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# OGC® Fusion Standards Study Engineering Report



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|---|---|
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## Preface

The Open Geospatial Consortium (OGC®) conducted a study of geospatial fusion including: a review of existing standards regarding fusion; a survey of standards and implementations using a Request For Information (RFI); and development of a set of recommendations for future standards and integration of other standards.

In the context of this OGC Engineering Report (ER), "Fusion is the act or process of combining two or more pieces of data or information regarding one or more entities in order to improve the capability for detection, identification, or characterization of that entity".

This scope and need for this study was based on requirements and contributions from several OGC Member organizations, including the National Geospatial-intelligence Agency (NGA), BAE Systems - C3I Systems, and Lockheed Martin.

This study addressed many challenging issues with a potentially enormous scope. Responses to the RFI were a major contribution toward focusing the study on topics that can be feasibly deployed in a distributed environment with interoperability based on open standards. OGC and the sponsors of the study are most grateful to the organizations that responded to the RFI – listed in Section 5.3.

This ER includes discussions and recommendations for fusion standards in three categories: sensor fusion, object/feature fusion, and decision fusion. Elements of this study will be implemented through the OGC Web Services, Phase 7 (OWS-7) Testbed.

 

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# OGC® Fusion Standards Study Engineering Report

## 1 Introduction

### 1.1 Scope

This OGC Engineering Report (ER) provides discussions and recommendations for information fusion, with a focus on geospatial information. In this ER, fusion is discussed in three categories: sensor fusion, object/feature fusion, and decision fusion. Recommendations in this ER will be considered in the planning of future activities including the OWS-7 Testbed.

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.

### 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), BAE Systems - C3I Systems, and Lockheed Martin.

## 1.3 Document contributor contact points

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## 1.4 Revision history

| Date | Release | Editor | Primary clauses modified | Description |
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| 28 August 2009 | 0.0.1 | G. Percivall | All | Initial annotated outline |
| 2 October 2009 | 0.1 | G. Percivall | All | Initial complete draft for review |
| 30 October 2009 | 0.2 | G. Percivall | Editorial changes | Version for posting to OGC Pending |

## 1.5 Forward

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.

 

## 2 References

The following documents are referenced in this document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the normative document referred to applies.

**Request for Information (RFI) for OGC Fusion Standards Study**, 16 July 2009, http://www.opengeospatial.org/standards/requests/59

**OGC Reference Model**, Version: 2.0, OGC Document 08-062r4, http://www.opengeospatial.org/standards/orm

The Bibliography of this ER provides extensive references to standards relevant to the study.

## 3 Terms and definitions

### 3.1

### 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

Note: See section 6.1 for a derivation of this definition.

## 4 Conventions

### 4.1 Abbreviated terms

| | |
|---|---|
| BPEL | Business Process Execution Language |
| CAP | Common Alerting Protocol |
| CSM | Community Sensor Models |
| CSW | Catalog Services for the Web |
| ER | Engineering Report |
| GEOINT | Geospatial Intelligence |
| IED | Improvised Explosive Device |
| IMINT | Imagery Intelligence |
| KML | (was Keyhole Markup Language, now just KML) |

 

| | |
|---|---|
| LIDAR | Light Detection and Ranging |
| LOC | Location Organizer Client |
| LOF | Location Organizer Folder (LOF) |
| MASINT | Measurement and Signature Intelligence |
| NGA | National Geospatial-intelligence Agency |
| O&M | Observations and Measurements |
| OGC | Open Geospatial Consortium |
| OWS | OGC Web Services |
| REST | Representational State Transfer |
| RFI | Request For Information |
| SANY | Sensors ANYwhere |
| SAS | Sensor Alert Service |
| SE | Symbol Encoding |
| SIGINT | Signals Intelligence |
| SLD | Style Layer Descriptor |
| SOA | Service Oriented Architecture |
| SOAP | (was Simple Object Access Protocol, now just SOAP) |
| SOS | Sensor Observation Service |
| SPS | Sensor Planning Service |
| SWE | Sensor Web Enablement |
| TOF | Track Object Format |
| TQAS | Topology Quality Assessment Service |
| UAV | Unmanned Aerial Vehicle |
| UGS | Unattended Ground Sensors |
| WCS | Web Coverage Service |
| WFS | Web Feature Service |
| WMS | Web Map Service |
| WNS | Web Notification Service |
| WPS | Web Processing Service |

# 5 Fusion Standards Study

## 5.1 Objectives of the Study

Fusion Standards Goal: The fusion standards study goal 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 from one client.

Fusion Portfolio Objectives: 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, identify, 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.

## 5.2 Standards Based Fusion

Much of the fusion processes described in this Engineering Report can be achieved in multiple closed architectures with existing single provider software and hardware solutions. Fusion is not a new topic. The problem addressed by this Engineering Report is to move those capabilities into an distributed architecture based upon open standards including standards for security, authorization, and rights management.

> State A (As-Is): 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.
>
> State B (Target): 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.

## 5.3 Request for Information

OGC issued a Request for Information (RFI) to solicit industry input into the Fusion Standards Study. The RFI served as an element of a market survey of the current state of standards and implementations (commercial and open source) to determine the as-is level of support for standards based geospatial fusion with specific interest in fusion of multi-INT sources in a net-centric environment. This market survey identified the level of maturity of identified standards and implementations to include any previous testing of these standards and services which may have occurred as part of the OGC interoperability program such as testbeds, interoperability experiments, etc.

**Table 1 – Organizations Responding to Fusion Study RFI**

| | |
|---|---|
| Aston University | Aston University is a technology-focussed university located in Birmingham, UK. The Aston researchers are the developers of UncertML and work on data assimilation, data fusion and probabilistic modelling in geospatial, epidemiological and other environmental and medical contexts. |
| Envitia | Envitia is a UK based SME operating for over two decades in the area of geospatial information technology and in particular in information harmonisation and fusion for analysis, situational awareness and decision support. |
| Fortius One | FortiusOne provides rich, dynamic Visual Intelligence. By providing easy-to-use, browser-based Visual Intelligence solutions, FortiusOne enables non-technical users across your enterprise to make better strategic business decisions. |
| Fraunhofer IITB | The core competences of the Fraunhofer Institute for Information and Data Processing (IITB) lie above all in the three domains of image analysis, control technology, and information and communication management. |
| Galdos | Galdos targets the rapidly growing Spatial Data Infrastructures (SDI) market. Galdos is a supplier to governments, government agencies and private companies that deal with geographic information. The Company's technology enables its customers to manage geographic information from multiple sources and share it across the Internet in real-time. For Galdos' customers this means increased efficiencies in data sharing and significant cost reductions. |
| Intelligent Automation, Inc. | Intelligent Automation, Inc. continues to maintain its core focus as an R&D company responding to the complex technological requirements of our Government and commercial clients. We are actively focusing on transitioning our technology to major government and commercial programs and are aggressively seeking partners to assist in the commercialization of our technology, for current and new market niches. |
| Intergraph | Intergraph Corporation is the leading global provider of engineering and geospatial software that enables customers to visualize complex data. Businesses and governments in more than 60 countries rely on Intergraph's industry-specific software to organize vast amounts of data into understandable visual representations and actionable intelligence. |
| Luciad | Luciad is building open software solutions for distributing, visualizing and editing geographical information in networked environments. Luciad's core product is LuciadMap™, a GIS enabling software. Luciad Web Map Server Suite™ is an OpenGIS compliant server for producing maps on the Internet and intranets. |
| PYXIS | PYXIS (application Geospatial Web is a digital medium designed to allow rapid distribution of content from many sources. The GeoWeb is also a participatory Web - everyone can contribute. While the Web uses text to organize content, the GeoWeb uses Earth location. |
| Northrop Grumman | Northrop Grumman Information Systems (NGIS) and Aerospace Systems (NGAS) provided a combined response to the RFI.<br>NGIS s a leading global provider of advanced solutions that deliver timely, enabling information to where its needed most for its military, intelligence, civilian, state and local and commercial customers.<br>NGAS is a premier provider of manned and unmanned aircraft, space systems, missile systems and advanced technologies critical to national security. |

 

# 6 Definition and Categories of Fusion

## 6.1 Definition of Fusion

The initial working definition used in this study was "Fusion is the act or process of combining two or more pieces of data or information regarding one or more entities in order to improve one's capability (or provide a new capability) for detection, identification, or characterization of that entity".

In addition to the initial working definition, the sponsors of the study also pointed out that according to the Joint Directors of Laboratories (JDL), data fusion is "A process dealing with the association, correlation, and combination of data and information from single and multiple sources to achieve:

- Refined position and identify estimates, and
- Complete and timely assessments of situation and threats, and their significance"

Several Fusion Study RFI responses commented on the definition of fusion:

Fraunhofer defines fusion as "the processing of sensor data together with general knowledge of the phenomenon of interest." This definition is in the context of the Bayesian Maximum Entropy method. It is recommended the inclusion of "general knowledge" or "knowledge framework" be used to modify the initial definition of fusion.

Galdos commented "Fusion from our perspective is the creation of a collection of named and possibly typed associations between instances of typically disparate data types." It is recommended that the initial definition of fusion be modified to not require "combining" but simply "association" of the source data.

PYXIS adopts a strong requirement that "Network-centric fusion requires that information is pre-aligned to a uniform model (or can be rapidly aligned) so that all data sets are self synchronized." A requirement for alignment and self-synchronization is too strong; whereas the ability to relate data based upon harmonized knowledge framework is offered as a less restrictive approach.

Based on the RFI Responses, this definition is derived from the initial working definition:

> *"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".*

## 6.2 Categories of Fusion

As indicated in the working definition of fusion listed above, fusion processes can apply to many types of entities. Categories of fusion depend on the processing stage or semantic level at which fusion takes place. Fusion processes are often categorized as shown in Figure 1. Sensor Fusion combines several sources of raw data to produce new data that is expected to be more informative and synthetic than the inputs. This kind of fusion requires a precise (pixel-level) registration of the available images, as well as perhaps synchronization of dynamic observations. In the intermediate category - Object or Feature Fusion - attributes or elements of geographic features are combined into new features and that may then be used by further processes. Creating associations between features that were not previously associated is also considered. Decision Fusion supports near-real-time manipulation and sharing of massive amounts of increasingly complex information collected and fused from diverse data sources to support collaborative decision making.

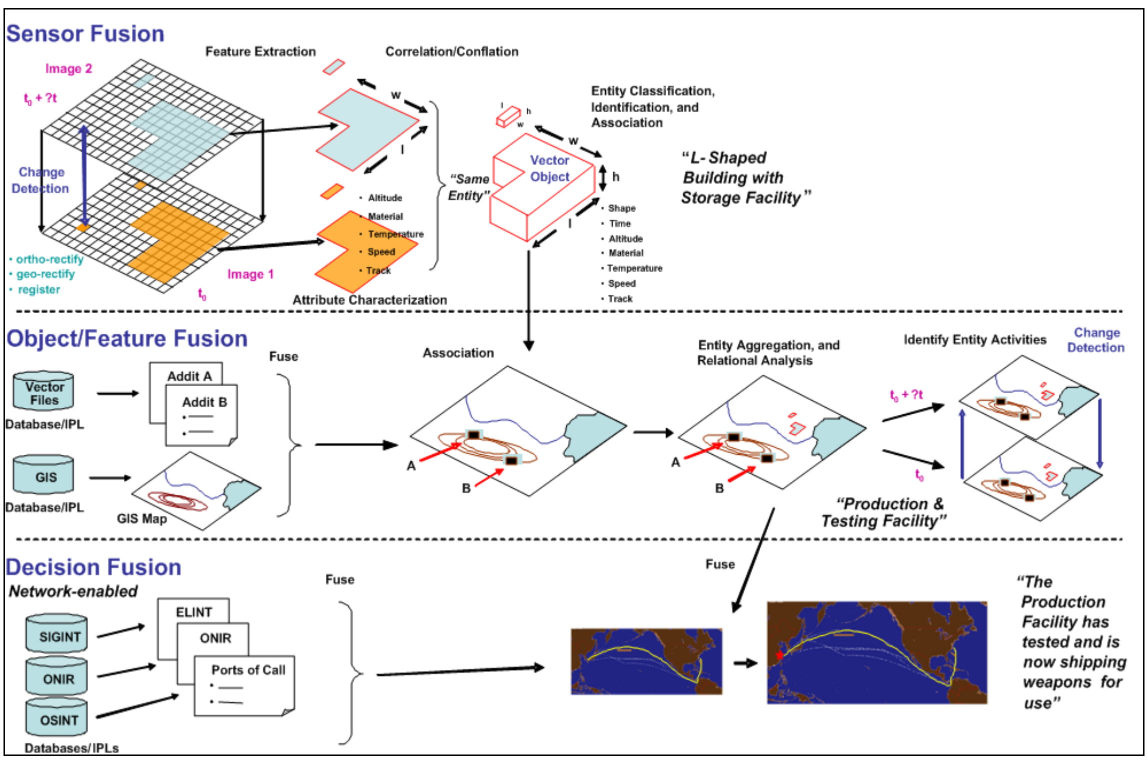


**Figure 1 –Categories of Fusion**

 

This Engineering Report is organized around three categories of fusion that build upon the categories displayed in Figure 1. The three categories are consistent with geographic information ranging from sensor *measurements* through feature operations to decision support[1]. The terminology for geographic information standards differs from terminology used in the field of image understanding[2]. A *feature* in the ISO 19100 series of standards is an "object" in image understanding terminology. A *geometric object* identified in an image in the ISO 19100 series is a "feature" in image understanding terminology.

The Galdos response to the RFI commented that "We believe that the distinctions drawn in the framework for the study, namely between Sensor, Feature and Decision Fusion are essentially correct, although we would change the first one to Observation Fusion, as term Observation as adopted by OGC includes sensor readings." As there was not consensus on this proposal and there is much mind share regarding the term "sensors," the project retained "Sensor Fusion".

The three categories of Fusion used in this Engineering Report are:

- Sensor Fusion: ranging from 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.
- 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: focuses on client environments for analysts and decision makers to visualize, analyze, and edit data into fusion products for an understanding of a situation in context. Decision fusion includes the ability to fuse derived data and information with processes, policies, and constraints. Collaboration with other analysts is done using social networking services and collaboration tools that are location enabled.

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.

[1] Cf. OGC Reference Model

[2] A discussion of the terminology can be found in ISO 19101-2 Geographic Information – Reference Model – Imagery

 

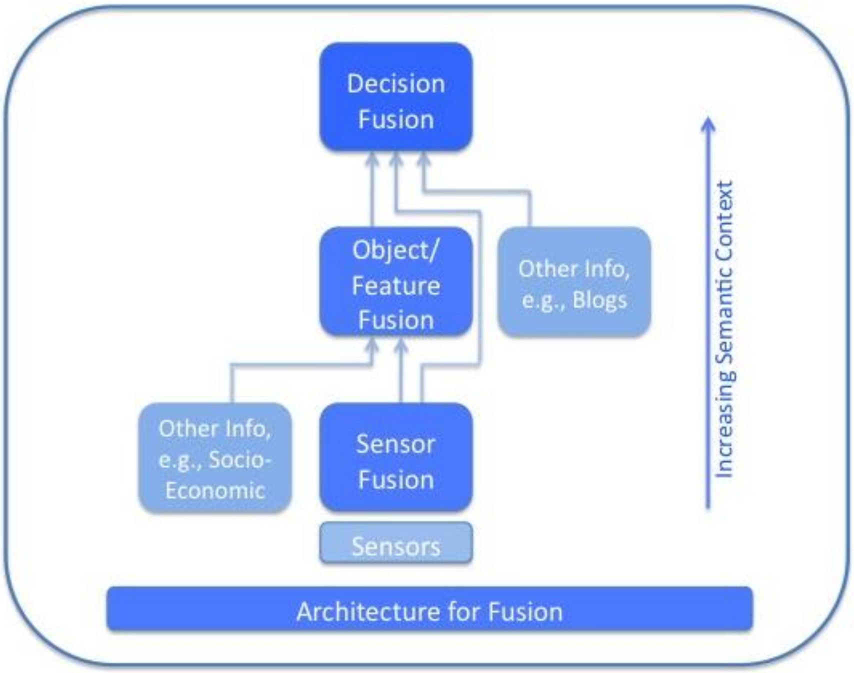


**Figure 2 - Fusion Categories for ER**

## 6.3 Organization of Fusion Sections

This ER is organized using the Fusion Categories with each category section of the ER following a common outline (Table 2). This common outline is based upon the commonality of the fusion process across the three fusion categories.

**Table 2 – Common Outline for Fusion Category Sections**

| | |
|---|---|
| Definition and Objectives | The definition for fusion is considered specifically for the category. The objectives for fusion processes for that category are identified. |
| Enabling Capabilities | Technical capabilities that enable or enhance fusion capabilities are identified. Descriptions of fusion processes for the category are provided. |
| Objects from Fusion Processes | Description of the information types that result from the fusion processes |
| Tools, Resources and Standards | Tools and Resources with relationship to existing standards that enable fusion are listed. |
| Recommendations | Recommendations toward reaching the "to-be" state of a standards based fusion environment are listed. For convenience, all of the recommendations are summarized in Section 7. |

 

# 7 Summary of Recommendations

The recommendations listed here in bullet form are discussed in detail at the end of their respective fusion category section.

## 7.1 Sensor Fusion

- Harmonization of the process of precise geolocation
- Online community sanctioned definitions for sensor terms
- Discovery and access of dynamic sensors
- Characterizing and propagating uncertainty of measurements
- Increasing use of geometric and electromagnetic signatures
- Fusion of video from airborne and ground based platforms
- Recognition and characterization of observed objects/features and events

## 7.2 Object/Feature Fusion

- Define a conceptual model of feature lifecycle – beyond conflation.
- Standardize metadata for provenance and uncertainty.
- Develop common data models supporting feature fusion.
- Define a portfolio of feature fusion services.
- Develop schema and encoding to support sharing of Track Features

## 7.3 Decision Fusion

- Develop an information model with decisions as a first class object
- Define interfaces and functionality for decision fusion engine component type
- Uncertainty propagation for a “hard fusion” topic
- “See and Talk” collaboration with common view
- Coordination through social networks
- Political Geography as a step to all information types
- Dynamic routing based on location
- Conduct Fusion Standards Study, Part 2 focused on decision fusion

## 7.4 Architecture and Infrastructure

- Use of Open, Community IT Standards
- Semantics mediation of community vocabularies, taxonomies
- Workflow driven by semantics
- Grid and Cloud implementations for performance and access

 

# 8 Sensor Fusion

## 8.1 Definition and Objectives

Sensor 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

Sensor fusion involves how measurements are made available to fusion processes and how the fusion processes make use of the observations to create semantically higher order entities, e.g., geospatial features.

The basic requirements for sensor fusion include:

- Discovery of sensor systems, observations, and observation processes that meet a user's immediate needs
- Determination of a sensor's capabilities and quality of measurements
- Access to sensor parameters that automatically allow software to process and geo-locate observations
- Retrieval of real-time or time-series observations in standard encodings including encoding the uncertainty of the measurement and parameters need to process the measurements.
- Tasking of sensors to acquire observations of interest
- Subscription to and publishing of alerts to be issued by sensors or sensor services based upon certain criteria
- Entity identification, classification and association.
- Enablement of fusion processing by providing access to processing engines and needed reference information (e.g. signatures and training data).

The relationships between sensor observations, recognized objects, and the fusion processes are illustrated in Figure 2 while each part is discussed in more detail below.

 

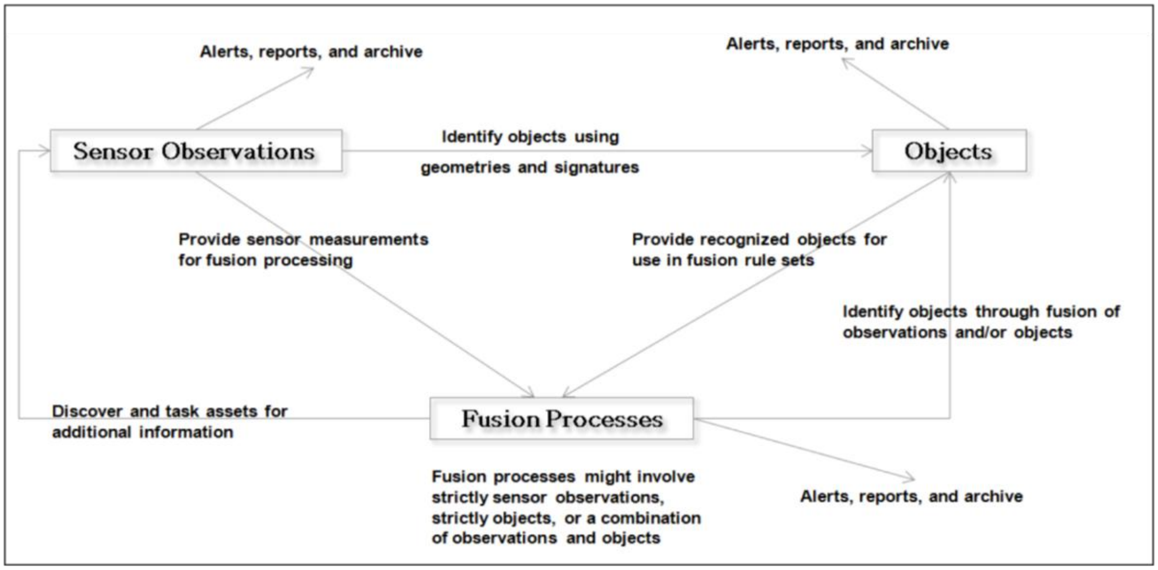


**Figure 3 – Sensor Fusion processes**

**Sensors Observations.** Much information suitable for fusion begins with or is derived from observations by sensors or humans. This is particularly true for information that is highly dynamic in nature and of a timely nature. These observations, either raw or processed, can serve as input into fusion processes or they may be used to identify recognizable objects or features that are then treated as input into a fusion process, as illustrated in Figure 3. Identification of objects from sensor observations typically relies on comparison of these observations against known signatures for select objects or on the use of various classification algorithms. Signatures can be sensor or signal-dependent, and may be based on geometry, electromagnetic response, or on the combination of properties measured by multiple sensor types. The results of sensor observations or object recognition can be streamed in real-time, published as alerts or reports, or distributed to archives.

As an example of using sensor fusion to recognize objects from multiple raw observations, consider capabilities able to recognize a particular moving object on the ground using multiple frames from a UAV-borne video camera. The shape and size of this feature may be able to be derived from multiple frames of the video, as might its speed and direction. While its color could be derived from a color camera, its temperature might be derived from an infrared imager upon the UAV or other platform. If this vehicle passes near a cluster of unattended ground sensors (UGS), a seismic sensor could determine its weight as well as potentially other properties based on certain signatures. An acoustic sensor might be able to discern additional properties of the vehicle based on known acoustic signatures. All of these observations provide additional knowledge about the properties of the features that may aid in recognizing the object itself and perhaps its intended purpose.

**Objects for Fusion.** Objects that are suitable for fusion and for enhancing situation awareness can include those that are fairly persistent and exist in a geospatial feature database (e.g. streets, buildings, etc.), as well as those that are highly dynamic and sensed in real time by sensors and human observers. Examples of highly dynamic features include explosions, gunshots, the passing of a vehicle, the movement of persons or objects of interest, the opening of a door, or the placement of an Improvised Explosive Device (IED), just to mention a few.

As discussed above, sensor observations can assist in recognizing features/objects and discerning their properties. Feature and feature properties may be stored in geospatial databases but may also be streamed or published as reports in real time. Relationships between features or differences in features over time can be used within a fusion process to enhance situation awareness

**Fusion Processes.** Fusion processes might take as input sensor observations, recognized objects/features, or a combination of both. The results of the fusion process might themselves include identified features of interests and might again be streamed in real-time, published as alerts or reports, or distributed to archives. Additionally the fusion process might result in a need to discover and task additional sensor assets that can provide information needed to refine or provide additional situation awareness.

Fusion processes can be viewed from many perspectives. Data fusion processes can be classified according to the measureable characteristics:

- Spatial, e.g.:
    - creating mosaics and tiles from multiple imagery
    - 3D geometric reconstruction of static objects from imagery taken from multiple directions
    - creating image composites (e.g. combining low-resolution color imagery with high-resolution panchromatic imagery)
    - recognition of objects based on texture (e.g. Fast-Fourier Transforms) or key spatial positions (e.g. facial recognition)
- Spatial-temporal (temporal differencing), e.g.:
    - determining paths of objects from video observations or other temporal observations
    - discovering long-term changes (e.g. new construction)
    - recognizing time-series patterns and subsequent anomalies, such as motion of crowds or traffic, or patterns in communication chatter
- Spectral (all measureable electromagnetic wavelengths). e.g:
    - determining chemical composition from hyperspectral signatures
    - event or object recognition based on spectral signature
    - object recognition based on magnetic or gravitational disturbance or seismic signature
    - voice or sound recognition
    - determining speed and direction using Doppler shift
- Disparate observable properties, e.g.:

 

    - deriving windchill from temperature and wind speed
    - determining vehicle type from acoustic and magnetic signals
    - determining a building's function from geometry and temperature measurements

Additionally, fusion can be classified by the source of the information:

- Multi-sensor, e.g.:
    - Same modality (e.g. video from different UAVs)
    - Different modality/multi signal (e.g. combining acoustic and seismic)
- Multi-INT or multi-agency (e.g. MASINT combined with IMINT)
- Multi-Object (e.g. an identified type of vehicle driven by a particular person)

Regardless, the fusion process can result in reports of information regarding events or feature of interest. This information can be of various quality and with various levels of uncertainty. It is important that the fusion process be able to provide some measure of quality, uncertainty, and lineage with any results that are reported. In many instances, the fusion process is likely to initiate a need for additional information to be derived by database search, by tasking of sensor assets, or by executing additional fusion processes.

## 8.2 Enabling Capabilities

There are certain fundamental capabilities that are essential to enabling the adequate fusion of observations, particularly if these observations are from multiple, disparate sensors. These capabilities are essential for discovery of available resources, for determination of their spatial, temporal, and semantic relationships to one another, for processing low-level data to higher-level information, and for assessing the reliability and lineage of the information.

These enabling capabilities include:

- Precise geospatial and temporal registration of observations
    - Harmonized sensor models for supporting precise geolocation (e.g. Community Sensor Models – CSM)
    - Accurate and consistent time tagging of observation results
    - Ready access to on-demand and automatic georectification of observations within web services, agents, and client tools
- Sensor and process descriptions, important for:
    - Discovery of available assets capable of meeting fusion needs
    - Observation lineage, providing a measure of Quality Control
    - Quality assurance based on observations and sensor/process characteristics
    - Enablement of on-demand processing of observations to higher-level information

  - Provides a taxonomy of sensors and processes
- On-demand and automated observation processing (both web service and tool-based)
  - Georegistration, georectification, and regridding
  - Image and signal processing
  - Advanced spatio-temporal processing, e.g., stereoscopy and oblique imagery reconstruction of 3D
  - Time differencing and change detection
  - Classification and signature matching
  - Object identification and pattern recognition
- Harmonization and interoperable models and encodings for disparate sensors, observations, and processes
  - Development of common semantics for sensor observations, and processes
  - Online, referenceable dictionary/ontology of terms: Observable properties, Sensor and process properties, Relationships, and Recognized objects
  - Development of common profiles or models for sensors, observations, and processes
  - Use of a common encoding for sensors, processes, and encodings (e.g. SensorML, O&M with SWE Common)
- Timely discovery of highly dynamic and mobile assets, observations, and alerts
  - Ability to obtain real-time knowledge of the availability of appropriate assets within an area of interest
  - Ability to rapidly update discovery registries based on streaming data
  - Ability to query sensor resources closer to the source (e.g. "Did you look at this particular area during this particular time?")
  - Investigation into non-traditional means of discovery, including for instance peer-to-peer (P2P) and similar technologies
- Efficient streaming protocols for delivery of large, real-time or archived observations (e.g. JPIP/JP2, RTSP, HTTP Streaming, etc.), as well as alerts
  - Maintaining sufficient metadata and semantics while supporting efficient encodings
  - Including support for on-demand geolocation and processing of streams
  - Accurate time-tagging of streaming observations (often essential for effective data fusion)
- Security and Authentication for sensor and actuator assets
  - Classification tagging within encodings and service descriptions

 

- Controlled access to discovery engines, decryptions, and web services
- Protection of messages during transmission

- Treating signatures as observations
  - Providing full lineage of signatures including sensors, processing, and the environment (typically itself measured with sensors)
  - Allowing easy discovery of signatures for particular sensor types and needs
  - Allowing easy access to signature with common formats
  - Allowing easy means of processing and comparing signatures against observations
  - Accumulating and mining the whole of observations as a means of deriving signatures and recognized patterns
- Accounting for uncertainty
  - Providing common semantics of uncertainty (both with measurements and relationships)
  - Defining and tagging uncertainty within sensor, process, and observation metadata
  - Providing algorithms for the propagation of uncertainty (error) through a process chain
  - Providing means for improving uncertainty using measurements from disparate or multiple sensors (e.g. Bayesian methods)

Some of these enabling capabilities exist to some degree but are in need of focus within research and implementation projects. Many of these capabilities have been enabled by technologies such as the SWE encodings and services, but the creation of semantics and profiles for sensors, processes, and web services would greatly improve the interoperability that is needed for achieving a high-degree of sensor fusion.

As stated above, geospatial and temporal registration of observations is necessary for sensor fusion. There are several approaches on how to achieve such registration including consideration of reformatting in a distributed environment. PYXIS responded to the Fusion RFI promoting the use of a multi-resolution, equal-area, discrete global grid for aiding in the fusion process. Particularly focused on a hexagonal tessellation of the Earth called the optimized Icosahedral Snyder Equal Area aperture 3 Hexagon Grid (ISEA3H). With regard to sensor fusion, PYXIS advocates resampling sensor data to ISEA3H grid to aid in fusion and application of grid specific algorithms for image processing, pixel-to-pixel operations, and fusion. While the ISEA3H tessellation work is impressive and may be useful for an individual fusion algorithm; standardizing data exchange formats to a particular grid is too brittle of an approach for a distributed system. A more robust process is to standardize how a dataset describes its gridding thereby allowing downstream fusion algorithms to re-grid if necessary as late as possible. Such an approach – regrid as little and as late as possible – is supported by the existing SWE standards.

 

As an example of the sensor fusion using open standards consider the approach developed by Fraunhofer and the SANY project (Figure 4). "Fraunhofer IITB has realized a testbed for sensors and services in order to test the architecture and specifications developed in the EU Project SANY (Sensors Anywhere) based on going work of OGC (in particular the Sensor Web Enablement suite of standards). At the sensor network level, an ad hoc wireless network (ZigBee) is complemented by simulated sensor nodes." [FRA]

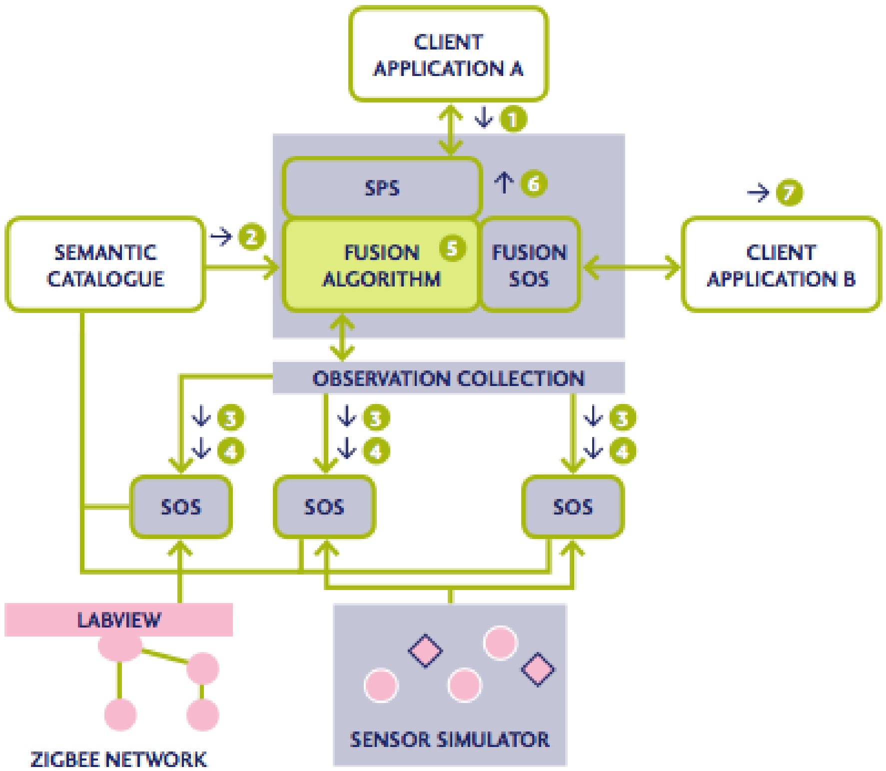


**Figure 4 – Sensor Fusion using SOS**

Based on the experience of this implementation, the Fraunhofer team's conclusions included:

- OGC services were easily and rapidly deployed in typical environmental monitoring applications. The largely self-describing information sets (XML files in specific schemas) delivered by the services are an important step towards plug & measure of sensors and application components. The progress beyond proprietary exchange formats requiring customized processing is not to be underestimated.
- However, further standardization work is required to harmonize the formal description of resources such as observed properties and to specify techniques to map between the resources defined in different expert communities.  One approach is to develop network accessible identifiers, e.g, URNs, that represent defined phenomena.

## 8.3 Objects from Fusion Processes

Objects resulting from sensor fusion processes include:

 

- Recognition of an event or phenomenon as a feature of potential interest
- Estimation of the attributes of geographic features including presence or absence
- Location and geometric shape of physical entities
- Estimation of physical and functional attributes of objects/features
- Provenance and uncertainties of the information about objects.

In the same way that Observations should be linked to the processes that created them (e.g. sensors and post-processing), Objects and object properties should be linked to the observations and fusion processes that allowed them to be identified and measured. This could be accomplished through links within the Object's XML instance that point to the observations that helped identify the object and discern the property value. Alternatively, and perhaps more practically, relationships could be provided outside of the XML using links (in databases or registries or ontologies) that allow one to discover linkage between observations and objects.

### 8.4 Tools, Resources and Standards

The ability to discover, access, and fuse multiple observations for the purpose of enhancing situation awareness is or will be enabled by the development, refinement, and implementation of several standards and tools. These resources include encoding for assets and data, web services for standard access to observations, sensor tasking, processing, and discovery, and software tools for processing, visualization, analysis, and decision support.

The technologies and standards (emerging and adopted) thought to be relevant to enabling open and interoperable fusion in this category are identified in Table 3.

The following standards (emerging and adopted) are thought to be relevant to enabling open and interoperable fusion in this category. Standards are listed below in brief with full citations in the Bibliography.

- SensorML
- SWE Common
- Observations and Measurements (O&M)
- Sensor Observation Service (SOS)
- Sensor Alert Service (SAS)
- Sensor Planning Service (SPS)
- Web Coverage Service (WCS
- Web Processing Service (WPS)
- Business Process Execution Language (BPEL)
- ebRIM

 

**Table 3 – Technologies for Sensor Fusion**

| | |
|---|---|
| Encodings | Sensor and process descriptions (e.g. SensorML, CCSI)<br>Observations and signatures (e.g. O&M, SensorML, SWE Common, NITF, netCDF, HDF, etc.)<br>Tasking messages (e.g. SWE Common, ACTM, etc.)<br>Alert and event messages (e.g. SWE Common, CAP, EDXL, etc.) |
| Web services | Asset discovery: Sensors and processes; Observations; Signatures<br>Observation and signature access (e.g. SOS, WCS, WFS, etc.)<br>Alert and event subscription (e.g. SAS, SES, etc.)<br>Tasking (e.g. SPS)<br>Web service access to processing algorithms (e.g. WPS, BPEL)<br>Catalogue services for discovery (CSW) |
| Clients | Discovery<br>Observation portrayal<br>Observation analysis<br>Observation processing<br>Decision support |
| Middleware | Rule-based alert/event recognition and notification<br>Semantic discovery and term resolution<br>Temporal synchronization and spatial coincidence detection<br>Alert detection, observation processing, fusion processing, and asset tasking coordination |

### 8.5 Recommendations

A key requirement for sensor fusion is the interoperability between disparate sensor systems and between different observation provider and consumer communities. The ability to fuse vital information from various observation sources is currently limited or inhibited by our inability to:

- Discover available dynamic assets across domains, to access observations in a common format using common interfaces
- Submit task requests through common interfaces and message structures
- Readily feed all of these observation results into fusion processes.

The appropriate profiling and implementation of open standards for sensor encodings and sensor web interfaces can greatly improve our abilities to achieve sensor fusion not only within traditional communities, but between communities who have traditionally found interoperability challenging because of differences in sensors, observations, and processing, differences in the ultimate application of the fusion processes, or simply due to multi-agency differences.

 

The following recommendations are offered for improving our capabilities for employing sensor fusion readily and in a highly effective manner.

#### 8.5.1 Harmonization of the process of precise geolocation

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.

#### 8.5.2 Online community sanctioned defintions for sensor terms

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.

#### 8.5.3 Discovery and access of dynamic sensors

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.

#### 8.5.4 Characterizing and propogating uncertainty of measurements

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.

#### 8.5.5 Increasing use of geometric and electromagnetic signatures

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.

### 8.5.6 Fusion of video from airborne and ground based platforms

Video from airborne (e.g., UAVs) and ground-based platforms provides a sensor source that both challenges many data handling systems, as well as provides opportunities for advanced fusion processing. Challenges include the need for common tasking interfaces for all UAVs and video systems, the difficulties in discovering coverages from highly dynamic sensor systems, the need for supporting large volumes of streaming data, the importance of efficient on-demand precise geolocation of video frames, the opportunity to derive 3D geometric from multiple frames, and the ability to derive advanced knowledge from temporal differences. It is recommended that profiles for airborne video be developed for SWE standards (particularly SensorML, O&M, SOS, and SPS) and that these be tested and demonstrated.

### 8.5.7 Recognition and characterization of observed objects/features and events

It is important to test and demonstrate whether existing standards and technologies can improve the connection between sensor measurements and the recognition and characterization of observed objects/features and events.  The process of sensor fusion for the purpose of object recognition and characterization can challenge traditional systems that struggle with disparities between both sensor systems and community standards. It is recommended that testbeds be establish to test and demonstrate the application of SWE standards for improving sensor fusion across various sensor communities and agencies.

 

# 9 Object/Feature Fusion

## 9.1 Definition and Objectives

### 9.1.1 Definition

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.

Users want to see domain specific objects presented to them in a manner relevant to the function being performed. For example in air navigation a user will be more interested in, say, ‘aerial obstructions’ and will not usually care if it is a ‘communications tower’. Given the continual requirement to cross-link information or use it in alternative contexts (information interoperability), it is very important to users that the information they see is consistent (or at worse has well defined inconsistency) with other information even if it is presented in a different form. Envitia labels this harmonised information feed.

Critical to Object/Feature Fusion is understanding and generating metadata that record the provenance (i.e., lineage, pedigree, chain of custody and processing) of the sources and the nature of feature fusion processes that have been applied to derive “value-added” information from them.

The “end game” is to improve understanding of the operational situation and assessment of potential threats and impacts by integrating multiple data formats, data models, and tools to identify, classify, associate, and aggregate entities of interest (i.e., targets, features, tracks, objects, activities). The ability to automate processing and scale storage, network, and compute capabilities to suit growing data volumes and evolving analytical complexities becomes increasingly critical.

As stated in the Fusion Categories (Section 6.2): The terminology for geographic information standards differs from terminology used in the field of image understanding[3]. A *feature* in the ISO 19100 series of standards is an "object" in image understanding terminology. A *geometric object* identified in an image in the ISO 19100 series is a "feature" in image understanding terminology.

### 9.1.2 The Feature Lifecycle

The Feature Lifecycle concept introduces a model of managed, automated, scalable, and repeatable processes for handling geospatial feature objects as a “continuous response to observations made in the physical world and propositions about the state of the physical world that are represented in a digital world.”[4] The model provides context for the role of Object/Feature fusion in a larger information production and management environment. From this perspective, feature fusion “encompasses a much broader scope of problem than

[3] A discussion of the terminology can be found in ISO 19101-2 Geographic Information – Reference Model – Imagery

[4] Feature lifecycle presented here is derived from Northrop Grumman response to the Fusion RFI.

 

simply feature conflation" to include aspects such as spatio-temporal data models, active behavior through change/anomaly detection and triggered event processing, multi-source spatio-temporal discovery, and temporal conflation.

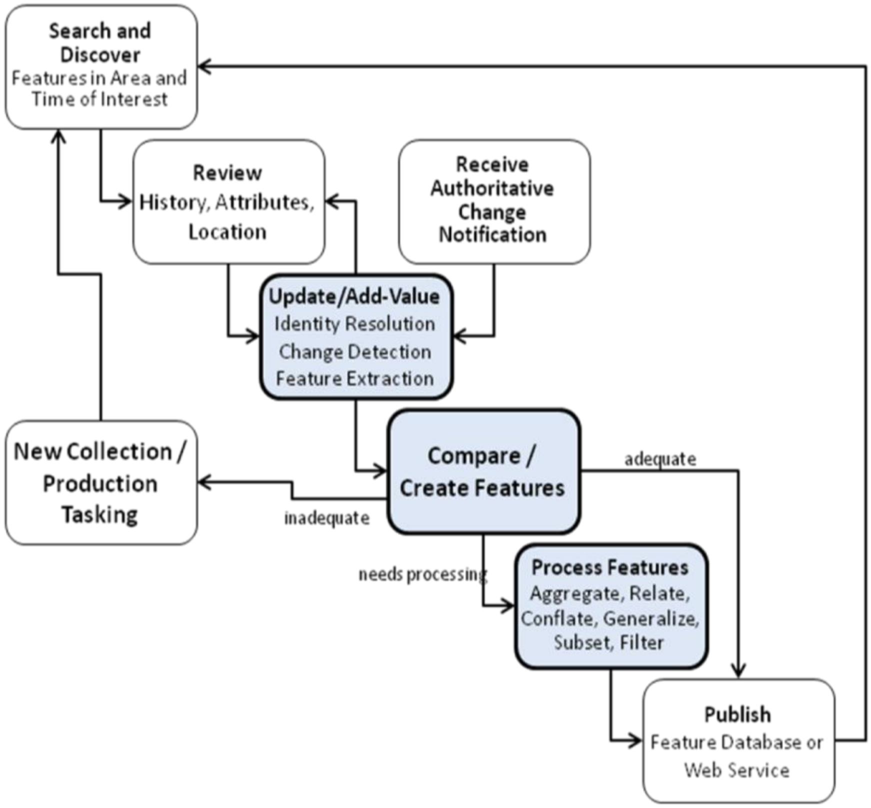


**Figure 5 – Feature Lifecycle[5]**

The emphasis of the Feature Lifecycle model is on managing, adapting, and responding to changing states of features and the "capabilities to manage change with dependencies upon external sources of knowledge." The core Object/Feature Fusion activities in the model are:

**Update/Add-Value** – integrating data with processes and tools for *identity resolution* (matching observations and facts to individual object instances), *feature extraction* (from unprocessed geospatial and non-geospatial sources in order to rapidly generate features, their location, attributes, and metadata), and *change/anomaly detection* (to identify change in object state over time as well as to guide feature generation processes).

**Compare/Create Features** – compare and assess the suitability (including e.g., quality, accuracy, currency, relevance, and information value) of objects, potentially creating new spatio-temporal objects in the process, and determining whether the objects are adequate for their purpose (in which case they are ready for publishing), inadequate (triggering, e.g., new collection and production activities), or require further value-add processing.

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[5] Adapted from Northrop Grumman response to Fusion RFI.

 

**Process Features** – apply spatio-temporal-semantic operators to features to aggregate, relate, conflate, generalize, subset and filter the object/feature entities for use as input to decision-making processes.

### 9.1.3 Object/Feature Fusion Viewpoints

The Feature Lifecycle model can be further described, and related to the functional model above, from the perspectives of *information* and *computation*. Together these perspectives provide a more complete model of the Object/Fusion space.

**Information View** – focuses on means for standardizing information content, semantics, data models, and schema thereby enabling interoperable processing and data sharing. Robust approaches to Object/Feature fusion must integrate and leverage each of these aspects of the model:

- Semantic – representations of vocabulary and meaning enabling the ability to resolve identity, align schemas, relate features, and support higher-order classification and inference.
- Schematic – representations of type, structure, and association of feature objects enabling the means to resolve identity, translate data across mixed schema, perform type conversions, etc.
- Temporal – representations of temporal context and process necessary for identity resolution, change detection, tracking, relating, conflating, generalizing, filtering, etc.
- Geometric – representations of spatial context and process for identity resolution, tracking, relating, conflating, generalizing, filtering etc.

**Computational view** – the computational view focuses on the means for standardizing algorithms, components, interfaces, interactions, and workflows thereby enabling interoperable Object/Feature fusion services deployed in distributed, heterogeneous computing environments. Robust approaches to Object/Feature fusion must also integrate these computational aspects of the model:

- Event processing – Supporting the more dynamic aspects of the Feature Lifecycle, including handling of object/feature state transitions, anomaly detection, automated triggering of processing, and just-in-time approaches to Object/Feature fusion.
- Algorithm – The means for specifying computational patterns, approaches, and functions for solving complex problems.
- Transformation – The means to align, filter, translate, and transform data efficiently and with minimal loss of information.
- Workflow – The means to automate, integrate, and orchestrate Object/Feature fusion algorithms that also enable human input, monitoring, control, and feedback in support of business/mission-specific processes.

 

## 9.2 Enabling Capabilities

The key analytical activities of Object/Feature fusion shown in Figure 1 are: entity association, aggregation and relational analysis, and identification of entity activities and their structural and functional changes in space and time. Enabling capabilities supporting feature fusion activities include:

- Metadata for describing provenance, quality, and uncertainty
- Data and service discovery
- Data quality / uncertainty modeling and representations
- Definition and use of common and mission-specific datasets/schemas with supporting tools for schema validation and schema mapping of datasets
- Data integration, conflation and generalization (e.g., geometries, schemas, duplicates, associations, etc)
- Spatial-Temporal-Semantic analytics (e.g., entity mapping, filtering, correlation, uncertainty modeling, simulation, visualization, etc.)
- Data models, encodings and services for geoparsing, linking, organizing and sharing of fusion sources and outputs. Parsing and linking involves automated text recognition and association to location and other entities e.g., parsing a text document that contains the word-phrase “Baghdad” in it with detailed information about the city, and linking the document (and/or just the word-phrase in it) to a feature representation for the place called “Baghdad”. Organizing and sharing of fusion sources and products is accomplished using organizing constructs for tagging, categorizing, and grouping into digital structures such as folders, compound documents, or blogs for collaboration.
- Geoprocessing workflow combines two concepts to achieve its value for the consumer: ‘geoprocessing’ and ‘workflow’. *Geo-processing* involves processing of spatially related data, which may fall into one or more of the following categories: Spatial processing, Thematic processing, Temporal processing, Metadata processing. *Workflow* involves automated or semi-automated sequencing of tasks and processing to enable standardized and repeatable business processes that can scale with demand. Workflows are typically scripted to process routinely available information but may also be triggered by external events or alerts.
- Schema for interoperable definition of rules for geoprocessing. The rules can be inspected and compared and subsequently executed on a variety of workflow processing services. Rules-based services enable configurable, specialized, and tunable processing e.g., conflation.

The following sections detail enabling capabilities in need of focus within research and implementation projects. Many of these have been developed or demonstrated in past OGC initiatives but require further specific refinement for purposes of developing Object/Feature fusion standards and demonstration in limited operational settings.

 

#### 9.2.1 Provenance Metadata

Object/Feature fusion processes must both consume and produce provenance metadata – the trace (a graph) of ancestor and descendant data and processes that are used, produced and transformed at each step (a graph node) in the feature lifecycle (a workflow). The derivation history of a data product or feature used as input to Object/Feature fusion processes or produced as output, must address questions such as these:

- What created the feature? When and where?
- What were the parameters and configuration used?
- What were the input data used?

Critical to the feature lifecycle are these activities in which provenance metadata plays an important role:

- Trace workflow execution: What services were used in a fusion workflow? Were all steps completed and successful/valid?
- Auditing: What resources were used during fusion workflow?
- Data quality and reuse: what applications/services were used to derive results? Which workflows use a certain data product?
- Attribution: Who performed the work? Who owns the workflow and data products?
- Discovery: Where is the resulting dataset? What workflows were executed using *Service-Y?*

#### 9.2.2 Uncertainty Metadata

Uncertainty metadata provides the means to quantify and evaluate data quality and is, according to the Aston University response to the RFI, at the heart of useful Object/Feature fusion approaches. Aston argues that “probabilistic modeling for combining and relating features from a range of processing methods” is necessary. Achieving this is especially challenging when considering that different processing methods in a Object/Feature fusion workflow will likely yield very different associated uncertainties. The Aston premise is that a probabilistic representation of uncertainty provides a “common language between a wide range of models, applications, and measurements” and is needed at all stages of Object/Feature fusion and throughout the Feature Lifecycle.

#### 9.2.3 Object/Feature Associations

In the conception of Object/Feature fusion posited in the Galdos response to the Fusion RFI, “two data elements can be said to be fused if there exists an association between them, or if they are a member of a package of elements that defines that association.” From an information viewpoint, additional information (e.g., algorithms) may also be attached to an association that may be used to further process the associated items. When considering associations in the context of the Feature Lifecycle, tools and services for creating, managing, and exploiting associations become essential. Catalog Services (e.g., OGC CSW-ebRIM) for management and discovery of associations, packages, and classifications can play an important enabling role – a key element of the computational perspective.

 

Features may be dynamic, with time-varying properties including time-varying geometry and topology. Modeling the associations between time-varying features and their properties provides a robust mechanism for dynamically "fusing" Objects/Features for purposes of tracking, detecting change, and triggering actions (e.g., sensor collection tasking, alerts, etc).

Galdos argues that controlled vocabularies of association types are a key part of an Object/Feature fusion information model and are necessary for automation. Such a set of association types may include:

- **Same Type** – two or more features (with different schema) represent the same thing
- **Generalizes** – geometrically/topologically a generalization of another
- **Evolves-From** – a feature evolves over time into another
- **Spatially-Related** – features in spatial proximity or topology
- **Temporally-Related** – features related temporally (e.g., by time instant, time period, or time series)
- **Topically-Related** – features related by topic or theme
- **Decision-Related** – features related to a specific decision

In a similar fashion, FortiusOne identifies the key functionality of joining data feeds to arbitrary geometries on the fly based through toponyms, addresses or coordinates. This capability can be extended to provide spatial aggregation of data to geometries allowing the aggregated data to be summed, averaged, and ranged or any other statistical function enabling better consumption and analysis of sensor data.

### 9.2.4 Conflation & Generalization

Conflation is the process of unifying multiple separate sources of data into one integrated result. Conflation may be applicable to both raster sources and vector sources. Digital representations of geospatial features (such as roads, rivers, and forests) vary between databases, and while conflation processing is akin to forming a union between databases, differences in how features are represented in each database makes forming an integrated result challenging. When features from different sources are superimposed, they will typically differ in alignment, precision, location, completeness, and potentially in geometric representation as well. Not initially visible are differences in attribution and topology.

The core of the conflation process is identifying and associating the common features across multiple data sources, in spite of aforementioned challenges, reconciling the differences between them, and constructing one integrated result. The integrated result should contain: all the unique features and all the unique attributes from the sources being processed, the "best" geospatial representation of features deemed to be common, the combined attribution for features in common, and where values differ for attributes in common, the "best" value likewise must prevail as well.

Conflation capabilities may include:

- Pre-processing (transformation of schema, projection, datum, topology quality assessment, generalization or geometry simplification)

 

- Feature matching criteria and methods
- Preconfliction (merge/map schemas, integrate features, edge matching, etc)
- Imagery search and retrieve and image matching

### 9.2.5 Harmonised Information Feed

One goal is a common approach to the process of harmonisation and fusion. It is important first of all to define concepts of source and target and then define the harmonisation mapping between them. Envitia has identified a number of common requirements for harmonisation through their research with our stakeholder groups. These are:

- Thematic Harmonisation. This refers to the standardisation of a set of features based on an identified theme. (e.g., find all 'Transportation Routes', find all 'Roads and/or Tracks').
- Feature Concept Harmonisation. This refers to the standardisation of a set of features based on a common feature concept definition.
- Feature Type Harmonisation. This refers to the standardisation of a set of features based on a common feature type definition. For example harmonising where, say, the real-world "church" entity is modelled in one case as a Church feature or in another case as a Building feature with property restriction categoryOfBuilding=Church.
- Geometric Harmonisation. Features are often represented by different geometric representations. For example a contoured representation as opposed to a tin or coverage, or a road centre line and width as opposed to a polygon.
- Coordinate Reference System and Unit Harmonisation. Feature attribution often makes reference to units of measure or coordinate reference systems. Conversions between these are already granular and well defined.
- Metadata Harmonisation. This refers to standardisation of the use of metadata objects to represent the "meta" characteristics of a feature in a consistent way. In some schemas accuracy is in the metadata whilst in others it is in the data schema.
- Carrier Harmonisation. Data is often encoded in different carrier models. In this case harmonisation refers to the standardisation of the use of particular exchange or boundary formats.
- Portrayal Harmonisation. In this case harmonisation refers to the standardisation of the use of particular portrayal specifications, including the symbol sets/rules. SLD is doing this well for vector but gridded data does not have a similar set of definitions.

### 9.2.6 Feature Fusion Workflows

Combining conflation and conflation rules services within a service-oriented architecture with workflow is an enabling enabling technology for Decision Fusion. As part of the OWS-5 test bed a sample set of conflation rules were to be implemented to prove the concept of rule-based conflation (See Figure 6)[6]. The OWS-5 implementation used a Topology Quality Assessment Service (TQAS) that was developed in OWS-4[7].

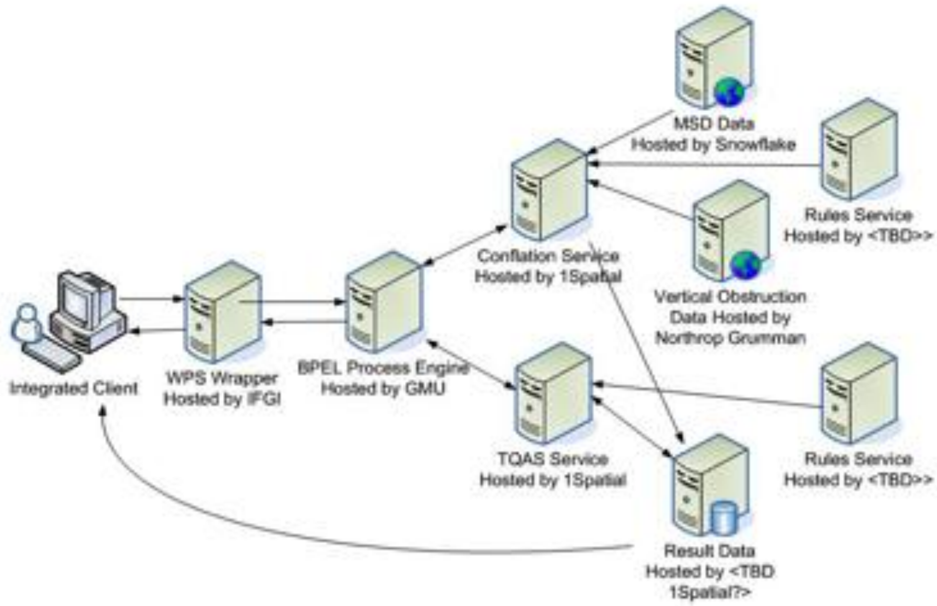


**Figure 6 – Feature Fusion workflow example**

As discussed in the NGC response to the RFI: "Selecting the "best" of all sources to be conflated 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."

NGC notes that several conflation engines exist commercially (Automated Conflation Service™ (ACS™), Fusion, MapMerger, Conflex, Radius) and are designed to use proprietary algorithms and methods for competitive advantage. Therefore, a subset of conflation rules is expected to remain specific to a conflation engine in order to control the proprietary algorithms.

The Intergraph response to the RFI notes that they support similar functionality as their customers want these capabilities available as services that can be chained together into higher order workflows. "How to access these functions and orchestrate are keys to further standardization."

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[6] Figure from OGC Document 07-061r1: "OWS-5 Conflation Engineering Report"

[7] OWS4 – Topology Quality Assessment IPR, OGC document 07-007r

 

“For interoperability, these rules require a common schema and web service interface for storage, discovery and reuse. An XML schema for feature similarity called FeatSim was designed to be a non-proprietary definition of business rules that are shared among conflation applications and services. The schema for FeatSim is modeled in **Figure 7**. The schema also defines metadata for search of business rules in a catalog. WPS defines a standardized interface that facilitates the publishing of geospatial processes, and the discovery of and binding to those processes by clients. The conflation clients and engines could use the WPS interfaces to query the rules, but WPS lacks an metadata query interface for discovery. Therefore, the OGC Catalog Web Service is a preferable alternative for storage, discovery and retrieval if the catalog’s metadata can be adapted in a profile to store and query the metadata for conflation business rules.

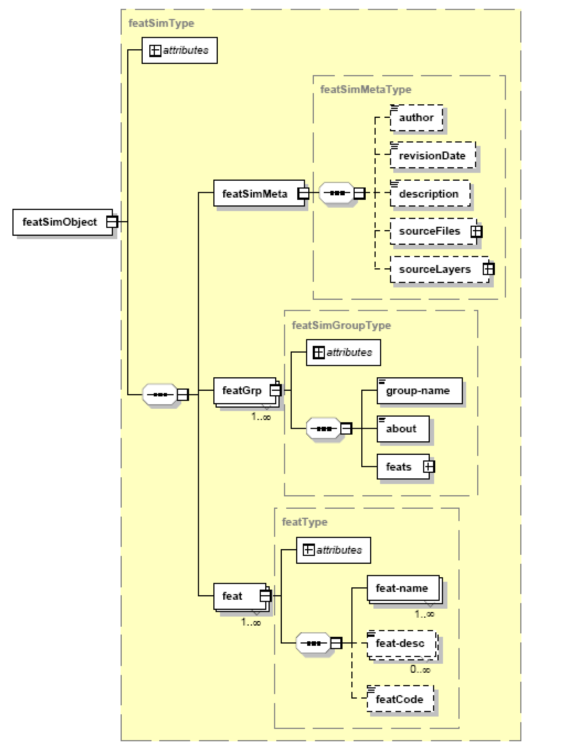


**Figure 7 – FeatSim Rule Schema**

### 9.2.7 Geoparser, Geocoder, Gazetteer, and Location Organizer Folder[8]

In an operational setting, the Location Organizer Client (LOC) is used by analysts to compile related sets of spatial-temporal information from multi-source information for any intelligence problems. Analysts capture and manage information in LOFs. Cooperating analysts use LOCs and supporting workflows and rules to discover, access, register, correlate and analyze information and then store and share the resulting LOFs. In the figure below, the GFS Environment consisting of applications, workflows, business rules, and services used to manage LOFs.

- Location Organizer Client (LOC) – client application that integrates multiple services for viewing, editing, discovery, analysis, publishing and collaboration.
- Location Organizer Folder (LOF) – means for storing, associating, and managing spatial-temporal resources as a geo-organized, geo-connected collection of information; a structured way to associate, organize, and share relevant information about a topic of interest.

[8] The LOC, LOF – along with geoparsing, geolinking, geocoder, and gazetteer services –were constructs conceived and demonstrated during OGC’s Geospatial Fusion Services Testbed and Pilot initiatives in 2000-2001. A LOF is a structured way to associate, organize, encode, and share relevant information about a topic of interest.

- Geoparser - Function to scan text and discover geographic locations and related temporal information (which can then be geocoded or geolinked).
- Geocoder - Function to transform “parsed” location and event references (e.g., address, landmark) to a *location* (i.e., a feature with geometry).
- Gazetteer - Function for “looking up” geographic feature locations based on feature names.

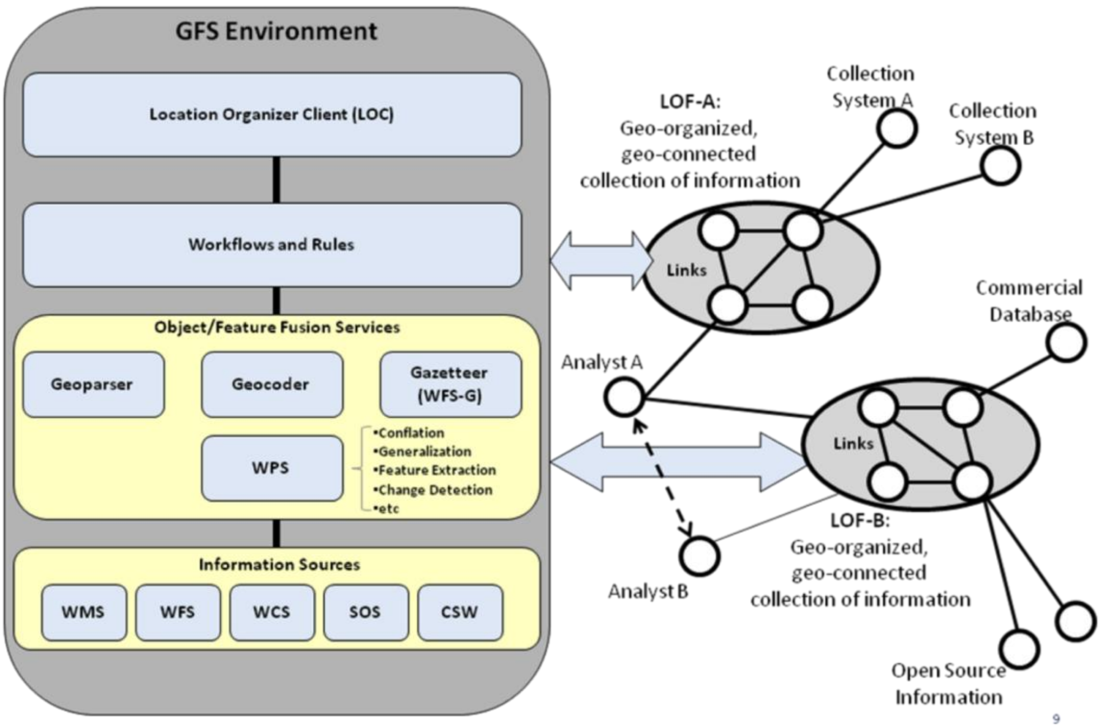


**Figure 8 – A Geospatial Fusion Services environment**

## 9.3 Objects from Fusion Processes

Objects resulting from the fusion processes of this fusion category include:

- Integrated datasets
- Conflated entities
- Semantically-enhanced “value-add” entities (via aggregations, associations, mappings)
- Metadata for describing provenance and uncertainty
- New actionable information
- Track reports including provenance, e.g., sensor-to-track and track-to-track

 

## 9.4 Tools, Resources and Standards

Following are technologies and standards (emerging and adopted) thought to be relevant to enabling open and interoperable fusion in this category. Standards are listed below in brief with full citations in the Bibliography.

**Table 4 – Technologies and Standards for Object/Feature Fusion**

| | |
|---|---|
| Metadata: | ISO19115, UncertML |
| Discovery | OGC CS, OASIS ebXML Reg/Rep |
| Common Application schema and Mission-specific datasets: | GML, profiles, and subsetting tools |
| Data quality / uncertainty modeling and representations: | UncertML, SensorML, O&M |
| Data integration/conflation | WCPS, WPS, WFS-G (Gazetteer), OLS Geocoder Service |
| Spatial-Temporal-Semantic analytics | UncertML, OGC O&M, SensorML, EML (Event Pattern Markup Language), WPS, W3C OWL, SKOS, and SWRL |
| Linking, organizing, sharing | GML, GeoRSS, KML, Location Organizer Folder (LOF), Geolinking Service, Geoparser Service, Geocoder Service |
| Automation and workflow | WPS, WCPS, WfCS, Wf-XML, XPDL, BPEL |
| Grid and Cloud infrastructures. | Open Grid Forum and cloud standards by other organization[9]. |

## 9.5 Recommendations

### 9.5.1 Define a conceptual model of feature lifecycle – beyond conflation.

Object/Feature fusion has been shown to be larger in scope than a "traditional" feature conflation problem, encompassing spatio-temporal-semantic models for discovery, temporal conflation, active/dynamic behaviors for event processing of detected changes and anomalies, and leveraging semantics for rules and reasoning. Development of a conceptual model, like the "feature lifecycle" model discussed above, is needed to provide context for and unification of the functional, informational, and computational aspects of Object/Feature fusion. Such a model will also provide the basis for operational exploitation of the full scope of fusion services and a roadmap for addressing key interoperability bottlenecks with standards developed through multiple phases in multi-participant activities.

[9] http://cloud-standards.org/wiki

 

### 9.5.2 Standardize metadata for provenance and uncertainty.

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 is needed.

### 9.5.3 Develop common data models supporting feature fusion.

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.

### 9.5.4 Define a portfolio of feature fusion services.

The computational toolkit for Object/Feature fusion is large and varied. Tools and services for creating and managing associations exist or have been recently proposed. Tools and services for rules-based conflation have been demonstrated. COTS tools are available for advanced processing of feature geometries for generalization (simplifying, aggregating, merging, collapsing). 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. What is needed is a “portfolio” of fusion services defining standard, interoperable, compose-able service interfaces enabling wider (Web or SOA-based) access and orchestration of disparate fusion services into workflows supporting decision-fusion and other means of making sense out of the volume of data and complexity of the problems that confront us.

### 9.5.5 Develop schema and encoding to support sharing of Track Features

Today’s family of tracking and fusion applications are capable of operating in a broad range of physical and tactical environments. The data format for a track must be sufficient to address the needs of the individual sensors in the sensor suite, plus those of the different levels of fused tracks. NGC offers a Track Object Format (TOF) including an interface and data structures of a neutral track format. The TOF is a generalized format for the representation of track data – fused or un-fused – in a bandwidth-challenged, time-constrained embedded processing environment.

# 10 Decision Fusion

## 10.1 Definition and Objectives

### 10.1.1 Definition

Decision Fusion focuses on client environments for analysts and decision makers to visualize, analyze, and edit data into fusion products for an understanding of a situation in context. Decision fusion includes the ability to fuse derived data and information with processes, policies, and constraints. Collaboration with other analysts is done using social networking services and collaboration tools that are location enabled.

Several responses to the Fusion Standards RFI commented on the Decision Fusion Category:

- Aston University: "…a correct assessment of the uncertainty about the particular 'thing' must be propagated correctly along the entire processing chain." And "Communicating uncertain information to users is a non-trivial task, and remains an open research question."
- FortiusOne: fusion by visualizing and analyzing data, driving data backed decisions and solving problems with no prior training using traditional mapping tools
- Fraunhofer: "Processing of sensor data together with general, prior knowledge of the phenomenon of interest"
- Galdos: data fusion from our perspective is the creation of a collection of named and possibly typed associations between instances of typically disparate data types.
- PYXIS: "Network-centric fusion requires that information is pre-aligned to a uniform model (or can be rapidly aligned) so that all data sets are self synchronized."

### 10.1.2 Decision Data Fusion Objectives

The Decision Fusion Engineering Report (ER) addresses how data sources are integrated into a fusion processes and how the fusion processes provide input to the decision making process. The objectives for fusion in this category include:

- Discovery of data (static and dynamic) resources that meet a users immediate requirements and to make those resources part of a fusion process under the control of the decision maker or analyst.
- Retrieval of real-time or time-series data in standard encodings that provide the ability to fuse the data into useable information based upon the users uncertainty of the measurement and parameters needed to process the data
- Determination of the quality and validity of the data and fusion products produced from the data
- Ability to fuse derived data and information with processes, policies, and constraint information as set by the data/information owners (i.e., Concept of Operations) and decision services processing nodes.

 

- Ability to present the derived information in a spatial client application (e.g., SLD, SE, W3D) including portrayal of maps and 3D visualization.
- Ability to collaborate with other decision makers and analysts using social networking services and collaboration tools that are location enabled. Documents that capture an analysis result and allows for distribution to others for viewing the same context.

While Sensor Fusion and Feature Fusion provide the "right data", Decision Fusion provides that information in the "right time and for the right place". Decision Fusion pulls together Sensor Fusion and Feature fusion results, combines those with additional data inputs to provide a result on which decisions or actions can be executed. Fixed and mobile sensors of many kinds, including Full Motion Video, are providing dynamic data and emerging location-based services.

### 10.1.3 Mirror Worlds

With incredible prescience in 1991, David Gelernter put forth the concept of Mirror Worlds[10] as "software models of some chunk of reality, some piece of the real world going on outside your window. Oceans of information pour endlessly into the model (through a vast maze of software pipes and hoses): so much information that the model can mimic the reality's every move, moment-by-moment." Such a Mirror World could answer the question: "what's going on out there? What's happening?"

Many of Gelernter's Mirror World concepts now exist in some fashion through Internet access to databases and sensors. A novel concept of Mirror Worlds that has not been realized is the notion of a "FGP Machine, after its three operations – called Fetch Generalize and Project." Fetch is *plunge*. Generalize is *squish*. Project allows you to pick what you want from a squish.

*Plunge* looks around in a database for other cases that are similar to a new case that is of current interest. A case is similar to the extent that its attributes match those of the new case. The cases that are close to the new one are the cases that tend to match on evocative attributes.

Squish means to look at the closest cases that are attracted by a plunge, and compact the together in to a single "super case." Squish helps to build abstract ideas out of concrete memories. The way to attach meaning to a label is by plunging and squishing.

There are many research efforts that seek to achieve the vision of plunge and squish, e.g., knowledge engineering, induction, and semantic web. As these research efforts produce practical results they will advance our capabilities of decision fusion.

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[10] "Mirror Worlds: or the day software puts the universe in a shoebox…how it will happened and what it will mean," David Gelernter, Oxford University Press, 1992.

## 10.2 Enabling Capabilities

### 10.2.1 Decision support services

The fundamental concept underlying Decision Fusion is that a decision maker is able to sit down at a single workstation, identify any resource anywhere, access that resource, bring it into their operational context, integrate it with other resources to support the decision process, and to share the resulting context with others. All of this takes place in a global enterprise made up of many different organizations and many different information communities. Each of them has their own information models and semantics as well as their own policies and procedures. Decision Fusion tools allow the decision maker to navigate this environment with minimal distraction from the issue at hand. Figure 9 displays a generic view of the Decision Support Services (DSS) concept:

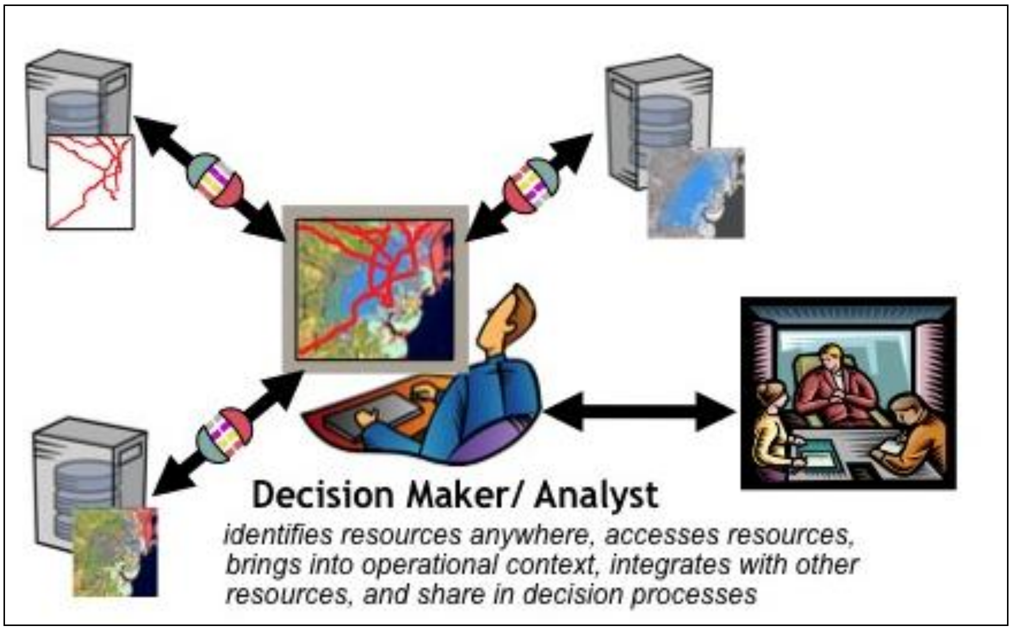


**Figure 9 – Decision Fusion Integrated Client**

At the heart of Figure 9 is an integrated client that allows a user to visualize, analyze, and/or edit data from feature, imagery, video and sensor web data sources within a single client. The integrated client allows the user to fuse information from various sources into a common view or context to convey a conclusion about a specific geographic situation and to share and collaborate the perspective.

Decision fusion happens within and between client applications. Within the context of the OGC, this means that the integrated client allows a user to publish, discover, access, integrate and apply all types of spatial data (e.g., raster, vector, coverages and sensor observations) from a wide range of vendor web services through OGC standard interfaces.

Integrated client applications provide access to distributed functionality in the following categories:

- Service Discovery & Binding
- Feature Production

 

- Imagery Production/Exploitation
- Sensor Web Planning/Exploitation
- Project Persistence and Sharing
- Process and Policy Services
- Portrayal of 2D/3D geospatial information
- Utilization of emergency alerting and situational awareness updates
- Collaboration encodings: KML, OWS Context, LOF

### 10.2.2 Decisions as information objects

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 identifies, "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."

An information model for decisions is not readily available, e.g., an abstract model in UML with Decision Type as a first class object with attributes, operations and associations. Such a model of decisions would then allow for placing decision instances in a registry for rapid reuse in situation as typical to a specific operational environment. As Galdos points out, "this would include such things as dynamic decision trees, stored queries related to decision types, and specific types of auditable events."

### 10.2.3 3D Visualization for Built Environment

A key aspect for establishing context is the visualization of an environment, including 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. Such information about the built environment includes

- Buildings
- Transportation infrastructure
- Utilities infrastructure
- Other physical infrastructure and their surroundings

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.

### 10.2.4 Events and Alerts

Key inputs to Decision Fusion are events and alerts. OGC has developed several services related to notification WNS, SAS, and recently a subscription service for to events. Other communities have defined event encodings such as Common Alerting Protocol from OASIS and Cursor on Target from the Air Force. OASIS also defines web service mechanisms for communicating events and alerts, e.g., WS-eventing, WS-Messaging. In OWS-6, an Event Architecture was developed for use with OGC services.[11] The event service was implemented for an air flight diversion scenario in OWS-6. Work on events and alerts work should be continued in future developments.

As Galdos states: "Decision makers are very busy, hence it is important that the fusion system be able to automatically notify them of important events. Such events can be widely varying and include such things as arrival of new sensor information, the creation of a feature instance from observations, fusion of features or sensor data, or the evolution of some feature past an important critical point (e.g. fire comes within 500 meters of a town boundary). As decision makers are very busy many of these processes (data association, aggregation etc) must be automated and happen at the database or mid-tier levels but be capable of being communicated immediately to the user interface level. "

### 10.2.5 Fetch, Generalize and Project

Decision support includes fetching historical cases similar to those of the current decision case, generalizing the historical cases, and projecting the generalized results that most relevant to current case.

As example of this kinds of operations consider Google's MapReduce, which is a programming model, composed of separate Map and Reduce operations[12]. (Here Map is not a geographic concept.) MapReduce is used for the generation of data for Google's production web search service. Hadoop includes an open source implementation of MapReduce. MapReduce has been used as inspiration in development of at least one WPS used in a grid computing operation[13]. Applying MapReduce to geospatial decision fusion perhaps through WPS interface could achieve some decision fusion objectives.

### 10.2.6 Information 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.

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[11] OWS-6 SWE Event Architecture Engineering Report, OGC Report 09-032.

[12] http://labs.google.com/papers/mapreduce.html

[13] 09-041r3_OWS-6_WPS_Grid_Processing_Profile_Engineering_Report

 

- Location Organizer Folder (LOF)

The Location Organizer Folder (LOF) is a GML document that provides a structure for organizing the information related to a particular event or events of interest. It may be used in various analysis applications, like disaster analysis, Intelligence analysis, etc. It is spatially enabled, and capable of managing disparate types of information.

The LOF is an information structure. There may be a variety of services external to the LOF that provide the means for generation and manipulation of the information in the structure. This includes search and discovery, parsing different resources and the extraction of useful information, assigning spatial attributes, relating (linking) resources of interest, and so on.

- OWS Context

OWS Context document is an XML encoding that references remote and/or local OGC Web Services.  OWS Context is related to, but more powerful than, Web Map Context. Web Map Context specification states how a specific grouping of one or more maps from one or more WMS can be described in a portable, platform-independent format for storage in a repository or for transmission between clients.  OWS Context can reference WMS and other OGC Web Services such as WFS and WCS.

- KML

KML is an XML grammar used to encode and transport representations of geographic data for display in an earth browser, such as a 3D virtual globe, 2D web browser application, or 2D mobile application. A KML instance is processed in much the same way that HTML (and XML) documents are processed by web browsers. Like HTML, KML has a tag-based structure with names and attributes used for specific display purposes.

### 10.2.7 Geospatial 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 10.

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.).”

 

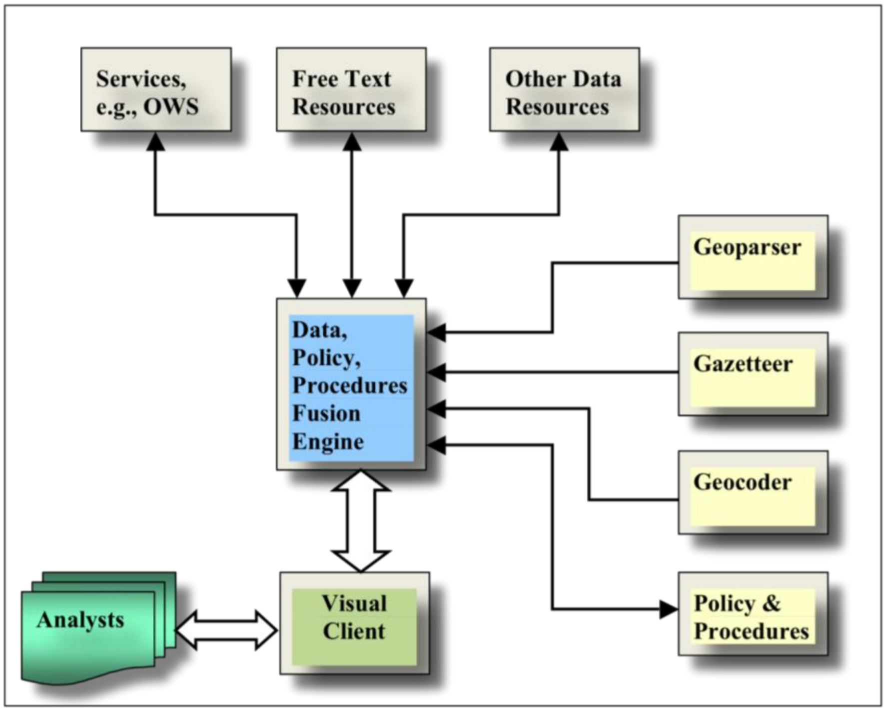


**Figure 10 – Geospatial Fusion Services Engine Environment**

### 10.2.8 Dynamic routing based on location

When it comes to distributing alerts, "where" is as important as "what" because only organizations with authorization and jurisdiction should be notified about each situation, otherwise they could be overwhelmed by the sheer volume of events. Events typically include a defined location either by location identifier (e.g. zip code) or by coordinate geometry (e.g. polygon). Routing based upon location in high volume messaging environments must move beyond the DBMS-based approach to a streaming approach. For example, Solace Systems[14] has a hardware-based messaging technology that can route messages based upon location. An example use case is to identify the overlap between multiple polygons to determine message routing. The need for open standards for this high volume messaging use case is clear from other Internet applications. Open standards are needed for messages including location and the service protocols for interacting with message routers.

## 10.3 Objects from Fusion Processes

Objects resulting from decision fusion processes include:

- Informed decisions based upon the data, information, policy and procedures being fused together.

[14] www.solacesystems.com

 

- Visualize, analyze, and edit data into fusion product. This is to include SE, SLD portrayal and 3D visualization.
- Ability to publish, discover, consume and integrate spatial data (e.g., raster, vector, coverages, sensor observations) from feature, imagery, video, and sensors
- Provide interoperable access to distributed geospatial web services and data objects
- Ability to provide decision makers relevant data to aid in forming, analyzing, and selecting alternate solutions based upon dynamic situations
- Workflow management to produce context specific results from information and knowledge from multiple communities
- Alerts distributed to affected parties based upon location

## 10.4 Tools, Resources and Standards

Following are technologies and standards (emerging and adopted) considered relevant to enabling open and interoperable fusion in this category[15]:

[15] See also Tables A-6 and A-7 in the Appendix of this report.

**Table 5 – Technologies and Standards for Decision Fusion**

| | |
|---|---|
| Web Services | Means to connect producers and consumers of resources (data and services), e.g., SOAP and REST |
| Security | Means to enable authentication, authorization, confidentiality, and integrity of resources and interconnections |
| Workflow | Standardized means for automation of business processes and event processing |
| Grid computing | High performance distributed computing and very large datasets |
| Cloud computing | Software as a Service (SaaS) and Infrastructure as a Service (IaaS) |
| Metadata | ISO19115, UncertML |
| Discovery | CSW, ebRIM, SOA |
| Portrayal | ISO19117, Styled Layer Descriptor (SLD) and Symbol Encoding (SE) |
| Application schema | GML, profiles, and subsetting tools |
| Data quality / uncertainty modeling and representations: | UncertML, SensorML, O&M, ISO 19115 and 19115 part 2. ISO 19113, 19114, 19138 provide quality requirements |
| Data integration/conflation: | Conflation rules, WCPS, WPS, WFS-G, OLS Geocoder, |
| Spatial-Temporal-Semantic analytics: | O&M, SensorML, UncertML, Event-PatternML, OWL, WPS |
| Visualizing, linking, organizing, sharing: | GML, CityGML, X3D ISO/IEC 19775, VRML, GeoRSS, KML, LOF, OWS, etc |
| Automation: | WPS, WCPS, WfCS, Wf-XML, XPDL, BPEL |
| Grid and Cloud computing | Open Grid Forum and cloud standards by other organization[16]. |

## 10.5 Recommendations

### 10.5.1 Develop a information model with decisions as a first class object

Interoperability in distributed information systems is dependent upon a rich understanding of the information to be shared. For Decision Fusion an information model should 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.

[16] http://cloud-standards.org/wiki

 

### 10.5.2 Define interfaces and functionality for decision fusion engine component type

As defined in Figure 11, 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.). Interfaces for the engine need to be defined for both service interfaces as well as human-machine interfaces. One result of this effort would be a best practice similar to the OGC Geospatial Portal Reference Architecture.

### 10.5.3 Uncertainty propagation for a "hard fusion" topic

A theme across all of the fusion categories has been uncertainty propagation. This theme should continue in Decision Fusion. 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. Mathematical formulas to combine various reliability components and associated data elements into a useable output(s) in a dynamic environment is needed. This proof of concept would focus on hard fusion while recognizing that soft fusion is still in scope. Change Detection might be considered as the topic.

### 10.5.4 "See and Talk" collaboration with common 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.

### 10.5.5 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. Use of technologies like wikis and blogs that are spatially enabled and support the decision object approach defined above, would provide a basis for collaborative decision making.

### 10.5.6 Political Geography as a step to all information types

Political geography can be a basis for broadening future developments of decision fusion. This would include topics of human culture mapping, text scanning/language translations, place names and historical events with vague location that are identified by dates. One element of this direction would be temporally enabled gazetteer. Incorporating current social events through new feeds and blogs supported by Internet technologies such as RSS and Atom.

### 10.5.7 Dynamic routing based on location

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 availability data (maps, digital data, imagery) based on geographic area of interest

### 10.5.8 Phase 2 Study on Decision Fusion

For successful decision fusion, the information taken into consideration must be as broad as possible for all thematic domains and through a broad variety of technology platforms. Thematically, decision fusion must be fully encompassing of a multi-INT approach. For technology platforms, decision fusion must consider standards that will enable a broader solution, e.g., mass markets and mashups. To address this, it is recommended that a Phase 2 of Fusion Standards Study to focus on Decision Fusion (Multi-INT)

 

# 11 Architecture for Fusion

## 11.1 Definition and Objectives

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. These would allow geospatial information (and other forms of INT) to be collected, stored, managed, fused and disseminated vertically (from the National to the Soldier 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 11). 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 (soldiers, systems and other assets) and to provide a common situational understanding and a cohesive set of decision solutions. The fusion architecture will facilitate system interoperability, which is the capability of components or systems to share data and services with other components or systems and to perform in multiple environments.

The discussion that follows is intended to be informative, providing an operational, technical and performance context for Fusion Services.

In the conceptual fusion environment depicted in Figure 11, 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. Seamless and interoperable flows between aggregators, processors, viewers, workflows, and client applications occur via Interoperability Nodes within the fusion environment. Information flows with external resources often occur via translator (gateway/guard) nodes. Interoperability Nodes and External Source Nodes may support a variety of service and encoding standards, supporting both producer and consumer interconnections.

 

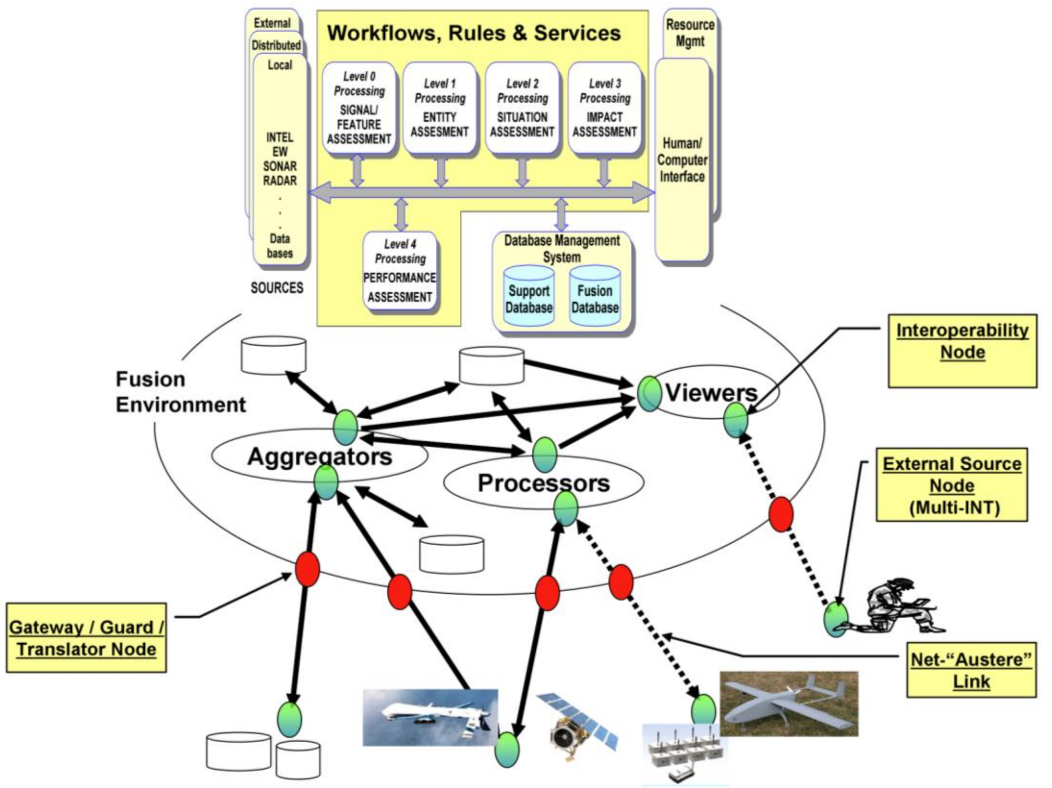


**Figure 11 – Fusion Services Architecture Concept**

## 11.2 Enabling Capabilities

### 11.2.1 Distributed Information Systems

There are certain infrastructure capabilities that are essential to enabling fusion. These capabilities are essential for distributed information systems in general, but may have particular requirements or emphasis for fusion processes. Some relevant enabling capabilities are:

- Scalable to massive data volumes and complex processing
- Streaming and caching
- Managed and hosted (distributed, off-premise)
- Automated and manage processing and workflows
- Reliable and available
- Security in distributed information systems
- Distributed, virtualized nodes made accessible and interconnected via open Web services and standards-based grid and cloud-computing infrastructures
- Scalable, reliable, cost-effective storage, network and computing capabilities for enabling fusion.

 

The example architecture shown in Figure 12 enables the fusion of geospatial data among sensors, image libraries, geospatial products, and other intelligence data sources. In the figure, the Enterprise Services level include Sensor and Feature fusion processing in the Processing Services. These processing services for fusion include feature conflation and image enhancement that use multiple sources from the information and data management level, brokered through standard information exchange mechanisms. Discovery of fusion sources; schema and business rules for conflation would be the provided through the Discovery services. Decision level fusion is provided through Information Management services and Integrated Clients as part of the Enterprise Applications.  Workflows at the Enterprise Management level provide the logical flow and chaining to run services together in application of fusion for clients, whether a person using a client interface or another web service.

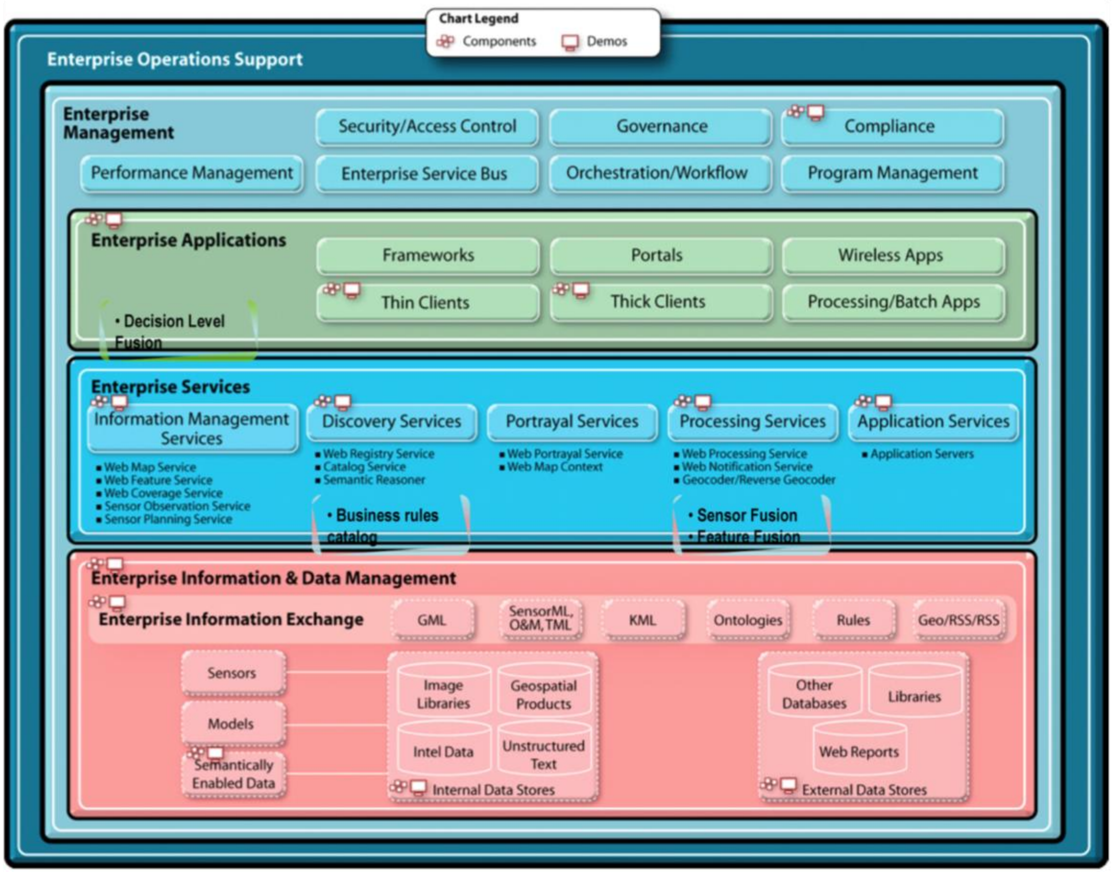


**Figure 12 – Example Fusion Architecture[17]**

### 11.2.2  Catalogue as a cross-fusion resource

A key pattern in a services architecture is "publish-find-bind."  This pattern and other variants depend on having access to information about on-line resources through catalogues

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[17] The Northrop Grumman GeoEnterprise Solutions™ Architecture

or more generally through registries.  Galdos response to the Fusion RFI recommends the use of registries at multiple levels of the architecture to manage key artifacts including units of measure, coordinate reference systems, feature classification hierarchies, feature ontologies, feature/sensor/decision associations, service offers, feature schemas, sensor models and decision trees (See Figure 13).

OGC members are working with several registry technologies including approved standards for CSW with extensions using ebRIM.  Further work by OGC members is using ebXML RegRep.

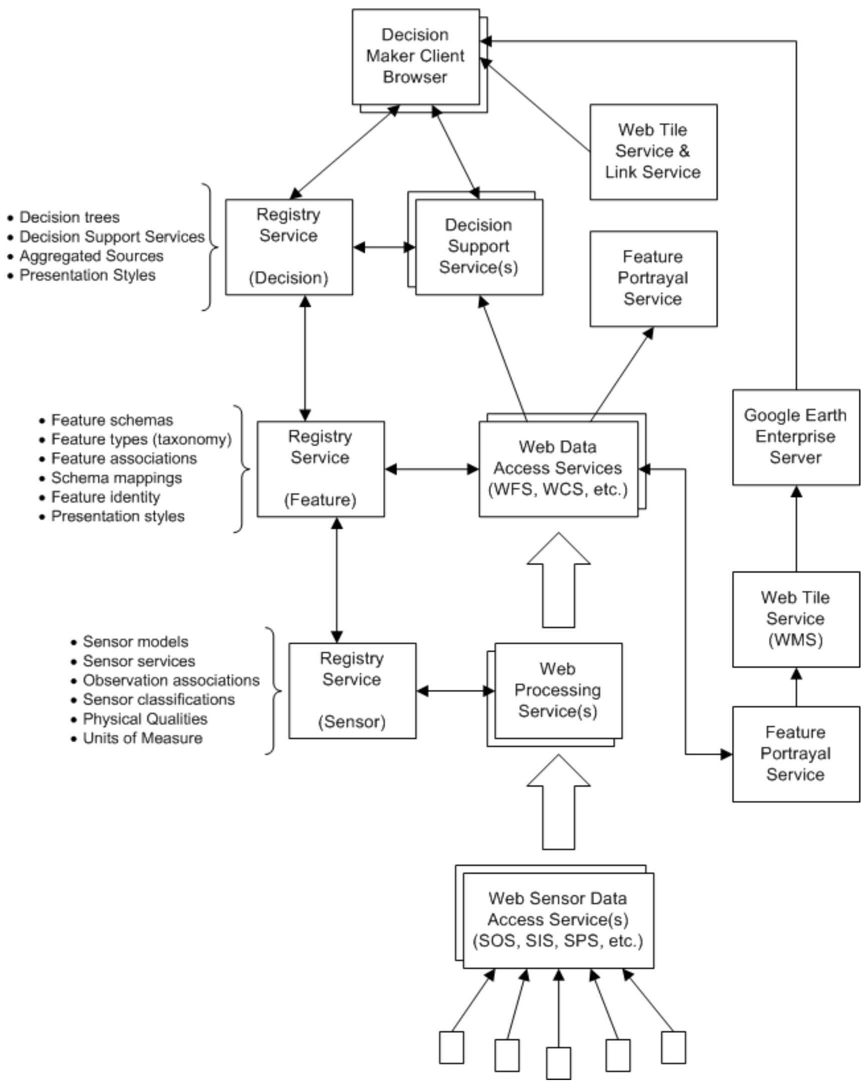


**Figure 13 – Multiple Registries for Fusion Architecture**[18]

[18] Figure from Galdos response to the Fusion Study RFI.

 

### 11.2.3 Support for multiple web service architectural styles

Many of the services we discuss in this report are web services. There are several architectural styles for defining web services. The two most commonly discuss approaches are SOAP and REST. Each approach has advantages so the key is to choose the approach that works best for a particular environment. The OGC approach[19] is to promote development of 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.

### 11.2.4 Geoprocessing 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. These technologies have mostly focused on implementation of workflow processes in the form of a runtime execution language or script for an associated process engine. This approach provides an effective means to deploy and execute processes within a homogeneous environment served by a particular process engine. However, 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* brings both terms together. It can be seen as 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.

Geoprocessing Workflows integrate data and services in an interoperable way, where each part of the workflow is responsible for only a specific task, without being aware of the general purpose of the workflow. Due to the distributed nature of geographic data, Geoprocessing Workflows provide flexible means of processing highly distributed and complex data for a wide variety of uses.

Workflow is applicable across all categories of fusion. Workflow for Object/Feature Fusion was discussed in Section 9.2.6.

Figure 14 shows an example – from PYXIS – of fusion workflow using OGC standards such as Web Processing. PYXIS advocates a strong focus on a standardized discrete global grid for this architecture. The architecture in the figure can be deployed using the grid advocated by PYXIS along with many other data structures and types using an open standards approach that delays re-gridding. Nonetheless, the figure portrays the functional architecture to be deployed for fusion workflow.

[19] As agreed in a unanimous motion by the OGC Technical Meeting, December 2008.

 

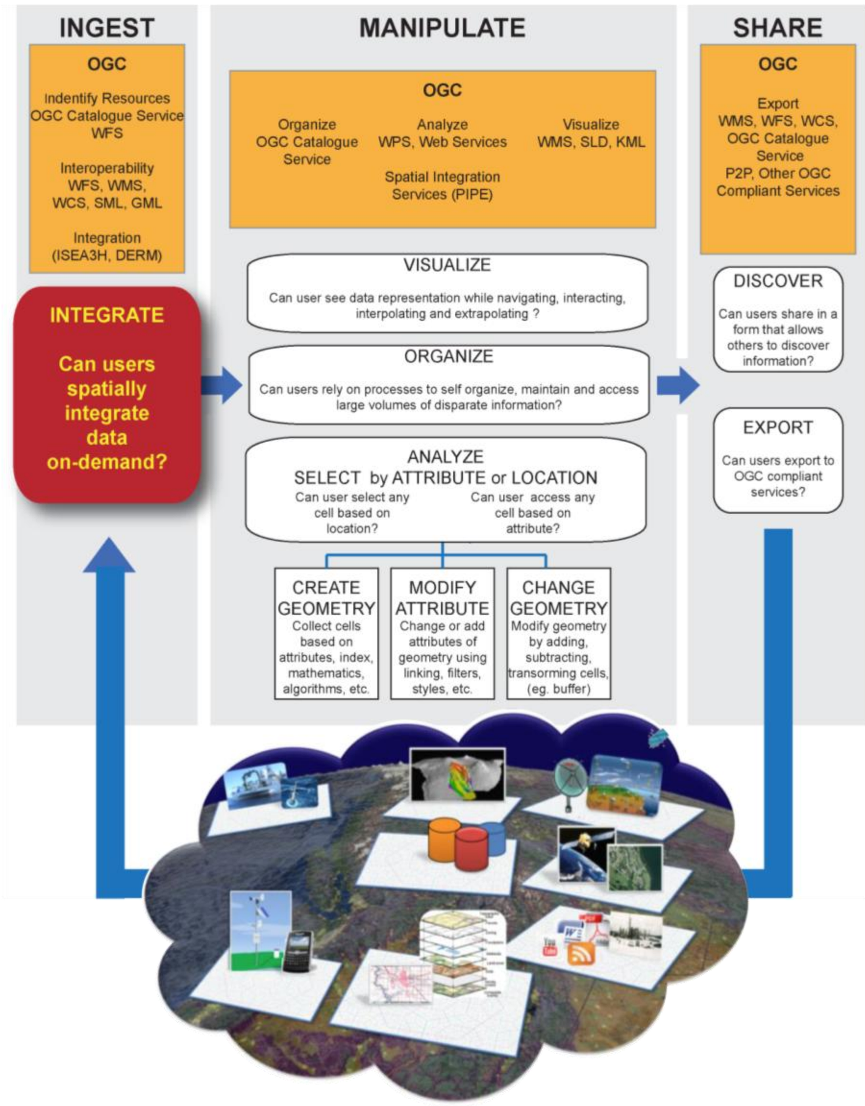


**Figure 14 – Fusion Workflow [20]**

### 11.2.5 Grid and Cloud Computing

Highly specialized geospatial applications based on large volumes of distributed data such as live sensor data streams at different scales combined with high resolution geospatial data, which have to be analyzed in real-time for risk management issues, require often the functionality of multiple processes. In such highly specialized large-scale geospatial applications, not every processing step can potentially be handled by a single processing entity (for example with the resources of a single computer). To improve the computational

[20] Figure from PYXIS response to the Fusion Study RFI.

 

performance of processing large amounts of dynamic geospatial data, Grid and Cloud computing provides appropriate tools[21].

OWS-6 demonstrated the use of grid computing in a web services environment using the OGC WPS as a gateway to the grid[22]. In that deployment, WPS was used to access grid resources using standards from the Open Grid Forum.

Cloud computing is a pay-per-use model for enabling convenient, on-demand network access to a shared pool of configurable and reliable computing resources (e.g., networks, servers, storage, applications, services) that can be rapidly provisioned and released with minimal consumer management effort or service provider interaction.

Several OGC members have deployed their software solutions with OGC interfaces in various Cloud providers. FortiusOne highlighted in their response to the Fusion RFI (See Figure 15).

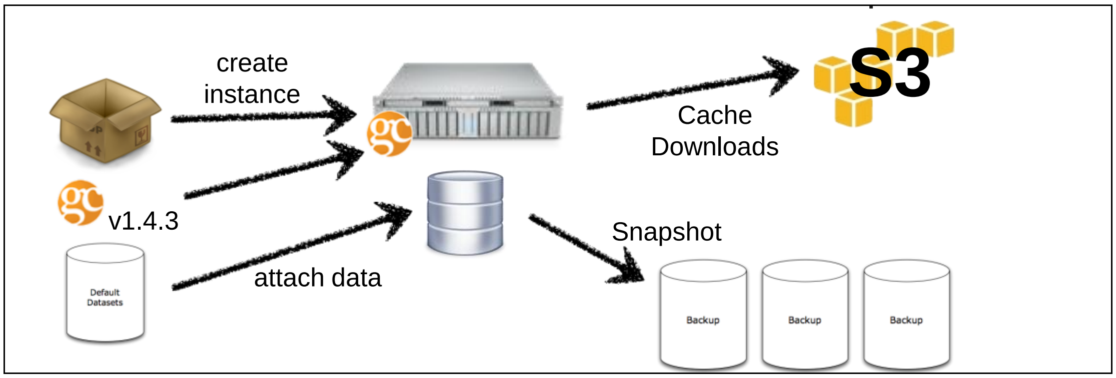


**Figure 15 – Deploying into a Cloud Architecture[23]**

Cloud computing infrastructures often leverage the following characteristics:

- Massive scale
- Virtualization
- Free software
- Autonomic computing
- Multi-tenancy
- Geographically distributed systems
- Advanced security technologies

To be considered a "cloud" the offered service must be deployed on top of cloud infrastructure that enables the key characteristics stated above.

### 11.2.6 Security-enabled Architecture for Fusion

Realization of web services security architectures and mechanisms must be robust and mature to meet the challenges facing a fusion of rich sets of data or information from a

[21] See also Table A-7 for references related to Cloud and Grid.

[22] OWS-6 WPS Grid Processing Profile Engineering Report, OGC Document 09-041r3

[23] Figure from FortiusOne response to the RFI.

 

variety of disparate resources in order to improve one's capability to detect, identify, and characterize an entity for useful and timely action. Web services security is founded on the following concepts[24]:

**Authentication**: Who is accessing the resource? Verify that principals (humans or application components) are who they claim to be through appropriate proof of identity. Determine the identity or role of a party attempting to perform some action, such as accessing a resource or participating in a transaction.

**Authorization**: What can they do? Grant permission for principals to access resources based upon access rights. Determine whether some party is allowed to perform a requested action or access particular resources.

**Integrity**: Ensure that information is intact. Ensure that information is not changed in transit, either due to malicious intent or by accident. This may be information transmitted over a network, information stored in a database or file system, or information passed in a Web services message and processed by intermediaries.

**Non-repudiation**: Verify the identity of authors using electronic signatures. Produce or verify an electronic signature for purposes such as approval, confirmation of receipt, acceptance or agreement.

**Confidentiality**: Make content unreadable by unauthorized parties. Ensure that only legitimate parties may view content, even if other access control mechanisms are bypassed, and guarantee that exchanged information is protected against eavesdroppers. Confidentiality is generally associated with encryption technologies.

**Privacy**: Limit access and use of individually identifiable information. Personally identifiable information is required by individuals and organizations to perform services for an individual.

Ensuring the security of web services involves implementation of security frameworks based on use of authentication, authorization, confidentiality, and integrity mechanisms that include the following security standards.

Confidentiality - XML Encryption as a mechanism to encrypt XML documents

Integrity - XML Signature to provide a means to selectively sign XML data

Authentication and Authorization – SAML, GeoXACML, XACML and resource-oriented approaches such as OpenID and OAuth

Public Key Infrastructure (PKI) - using XKMS and X.509 Certificates

WS-Security - SOAP header extensions for end-to-end SOAP messaging security that supports message integrity and confidentiality.

## 11.3 Tools, Resources and Standards

Following are technologies and standards (emerging and adopted) considered relevant to enabling open and interoperable fusion in this category[25]:

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[24] Guide to Web Services Security, NIST Special Pub 800-95, August 2007

[25] See also Tables A-6 and A-7 in the Appendix of this report.

 

**Table 6 – Technologies and Standards for Fusion Architecture**

| | |
|---|---|
| Web Services | Means to connect producers and consumers of resources (data and services), e.g., SOAP and REST |
| Security | Means to enable authentication, authorization, confidentiality, and integrity of resources and interconnections |
| Workflow | Standardized means for automation of business processes and event processing |
| Grid computing | High performance distributed computing and very large datasets |
| Cloud computing | Software as a Service (SaaS) and Infrastructure as a Service (IaaS) |
| Streaming and Caching | Supported by standard encodings and services, including but not limited to MPEG4 (video/multi-media streaming), JPIP (JPEG2000 streaming), WMTS (Web Map Tiling Service), and advanced caching and content delivery mechanisms (see CDN below). |
| Content Delivery Networks (CDN) | Technology and network infrastructure for video streaming, large-volume-files downloads, and image caching, the purpose of which is to deliver improved quality of service for Internet users |
| Austere networks | Expeditionary infrastructure for operations in “network austere” environments with disconnected, intermittently connected and/or very low-bandwidth network communications |

## 11.4 Recommendations

It is a core requirement that the various fusion processes will be performed within and across a net-centric environment, thus calling for Service-Oriented Architecture (SOA). Service in network-austere environments is less well understood and supported. The findings from this study will be discussed in terms of the following:

- Use of OGC/ISO standards (CSW, WPS, WMS, WFS, WCS, metadata, etc.)
- Semantics mediation of community vocabularies, taxonomies
- Workflow driven by semantics
    - Role of human in the loop vs. automation
- Grid and Cloud implementations

These essentially represent crosscutting issues effecting most or all of the various types of fusion to be performed (sensor, feature, decision), and will each be discussed in turn.

### 11.4.1 Use of Open, Community IT Standards

There is a veritable forest of encoding, processing, communications, and security standards from which to choose that are from at least a dozen international Standards Development Organizations (SDO). Of primary interest are open community standards. For core Internet communications and data exchange, the relevant SDOs include IEEE (http://www.ieee.org), the Internet Engineering Task Force (IETF, http://www.ietf.org/), the World Wide Web Consortium (W3C, http://www.w3.org), the Organization for Advancement of Structured Information Standards (OASIS, http://www.oasis-open.org), and ISO TC211 (http://www.isotc211.org/). Additional SDO's cover narrower niches of technology standards, such as UncertML (http://www.uncertml.org).

Regardless of any other SDOs' standards for SOA that may apply in a given context (e.g., from W3C, OASIS, IETF, etc.), it is important to factor in OGC/ISO geospatial encoding and web services standards. The OGC/ISO standards address mathematically complex issues having to do with proper encoding of geometric data and associated coordinate reference systems, as well as proper handling of the data structures throughout various types of spatial, topological, temporal, statistical, and other operations on the data. The relationships which have emerged between OGC and other IT-community SDOs respect and reflect this expertise, delegating to OGC the definition of geospatial and temporal interface specifications and styles of usage for the non-spatial communities.

A good example of this is the OASIS standard, Common Alerting Protocol (CAP), used for emergency dispatch. This XML-based protocol includes a data entity for the location point and/or polygon affected by the particular emergency in a given message. In the current versions 1.0/1.2 the locational data is very simplistic. However, a new version 2.0 in development will allow extensions, such as to use a GML application schema for location information. OGC is now working on the GML application schema to be proposed to OASIS for use in all its location-dependent standards. OWS-7 may provide an ideal setting in which to exercise various implementations of the new CAP standard.

Specific standards called out in the RFI responses include WFS, SOS, SPS, SWE Common, O&M, SensorML, Web Notification Service (WNS), GeoRSS, Catalogue Service (CSW) with ebRIM, ebXML Reg/Rep, KML, SOAP.

### 11.4.2 Semantics mediation of community vocabularies, taxonomies

It is an immutable condition that data fusion will involve disparate sources and forms of expression. While some consolidation of classifications can take place through community standards and best practices, the differences in perspective and requirements across any one or more communities of practice will inevitably bring about some number of conflicting terms and meanings in datasets. In some cases, the same term may be used with different meanings, while in others different terms may have the same or similar meaning. There will never be a single, overarching classification system on which all others are based or derived.

Progress has been made in developing semantics mediation tools for simplifying user interfaces to multiple data sources with similar content but different labels. These tools have so far concentrated on "hard fusion" subject matter such as coding values for air and water quality variables, since that is more precise and easily automated. Further work is needed in the area of semantics mediation for “soft fusion” applications that are more dependent on the user’s subjective understanding.

It is also important to stay aware of the limits of both automated and human-subjective processes, and avoid the trap of over-classification. Ontology creation and maintenance can become a seductive but endless process of ever-more precise definition of the entities of interest. As semantics development projects are carried out, the participants in these tasks should keep continual vigilance to develop vocabularies and taxonomies that strive to be simple yet elegant. This will help in achieving faster and more often correct mediation processing.

#### 11.4.3 Workflow driven by semantics

To cope with the crush of huge and growing data volumes to be processed, it is important to incorporate human awareness and expert knowledge into 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.

#### 11.4.4 Grid and Cloud implementations for performance and access

Both Grid and Cloud infrastructures (in the information technology perspective) may be useful approaches to coping with the growing large volumes and increasing sophistication of data processing. It was interesting to note that more of the RFI responses referred to cloud infrastructures than to grid infrastructures.  This may be partially due to the more recent entry of clouds in IT, but it is probably also due to the greater simplicity of access and usage for client applications of clouds.

# Bibliography

## Table A-1. Approved OGC Specifications Related to Fusion Study

| Title | Version |
|---|---|
| Catalog Service for the Web (CSW) with Corrigendum, profiles and extensions | 2.0.2 |
| Web Coverage Service (WCS) | 1.1.2 |
| Web Coverage Service (WCS) - Transaction Operation Extension | 1.1.4 |
| Web Coverage Service - Processing Extension (WCPS) | 1.0.0 |
| Web Feature Service (WFS) | 1.1 |
| Web Map Service (WMS) | 1.3.0 |
| Web Map Context (WMC) with Corrigendum | 1.1 |
| Web Processing Service (WPS) | 1.0 |
| Web Service Common | 1.1 |
| Geography Markup Language (GML) | 3.2.1 |
| CityGML Implementation Specification | 1.0 |
| Styled Layer Descriptor (SLD) | 1.1 |
| Symbology Encoding (SE) | 1.1 |
| Filter Encoding (FE) | 1.1 |
| Geospatial eXtensible Access Control Markup Language (GeoXACML) | 1.0 |
| KML | 2.2 |
| Open Location Services (OpenLS) | 1.1 |
| Observations and Measurements - Part 1: Observation schema | 1.0 |
| Observations and Measurements - Part 2: Sampling Features | 1.0 |
| SensorML with corrigendum | 1.0.1 |
| Sensor Observation Service | 1.0 |
| Sensor Planning Service | 1.0 |

## Table A-2. Candidate Standards Related to Fusion Study

| Title | Version |
|---|---|
| Web Map Tiling Service (WMTS) Candidate Standard | - |

 

**Table A-3. Approved OGC Best Practice Documents Related to Fusion Study**

| Title | Version |
|---|---|
| Binary Extensible Markup Language (BXML) Encoding Specification<br>(03-002r9) | - |
| EO Products Extension Package for  Profile of CSW 2.0 | 0.1.9 |
| Gazetteer Service - Application Profile of the Web Feature Service Implementation Specification | 0.9.3 |
| GML Application Schema for EO Products | 0.9.0 |
| GML Encoding of Discrete Coverages (interleaved pattern) | 0.2.0 |
| GML PIDF-LO Geometry Shape Application Schema for use in the IETF | 0.1.0 |
| Ordering Services for Earth Observation Products | 0.9.0 |
| Sensor Alert Service | 0.9.0 |
| Sensor Planning Service Application Profile for EO Sensors | 0.9.5 |
| Sensor Web Enablement Architecture | 0.4.0 |
| Units of Measure (UoM) Recommendation | 1.0.0 |
| Web Map Services - Application Profile for EO Products | 0.2.0 |
| Web Notification Service (WNS) | 0.0.9 |

 

**Table A-4. Discussion Papers Related to Fusion Study**

| Title | Version |
|---|---|
| URN namespace for the Open Geospatial Consortium (OGC) | 2.0.0 |
| Access Control & Terms of Use (ToU) "Click-through" IPR Management | 1.0.0 |
| Discussions, findings, and use of WPS in OWS-4 | 0.9.1 |
| Feature Portrayal Service (05-110) | - |
| Feature Styling IPR | 0.4.1 |
| Frame image geopositioning metadata GML 3.2 application schema (07-032) | - |
| Geocoder Service Draft Candidate Implementation Specification, Discussion Paper (retired) | 0.7.6 |
| GeoDRM Engineering Viewpoint and supporting Architecture | 0.9.2 |
| GEOINT Structure Implementation Profile (GSIP) Schema Processing | 0.5.0 |
| Geolinked Data Access Service | 0.9.1 |
| Geolinking Service (GLS) | 0.9.1 |
| Geoparser Service Draft Candidate Implementation Specification, Discussion Paper (retired) | 0.7.1 |
| Geospatial Portal Reference Architecture | 0.2.0 |
| Geospatial Semantic Web Interoperability Experiment Report | 0.5.0 |
| GML Performance Investigations by CubeWerx | 1.0.0 |
| GML Point Profile | 0.4.0 |
| Imagery Metadata | 1.0.0 |
| Integrated Client for Multiple OGC-compliant Services | 0.1.18 |
| Location Organizer Folder (LoF) Draft Candidate Implementation Specification, Discussion Paper (retired) | 1.03 |
| Loosely Coupled Synchronization of Geographic Databases in the CGDI | 0.0.9 |
| OGC Web Services Architectural Profile for the NSG | 1.3.0 |
| OWS-3 GML Investigations - Performance Experiment by Galdos Systems | - |
| OWS-5 SOAP/WSDL Common Engineering Report | 0.1.0 |

| Title | Version |
|---|---|
| OWS Context IE Final Report (05-062) (See Note 1) | 0.0.3 |
| OWS Messaging Framework (03-029) | - |
| OWS-3 GML Topology Investigation (05-102r1) | - |
| OWS-3 Imagery Workflow Experiments: Enhanced Service Infrastructure Technology Architecture and Standards in the OWS-3 Testbed | 0.9.0 |
| OWS-3 Integrated Client (GeoDSS Client) (05-116) | - |
| OWS-3 UML to GML Application Schema (UGAS) Tool (05-118) | - |
| OWS-4 CSW Modeling Guidelines IPR (06-155) | - |
| OWS-4 Web Processing Service IPR (06-182r1) | - |
| OWS-4 Workflow Descriptions and Lessons Learned (06-187r1) | - |
| OWS-5 Conflation ER (07-160r1) | - |
| OWS-5 Data View Architecture ER (07-163r1) | - |
| OWS-5 Geoprocessing Workflow Architecture ER (07-138r1) | - |
| OWS-5 GeoRM License Broker Specification ER (See Note 2) | 0.9 |
| OWS-5 GSIP Schema Processing ER | 0.0.2 |
| OWS-5 OGC Web Services Architectural Profile for the NSG (07-009r3) | - |
| OWS-5 SOAP/WSDL Common ER | 0.1.0 |
| OWS-4 Topology Quality Assessment Interoperability Program Report | 0.3.0 |
| Schema Maintenance and Tailoring (05-117) | - |
| Some image geometry models | 1.0.0 |
| Temporal Standard Recommendations (06-022r1) | - |
| Trusted Geo Services IPR | 0.9.0 |
| Uncertainty Markup Language (UncertML) (08-122r2) | 0.6 |
| Web 3D Service | 0.3.0 |
| Web Coordinate Transformation Service (WCTS) | 0.4.0 |
| Web Image Classification Service (WICS) | 0.3.3 |
| Web Object Service Implementation Specification (03-013) | - |
| WFS Temporal Investigation | 0.1.0 |
| WMS - Proposed Animation Service Extension | 0.9.0 |

| Title | Version |
|---|---|
| WMS Change Request: Support for WSDL & SOAP | 0.1.0 |
| WMS Part 2: XML for Requests using HTTP Post (02-017r1) | - |
| XML for Image and Map Annotation | 0.4.0 |

Notes:

(1) Document 05-062 has not yet been approved for public release; draft may be made available upon request.

(2) Document 08-076 adoption as an OGC Discussion Paper is contingent on a modification of the document to add sufficient requirements and examples to demonstrate a license as defined by this document is always consistent with figure 5 General License Model, in OGC Document 06-004r3 GeoDRM Reference Model. Draft may be made available upon request.

**Table A-5. Recently Approved OGC Discussion Papers Relevant to Fusion Study**

| Title | Version or Doc# |
|---|---|
| OWS-6 SWE Summary Report | 09-064r2 |
| OWS-6 Georeferenceable Imagery ER | 09-034 |
| OWS-6 SWE Information Model ER | 09-031r1 |
| OWS-6 SensorML CR | 08-192r1 |
| OWS-6 SensorML Profile for Discovery ER | 09-033 |
| OWS-6 Secure Sensor Web ER | 08-176r1 |
| OWS-6 SWE CCSI ER | 09-007 |
| OWS-6 Event Architecture ER | 09-032 |
| OWS-6 SWE PulseNet (rm) ER | 09-073 |
| OWS-6 GPW Summary ER | 09-063 |
| OWS-6 Security ER (See Note 3) | 09-035 |
| OWS-6 GeoXACML ER | 09-036r1 |
| OWS-6 Urban Topographic Data Store (UTDS) - CityGML Implementation Profile ER | 09-037r1 |
| OWS-6 CityGML CR | 09-039 |
| OWS-6 GML Profile Validation Tool Guidelines ER | 09-038r1 |
| OWS-6 WPS - Grid Processing ER | 09-041r2 |

 

| Title | Version or Doc# |
|---|---|
| OWS-6 GeoProcessing Workflow Architecture ER | 09-053r3 |
| OWS-6 DSS Summary Engineering Report | 09-068r1 |
| OWS-6 WMS-Tiling ER | 09-006 |
| OWS-6 Symbology-Encoding Harmonization ER | 09-012 |
| OWS-6 Symbology Encoding (SE) CR | 09-014 |
| OWS-6 Symbology Encoding (SE) Changes ER | 09-016 |
| OWS-6 Styled Layer Descriptor (SLD) CR | 09-013 |
| OWS-6 Styled Layer Descriptor (SLD) Changes ER | 09-015 |
| OWS-6 W3DS - 3D Flythrough ER | 09-075r1 |
| OWS-6 Outdoor and Indoor 3D Routing Services ER | 09-067 |
| WCS Change Request to Support Error Propagation | 09-099 |

Notes:

(3) Document 09-035 still in revision; draft may be made available upon request.

**Table A-6. Non-OGC Standards Related to Fusion Study**

| Name | Specification | Description |
|---|---|---|
| WSDL | Web Services Description Language v 2.0 W3C Recommendation http://www.w3.org/TR/wsdl20/ | Web Services Description Language (WSDL) is a specification from W3C to describe networked services. WSDL is used to describe what a web service can do, where it resides, and how to invoke it. It provides a simple way for service providers to describe the basic format of requests to their systems. |
| SOAP | Simple Object Access Protocol (SOAP) 1.1 http://www.w3.org/TR/soap11/ ; SOAP 1.2 http://www.w3.org/TR/soap/ | Simple Object Access Protocol (SOAP) is a protocol specification from W3C for exchange of information in a decentralized, distributed environment. |
| BPEL | Web Services Business Process Execution Language 2.0 – OASIS Standard http://docs.oasis-open.org/wsbpel/2.0/wsbpel-v2.0.html | The Business Process Execution Language for Web Services (BPEL4WS or BPEL for short) defines a notation for specifying business process behavior based on Web Services. |

| Name | Specification | Description |
|---|---|---|
| ebXML | OASIS Standard 2.0 http://www.oasis-open.org/specs/index.php#ebxmlbp2.0.4 , see also ISO/TS 15000-5:2005 | Defines a standards-based business process foundation that promotes the automation and predictable exchange of Business Collaboration definitions using XML. |
| ebXML RIM | ebXML Registry Information Model 2.0 – OASIS Standard http://www.oasis-open.org/committees/regrep/documents/2.0/specs/.pdf | Defines what information is in the Registry and how that information is organized. This leverages as much as possible the work done in the OASIS and the ISO 11179 Registry models. |
| Wf-XML | Workflow-XML 1.1 and 2.0 - Workflow Management Coalition (WfMC) Standard http://www.wfmc.org/standards/wfxml.htm | Wf-XML is designed and implemented as an extension to the OASIS Asynchronous Service Access Protocol (ASAP). ASAP provides a standardized way that a program can start and monitor a program that might take a long time to complete. Wf-XML provides additional standard web service operations that allow sending and retrieving the “program” or definition of the service which is provided. Wf-XML is an ideal way for a BPM engine to invoke a process in another BPM engine, and to wait for it to completed. |
| Wf-XML-R | Workflow-XML (RESTful Binding) Draft 0.4 - WfMC Standard http://www.wfmc.org | |
| XPDL | XML Process Definition Language 2.1 – WfMC Standard http://www.wfmc.org/standards/xpdl.htm | XPDL provides a file format that supports every aspect of the BPMN process definition notation including graphical descriptions of the diagram, as well as executable properties used at run time. |

| Name | Specification | Description |
|---|---|---|
| WS-Security | Web Services Security 1.1 – OASIS Standard http://www.oasis-open.org/committees/download.php/16790/wss-v1.1-spec-os-SOAPMessageSecurity.pdf | This specification and associated token profiles (Username, X.509, SAML, Kerberos, REL, and SOAP with Attachments) provide the technical foundation for implementing security functions such as integrity and confidentiality in messages implementing higher-level Web services applications. |
| SAML | Security Assertion Markup Language 1.1 – OASIS Standard http://www.oasis-open.org/specs/index.php#samlv1.1<br>SAML 2.0 – OASIS Standard http://www.oasis-open.org/specs/#samlv2.0 | This specification defines the syntax and semantics for XML-encoded assertions about authentication, attributes, and authorization, and for the protocols that convey this information. |
| XACML | eXtensible Access Control Markup Language 2.0 – OASIS Standard http://www.oasis-open.org/specs/#xacmlv2.0 | This specification, together with associated schemas and resource profiles, defines the syntax and semantics for access control. |
| XML Signature | W3C Recommendation http://www.w3.org/TR/xmldsig-core/ | Specifies XML digital signature processing rules and syntax. XML Signatures provide integrity, message authentication, and/or signer authentication services for data of any type, whether located within the XML that includes the signature or elsewhere. |
| XML Encryption | W3C Recommendation http://www.w3.org/TR/xmlenc-core/ | Specifies a process for encrypting data and representing the result in XML. The data may be arbitrary data (including an XML document), an XML element, or XML element content. |
| PKI | Public Key Infrastructure – IETF Standard http://www.ietf.org/html.charters/pkix-charter.html | Internet standards to support X.509-based Public Key Infrastructures (PKI) for data encryption. |

 

| Name | Specification | Description |
|---|---|---|
| XKMS | XML Key Management System – W3C Note http://www.w3.org/TR/xkms/ | Specifies protocols for distributing and registering public keys, suitable for use in conjunction with the proposed standard for XML Signature. This document is a NOTE made available by the W3C for discussion only. |
| RSS 2.0 | Web syndication system http://www.rssboard.org/rss-specification | RSS is a family of Web feed formats to publish frequently updated content. |
| Atom 1.0 | Atom Syndication Format is IETF RFC 4287 http://tools.ietf.org/html/rfc4287 while Atom Publishing Protocol is IETF RFC 5023 http://tools.ietf.org/html/rfc5023 | Alternative to RSS to ease the development of applications with web syndication feeds. |
| GeoRSS GML | Geographically Encoded Objects for RSS Feeds as GML Application Schema, http://georss.org/gml | Encoding of GeoRSS' objects in a simple GML version 3.1.1 profile. Compatible with RSS and Atom. |
| ISO 19117:2005 | ISO TC211 Document n1578 http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=40395 | Geographic Information - Portrayal |
| ISO/IEC 21000-5: 2004/Amd 2:2007 | Rights Expression Language, REL http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=44341 | ISO/IEC 21000-5:2004 specifies the syntax and semantics of a Rights Expression Language. |
| ISO/IEC 15408: 2005 | Part 1 - http://standards.iso.org/ittf/PubliclyAvailableStandards/c040612_ISO_IEC_15408-1_2005(E).zip ; Part 2 - http://standards.iso.org/ittf/PubliclyAvailableStandards/c040613_ISO_IEC_15408-2_2005(E).zip ; Part 3 - http://standards.iso.org/ittf/PubliclyAvailableStandards/c040614_ISO_IEC_15408-3_2005(E).zip | Information technology – Security techniques – Evaluation criteria for IT security. |

 

| Name | Specification | Description |
|---|---|---|
| ISO/IEC TR15443: 2005 | Information technology -- Security techniques -- A framework for IT security assurance http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=39733 | Technical Report to guide the IT security professional in the selection of an appropriate assurance method when specifying, selecting, or deploying a security service, product, or environmental factor such as an organization or personnel. |
| ISO/IEC 10181: 1996 | ISO catalogue link for ordering: http://www.iso.org/iso/search.htm?qt=10181&published=on&active_tab=standards | Security Framework for Open Systems; Part 1-Overview, Part 2-Authentication framework, Part 3-Access control framework, Part 4-Non-repudiation framework, Part 5-Confidentiality framework, Part 6-Integrity framework, Part 7-Security audit and alarms |
| ISO 19134 | ISO/TC211 N2045, 2006-07-17 – Geographic Information – Location based services – Multimodal routing and navigation | This International Standard provides a conceptual schema for describing the data and services needed to support routing and navigation application for mobile clients who intend to reach a target position using two or more modes of transportation. |
| INFOD | www.ogf.org | Open Grid Forum (OGF) specification for metadata registry system for use in grid computing. |
| CSM TRD | Community Sensor Model (CSM) Technical Requirements Document (TRD) from Community Sensor Model Working Group (CSMWG), http://www.csmwg.seicorp.com/CSM2Doc.htm | The CSM Program will provide Government and Industry with the capability to create and maintain a standard program for developing, testing, and evaluating a collection of current and future sensor models. The models support Sensor Exploitation Tools (SETs) and other application tools that require a precise understanding of the image (data) and ground coordinate relationships. The CSMs are dynamically linked (or loaded) libraries that do not require re-compilation of the SET. |

 

**Table A-7. Grid/Cloud References Related to Fusion Study**

| Reference | Description |
|---|---|
| http://forge.gridforum.org/sf/projects/ogsa-hpcp-wg | High Performance Computing Profile Working Group |
| http://ogf.org/hpcp/ | OGF High Performance Computing (HPC) Basic Profile |
| http://ogf.org/hpcp/specs.php | OGF HPC Basic Profile Related Specs |
| http://portal.opengeospatial.org/files/?artifact_id=34410 | OGF-OGC_2_Overview_Lee.ppt |
| http://portal.opengeospatial.org/files/?artifact_id=34411 | OGF-OGC_3_Research_Agenda_Baranski.ppt |
| http://portal.opengeospatial.org/files/?artifact_id=34419 | OGF-OGC_7_Grid_SDI_Kiehle.pdf |

**Additional Grid/Cloud related publications:**

[1] Baranski, B. (2008). Grid Computing Enabled Web Processing Service. GI-Days 2008, Münster, Germany.

[2] Kiehle, C., Greve, K. & C. Heier (2007). Requirements for Next Generation Spatial Data Infrastructures - Standardized Web Based Geoprocessing and Web Service Orchestration. In: Transactions in GIS. 11(6), p. 819-834.

[3] Di, L., Chen, A., Yang W., & Zhao, P. (2003). The Integration of Grid Technology with OGC Web Services (OWS) in NWGISS for NASA EOS Data . GGF8 & HPDC12. 24 – 27 June at Seattle.

[4] Woolf, A (2006). Wrappers, portlets, resource-orientation and OGC in Earth-System Science Grids, Grid ad-hoc, OGC TC Edinburgh, June 2006 [http://portal.opengeospatial.org/files/?artifact_id=15966]

 