Position Paper on the
Refinements to the Concepts of a Global Sensor Web
per the
Multi-Agent System for Coordinated Responsive Observations (MACRO)

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1. Introduction

This paper presents the position of the developers of the "Multi-Agent System for Coordinated Responsive Observations (MACRO)" vis-à-vis its ability to provide smart sensing in the context of a sensor web. We discuss here, our understanding of the sensor web as the observational component of a larger system (as described in the "Advanced Weather Prediction Technologies: Two way Interactive Sensor Web & Modeling System Phase II Vision Architecture Study" report) and those characteristics that motivate the design of and functionality provided by MACRO.

2. What is a Sensor Web?

The NRA defined the sensor web to be:

- a system composed of multiple platforms interconnected by the communication network for the purpose of performing specific observations and processing data required to support specific science goals. It is a networked set of instruments and analysis platforms sharing information in which sensor behavior is modified based on that shared information and the specific science goals.

In our view this definition is sound and a good starting point with the understanding that the instruments and analysis platforms are globally distributed and consist of interconnected space (including deep space), airborne, oceanic, and terrestrial assets. The actual boundary between "instruments" and "analysis platforms" must necessarily be blurred. The definition of an instrument should be expanded to suggest that in many cases they will be capable of performing real-time processing and analysis - either autonomously or by external direction – leading to adaptive behaviors in order to meet defined observation objectives. This may suggest the following as a revised definition:

- a system composed of multiple, globally *distributed heterogeneous nodes* interconnected by *a* communication network for the purpose of performing specific *real-time* observations and data processing required to support specific science *and policy* goals. It is a networked set of instruments and analysis platforms sharing information in which *system* behavior *can be autonomously* modified based on that shared information and specific *user defined* goals.

3. Distinguishing Features of a Sensor Web

Liang et al[1] have described well some of the distinguishing features of such a networked system that we consider salient and expand upon:

Interoperability – is essential given the heterogeneous nature of the constituents of a sensor web. In our case, we pay particular heed to this important aspect through the use of both mature and emerging terrestrial standards as a foundation of the infrastructure e.g.

[1] Liang, Tao, Croitoru, "SENSOR WEB AND GEOSWIFT - AN OPEN GEOSPATIAL SENSING SERVICE"

the Object Management Group's (OMG) CORBA, Lightweight CORBA Component Model (CCM) and Deployment & Configuration (D&C) Specification. We will further augment our system through the use of SensorML and tailor/adapt standards required for the unique operational requirements of the sensor web e.g. reduced footprint and federated implementations of the CORBA Services e.g. Trading (Yellow Pages) and Notification (Publish/Subscribe) Services. The OMG standards address the lower level hardware and communication interoperability of heterogeneous distributed systems and SensorML that of data access and processing.

Scalability – is a significant factor since the sensor web will evolve and grow via the accretion of new platforms, instruments, and other hardware components over a time span of decades. This naturally dictates that the underlying technologies allow easy insertion and integration within the existing structure. From our perspective however, we must be cognizant of scalability in terms of resource utilization as the number of interacting agents increases to levels not routinely seen in deployed applications today, and that are amenable to adaptive organizational structures and coordination policies[2] in order to provide the required functionality using limited computational resources. For example, results such as that of Nwana et al.[3] - whose architecture was very similar to our proposed MACRO system – found that system performance degraded exponentially as the number of agents and task loads increased and then failed prematurely. However, it is encouraging to note that the authors attribute this premature failure to the inherent limitations of their underlying implementation technology viz. memory limitations of the JAVA virtual machine. This is in contrast to our use of C++ which does not suffer the same limitations having evolved into the de facto standard (due to its maturity compared to Real-Time JAVA) for real-time systems allowing for finer grained control of computational resources. RACE and the OMG CCM and D&C Specifications will continue to be key building blocks in addressing the demands of scalability of a system such as the sensor web.

Intelligence – includes aspects of cognition that encompass the ability of the components to autonomously carry out tasks such as data collection, analysis, and communication. Again, it is our position that given the complexity of a sensor web, coupled with the recognition that software will be critical in achieving the objective of smart sensing, that agent technology is an appropriate software engineering mechanism for providing the autonomy envisioned for a fully functional sensor web. However, with proposals of Multi-Agent Systems (MAS), developed by disparate groups, a new concern related to interoperability arises – that of a standard ontology for communication between Agents. Researchers of agent technology propose that an essential characteristic of an Agent is an ability to communicate via an Agent Communication Language (ACL). Nwana[4] has rightly pointed out (and it remains true today) that although the Foundation for Intelligent

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[2] Philip Turner, Nicholas Jennings, "Improving the Scalability of Multi-Agent Systems", Proc. 1st International Workshop on Infrastructure for Scalable Multi-Agent Systems, 2000. http://eprints.ecs.soton.ac.uk/6035/01/Improving_Scalability_of_MAS_PJTurner_NRJennings_2000.pdf
[3] LC Lee, HS Nwana, DT Ndumu, P De Wilde, "The Stability, Scalability and Performance of Multi-Agent Systems", BT Technology Journal Vol 16 No 3, 3 July 1998
[4] Nwana H, Ndumu D, "A Perspective on Software Agents Research", http://agents.umbc.edu/introduction/hn-dn-ker99.html

Physical Agents (FIPA) has made significant strides in defining ACLs, little has been done to resolve the ontology problem. Developing a standardized domain ontology is an issue that the developers of the Sensor Web technologies must address. SensorML although a logical first step for establishing such an ontology, will either need to be extended or a new effort – under AIST auspices - put into motion with the specifics of ACLs taken into consideration.

4. Other Considerations/Needs

Verification of technologies that provide smart sensing implies that developers have the requisite understanding of the operation of the sensor web and that of the interfacing entities. We will need to tap into the knowledge reserves of domain experts in order to develop scenarios that will guide the detailed design and implementation of the system, the development of simulations and associated tools, and ultimately test cases that will exercise the constituent functionalities to the maximum extent possible.