Contemporary Concerns in Geographical/Geospatial Information Systems (GIS) Processing

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Abstract *– With the advent of advances in Geospatial Information Systems (GIS); there is a need to determine the areas of research and new tools available for GIS systems. GIS consists of the collection, integration, storage, exploitation, and visualization of geographic and contextual data and spatial information. Future GIS needs, techniques, models, and standards should be shared openly among developers for future instantiation of products. The summary of selected areas include (1) support for large-data formats including meta-data transparency, (2) adherence to open standards, (3) generation of extensible architectures, and (4) development of a consistent set of metrics for analysis. The future of GIS products will include non-spatial as well as spatial data which requires information fusion, management functions from machine-processed data to user-defined actionable information, and use-case challenge problems for comparison.*

Keywords: *Geospatial, Geographical Information Systems, metrics, information fusion, user refinement*

1 Introduction

Geospatial Information Systems (GIS) includes the data management, tools, and mathematics for geographical spatial information analysis and modeling. [1, 2] For example, an image overlay is a data fusion tool that creates a mathematical model to support spatial data management and analysis [3]. Spatial data fusion, as a part of information fusion, includes methods of data registration [4], image quality and uncertainty analysis [5], and image fusion [6]. Image fusion includes signal/pixel [7], feature [8], and decision-level [9] analysis. GIS is an enabling tool for environmental weather analysis, target tracking [10, 11], target identification [12], situation assessment [13], and sensor control [14] for such applications as defense [15], robotics [16], agriculture, and transportation [17].

Typically, the GIS community has focused on visualization and spatial mapping to support decision making while incorporating new technologies for data and workflow management. For example, the Global Earth Observation "System of Systems," (GEOSS) concept shown in Figure 1 provides both the visualization and spatial mapping of weather and terrain information to a graphical user interface (GUI).

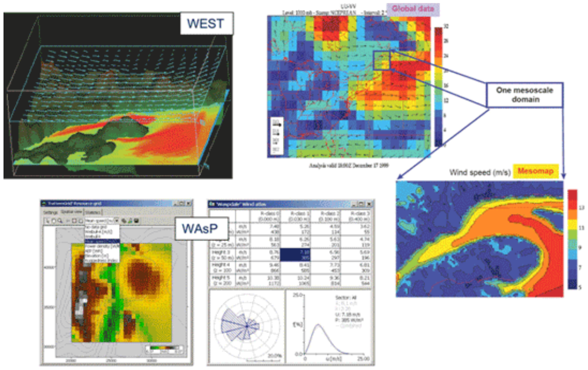


Figure 1. GIS product example [18].

Geospatial Information Systems includes many tools and products to exploit and utilize spatial data (i.e. images, road data [19, 20], terrain information [21], etc). GIS systems have existed for many centuries; however, with digital processing, the field began to take shape with automated collections, dissemination, and storage of the data. In the last few decades with the development of the World Wide Web, there have been many GIS products that are embedded in modern culture. GIS products support data analysis to a user over operating conditions of targets, sensors, and the environment respectively [22].

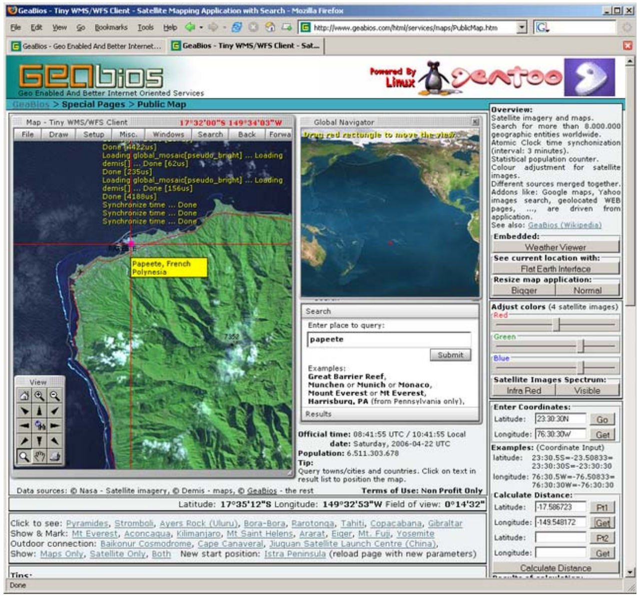
GIS consists of five areas [23]:

1) Visualization
2) Spatial Analysis
3) Data Management
4) Workflow Management
5) Dissemination of Information.

Future developments in GIS will be shaped by current requirements which are not yet fully satisfied.

1.1 Current Trends in GIS

Numerous developments and historical context is available in textbooks [1, 2] and websites [24]. Key to the developments is the increasing use of tools that support the user; however, these tools require adaptations to future needs. Figure 2 presents a GIS product that enables visualization, analysis, and user control.



Done [4422us]
Loading global_mosaic[pseudo_bright] ... Loading demis[] ... Done [62us]
Done [235us]
Loading global_mosaic[pseudo_bright] ... Loading demis[] ... Done [156us]
Done [4188us]
Synchronize time ... Done
Synchronize time ... Done
Synchronize time ... Done

Enter place to query: papeete

Examples: **Great Barrier Reef**, **Munchen** or **Munich** or **Monaco**, **Mount Everest** or **Mt Everest**, **Harrisburg, PA** (from Pennsylvania only),

Official time: 08:41:55 UTC / 10:41:55 Local
date: Saturday, 2006-04-22 UTC
Population: 6.511.303.678
Tip: Query towns/cities and countries. Click on text in result list to position the map.

Data sources: © Nasa - Satellite imagery, © Demis - maps, © GeaBios - the rest **Terms of Use: Non Profit Only**

Latitude: **17°35'12"S** Longitude: **149°32'53"W** Field of view: **0°14'32"**

Click to see: Pyramides, Stromboli, Ayers Rock (Uluru), Bora-Bora, Rarotonga, Tahiti, Copacabana, Gibraltar
Show & Mark: Mt Everest, Aconcagua, Kilimanjaro, Mt Saint Helens, Ararat, Eiger, Mt. Fuji, Yosemite
Outdoor connection: Baikonur Cosmodrome, Cape Canaveral, Jiuquan Satellite Launch Centre (China),
Show: Maps Only, Satellite Only, Both New start position: Istra Peninsula (reload page with new parameters)

Overview:
Satellite imagery and maps.
Search for more than 8.000.000 geographic entities worldwide.
Atomic Clock time synchonization (interval: 3 minutes).
Statistical population counter.
Colour adjustment for satellite images.
Different sources merged together.
Addons like: Google maps, Yahoo images search, geolocated WEB pages, ..., are driven from application.
See also: GeaBios (Wikipedia)

Enter Coordinates:
Latitude: 23:30:30N
Longitude: 76:30:30W
Examples: (Coordinate Input)
latitude: 23:30.5S=-23.50833=23:30:30S=-23:30:30
longitude: 76:30.5W=-76.50833=76:30:30W=-76:30:30
Calculate Distance:
Latitude: -17.586723
Longitude: -149.548172
Latitude:
Longitude:

Figure 2. GIS product [24].

User interaction with the GIS interface should enhance decision-making [25], afford user refinement [26], improve knowledge representation [27], support situation awareness [28], and enable resource coordination [29]. We highlight that there are general categories of contemporary needs for GIS processing including:

1. Large Data Formats
2. Standards Developments
3. Common Metrics
4. Common architectures.

Large volume data management includes spatial and non-spatial data which is growing in size that requires joint data management [30] and compression [31]. To support workflow management, there is a need for user refinement in the collection and analysis of net-centric distributed multimodal data [32]. Supporting both data and workflow management requires a standard metrics of analysis over the fusion, integration, and association of data. Common architectures would support the current trends of ontology-based semantic analysis of contextual information [33].

Table 1. Panelist Category of Concerns for Contemporary GIS developments

	Large Data	Standards	Metrics	Architecture
Blasch	Collection and Management	Approved Formats and headers info	QOS, IQ Multi-modal	SOA Interoperable
Deignan	Tagged	Industry Standard	Information Theoretic	Open Source
Pellechia	Extraction	Compression	Confidence	Extensible
Dockstader	Limits of analysis (Imagery Format)	Unified Data Language	Visualization (Social network analysis)	Shared Architectures
Palaniappan	WAMI	Image Standards	Representation	Graph Theory
Seetharaman	Database Storage	Imagery Protocols	Computing analysis	Layered Sensing

1.2 Emerging Concerns for GIS

In the last few years, with the advent of social media, individual contributions (e.g. apps for person data assistant), and customer need (e.g. GPS devices in cars) there are many new commercial developments that will continue to expand GIS needs. It is therefore important to look at the trends and determine the directions for GIS developments. With the new developments, there is a need for the GIS community to coordinate on the directions and needs for the future. In this paper, we organized our collective wisdom in what are the current concerns, challenges, issues, to be prioritized such that GIS developments continue to coordinate with current technology. The ideas presented here are the result of the individual authors and are representative of a significant amount of publications in regard to the future assessment.

Based on the supporting research, experience, and use of GIS systems, the authors organized their thoughts in a consistent set of issues that are important for the next generation of GIS developments. Based on the inputs, the key categories are summarized in Table 1. Section 2 provides a discussion on architectures and Section 3 looks at standards as enabling a consistent architecture. Section 4 encourages the use of open-sources and Section 5 discusses metrics with Section 6 presenting a Challenge problem for the use of large-data formats.

2 Geo-information Architectures

There are many proposed developments in architectures and the concern is to have an open-source common architecture from which new developments are easily added and previous developments improved. One general example of an architecture [23] is shown in Figure 3. The architecture consists of four components of a (1) user interface, (2) web applications area, (3) GIS server, and (4) database of spatial and non-spatial data. The user interface provides ubiquitous connectivity to software applications which themselves communicate via web services.

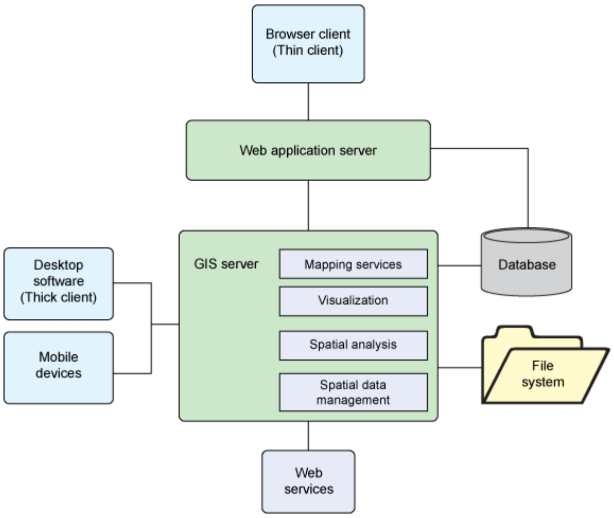


Figure 3. IBM general architecture [23].

User interface: To support future GIS architectures, there is a need to start with the end need in mind for GIS system design approach considerations. The user interface can be designed and tailored to support various users.

GIS Server: Visualization, analysis, and management support functions should be transparent to the user for effective decision-making. An increase reliance on pre-processing feature extraction and metadata to enable GIS triage should be available such that feature analysis is overlapped on the spatial information for highlighting events of interest

GIS database: Future requirements will require Large Volume Data Management and Compression Standards that support the use and processing of GIS spatial and non-spatial data. In addition, we highlight that the database needs development and reporting of deterministic GIS-based confidence, throughput, and accuracy metrics to support timely and actionable decision-making.

Web applications: To support future developments, there is a need for an Extensible architecture that enhances existing capabilities via replacement and refinement.

2.1 Extensible Architectures

GIS must support the user and developer requests for future capabilities. Environmental Systems Research Institute (ESRI) [34] is a leading software vendor for GIS. One of many ESRI architectures is shown in Figure 4, which focuses on messaging services between GIS products. ESRI provides many different software tools: desktop software to manage and visualize GIS data and Web-based user interfaces design tools. For example, ESRI's ArcGIS server provides mapping, visualization, and data management capabilities to do complex tasks. ArcGIS server works very well with leading database products such as DB2, Oracle, and SqlServer. ArcGIS server version 9.3 [35] also supports PostGres/PostGIS open source database for extending future application [23].

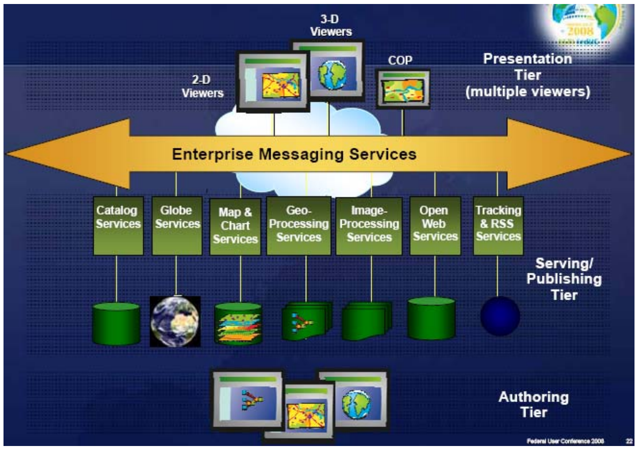


Figure 4. ESRI architecture [24].

Key to the ESRI products is ArcGIS, which is shown in Figure 5. Future capabilities can be added to the interface, such as presentation of metrics, use of open standards, and support large data formats. To complement the developments in GIS, we present an information fusion architecture that supports data analysis.

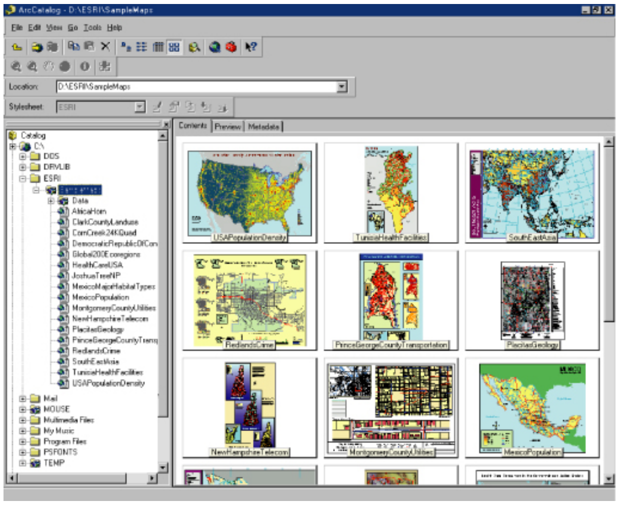


Figure 5. ArcGIS [35].

To complement the developments in GIS, we present an information fusion architecture that supports data analysis.

2.2 DFIG Model for Information Fusion

A useful model is one which represents a real world system instantiation. The information fusion (IF) community currently proposes the *Data Fusion Information Group* (DFIG) process model (a modification of the JDL model) with its revisions and developments as a point of reference for the facilitation of collaborative development efforts [26, 27]. In Figure 6, management functions are divided into sensor control, platform placement, and user selection to meet mission objectives and support data management from Levels 0-5. The DFIG architecture supports GIS in future capabilities of data exploitation, object assessment, and event analysis. Current definitions include:

Level 0 – Data Assessment: estimation and prediction of signal/object observable states on the basis of pixel/signal level data association;

Level 1 – Object Assessment: estimation and prediction of entity states on the basis of data association, continuous state estimation and discrete state estimation;

Level 2 – Situation Assessment: estimation and prediction of relations among entities, to include force structure and force relations, communications, etc.;

Level 3 – Impact Assessment: estimation and prediction of effects on situations of planned or estimated actions by the participants; to include interactions between action plans of multiple players;

Level 4 – Process Refinement (an element of Resource Management): adaptive data acquisition and processing to support sensing objectives.

Level 5 – User Refinement (an element of Knowledge Management): adaptive determination of who queries information and who has access to information (e.g. information operations) and adaptive data retrieved and displayed to support cognitive decision making and actions.

Level 6 – Mission Management (an element of Platform Management): adaptive determination of spatial-temporal control of assets (e.g. airspace operations) and route planning and goal determination to support team decision making and actions (e.g. theater operations) over social, economic, and political constraints.

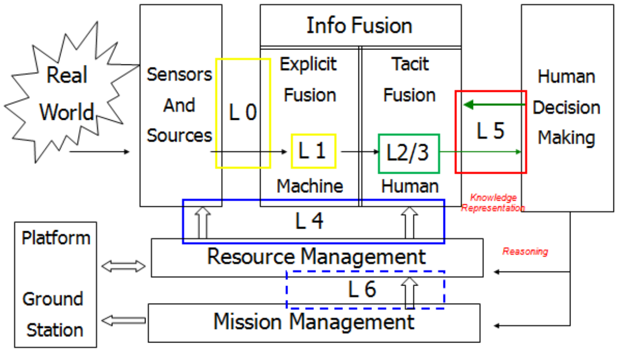


Figure 6. DFIG user-fusion model [26].

GIS developments utilize signal processing, database management, and information fusion. The individually collected products are often exploited, stored, and disseminated as separate systems. Naturally, individual collections result from the developers, companies, and users that are interested in the products. There is a need to look at information fusion architectures to bring together spatial and non-spatial data. For instance, hydrology data (from the USGS) meets a specific need for government planning and agriculture. However, the hydrologic data could also be useful for target tracking in determining where a target might be able to transverse, the industrial transportation of products, or the social connections between agricultural business relations. To make the architectures meaningful, we need open and consistent standards for analysis.

3 Meta-Data Standards

The *Open Geospatial Consortium* (OGC) is an international industry consortium of companies, government agencies, universities, and individuals participating in a consensus process to develop publicly available geoprocessing specifications [36]. Open interfaces and protocols defined by OpenGIS specifications support interoperable solutions that "geo-enable" the Web and afford individual services accessible and useful to a wide variety of applications. For example, OGC protocols include *Web Map Service* (WMS) and *Web Feature Service* (WFS).

3.1 Meta-data support for GIS Collection Systems

To further the OCG goals, there is a need for meta-data support. Geo-referenced information should be tagged by meta-data for cross-correlation with fusion algorithms (the over abundance problem). The imagery should industry standards in order to make maximal use of commercial off-the-shelf (COTS) tools. One example is the use information-theoretic metrics (model independent) on the meta-data for multi-INT associations, complex pattern retrieval, and anomaly detection. Since the architecture is driven by COTS rather than proprietary programs, the emphasis of development is assure the use of best of breed tools for data collection, analytics, archival, and presentation.

3.2 Tactical Needs of GIS-based Collection Systems

We can survey a geographical area, develop hydrology, logistic, and "human terrain" overlays, but we cannot attach human activity of tactical interest to an area without seeing it with our own eyes. Listening to communications and interviewing the local population is one thing, but to see is to believe. We presently are accumulating imagery of areas of tactical interest at a rate measured in the petabytes per month [37]. The problem is not simply to manage the intake of information, but to produce the intelligence that had prompted the effort to collect the information. There is a difference of importance in which thrust we adopt as our technical solution. If we focus on managing the intake of information, our solution quickly devolves into an information archiving management system. If, rather, we keep in mind that the purpose of the intelligence is in ultimately aiding the tactical decision-maker, our solution methodology will be pressed to conform to the end-user.

The *information archiving solution* has the unintended side-effect of elevating the collection of raw imagery to echelons in the organization well-above the echelon of maximal decision-making value. We can measure the decision-making value by integrating the value of intelligence to decision-making throughout the affected subordinate echelons. Greater intelligence allows for greater autonomy in operations and for more immediate and tailored tactical effects. There is a natural balance in the hierarchy in the allowed autonomy of subordinate echelons that is partially determined by the relative intelligence production capabilities of the various echelons. The centralization of collection above the echelon of maximal utility creates a stovepipe such that potential tactical users are isolated in time and influence over collection priorities and collection products. (These observations from first hand assessment of the second author of operations in Iraq parallel those made by Flynn [38] of intelligence operations in Afghanistan.)

If, on the other hand, we utilize the *information utilization solution*, we direct collections by expected tactical utility. The paramount engineering concern becomes the structuring of the intelligence for accessibility over timespans that extend well beyond that needed to shunt the collections through a hierarchy of depositories. Furthermore, the optimal collection targets are not well determined since it cannot always be known ahead of time how the tactical situation will evolve. Therefore, the structure of the imagery depository must be amenable to access by general queries by the tactical decision-maker using terms and relations native to the operations domain.

For example, in defense application there is defined a translation from collection measurables to operational indicators in the backwards formulation of essential elements of information (EEIs) from information requirements (IRs). These IRs are formulated by the intelligence staff in cooperation with the operations staff in order to support the commander's decision-making through potential courses of action. While the formulation is ill-posed, the process that creates the formulation is codified within the military decision-making process and is unlikely to be relegated to fully automated methods. This leaves the problem of marking the collected imagery with terms accessible by the lexicon of the EEI.

To illustrate the tactical problem and to further motivate a technical solution, consider the problem common in irregular warfare of distinguishing combatants from noncombatants. Suppose that the pattern of activity of the enemy within an area of interest suggests the presence of either multiple enemy cells with limited mobility or a single cell utilizing a vehicle. The area is highly trafficked by vehicles so the test of the later hypothesis becomes a problem of associating known enemy events with vehicular traffic over multiple roadways over multiple time intervals. Further suppose that the various named areas of interest fall within the range of a signals intelligence (SIGINT) collection asset which may then cue an imagery intelligence (IMINT) collection asset. The final association might be made unambiguously through a review of imagery queried by vehicle color and type over the restricted range of a synchronous SIGINT and IMINT collect, as shown in Figure 7.

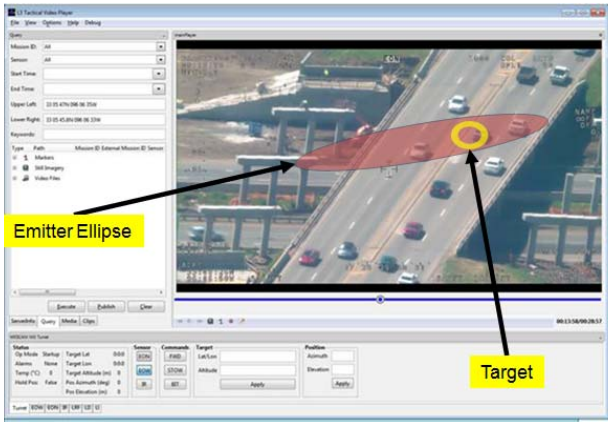


Figure 7. Critical association of target vehicle from a collection of queried meta-data tagged collects.

The ability to focus the collection effort onto an *actionable engagement set* over as little characteristic enemy activity as possible is dependent on the quality of the meta-data accessible by the undetermined EEIs. In order to provide the collection asset manager with the greatest opportunity to produce high quality tagged imagery responsive to an intelligence analyst's EEIs, we suggest that the collection architecture should be accessible by subscription such as is possible in a service oriented architecture, that the collections themselves be indexed semantically, and that the metrics of association admit the mixed data types common to the EEI lexicon, i.e. information-theoretic. In respect to standards, it seems that there is sufficient overlap between civilian and military application so that we expect civilian industry standards to drive military technology.

4 Open Source Development

Open-source development would enable information fusion solutions such as sensor cross-cueing from primary and secondary constellations as defined in the spatial imagery. The visualization of multisource data needs to go beyond methods of image registration and image fusion for spatial data presentation to new methods for fusing non-IMINT data in a holistic presentation.

Open source sharing (*OSS*) includes methods such as the computer vision (sourceforge) and the military (forge.mil) enable and open source development environment that includes code and documentation. Such attributes of cloud computing and social networks are proving innovative methods of open-source rapid development. With OSS, developers can design front end services and tailored products for industry collaboration. One emerging example of a GIS service need is social network analysis (SNA).

Social networking analysis among agents is important for the user-defined *information utilization solution.* An analyst is part of the social network in the queuing and request for data. For instance, intelligence analysts (IA) send and receive products to answer an information requirement. Weeks later, another IA might query the same message and a social network could be established to deliver the same methods prescribed by the first analyst. Thus, a social network tool could incorporate both the products and processes for decision making. One such method is to provide the information delivered to the last analyst that requested similar data. If the person asks for a solution, they would get products with metadata on information collected, range, look angles, time stamps and other important information that could be passed to the current analysts. There must be ways to "suggest" information. Linking data across timelines requires a unified data language.

Unified data languages include spatial (IMINT) and non-spatial data. IMINT data has been referenced to a common procedure of spatial attributes (i.e. geodetic coordinates). However, methods need to incorporate other data sets such as audio and non-IMINT data for data association and correlation. There is a limit of persistent surveillance and methods and metrics are needed to determine, how much data is too much data, which data to present to the analyst, and the value of the information to the decision-maker.

5 GIS Data Metrics Analysis

With an over abundance of data, metrics determine how to use what gets collected. Data management requires metrics for confidence, accuracy, and timeliness of products. Some methods exist for the efficient and effective use of sensors tailored for specific user-defined missions that enforce the economies of scale and scope necessary for the joint management of the vast stream of available data. The current pressing capability shortfall is incorporating unstructured data into data base management systems via source agnostic formats and standards. As shown in Figure 8, a human decision-maker oversees the data, whether structured or unstructured, and use of all GIS products.

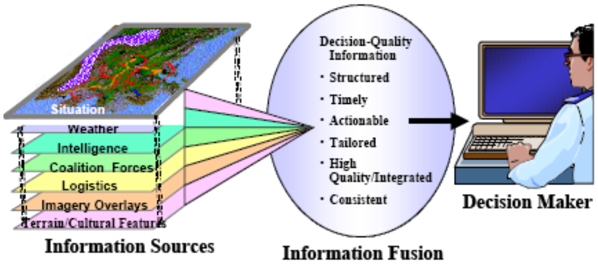


Figure 8. Decision-maker in the data intake loop.

With a user in the loop, it is essential that metrics of GIS data association are comprehensible by a human. For example, one shortcoming of Google Earth is that while it represents information spatially, it does not have manageable layer control features so that the image is often cluttered by tags. A tailored product would include the correct data overlayed at the appropriate resolution to make decisions. Future developments will require novel methods to address the paradox of how to visualize the situation when it is not just a picture.

Dynamic decision-making requires: adequate SA, dynamic responsiveness to changing conditions, and continual evaluation to meet throughput and latency requirements. These three factors are instantiated by an IF system, an interactive display to allow the user to make decisions, and metrics for replanning and sensor management [26]. To afford interactions between future GIS designs and users *information needs*, metrics are required. The metrics chosen include timeliness, accuracy, throughput, confidence, and cost. These metrics are similar to the standard QoS metrics in communication theory and human factors literature, as shown in Table 2 [39]. In addition to the metrics that establish the core quality (reliability/integrity) of information, there are issues surrounding information security and parsimony. To enhance the development of metrics standards, challenge problems are required from which we see large-data formats as one area of investigation.

Table 2: Metrics for various disciplines.

Comm.	**User**	**Info Fusion**	**ATR/ID**	**Tracking**
Delay	Reaction Time	**Timeliness**	Acquisition /Run Time	Update Rate
Probability of Error	Confidence	**Confidence**	Prob. (Hit), Prob. (FA)	Prob. of Detection
Delay Variation	Attention	**Accuracy**	Positional Accuracy	Covariance
Throughput	Workload	**Throughput**	No. Images	No. Targets
Cost	Cost	**Cost**	No. platforms	No. Assets

6 Challenge Problems for GIS with Large Data/Image Formats

Future GIS needs extend to non-saptial data; however, even the spatial data requires new technologies as the size, amount, and speed of data is of the data being collected is increasing. One way to address the problem is to collect large imagery data for challenge problem development. The data would enable development of tools needed for data formatting and cross cueing as well as data analysis through algorithm innovation.

One recent example of algorithm innovation is "context-free grammar" [40] that enable sharing between systems. To support GIS interoperability, the methods of exploitation must switch between pixel-level views (i.e. imagery) versus the graph-level analysis (i.e. social networks) which can be linked between large graphs and images. The distance-level metrics in the graph should quickly be coordinated with the pixel-level information to provide linkage metric. A general framework for challenge problem testing and evaluation is shown in Figure 9 [41] that includes the metrics visualization such as receiver operator curves [42].

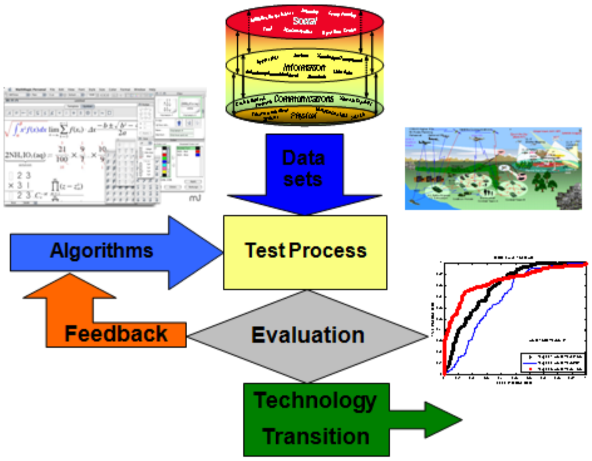


Figure 9. Evaluation process [41].

An example of a benchmark challenge problem was created by Blair [43] and the automatic target recognition (ATR) community has produced a set of challenge problems [44] such as the Synthetic Aperture Radar (SAR) [45] set to address object recognition over sensor, targets, and environments operating conditions. A scenario includes various kinematic target movements, possible sensor signals and target signatures, and terrain details.

A *challenge problem* includes:

- Problem Definition: The scope and significance
- Data: Applicable data for the defined problem
  - Tools for reading and processing data
  - Suggestions on training and test sets
  - Characterization of the data
- Goals: Research questions and suggested experiments
- Metrics: Guidance on reporting results
- Tools: Baseline code & results which show reproducible minimum performance standards for the defined problem

Scenarios provide data and support documentation for real world analysis either through analytical, simulated, or empirical results; however as in software design, "You can't control what you can't measure" [46]. One example of an open-source WAMI challenge problem is the Columbus Large Image Format (CLIF) collection which includes baseline methods for image registration [47]. Figure 10 shows the image data set from which results can be compared for infrared [48], multimodal source [49], and operating conditions solutions [50] for object tracking and identification [51] and event detection.

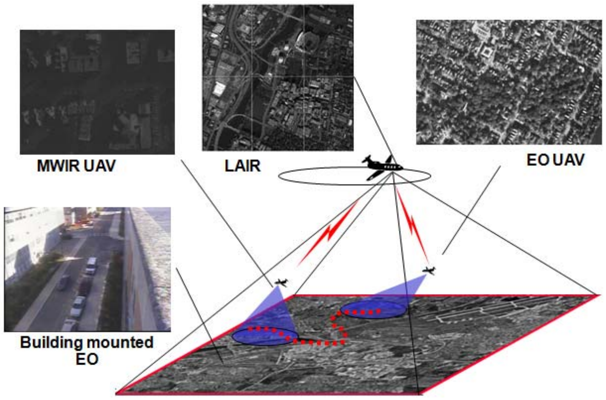


Figure 10. WAMI data set [47].

7 Conclusions

We have summarized the current issues associated with GIS techniques in terms of: **large data formats**, **standards**, **metrics**, and **architectures**. Since GISs utilize imagery as a baseline product, there is a need for future processing and exploitation of wide-area imagery as well as imagery annotation from non-spatial databases. Open-source algorithms, extensible architectures, and standards are essential enabling technologies in the development of interoperable systems. To facilitate progress along these lines, challenge problems should be created that foster innovative algorithms to collect, process, exploit, and store the information for retrieval.

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