ISAS: A Human-Centric Digital Media Interface to Empower Real-Time Decision-Making Across Distributed Systems

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ABSTRACT
The **Integrated Situational Awareness System (ISAS)** initiative at the University of Florida Digital Worlds Institute has demonstrated an effective web services-enhanced graphically-based environment for globally-distributed operations ranging from humanitarian aid during large-scale environmental disasters to high-level collaboration and augmented decision-making in civil and coalition activities.

Categories and Subject Descriptors
J.7 [**Computers in Other Systems**]: Command and control, Industrial control, Military, Process control, Real time.

Keywords
Situational Awareness, Decision-Making, Integrated Media Systems, Real time, Virtual Reality, Ontologies, Human Factors.

1. INTRODUCTION
ISAS combines and correlates diverse streams of data and sensor information using a variety of advanced algorithms to accurately correlate current data points with expected or potential future moments. ISAS is designed to offload the majority of operational processing and information seeking and acquisition into the background until the requested data or confluent situation is found. At that point, the ISAS will alert the individual Operator and display the relevant data using an interactive digital media mapping display. Our team is also investigating the scalable integration of Ontology-based Virtual Reality Environments as a means of extending to power and timely access to information provided by both fixed and mobile assets in the ISAS environment. If the results are needed or helpful to the decision-maker, they are then routed to the large-scale interactive display.

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Multiple ISAS nodes can be linked in real-time to augment and positively enhance decision-making in complex situations. This flexible architecture enables high-level collaboration and augmented decision-making for large-scale complex project operations and initiatives in the early 21st century.

Accordingly, the ISAS is being developed to fill the need for a system and methods that can efficiently and effectively receive data from multiple sources, and then synthesize, integrate and fuse that data into a sense-making picture that can lead to effective and timely decision-making. More fundamentally, ISAS represents a flexible platform and methods for combining inputs received from multiple or diverse sources simultaneously, and utilizing said combined input to augment the decision-maker's situational awareness.

Through the use of an innovative Human User Interface (HUI) the ISAS provides a rich and intuitive graphical environment for situational cueing and the correlation of diverse data streams into a comprehensible, multi-modal and intuitive "big picture" that empowers the decision-maker towards rapid and functionally-enhanced calls.

2. OVERVIEW OF THE NEED FOR ISAS
Dynamic and unexpected events are defining characteristics of numerous application domains. Such situations – including natural disasters, military and civil conflicts, and incidents of terrorism – require the deployment and management of a wide variety of different resources in order to bring the situation to a successful conclusion, or at least to mitigate the consequences that can be caused by such incidents. Achieving real-time situational awareness and sustaining knowledge superiority in a complex, distributed team environment requires a robust network of systems of systems. The distributed theater environment requires decision-makers to solve many complex problems in a limited time, under resource constraints.

In the event of a large-scale disaster, for instance, response-and-relief agencies must quickly assess the magnitude and nature of the disaster and must then rapidly deploy personnel and materials to contain the effects of the disaster. Similarly, in cases of civil unrest, military and/or law enforcement agencies must quickly gain an accurate assessment of events and take steps to diffuse the situation notwithstanding the uncertainty inherent as it unfolds.

To effectively address these challenges, decision-makers require tools for situational analysis and decision support tools to facilitate making rapid, robust decisions. Effective decisions do not occur in isolation but rather are often made in complex environments with competing sources of information. There is a need to de-conflict information and enhance situational awareness and facilitate decision-making in the distributed team environment.

The operational level of the decision-maker is key to their ability to respond to dynamic situational context information (e.g. events, goals, objectives, etc.) in a complex distributed team environment. ISAS provides a rich and intuitive environment for situational cueing and the correlation of diverse data streams into a comprehensible, multi-modal and intuitive "big picture" that empowers the decision-maker towards rapid and functionally-enhanced calls.

3. BACKGROUND AND DEVELOPMENT

Decision-makers are charged with deploying and managing various resources received from myriad sources. Such sources include reports by on-site personnel, imagery from live video feeds, aerial reconnaissance, diverse databases and/or satellite images. The plethora of data received from a wide array of sources, while necessary for effective decision-making, can nonetheless quickly overwhelm the ability of civil and/or military personnel to synthesize the data and process it into a form that best serves decision-makers facing a rapidly changing situation.

Accordingly, the Integrated Situational Awareness System **(Figure 1)** is being developed to fill the need for a system and methods that can efficiently and effectively receive data from multiple sources, and then synthesize, integrate and fuse that data into a sense-making picture that can lead to effective and timely decision-making. ISAS provides a flexible and multi-use platform capable of interfacing with divergent data streams and formats simultaneously. The resultant shared interactive environment functionally enhances the decision-maker's effectiveness.

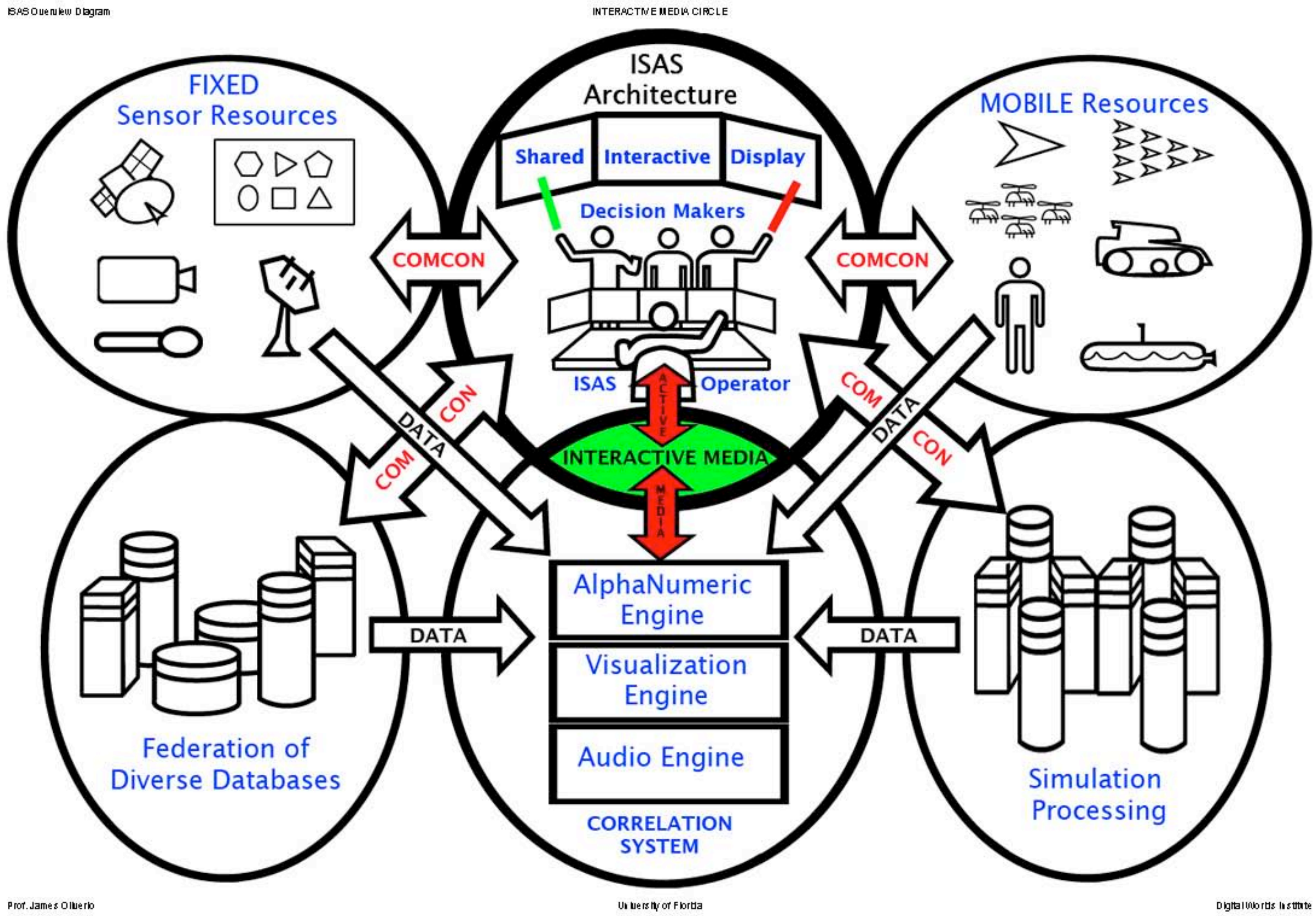

Figure 1. ISAS Architecture.

The major ISAS subsystems include data from both FIXED and MOBILE Resources correlated into a single intuitive media framework before being presented to the decision-maker(s).

Other important subsystems include a federation of diverse databases and the scalable integration of Ontology-based Virtual Reality Environments whose output can be graphically displayed through the ISAS Visualization Engine. ISAS provides not only the tools for enhancing situational awareness, sense-making and reasoning, but also a shared interactive display environment in which one or more commanders can make rapid, robust and accurate decisions.

4. TECHNICAL CONTRIBUTION AREAS

4.1 Continued Refinement of the Multi-modal Interactive Gestural Interface environment for ISAS Operators and Decision-makers

Most current monitoring and response systems still use PC-based standard keyboard/mouse interfaces to gather and display information. The current version of the ISAS system is already based in next-generation visualization and user interfaces, representing a substantial improvement in intuitive usage and response (Figure 2.1-2.4). A metaphor for the procedural functionality of the ISAS Operators may be thought of as a “Virtuoso in Data Space” where the Operator “plays the data” to quickly correlate and display it for the decision-makers. Thousands of young people currently display extraordinary motor skills and cognitive dexterity in the use of screen-based video games for entertainment. Their increasing interest and skill with interactive media systems represents a vast potential to be channeled into a productive pursuit that can ultimately result in career placement in important positions within the military and civil servant sectors.

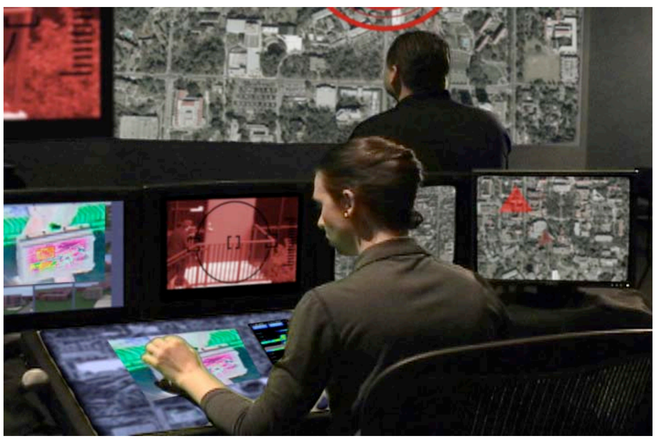

Figure 2.1 Operator correlates data into imagery to be displayed for the Decision-maker

Figure 2.2 Multiple mobile resources can be rapidly deployed to respond to any number of routine or emergency situations

Figure 2.3 Polyphonic touch-display created at the UF Digital Worlds Institute allows Operator to quickly select and interact with target areas

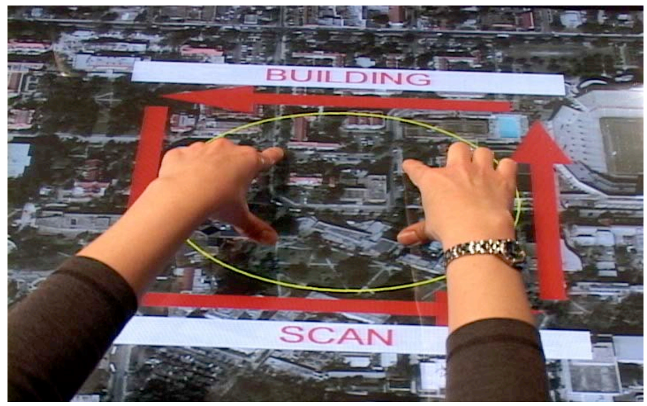

Figure 2.4 Polyphonic interaction surface eliminates the need for PC keyboard-based commands and instead uses shapes and gestures

4.2 Development of Ontology-based Virtual Reality Environments

Traditionally 3D Virtual Reality (VR) environments are specified by files (VRML, X3D) or relatively simple databases that describe the geometry of 3D objects but contain very little additional knowledge of the objects in the VR world. There are many reasons to enhance VR environments with better database support.

In a VR world, we need to know not only what an object looks like, but also what the object is, what its properties and characteristics are, how it behaves, and how it relates to other objects. We also need to be able to interact with and refer to objects by pointing and by voice commands. In our approach we utilize an ontology management system, a database management system based on ontologies, to provide semantically rich descriptions of objects in the VR environment.

In fact the VR environment can be considered a projecting of objects described by the ontology into a 3D visualization environment. The ontology provides a way of describing object properties and behaviors, describing object taxonomies, and, using ontology reasoners, automatically classifying and cluster objects into categories. The ontology acts as a dictionary that defines the meaning of concepts, and provides support for natural language references to objects.

4.2.1 Ontology Management Systems (Lyra)

An ontology management system (OMS) is a database management system that utilizes formal ontology languages as the basis for modeling and manipulating data. Description logics such as OWL-DL [1] are well-defined languages for building descriptions of complex concepts. In addition, the OMS provides facilities typically available in database management systems including maintenance of database integrity, physical storage management, security, transactions, backup/recovery, and data manipulation (query processing and other reasoning facilities). Physical storage management is particularly important because the VR environment requires management of very large numbers of objects. Dynamic scene generation requires that just the right objects to be loaded into memory at the appropriate time to expand a scene or increase level of detail in object presentation. We have developed an OMS called Lyra [2] that is being used for ontology-based applications in a variety of domains, and we are using Lyra as a core database management facility in ISAS.

ISAS requires access to many sources of data, and while the ontology provides a core facility for coordinating and managing objects of all types, the ISAS architecture allows for distributed access to multiple data source. Multiple ontology management systems as well as relational databases can be accessed remotely by ISAS using various techniques (Web Services, Remote Method Invocation, CORBA, or other database wrapping services). Thus these data sources can be distributed broadly across distant geographic areas.

4.2.2 Query Processing, Language Processing and Other Reasoning Functions

Ontology reasoners compare the structures of objects to determine how they are the same or different. They can automatically classify new concepts and build categories by grouping together similar objects. This capability leads, among other things, to query processing as a query can be classified in order to identify objects related to the query (e.g. find all instances that satisfy the constraints of a query).

In VR environments, such reasoning processes have many applications. One is to create the desired scene from specifications (see next section). Retrieving a particular object or group of objects from a vast collection (hundreds of thousands) in the OMS is another important function. Highlighting specific objects within a scene ("show the emergency exits in a building"), and spatial queries ("find the flight path for an Unmanned Autonomous Vehicle (UAV) across a landscape of buildings and trees") are specific requirements of VR applications.

Support for natural language queries provided by the ontologies enables objects to be named or referenced in many different ways. Multilingual naming and facilities for managing synonyms and homonyms enabled the same object to be named and referenced many different ways. The Lyra OMS includes facilities for creating dictionaries and storing phrase patterns needed to process more complex definite descriptions in natural language. Ways are being developed for interacting with the VR scene using simple voice commands (naming objects, issuing queries in short phrases).

4.2.3 Automatically Generating VR Scenes from the Ontology

The semantic richness provided by ontologies can be utilized in several ways. Using an ontology to represent the concepts in the domain that is being virtualized in 3D makes it possible for a domain expert to provide information about domain objects to a very high degree of detail without having to know anything about generating the VR application itself (which usually demands an in depth knowledge of some GUI or modeling language like VRML). For example, in a task involving the VR modeling of a building, a domain expert could provide all relevant information about a building by creating a "Building Modeling Ontology" without having to worry about how the VR application would be generated.

Multiple ontologies can be combined to automatically generate VR applications. This ability comes from combining a domain ontology that models the concepts of a domain with a scripting ontology to model the geometry of the concepts in a scripting language like VRML. It is possible to map the concepts from one ontology to the other. For example, a "Lamp" in a building ontology can be mapped to a particular shape such as a "Box" in the VRML ontology. The "Lamp" concept in a domain ontology can be modeled in such a way that it refers to all kinds of lamps or a lamps of a particular kind depending on the domain. In case a change in mapping is necessary to accommodate showing lamps in a different shape in the VR World, all that is required is a change to the mapping semantics. For example, changing the mapping such that a "Lamp" concept maps on to a sphere in VRML Ontology would make it possible to generate Lamps in spherical shape. Once the mapping has been defined, a code block that takes the mapping and generates the VRML file corresponding to that mapping would generate a VR World automatically.

The VR Wise group [3] has used a similar approach to auto-generate semantically rich VR applications using ontologies [4,5,6] and they have developed a VRML file generator that auto generates the VRML file corresponding to the VR World once the mapping has been defined. Our approach is similar, but uses the OMS to store objects that can write themselves out in various XML formats, including VRML, or simply create the VR scene directly using a VR API such as Xj3D as explained in the next section.

4.2.4 Demonstration Applications

We have created an ontology for describing buildings on the UF campus **(Figure 3)**, as one instance of Fixed Resources in the ISAS, and have constructed a 3D model of a building **(Figure 4)**. The UF campus ontology describes buildings which comprise the campus, categorizing them into various functions. Object properties are used to describe building details. Terms referring to objects enable each building to have several different names. A geospatially referenced campus map was imported into the OMS by parsing ESRI Shape Files. A detailed 3D model for one building (Rinker Hall) was extracted from the CAD programs used to create the building. A VRML file was exported from the CAD program, and the VRML file was parsed into data objects that were then stored in the OMS. To generate a VR scene, the objects are retrieved from the OMS and rendered in a VR environment. We interfaced the Lyra OMS with the Java Xj3D environment that provides a VR API and rendering engine based on OpenGL. Users can interact with the VR scene and click on building features to display properties in real time.

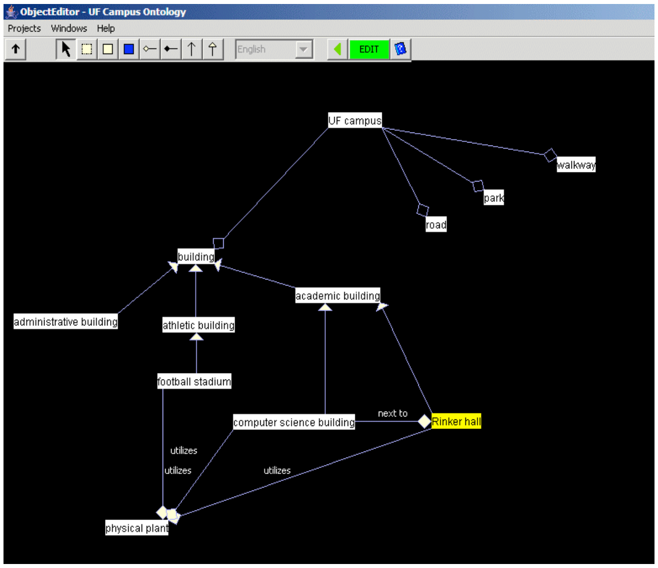

Figure 3. Top portion of the UF campus ontology showing the most general concepts and relationships. Rinker Hall is shown as an object within the *academic building* class, that is physically *next to* the *computer science building*, and which *utilizes* the *physical plant*.

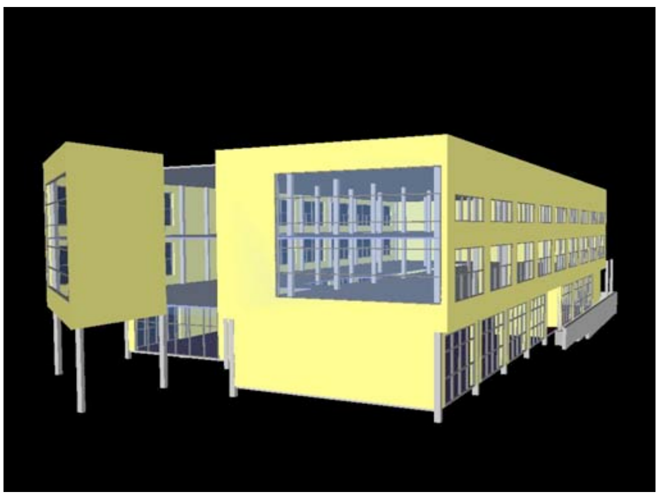

Figure 4. Rinker building retrieved from the Lyra OMS and rendered in the Java Xj3D environment for integration into the ISAS environment.

4.3 Extracting and enhancing domain knowledge for the decision-maker via cognitive research and interactive digital media tools

4.3.1 Concurrent Knowledge Assessment (KA):

Using a process tracing methodology, the system permits the collection of verbal and action protocols by video/audio taping operators from the Naval Undersea Warfare Center (NUWC) during a simulated maritime engagement in simulated operational settings to (1) ascertain the germane data used by operators to form hypotheses and validate which hypotheses are used to make threat assessments and (2) evaluate human performance with regard to accuracy, timeliness, change blindness, memory load, event processing capacity, etc. for comparison to performance using digital mapping under the same scenarios.

4.3.2 Cognitive Task Analysis

Cognitive task analysis (CTA) is a set of methods for identifying cognitive skills, or mental demands, needed to perform a task proficiently. The product of the task analysis can be used to inform the design of interfaces and training systems. Applied Cognitive Task Analysis (ACTA) allows the practitioner to represent this information in a format that will translate more directly into applied products, such as improved training scenarios or interface recommendations. [7, 8]

4.3.3 Naturalistic Decision-making Analysis

Naturalistic Decision-making (NDM) provides observations, models, and controlled experimentation provides the testing and formalization. NDM will provide a critical means of evaluating how operators/decision-makers actually use the output of digital mapping as a means of making decisions, and performing cognitively complex tasks in a demanding operational environment. [9,10]

4.3.4 Recognition Primed Decision-making Analysis

Recognition Primed Decision-making (RPD) emphasizes situation assessment vs the comparison of options. For example, a decision-maker's mental model provides a set of expectations, against which the decision-maker can evaluate their situation and course of action. [10]

NDM and RPD provide a means of evaluating the decision maker's strategies in conducting tasks in dynamic, complex environments. NDM & RPD analyses also affords the system designer the means to evaluate the optimum configuration and effectiveness of a system that will facilitate accurate decision making where information is ambiguous and the course of action is uncertain. The management of autonomous unmanned vehicles challenges the operator as they attempt to manage AUVs by reducing uncertainty within the context of a dynamic, complex operational environment. We will utilize ACTA as a means of identifying critical cognitive strategies during decision-making. This approach will afford us the opportunity to capture individual strategies in naturalistic decision-making and analyze those strategies that prove most effective during task performance. This analysis will inform and influence the future system design of ISAS. [8, 11]

5. Continued assessment of the impact/effectiveness of Interactive Digital Mapping (IDM) on the decision-maker's abilities in the face of information overload.

We propose continual, *in situ*, Knowledge Assessment and learning techniques using digital mapping, working in parallel with tactical systems, to augment human performance and assess performance. There are numerous types of alerts that can inform, alarm an operator/decision-maker in the performance of their tasks. US Navy Fleet operators have reported frustration in the use of various alerts as they often impede rather than support their decision-making. Interactive Digital Mapping will guide the user/operator to make fewer false alarms, and more accurate decisions. [7,10, 8, 11]

6. SITUATIONAL AWARENESS

6.1 Situational Assessment using real-time Interactive Digital Mapping (IDM)

Situational Awareness (SA) refers to an individual's ability to achieve an awareness and understanding of what is going on around them. SA includes the perception of cues, comprehension of information, the projection of events, and the temporal dynamics associated with events as they change. [12,13,14]

SA is a critical component of system design since operators/decision makers are confronted with massive amounts of data and need to sort through the data to make accurate and rapid decisions. It is critical to maintain situational awareness in environments that are replete with sensors and systems, such as autonomous, unmanned vehicles. The distributed network operational environment adds to the complexity of achieving SA since information management and technologies present challenges to the operator attempting to manage systems, make decisions in dynamic, distributed networks. There is a need, therefore, to design systems that will enhance situational awareness. To accomplish this goal, we need tools that will help the decision maker achieve an understanding of their environment and support their efforts in managing systems and technologies in an effective manner. For a given decision maker, there is a need to establish SA and remain informed throughout task performance. To this end, situational awareness analysis will provide details regarding a decision maker's cognitive processes and perspectives that impact their ability to optimize their task performance in a dynamic operational environment. [8,13,15]

6.2 Tactical Readiness

Tactical readiness presumes that we have a well-defined tactical and operational plan, as well as the ability to swiftly act when necessary. By utilizing the output of the real-time IDM system, we will enhance situation awareness and sustainable knowledge superiority over the adversary. One of the desired outcomes is to maximize the probability of correctly determining likely imminent events, threat levels and optimize the time to decide and act. [11,16]

7. FUTURE WORK

A phased approach to further ISAS enhancements and technological integration is being undertaken. Phase I (FY07) invests in the exploitation of gestural-based interactive interface development using combinations of new and existing mapping technologies with VR scenes automatically generated from ontologies to identify the feasibility of research across identified domains. Phase II (FY08) conducts applied research and produces an enhanced design. Phase III (FY09) will complete the detailed design and produces an initial demonstration in an operational setting geared toward both Homeland Security and U.S. Navy assets. Phase IV (FY10) completes the development of the ISAS prototype for digital mapping with integrated display systems to augment human decision-making in complex, distributed networked environments for utilization in collaborative global-scale platforms.

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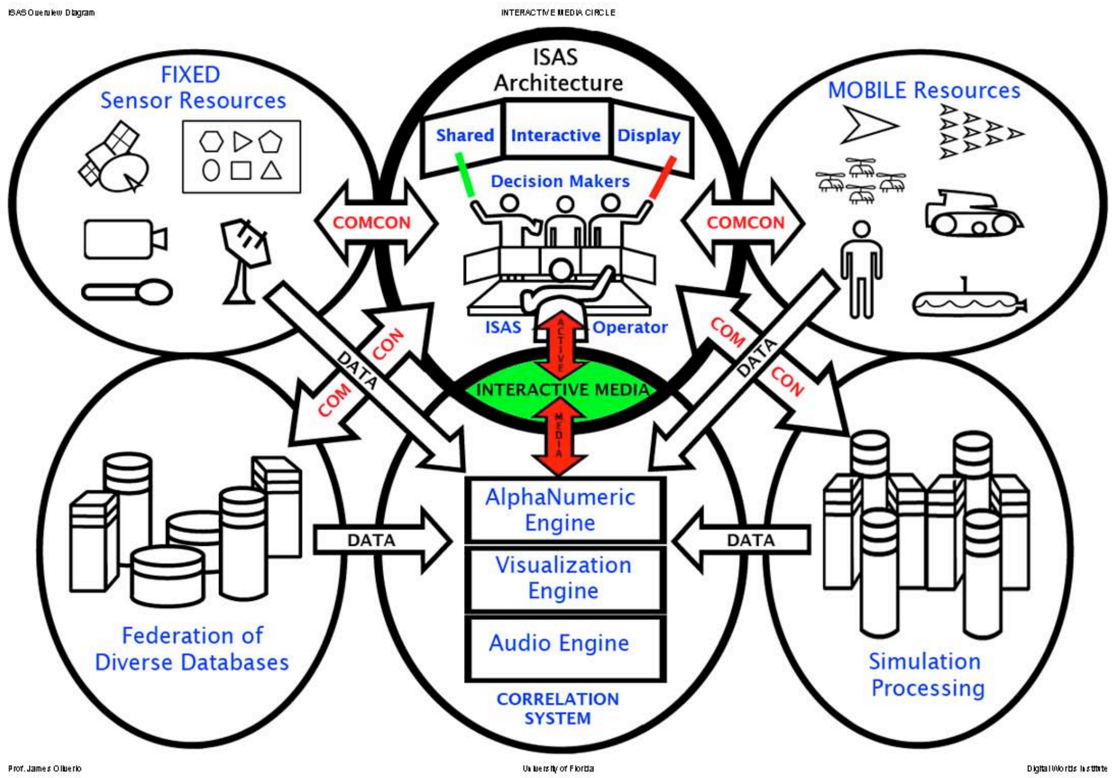
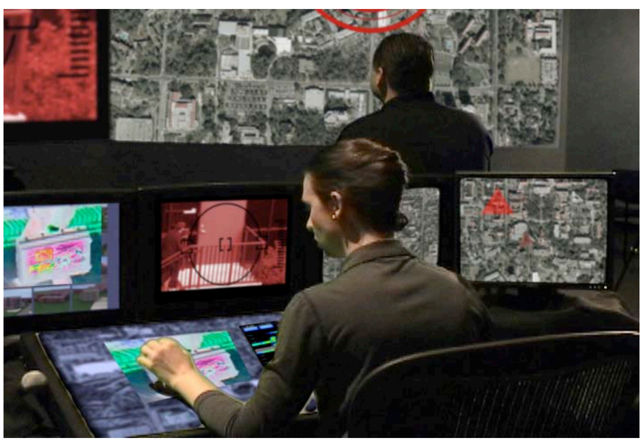


Figure 1. ISAS Architecture



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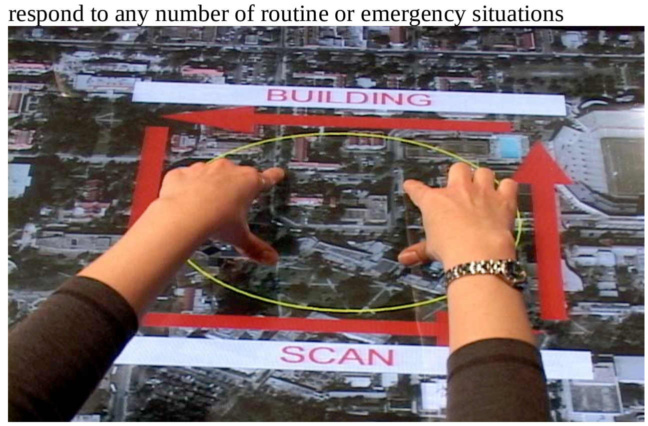

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