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OGC®
Fusion Standards Study, Phase 2 Engineering Report

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Preface

Making new connections in existing data is a powerful method to gain understanding of the world. Such fusion of data is not a new topic but new technology provides opportunities to enhance this ubiquitous process. Data fusion in distributed information environments with interoperability based on open standards is radically changing the classical domains of data fusion while inventing entirely new ways to discern relationships in data with little structure. Associations based on locations and times are of the most primary type.

This Engineering Report summarizes two phases of the Open Geospatial Consortium (OGC®) Fusion Standards study and of the fusion prototypes developed during the OWS-7 Testbed which occurred between the two study phases. Recommendations from the first phase of the study were implemented in OWS-7. Based upon the results of OWS-7, responses to two Requests for Information and a multi-day workshop, this report provides a cumulative set of recommendations for advancing fusion based on open standards.

This Study was based on requirements and contributions from OGC Member organizations – in particular the National Geospatial-intelligence Agency.

In the context of this study, Data Fusion is defined as:

> *"the act or process of combining or associating data or information regarding one or more entities considered in an explicit or implicit knowledge framework to improve one's capability (or provide a new capability) for detection, identification, or characterization of that entity".*

Three categories were used to organize this study: Observation (sensor) fusion, Object/Feature fusion, and Decision fusion. The study considered classical fusion as exemplified by the JDL and OODA models as well as how fusion is achieved by new technology such as web-based mash-ups and mobile Internet. The study considers both OGC standards – such as the OGC Web Processing Service (WPS) – as well open standards from other standards organizations. These technologies and standards aid in bringing structure to unstructured data as well as enabling a major new thrust in Decision Fusion.

This study addressed many challenging issues with a potentially enormous scope. The recommendations summarized in Section 7, identify future work, which in OGC means both specifications and prototyping. Elements of this study will be implemented in future OWS Testbeds. If your organization has an interest in data fusion, you are encouraged to contact OGC and join this association based on open standards.

Contents

Page

Figures

Page

Tables

Page

OGC® Fusion Standards Study, Phase 2 Engineering Report

1 Introduction

1.1 Scope

This OGC Engineering Report (ER) provides discussions and recommendations for data fusion, with a focus on geospatial information. In this ER, fusion is discussed in three categories: observation (sensor) fusion, object/feature fusion, and decision fusion. Recommendations in this ER will be considered in the planning of future activities including OWS Testbeds.

The OGC Interoperability Program utilizes a multi-step methodology in defining an interoperability initiative. Part one of the methodology is Concept Development which may use an RFI to gain better understanding of the current state of a given technology thrust and discover stakeholder insights about the architecture(s) to be used in subsequent testbeds. Subsequent steps of the methodology include development of recommendations from the concept development study.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. The Open Geospatial Consortium Inc. shall not be held responsible for identifying any or all such patent rights.

Recipients of this document are requested to submit, with their comments, notification of any relevant patent claims or other intellectual property rights of which they may be aware that might be infringed by any implementation of the standard set forth in this document, and to provide supporting documentation.

1.2 The Open Geospatial Consortium

The Open Geospatial Consortium (OGC) is an international not for profit voluntary industry consensus standards organization that provides a forum and proven processes for the collaborative development of free and publicly available interface specifications (open standards). These open standards enable easier access to and use of geospatial information and improved interoperability of geospatial technologies (across any device, platform, system, network or enterprise) to meet the needs of the global community. OGC open standards have been implemented broadly in the marketplace and are helping to foster distributed and component technology solutions that geo-enable web, wireless, and location based services as well as broader government and business IT enterprises worldwide.

To accomplish the mission of the Consortium, OGC conducts three programs:

- OGC’s Specification Program facilitates formal consensus-based committees, working groups and special interest groups that establish a forum for OGC’s industry, academic/research and user community members to collaboratively identify, prioritize and advance solutions to meet standards needs of the global community.

- OGC's Interoperability Program promotes rapid prototyping, testing and validation of emerging standards through fast paced testbeds, experiments, pilot initiatives and related feasibility studies.
- OGC's Outreach and Community Adoption Program conducts programs (training, articles in publications, workshops, conferences, etc) to promote awareness and implementation of OGC standards across the global community.

This ER was developed as part of the OWS-7 Concept Development initiative that is an element of the OGC Interoperability Program. The initiative was based upon interest and contributions from several OGC Member organizations, including, the National Geospatial-intelligence Agency (NGA) and Lockheed Martin.

1.3 Document contributor contact points

The contents of this Engineering Report are based on responses to Requests for Information, OWS-7 testbed and a multi-day workshop as described in Section 5.3. The developers of this document are extremely grateful for this base material. All questions regarding the specific content of this document should be directed to the editor and contributors listed in this table:

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1.4 Revision history

Date	Release	Editor	Primary clauses modified	Description
2010-09-26	0.1	G. Percivall	All new	Initial Draft
2010-10-29	0.2	G. Percivall	Modifications throughout	Final Draft after a Webex discussion to review Initial Draft.
2010-11-11	0.3	G. Percivall	Slight edits	Posted for TC consideration to be made public

1.5 Future work

Recommendations contained in this ER are under consideration for implementation in the OWS-8 Testbed. Updates of the ER based on any implementation of the recommendations will be considered for future versions of the ER.

1.6 Intellectual Property Foreword

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. The Open Geospatial Consortium Inc. shall not be held responsible for identifying any or all such patent rights.

In particular there is a known patent for one type of index for use with the DGGS discussed in Section 9.3.4.

Recipients of this document are requested to submit, with their comments, notification of any relevant patent claims or other intellectual property rights of which they may be aware that might be infringed by any implementation of the standard set forth in this document, and to provide supporting documentation.

2 References

The following documents provide general reference for the topics of the Fusion Standards Study. A Bibliography is provided at the end of the ER for particular references. Any reference for an OGC document can be found on the OGC web site.

OGC Fusion Standards Study Engineering Report, (Phase 1 ER), 2010-03-21, OGC Document 09-138, Version 0.3, http://portal.opengeospatial.org/files/?artifact_id=36177

Summary of the OGC Web Services, Phase 7 (OWS-7) Interoperability Testbed, 2010-09-17, OGC Document, 10-094, Version 1.0.

OGC Request for Information (RFI) for Fusion Standards Study, (Phase 2 RFI), 2010-04-21, http://www.opengeospatial.org/standards/requests/67

OGC Standards and Specifications, http://www.opengeospatial.org/standards/

OGC Reference Model, http://www.opengeospatial.org/standards/orm

3 Terms and definitions

For the purposes of this report, the following terms and definitions apply.

3.1
feature
representation of some real world object or phenomenon.

image_feature
some region in an image of interest. Typically, an image_feature is a distinguished region in an image such as a bright spot or stroke.

3.2
observation
model of the act of observing. A **feature** may be the target of an observation. (See GML and O&M). Observation has properties including result (of the observing) such as an image or sensor data value, time (of the observing) and location (of the observer or sensor).

3.3
decision
a choice between several alternative courses of risky or uncertain action. [Das, 2008]

3.4
data fusion
the act or process of combining or associating data or information regarding one or more entities considered in an explicit or implicit knowledge framework to improve one's

capability (or provide a new capability) for detection, identification, or characterization of that entity [OGC, 2009]

Note: A fundamental notion in any type of data fusion is the construction of associations between one or more data elements.

3.5

observation fusion

data fusion where the data elements being associated are **observations**.

Note: Sensor Fusion, Observation Fusion, Sensor/Observation Fusion are used synonymously in this ER.

Note: Fusion of two observations may result in the creation of an observation, or a feature.

3.6

feature fusion

data fusion where the data elements being associated are **features**.

3.7

decision fusion

data Fusion where the data elements being associated are **decisions**.

3.8

event

action that occurs at an instant or over an interval of time [ISO 19136]

3.9

complex event

event that contains information derived by processing the information of one or more other events

3.10

incident

declaration/classification of a type of **event –** e.g. fire, explosion, flood etc.

3.11

situation

state of an **incident** or **incidents**.

4 Conventions

4.1 Abbreviated terms

The abbreviated terms clause gives a list of the abbreviated terms necessary for understanding this document.

AAF	Advanced Authoring Format
ADSD	Authoritative Data Source Directory
CAP	Common Alerting Protocol
CITE	Compliance and Interoperability Test and Evaluation
CMAS	Commercial Mobile Alert Service
COP	Common Operating Picture
CI	Counterintelligence
CSM	Community Sensor Model
CSW	Catalog Services for the Web
DDMS	Department of Defense Discovery Metadata
DGGS	Discrete Global Grid System

DHS	Department of Homeland Security (US)
DIC	Emergency Interoperability Consortium
DoJ	Department of Justice (US)
ebRIM	ebXML registry information model (OASIS)
EDXL	Emergency Data Exchange Language
EML	Event Pattern Markup Language
EMS	Emergency Medical Services
ER	Engineering Report
FDF	Feature and Decision Fusion (OWS Testbed)
FEMA	Federal Emergency Management Services (US)
FGDC	Federal Geographic Data Committee (US)
FSA	Feature and Statistical Analysis
GeoDRM	Geospatial Digital Rights Management
GEOINT	Geospatial Intelligence
GeoXACML	Geospatial eXtensible Access Control Markup Language
GIS	Geographic Information System
GML	Geography Markup Language
GMTIF	Ground Moving Target Indicator Format (NATO)
HDF	Hierarchical Data Format
HUMINT	Human intelligence
IC	Intelligence Community
IMINT	Imagery Intelligence
IPAWS	Integrated Public Alerting and Warning System (FEMA)
ISE	Information Sharing Environment
ISEA3H	Icosahedral Snyder Equal Area aperture 3 Hexagon Grid (DGGS)
JDL	Joint Directors of Laboratories
JTS	Georeferenced Table Joining Service Implementation Standard
KML	(was Keyhole Markup Language, now just KML)
LAS	(LASer Encoding specification from ASPRS)
LIDAR	Light Detection and Ranging
MASAS	Multi-Agency Situational Awareness System (Canada)
MASINT	Measurement and Signature Intelligence
METS	Metadata Extraction and Tagging Service
MISB	Motion Imagery Standards Board (US DoD)
NAS	NGA Application Schema
NetCDF	Network Common Data Format
NGA	National Geospatial-intelligence Agency
NIEM	National Information Exchange Model
NSI	Nationwide SAR Initiative
O&M	Observations and Measurements
ODNI	Office of the Director of National Intelligence (US)
OGC	The Open Geospatial Consortium Inc.
OODA	Observe, Orient, Decide, and Act
OpenLS	Open Location Services
OPIR	Overhead Persistent Infrared
OSINT	Open source intelligence
OSM	Open Street Map

OWL	Web Ontology Language
OWS	OGC Web Services
PAN	Personal area network
PDA	Personal data assistant
PIDF-LO	Presence Information Data Format - Location Object (IETF)
RDF	Resource Description Framework
REST	Representational State Transfer
RFI	Request For Information
SAS	Sensor Alert Service
SDI	Spatial Data Infrastructure
SE	Symbology Encoding
SensorML	Sensor Model Language
SFE	Sensor Fusion Enablement (OWS Testbeds)
SIGINT	Signals Intelligence
SLD	Style Layer Descriptor
SNS	Social Networking Services
SOAP	(was Simple Object Access Protocol, now just SOAP)
SOS	Sensor Observation Service
SPS	Sensor Planning Service
SWE	Sensor Web Enablement
TECHINT	Technical intelligence
TQAS	Topology Quality Assessment Service
UnCertML	Uncertainty Markup Language
W3C	World Wide Web Consortium
W3DS	Web 3-D Services
WCS	Web Coverage Service
WCPS	Web Coverage Processing Service
WFS	Web Feature Service
WMS	Web Map Service
WNS	Web Notification Service
WPS	Web Processing Service
XMPP	Extensible Messaging and Presence Protocol

5 Fusion Standards Study

5.1 Objectives of the Study - Standards Based Fusion

Fusion Standards Goal: The sponsor's goal for the fusion standards study is to define and develop fusion standards to give analysts an environment where they can use interoperable tools to analyze, process and exploit two or more different types of data or products from the same or multiple sensors and databases utilizing just one system.

Fusion Objectives from the NGA InnoVision R&D Portfolio: Developing new or exploiting current capabilities for fusing information from multiple sensors, from multiple sources, and from multiple INTs in ways that dramatically improve the ability to detect, indentify, locate, and track objects. Research addresses fusing information from different sensors of the same modality, fusing information from IMINT sensors of different modalities (e.g. fusing LIDAR, hyperspectral, and OPIR), fusing information from different INTs (e.g. fusing IMINT and SIGINT), fusing disparate GEOINT data types, developing new ways to reason and make decisions from fused information, and providing fusion-based solutions to hard problems in a net-centric environment. The research also addresses measurements and databases for fused and composite signatures of targets of interest, conflation of multi-sensor, multi-modality data, and development of automated fusion exploitation algorithms for hard problems.

This study considers information technology standards – for data and services – supporting situations characterized by information from multi-sources of intelligence; some highly structured, others highly unstructured and open; where the situations include the need for analysis and decision in an ambiguous and possibly urgent environment based on partially complete assessment of the situation.

Previous studies of fusion process have identified a need for standards:

> "Developing a system that utilizes existing or developmental data fusion technology requires a standard method for specifying data fusion processing and control functions, interfaces, and associated data bases. The lack of common engineering standards for data fusion systems has been a major impediment to integration and re-use of available technology." [Steinberg, Bowman, & White, 1999][1]

The OGC Reference Model provides a discussion of the benefits of open standards along with several examples. [OGC, 2008]

5.2 Standards Based Fusion

Fusion is not a new topic. Many of the fusion processes described in this Engineering Report can be achieved in closed architectures with existing single provider software and hardware solutions. The objective addressed by this Engineering Report is to move those capabilities into a distributed architecture based upon open standards including standards for security, authorization, and rights management. The objective is to move from the "As-Is" state to the "Target" state:

[1] References are listed in the bibliography at the end of this document

<u>As-Is State:</u> Lack of identified and adopted standards results in multiple islands of data and stovepipe applications and services that are difficult to automate and scale for large data volumes and challenging analytical problems.

<u>Target State:</u> Standards-based data, applications and services enable an automated and interoperable fusion environment supporting secure sharing of data and transparent reuse of “pluggable” services for handling large data volumes and unanticipated analytical challenges.

Establishing a framework of open standards for data fusion environments will enable functional and programmatic developments for fusion beyond the current state of data fusion. Functional expansion will include fusion in manual and semi-automated multi-INT visualization and analysis as a preferred practice among analysts. Open standards will enable multiple fusion R&D projects with diverse technical approaches to collaborate. R&D prototypes can be enhanced for improve operational capability including improved access to data, integration of diverse inputs and value-added applications.

As described in The Importance of Going Open – an OGC White Paper – non-interoperability impedes the sharing of data and the sharing of computing resources, causing organizations to spend much more than necessary on geospatial information technology development. For OGC, “Open” Standard means that the document is freely and publicly available in a non-discriminatory fashion with no license fee, vendor and data neutral, and agreed to by a formal consensus process.

Some elements of the desired open standards-based fusion framework are pervasive now. The OGC Web Map Service (WMS) enables fusion of maps. WMS allows for maps as pictorial layers from different sources to be geographically-overlaid to create a composite map suitable to the user’s need (Figure 1).

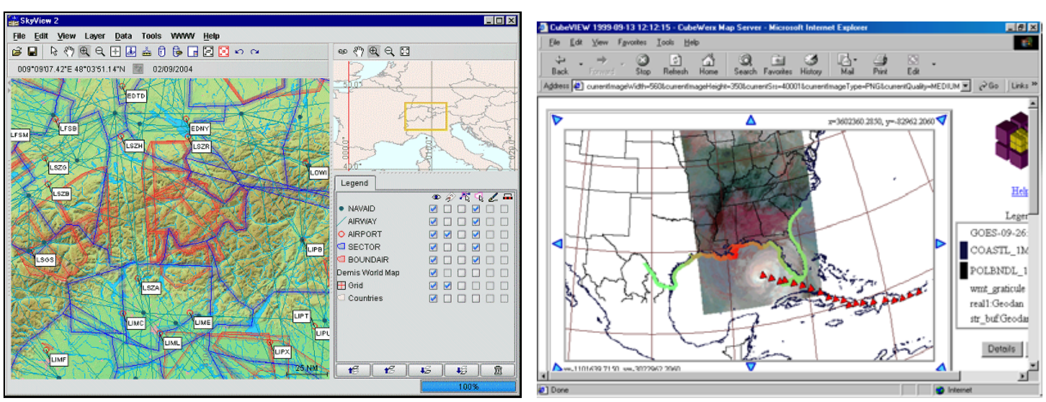

Figure 1 - Examples of Fusion based on OGC WMS standard

Further development of the open-standards fusion framework is needed and is defined in the remainder of this ER. The results will include:

- Rapidly deployable interoperable tools to analyze, process and exploit two or more different types of data or products from the same or multiple sensors
- Develop new or further exploiting current capabilities for fusing information from, multiple sensors, multiple sources, and multiple INTs in ways that dramatically improve the ability to detect, identify, locate, and track objects.

5.3 Phases of the Study

The OGC Fusion Standards Study was conducted in two phases that were linked with the OWS-7 and OWS-8 Testbeds:

- Phase 1 of the Study began with public announcement of a Request for Information (RFI-1). Ten organizations responded to RFI-1. An Engineering Report based on the RFI-1 responses was publically issued. [OGC, 2009]
- OWS-7 Testbed took up several of the recommendations from the Phase 1 Study ER (ER-1). The OWS-7 Testbed was conducted in 2010 and produced implementations, demonstrations and Engineering Reports. OWS-7 focused on recommendations. OWS-7 results are summarized in this ER for Phase 2 study (ER-2) in particular regarding observation fusion and feature fusion.
- Phase 2 of the Study included an RFI for Decision Fusion, Responses to the RFI, a two-day workshop and this ER. The workshop was - hosted by Intergraph Corporation – was held on August 10 and 11, 2010.
- The OWS-8 Testbed is being planned concurrently with the development of this ER-2. The Recommendations contained in this ER-2 are being considered for implementation in OWS-8.

Twenty-one organizations participated in the Fusion Standards Study (Table 1). Participation included responding to a Request for Information (RFI-1, RFI-2), contributing to an Engineering Report (ER-1, ER-2), participating in the Workshop in Phase 2, being a member of the OGC interoperability team for the study (IP Team) and sponsoring the study (Sponsor)

Table 1 – Organizations participating in Fusion Standards Study

Organization	Participation in Fusion Study
Aston University	RFI-1
BAE Systems	OGC IP Team, ER-1
Botts Innovative Research	OGC IP Team, ER-1
Envitia	RFI-1, Workshop
Evolution Technology	RFI-2, Workshop, ER-2
FortiusOne	RFI-1, RFI-2, Workshop
Fraunhofer IITB	RFI-1
Galdos	RFI-1, RFI-2, Workshop, ER-2
Intelligent Automation	RFI-1
Image Matters	OGC IP Team, ER-1
Intergraph	RFI-1, RFI-2, Workshop Host
Jacobs University	RFI-2, Workshop, ER-2
Lockheed Martin	OGC IP Team, ER-1,Workshop
Luciad	RFI-1
MISB	Workshop
Northrop Grumman	RFI-1
NGA	Sponsor, Workshop
NR Canada - GeoConnections	RFI-2, Workshop
OGC Staff	All elements.
PYXIS	RFI-1, RFI-2, Workshop, ER-2
Raytheon	RFI-2, Workshop

6 Definition and Categories of Fusion

Data Fusion as defined for this study is:

> *"Fusion is the act or process of combining or associating data or information regarding one or more entities considered in an explicit or implicit knowledge framework to improve one's capability (or provide a new capability) for detection, identification, or characterization of that entity"* [OGC, 2009].

Three categories of data fusion (Figure 2) were used to organize the study:
1) Observation (sensor) Fusion,
2) Object/Feature Fusion, and
3) Decision Fusion.

A fundamental notion in any type of data fusion is the construction of associations between one or more data elements. In many cases this association may also involve additional processing and abstraction and result in a new type of data element. This notion leads to categories of data fusion based on the type of the data elements being associated: fusion of observations, fusion of features/objects, and fusion of decisions.

Typically "sensor fusion" has been used to label the fusion of observations. Observation fusion is more accurate and is the preferred term going forward. Object/Feature Fusion is more problematic as the two terms have different meanings in the historically separate domains of image processing and GIS.

Multiple organizations and authors have offered categorization schemes for fusion. The three categories used in this ER have been found in publications extending back to 1974 [Wald, 1998]. For example these fusion categories was used in [Dasarathy, 1994]. Other approaches to fusion categories – in particular the JDL approach – are discussed later in this document.

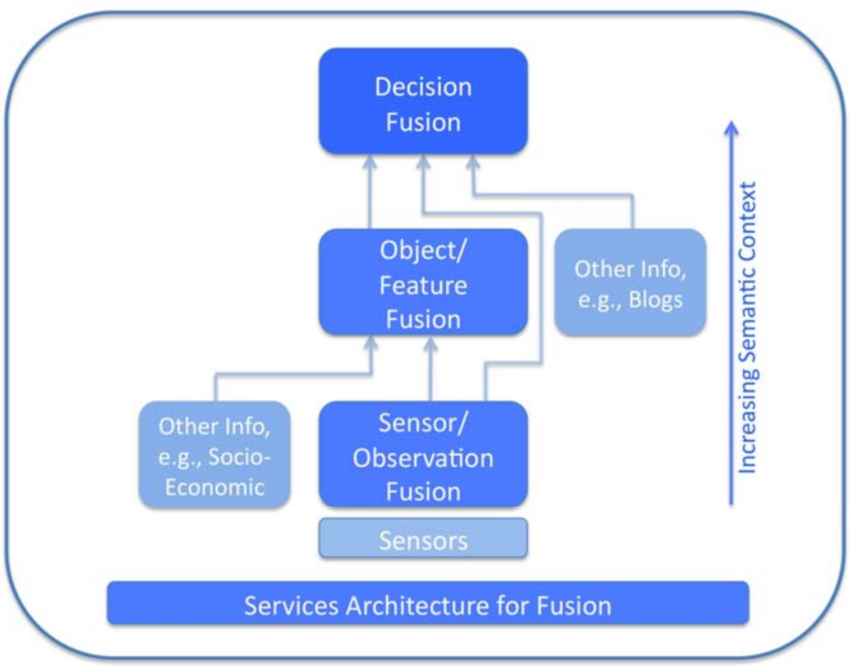

Figure 2 – Fusion Categories

Definitions for the three categories of Fusion used in this Engineering Report are:

- Observation (sensor) Fusion: Fusion processes involve merging of multiple sensor measurements of the same phenomena (i.e., events of feature of interest) into a combined observation; and analysis of the measurement signature. Fusion ranging from sensor measurements of various observable properties to well characterized observations including uncertainties.
- Object/Feature Fusion: includes processing of observations into higher order semantic features and feature processing. Object/feature fusion improves understanding of the operational situation and assessment of potential threats and impacts to identify, classify, associate and aggregate entities of interest. Object/feature fusion processes include generalization and conflation of features.
- Decision fusion: the act or process of supporting a human's ability to make a decision by providing an environment of interoperable network services for situation assessment, impact assessment and decision support, using information from multiple sensors, processed information, e.g., multi-INT sources.

These categories of fusion are useful but are not completely distinct. Assigning a fusion process to a specific category is done as a convenience for explanation in this Engineering Report and should not be considered a normative classification scheme.

7 Summary of Recommendations

7.1 Basis for Recommendations

The summary of recommendations presented here is drawn from the other sections of the ER. The basis for the recommendations is contained in the sections for each fusion category. Several of the recommendations are annotated with "(Phase 1)" indicating that the recommendation was made in Phase 1 of the Fusion Study and have yet to be acted upon. Many of the Phase 1 recommendations were investigated in the OWS-7 Testbed and do not appear here as they were in Phase 1.

7.2 Decision Fusion

- 8.5.1 Develop Decisions as First Class Objects in an Information Model
- 8.5.2 Develop a design pattern relating events and decisions
- 8.5.3 Standardize methods for Information Sharing between clients.
- 8.5.4 Promote diversity of interoperable Fusion Analyst Components
- 8.5.5 Develop registry for Decision Fusion, e.g., using ebRIM.
- 8.5.6 Develop open standards for visualization relevant to fusion
- 8.5.7 "See and Talk" collaboration with common geographic view
- 8.5.8 Coordination through social networks
- 8.5.9 Conduct a Decision Fusion initiative: Decision Fusion Pilot

7.3 Object/Feature Fusion

- 9.4.1 Develop WPS Profiles for Geoprocessing Fusion
- 9.4.2 Further develop rule-based geoprocessing to an OGC Best Practice
- 9.4.3 Develop approaches for fusing "unstructured" data
- 9.4.4 Registries for Object/Feature Fusion
- 9.4.5 Adding geographic structure with OGC Georeferenced TJS
- 9.4.6 Further develop Authoritative Data Source Directory
- 9.4.7 Apply the OGC standards to Political Geography
- 9.4.8 Continue to improve methods for GML schema handling
- 9.4.9 Review Discrete Global Grid Systems with OGC
- 9.4.10 Develop semantic data models supporting feature fusion (Phase 1)
- 9.4.11 Standardize metadata for provenance and uncertainty (Phase 1)

7.4 Observation (sensor) Fusion

- 10.4.1 Coverage fusion based on WCS 2.0, WCPS and GML.
- 10.4.2 Further develop Events in the OWS Architecture
- 10.4.3 Motion Imagery and location – coordinated with MISB
- 10.4.4 Apply SWE to Mobile Internet
- 10.4.5 Further develop Secure Sensor Web
- 10.4.6 Registries for Sensor/Observation Fusion
- 10.4.7 Online community sanctioned definitions for sensor terms (Phase 1)
- 10.4.8 Harmonization of the process of precise geolocation (Phase 1)
- 10.4.9 Characterizing and propagating uncertainty of measurements (Phase 1)
- 10.4.10 Increasing use of geometric and electromagnetic signatures (Phase 1)

8 Decision Fusion

8.1 Introduction

The definition of decision fusion used in this study is:

> *Decision fusion is the act or process of supporting a human's ability to make a decision by providing an environment of interoperable network services for situation assessment, impact assessment and decision support, using information from multiple sensors, processed information, e.g., multi-INT sources.*

Decision Fusion provides analysts an environment where they can – using a single client interface – access interoperable tools to review, process and exploit multiple types of data or products from multiple sensors and databases. Decision Fusion includes the use of information from multiple communities, e.g., multi-INT, in order to assess a situation, and to collaborate with a common operational picture. A more detailed description of the decision fusion process, e.g., JDL and OODA models, is provided in Section 8.3.1. This study also considered more recent advances such as social networking to support decision fusion. Though the focus of the study is on military intelligence ("INT"), decision fusion is relevant to business intelligence, urban planning, and many other domains.

Figure 3 shows an example of decision fusion that goes beyond current Web Mapping Tools to associate trends and causes from multiple sources. In an Afghanistan election attack scenario (Figure 3) a likely target for an attack against the Pashtun during the 2009 election would be in Jalalabad, a largely Pashtun area with strong ties to Karzai, and a target of recent IED. The largest polling station in the area is at Compano Mosq, with an estimated 13,700 voters. An attack here on election day could impact the outcome.

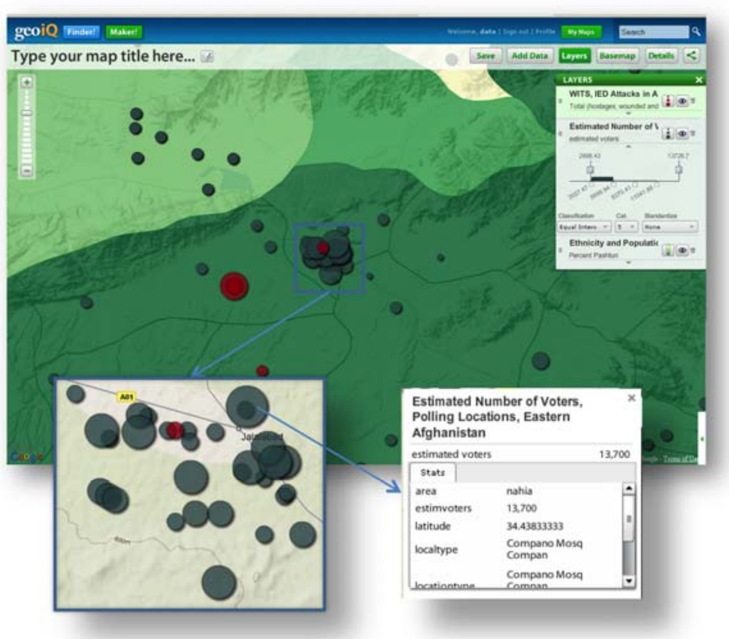

Figure 3 - Decision Fusion Example (Source: FortiusOne)

8.2 Enterprise Objectives for Decision Fusion

8.2.1 Decision Fusion Node

To structure the context for decision fusion, this study defines an “operations node conducting decision fusion”. External interfaces for a Decision Fusion Node are shown in Figure 4. Descriptions of each arrow on the context diagram are provided in Table 2.

The Decision Fusion Node defined in this study is a scalable concept ranging from a person with a mobile computer to a Fusion Center such as the centers identified in the US ODNI Analytic Transformation [ODNI, 2008] and the Information Sharing Environment (ISE) Fusion Centers as operated by the US Department of Homeland Security [DoJ Global, 2008].

The Decision Fusion Node described in this section is intended to apply to a wide variety of situations ranging from local to international operations; from civilian emergency response to military command and control. Implicit in the concept of the Decision Fusion Node is the collaboration with other nodes, e.g., distributed decision fusion.

Functions of a Decision Fusion Node are those steps necessary to perform a fusion process [DoJ Global, 2008], [ODNI, 2008], [Randol, 2009]:

1. **Information collection** and recognition of indicators and warnings
2. **Situation Assessment**: Processing and collation of information
3. **Impact Assessment and Decision**: Analysis and decision
4. **Information dissemination**: to associated nodes and to public networks
5. **Process Refinement**, including planning and requirements development

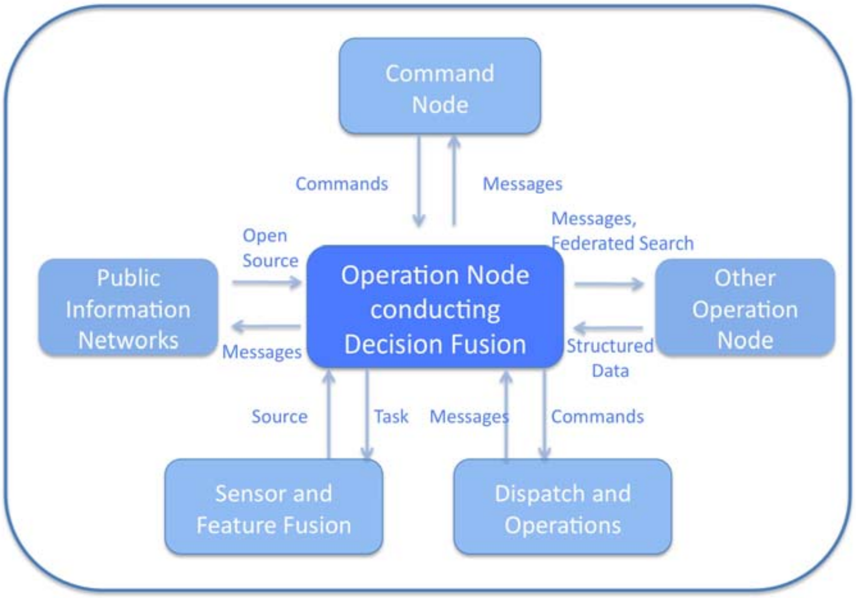

Figure 4 – Decision Fusion Node Context Diagram

Table 2 – Decision Fusion Node Information Flows

Information Flow	**Description of Information Flow in** Figure 4
Commands from Command Nodes	Structured information on which the Decision Fusion Node is to act.
Messages to Command Nodes	Structure information resulting from Fusion activities at the Decision Fusion Node
Open Source from Public Information Nodes	Collection of Unstructured Information by Decision Fusion Node from the open internet (or through a Open Source collection node)
Messages to Public Information Nodes	Structured messages, e.g., alerts, posted by the Decision Fusion Node to the public. Messages may be targeted to a specific public category, e.g., based on location.
Source from Sensor and Feature Fusion	Structured information resulting from fusion of sensor observations and object/feature processing (See Fusion Study Phase 1 ER)
Task to Sensor and Feature Fusion	Structured messages requesting observations or collection of information including request for fusion processing.
Commands to Dispatch and Operations	Structured information directing an activity to be conducted by Dispatch and Operations.
Messages from Dispatch and Operations	Structured information reporting on the status of activity by Dispatch and Operations.
Federated Search to Other Operations Nodes	Search requests to an operation node recognized by the Decision Fusion Node
Messages to Other Operations Nodes	Structured information transmitted to an operation node recognized by the Decision Fusion Node
Structured Data from Other Operations Nodes	Structured information received from an operation node recognized by the Decision Fusion Node

8.2.2 MASAS

The Multi-Agency Situational Awareness System (MASAS) initiative is a collaborative effort of Canadian emergency management agencies and content providers, co-led by GeoConnections and the Centre for Security Science, to develop a national capability for the exchange of geospatial emergency incident information. Based on open and interoperable standards, the system will combine information from multiple sources to support decision-making through improved situational awareness for participating organizations. An opportunity exists to study the required standards, both existing and potential, for decision fusion processes within MASAS. GeoConnections responded to the Fusion Study Phase 2 RFI with the MASAS architecture.

The MASAS Architecture was developed in response to requirements from the public safety and security community. It has been used to design and deploy component MASAS systems for Multi-Agency incident information sharing. The opportunity exists to expand MASAS to a number of other decision fusion applications such as the fusion of science-based emergency response information and cross-border information fusion. Additionally, the MASAS initiative could benefit from many of the study areas identified in the RFI-2 for fusion standards.

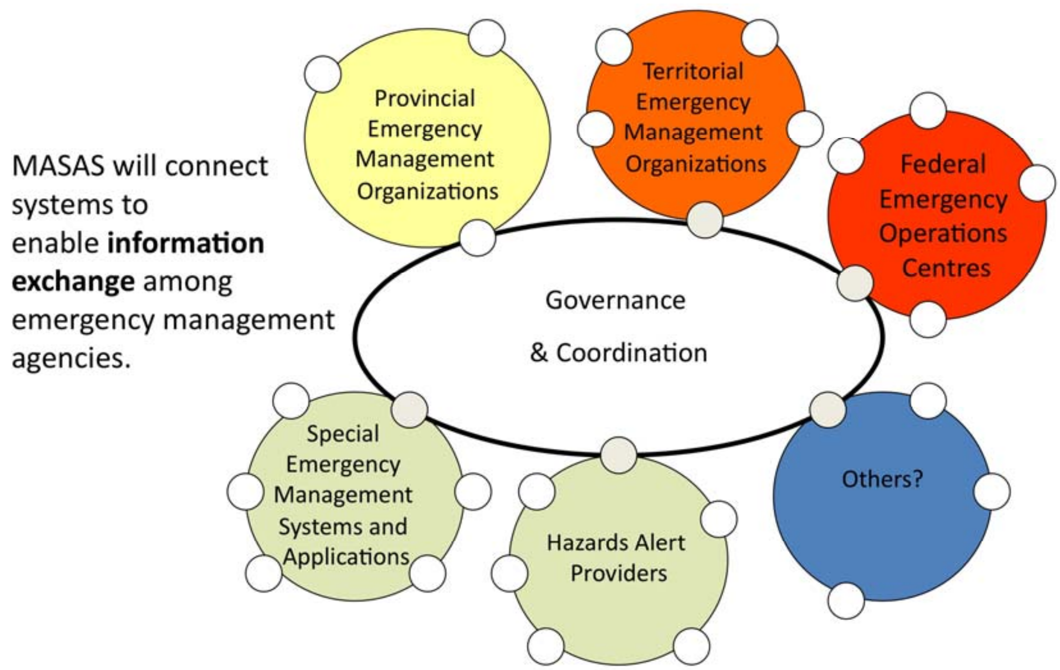

Figure 5 – Decision Fusion in a distributed environment (Source: NR Canada MASAS)

8.2.3 Integrated Public Alerting and Warning System (IPAWS)

IPAWS is designed to improve public safety through the rapid dissemination of emergency messages to as many people as possible over as many communications devices as possible. The US Department of Homeland Security FEMA is upgrading the alert and warning infrastructure so that no matter what the crisis, the public will receive life-saving information. In IPAWS, several project initiatives are using EDXL messaging technologies to enhance and expand the alerting capabilities available to emergency responders, incident managers, and public officials at all levels of government to inform and advise the public as shown in Figure 6.

- Common Alerting Protocol (CAP)
- EDXL Distribution Element (EDXL-DE)
- EDXL Hospital Availability Exchange (EDXL-HAVE)
- EDXL Resource Management (EDXL-RM)

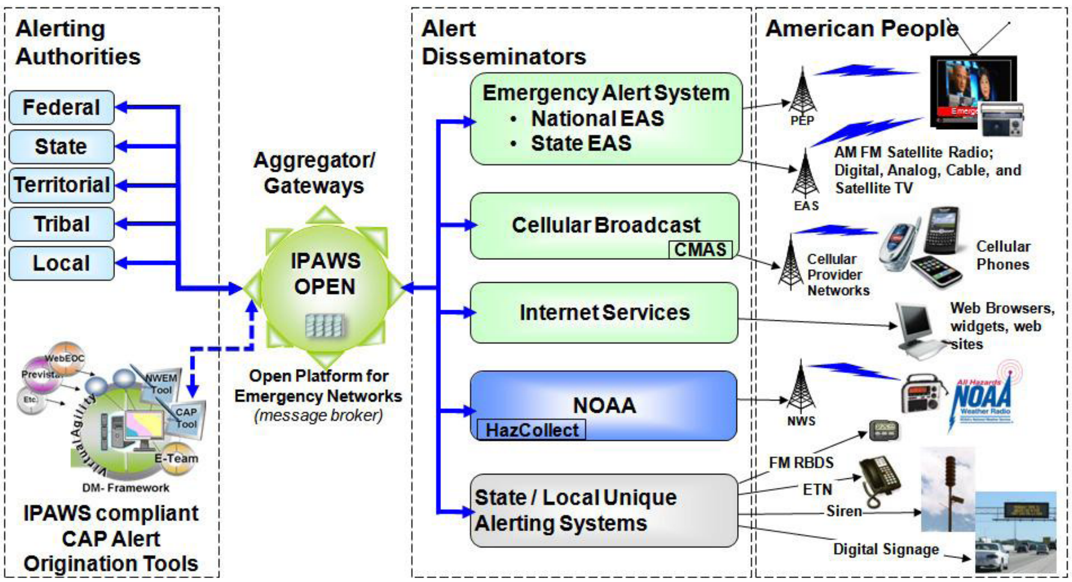

Figure 6 - IPAWS Architecture

8.2.4 Enterprise Scenarios

8.2.4.1 Scenario: Connecting the Dots

This scenario considers connecting information held by several Decision Fusion Nodes in the determination of a plan of attack by an individual or small group.

This scenario is motivated by the "Christmas Day Attack" of 2009 when a terrorist onboard a flight bound for Detroit attempted to ignite a bomb attached to his body. Lessons learned from the attack included [Travers, 2010]:

- This incident does not raise major information sharing issues. The key derogatory information was widely shared across the U.S. Counterterrorism Community. The "dots" simply were not connected.
- The U.S. Government needs to improve its overall ability to piece together partial, fragmentary information from multiple collectors. This requirement gets beyond watchlisting support, and is a very complicated challenge involving both numbers of analysts and the use of technology to correlate vast amounts of information housed in multiple agencies and systems.

This scenario also considers the Nationwide SAR Initiative (NSI) that is designed to increase the amount of information—the intelligence "dots"—that will flow from state, local, and tribal law enforcement agencies to the federal government. The goal of "connecting the dots" becomes more difficult when there is an increasingly large volume of "dots" to sift through and analyze. [Randol, 2009]

8.2.4.2 Scenario: Human presence detection through Multi-INT

Prior to committing personnel to investigate a building or suspicious site such as a cave, it is imperative to determine the importance and current danger of the site. This scenario aims to integrate information from multiple sources, i.e., multi-INT. The scenario will involve fusing information from sensors with cultural and human information about the area, and recent intelligence reports from human observers. [Thyagaraju Damarla, 2007], [ODNI, 2010]

This scenario will consider observing and characterizing the "human landscape" or "human terrain." The scenario will also include quantification of the uncertainty and provenance in the decision fusion.

8.2.4.3 Scenario: Disaster Management

Actors for a Disaster Management scenario would be located at multiple command centers, each operating with different jurisdictions and perspectives.

- National/Regional/Local Command Centers
- Analytical Staff in support of Decision Maker
- Analytical staff that make recommendations.
- "on the scene" (in theatre) field personnel.
- Consumers and Producers of information.

A concrete example is EMS professional on site of a disaster, e.g., a major flood. Flood is reported to local command center – need ingress/egress routes and support vehicles to respond. Analyst looks at this request and determines possible routes, available resources etc to respond. Analyst makes recommendation to Decision Maker who dispatches resources to site. Which resources to send and what routes taken? Are the resources sufficient? May have "patients" at site(s) – what medical care is needed?

8.3 Information for Decision Fusion

8.3.1 Fusion Process Models

8.3.1.1 JDL Fusion Model

The JDL Fusion Model has a rich history of discussion (see for example [Eloi Bosse, 2007]). A revision of the JDL Model by [Steinberg, Bowman, & White, 1999] depicts typical information flow across the data fusion "levels." JDL Level 0 and Level 1 correspond to the Sensor Fusion and Object/Feature Fusion. JDL Levels 2, 3, and 4 are relevant to Decision Fusion.

- **Situation Assessment** (Level 2): Perception of environmental elements within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. [Wikipedia, 2010]
- **Impact Assessment** (Level 3): process for considering the implications, for people and their environment, of proposed actions while there is still an

opportunity to modify (or, if appropriate, abandon) the proposals. It is applied at all levels of decision-making, from policies to specific projects. [IAIA, 2010]

- **Process Refinement** (an element of Resource Management) (Level 4): adaptive data acquisition and processing to support mission objectives. [Steinberg, Bowman, & White, 1999]

The terms Situation Awareness and Common Operating Picture (COP) are often conflated. Situation awareness is the combined product of perception, comprehension, and projection. COP is a combination of products of psyhcology, technology and integration processes. The conclusion of [Eloi Bosse, 2007] is that COP provides only a partial full situation awareness.

Processing of spatial, temporal, and semantic attributes of multi-source object metadata results in situation assessment. On the basis of a situation assessment an analysis of threats can be conducted. Solano and Tanik [Solano & Tanik, 2008] define an extension to the ISO 19115 metadata standard to capture the necessary metadata for a fusion framework which implements the Joint Directors of Laboratories (JDL) Data-fusion model.

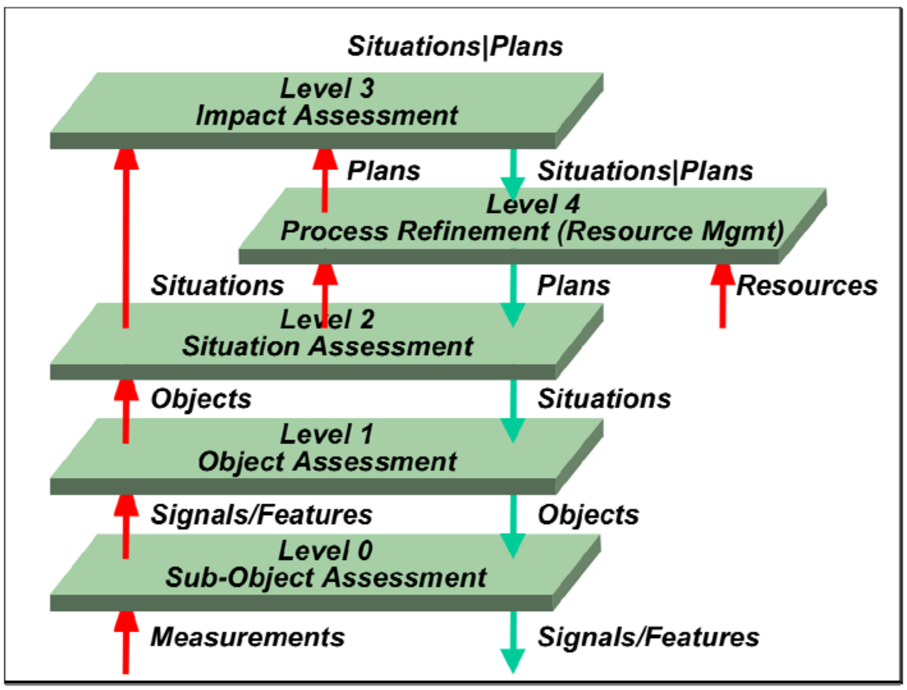

Figure 7 – Refined JDL Data Fusion Model

8.3.1.2 Decision Models

Once Situation Assessment and Impact Assessment are accomplished, an operations node is well poised to consider decision and action. Again there is a rich history of research on decision-making models (See for example [Das, 2008]).

Decision fusion can be seen as the top of the information pyramid both in terms of information consumption and in terms of generating requests for new information. As Galdos identified [OGC, 2009], "Decision making is about making choices amongst alternatives (decision tree). It should be noted, however, that the set of choices might be quite dynamic and evolve in the course of an event (i.e. driven by the evolution of the event), or in an event independent manner. Decision makers want to learn from past mistakes (and are often also liable for their actions) hence the ability to automatically maintain an audit trail of decisions and their connection to particular feature and sensor information is critical."

The OODA loop (for observe, orient, decide, and act) is a concept originally applied to the combat operations process, often at the strategic level in both the military operations. It is now also often applied to understand commercial operations and learning processes. The concept was developed by military strategist and USAF Colonel John Boyd. Any Internet search of Boyd and OODA will provide sources of all types on this topic. Figure 8 shows how current OGC standards support OODA. Observe and Orient are well supported by the current OGC standards baseline. Additional development and application of open standards is needed for Decide and Act, e.g., Decision Objects.

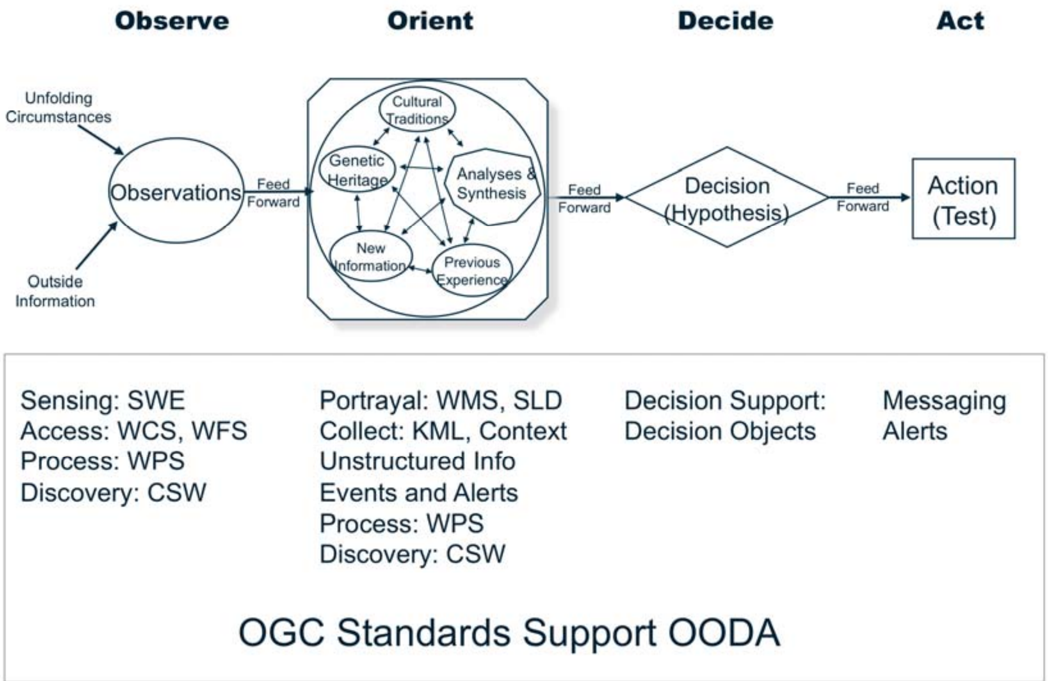

Figure 8 – OGC standards support of OODA

The OGC Fusion Study, Part 1 recommended that an information model be developed treating "Decision" as a first class object. The model needs to be done at abstract and implementation levels. The abstract model should define the attributes, operations and associations of a decision. For example a decision object should include an aggregation with decision trees, policies and audit trail. The decision object should include geospatial data and non-geospatial data. This abstract decision object should then be tested with real decisions from routine operational settings. Realizations of the decision should be made so that decision types can be used in registry and encodings defined for exchange.

8.3.1.3 Multi-INT information

Information available to an operations node is not just multi-source, but is from multiple intelligence collection types (multi-INT). Intelligence sources are people, documents, equipment, or technical sensors, and can be grouped according to intelligence disciplines (Table 3).

Table 3 – Multi-INT Sources [Joint Chiefs of Staff, 2007]

- Human intelligence (HUMINT);
- Geospatial intelligence (GEOINT), including Imagery Intelligence
- Signals intelligence (SIGINT);
- Measurement and signature intelligence (MASINT);
- Open-source intelligence (OSINT);
- Technical intelligence (TECHINT);
- Counterintelligence (CI).

Open source intelligence (OSINT) is a form of intelligence collection management that involves finding, selecting, and acquiring information from publicly available sources and analyzing it to produce actionable intelligence. In the intelligence community (IC), the term "open" refers to overt, publicly available sources (as opposed to covert or classified sources); it is not related to open-source software or public intelligence.

Examples of multi-INT for an urban situation are shown in Figure 9. [Marco A. Pravia, 2008]. Information elements are placed in the table according to generating source (header row) and classification between hard and soft information (below and above the diagonal, respectively).

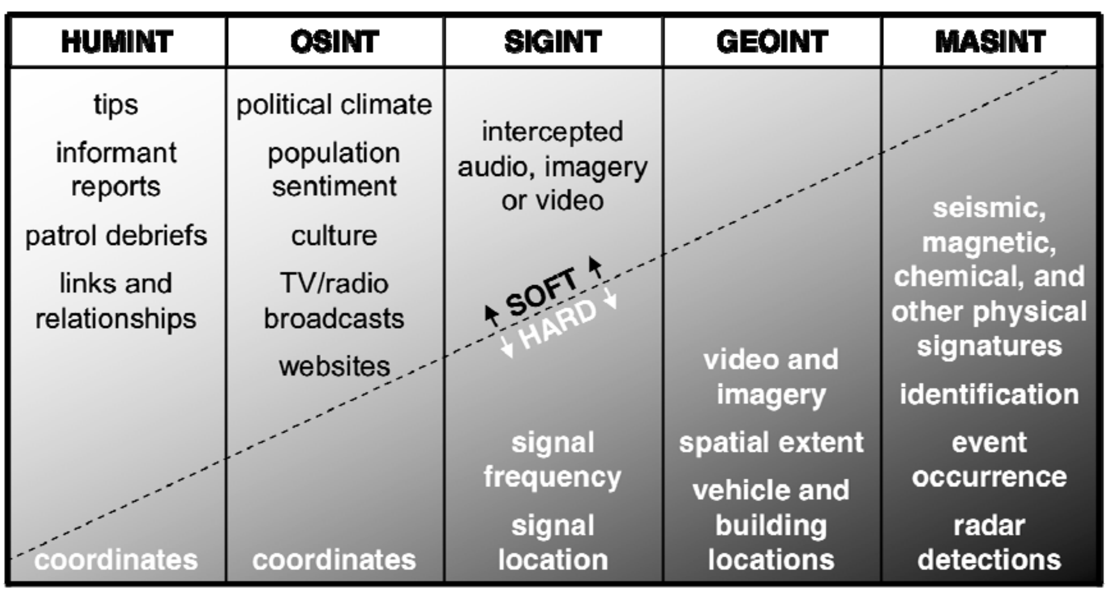

Figure 9 – Multi-INT examples for an urban situation

Consideration of multi-INT in fusion is a basis for two major trends data fusion related to “soft” fusion. [Hall, 2008]

- First, the entities that we are interested in are no longer exclusively physical and may include events, patterns and activities. We are becoming interested in the location, identity, and interactions of individuals and groups (social networks).
- The second major trend in information fusion is the emergence of two new categories of information that have previously been relatively neglected; human observations and web-based information. With the advent of ubiquitous cell phones, personal data devices (PDAs) and mobile computing devices (with associated GPS, image sensors and on-board computing), we can consider formal and informal “communities of observers” that provide information about an evolving situation. (See Section 10.3.6)

8.3.2 Structured Information

8.3.2.1 Overview

Having discussed several models for fusion, the information used in those models is now considered in two broad categories: structured information, and unstructured information. Here structured information is defined to conform to structures, e.g., standards, defined by a community of practice. The categories of this section are inspired by the intelligence communities listed in Table 3. Some of the material in this section applies to Feature Fusion, but is described a single time here in the Decision Fusion section.

An outcome of the Decision Fusion Workshop was that OGC should continue to apply those standards that have been previously developed to the Decision Fusion topics. Existing OGC standards for structured information include the OGC Abstract Specification with focus on the Topics of Features, Coverages, Observations, and Geometry.

A conclusion of the Decision Fusion Workshop is that additional development is to be done on standards for structured information that support Decision Fusion both internal to OGC and with other standards bodies. For example, further work is needed on methods for schema mapping, e.g., identification of rules for mappings, and an increase in the focus on handling of Associations as the identification of an association between entities is at the heart of fusion.

8.3.2.2 Decision Information Standards

Decision-making is a topic that reaches beyond geospatial information. Decision fusion should be based on standards for decisions that have a general perspective. More work is needed to identify standards in this area.

8.3.2.3 Geographic and Imagery Information Standards

Standards for geographic and imagery information directly relevant to decision include the following:

- OGC Geography Markup Language (GML) Implementation Specification
    - Also published as ISO 19136:2007 - Geography Markup Language

    - Multiple GML profiles and applications schemas have been defined.
- OGC CityGML Implementation Specification
- OGC GML Application Schema for Coverages 1.0 Interface Standard
- OGC Symbology Encoding (SE) Implementation Specification
- OGC Geospatial eXtensible Access Control Markup Language (GeoXACML) Implementation Specification
- OGC KML Implementation Specification
- OGC GeoPDF Encoding Best Practice
- OWS-5 GEOINT Structure Implementation Profile (GSIP) Schema Processing Engineering Report
- OWS-5 Data View Architecture Engineering Report
- OWS-6 Urban Topographic Data Store (UTDS) - CityGML Implementation Profile ER
- ISO 19109:2005 – Geographic Information – Rules for application schema
- ISO 19115:2003 – Geographic Information – Metadata
    - 19115-2:2009 – Geographic Information – Metadata - Part 2: Extensions for imagery and gridded data
    - ISO 19139:2007 – Geographic Information – Metadata - XML schema implementation
- 19153 – Geographic Information – Geospatial Digital Rights Management Reference Model (GeoDRM RM)
- NATO Ground Moving Target Indicator Format (GMTIF
- Imagery encoding specifications: NITF, GeoPDF, GeoTIFF, HDF, NetCDF, LAS, SensorML, SWE Common

8.3.2.4 Human Reported Information Standards

Standards for human reporting of information directly relevant to decision include the following:

- OASIS Emergency Data Exchange Language (EDXL), including CAP
- OGC Event Pattern Markup Language (EML)
- NATO STANAG 2022 "Intelligence Reports”
- ISE Suspicious Activity Reports (SAR) (US Government specification)
- National Information Exchange Model (NIEM) (US Government specification)
- Army SALUTE reporting guidelines, 301-371-1000 (SL1) - Report Intelligence Information Standards

8.3.2.5 Emergency Data eXchange Language (EDXL) Messaging Standards

EDXL is a suite of XML-based messaging standards that facilitate emergency information sharing between government entities and the full range of emergency-related organizations. EDXL standardizes messaging formats for communications between these parties. EDXL was developed as a royalty-free standard by the OASIS International Open Standards Consortium. EDXL standards support operations, logistics, planning and finance:

- EDXL Common Alerting Protocol (EDXL-CAP)

- EDXL Distribution Element (EDXL-DE)
- EDXL Hospital AVailability Exchange (EDXL-HAVE)
- EDXL Resource Message (EDXL-RM)
- EDXL Reference Information Model (EDXL-RIM)
- EDXL Situation Reporting (EDXL-SitRep)
- EDXL Tracking Emergency Patients (EDXL-TEP)
- OASIS GML profile. (Also known as OASIS "where")

The EDXL program is sponsored by the DHS Science & Technology Directorate, Office of Interoperability and Compatibility (OIC). Practitioner requirements and draft specifications are submitted in partnership with the Emergency Interoperability Consortium (EIC). Draft specifications emerging from this process are forwarded to the OASIS Emergency Management Technical Committee for consideration, vote and possible adoption as free, international, public XML-based messaging standards.

8.3.2.6 Signals intelligence standards

Standards for signals intelligence (SIGINT) directly relevant to decision include standards for alerts for tactically significant events and SIGINT identity information

8.3.2.7 Measurement and signature intelligence standards

Standards for measurement and signature intelligence information (MASINT) directly relevant to decision include standards for: alerts for tactically significant events and MASINT identity information

8.3.2.8 Political geography

The increasing interest in observing and characterizing the "human landscape" or "human terrain" using both conventional and emerging information sources motivated the assessment of technologies related to understanding and modeling the new domains. [InnoVision, 2009]

Standards are needed for sharing of information in these key sub-areas: (1) human landscape modeling technologies, (2) identifying and representing data imperfections and lineage, (3) modeling object data acquisition and management, (4) addressing moving objects – map merging and tracking, (5) understanding what data needs to be observed or collected, and (6) mapping observables to parameter needs of selected models.

8.3.3 Unstructured Information

8.3.3.1 Overview

In the world of information sharing there is much "unstructured data". Unstructured data is data for which there is no data model, or at least no data model that exposes any of the semantics of the data. An HTML document, for example, might have a well-defined structure, but this is no help in understanding the document, since the markup is only intended for visualization and browser interaction control. Sometimes much can be inferred, but in essence the HTML model for the document is not very helpful for understanding the content. The same can be said of other machine-readable but not machine understandable document formats such as PDF. Of course, what it means to understand a document may be very application related, so in some sense all data can be considered unstructured if used outside of its native application.

Since a great deal of information falls into this unstructured category there is interest in attaching new information to add structure or meaning to the content. Of course this is to be done where possible without changing the content itself. (This topic was discussed in the Phase 2 Workshop and reported in Section 9.3.1)

8.3.3.2 Open Source information

OSINT is based on publicly available information as well as other unclassified information that has limited public distribution or access. Examples of OSINT include on-line official and draft documents, published and unpublished reference materiel, academic research, databases, commercial and noncommercial websites, “chat rooms,” and web logs (“blogs”).

8.3.3.3 OpenSource.gov

One source of consolidated OSINT is OpenSource.gov that provides timely and tailored translations, reporting and analysis on foreign policy and national security issues from the OpenSourceCenter and its partners. Featured are reports and translations from thousands of publications, television and radio stations, and Internet sources around the world. Also among the site's holdings are a foreign video archive and fee-based commercial databases for which OSC has negotiated licenses. OSC's reach extends from hard-to-find local publications and video to some of the most renowned thinkers on national security issues inside and outside the US Government. Accounts are available to US Government employees and contractors.

8.3.3.4 Metadata Extraction and Tagging Service (METS)

The Metadata Extraction and Tagging Service (METS) is a Department of Defense Intelligence Information System (DoDIIS) Core Service that extracts information found within unstructured documents. This promotes integration with structured data and will significantly improve search, analysis, and knowledge discovery. METS automates the normalization of, and extraction of information from, text documents, making the content of the documents quickly available as XML and OWL (Web Ontology Language) / RDF (Resource Description Framework) for intelligence analysis.

GML in METS is a conversion of a very small piece of the GML XML spec. It lumps together some small ontologies recommended by the W3C. It was supplemented by a few additional GML concepts used by DoD Discovery Metadata Specification (DDMS).

8.3.4 Information Integration

8.3.4.1 Linking

In order to connect the dots, information elements must be linked which many times depends upon the information being tagged with attributes describing its semantics. OGC discussions have focused on the need to increase the use of linking standards such as xlink and 'URIReference'. [Cox, 2010]

OGC has developed draft proposed standards for linking unstructured information with geographic tags:

- Geolinked Data Access Service
- Georeferenced Table Joining Service (TJS) Implementation Standard

8.3.4.2 Tagging

Tagging of data from structured and unstructured sources is valuable towards integration of

- UCore
- Department of Defense Discovery Metadata (DDMS)
- Dublin Core

Tagging is done differently for hard versus soft sources. In hard fusion from a known sensor, tagging is often object attribution and feature characterization. While soft fusion must deal with increased uncertainty and provide basic context, e.g., location for hand-held photos, semantic labels for correlation, etc.

Geo-tagging is the process of attaching a location to an information element. There are multiple information structures for geo-tagging. Many of the geo-tags have been developed within specific communities.

- Standards developments for geo-tags
  - OGC OpenLS Point of Interest
  - IETF PIDF-LO
  - URISA/FGDC US Street Address Data Standard
  - ISO 19160, Addressing
  - W3C Point of Interest Working group (proposed)
- Formats
  - http://microformats.org/wiki/implementations
  - Open formats: KML, GPS (waypoints), GeoRSS/GeoJSON
  - Vendor formats: NAVTEQ, TomTom, TIGER
  - Nokia Landmarks Exchange Format (2005)
  - Yahoo: Where On Earth ID (WOEID).

8.3.4.3 Ontology Alignment

Current conceptual models for information fusion, including the JDL model do not consider the fact that their information sources are often based on different ontological bases. [Dorion, 2007] therefore suggests that the JDL model, which caters for space and time common referencing, be augmented with the notional aspect of common ontological alignment. Ontology alignment is the act of establishing a relation of correspondence between two or more symbols from distinct ontologies, for those symbols that denote concepts that are semantically identical, or similar.

Standards directly relevant to decision fusion for ontologies include:

- OWL
- RDF
- Advanced Authoring Format (AAF)

Understanding a timeline events can be critical to Situation Awareness. Advanced Authoring Format (AAF) can be used to place various information elements into a timeline. AAF was developed for the interchange of audio-visual material and associated metadata. While the original purpose of AAF is for video postproduction and authoring environment, AAF has been applied to fusion of multiple information sources regarding an actual timeline. [AMWA, 2010]

8.3.4.4 Uncertainty

Uncertainty propagation was a theme across all of the fusion categories discussed in the Phase 1 of Fusion Standards Study. Methods for propagating uncertainty into a decision framework are needed. Methods for presenting uncertain information in human-machine interface are needed. Communicating uncertain information to users is a non-trivial task and must build upon the results of on-going research. Development of this topic should begin with a "hard fusion" topic, i.e., a topic for which the uncertainty can be calculated from input uncertainty values.

- Uncertainty Markup Language (UnCertML) – OGC Discussion Paper

8.4 Services for Decision Fusion

8.4.1 Service-Oriented Architecture

The most effective environment for accomplishing the various types of fusion is expected to be a network-centric architecture with distributed databases and services based on a common core of standards-based data formats, algorithms, services, and applications. Such an environment allows the various forms of information to be collected, stored, managed, fused and disseminated vertically (from international to individual level) and horizontally (peer to peer).

A fusion environment involves people, processes, data, and technology that combine functional information with information about space and time (Figure 10). This means combining information from ISR, C2, planning assets, and multi-INT in space and time in order to assemble, relate, and coordinate relevant information from a variety of disparate sources and to provide a common situational understanding and a cohesive set of decision solutions.

In the conceptual fusion environment depicted in Figure 10, there are aggregator, processor and viewer services supporting collecting and consolidating, generating and synthesizing, and viewing and filtering activities, respectively. Information flows in various raw, processed, and fused representations into the fusion environment via network linkages enabled by connections between external source nodes and interoperability nodes. Interoperability Nodes and External Source Nodes may support a variety of service and encoding standards, supporting both producer and consumer interconnections.

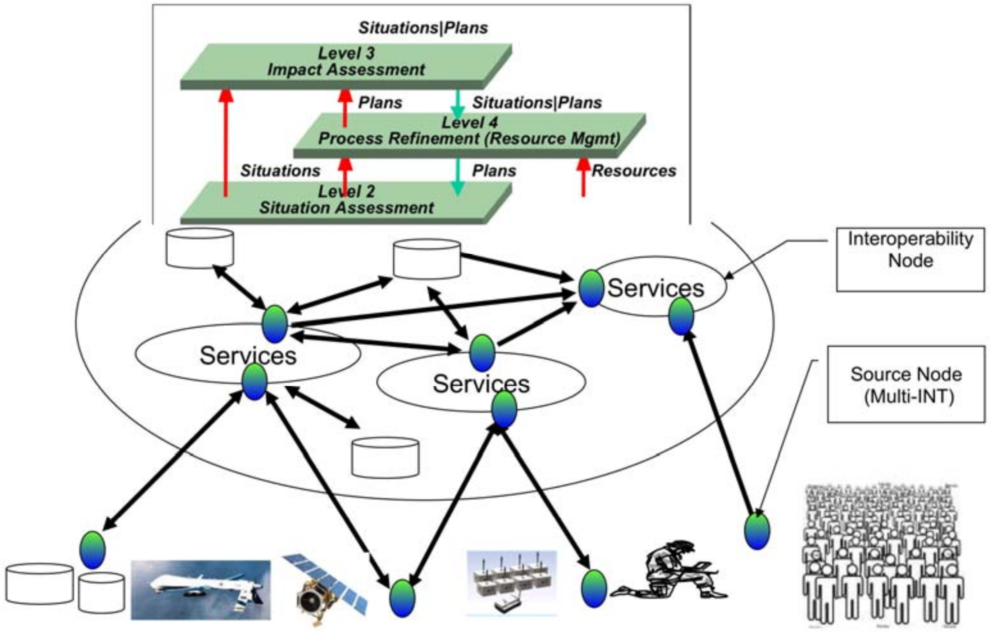

Figure 10 – Fusion Services Environment

8.4.2 Service Platforms

Services may be deployed using multiple technologies, e.g., REST, SOAP, and JAVA. The OGC recommends development of service oriented architecture standards using platform-independent abstract specifications and platform-dependent implementation specifications for all OGC service standards that support both procedure-oriented and resource-oriented service styles or patterns.

8.4.3 Services

8.4.3.1 Overview

The section identifies standards relevant to the services and components identified in the service-oriented architecture of the previous section. Services for data fusion were a topic during the Phase 2 Workshop with one result being Figure 10. On the right-side fo the figure are listed the types of services in which OGC has established a mature baseline of open standards. The left side of the figure considers services that are beyond the scope of just OGC. A key part of Decision Fusion is the ability to bring these two sides together. For example most data has a location component but many times this location information is implicit. In order to make associations based on location, the non-geo data needs to be geotagged and associated with the rich stores of geographic information resulting in a new level of understanding based on the new associations.

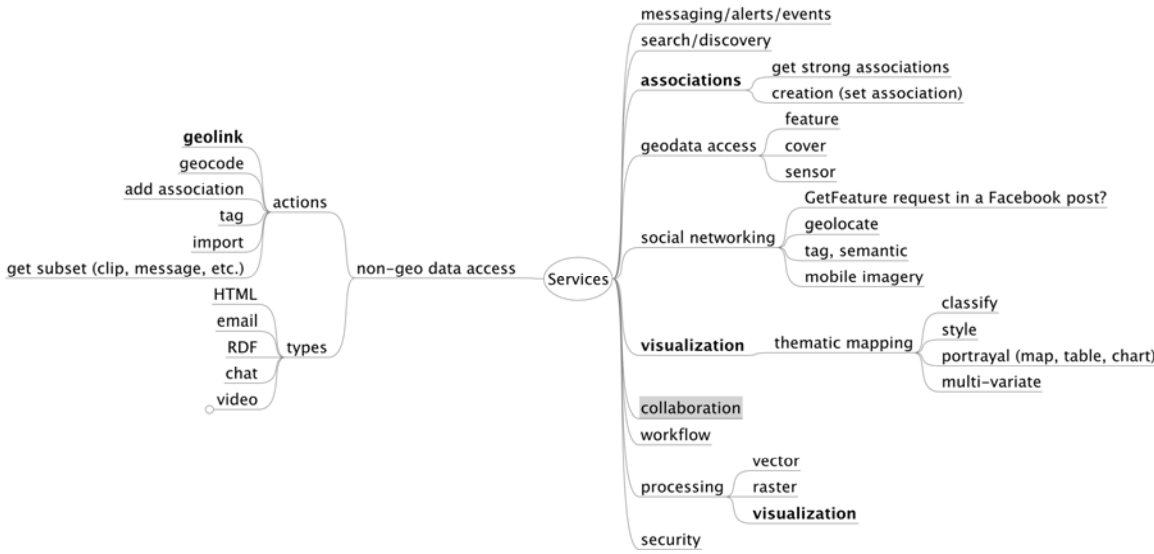

Figure 11 - Mind Map of Decision Fusion Services

8.4.3.2 Messaging: Alerts and Events

Much exchange of messages in a fusion environment is done using e-mail. These messages relate to specific events and are also used for planning and requirements

Alerts are structured information intended for immediate human attention. Alerts maybe passed by e-mail and more specialized services defined for SOAP and REST environments.

Events are structured information but not necessarily intended for immediate human attention. Events maybe passed by e-mail and more specialized services defined for SOAP and REST environments. OGC has defined events services for sensor related services. [Everding, 2009]

In addition to direct exchange of messages from producer to consumer, the publish/subscribe pattern allows for looser coupling of the source and receiver of messages.

In the SOAP oriented, “WS-*” world, publish / subscribe can be handled with WS-Notification [OASIS, 2006]. WS-Notification makes use of notification topics, which support a mix of the subscription models channels and types.

Instant messaging approaches may be considered for message passing. XMPP is a standard for XML message streaming. Various commercial vendor solutions for instant messaging also exist.

Methods based on open standards are needed to quickly communicate situation conditions and response of decisions makers to a large number of people in a specific geographic region. These announcements need to be coordinated though standards from a variety of communities, e.g., emergency response community using CAP and EXDL-DE. Methods involving dynamic high-speed routing of alerts to geographic regions are needed. This notification needs to include the available data (maps, digital data, imagery) based on geographic area of interest

8.4.3.3 Search including filters

Search has many variations: searching of a catalogue, federated search across multiple catalogues, real-time filtering of feeds.

The OGC Catalog Service Specification is an interface standard that can be used on any catalogue and includes geospatial extensions. The OGC Catalogue service can be applied to centralized or federated search architectures.

Harvesting of distributed information in advance allows for a user query to be evaluated against a single catalogue. As examples, two centralized catalogues are:

- The Catalyst program uses metadata to correlate information from diverse intelligence sources (multi-INT), without attempting to fuse all of the original intelligence directly. Catalyst will operate upon tagged entities such as person names and place names and expose this metadata to algorithms. [ODNI, 2008]
- Google crawls the Web to collect the contents of every accessible site. This data is broken down into an index (organized by word, just like the index of a textbook), a way of finding any page based on its content. Every time a user types a query, the index is combed for relevant pages, returning a list that commonly numbers in the hundreds of thousands, or millions. The trickiest part, though, is the ranking process — determining which of those pages belong at the top of the list. [Levy, 2010]

Federated search is the process of performing a simultaneous real-time search of multiple diverse and distributed sources from a single search page, with the federated search engine acting as intermediary. Important Features of Federated Search: aggregation, ranking, and de-duplication (or “dedup’ing”).

As resources become more dynamic new methods for search are needed. This is in particular true for web resources such as news feeds, blogs, and social media. Typical catalogues first aggregate content via time-consuming harvesting. These factors have increased the demand for an opportunity for real-time search using filters. [Geer, 2010]

Search functionality is desirable and, in fact, available also on further geographic data types: Filter Encoding allows predicate based search on features, the Web Coverage Processing Service (WCPS) allows the same on multi-dimensional raster coverages.

8.4.3.4 Data access: structured and unstructured

Access services to unstructured, open-source data focus on the WWW – http and associated protocols.

Structured data access services may include additional semantics related to the data structure. For example access to geospatial data can be accomplished with these open standards:

- OGC Web Map Service
- OGC Web Feature Service
- OGC Web Coverage Service

8.4.3.5 Social Networking

Data Fusion needs access to tools such as Social Networking Services (SNS), social media, user- generated content, social software, e-mail, instant messaging, and discussion forums (e.g. YouTube, Facebook, MySpace, Twitter, Google Apps).

Social networking can be used on trusted networks perhaps within a decision node or set of coordinate nodes, e.g., A-space. Social networking using public is relevant to the mission of decision fusion, where the sources may not be trusted.

Social networking is becoming recognized as integral to operations in many domains, e.g., US Department of Defense [DoD, 2010].

Examples of Social networking relevant to Decision Fusion, several need to be enhanced with geospatial capabilities:

- A-Space is a common collaborative workspace for US intelligence community analysts. A-Space, will give analysts shared access to corporate data and to numerous databases maintained by individual IC organizations. [ODNI, 2008]
- Intellipedia is the US Intelligence Community's (IC) version of the world's user-annotated online encyclopedia, Wikipedia. Intellipedia enables collaborative drafting of short articles, which can be combined to form lengthy documents, all using a simple interface in a web browser. [ODNI, 2008]
- GeoChat aims to integrate mobile field communications with situational awareness. GeoChat - a google.org supported project for responding to disease spread and disasters GeoChat emerged from a simple concept - can I send an SMS message and see it on a map? InSTEDD GeoChat is a unified mobile communications service. [InSTEDD, 2010]

Of particular importance for social networking is the need to identify methods for capturing and retaining provenance of the source.

8.4.3.6 Visualization and Portrayal

A key aspect for establishing context is the visualization of an environment. Visualization for decision fusion in a network environment can be accomplished in two, three, or more dimensions, for example including temporal or parametric content, or links to relational data tables. From a distributed information system point of view, the visualization can occur within a component located on the clients computer ("smart" or integrated client) or the visualization can be accomplished remotely and simply displayed on a client's computer ("thin" client). See Section 8.4.4.2 for discussion of Integrated Clients. This clients rely on standards that provide for remote visualization:

- The OGC Web Map Service (WMS) standard allows fusion of two-dimensional images to be fused based upon common coordinate reference system.
- The OGC Web 3-D Services (W3DS) discussion paper allows fusion of three-dimensional models to be fused based upon common coordinate reference system: scene composition.

Visualization must include the ability to change the Symbology for features displayed. Symbology styles may be used to provide still more hints to an analyst or other user. Data and map product specifications generally determine the precise symbology to be used in a given context. But additional conventions may be suggested and prototyped for distinguishing selected features and/or feature properties from their neighbors and surrounding background. As information sources become ever more cluttered with detail, it becomes increasingly important to find ways to focus attention where it is most needed.

The OGC SLD Profile for WMS standard defines an encoding that extends the WMS standard to allow user-defined symbolization and coloring of geographic feature and coverage data. SLD addresses the need for users and software to be able to control the visual portrayal of the geospatial data. The ability to define styling rules requires a styling language that the client and server can both understand. The OGC Symbology Encoding Standard (SE) provides this language.

Of particular interest for urban situations is viewing the built environment. The surveying and photogrammetry community are developing broad-scale, wholesale three-dimensional models of cities; architects and engineers are developing very detailed infrastructure models, and ordinary citizens are using free tools to create and share models of their neighborhoods. There are many types of documents or data objects that might be referenced to the built infrastructure and natural environments. The documents and data may be items such as evacuation plans, road conditions, inventories of hazardous materials, current environment indicators and weather conditions that would be useful to be able to discover and access based on references to locations.

8.4.3.7 Collaboration

Decision Fusion includes collaboration of various persons in developing an understanding of a specific context. Collaboration with other decision makers and analysts can be accomplished using social networking services and collaboration tools that are location enabled.

One enabling element of collaboration is encoding methods for capturing and sharing the context or picture created by one analyst to be shared with others. Several of these encoding methods are described in the following.

- OWS Context standard
- KML standard

For decision making in a collaborative environment, communications mechanisms and services are needed. As demonstrated in OWS-3, a video feed from a UAV over a fire location is broadcast to several locations [OGC, 2005]. The several locations are connected so that they can see the same video, with the ability for each location to highlight a location on the video for the other locations to see. While sharing and co-interacting this common picture the locations are able to talk and chat. The result being artifacts to be saved and made part of the decision object. This coordination can be achieved with OWS Context, KML, LoF, and other mechanisms. This would require that OWS Context be extended to support imagery, video, audio, digital data, map represented data – for multi-int fusion.

8.4.3.8 Sensor webs

Decision nodes need access to sensor fusion results and the ability to request additional sensor information. Access to sensors using standards is accomplished with the OGC Sensor Web Enablement (SWE) standards:

- Sensor Observation Service
- Sensor Planning Service
- Sensor Alert Service

8.4.3.9 Processing and Analysis

In order to support decision fusion, in some cases processing of the source data is required.

Use of the OGC Web Processing Service (WPS) with profiles enables a standards based approach to many types of analysis. One such processing profile, which is under development, is the Web Coverage Processing Service (WCPS) defining a declarative language for multi-dimensional raster processing.

Processing to provide thematic, statistical, exploratory, spatial/topological and other forms of analysis with open access (public, non-standard) and multi-media data of a socio-cultural nature is a topic in the OWS-7 Testbed using WPS. This is of primary importance to anticipate, prepare for, and mitigate situations requiring urgent and emergency response. In OWS-7 Testbed this type of analysis is referred to simply as *Feature and Statistical Analysis (FSA)*, which we define as a *multidisciplinary scientific approach to describe and predict spatial and temporal patterns of human behavior by analyzing the attributes, actions, reactions and interactions of groups or individuals in the context of their environment*. FSA incorporates elements of Human Geography in a spatial, temporal context. FSA includes aspects of Socio-Cultural Dynamics (SCD), which is defined as information about the social, cultural and behavioral factors characterizing the relationships and activities of the population of a specific region. FSA also includes geospatial vector and topology processing operations.

8.4.3.10 Workflow

In enterprise environments, it becomes necessary to produce complex functional capabilities that are composed from a variety of existing services using workflow orchestration and choreography using such standards as BPEL. To meet the needs within and across enterprises that may be using different process engines and languages a more abstract approach is needed to facilitate design, integration, execution and management of these processes many of which will be asynchronous by nature.

Geoprocessing Workflow is an automation of a spatial process/model, in whole or part, during which information is passed from one distributed geoprocessing service to another according to a set of procedural rules using standardized interfaces. [Schäffer, 2009]

To cope with the crush of huge and growing data volumes to be processed, it is important to augment human awareness and expert knowledge with service-supported workflow processes as much as possible. This could be in the form of enhanced context awareness governing choices available and properties of each choice in a workflow. A key objective is to improve the quality of any given workflow, while lowering its cost, and improving performance. Tradeoffs of regarding roles of human in the loop vs. full automation of workflow should be investigated.

8.4.3.11 Security

The architecture must apply standards-based security solutions for deploying services in the fusion domain. This brings in the requirement for handling services that sensors and other data sources that produce classified information and the main objective of accreditation.

Requirements for secure services are based on the Trusted Computer System Evaluation Criteria (TCSEC), A Security Architecture for Net-Centric Enterprise Services (NCES), the Internet Threat Model, as defined in IETF RFC 3552, and ISO 10181, "Security Frameworks for Open System."
RFI responses should respond with requirements and solutions for approaches to security, e.g., authentication and authorization, based on existing products. RFI is seeking to identify major drivers related to fusion anticipating that much of the existing certification applies directly to the deployed solutions.

8.4.4 Fusion Client Components

8.4.4.1 Decision analysts toolbox

In order to access the services and to exchange information, a Decision analyst needs to be provisioned with a set of tools including desktop clients and access to distributed/cloud services.

The Global Justice program identifies a set of tools as the basic toolbox that an intelligence analyst will need. In addition to the basic office applications on a personal computer, the toolbox should allow access to this information locally or remotely [Global Justice, 2006]:

- Mapping/Geographic Information System (GIS)
- Public Information Database Resources
- Statistical Analysis Software
- Timeline/Flowcharting
- Link Analysis
- Investigative Case Management
- Communications/Telephone (Toll) Record Software

An option presented to NGA based on a previous study was an "Analyst Fly-away kit" as a pre-configured analyst environment containing information (e.g. open source information, RSS feeds, etc.) that would support the analysis process. This would enable experienced analysts to develop "lessons learned" from deployments (i.e., " if only I had known this information, or included this tool...") to help other analysts. [InnoVision, 2009]

8.4.4.2 Integrated client

Decision fusion client components access remote data from one or more Web services and provide manipulation of the data in the client application. Decision support functionality may include filtering, aggregation, analysis, visualization, presentation, and interpretation of multiple sources of data. Decision clients may provide a "dashboard" style user interface. Decision support clients may be specific to a user community or may be more generic geospatial data applications.

Client applications which can be distributed free of charge are desired, note that this does not necessarily require that the code be open source. While this type of application is generally understood to be a user-facing component, this does not restrict the computing platform by which it is implemented.

The OWS Testbeds have developed the concept and requirements for an OWS Integrated Client. See for example OWS Integrated Client Discussion Paper (OGC 05-116) from OWS-5. The Integrated Client concept was advanced further in OWS-6 and OWS-7.

8.4.4.3 Fusion Portal

A Web portal is a single point of access to information, which is linked from various logically related Internet based applications and is of interest to various types of users. Development of reusable portlets increases reuse between portals.

Portals present information from diverse sources in a unified way; they provide a consistent look and feel with access control and procedures for multiple applications, which otherwise would have been different entities altogether. Generally, a portal provides:

- Intelligent integration and access to enterprise content, applications and processes
- Improved communication and collaboration among customers, partners, and employees
- Unified, real-time access to information held in disparate systems
- Personalized user interactions
- Rapid, easy modification and maintenance of the website presentation

8.4.4.4 Geospatial Decision Fusion Engine

In an operational setting, the decision fusion services are used by analysts to compile related sets of spatial-temporal information from multi-source information for a specific context. There is a need for increasingly capable client applications or “fusion engines” that can support decision fusion as shown in Figure 12. A Decision Fusion Engine is conceived as a component that has access to streams of information relevant to an operational decision setting. The fusion platform would create visualizations, and support analysis of aggregated data. Temporal analysis should also be supported by animation and filtering. Any of these analyses or visualization can be shared as embeddable objects into a variety of Web based collaboration software (wiki’s, blogs, web pages etc.).

As an example, the FortiusOne GeoIQ platform allows results of any analysis or data aggregation to be visualized including dynamic aggregation and disaggregation of data. Data can be also visualized through its temporal dimensions by animation and filtering. Any of these analyses or visualization can be shared as embeddable objects into a variety of Web based collaboration software (wiki’s, blogs, web pages etc.).” [FortiusOne, 2009]

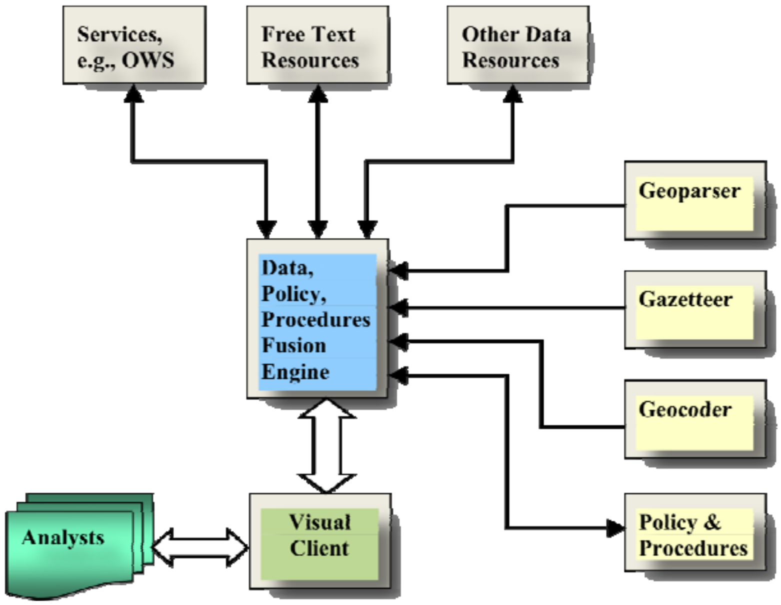

Figure 12 – Geospatial Fusion Services Engine Environment

8.4.4.5 Information sharing between clients

The OWS-7 Testbed investigated information sharing client applications including use of OWS Context document. Analysis and testing conducted in the Feature and Decision Fusion (FDF) thread of OWS-7 evaluated various methods of sharing information within a collaborative environment. The intent of the OWS-7 Information Sharing activity was to move toward a standardized method of sharing geospatial data between Integrated Clients and potentially catalogs.

Experimentation on an Atom-based approach for OWS Context was conducted in OWS-7. Based on those experiments the participants identified topics of further study to improve the viability of a future OWS Context specification. The detailed topics are documented in the OWS-7 Information Sharing, including OWS Context Engineering Report (OGC 10-035r1). This topic is also relevant to the discussion about unstructured data (See Section 8.3.3)

8.4.5 Registries for Fusion

Registries are needed for all categories of Fusion. Figure 13 shows the use of registries for the three categories of fusion. Several standards for interfaces and data models for registries exist.

In particular it would be useful to develop an ebRIM (V3.0) model for Decision fusion. This would use ebRIM Associations, Packages and ClassificationScheme registry objects to model feature associations for feature fusion. Version 3.0 of ebRIM is selected since it is the basis of the OGC CSW-ebRIM specification for which several OGC members have developed commercial implementations.

For Object/Feature Fusion, registries can be used to support use of unstructured information. The unstructured item is placed in the repository and the added information is held in the registry along with a link to the original data. The OGC CSW ebRIM standard can be used in this later case

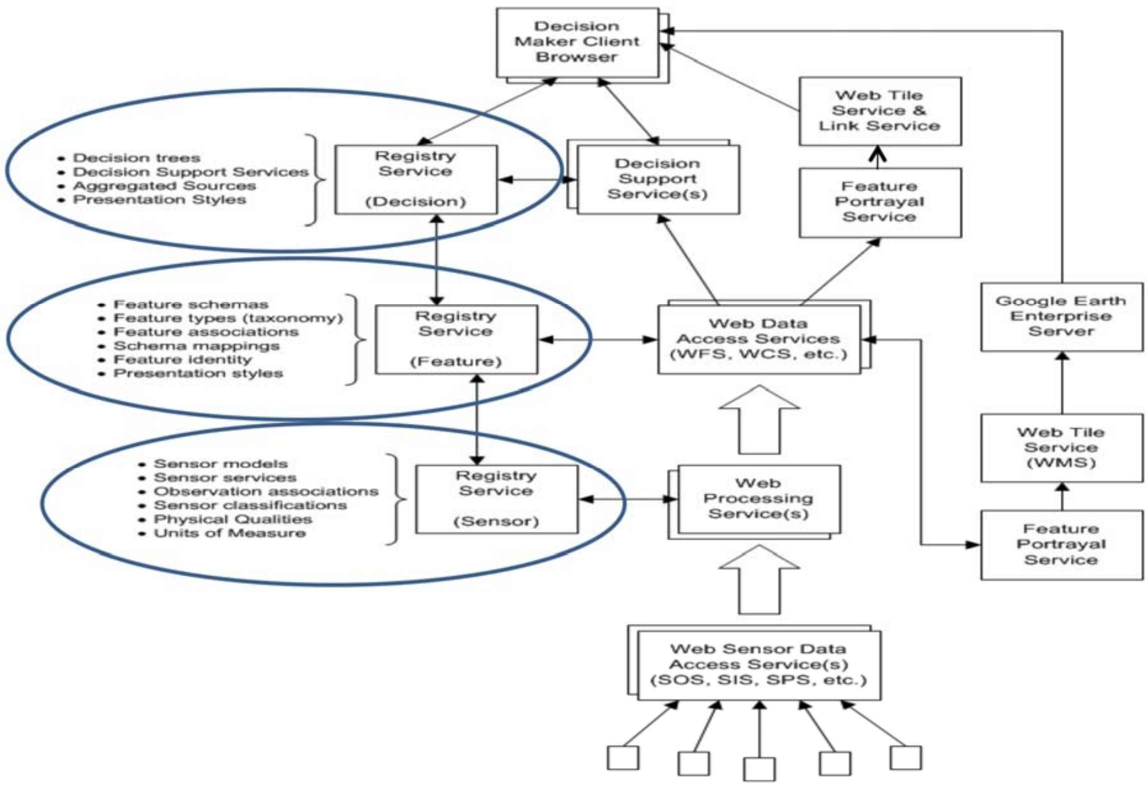

Figure 13 – Registries for Fusion (Source: Galdos)

8.5 Recommendations

8.5.1 Develop Decisions as First Class Objects in an Information Model

Decisions should be modeled as first class object in an information model. Such an information model would allow development of software for better sharing and processing of decisions in a distributed services environment. A UML model showing a Decision Object would show attributed, relations and subclasses that describe the information associated with an object: attributes of the situation, e.g., location, alternatives courses of action, decision selection scheme, e.g., decision trees. Defining a decision as an object allows for association between decisions. Decisions would link to structured and unstructured data with some unstructured data useful directly in the decision. The model should support linking to events that trigger consideration of a decision and support traceability of post-decision. The UML model should be built with and in the context of existing UML information models.

8.5.2 Develop a design pattern relating events and decisions

Develop a design pattern that triggers consideration of decision alternatives upon occurrence of an event: "if you see this event, then consider these decisions". When a registered event occurs a set of possible decision templates would be presented to a person. Decisions would be based on Complex Events. Show use of the event/decision pattern with several use cases. Connect the pattern to the OGC Event Architecture and consider other eventing models. Link the pattern to the Decision Object modeling in the previous recommendation.

Continued harmonization of location in Emergency Management Standards in particular OASIS standards EDXL and GML is recommended. EDXL provides a rich set of standards for Emergency Management decision-making. These standards include information about location. Carl Reed of OGC has been working with the OASIS Emergency Management Technical Committee towards harmonization of the OASIS and OGC standards. Of particular importance is the continued work on the OASIS GML profile or "EDXL Where". Also relevant is coordination on NIEM and UCORE.

8.5.3 Standardize methods for Information Sharing between clients.

Conduct further experimentation and development on Information Sharing between fusion client components. This work can build on the recommendations regarding OWS Context contained in OWS-7 Information Sharing, including OWS Context Engineering Report (OGC 10-035r1). The activity should result in a standardized method of sharing data, including geospatial, between Integrated Clients and potentially catalogs.

8.5.4 Promote diversity of interoperable Fusion Analyst Components

The standards developed for fusion should focus on interoperability. It is desirable to minimize the number of interoperability standards in order to optimize and stabilize the communications. In contrast, for components it is desirable to have a diversity of components that implement the standards. This diversity of clients allows for meeting the various needs of different analysts and communities. Components for the fusion analyst are the focus on the results of all three categories of fusion. The analyst clients must be able to accept results from components performing observation, feature and decision fusion using interoperability standards. The Analyst component may additionally perform fusion internal to the component. (See Section 8.4.4)

8.5.5 Develop registry for Decision Fusion, e.g., using ebRIM.

Develop registries to support Decision Fusion, for example using an ebRIM (V3.0) model. This would use ebRIM ClassificationScheme registry object to model a decision process as in a decision tree. Version 3.0 of ebRIM is selected since it is the basis of the OGC CSW-ebRIM specification for which several OGC members have developed commercial implementations.

8.5.6 Develop open standards for visualization relevant to fusion

OGC has developed an initial baseline of standards to support geographic visualization in a distributed, interoperable environment. These standards should continued to be matured for example in the areas of: 3D, uncertainty, provenance, and decision alternatives and selection.

8.5.7 "See and Talk" collaboration with common geographic view

For decision making in a collaborative environment, communications mechanisms and services are needed. As demonstrated in OWS-3, a video feed from a UAV over a fire location is broadcast to several locations. The several locations are connected so that they can see the same video, with the ability for each location to highlight a location on the video for the other locations to see. While sharing and co-interacting this common picture the locations are able to talk and chat. The result being artifacts to be saved and made part of the decision object. This coordination can be achieved with OWS Context, KML, LoF, and other mechanisms. This would require that OWS Context be extended to support imagery, video, audio, digital data, map represented data – for multi-int fusion.

8.5.8 Coordination through social networks

To be effective decision fusion must go beyond a strictly geospatial context. This broadening must bring other data types as well as interaction with broader standards communities. Social networks to collaborate, develop common understanding and make decisions should become part of our understanding of decision fusion. Social networks can be used by the analyst to add structure to unstructured information. Use of technologies like wikis and blogs that are spatially enabled and support the decision object approaches defined above, would provide a basis for collaborative decision making.

8.5.9 Conduct a Decision Fusion initiative: Decision Fusion Pilot

Conduct an initiative involving several Operational Nodes that perform decision fusion. To maximize the variability in the initiative, involve Nodes from different management federations, different domain responsibilities, different architectures and different countries – but using common interface standards. Such diversity will aid in developing international standards that support interoperability across multiple functional domains. For example in the civilian domain, interoperability testing based on open standards for an event that involves MASAS and IPAWS would meet this recommendation (See Section 8.2).

9 Object/Feature Fusion

9.1 Introduction

The Fusion Standards Study ER, Phase 1, made recommendations regarding Object/Feature Fusion. The supporting discussion for those recommendations is not repeated here. Several of the Phase 1 recommendations were implemented in the OWS-7 Testbed. Many of the standards described in the Decision Fusion section of this ER apply also here to Feature/Object Fusion.

Object/Feature Fusion is the processing of multiple sources of observations and features into higher order semantic features using techniques for identifying, aggregating, relating, parsing, and organizing and includes feature processing such as generalization, conflation, feature extraction, and change detection. Object/Feature fusion yields information resources that are more powerful, flexible, and accurate than any of the original sources. A workflow of Feature Fusion is presented in Figure 14.

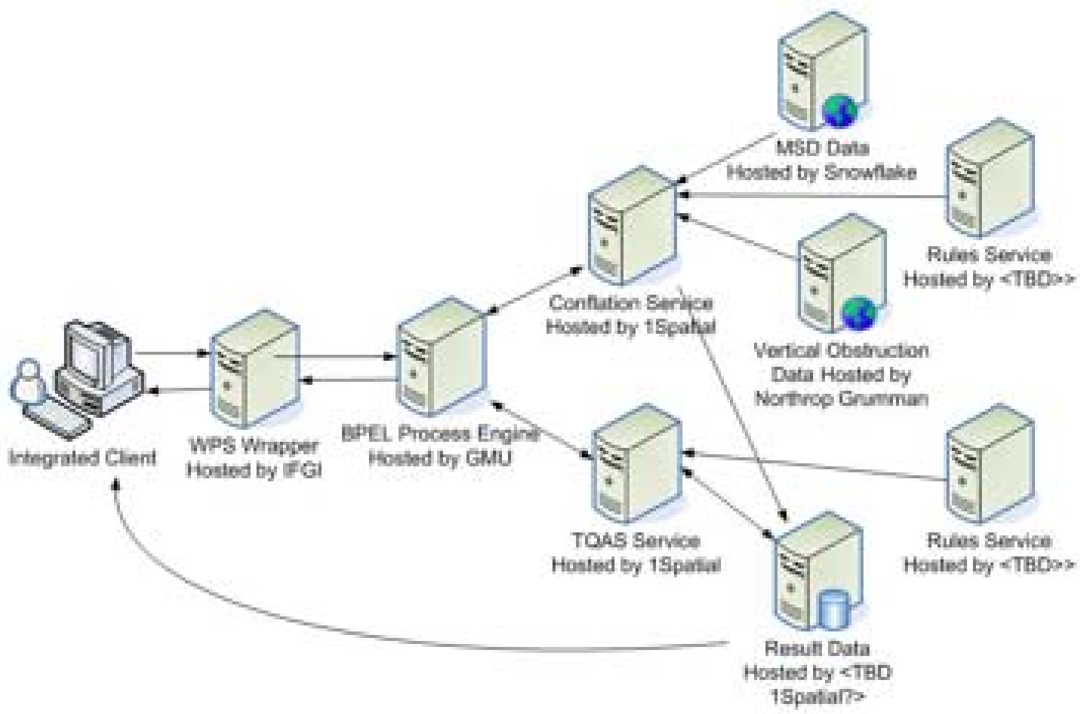

Figure 14 - OWS-5 Feature Fusion workflow example

Conflation technology offers useful options to deal with imperfect, heterogeneous, conflicting, and duplicated data. It is possible to use conflation to correlate disparate data sources, but not necessarily with a goal of merging them. Conflation has algorithms to compare, match, or link multiple representations of features using measures of similarity in semantics, geometry, and topology. Understanding how two data representations correlate or differ helps to reinforce, refute, or augment knowledge of an area, and are key to conflation's role in data fusion. [NTA, 2009]

Conflation for selecting the "best" of all sources is not a one-size-fits-all problem, subject to the actual feature data being processed, user knowledge and expertise, and other criterion. As such, a comprehensive set of business rules is necessary to control aspects of the process such as feature prioritization, attribute handling, coding standard conversions, and more, and be applicable to the core conflation processing as well as pre- conflation data setup and preparation steps.

A service-oriented architecture is well suited to support distributed conflation rules services. A rule “provider” could define custom rules and make those rules available to conflation services and applications. We envision two use cases for handling conflation rules services, 1) where the client only supports predefined sets of rules and 2) where the client allows user customization of the conflation rules. (OGC 07-160r1)

9.2 OWS-7 FDF Implementations

9.2.1 OWS-7 FDF Overview

Recommendations from the Fusion Study Phase 1 were implemented in the Feature and Decision Fusion (FDF) thread of the OWS-7 Testbed. OWS-7 FDF built on the OWS-6 Geoprocessing Workflow and Decision Support Services work, to advance common interfaces for information cataloguing and sharing, feature and statistical analysis, synchronization of multiple geospatial databases, Web Processing Services (WPS) profiles, and the Integrated Client. Task areas for FDF in OWS-7 were:

- Schema Automation: Transformation of NGA Application Schema (NAS) from UML to profiles of GML and KML.
- Data Discovery, Organization and Sharing: Use of thematic categories in multi-source data discovery, including augmented metadata for quality of source, and fitness for use. Organize in OWS Context documents—the analyst’s information resource “shoebox”.
- Feature and Statistical Analysis (FSA): WPS profiles for feature fusion, including statistical analysis, vector and topological processing.
- Geosynchronization: Components to support synchronization of geospatial data and updates across a formal or ad hoc Spatial Data Infrastructure (SDI).
- Alerting: Fuse alerts with geospatial analysis using OASIS Common Alerting Protocol (CAP) format.
- Integrated Client: A field-ready client application to support and display sensor information, cataloguing metadata, notification alerts, statistical analyses, and save it all in a Context document.

Table 4 - OWS-7 FDF Thread Implementations

FDF Services/Components	Participants
ShapeChange UGAS Enhancements	interactive instruments
ShapeChange extension for KML 2.2	interactive instruments
Automation of ISO 19139 compliant metadata from NAS	interactive instruments
Authoritative Data Source Directory services	Compusult, ERDAS
WPS for Feature and Statistical Analysis	Intergraph, 52North
Services for Feature and Statistical Analysis	lat/lon
Geosynchronization service, including CAP	Carbon Project
Geosynchronization client	Carbon Project
“Embedded” Geosynchronization service/client	GIS Center, Feng Chia Univ
“Embedded” WFS-T for geosynchronization with mobile devices	CubeWerx
WFS-T for desktop synchronization	CubeWerx
Integrated Clients	Intergraph, ESRI

Table 5 - OWS-7 FDF Thread Engineering Reports

FDF Engineering Reports	Participants	OGC Doc #
Schema Automation	interactive instruments	10-088r1
Feature and Statistical Analysis	Univ Muenster IfGI	10-074
Authoritative Data Source Directory	FortiusOne, Envitia	10-086
Information Sharing, including OWS Context	Intergraph, LISAsoft	10-035r1
Geo-synchronization, including CAP	CubeWerx	10-069
WPS Profiling, with cross-thread coordination	lat/lon	10-059

9.2.2 WPS for Fusion

Based on the results documented in Feature and Statistical Analysis ER (OGC 10-074) and WPS Profiling ER (OGC 10-059), these recommendations relevant to Fusion Standards Study are noted:

- WPS profiles are needed in order to achieve semantic interoperability of Geoprocessing. Grouping of algorithms is needed. The FAS ER identified hierarchies and classifications such as “Topology Analysis” and “Statistical Analysis”.
- Designing WPS Profiles is a challenge not only regarding choosing the appropriate input and output type definitions, but also regarding choosing appropriate classifications. For this reason, a holistic approach is required to reflect the complexity of appropriate process design.
- Metadata profiles for registering WPS in OGC Catalogs are missing and hinder the use of the publish-find-bind pattern.

Future work should consider the prior development of WPS Profiles in OWS-5 regarding Conflation Rules. Further consideration of the rules approaches identified in OWS-5 should be considered. OGC Document 07-160r1 from OWS-5 made this statement:

- One possible approach to implementing rules as services would be to use the OGC WPS standard with the various conflation rules processes defined, for example, as GetRuleX, SetRuleY, etc. The DescribeProcess would describe the inputs needed to retrieve the Rule as well as a description of the rule and its assumptions.

9.2.3 Authoritative Data Source Directory

A key part of supporting feature and decision fusion are catalog, or registry services, providing sophisticated capabilities to discover, organize and access relevant data sources. One currently popular term for this kind of information service is an Authoritative Data Source.

An Authoritative Data Source Directory (ADSD) was investigated in the OWS-7 FDF Thread (OGC 10-086). ADSD is a resource capable of organizing and discovering a wide variety of types of data such as web sites, books, pictures/images, et al. as well as available web services. The directory is to have the ability to identify and query for data sources based on socio-cultural themes, geographic area (either coordinates or geographic name), temporal relevance, and data quality (e.g. precision, fitness for use). The ADSD concept was implemented as an OGC Catalog Service supporting all interfaces of CSW 2.0.2 plus extensions developed to support ADSD. OpenSearch was adopted as a metaphor for the extensions.

9.3 Phase 2 Study results on Object/Feature

9.3.1 Structuring Unstructured Information

9.3.1.1 Workshop discussion

Unstructured information was a topic of discussion in the Fusion Standards Study Workshop. Data having "no structure" was challenged with discussion leading to use of the definition from Wikipedia contained in RFI-2: "Unstructured data is data for which there is no data model, or at least no data model that exposes any of the semantics of the data" (See Section 8.3.3). Several topics were identified in the workshop:

- One challenge is for an information system to offer services on data for which it does not have an information model.
- Recent web based collaborative and mashup techniques support moving less-structured information to more-structured information through human-based interactions.
- Techniques based on open standards are needed for gathering unstructured, public information
- Methods for adding context and meaning to information in structured fashion are needed based on open standards for information models.

In structuring information about an unstructured information item, one creates a model of the information item – meaning we select tags that help convey the meaning of information item. These can be completely arbitrary, and the "model" (or list of tags) can be changed on the fly at any time. The attached information items (tags) can have more or less arbitrary types – so can include simple types (integers, strings etc) but also geospatial or temporal tags. We can use the tags to enable searching and retrieve it. The search requests can make use any of the attached tags, including geospatial and temporal constraints, and can even look inside the unstructured items (e.g. look at the internals of an HTML document) where that might help in the discovery/access process.

9.3.1.2 Registries for structuring information

Management of the unstructured information and the newly associated information can be done using several alternative methods. The new information can be directly added to the unstructured item or a registry/repository approach can be used. In the latter case, the unstructured item is placed in the repository and the added information is held in the registry along with a link to the original data. The OGC CSW ebRIM standard can be used in this later case (see Section 8.4.5). The advantages and disadvantages of each approach can be obvious. In the embedded case, the clear advantage is that all of the information is in one information package. In the exterior description approach the clear advantage is that can support multiple descriptions (perhaps for different applications) and not clutter a given package with extraneous information.

CSW-ebRIM can be used for the management of unstructured data. CSW-ebRIM is a standard from the OGC that builds on OASIS called ebRIM (eBusiness Registry Information Model). CSW-ebRIM makes use of something called Reg-Rep, with Registry objects referencing and pointing to associated Repository items. Think of the repository items as the unstructured information items, and the related registry objects as descriptions that expose their semantics. Each repository item (e.g. an HTML document) has a URN (which is a URI) and can be readily retrieved from the Registry using a simple GET request (e.g. from a browser).

In particular it would be useful to develop an ebRIM (V3.0) model for feature fusion. This would use ebRIM Associations, Packages and ClassificationScheme registry objects to model feature associations for feature fusion. Version 3.0 of ebRIM is selected since it is the basis of the OGC CSW-ebRIM specification for which several OGC members have developed commercial implementations.

The Galdos implementation of CSW-ebRIM enables the automated transformation of the output from the registry using XSLT scripts, these scripts being associated to a given registry object type (e.g. audio clip). Whenever a request is made for such an object, the transformation script is retrieved and automatically applied to the registry object and its associated repository items. In this manner one can generate say an ATOM feed in which the registry descriptions are attached (embedded) together with the content (repository item).

9.3.1.3 Adding geographic structure with TJS

Many databases do not contain location as coordinates, but rather geographic identifiers are used, i.e., postal codes, municipality names, telephone area codes, or more special purpose identifiers such as school districts. This information appears unstructured to geospatial services that utilize geographic coordinates. In order to use the data with identifiers, the database must be linked to a geospatial framework that provides a mapping from identifiers to coordinates.

The OGC Georeferenced Table Joining Service (TJS) (OGC 10-072r2) offers a way to expose this data to other computers, so that it can be found and accessed, and a way to merge that data with the spatial data that describes the framework, in order to enable mapping or geospatial analysis.

TJS is a powerful open standard for bridging from databases without geographic coordinate-based structure to geospatial services that can fuse that information with geographic coordinate based information.

9.3.2 Schema harmonization and adaptors

OGC has extensive experience in working with information schemas, e.g., GML schemas. Even so, OGC can continue to improve and refine methods for schema handling, harmonization and run-time mapping with adaptors. Rules for mapping between schemas can be further defined. These mappings can be used in advance and at run-time. In maintaining data “closet to source”, different communities will continue to be use schemas optimized for local use. In order to support sharing between communities, data adaptors– connectors – bridges – data transformations are needed to function in real time to map data from one schema to another.

Relevant tools for GML handling have been developed in OWS Testbeds and elsewhere. For example the UML-to-GML tools like ShapeChange and the GML Validation tools are critical to improving handling of GML schemas.

Further efforts on improving handling of associations is needed, in particular considering the primacy of associations to data fusion. OGC has made use of XLink even while that specification has been in development and refinement. Further refinements in OGC use of XLink should be considered.

9.3.3 GML and Application Schemas

GML Application Schemas are developing rapidly in many communities. In some communities the GML Application Schemas have matured to become a basis for high degree of data interoperability. Framework Data Sets have been defined by the USGS including GML application schemas. INSPIRE is defining Data Specifications.

Recently there has been discussion of increasing the use of political geography and soft fusion in decision making (See section 8.3.2.8). This is also related to increasing the use of soft fusion and HUMINT in fusion.

9.3.4 Discrete Global Grid System

Spatial tessellations of the globe that do not have singularities of poles or date lines are valuable in many applications. The tessellation or gridding system provides for complete coverage of the globe at multiple resolutions using geometric objects with desirable properties. In addition to the geometries, an index of the locations based on the tessellations is needed for efficient processing, query, access, etc.

The Discrete Global Grid System (DGGS) is example of such a tessellation system. The DGGS includes equal area cells that exhaustively cover the globe in closely packed hierarchical tessellations, each cell representing a homogenous value, with a uniquely identifier or indexing that allows for linear ordering, parent-child operations, and nearest neighbor algebraic operations.

The DGGS as an Earth reference is designed for digital environments where storage, processing, transmission, discovery, visualization, aggregation, and transformations of multi sources of geo-referenced data are required.

Conventional Earth references, based on a continuous analog model, are designed primarily for navigation and analytical geometry between points and using them within a digital environment introduces significant disadvantages and dependencies when multi-source fusion is a goal.

Quantizing values into a DGGS provides an efficient way of fusing data on-demand. It has the mathematical properties to aggregate and decompose information described in each cell to coarser or infinitely finer resolutions – down to pixels. Data can be pre-processed to the DGGS or done at the source. When pre-processed, individual data elements, as opposed to full data files, become searchable and extractable. It can act like a spreadsheet of synchronized cell values taking multi-sources of data to describe the planet.

The DGGS may provide a powerful new paradigm for enabling GEOINT2 and decision fusion supporting data discovery, automated integration, multi-source analysis, net-centric dissemination, preservation and reuse within a standards based environment. Further, the future of GEOINT cannot presume an architecture dependant on a central decision fusion engine. Information and the decision-makers are distributed, though the environment net- centric. The properties of the DGGS within a net-centric reality provide opportunities to rely on the scalability of networks, variable node sizes and capabilities, distribution of services, and shared processing and storage.

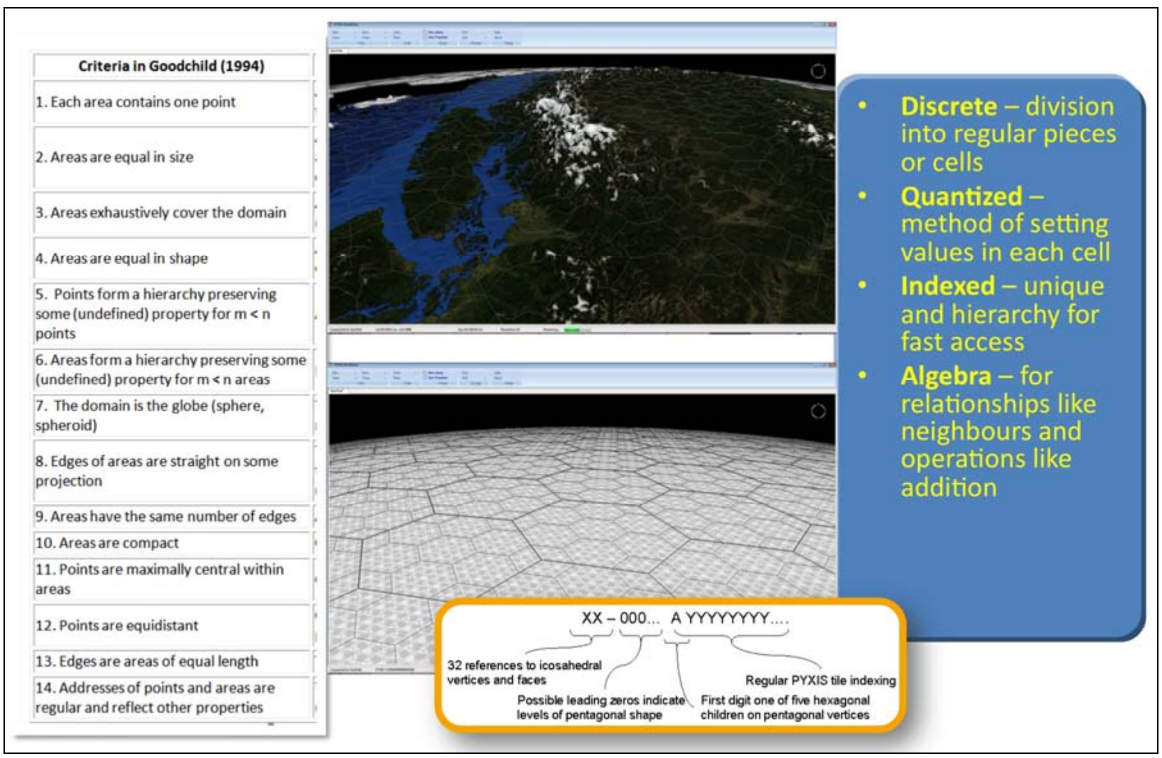

Figure 15 – Discrete Global Grid System (Source: PYXIS)

So how might a DGGS be used in OGC standards?

Tessellations of the Earth surface are considered in an annex to the OGC Abstract Specification, Topic 6 – Coverages. The topic is included in that document for discussion with discrete coverages. Topic 6 lists several methods for discrete coverages. The specific discrete global grid ISEA3H (Icosahedral Snyder Equal Area aperture 3 Hexagon Grid) advocated by PYXIS could be added to Topic 6 (also known as ISO 19123).

Using DGGS and in particular ISEA3H for discrete coverages would enable coverage processing that employs the ISEA3H structure for efficient processing. Specific profiles of WCS, WPS and WCPS using ISEA3H could be defined. PYXIS has internally developed a similar approach.

Visualization of geographic data could also be more efficient using a DGGS. GeoBrowser developments in the Digital Earth activities early in this decade included major consideration of DGGS's. Use of DGGS in open geobrowser developments should be considered. KML has answered an element of GeoBrowsers but more is needed.

The ISEA3H DGGS has been published in multiple articles and is believed to be in the public domain concerning intellectual property. The PYXIS Innovation has developed and patented an efficient indexing scheme for DGGS. Within OGC discussion of patented IP is subject to the OGC Intellectual Property Rights policy of the OGC.

9.3.5 Registries for Feature/Object Fusion

Section 8.4.5 describes an overall approach to supporting all categories of fusion using registries.

In particular it would be useful to develop an ebRIM (V3.0) model for feature fusion. This would use ebRIM Associations, Packages and ClassificationScheme registry objects to model feature associations for feature fusion. Version 3.0 of ebRIM is selected since it is the basis of the OGC CSW-ebRIM specification for which several OGC members have developed commercial implementations.

9.4 Recommendations

The following recommendations for Object/Feature Fusion are based on the earlier material in this ER-2 and from the ER-1 of the Fusion Standards Study.

9.4.1 Develop WPS Profiles for Geoprocessing Fusion

OGC approved the WPS standard several years ago. At the time of approval it was well known that the WPS Standard would serve as a framework for the deployment of numerous (100's) of geoprocessing algorithms in distributed information networks. The OGC is now undertaking the deployments of WPS coordinated through WPS Profiles. A current challenge is to have consensus development of WPS profiles that encourages the highest level of interoperability. Many of the WPS Profiles will be relevant to Fusion in all categories. It is recommended that a strategy for development of WPS profiles be developed in the TC with the WPS SWG and deployed through several Interoperability Program initiatives. One such geoprocessing standard is WCPS. Harmonization with WPS through a WPS Application Profile should be pushed to completion. This should be part of an initiative to define canonical WPS extension approaches.

9.4.2 Further develop rule-based geoprocessing to an OGC Best Practice

Combining processing and rules services within a service-oriented architecture with workflow is an enabling technology for Fusion demonstrated in OWS-5. As part of the OWS-5 test bed a sample set of conflation rules were to implemented to prove the concept of rule-based conflation. The OWS-5 implementation also used a Topology Quality Assessment Service (TQAS) in the workflow. The rules can be inspected and compared and subsequently executed on a variety of workflow processing services. The technology demonstrated in OWS-5 should be developed further into an OGC Best Practice supported by existing OGC standards, and potentially new standards e.g., for Rules Schema.

9.4.3 Develop approaches for fusing “unstructured” data

This ER has identified many types of information that need to be handled in data fusion – much of the data is “unstructured” (Sections 8.3 and 9.3.1). This is a broad filed that can benefit from experimentation in the OWS Testbed series. Internet mashup methods are evolving quickly and should be tested with the more structured information types. Mechanisms exist for parsing non-geospatial data, linking, tagging, and organizing them to form “fused” information products packaged for sharing. Many of these capabilities are “locked-up” in desktop applications and tools, not easily accessible over networks or interoperable across implementations.

9.4.4 Registries for Object/Feature Fusion

It would be useful to develop an approach for using registries for feature fusion. For example this could use ebRIM Associations, Packages and ClassificationScheme registry objects to model feature associations for feature fusion. Version 3.0 of ebRIM is suggested since it is the basis of the OGC CSW-ebRIM specification for which several OGC members have developed commercial implementations.

9.4.5 Adding geographic structure with OGC Georeferenced TJS

Apply the OGC Georeferenced Table Joining Service (TJS) to fuse information lacking geographic coordinate structure with geographic coordinate-based information using geospatial services.

9.4.6 Further develop Authoritative Data Source Directory

The Authoritative Data Source Directory (ADSD) sub-thread of OWS-7 explored the ability of a decision support system to provide a unified environment for searching and reviewing all these different types of information resources through a single interface. Identifying authoritativeness in data sets from less structured sources is more complex, and involves being able to account for authoritative concepts built up using the “wisdom of crowds”. OWS-7 was able to delve into these concepts in some depth, but there is still a wealth of research and prototyping experience required to fully explore the agenda set out in (OGC 10-086).

9.4.7 Apply the OGC standards to Political Geography

Development of GML Application Schemas for Political Geography, Soft Fusion and Human-centered information. Services for creating the instances of political geography data instances are also needed – a topic closely related to ADSD and fusion of unstructured data.

9.4.8 Continue to improve methods for GML schema handling

OGC has extensive experience in working with information schemas, e.g., GML schemas. Even so, OGC can continue to improve and refine methods for schema handling, harmonization and run-time mapping with adaptors. Further efforts on improving handling of associations are needed.

9.4.9 Review Discrete Global Grid Systems with OGC

Tessellation systems have been discussed previously in OGC in particular in the OGC Abstract Specification, Topic 6 Coverages and Topic 2 Coordinate Reference Systems. During OGC TC meetings, there have been recent discussions about the need for coordinate reference systems without singularities at the poles and date line. The DGGS system presented by Pyxis has desirable properties and may meet the OGC needs. It is recommended that discussion of DGGS be taken up with the OGC membership to determine if a movement toward consensus can be achieved. A testbed might be established which demonstrates the advantages of DGSS through a WCS.

9.4.10 Develop semantic data models supporting feature fusion (Phase 1)

Common data models and encoding patterns are needed for representing feature semantics, feature associations, and their geometry, topology, and temporal properties in standard ways for enabling interoperable Object/Feature fusion. Elements of the data model include common ontologies, vocabularies and taxonomies, association types, link encoding mechanisms/patterns, and the means for publishing/sharing/processing of "fused" features. Clearly GML and O&M are the starting-point for an Object/Feature fusion model. Such models and patterns are essential for interoperable transformation and automated processing of data in fusion workflows. With stable and finite representations of features (i.e., their structure, associations, and semantics) derived from a common data model, come the means for discovery, transformation, and reasoning in support of compose-able and higher-order Object/Feature fusion capabilities needed to solve increasingly more complex problems and to share the results.

9.4.11 Standardize metadata for provenance and uncertainty (Phase 1)

Fusion is a hard problem in part because we are drowning in a volume of data from multiple sources, all with different levels of detail and uncertainty. The challenge in Object/Feature fusion is not getting data but making sense of them! While it is important to minimize the introduction of uncertainty during processing and handling of data, it is equally important to recognize and quantitatively characterize the uncertainty in a result. Quantitative representations of uncertainty support provenance (history of a data product) within the feature lifecycle model. The use of metadata, and specifically uncertainty metadata, must be shown in real-world/practical fusion scenarios. UncertML should be considered with evaluation of the Gaussian model for the variety of types of uncertainty. Demonstration of methods and tools for creating and interoperably using provenance and uncertainty metadata to support automation and improved (faster, valid, more accurate) fusion results are needed.

10 Observation (sensor) Fusion

10.1 Introduction

Observation Fusion considers sensor measurements of various observable properties to well characterized observations including uncertainties. Fusion processes involve merging of multiple sensor measurements of the same phenomena (i.e. events of feature of interest) into a combined observation; and analysis of the measurement signature.

Sensor fusion concerns the acquisition and exploitation of multiple measurements for the purpose of:

- Obtaining a higher-level or more accurate measurement
- Recognizing objects and events of interest
- Determining properties of particular objects or events

Standards for Observation Fusion are relatively mature; in particular the OGC Sensor Web Enablement (SWE) standards have been adopted as consensus standards with implementations for several years. Currently the second major version of the SWE standards is being finalized in OGC. The SWE architecture document provides a overview [Botts, 2007]

The Fusion Standards Study Phase 1 ER made recommendations regarding Observation Fusion. The supporting discussion for those recommendations is not repeated here. Several of the Phase 1 recommendations were implemented in the OWS-7 Testbed.

10.2 OWS-7 SFE Implementations

The Sensor Fusion Enablement (SFE) thread of the OWS-7 Testbed implemented several recommendations from the Fusion Standards Study, Phase 1:

- Discovery and access of dynamic sensors
- Fusion of video from airborne and ground based platforms

The OWS-7 SFE thread built on the SWE framework of standards, focusing on integrating the SWE interfaces and encodings with workflow and web processing services to perform dynamic sensor tracking and notification, and motion video change detection. The SFE thread also continued work on the interoperability of SWE and Common CBRN (Chemical, Biological, Radiological and Nuclear) Sensor Interfaces (CCSI).

Table 6 - OWS-7 SFE Thread Implementations

SFE Services / Components	**Participants**
SOS Server for Motion Imagery	52North, Compusult
WPS Server for Change Detection	GMU CSISS
Tracking and Notification Service, including CAP	Compusult, Univ Muenster IfGI
Motion Video Data collection and SOS server	BIRI
SFE Client for motion video	Compusult, BIRI
Catalog Service for Motion Video Sensors and Imagery	Compusult
SOS Client for CCSI toxic sensors	NGIS

Table 7 - OWS-7 SFE Thread Engineering Reports

SFE Engineering Reports	Participants	OGC Doc #
Dynamic Sensor Notification	iGSI	10-061
Motion Imagery Discovery and Retrieval	GMU CSISS, BIRI	10-087
WPS Motion Video Change Detection	Intergraph	10-036
CCSI-SWE Best Practices	NGIS	10-073

10.2.1 Dynamic Sensor Notification

The OWS-7 SFE tested the tracking of sensors and notifying users based on a geographic Area of Interest (AOI). In the context of OWS-7, tracking means receiving updates of a sensor's position. Clients subscribed at a service to automatically be notified once the presence or absence of sensors over or within an AOI was determined. This work included review of standards and specifications like OASIS Common Alerting Protocol (CAP), OGC Sensor Alert Service (SAS), OGC Web Notification Service (WNS) and the OWS-6 Event Architecture. Results are documented in OGC 10-061.

10.2.2 Motion Imagery Discovery, Retrieval and Change Detection

OWS-7 SFE activities on Motion Video Fusion included testing geolocating of motion video for display and processing, and change detection of motion video using Web Processing Service (WPS).

Metadata was defined to tag geolocation of Motion Imagery (MI) for discovery, retrieval and linkage with other data sources over the same location, especially the metadata information required to geometrically co-register multiple motion images at pixel level so that data recorded at different times (e.g., different days) and/or by different providers for common or overlapped FOVs can be compared and pixel level changes among the different images can be accurately detected and delineated. Results are documented in OGC 10-087.

OWS-7 tested a change detection algorithm on two motion video streams. The web services of principle concern in this exploration were WPS, SOS and a SFE Integrated Client. Results are documented in OGC 10-036.

10.3 Phase 2 Study results on Observations/Sensors

10.3.1 WCS and WCPS

Based on the current taxonomy in OGC, Coverages are Features. Coverages are a type of feature where attributes have a value for every position within the geographic extent of the coverage. Coverages support "mapping" (in the mathematical sense) from a spatial, temporal or spatiotemporal domain to feature attribute values where feature attribute types are common to all geographic positions within the domain.

Coverages may be "authorized models" derived from hundreds or thousands of measurements or predictions and making use of some numerical model. In this sense, coverages should be discussed under features.

An observation is a representation of the act of observing or measurement. The act of a person (or a satellite) taking a photograph is an example. It has a time (time of the observing), location (of the observer), a result (what results from the act of observing) etc. A coverage may then be the result of an observation (the photograph). In this sense coverages should be discussed in Observations.

Since the following discussion regarding coverages, WCS and WCPS mainly focus on coverages as derived from observations, the discussion is included in this Observation Fusion section.

With WCS 2.0, an important step towards harmonization of coverage data across OGC has been accomplished. The **coverage data structure** and **service definitions** have been separated into the *GML Application Schema for Coverages 1.0 Interface Standard* and the *WCS 2.0*. This allows coverages to float freely between different services.

The specification set, which was the first to follow OGC's new core/extension paradigm, is distinguished by several properties:

- support for multi-dimensional raster data, plus a broad range of further coverage types, such as curvilinear grids and point clouds;
- crisp and easy to understand for both implementers and users;
- flexible and adaptive to a broad range of different domains, such as remote sensing, web mapping, climate and ocean research, and geology;
- allowing for efficient and scalable implementations, to multi-Terabyte object access;
- harmonized with Geography Markup Language (GML) and Sensor Web Enablement (SWE);
- reflecting OGC's core/extension model; and
- improved testability of the specification.

WCS 2.0 has been developed based on lots of stakeholder consultations, requirements elicitation workshops, and active participation by many scientific disciplines (remote sensing, atmospheric research, ocean research, astrophysics, …), as well as industry, and governmental bodies. In parallel, experiments on implementation feasibility have been conducted. Currently, a *WCS Earth Observation Application Profile* is under work.

Further, the coverage model is harmonized with GML and SWE Common; harmonization with WPS and further standards are next steps. Hence, for the first time OGC has one coherent, ubiquitously usable coverage definition. For GML 4.0 an integration of this coverage model is foreseen by the GML group.

The **Web Coverage Processing Service (WCPS) Interface Standard** allows ad-hoc filtering, processing, extraction, and analysis of multi-dimensional raster coverages. A protocol-neutral language is defined which can be embedded into both WCS and WPS. This language allows to filter and process **sensor, image, and statistics** coverages like

- 1-D in-situ sensor time series
- 2-D ortho images
- 3-D image time series (x/y/t) and geological data (x/y/z)
- 4-D climate and ocean data (x/y/z/t)
- "abstract coverages" which additionally have non-spatiotemporal axes.

Heterogeneous coverages can be combined in one request, enabling **multi-sensor fusion**. The language is **safe** in that no non-terminating requests can be sent, thereby preventing a class of denial-of-service attacks.

The following example shows the principle: "*From MODIS scenes M1, M2, and M3, the absolute of the difference between red and nir, in HDF-EOS, but only those where nir exceeds 127 somewhere inside region R*":

```
for $c in ( M1, M2, M3 ),
    $r in ( R )
where
    some( $c.nir > 127 and $r )
return
    encode( abs( $c.red - $c.nir ), "hdf“ )
```

10.3.2 Motion Imagery

The integration of georeferenced motion video into a decision fusion environment, specifically as prescribed by Motion Imagery Standards Board (MISB)[2] specifications, was identified as a focal point of future work and specifically a topic for OWS-8. The integration should be through a distributed, streaming, services based environment.

The MISB standards are emerging as the defacto standards for motion video. Further development will depend upon broader implementation. Inclusion of MISB access in an initiative like OWS-8 could serve to further exercise the standard and increase its profile in the intelligence community with all participants. Intergraph and other OGC members have the technology to support these developments.

Distributed access to MISB formatted data through a services framework specified by existing OGC standards such as SWE and WCS should be tested in OWS-8. In terms of executing on such an exercise, Intergraph can bring to the table high level COTS with a SWE / WCS access. A second key component of any test bed activity can be Intergraph's Motion Video Analyst Professional (MVAP) that can access WMS, WFS and SWE data sources. This platform would allow for the examination and investigation of various decision fusion scenarios including how to better exploit motion video when it is delivered in a geospatial context. WPS should be included to perform motion video processing.

Specific topics identified in the Fusion Study Workshop were

- MISB coordination
- Motion imagery metadata
- Video Search and Annotation
- WPS for near real-time quality improvement of MISB video feeds

10.3.3 Fusion scenario: Flight path generation from hotspots

Figure 16 sketches a scenario using open standards for fusion. Multi-INT information is used to develop a flight path for a UAV. SIGINT information based upon cellular phone traffic is geotagged. The collection of points can be processed into a density representation that can be used to command a UAV flight path. Geotagging can be done using the OGC Georeferenced Table Joining Service (TJS) standard. The density

[2] http://www.gwg.nga.mil/misb/

representation can be done using OGC WPS standard. Tasking the UAV can be done using the OGC SPS standard.

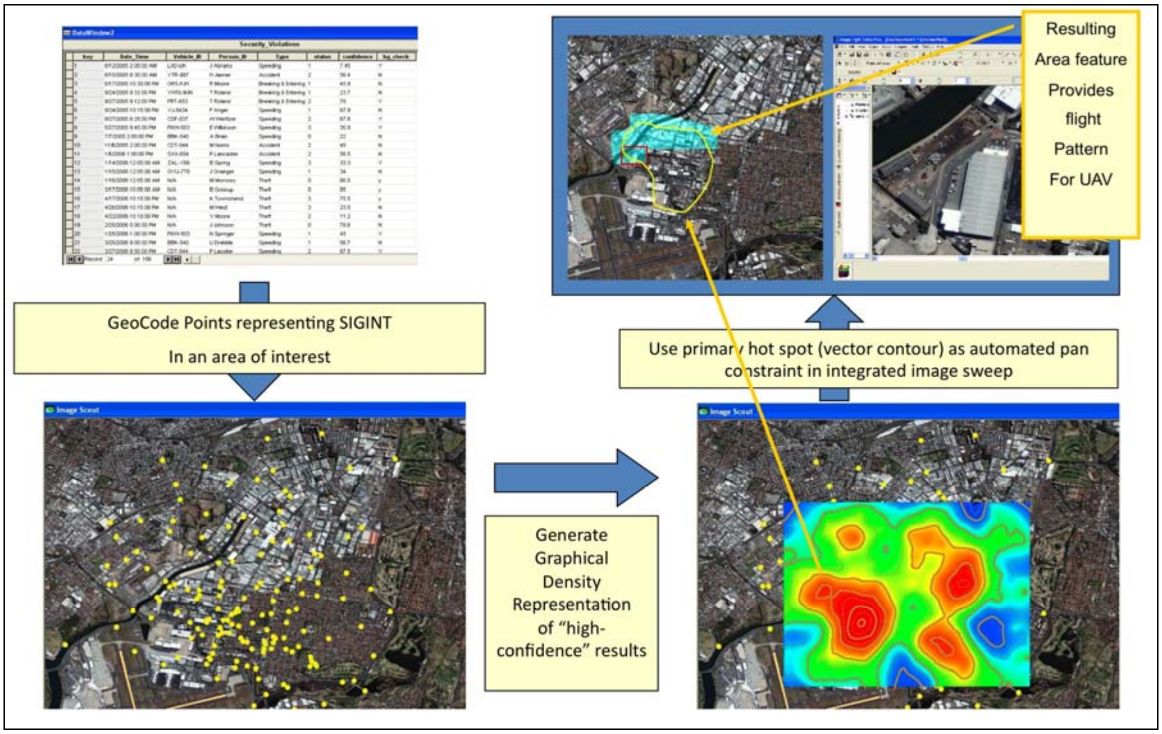

Figure 16 - Fusion via Multi-INT integration (Source: Intergraph, Inc.)

10.3.4 Security and GeoDRM for Observations

Security and GeoDRM are different topics that typically get discussed at the same time as they did at the Fusion Workshop.

Secure SWE Architecture was a development in previous OWS Testbeds. The Fusion Workshop recommended the further development of a security architecture (mission- and role-based) to enable observation fusion. Topics include multi-level authentication and control over imagery data collection

GeoDRM for data can also affect data fusion. For example, providing interoperable mechanisms for handling of licenses for commercial imagery would make the imagery more widely available.

10.3.5 Registries for Observation Fusion

Section 8.4.5 describes an overall approach to supporting all categories of fusion using registries.

In particular it would be useful to develop an ebRIM (V3.0) model for observation fusion. This would use ebRIM Associations, Packages and ClassificationScheme registry objects to model observation associations for observation fusion. Version 3.0 of ebRIM is selected since it is the basis of the OGC CSW-ebRIM specification for which several OGC members have developed commercial implementations.

10.3.6 Mobile clients and soft fusion

The OGC Board of Directors identified the Mobile Internet as a “ripe issue” to be addressed by the consortium. It is clear that mobile communications are moving beyond the walled gardens of the cellular providers allowing for development similar to the wired Internet. OGC is assessing standards that make up the Mobile Internet and as appropriate will begin developing open geospatial standards tuned to the mobile environment.

Mobile devices provide access to sensors both in the handheld device and accessed within a personal area network (PAN) enabled by the mobile device. The sensed data is available for fusion locally as well as through the Internet. The mobile platform can host applications that fuse the observations from the local sensors using resident applications. Further, the mobile device serves as a gateway from the PAN-based local sensor network to the Internet for which the OGC SWE standards provide for interoperability.

Sensors accessed through mobile Internet devices supports an element of “Soft Fusion” identified by [Hall, 2008] (see also Section 8.3.1.3)

10.4 Recommendations

Recommendations for further development of Observation Fusion based on open standards:

10.4.1 Coverage fusion based on WCS 2.0, WCPS and GML.

WCS is a basic data access service, whereas WCPS adds advanced processing capabilities, including multi-coverage fusion. Both deliver coverages, which can be consumed further by other tools, or – where the result can meaningfully be interpreted as an image – can be displayed to humans. This allows for a staged deployment, depending on the level of server-side processing capabilities. Actually, WCPS more and more turns out to be a link between WPS, WCS, SWE, also by lining up with OGC's further query/filter languages.

Version 2.0 of the OGC Web Coverage Service has been adopted by the OGC membership. WCS 2.0 provides the basis for defining a new level of interoperability of geographic coverages. Profiles of WCS 2.0 should be developed to meet the needs of several different communities while still seeking the minimum number of standards – more profiles means less interoperability. Fusion of coverages will be enabled by use of WCS 2.0 in combination with the WPS and WCPS. The newly approved GML schema for coverages will also enable a higher degree of coverage fusion.

It is recommended to assess **multi-coverage fusion** capabilities involving both WCS and WCPS in a scenario with different, heterogeneous raster types, for example 1-D sensor time series, 2-D hyperspectral remote sensing data and bathymetry/elevation data, 3-D EO time series, 4-D climate data. Server-side processing needs to include sufficiently complex queries, taken from real-life examples, to make them convincing to domain experts. All coverages delivered must be encoded following the GML Application Schema for Coverages (09-164r1) in combination with the (currently drafted) coverage formats like GeoTIFF, NetCDF, and JPEG2000. To this end, the WCPS specification should be updated to make use of this new standard.

It is recommended to establish proof-of-concept services for **non-raster coverages**. A whole new set of coverage types has been gained by aligning with GML, but little is known about *serving* non-grid coverages in an OGC environment. Emphasis should not be on "yes, we can serve these data too" (this would repeat GALEON IE and recent Ocean activities, ending up in serving format X with so-so WCS conformance), but an offering of representative data strictly adherent to the WCS 2.0 model.

It is recommended to conduct an experiment on the **integration of workflow, processing, and data access** services. Initial work has been performed by NASA on WCPS as a value-adding ground/space interface, which may serve as a role model and/or basis for continuation. For example, a (simulated) on-board WCPS might deliver some derived data, which are fed, via WCS-T, into a ground-based WCS. WCPS Change Requests submitted NASA and other users should be considered for incorporation in the standard.

It is recommended to complete the **WPS Application Profile** fusing coverages, via WCPS, into WPS. As this very much depends on progress with the WPS 2.0 specification, this needs to be performed in close contact with the WPS.SWG. The concept of offering the coverage request language through different protocols, which fosters harmonization between WCS and WPS, should be evaluated and demonstrated.

It is recommended to **develop WCS extensions** which do not have assignments for now, among them EPSG coordinate handling, scaling & interpolation, and range subsetting ("band selection"). Existing WCS 1.1 extensions (WCS-T, WCPS) need to be carried over to WCS 2.0.

It is recommended to pursue a **WCS 2.0 CITE conformance testbed** in order to obtain a stable basis for future mission-critical implementations of coverage fusion tools.

Finally, one outcome of such activities should be **best practices on WCS 2.0 use** to support community uptake.

10.4.2 Further develop Events in the OWS Architecture

Recent OWS testbeds have developed the initial approach for adding events to the OWS architecture. Events and alerts were initially treated in SWE through the definition of SAS, but events have a wider applicability than just SWE. OWS-7 advanced an event architecture and event service concepts and identified further work to be done. Several items of further work are described in this recommendation.

Within SWE domain, the event architecture has been used for the discovery and access of dynamic sensors. This activity should be continued. It is vital for timely recognition of situation awareness that we are able to readily discover and access information about dynamic sensor assets that might be useful for us, to access observations or receive alerts from these systems in a readily meaningful and usable encoding, and to easily task these systems to provide much needed observations in order to fill gaps in our knowledge. Currently, timely discovery and access to highly dynamic assets is currently challenging at best. Investigating alternatives for improving rapid discovery and access to highly-dynamic are encouraged, including investigations into non-traditional technologies such as P2P and the query of web services that are closer upstream to the sensor system.

Definitions for events, alerts and warnings need to be developed further. An event is an action that occurs at an instant or over an interval of time [ISO 19136]. With event as the more general class, definitions for the terms alert and warning can be developed. These definitions should be done in coordination with the standards bodies, e.g., OASIS, and the programs, e.g., CMAS, that are actively working on these definitions as well. Inherent to the OGC work will be the notion of location for events, alerts, and warnings.

Event Service Workflows were identified in OWS-7 for further development. The use cases tested in OWS-7 concentrated on delivering events that were detected or derived by an Event Service to a client(s). The clients were then responsible for reacting as they see fit. To facilitate automation of workflows – like the invocation of a change detection service upon receipt of an area-of-interest entry event – the community should test the integration of event services in automated processing environments, leveraging available functionality from workflow and chaining services. Tools could also be developed or tested to facilitate this kind of integration.

SWE Events & Event Channels were identified in OWS-7 for further development. The work started in the OWS-6 SWE thread to define an OGC Event Architecture was continued in the OWS-7 Event Architecture cross thread. The results show that the definition of event types as well as event channels is specific to certain application domains. SWE 2.0 service specifications like the SWE Service Model or Sensor Planning Service already started with that work. However, further work in the area of eventing in Sensor Web applications should consider defining events and channels that are of common use. For example, sensor status update events would be of interest. Event channels where observations are posted that are made by certain types of sensors, that contain certain observed properties or that contain results that apply to certain geographic regions could also be beneficial (e.g. performance wise).

10.4.3 Motion Imagery and location – coordinated with MISB

Beginning with OWS-4, OGC initiatives have addressed motion imagery coming from sensors on-board moving platforms. Further work was done in OWS-7 and was discussed extensively in the Fusion Workshop.

Motion imagery change detection was developed in OWS-7 with further development needs identified. OWS-7 SFE was a relatively controlled experiment environment for motion imagery and change detection. More experiments will be needed to test use cases with less a prior knowledge on motion imagery collection. The ability to consume near real-time video at higher frame rates to evaluate a more real-world environment. Further development of imagery metadata to support the services is needed.

MISB and OGC should undertake coordinated development of Motion Imagery as to location elements. The integration of georeferenced motion video into a decision fusion environment, specifically as prescribed by MISB specifications, is recommended. Inclusion of MISB access in an initiative like OWS-8 could serve to further exercise the standard and increase its profile in the intelligence community with all participants. Intergraph and other OGC members have the technology to support these developments using OWS services.

A **motion video fusion scenario** was identified in the workshop including flight path generation from hotspots. The scenario presented at the workshop enabled tasking of a UAV based on SIGINT information from geotagged cellular phone traffic.

10.4.4 Apply SWE to Mobile Internet

Mobile devices connected to the Internet are becoming the main method for access to the Internet. Use of mobile communications is vital to scaling to the trillions of sensors to be deployed in the near future. Scaling access to sensors will require the techniques like in SWE to access sensors that have never been seen before. Application of the SWE services to sensors connected to the Internet via mobile communications including personal area sensor networks should be undertaken.

10.4.5 Further develop Secure Sensor Web

Previous testbeds defined a Secure Sensor Web architecture and tested several elements of the architecture. Application of widely adopted security standards to SWE is important to the diffusion and uptake of SWE broadly into differing security administration domains. OGC makes use of standards for security from other standards organizations. Further testing and refinement of the results reported in the OWS-6 Secure Sensor Web ER [OGC 08-176] should be undertaken.

10.4.6 Registries for Sensor/Observation Fusion

Section 8.4.5 describes an overall approach to supporting all categories of fusion using registries.

In particular it would be useful to develop an ebRIM (V3.0) model for observation fusion. This would use ebRIM Associations, Packages and ClassificationScheme registry objects to model observation associations for observation fusion. Version 3.0 of ebRIM is selected since it is the basis of the OGC CSW-ebRIM specification for which several OGC members have developed commercial implementations.

10.4.7 Online community sanctioned definitions for sensor terms (Phase 1)

The creation of sanctioned definitions and semantics within the sensor and data fusion communities is essential. Some activities are already underway in some communities, while many completed works exist in published documents. These efforts should be harmonized resulting in dictionaries and ontologies that are resolvable online and thus able to be utilized within metadata tags for sensor, observation, and process descriptions.

10.4.8 Harmonization of the process of precise geolocation (Phase 1)

Harmonization of the process of precise geolocation has been improving with the efforts of the Community Sensor Model (CSM) Working Group, the near completion of the ISO 19130 standards, based on CSM, and the demonstration of the effectiveness of encoding these models into SensorML. Such models have been shown to be applicable to remote sensors on-board satellite, aircraft, ship, mobile ground-based vehicles, and immobile stations. We feel that these efforts should continue and become more widely applied throughout the remote sensing communities.

10.4.9 Characterizing and propagating uncertainty of measurements (Phase 1)

All measured and processed results include a certain degree of uncertainty. No measurement, no recognition of an object or event, and no determination of an object's properties are free from possible error and uncertainty. Errors and uncertainty can arise from inevitable limitations in the sensor systems, from errors introduced or propagated during the processing of the data, or in act of comparing observations with signatures taken under varying environmental conditions. Thus, while it is important to minimize uncertainty, recognizing the amount of uncertainty in a result is equally important. It is recommended that efforts be taken to define terms of uncertainty, to insure the inclusion of values of uncertainty within sensor and observations metadata, and to determine algorithms for propagating error through processing algorithms or workflows.

10.4.10 Increasing use of geometric and electromagnetic signatures (Phase 1)

Since geometric and electromagnetic signatures can play a significant role in recognizing objects and events from measurements, and in determining their properties, it is important that the current state of managing signatures be improved. This includes expecting signatures to be treated as we should treat observations. They should be provided with a complete description of the signature's lineage including a robust the sensor and process descriptions, measures of uncertainty, and a description of the environmental conditions under which they were measured. They should also utilize standardized terms and semantics, and should be easily discoverable and accessible. Furthermore when such information is provided for all observations, it can enable new paradigms for creating new signatures based on large numbers of observations taken under varying conditions.

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