Defining Standard Interfaces for Image Exploitation Services

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Abstract

The current effort in the Open GIS Consortium, Inc. (OGC) to develop open specifications for a set of software interfaces that enable diverse geoprocessing systems to access each other's image exploitation functions and image data is described. The objective is to specify standard interfaces to the functions needed for both use and production of data. Developing the Abstract Model of these services is the task of the OGC Technical Committee's Image Exploitation Services Special Interest Group (IES SIG). The specification will become part of OGC's OpenGIS Specification, which is intended to address software and data interoperability in every kind of geoprocessing, including GIS, photogrammetry, remote sensing, digital cartography, and others.

Introduction

The Open GIS Consortium (OGC) uses a process of consensus gathering among its membership to develop abstract specifications and implementation specifications for software components supporting geoprocessing (Open GIS Consortium, 1998a). Through the activities of working groups of members of the Consortium, essential models (i.e., descriptions of how the world works [or should work]) and specification models (i.e., descriptions of how software for this world should work) are developed (Cook and Daniels, 1994). These are brought before the Technical Committee, where consensus is achieved. The essential model and the specification model, together, are called the Abstract Specification.

When the Abstract Specification is sufficiently mature, the OGC membership may issue a Request for Proposal (RFP) for more specific implementation specifications. Responses to such a proposal provide implementation-level specifications in a platform-neutral fashion, such as in Interface Definition Language (IDL) (Open GIS Consortium, 1997). Vendors then produce software that uses the specified standard interfaces.

In the area of image exploitation services, OGC's goal is to define standards for software interfaces through which diverse systems can understand each other's requests for various operations needed to exploit images. This article describes some of the considerations in developing such interfaces, and explains how the services are modeled in the specifications. (Note that the Open GIS Consortium's OpenGIS Abstract Specification [Open GIS Consortium, 1998b] provides background primarily on OGC's Earth image geometry model. OpenGIS Project Document Number 99-115, *Image Exploitation Services*, may, at the date of this printing, still be an OGC internal document, not yet available on OGC's public web site. When that part of the Abstract Specification has been approved by OGC, and OGC issues a request for proposals for an implementation specification involving image exploitation services, that document will be made public.)

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Image Exploitation Services Use Cases

In order to help identify the image exploitation services that are required by information communities, we describe use cases that provide examples of the kinds of actors, behaviors, and relationships that must be considered in order to understand how image exploitation services are used in the "real world." Developing use cases is an important first step in the process of specifying detailed requirements for services that need to be accessible through the interoperability interfaces.

The following futuristic "use cases" describe different situations in which information consumers perform a series of activities using image exploitation services. Most listed steps in each use case will use one or more image exploitation services. (Other use cases are included in the OpenGIS project documents, including currently more common use cases where digital feature and elevation data is produced using images.)

The Farmer

The farmer obtains a map of his fields, through an interface to a local or remote map library or to a map creation service. (Note that this interface determines the spatial datum and projection and scale, or units, of the map.) The farmer overlays this map with

- Last year's image of his crop (obtained through an interface to a local or remote crop image library containing orthorectified images),
- Last year's yield profiles (note that the yield profiles may be polygons or linear features), and
- This year's soil samples (note that the soil samples are point features).

Using these data, the farmer assesses the need for fertilizer as a function of location on his fields. (Note that the algorithm which produces the fertilizer need requirements is provided by the local farmer's cooperative. That algorithm uses the map, the crop imagery, last year's yield profiles, and the soil samples as input.) The fertilizer need function produces a polygon coverage that aligns with the farmer's fields, where each polygon represents certain fertilizer application requirements.

Next, the farmer overlays all previous data with multispectral satellite images from each of the past 5 years that have been processed to highlight insect infestation, and assesses the need for insecticide. (Note that the multispectral imagery is obtained via an interface to USDA's database, with rectification parameters that ensure that it will fit the map automatically. The "insecticide need" is a partition of the farmer's fields into polygons, each of which specifies a certain mixture and concentration of chemicals. The algorithm that

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computes these polygons and concentrations from the multispectral imagery is provided by the local extension service.)

The farmer overlays the "insecticide need" polygons and values, and the "fertilizer need" polygons, with wetlands data from the county or state (note that the wetlands data are in a vector file), together with sensitivity factors from the Fish and Wildlife office (this is a raster file), and using an algorithm from the EPA, modifies his insect and fertilizer plans to protect a creek with an endangered species.

Finally, the farmer overlays all of the above with a soil moisture profile (obtained through an interface to NASA's real-time data) and plans today's and tomorrow's irrigation.

Notice the various actors: the farmer, the state university extension service (with insect data), the EPA, fish and wildlife, the farmer's cooperative (with algorithms), the image library (could be a commercial or a government source), etc.

Table 1 summarizes the steps in this use case and lists some of the image exploitation services needed by each step.

TABLE 1. IMAGE EXPLOITATION SERVICES NEEDED BY "THE FARMER"

Use Case Step	Image Exploitation Services Used
(1) Obtains map of his fields	
(a) through interface to local or remote map library or to map creation service	
(b) overlays it with last year's imagery of his crop	Display image with overlaid graphics
(c) overlays that with last year's yield profiles	Display image with overlaid graphics
(d) overlays that with this year's soil samples	Display image with overlaid graphics
(2) Assesses need for fertilizer as function of location on fields (displaying fertilizer need)	Classify pixels and segment image, Display image with overlaid graphics
(3) Overlays all previous data with satellite imagery from each of past 5 years	Display image with overlaid graphics
(a) that has been processed to highlight insect infestation	Classify pixels and segment image
(b) assesses need for insecticide (displaying insecticide need)	Classify pixels and segment image, Display image with overlaid graphics
(c) satellite imagery is obtained via interface to USDA's database	
(4) Overlays (above) with wetlands data	Display image with overlaid graphics
(a) together with sensitivity factors	Display image with overlaid graphics
(b) modifies his insect and fertilizer plans to protect creek	Classify pixels and segment image, Display image with overlaid graphics
(5) Overlays all above with soil moisture profile	Display image with overlaid graphics
(a) obtained through interface to NASA's real-time data	
(b) plans today's and tomorrow's irrigation	Classify pixels and segment image, Display image with overlaid graphics

The Prospective Home Buyer

The buyer, in the real estate broker's office or from home, selects a neighborhood (from an Internet service provided to support home-buying in a region), and is provided an aerial view of it. Service functions allow the buyer to zoom and roam through the region covered by the broker or service provider. Houses for sale appear in a red tint. Service interfaces allow the buyer to state a price range and mandatory features. Houses for sale in the desired price range and with the mandatory features flash red and green.

A few candidate green-and-red homes are selected through interfaces provided to the prospective buyer.

Functions using elevation data produce a three-dimensional perspective that allows the buyer to assess the view from each back porch.

A function that allows a virtual walk-through of the rooms of the house may be available.

Using orthorectified county imagery from 5, 10, 15, and 20 years ago, the buyer assesses the age of the roof, the health of the trees, and the trends in the neighborhood.

Using city, county and state data, the imagery is superimposed with

- Underground pipe and wire information (linear features),
- The assigned school districts and schools (point and area features),
- The nearest hospital and fire station,
- The lot lines, and
- All easements and right-of-ways.

Using chamber of commerce data, the nearest shops and supermarket and auto repair shops are located and superimposed.

Using Automobile Association data, a family of alternate routes to work are determined, with the conditions that make each optimal. Each route is displayed, registered to the image backdrop.

Using thermal infrared imagery from the department of energy, the prospective buyer assesses the heat loss in winter, and the need for new insulation. The algorithm is provided by EPA and DoE, jointly.

Using measuring tools, the sizes of the lot and house are separately measured. The size of the parking area is assessed and compared to the number of cars owned by the buyer.

Using census tract data and interfaces provided to the buyer, the demographics of the neighborhoods are visualized.

Table 2 summarizes the steps in this use case and lists some of the image exploitation services needed by each step.

The image exploitation services listed in Table 2 assume that

- All displays are in a (scaled and windowed) ground coordinate system (not in an unrectified image coordinate system),
- Selection of a neighborhood is done using either a text menu or a graphic map display (not using an image display), and
- Virtual walk-through of a house is done using images of the house interior.

Essential Image Exploitation Services

This section describes in more detail some of the image exploitation services listed in the use cases above.

Display Image with Overlaid Graphics

As listed above, many use case steps display an image, usually with overlaid graphics. The overlaid graphics are used to display features or elevations plus measurement cursors and perhaps other information. Such image display uses a number of image exploitation services, including

(1) Retreive selected image window from larger image, centered on a specified image position (roaming) and with a specified window size (zooming);
(2) Resample pixels of retrieved image window to change pixel spacing (zooming);
(3) Enhance images, to make desired features more easily visible;
(4) Rectify or orthorectify original image, either whole image or retrieved window of image;
(5) Mosaic multiple rectified or orthorectified images (mosaicking is not always needed);

TABLE 2. IMAGE EXPLOITATION SERVICES NEEDED BY "THE HOME BUYER"

Use Case Step	Image Exploitation Services Used
1) Selects neighborhood and is provided aerial view of (neighborhood)	
a) Selects neighborhood	
b) provided aerial view of (neighborhood)	Display image
c) Houses for sale appear in red tint (or) flash red and green	Display image with overlaid graphics
2) A few candidate homes are selected by prospective buyer	Display image with overlaid graphics
3) (Display) three-dimensional perspective view from each back porch	Generate perspective scene, Display image (optionally, with overlaid graphics)
4) Virtual walk-through of rooms of house	Generate perspective scene, Display image (optionally, with overlaid graphics)
5) Assess age of roof, health of trees, and trends in neighborhood, using county imagery from 5, 10, 15, and 20 years ago	Classify pixels and segment image, Display image with overlaid graphics
6) Imagery is superimposed with:	Display image with overlaid graphics
a) underground pipe and wire information	
b) school districts and schools	
c) nearest hospital and fire station	
d) lot lines	
e) easements and rights of way	
7) Nearest shops and supermarket and auto repair shops are located and superimposed	Display image with overlaid graphics
a) Using chamber of commerce data or images	Classify pixels and segment image
8) Family of alternate routes to work are charted, with conditions that make each optimal	
a) Using Automobile Association data	Display image with overlaid graphics
b) Each is registered to image backdrop	
9) Assesses heat loss in winter, and need for new insulation, using thermal infrared imagery. The algorithm is provided by EPA and DoE jointly	Classify pixels and segment image
a) (display color-coded heat-loss rating results)	Display image with overlaid graphics
10) Size of lot and house are independently measured	Compute area of polygon visible in image
11) Size of parking area is assessed and compared to number of cars owned by buyer	Compute area of polygon visible in image, Compute length of object visible in image
12) Demographics in neighborhoods are visualized, using census tract data	Display image with overlaid graphics

(6) Convert data positions stored in another coordinate system into the ground coordinate system of the display window;
(7) Convert data positions stored in all other coordinate systems into the image coordinate system of the display window; and
(8) Allow user to pick a graphically displayed item, and then present a full description of the selected item.

Note that items 4 through 6 listed above are appropriate when the display is in a ground coordinate system, as assumed for "The Farmer" and "The Prospective Home Buyer" use cases.

Generate Perspective Scene

Generation of a perspective scene (or image perspective transformation) is the generation of a synthetic image by processing one or more actual images. Each synthetic image is generated to simulate a different image geometry, such as an image taken from a different point in space and/or looking in a different direction. In addition to using one or more actual images, perspective scene generation uses data defining the (approximate) shape of the visible surface that was imaged. This shape data is usually derived from grid elevation data, and can include vector feature 3D shape data.

Classify Pixels and Segment Image

As listed, many use case steps classify image pixels and segment the resulting image (or raster data set). Such image manipulation can use a number of image exploitation services, including

(1) Register multiple images, coverages, and feature collections to one another.
(2) Reproject and resample vector feature coverages and raster image coverages to one another, or to a third common coverage scheme (e.g., grid).
(3) Change pixel values, to make the properties of interest more easily visible (including reduction of effective "noise"). These imagery enhancement operations can use (input) data from only one pixel at a time, or from a small neighborhood of adjacent pixels.
(4) Apply previously defined classification or other analysis algorithms to multispectral pixel data. These classification or analysis algorithms can:
  - Produce results that are discrete (assigning each pixel to one of several possible categories) or continuous (assigning a numeric value to each pixel, as derived from a continuous function).
  - Use data from only one pixel at a time, or from a small neighborhood of adjacent pixels.
  - Use multiple bands from the same image or from different images that have been registered to each other (see Item 1). One or more bands can also be non-image coverages, that are registered to all other data.
(5) Segment classified or analyzed image into discrete regions with similar properties, by finding groups of adjoining pixels with the same or similar values. The segmentation results can be produced in either raster or vector form. Such segmentation usually ignores single pixels or very small regions that may differ from all surrounding pixels.

Automated Feature Detection

Automated feature detection can also use a number of image exploitation services, including all those listed above for Classify Pixels and Segment Image. The results of such Classify Pixels and Segment Image operations are then automatically and/or manually analyzed to detect the feature types of interest and their attributes. Alternately or in addition, the image being analyzed can be compared with sample images showing the feature types of interest.

The Image Exploitation Services Taxonomy

Below is the categorization and taxonomy of image exploitation services that are currently planned to be accessible through Open GIS Standardized Interfaces:

1. Ground Coordinate Transformation Services:
  1.1. Ground coordinate conversion (exact) services:
    1.1.1. Geodetic coordinate conversion services

1.1.2. Map projection conversion services
1.2. Ground coordinate transformation (approximate) services:
1.2.1. Datum transformation services
1.2.2. Affine 2D transformation service
1.2.3. General 2D Polynomial transformation service
1.2.4. Polynomial 3D transformation service
1.2.5. Vertical ground position transformation services
1.2.6. Other 3D coordinate transformation services
1.2.7. Other 2D horizontal ground position transformation services
1.3. Concatenated ground coordinate transformation services (including two or more of the above transformations and/or conversions):
1.3.1. 3D to 3D concatenated transformation
1.3.2. 2D to 2D concatenated transformation
1.3.3. 1D to 1D concatenated transformation
2. Image Coordinate Transformation Services:
2.1. Image-ground position transformation services:
2.1.1. Ground to image position transformation service (3D to 2D)
2.1.2. Stereoscopic images to ground position transformation service (multiple 2D to one 3D)
2.1.3. Monoscopic image plus elevation to ground position transformation service (2D plus elevation to 3D)
2.1.4. Monoscopic image plus other data to ground position transformation service (2D plus other data to 3D)
2.2. Image position transformation services: (2D to 2D)
2.2.1. Polynomial transformation service
2.2.2. Image to rectified image position transformation service
2.2.3. Rectified image to image position transformation service
2.3. Concatenated image coordinate transformation services (including two or more of the above image transformations plus ground coordinate transformations and conversions):
2.3.1. 3D to 2D concatenated transformation
2.3.2. 2D to 3D concatenated transformation
2.3.3. 2D to 2D concatenated transformation
2.4. Imaging time determination service
3. Image Modification Services:
3.1. Change pixel values services:
3.1.1. Tone modification services
3.1.2. Spatial filtering (or convolution) services
3.1.3. Pixel (multi-band or multi-image) classification services
3.1.4. Image segmentation services
3.1.5. Band and image combination services
3.1.6. Other image enhancement services
3.1.7. Simulate non-idealities services
3.1.8. Histogram generation service
3.1.9. Fourier analysis service
3.1.10. Other frequency domain services
3.1.11. Graphical overlay application service
3.1.12. Grid overlay generation service
3.2. Change pixel positions services:
3.2.1. Pixel resampling service (services used by following subtypes)
3.2.2. Polynomial transformation warping service
3.2.3. Computer graphics warping services (including splines, piece-wise transformations)
3.2.4. Image rectification service
3.2.5. Orthorectification service
3.2.6. Image mosaicking service
3.2.7. Perspective scene generation service
3.3. Change image data format services: (Note: Includes or uses image coverage access services)
3.3.1. Image section retrieval services
3.3.2. Image section replacement services
3.3.3. Tiling change services
3.3.4. Reduced resolution generation service
3.3.5. Increased resolution estimation (or creation) services
3.3.6. Image compression and decompression services
3.4. Composite image modification services, including two or more of above image modifications
4. Dimension Measurement Services:
4.1. Line segment dimensions service:
4.1.1. Compute horizontal length and azimuth angle of a line segment, from one point to a second point
4.1.2. Compute 3D length and direction angles of a line segment, from one point to a second point
4.2. Multi-segment line length service:
4.2.1. Compute length of multi-segment line feature or real world object, from sequence of vertices representing spatial position of that line
4.3. Area dimensions services:
4.3.1. Compute area and perimeter of area feature or real world object, from sequence of vertices representing boundary of that area
4.3.2. Compute size, orientation, and center position of a standard geometrical shape, from a sequence of points on the perimeter of that shape
4.4. Height dimension service:
4.4.1. Compute height of a vertical real-world object (such as a pole or building), from one point on the image of the top and a second point on the image of the base
4.4.2. Compute height of a vertical real-world object (such as a pole or tower), from one point on the image of the top and a second point on the image of the shadow of the first point
4.5. Volume dimension service:
4.5.1. Compute volume of a solid features using its shell, from a sequence of vertexes for each facet of the shell
4.5.2. Compute cut and fill volumes between two different elevation surfaces, specified by a digital terrain matrix, regular triangulated network, or triangulated irregular network
4.6. Temporal dimension service:
4.6.1. Support time-stamping of features, or of each vertex of a feature, as a single value or as a time range. (The image exposure time of the feature, or its vertexes, could be associated with each feature or its vertexes. A feature time-stamp can be stored in feature attribute (or property) fields, using separate attributes for the beginning and ending times. A vertex time-stamp can be stored as a fourth dimension.)
5. Geodata Registration Services:
5.1. Adjust one SRS (Spatial Reference System) to another SRS.
5.2. Adjust multiple SRSs to each other (but not adjust to a fixed SRS)
5.3. Adjust multiple SRSs to a fixed SRS and to each other
6. Automated Image Matching Services:
6.1. Basic image matching services (services used by following subtypes)
6.2. Tie point extraction service
6.3. Control point transfer service
6.4. Elevation extraction service
6.5. Image pattern following services
6.6. Fiducial mark measurement service
6.7. Sample image matching services:
6.7.1. Object detection and location services
6.7.2. Object identification services
6.7.3. Object dimension determination services
6.7.4. Object classification services
7. Automated Image Understanding Services:
7.1. Pattern recognition services:
7.1.1. Object detection and location services
7.1.2. Object identification services
7.1.3. Object dimension determination services
7.1.4. Object classification services
7.2. Image comparison services:
7.2.1. Pixel values difference determination services
7.2.2. Change detection services
7.2.3. Trend analysis services
7.2.4. Model-based differencing services
7.2.5. Negation (determination of origin) of changes services
8. Accuracy Conversion Services:
8.1. Convert covariances to other forms:
8.1.1. Convert 3D covariances to CE plus LE
8.1.2. Convert 2D covariances to CE
8.1.3. Convert 1D variance to LE
8.1.4. Convert 1D variance to Standard Deviation
8.1.5. Convert 3D covariances to Spherical Error
8.2. Convert other forms to covariances:
8.2.1. Convert CE plus LE to 3D covariances
8.2.2. Convert CE to 2D covariances

8.2.3. Convert LE to 1D variance
8.2.4. Convert Standard Deviation to 1D variance
8.2.5. Convert Spherical Error to 3D covariances
9. Composite Image Exploitation Services: (Note: These higher level services use multiple lower level services)
9.1. Display window generation services: (Note: Including image pan, zoom, rotate, and change histogram)
9.1.1. Monoscopic display window generation service
9.1.2. Stereoscopic display generation service
9.2. Object counting services
9.3. Feature extraction (automated) services
9.4. Synthetic image generation service
9.5. Intelligence data extraction services
9.6. Image registration services
10. Support Metadata Access Services:
10.1. Image geometry model metadata access service
10.2. Spatial reference system (SRS) metadata access service
10.3. Coordinate transformation metadata access service
10.4. Image format metadata access service
10.5. Values (of pixels) metadata access service
10.6. Service capabilities metadata access service
10.7. Service properties (or strategies) metadata access service
10.8. Image geometry model transformation services
10.8.1. Fit approximate image geometry model to existing image geometry model
10.8.2. Convert image geometry model to different, mathematically equivalent model

Comments on Taxonomy of Services
Several comments on the above taxonomy and categorization:
(1) This taxonomy of services favors similarity of the fundamental interfaces needed by different services (instead of similarities of services functions or use). Similarity of interfaces is more appropriate for development of multiple standard APIs to image exploitation services.
(2) This taxonomy includes certain low-level services that are used by higher level image exploitation services, although these lower level services may be partially the same for features and/or collections of features with geometry. For example, Ground Coordinate Transformation Services (Item 1) are included.
(3) This taxonomy excludes high level services that are largely the same for features and/or collections of features with geometry. For example, geodata discovery and access services (Catalog Services) are not included.
(4) Most listed image exploitation services are also applicable to other grid coverage types, and some listed services are also applicable to non-grid coverage types. However, other grid and non-grid coverage types will probably need additional services, not included here.
(5) Some of the listed services will have distinct sub-items (not all listed), for example, (a) using only one image and (b) using multiple images.

Uses of Other Services
Many of the image exploitation services listed above will use other listed services. For example, the Change Pixel Positions Services may use the Image-Ground Position Transformation Services. The service usage relationships are expected to produce a network of connected services, with some services being higher level and some being lower level in the service use network.

Figure 1 shows some of the expected usage relationships between the listed services, in the form of a UML class diagram. This diagram also shows possible usage of these services by mission-specific client applications, plus usage of the OpenGIS Catalog and Coverage Services by these image exploitation services. To simplify this diagram, it does not show the multiplicities of the relationships shown; most relationship multiplicities could be many to many. This diagram also shows one box titled "Coordinate Transformation Services" that combines the "Ground Coordinate Transformation Services" plus the "Image Coordinate Transformation Services."

More Detailed Service Descriptions
The OGC project documents provide much more detailed descriptions of most of the image exploitation service categories listed in the preceding taxonomy. Also included are lists of the "needed data," or inputs, and "result data," or outputs, of each service category. The "needed data" and "result data" of multiple services are often identical or similar. The image exploitation services will often use and produce metadata about the geospatial data that are manipulated.

Data Structures Used in Interfaces
Open standard interfaces require the standardization of data structures and meanings, in addition to standardizing the functions or operations provided by each service. The following subsections discuss many types of data that are used by multiple listed image exploitation services.

Metadata
Several aspects of metadata have already been standardized and thus do not need to be standardized as part of defining standard interfaces to various image exploitation services. Indeed, these aspects of metadata organization should be the same for all OpenGIS services.

The draft ISO Metadata Standard, 15046-15, specifies the logical organization to be used for metadata, including both standard and custom metadata. Related metadata "elements" are grouped into metadata "entities" (including metadata "sections"). Each metadata entity (or section) contains a defined set of metadata elements and/or a set of lower level metadata entities. Each metadata element, entity, and section has a name and a definition.

OpenGIS Abstract Specification Topic 11: Metadata, requires use of the ISO metadata concepts and terminology. In addition, Topic 11 provides object-oriented notation for ISO-

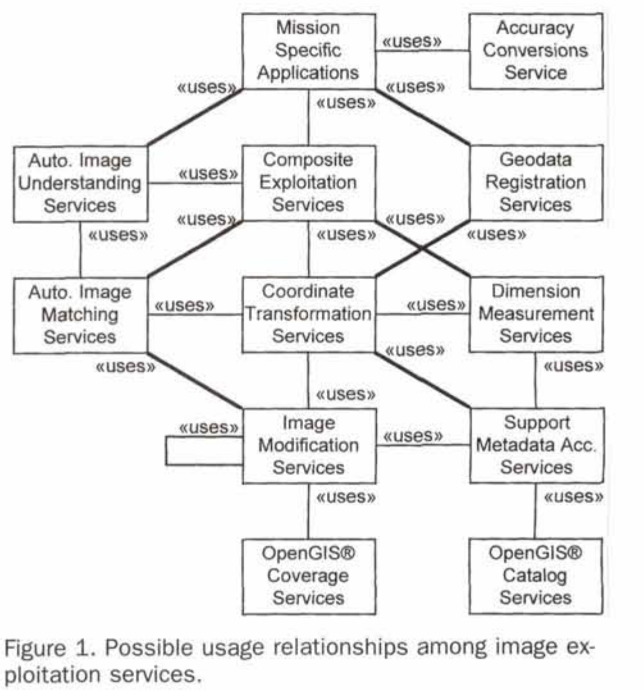

Figure 1. Possible usage relationships among image exploitation services.

structured metadata. All metadata entities (and sections) comprise one abstract class, and each type of metadata entity (and section) is a concrete subclass. Each metadata entity (or section) subclass contains a set of metadata elements and/or lower level entities. The included metadata element names and corresponding values are captured as attributes of the object subclass.

The draft ISO Metadata Standard, 15046-15, also specifies the names, definitions, data types, and units for many metadata elements in many metadata entities. Some of these metadata elements and entities are mandatory and some are optional. In many cases, an image exploitation service input or output is all or most of one ISO metadata entity. Table 3 lists various service inputs and outputs with the exactly or approximately corresponding ISO metadata entities. (Note: This table is based on the July 1998 draft of 15046-15; some items are expected to change in later versions.)

Table 3. ISO Metadata Used as Service Inputs and Outputs

Image Exploitation Service Input or Output	ISO Metadata Name	
	Section	Entity
Ground position SRS definition, Coordinate transformation parameters, Adjusted parameters of transformation between SRSs	Reference system information	Spatial reference by coordinates (and lower level entities)
Illumination direction, azimuth and elevation angles	Spatial data representation information	Image spatial representation information (part of entity)
Image or dataset identification	Identification information	Identification Citation, Image identification information
Imaging times, Accuracy estimates for imaging times	Identification information	Temporal extent (in Extent information)
Temporal SRS definition	Reference system information	Temporal reference system information
Specification of metadata format	Metadata reference information	Metadata standard information, Metadata extension information

Image Pixels

Image pixels are inputs and outputs of several image exploitation service categories. In addition to transferring pixel values, the size of the pixel grid must be transferred, plus the sequencing scheme used when transferring pixel values. Responses to the OpenGIS Simple (or grid) Coverages RFP are expected to specify standard formats for transferring image pixels and other grid data, as inputs and outputs to Coverage access operations. This document assumes that these grid coverage formats can be used to transfer image pixels for image exploitation services inputs and outputs.

Desired Image Section

The desired image section is also an input or output of several image exploitation service categories. The location and size of the desired image section must be specified, within a larger image. Responses to the first (or grid) Coverages RFP are also expected to specify standard formats for specifying the desired image section, as inputs and outputs to Coverage access operations. This document assumes that this image section specification format can be used for image exploitation services.

Alternately, the desired image section could be specified using an area feature geometry, such as specified in the three Simple Features implementation specifications that have been accepted by OGC. We assume this area feature geometry would be in 2D image coordinates, not 3D or 2D ground coordinates.

If the desired image section is a rectangle in image space, such a rectangle could be specified by the pixel position of one corner, plus the pixel section width and height. Using this approach, an Image Section data type defined using ISO standard IDL data types and structures is

```
// Type: Image Section, rectangular section of an image
  struct ImageSection {
    long corner_column;    // Smallest pixel column number
    long corner_row;       // Smallest pixel row number
    long width;            // Number of image pixel columns
    long height;           // Number of image pixel rows
  };
```

Point Position Coordinates

Point position coordinates are also inputs and outputs of several image exploitation service categories. Such a point position requires specifying the values of three, two, or one coordinates. All three OpenGIS accepted implementation specifications for Simple Features include data formats for point positions in two coordinates. (We are referring to the vertices of feature geometries, not to point geometries.) That format is a data structure containing two floating point numbers. The modification of this data format to three or one coordinate is obvious.

Position Accuracy Estimates

Absolute and relative position accuracy estimates are also inputs and outputs of several image exploitation service categories. The accuracy inputs and outputs are often optional, needed by operations only when accuracy output data are desired by a client program or user. Several alternative forms of accuracy data could be used. However, Abstract Specification Topic 9: Quality, specifies that accuracy be recorded as covariance matrices, sometimes called variance-covariance matrices. For the three ground coordinates of one point, a covariance matrix is a 3 by 3 matrix, with the matrix rows and columns each corresponding to the three coordinates. For just the two horizontal ground coordinates, a covariance matrix is a 2 by 2 matrix, with the matrix rows and columns each corresponding to the two horizontal coordinates. Covariance matrices can be used to record absolute and/or relative accuracies.

Elevation Data

When a position in a monoscopic image is used to find the corresponding ground position, elevation (or height) data are usually needed. Elevation data are thus an input to several image exploitation service categories. Such elevation data could take one of several forms, including

- Single elevation value, to be used for one or more image positions;
- List of elevation values, to be used with a corresponding list of image positions; or
- Elevation coverage, that defines the elevation as a function of ground position, to be used for one or more image positions.

Each elevation could be transferred as one double precision floating point value. (Note: The SRSs used for elevations are listed as separate service inputs and outputs.) Elevation data structures defined using ISO standard IDL data types and structures are

```
// Type: Double List, list of elevation or other numbers
   typedef sequence <double> DoubleList;

// Type: Elevation Data Type
   enum ElevationType {
    SINGLE,          // One elevation for all image positions
    LIST,            // One elevation for each image position
    MODEL            // Elevation is modeled function of
     // horizontal position
    };

// Type: Elevation Data, used with monoscopic image positions
   union ElevationData switch (ElevationType) {
    case SINGLE:     double               elevation;
    case LIST:       DoubleList           elevations_list;
    case MODEL:      ElevationCoverage    elevation_model;
     // Reference to an Elevation Coverage object
    };
```

When elevation is used and output accuracy is needed, elevation accuracy data are a needed input to several image exploitation service categories. The accuracy of a single elevation value, or of all elevations in a list, can be specified by a single precision floating point number. This value could have one of several meanings, including variance, standard deviation, or LE (Linear Error). An LE value could use one of several confidence probabilities. For consistency with using a covariance matrix to specify the accuracy of two or three dimensional coordinates, a variance value should be used for elevation value accuracy.

Image SRS Definition

The Spatial Reference System (SRS) of an image is often specified by a ground position SRS definition plus an image geometry model, that together relate image positions to ground positions (in that ground SRS). The ground position SRS can be specified as in the July 1998 draft ISO standard for geospatial metadata, including the "Spatial reference by coordinates" and lower level metadata entities (as discussed in Table 3). The image geometry model can be specified by the values of the set of parameters used by a specified mathematical model of the image geometry. These parameters are considered metadata for the image.

Image geometry model metadata is already partially discussed or implied in Abstract Specification Topic 7: The Earth Imagery Case (Open GIS Consortium, 1998b), and in proposal document 98-033: *Alternatives for Transferring Orientation Data of Digital Aerial Images.* These documents describe a number of possible forms of image geometry model metadata:

1. Values of image geometry model parameters:
   1.1. For rigorous geometry models (there are many existing rigorous geometry models)
   1.2. For real-time geometry models, including:
      1.2.1. Polynomial models (Section 3.2 of Topic 7)
      1.2.2. Ratios of Polynomials (Section 3.4 of Topic 7)
      1.2.3. Universal Real-Time Model (Section 3.5 of Topic 7)
2. Positions of points in both ground and image coordinates:
   2.1. Grid of Points with Interpolation (Section 3.3 of Topic 7)
   2.2. Set of reference points, used by client for fitting parameters of image geometry model (Sections 2.3 and 3.2 of 98-033)

The OGC Technical Committee (TC) must answer several questions on the possible forms of image geometry model metadata, including:

- Are there other possible forms of image geometry model metadata?
- To what degree can or should the TC leave the selection of one or more forms of image geometry model metadata up to organizations that propose implementation specifications in response to an RFP?
- For which future RFP should the form(s) of image geometry model metadata be selected (whether selected by the TC or by the RFP responders)?
- Which one or more forms of image geometry model metadata should the TC select or prefer?

Features with Geometry

Features with geometry are also inputs and outputs of several image exploitation service categories. Some of these features include a full set of feature attributes, while other input/output features may include few feature attributes other than the geometry. All three OGC-accepted implementation specifications for Simple Features include data formats for features with geometry, including collections of features. This document assumes that these feature formats can be used to transfer features with geometry for inputs and outputs to image exploitation services.

The possible feature geometries used as service inputs and outputs include

- Single point
- Set of points
- Grid of points
- Linear feature geometry
- Area feature geometry

Strategy Parameters

Some image exploitation services require inputs containing values of strategy parameters, which are used by the service algorithms to control service operations. The values of such strategy parameters are often heuristic, being experimentally found to produce the best results for some set of primary input data. However, the most effective set of values differs for different categories of other input data.

In some cases, the categories of input data affecting strategy parameters are types of ground details that are visible in the input image(s). For example, the most effective set of strategy parameter values for automatic elevation extraction depends heavily on the roughness of the (visible) ground surface over the ground area to be extracted. The most effective sete of strategy parameter values for automatic elevation extraction also depends on the amount of high-frequency detail visible in the ground cover. Similarly, the most effective set of strategy parameter values for geodata registration services depends on the spatial distributions of control and tie points (a control point has a known correct ground location, and a tie point does not).

The needed set of strategy parameters is different for different image exploitation services and is very likely to be different for different implementations of the same service. However, a name value list could be used as a standard data structure for all possible sets of strategy parameters. Of course, each implementation of each service must specify the set of names and definitions that it uses for strategy parameters, together with the data type, units, and range (or domain) of the values for each parameter name. Each service probably should make all this information available to a client by providing an operation that retrieves this strategy parameter description information.

Other Inputs and Outputs

Some image exploitation service inputs and outputs do not fall in the above categories. OpenGIS Project Document Number 99-115 lists many of these other inputs and outputs, with some information on the possible data format, mostly using ISO standard IDL data types and structures.

Conclusions and Future Work

While it is certainly a non-trivial technical and organizational task to specify consensus-approved open interfaces to the many needed image exploitation services, the effort is believed to be worthwhile. Standardization is worthwhile in order to avoid otherwise repetitious work, to model the behaviors of well-understood services, and to provide the permanent and far-reaching benefits of making these image exploitation services part of a network-based Information Infrastructure. However, these interfaces alone are not sufficient to enable complete interoperability. Not all of the problems related to the use of different data formats and meanings can be overcome through these interfaces. Data and metadata coordination activities will continue to be necessary, though the interfaces will make them less critical for many activities. Differences between distributed computing platforms, such OLE/COM and CORBA, present obstacles. Also, there are benefits to be derived from further consensus on the general "software frameworks" by which different software vendors organize the functions that provide the image exploitation services described in this article.

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