role. In a global system, multiple flight managers and weather forecasters would split the globe into regions of responsibility. As the analysis agents produce indications of critical weather, it would be the job of a presentation agent to present this information to only those users who would be interested.

One of the considerations in the design of the agent architecture was to create a structure that could be understandable, inspectable, and modifiable by the forecasters. While the literature on software agents has tended to focus on the high level tasks delegated to agents and their level of autonomy, the value of agent technology from a software development perspective is that software agents are small, independent 'chunks' of software that each address a small unified set of tasks, are separately controllable, and separately modifiable. In creating the agent architecture, a key consideration was to structure the software so that the capabilities of the software 'chunks' and implemented as agents will be meaningful to the user in terms of his/her work domain, as indicated earlier. The agents are configured in such a manner as to mirror the basic terms of reference the user employs in addressing his/her work. This applies both with respect to the agents' functions (e.g., acquiring, analyzing, and presenting data) and to the domain objects that the software agents work on (e.g., missions, forecasts, watch areas). Once the software is organized into domain meaningful 'chunks' implemented as software agents, users can more readily observe and direct their operation

Framework for understanding and integrating interface agents

As client interfaces utilizing interface agents continue to mature and agent behavior becomes more sophisticated, additional issues will have to be addressed to enable greater and more efficient agent integration. Interface agents should maximize the amount of help they provide the user while minimizing their potential negative effects – such as increased cognitive burden and decreased work efficiency caused by data overload and automation surprise.

The development of the WCSS-GWM have helped us to begin to build a systematic framework for understanding interface agent behaviors, their interactions with users and ways of thinking about how to express and integrate them into the interface in a work-centered manner. One dimension for classifying agents is in terms of the level of interactivity with the user. Another is their level of sophistication in terms of the complexity of the activities they can perform, either singly or in groups.

The level of interactivity can be classified as two general types of behaviors that could be termed "directed" and "cooperative". Directed agents perform services for users with little or no human interaction and normally provide little or no visibility into how they are performing their services. Other types of agents exhibit cooperative behaviors, which are highly interactive in terms of allowing direct manipulation and custom tasking by the user. This type of agent and interactivity has the potential to be very useful to a user and provides a higher degree of flexibility in terms of the information it can provide and the ways it can be presented. It also presents larger challenges in terms of integrating the behaviors and enabling user manipulation in an appropriate work-centered manner. Some agents exhibit aspects of both directed and cooperative behaviors.

As mentioned earlier, in the WCSS-GWM, we have employed three types of agents – acquisition, analysis and presentation types. In the WCSS-GWM, acquisition agents are the least sophisticated. Some information obtained by acquisition agents is ready for directly expression in the interface as the information is acquired. Examples are SIGMETs, expressed as green polygon outlines, PIREPs, expressed as purple diamonds and TAFs linked to airfields and accessible by hovering the mouse over the airfield.

Other information acquired by the acquisition agents is not ready for direct expression and is passed to analysis agents for further processing. Analysis agents have a higher level of sophistication that acquisition agents and perform analyses and higher level fusion, providing results and information that is ready to be displayed as an object, text or other representation in an appropriate work-centered format. An example is a mission level alert derived by geo-spatial and temporal fusion of weather information and mission flight path information as well as calculations to determine alert potential and if an alert threshold has been reached.

Presentation level agents have the highest level of sophistication and exhibit aspects of both directed and cooperative behaviors. An example is in the Agent Management Tool. Users prescribe a polygonal region and specify conditions to watch for and alert on. The user both defines the agent characteristics, which at the same time specifies the expression of the agent in the interface if the specified conditions are met. This duality has significant potential in terms of offering the user a greater degree of flexibility in terms of understanding the work domain and determining appropriate actions. This has the potential to directly translate into greater work efficiency, by saving process steps, continuing to enable work in the proper context by minimizing the requirements to work "off-line" or outside of the work-centered support system.

We believe a structured framework is necessary to enable mapping of work support requirements to agent behavior and expression types in a robust, systematic manner. For example, within a particular work frame, certain elements of agent behavior and level of user interactivity should be expressed to the user, while other elements should be used to specify the agent behavior, but not be visible to the user. This likely will have a direct relationship to the types of agents necessary to satisfy both user interactivity requirements and means and type of expression in the user interface. Additional research is needed to determine how work requirements can best be satisfied among both direct and indirect aiding, including interface agents and other forms of automation and expression.

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