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The OpenGIS™ Abstract Specification
Topic 9: Quality

Version 4

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Revision History

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2 March 1998	98-109r2 “Revision 3”
15 January 1999	Update with revisions from 98-026: convert the object diagrams from OMT to UML, correct some wording and change terms to be consistent with ISO metadata and Topic 11; update copyright for 1999; use revised document template
30 March 1999	Update Section 1 with new boilerplate; move former Section 2.1 to Section 1.2.

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1. Introduction

1.1. The Abstract Specification

The purpose of the Abstract Specification is to create and document a conceptual model sufficient enough to allow for the creation of Implementation Specifications. The Abstract Specification consists of two models derived from the Syntropy object analysis and design methodology [1].

The first and simpler model is called the Essential Model and its purpose is to establish the conceptual linkage of the software or system design to the real world. The Essential Model is a description of how the world works (or should work).

The second model, the meat of the Abstract Specification, is the Abstract Model that defines the eventual software system in an implementation neutral manner. The Abstract Model is a description of how software should work. The Abstract Model represents a compromise between the paradigms of the intended target implementation environments.

The Abstract Specification is organized into separate topic volumes in order to manage the complexity of the subject matter and to assist parallel development of work items by different Working Groups of the OGC Technical Committee. The topics are, in reality, dependent upon one another— each one begging to be written first. *Each topic must be read in the context of the entire Abstract Specification*.

The topic volumes are not all written at the same level of detail. Some are mature, and are the basis for Requests For Proposal (RFP). Others are immature, and require additional specification before RFPs can be issued. The level of maturity of a topic reflects the level of understanding and discussion occurring within the Technical Committee. Refer to the OGC Technical Committee Policies and Procedures [2] and Technology Development Process [3] documents for more information on the OGC OpenGIS™ standards development process.

Refer to Topic Volume 0: Abstract Specification Overview [4] for an introduction to all of the topic volumes comprising the Abstract Specification and for editorial guidance, rules and etiquette for authors (and readers) of OGC specifications.

1.2. Introduction to Quality

This document specifies extensions to the OpenGIS™ Abstract Specification to support recording the quality of "Feature," "Geometry," and “Coverage” objects. This abstract specification is submitted in response to recurring requests in OGC meetings for someone to detail how quality and accuracy should be handled. The specified extensions support recording the position accuracy of Feature objects, and recording the accuracy and quality of other Feature properties. Such feature quality and accuracy data is one category of metadata, and this specification includes partial capabilities for recording other metadata associated with each Feature.

In the Abstract Specification, a Feature object can have multiple properties, some of which have numerical values. One property of a Feature is often a Geometry, which defines the location of the Feature in 2 or 3 dimensional space. For a simple Geometry property, locations are specified in OpenGIS Well Known Structures (WKS) by the positions of one or more points, relative to a specified spatial reference system. A point can be a Point Geometry, or can be a component of a more complex Geometry. Each point has numerical values giving its position coordinates in 2 or 3 dimensional space.

A subclass of the Feature abstract class is the Coverage class. The Coverage class has a Coverage Generator property that is a function often called G, instead of having a Geometry property with a value that is an OpenGIS WKS. A subclass of the Coverage class is the Image class. For an image, the Coverage Generator function G relates positions in the Project World (usually in ground coordinates) to the corresponding positions in the image (in image coordinates). The ground coordinates used in G are in a specified spatial reference system.

The numerical values of (ground) point coordinates always have limited accuracies. If the accuracy were truly unknown, the numerical value would have little practical value. If the accuracy is known, that accuracy should be communicated from the data producer to the data user, so that the data user can properly interpret and use the numerical value. Recording of position accuracy information is therefore required by the OpenGIS™ Abstract Specification.

This proposal takes the "truth in labeling" approach. That is, the GIS data producer is expected to provide numerical accuracy data with GIS data provided. The data user is then expected to use that accuracy data to determine how to use this GIS data. A prospective user should use the accuracy data to check if available GIS data is accurate enough to support the intended use. (To the maximum practical degree, this checking should be done automatically by user software, instead of done manually by a human user.) This "truth in labeling" approach is employed in the Draft Geospatial Positioning Accuracy Standards, from the United States Federal Geospatial Data Committee (FGDC).

The "truth in labeling" approach is used instead of (or in addition to) a "suitable use labeling" approach. In a "suitable use labeling" approach, GIS data would be labeled with the data uses considered suitable. For example, GIS data might be labeled as suitable for printing a 1:24,000 scale paper map (that meets the old United States National Map Accuracy Standard). The "truth in labeling" approach is more suitable when there are many and increasing potential uses of any GIS data.

Many alternative forms of position accuracy could be recorded, ranging from very simple to very complex. This proposal specifies one way in which to record most of the position accuracy data currently used for images by the National Imagery and Mapping Agency (NIMA). This NIMA image accuracy data is fairly extensive and complex, and may not be needed by many users of a GIS. Therefore, this proposal allows recording of only a subset of the defined accuracy data.

The following sections of this topic volume define and discuss various position accuracy terms and concepts used later in this proposal.

1.3. References for Section 1

[1] Cook, Steve, and John Daniels, Designing Objects Systems: Object-Oriented Modeling with Syntropy, Prentice Hall, New York, 1994, xx + 389 pp.

[2] Open GIS Consortium, 1997. OGC Technical Committee Policies and Procedures, Wayland, Massachusetts. Available via the WWW as <http://www.opengis.org/techno/development.htm>.

[3] Open GIS Consortium, 1997. The OGC Technical Committee Technology Development Process, Wayland, Massachusetts. Available via the WWW as <http://www.opengis.org/techno/development.htm>.

[4] Open GIS Consortium, 1999. Topic 0, Abstract Specification Overview, Wayland, Massachusetts. Available via the WWW as <http://www.opengis.org/techno/specs.htm>.

2. The Essential Model for Quality

2.1. Absolute Accuracy

Absolute accuracy is the error estimate for a single point, relative to the specified spatial reference system (for example, WGS-84). This accuracy includes errors from all known and expected sources. The error estimate from a particular error source is usually called an error component.

2.2. Relative Accuracy

Relative accuracy is the error estimate for the distance between two points, or the accuracy of one point with respect to the other point. This accuracy includes errors from all known and expected sources. If the errors at two points are not correlated, the relative error is the Root Mean Square (RMS) of the individual point absolute errors. If the absolute errors are essentially the same at two points, the relative error is thus about 1.4 times the individual point absolute errors.

However, if the errors at two points are highly correlated, the relative error can be significantly less than the individual point absolute errors. For example, some error components can be exactly or approximately the same at two points. The relative accuracy excludes those error components that are the same at the two points. The relative accuracy includes those error components that are statistically independent at the two points, including such error components for each point.

Relative accuracy usually varies with the distance between the two points, being smaller for shorter distances. When the nominal distance between two points is not fixed, the accuracy variation with distance is often reflected by giving the relative accuracy estimate for each of several distance bins. Each distance bin specifies the minimum and maximum vector distances between two points, for which the stated relative accuracy applies. Alternately, the accuracy variation with distance might be specified by giving the relative accuracy as a mathematical function of the distance between points.

2.3. Value Accuracy

The accuracy of a numerical value is usually defined by giving one or more statistical measures of the expected error in the value, or in a group of similar values. If a specific, non-statistical measure of the error were known, the value should be changed to eliminate that error. Similarly, if an (arithmetic) average error were present and known, the value(s) should be changed to eliminate the average error.

In general, the possible error values have a probability distribution, which defines the probability or probability density of each error value. However, a complete probability distribution is usually much more detailed than is needed, so a simple statistical error summary is usually used. This summary often defines an error magnitude and the probability that the actual error is less than this magnitude. For example, we may say that a value has 0.9 probability of having an error (magnitude) less than 7 meters.

2.4. Vertical Linear Error

When a vertical coordinate, such as height or elevation, is defined for a ground point, the vertical coordinate accuracy should be specified. Vertical accuracy is often specified using a “Linear Error” or “LE”. In a Linear Error, we record that the value has a specified probability of having an error magnitude less than a specified distance. For example, we may say that the height value has 0.9 probability of having an error magnitude less than 7 meters. Vertical Linear Error can be used to record either absolute or relative accuracy.

2.5. Horizontal Circular Error

Two horizontal coordinates, such as Latitude and Longitude, are usually defined for a ground point, and the horizontal position accuracy should be specified. The accuracy of each horizontal coordinate could be separately specified, perhaps using a “Linear Error” or “LE”. However, the composite horizontal accuracy is often specified using a “Circular Error” or “CE”. In a Circular Error, we record that the horizontal position has a specified probability of having a vector error magnitude less than a specified distance. For example, we may say that the horizontal position has 0.5 probability of having a vector error magnitude less than 11 meters. Use of a Circular Error is appropriate when the accuracies are similar in the two horizontal coordinates. Horizontal Circular Error can be used to record either absolute or relative accuracy.

2.6. 3-D Spherical Error

The accuracy of 3-D ground coordinates are often specified using a Horizontal Circular Error plus a Vertical Linear Error. Alternately, the accuracy of 3-D coordinates might be specified using a "Spherical Error." A spherical error records that the 3-D position has a specified probability of having a vector error magnitude less than a specified distance.

Use of a Spherical Error would be appropriate if the accuracies are similar in all three ground coordinates. However, the vertical coordinate error is often either undefined or significantly different from the horizontal coordinates linear errors. If wanted, the approximate Spherical Error can be computed from the Horizontal Circular Error plus Vertical Linear Error, if uncorrelated errors and a normal distribution are assumed. 3-D Spherical Error could be used to record either absolute or relative accuracy.

2.7. Covariance Matrix

When there are 2 or 3 ground coordinates, more detailed accuracy information can be recorded using a covariance matrix, sometimes called a variance-covariance matrix. For the three ground coordinates of one point, a covariance matrix is a 3 by 3 symmetrical 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 symmetrical matrix, with the matrix rows and columns each corresponding to the two horizontal coordinates. The matrix elements are the expected average values of the product of the error in the row coordinate times the simultaneous error in the column coordinate.

In a covariance matrix, the diagonal elements are the error variances of the corresponding ground coordinates, or the squares of the standard deviations. The off-diagonal elements are the covariances between the errors in the corresponding ground coordinates; these covariances will be zero when the errors in different coordinates are not statistically correlated. The covariance matrix is always symmetrical, meaning that the same element values appear on both sides of the diagonal elements.

Covariance matrices can be used to record absolute and/or relative accuracies. A covariance matrix for relative accuracy uses the 3 coordinates of one point for matrix rows and the 3 coordinates of the second point for matrix columns. A complete covariance matrix for N specific points would contain 3N rows and 3N columns.

A 3 by 3 covariance matrix provides six independent numbers, while horizontal CE plus vertical LE are only two independent numbers. The information contained will be equivalent when:

1. The errors in the three ground coordinates are not statistically correlated.

2. The errors in the two horizontal coordinates have the same statistics.

When covariance matrices are computed and/or retrieved, the corresponding horizontal CE plus vertical LE are often computed for presentation to data users who have no need for more complex accuracy data. The horizontal CE plus vertical LE that correspond to a 3 by 3 covariance matrix can be computed from that covariance matrix. Similarly, the horizontal CE that corresponds to a 2 by 2 covariance matrix can be computed from that covariance matrix. In such computations, the off-diagonal matrix elements are usually neglected. The vertical LE with 0.6827 probability is the square root of the vertical coordinate variance, if the vertical coordinate error has a normal probability distribution. The horizontal CE is a somewhat complex function of the two horizontal coordinate variances and of the covariance between these coordinates (when known).

2.8. Confidence Probability

A variety of different values are used for the confidence probability of a Linear Error or Circular Error. Existing standardized probability values include 0.5, 0.6827, 0.9, and 0.95. A probability of 0.6827 corresponds to the standard deviation of a quantity with a normal distribution. (Note that a Circular Error does not have a normal distribution, but may be derived from independent normal distributions of the errors in each horizontal position coordinate.) The 0.9 probability was used in the old United States National Map Accuracy Standards. The 0.95 probability is used in the Draft

Geospatial Positioning Accuracy Standards. The 0.5 probability is now used in certain military applications.

2.9. Normal Error Distribution

The actual statistical distribution of errors is usually unknown, but is usually assumed to be a normal distribution for a Linear Error. A normal distribution is often assumed because:

1. Experimental tests of Linear Error distributions have often produced results that approximate a normal distribution.

2. A total error that is a combination of many statistically independent component errors tends toward a normal distribution, for any statistical distributions of the component errors.

When a normal distribution is assumed, the corresponding error values for different confidence probabilities are directly related. That is, the error distance for a different probability can be obtained by multiplying the distance by a constant. Different constant multipliers are needed for Linear Errors and for Circular Errors (assuming the individual coordinates have normal error distributions). Standard tables of multipliers exist for converting error distance values among 0.5, 0.6827, 0.9, and 0.95 probabilities. Table 1 is one such table. The constant multipliers listed for CE assume certain properties of the covariance matrix for the two horizontal coordinates. Specifically, these multipliers assume that the horizontal coordinates have the same variances with zero covariance between the two coordinates.

Error Type	Error Confidence Probability				
	0.3935	0.50	0.6827	0.90	0.95
LE		0.6745	1.0000	1.6449	1.9600
CE	1.0000	1.1774		2.1460	2.4485

Table 2-1. Error Magnitude as Function of Probabilities.

When a normal distribution applies, all elements of a covariance matrix have a 0.6827 probability.

2.10. Status of the Abstract Specification for Quality

This version of the Abstract Specification for Quality is an introduction to the technology, and focuses more on positional and geometry accuracy than on the broader topic of Quality.

Section 3 of this document is an "essential model," not an "abstract model" in the sense of Cook and Daniels [6].

This abstract specification for Quality has been waiting for mature "Quality" standards to emerge from the ISO TC/211 activity.

It should be expected that as the Committee Draft of the TC/211 circulates, it and the comments it generates will become the foundation for the next version of this document.

2.11. References for Section 2

[1] OpenGIS™ Abstract Specification, OpenGIS™ Project Documents 99-100 through 99-116, available through www as <http://www.opengis.org/techno/specs.htm>.

[2] An Essential Specification for Coverages and Images, OpenGIS Project Document 96-024R2

[3] Universal Image Geometry Model, OpenGIS Project Document 97-003R1

[4] Draft Geospatial Positioning accuracy Standards, Federal Geographic Data Committee, December 1996

[5] United States National Map Accuracy Standards, June 17, 1947

[6] Cook, Steve, and John Daniels, Designing Objects Systems: Object-Oriented Modeling with Syntropy, Prentice Hall, New York, 1994, xx + 389 pp.

3. Abstract Model for Quality

3.1. Accuracy and Other Metadata

The ability to record accuracy and other metadata for each Feature object is provided by allowing a relationship between a Feature object and a Metadata Set object. A Metadata Set object contains one or more Metadata Entity objects. Each Metadata Entity object contains multiple attributes that record values of metadata elements.

Many sub-classes of the Metadata Entity class can be defined. Nine of these Metadata Entity sub-classes contain accuracy data for Feature, Geometry, and Coverage objects, with tentative sub-class names:

1. Absolute Position Accuracy

2. Relative Position Accuracy

3. Monoscopic Image Absolute Accuracy

4. Monoscopic Image Relative Accuracy

5. Stereoscopic Images Absolute Accuracy

6. Stereoscopic Images Relative Accuracy

7. Metric Property Accuracy

8. Non-metric Property Accuracy

9. Intersection Threshold

All nine listed sub-classes have multiple attributes for recording values of accuracy metadata elements. The Absolute and Relative Position Accuracy sub-classes are appropriate for Geometry and some Coverage objects. The four Monoscopic and Stereoscopic Image Accuracy sub-classes are for images and certain other Coverages. The last three listed sub-classes are for other Feature properties.

Figure 3-1 is a class diagram showing the existing Feature and Feature Collection classes and these new metadata classes with the relationships between them. This diagram does not include the other previously defined classes to which the Feature and Feature Collection classes have relationships. The following subsections discuss each class shown in this diagram.

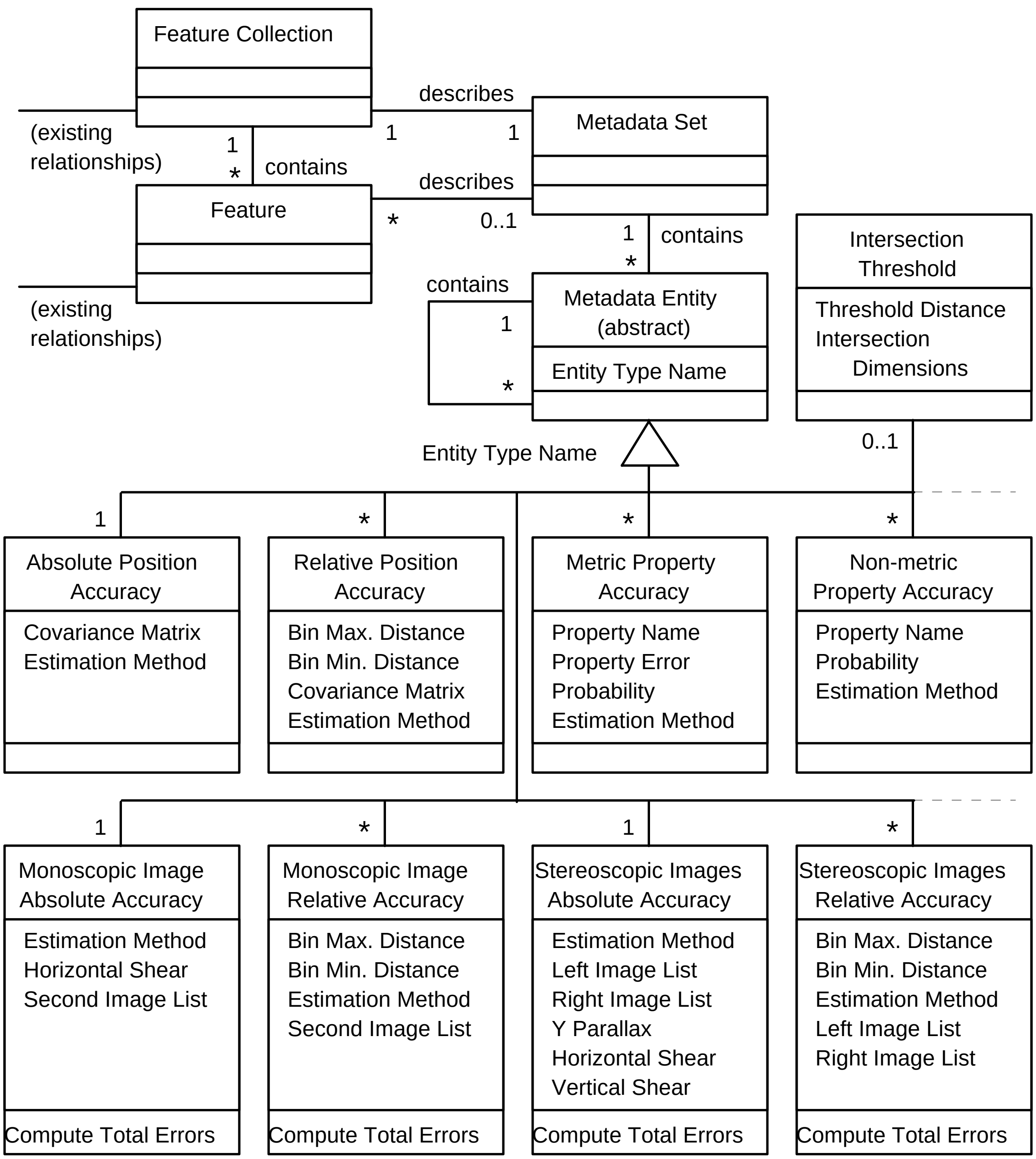

Figure 3-1 Accuracy Metadata Classes and Relationships

3.1.1. Feature

A Feature object, previously defined in the OpenGIS Abstract Specification, has one new relationship, to one Metadata Set object. This relationship is optional, included only when metadata is recorded for that Feature object. This relationship is recorded by a mandatory property of a Feature with the property name Metadata. The value of the metadata property is normally the ID of the associated Metadata Set object. If this property value is null, there is no related Metadata Set object, and all aspects of the Feature accuracy not associated with the Feature Collection(s) that contains this Feature are assumed to be unknown or unspecified.

3.1.2. Feature Collection

A Feature Collection object, previously defined in the OpenGIS Abstract Specification, has one new relationship to one Metadata Set object. This relationship is required, and is recorded by a mandatory property of a Feature Collection with the property name Metadata. The value of the metadata property is the ID of the associated Metadata Set object. If this property value is null, there is no related Metadata Set object, and all metadata are assumed to be unknown or unspecified except for any metadata associated with the individual features contained in that collection or with a higher level Feature Collection that contains this Feature Collection.

3.1.3. Metadata Set

A Metadata Set object contains, or is related to, a set of Metadata Entity objects. Each Metadata Set object is related to one or more Feature objects, or to one Feature Collection object.

3.1.4. Metadata Entity

A Metadata Entity object contains a set of object attributes that store the values of a logical group of metadata elements. Each metadata element is recorded as a name and value pair of object attributes. Since the set of metadata elements depends on the metadata to be recorded, the Metadata Entity class is abstract, and a concrete subclass is used for each different logical group of metadata elements to be recorded.

The Metadata Entity class defines one attribute included in all subclasses, a string giving the name of the specific Metadata Entity subclass. Each such name is expected to include a version identification number. Each Metadata Entity object is included in (related to) one or more Metadata Set objects.

Multiple subclasses of the Metadata Entity class are defined, with the specific attributes included in each subclass being a logical group of metadata elements. The following Sections specify several specific subclasses of the Metadata Entity class, defined for recording Geometry, Coverage, and Feature property accuracies.

3.2. Position Accuracy Metadata Entities

The Absolute and Relative Position Accuracy sub-classes of Metadata Entities record position accuracy data for Features with geometry or some coverage types.

3.2.1. Absolute Position Accuracy

An Absolute Position Accuracy object is a Metadata Entity object that records the absolute accuracy of the Geometry or Coverage Generator object that is included in a Feature object. That is, such an object records statistical measures of the position accuracy of the Geometry or Coverage relative to the specified spatial reference system. For a simple Feature, these statistical measures apply to all the points used in that Geometry. For a Coverage, these statistical measures apply to all the points or other items included in that Coverage.

The additional attributes included in an Absolute Position Accuracy object shall be name and value pairs that contain:

1. Covariance Matrix, a symmetrical square matrix of floating point numbers in meters squared units. The matrix dimensions shall correspond to the number of coordinates recorded for a point in a feature. Matrix elements shall be missing or have null values when an actual value for that element is not known.

2. Estimation Method, a string (alphanumeric text). This defines the method used to estimate the values in the Covariance Matrix.

The indirect inclusion of one Absolute Position Accuracy object in each Metadata Set object is optional, but is strongly encouraged whenever the related Feature object includes a Geometry or a relevant Coverage Generator function. If no Absolute Position Accuracy object is included, the position accuracy of the Geometry shall be interpreted as unknown or unspecified. Inclusion of more than one Absolute Position Accuracy object is allowed, using multiple objects to contain absolute accuracy data with different error Estimation Methods.

3.2.2. Relative Position Accuracy

Each Relative Position Accuracy object is a Metadata Entity object that records relative position accuracy data for the Geometry or Coverage Generator object that is included in a Feature object. That is, such an object contains statistical measures of the position accuracy between two points in the Geometry or Coverage. Each Relative Position Accuracy object contains accuracy data for one distance bin between points. For a simple Feature, these statistical measures apply to all the points used in that Geometry. For a Coverage, these statistical measures apply to all the points or other items included in that Coverage.

The additional attributes in a Relative Position Accuracy object shall be name and value pairs that contain:

1. Bin Minimum Distance, one number in meter units

2. Bin Maximum Distance, one number in meter units

3. Covariance Matrix, a symmetrical square matrix of floating point numbers in meters squared units. The matrix dimensions shall correspond to the number of coordinates recorded for a point in a feature. Matrix elements shall be missing or have null values when an actual value for that element is not known.

4. Estimation Method, a string (alphanumeric text). This defines the method used to estimate the Covariance Matrix. This text should specify or imply the quality of the values provided in the Covariance Matrix.

The indirect inclusion of one or more Relative Position Accuracy objects in each Metadata Set object is optional but is encouraged whenever the related Feature object includes a Geometry or a relevant Coverage Generator function. Inclusion of more than one Relative Position Accuracy object is allowed and encouraged for different distance bins. Multiple Relative Position Accuracy objects can also contain relative accuracy data with different error Estimation Methods.

If no Relative Position Accuracy object is included, the relative position accuracy shall be interpreted as being 1.4 times the Absolute Position Accuracy specified values in the Covariance Matrix. If no Absolute Position Accuracy object is included, the relative position accuracy of the Geometry shall be interpreted as unknown or unspecified.

3.3. Image Position Accuracy Metadata Entities

The Absolute and Relative Position Accuracy objects defined above do not contain all the accuracy data needed when the related Coverage Generator object is an image or certain other types of Coverage. Therefore, four separate Metadata Entity subclasses are defined for images, that include different attributes for recording this different position accuracy data. Since the appropriate accuracy data is somewhat different for monoscopic and stereoscopic images, separate Metadata Entity subclasses are defined for monoscopic and stereoscopic images.

For vector feature Geometries, the Covariance Matrix reflects the total error in the recorded coordinates of each point. For images, the ground coordinates are computed (directly or indirectly) from the image position coordinates (row and column) of an object. For images, Covariance Matrix values are recorded reflecting the estimated errors in ground positions of points computed from perfect image position coordinates. These ground positions are computed using the associated image geometry model and image support data. These accuracies reflect the estimated errors in the image support data and image geometry model, but not the errors of measuring points in the images.

In the monoscopic and stereoscopic image subclasses of the Metadata Entity class, the Covariance Matrix attribute (as defined in the Absolute and Relative Position Accuracy subclass) may exist but is private. That is, this attribute is not directly accessible since it does not represent the total error in a ground point extracted from the image(s). The total error includes a contribution due to the error in measuring the desired point in the image(s).

Therefore, these image accuracy subclasses shall each have an interface operation (or function) to compute and return the total position error estimates. These interface operations use inputs specifying the estimated errors in measuring a point in the image(s). For monoscopic images, these interface operations also use inputs specifying the estimated errors in the ground elevations used with the image positions to determine the ground horizontal position. The ability to compute total errors depends on certain (unspecified) private attributes of these objects, such as partial derivatives of ground position errors produced by image position errors. The ground position errors produced by image position measurement errors are expected to be combined with the other errors by computing the Root Mean Square (RMS) of the error components.

The four Monoscopic and Stereoscopic Image Accuracy sub-classes of Metadata Entities record absolute and relative position accuracy data for images and certain other Coverages.

3.3.1. Monoscopic Image Absolute Accuracy

A Monoscopic Image Absolute Accuracy object is a Metadata Entity object that records absolute position accuracy data for an image Coverage Generator function that is included in a Feature object. One Monoscopic Image Absolute Accuracy object should be indirectly included in a Metadata Set object whenever it is related to an image. The public attributes included in a Monoscopic Image Absolute Accuracy object shall be name and value pairs that contain:

1. Estimation Method, a string (alphanumeric text). This defines the method used to estimate the Horizontal Shear and the (non-visible) covariance matrices representing the image geometry model and support data absolute errors.

2. Horizontal Shear, one floating point number in meter units. This shear is the root-mean-square horizontal distance between ground positions derived from the related image and from any other listed overlapping images.

3. Second Image List, a sequence of strings (alphanumeric text). Each string identifies one other image to which this Horizontal Shear applies. That is, the specified Horizontal Shear is between a point measured in the related image and a point measured in any of the listed other images that overlaps the first image. The related image can also be included in this list, with no meaning.

A Monoscopic Image Absolute Accuracy object includes the interface operation Compute Total Errors. This operation computes the total error and returns:

1. Ground Covariance Matrix, a symmetrical 3 by 3 matrix of floating point numbers in meters squared units. This matrix estimates the total errors in the horizontal ground position computed. Matrix elements shall be missing or have null values when an actual value for that element is not known.

The Compute Total Errors operation inputs the parameters:

1. Image Position Covariance Matrix, a symmetrical 2 by 2 matrix of floating point numbers in pixel spacing squared units. The off-diagonal matrix elements shall be missing or have null values when an actual value for that element is not known.

2. Elevation Variance, one floating point number in meters squared units. This is the estimated error in the elevation or height value used with an image position to compute the corresponding ground position

3. Image Position, two numbers in pixel spacing units. Inclusion of this input allows the accuracy to depend on the actual image position.

4. Elevation, one number in meter units. Inclusion of this input allows the accuracy to depend on the actual ground elevation.

3.3.2. Monoscopic Image Relative Accuracy

A Monoscopic Image Relative Accuracy object is a Metadata Entity object that records relative position accuracy data for an image Coverage Generator function that is included in a Feature object. The public attributes included in a Monoscopic Image Relative Accuracy object shall be name and value pairs that contain:

1. Bin Minimum Distance, one number in meter units

2. Bin Maximum Distance, one number in meter units

3. Estimation Method, a string (alphanumeric text). This defines the method used to estimate the (non-visible) covariance matrices representing the image geometry model and support data relative errors.

4. Second Image List, a sequence of strings (alphanumeric text). Each string identifies one other image to which this relative accuracy data applies. That is, the specified relative accuracy is between a point measured in the related image and a point measured in any of the listed other images. The related image can also be included in this list, meaning that the relative accuracy applies between two points measured in that one image.

A Monoscopic Image Relative Accuracy object includes the interface operation Compute Total Errors. This operation computes the total error and returns:

1. Ground Covariance Matrix, a symmetrical 3 by 3 matrix of floating point numbers in meters squared units. This matrix estimates the total errors between two horizontal ground positions computed. Matrix elements shall be missing or have null values when an actual value for that element is not known.

The Compute Total Errors operation inputs the parameters:

1. First Image Position Covariance Matrix, a symmetrical 2 by 2 matrix of floating point numbers in pixel spacing squared units. The off-diagonal matrix elements shall be missing or have null values when an actual value for that element is not known.

2. Second Image Position Covariance Matrix, a symmetrical 2 by 2 matrix of floating point numbers in pixel spacing squared units. The off-diagonal matrix elements shall be missing or have null values when an actual value for that element is not known.

3. First Elevation Variance, one floating point number in meters squared units. This is the estimated error in the elevation value used with the first image position to compute the corresponding ground position.

4. Second Elevation Variance, one floating point number in meters squared units. This is the estimated error in the elevation value used with the second image position to compute the corresponding ground position.

5. First Image Position, two numbers in pixel spacing units. Inclusion of this input allows the accuracy to depend on the actual image position.

6. Second Image Position, two numbers in pixel spacing units. Inclusion of this input allows the accuracy to depend on the actual image position.

7. First Elevation, one number in meter units. Inclusion of this input allows the accuracy to depend on the actual ground elevation.

8. Second Elevation, one number in meter units. Inclusion of this input allows the accuracy to depend on the actual ground elevation.

One or more Monoscopic Image Relative Accuracy objects should be indirectly included in a Metadata Set object whenever it is related to an image Coverage. Inclusion of more than one Monoscopic Image Relative Accuracy object is allowed and encouraged for different distance bins. Furthermore, separate objects can be used for different groups of second images that have significantly different relative accuracies. Multiple Relative Position Accuracy objects can also contain relative accuracy data with different error Estimation Methods.

3.3.3. Stereoscopic Images Absolute Accuracy

A Stereoscopic Images Absolute Accuracy object is another Metadata Entity object that records absolute position accuracy data for an image Coverage Generator function that is included in a Feature object. The public attributes included in a Stereoscopic Images Absolute Accuracy object shall be name and value pairs that contain:

1. Estimation Method, a string (alphanumeric text). This defines the method used to estimate the Y Parallax, Horizontal Shear, Vertical Shear, and the (non-visible) covariance matrices representing the image geometry model and support data absolute errors.

2. Left Image List, a sequence of strings (alphanumeric text). The first string identifies one image of the stereoscopic pair to which this accuracy data applies, namely the image expected to be manually viewed with the left eye. The first image can also be included later in this list, with no meaning.

3. Right Image List, a sequence of strings (alphanumeric text). This sequence must contain the same number of elements as the Left Image List. The first string identifies one image of the stereoscopic pair to which this accuracy data applies, namely the image expected to be manually viewed with the right eye. The first image can also be included later in this list, with no meaning.

4. Y Parallax, one floating point number in meter units. This Y Parallax is the root-mean-square of the minimum distance between ground coordinates derived from the first listed stereoscopic pair of images.

5. Horizontal Shear, one floating point number in meter units. This shear is the root-mean-square horizontal distance between ground coordinates derived from the first listed pair of images and from any other listed stereoscopic pairs of images that overlap it.

6. Vertical Shear, one floating point number in meter units. This shear is the root-mean-square vertical difference between ground coordinates derived from the first listed pair of images and from any other listed stereoscopic pairs of images that overlap it.

A Stereoscopic Images Absolute Accuracy object includes the interface operation Compute Total Errors. This operation computes the total error and returns:

1. Ground Covariance Matrix, a symmetrical 3 by 3 matrix of floating point numbers in meters squared units. Matrix elements shall be missing or have null values when an actual value for that element is not known.

The Compute Total Errors operation inputs the parameters:

1. Left Image Position Covariance Matrix, a symmetrical 2 by 2 matrix of floating point numbers in pixel spacing squared units. The off-diagonal matrix elements shall be missing or have null values when an actual value for that element is not known.

2. Right Image Position Covariance Matrix, a symmetrical 2 by 2 matrix of floating point numbers in pixel spacing squared units. The off-diagonal matrix elements shall be missing or have null values when an actual value for that element is not known.

3. Left Image Position, two numbers in pixel spacing units. Inclusion of this input allows the accuracy to depend on the actual image position.

4. Right Image Position, two numbers in pixel spacing units. Inclusion of this input allows the accuracy to depend on the actual image position.

One or more Stereoscopic Images Absolute Accuracy objects should be indirectly included in a Metadata Set object whenever it is related to an image that is expected to be exploited stereoscopically. Separate Stereoscopic Images Absolute Accuracy objects should be included for each other image with which the Coverage image is expected to be exploited stereoscopically. One object can be used for both images of one stereopair. However, one object cannot be used for multiple stereopairs that have essentially the same absolute accuracy.

In addition to giving the ground position accuracy derivable from a stereoscopic pair of images, each Stereoscopic Images Absolute Accuracy object specifies one pair of images that can be exploited stereoscopically.

3.3.4. Stereoscopic Images Relative Accuracy

A Stereoscopic Images Relative Accuracy object is another Metadata Entity object that records relative position accuracy data for an image Coverage Generator function that is included in a Feature object. The public attributes included in a Stereoscopic Images Relative Accuracy object shall be name and value pairs that contain:

1. Bin Minimum Distance, one number in meter units

2. Bin Maximum Distance, one number in meter units

3. Estimation Method, a string (alphanumeric text). This defines the method used to estimate the (non-visible) covariance matrices representing the image geometry model and support data relative errors.

4. Left Image List, a sequence of strings (alphanumeric text). Each string identifies one image of a stereoscopic pair to which this accuracy data applies, namely the image expected to be manually viewed with the left eye. The available relative accuracy data is between a point measured in the first listed image and a point measured in any of the other listed images. The first image can also be included later in this list, meaning that the relative accuracy applies between two points measured in the same left image.

5. Right Image List, a sequence of strings (alphanumeric text). This sequence must contain the same number of elements as the Left Image List. Each string identifies one image of a stereoscopic pair to which this accuracy data applies, namely the image expected to be manually viewed with the right eye. The available relative accuracy data is between a point measured in the first listed image and a point measured in any of the other listed images. The first image can also be included later in this list, meaning that the relative accuracy applies between two points measured in the same right image.

A Stereoscopic Images Relative Accuracy object includes the interface operation Compute Total Errors. This operation computes the total error and returns:

1. Ground Covariance Matrix, a symmetrical 3 by 3 matrix of floating point numbers in meters squared units. Matrix elements shall be missing or have null values when an actual value for that element is not known.

The Compute Total Errors operation inputs the parameters:

1. First Left Image Position Covariance Matrix, a symmetrical 2 by 2 matrix of floating point numbers in pixel spacing squared units. The off-diagonal matrix elements shall be missing or have null values when an actual value for that element is not known.

2. First Right Image Position Covariance Matrix, a symmetrical 2 by 2 matrix of floating point numbers in pixel spacing squared units. The off-diagonal matrix elements shall be missing or have null values when an actual value for that element is not known.

3. Second Left Image Position Covariance Matrix, a symmetrical 2 by 2 matrix of floating point numbers in pixel spacing squared units. The off-diagonal matrix elements shall be missing or have null values when an actual value for that element is not known.

4. Second Right Image Position Covariance Matrix, a symmetrical 2 by 2 matrix of floating point numbers in pixel spacing squared units. The off-diagonal matrix elements shall be missing or have null values when an actual value for that element is not known.

5. First Left Image Position, two numbers in pixel spacing units. Inclusion of this input allows the accuracy to depend on the actual image position.

6. First Right Image Position, two numbers in pixel spacing units. Inclusion of this input allows the accuracy to depend on the actual image position.

7. Second Left Image Position, two numbers in pixel spacing units. Inclusion of this input allows the accuracy to depend on the actual image position.

8. Second Right Image Position, two numbers in pixel spacing units. Inclusion of this input allows the accuracy to depend on the actual image position.

One or more Stereoscopic Images Relative Accuracy objects should be indirectly included in a Metadata Set object whenever it is related to an image that is expected to be exploited stereoscopically. Inclusion of more than one Stereoscopic Images Relative Accuracy object is allowed and encouraged for different distance bins. Multiple Relative Position Accuracy objects can also contain relative accuracy data with different error Estimation Methods.

Separate Stereoscopic Images Relative Accuracy objects should be included for each other image with which the Coverage image is expected to be exploited stereoscopically. Separate Stereoscopic Images Relative Accuracy objects can be included for each of several groups of nearby stereopairs. Separate objects should be used when different groups of stereopairs have significantly different relative error estimates.

3.4. Property Accuracy Metadata Entities

The Metric Property Accuracy, Non-metric Property Accuracy, and Intersection Threshold subclasses of the Metadata Entity subclass record accuracy data for other Feature properties.

3.4.1. Metric Property Accuracy

A Metric Property Accuracy object is a Metadata Entity object that records the accuracy of a Feature property having a numerical value. Each Feature object should be indirectly related to a Metadata Set object that contains one Metric Property Accuracy object for each Feature property with a numerical value. If no Metric Property Accuracy object is included for a particular Feature property, the accuracy of that property value shall be interpreted as unknown or unspecified.

The additional attributes in a Metric Property Accuracy object shall be name and value pairs that contain:

1. Property Name, a string (alphanumeric text), identifying the specific property

2. Property Error, one floating point number in the same units as the property value

3. Probability, enumeration of the values 0.5, 0.6827, 0.9, and 0.95 probability

4. Estimation Method, a string (alphanumeric text). This defines the method used to estimate the error in the property value.

3.4.2. Non-metric Property Accuracy

A Non-metric Property Accuracy object is a Metadata Entity object that records the accuracy of a Feature property having an enumeration or string (text) value. Each Feature object should be indirectly related to a Metadata Set object that contains one Non-metric Property Accuracy object for each Feature property with an enumeration value. This Metadata Set object can also contain a Non-metric Property Accuracy object for some Feature properties with string values. If no Non-metric Property Accuracy object is included for a particular Feature property, the accuracy of that property value shall be interpreted as unknown or unspecified.

A Non-metric Property Accuracy object should also be used for the feature type to which a Feature object has been assigned, to record the probability that the assigned feature type is correct. If the next-most-likely feature types were also recorded as Feature properties, those feature type properties could also have their probabilities recorded. Similarly, if other next-most-likely property values were recorded as separate Feature properties, those alternative property values could also have their probabilities recorded. The result would be equivalent to recording a column (or row) of the confusion matrix, either the entire column or the most significant elements of a column.

The additional attributes in a Non-metric Property Accuracy object shall be name and value pairs that contain:

1. Property Name, a string (alphanumeric text), identifying the specific property

2. Probability, one floating point number giving the probability that the recorded (enumerated or text) property value is correct

3. Estimation Method, a string (alphanumeric text). This defines the method used to estimate the probability that the property value is correct.

3.4.3. Intersection Threshold

For some Geometry subtypes, the detection of any “incorrect” intersections between different parts of that Geometry is required, to ensure that a Geometry to be recorded is valid. Computation is required to detect an intersection between two line segments, or between a point and a line segment. Even double precision floating point computations have limited accuracy, depending on the equations implemented and the computation order. Furthermore, any subsequent transformation between spatial reference systems will introduce small errors. These (small) errors can cause two items to intersect or not intersect, when the opposite was true prior to the spatial reference system transformation.

The original author (Arliss Whiteside) does not know how Feature intersection accuracy should be handled in the OpenGIS® specifications. In certain previous work, he assumed that any two items were intended to intersect if they came within a specified small threshold distance of each other.

When this occurred, one or both items were automatically modified so that they used points with exactly the same recorded coordinates.

An Intersection Threshold object is a Metadata Entity object that records the criteria used to check if a Geometry intersected itself incorrectly. Such an object should be indirectly included in the Metadata Set object that is related to a Feature with a Geometry that could intersect itself incorrectly. The simple Geometry subclasses that could self-intersect include Curve and Surface.

The additional attributes in an Intersection Threshold object might be name and value pairs that contain:

1. Threshold Distance, one floating point number in meter units

2. Intersection Dimensions, one short integer, specifying whether 2 or 3 dimensions were considered in checking intersections

3.5. Discussion

The remainder of this Section provides a discussion of the topics introduced above. Section 3.6 provides some interpretations, and Section 3.7 provides assumptions. Section 3.8 lists Alternatives, and Section 3.9 discusses error estimation methods. Section 3.10 discusses possible levels of position accuracy. Section 3.11 provides possible levels of property accuracy. Section 3.12 provides detail on CE and LE computations.

3.6. Interpretations

Whenever a defined and applicable accuracy Metadata Entity object is not indirectly included in a Metadata Set object, that accuracy shall be interpreted as unknown or unspecified. Any user without additional information should assume that the unspecified accuracy is poor (should never assume that the recorded value is perfect).

Most of the listed attributes of Metadata Set objects and Metadata Entity objects might be read only. Certainly these attributes will be modified only during or immediately following object creation, often before the new object is fully related to other objects.

This proposal allows recording different accuracies for different types of Feature objects. That is, higher accuracies can be recorded for feature types consisting of “well defined points” as used in the Draft Geospatial Positioning Accuracy Standards, and lower accuracies can be recorded for feature types with not-so-well-defined points.

Many accuracy numbers are defined as being in meter units, since meters are an international standard for distances. Since accuracies are recorded using floating point numbers, the use of meter units does not imply any expected position accuracy. A position accuracy number can be many meters or only a few millimeters.

Some of the accuracy attributes discussed here are discussed from a different perspective in Sections 6.1.8, 6.2.5, and 6.2.6 of OpenGIS™ Project Document 97-003R1.

3.7. Assumptions

Key elements of this proposal assume that the errors in each ground coordinate have a normal probability distribution. For example, the elements of a covariance matrix have 0.6827 probability for a normal distribution, but not for most other probability distributions. The user of position accuracy metadata normally should assume normal error distributions. If the data producer expects some other probability distribution, the expected probability distribution should be recorded and transferred. The expected probability distribution should be recorded as part of the Estimation Method, or pointed to by the Estimation Method.

An image will often have multiple versions of its image support data, and perhaps of its image geometry model, with later versions providing higher accuracy or better computation efficiency. The same original image can thus have several different position accuracies. We assume that each version of an image with its support data will be recorded as a different Coverage. We also assume that each Image ID referred to in this proposal will include a support data version identification. This Version ID could be in the same Image ID string, or it could be recorded in a separate object attribute.

Multiple versions of the same original image can also exist, which have geometries that differ in simple ways. These multiple versions of one original image may exist simultaneously and/or at different times. For example, multiple reduced resolution versions of an image are often created and stored. Also, different patches or segments of an original image (or of a reduced resolution image) can be retrieved at different times, by the same or different users. Rotated, scaled, and simply-warped versions of an image can also be created and used.

Different versions of the same image which have somewhat different geometries could use separate accuracy metadata. Alternately, only the accuracy metadata for the original complete, full resolution image might be stored. This metadata would be used somewhat differently with each image version, as needed to account for the image version geometry differences. For example, the image positions and accuracies found in an image version would be transformed into the corresponding values for the original image.

When a Feature object has a Geometry property defined by an OpenGIS® WKS, the position accuracies of the WKS points (or vertices) are described by Absolute Position Accuracy and perhaps Relative Position Accuracy objects. If the Geometry is a Curve or a Surface, its positions are partly defined by interpolation between adjacent vertices. We assume that vertices are spaced sufficiently close together so that the specified interpolation algorithm does not introduce significant additional position error. Alternately, the Absolute and Relative Position Accuracy objects should represent the accuracy of the complete Curve or a Surface object after interpolation is applied.

One set of accuracy data is provided for an entire Geometry property defined by an Open GIS WKS, although a Geometry can contain multiple points or vertices. Recording of one set of accuracy data for a Geometry assumes that either:

1. The accuracies of all vertices are similar, and the typical accuracy is thus sufficient information. By similar accuracy, we mean the same Horizontal CE and Vertical LE (with a certain probability) within perhaps 30 percent.

2. The user has no practical way to use accuracy data that varies between the vertices of one Geometry object.

If different parts of a Geometry object have significantly different accuracies and if this is useful information, then each part should be recorded as a separate Feature and Geometry object. Each such Feature (and Geometry) object could then have a different recorded accuracy. A composite Feature can then be recorded that consists of all these smaller Features. Since this composite Feature does not directly include a Geometry, it would not be directly related to position accuracy data.

Although not fully described, we assume that a Feature Collection object can also be related to a Metadata Set object, for recording the metadata that applies to all features in the collection.

3.8. Alternatives

Many alternatives are possible to the objects and relationships defined here, including:

1. Record Horizontal Circular Error and Vertical Linear Error instead of, or in addition to, recording a covariance matrix of ground coordinate errors.

2. Record a 3N by 3N covariance matrix to record both the absolute and relative accuracies of N specific points.

3. Define simpler versions of the Image Absolute and Relative Accuracy subclasses, that contain less data. For example, Vertical Shear, Horizontal Shear, Y Parallax, and/or Image Lists might be eliminated. These simpler versions could be alternatives, or might replace the more complex versions. (These classes would be easier to understand, but could not record all the accuracy data that NIMA now keeps.)

4. Record relative accuracy data as a specified continuous function of the distance between two points (instead of using a discrete number of distance bins).

5. Require the recorded accuracy to be constant over an image, instead of allowing the accuracy to be a function of the image position.

6. Record a confusion probability matrix for selected enumerated-value properties of a Feature, including the assignment of the Feature to a specific feature type. This matrix could be recorded instead of, or in addition to, recording Non-metric Property Accuracy objects as defined herein.

7. Record the Metadata Set Object ID in a special attribute of a Feature, separate from the Feature property pairs of attributes.

8. Not record each metadata element in a Metadata Entity object with a corresponding name attribute (like properties are recorded in a Feature object). (This would be somewhat more efficient, but might be less flexible.)

9. Record all Probability attributes as floating point numbers, instead of enumerations.

10. Relate a Geometry or Coverage Generator object directly to a Metadata Set object that (only) records position accuracy metadata.

3.9. Error Estimation Methods

A variety of methods could be used to estimate position and property accuracies. Probably a standard set of methods should be defined, with corresponding standard (text string) values defined for the values placed in the Error Estimation Method attributes. A standard set of Error Estimation Methods might include: (numbers are not significant)

1. Professional Estimate, by an appropriate trained, registered, or certified professional, such as a surveyor, civil engineer, or photogrammetrist.

2. Computed Estimate, by combining estimates of all the significant error components. The error component estimates will normally be produced by a variety of methods.

3. Compared to Similar Quality Data, produced somewhat independently. If the similar data is produced by the same or similar methods, that data is likely to include some highly correlated error components. In this case, just using the value differences will produce overly optimistic error estimates. The error estimates produced from value differences should thus be increased to include the estimated errors not reflected in the difference data.

4. Tested Similar Quality Data, by comparing similar data produced by the same methods to significantly higher quality data.

5. Tested Sample Actual Data, by comparing a sample of the actual values in this Feature Collection to significantly higher quality data.

For items 4 and 5 listed above, the significantly higher quality data, or “ground truth” data, must have estimated standard deviation (or CE and LE) errors less than 1/3 of the resulting estimated errors, preferably less than 1/10. Furthermore, the error estimates produced should include the estimated errors in the reference data used. (As previously stated, the error estimates produced for vector Features also should include an allowance for the interpolation error between recorded vertices.)

In any case, the Error Estimation Method attribute should include an explicit or implicit reference to information (other metadata) describing in more detail the specific methods used.

3.10. Possible Levels of Position Accuracy

Many alternate forms of position accuracy data could be recorded, ranging from very simple to very complex. This proposal specifies one way in which to record most of the position accuracy data currently used for mapping images by the National Imagery and Mapping Agency (NIMA). This NIMA image accuracy data is fairly extensive and complex, and may not be needed by many users of a GIS. Therefore, this proposal allows recording of only a subset of the defined accuracy data. For example, inclusion of Relative Position Accuracy objects is optional. When included, separate Relative Position Accuracy objects could be provided for only one or two distance bins, or could be provided for many distance bins.

On the other hand, recording of more extensive or different accuracy data could be supported by future extensions of the structures defined in this proposal. For example, the ability to record covariance matrices across multiple points could be allowed, in addition to or in place of recording Absolute Covariance Matrices for single points and Relative Covariance Matrices between two points. This is likely to lead to the definition of multiple “levels” for recording position accuracy data, with the accuracy data proposed herein considered to be one or more of a larger set of accuracy data levels.

Some possible levels of position accuracy data are: (numbers are not significant)

1. No Position Accuracy - No position accuracy data is included.

2. Uncorrelated Absolute Position Accuracy - Absolute position accuracy covariance matrices are included without off-diagonal covariance matrix elements (and without relative accuracy data).

3. Correlated Absolute Position Accuracy - Absolute position accuracy covariance matrices are included with all off-diagonal covariance matrix elements (but not relative accuracy data).

4. Basic Relative Position Accuracy - In addition to absolute position accuracy data, relative position accuracy covariance matrices are included for one or two distance bins.

5. Extended Relative Position Accuracy - In addition to absolute position accuracy data, relative position accuracy covariance matrices are included for three or more distance bins.

6. Variable Position Accuracy - Absolute and relative position accuracy data is provided in a form that allows the accuracy to vary with the point position in one Feature, image, or stereopair.

7. Multiple Point Covariance Matrices - In addition to absolute and relative position accuracy varying with the point position, the absolute and relative position accuracy data is accessible in the form of 3N by 3N covariance matrices, where N refers to the number of points.

For images recorded using level items 2 through 5 above, the absolute and relative position error estimates are constant over each Feature, image, or stereopair.

A Feature containing multiple parts, or a Feature Collection, should be considered to have the lowest position accuracy level that is provided for any included component.

3.11. Possible Levels of Property Accuracy

For levels of property accuracy, the usually-multiple properties of one Feature need to be considered. However, the accuracy of certain properties is usually perfect or not relevant, such as properties that point to metadata or to the specification of the spatial reference system. All properties to which property accuracy applies should have the property accuracy specified in the Feature metadata. If a Feature Collection contains multiple types of Features, all relevant properties of all Feature types should have the Property Accuracy specified in the Feature (or Feature Collection) metadata.

Some possible levels of property accuracy data are: (numbers are not significant)

1. No Property Accuracy - No property accuracy data is included, or the provided property accuracy data is not complete.

2. Metric Property Accuracy - All relevant numerical or metric properties have associated Metric Property Accuracy objects.

3. Enumerated Property Accuracy - In addition to all relevant metric property accuracies, all relevant enumerated and text string properties have associated Non-metric Property Accuracy objects.

4. Enumerated Property Confusion Matrices - In addition to all relevant metric property accuracies, each relevant enumerated property has associated objects recording confusion matrices or rows.

3.12. CE and LE Computations

Whenever a GIS data user desires simpler accuracy data than a covariance matrix, standardized software can be used to compute horizontal CE and vertical LE from the proper covariance matrix. Such transformations of accuracy data might be performed by a service class or object that provides operations to:

1. Convert Ground Covariances to CE and LE. The operation inputs would include the 3 by 3 Ground Position Covariance Matrix (in meters squared units) and the desired confidence

Probability. The operation outputs would include the Horizontal CE and Vertical LE (in meter units).

2. Convert Horizontal Covariances to CE. The inputs would include the 2 by 2 Horizontal Ground Position Covariance Matrix (in meters squared units) and the desired confidence Probability. The outputs would include the Horizontal CE (in meter units).

3. Convert Image Covariances to CE. The inputs would include the 2 by 2 Image Position Covariance Matrix (in pixel spacing squared units) and the desired confidence Probability. The outputs would include the Image Position CE (in pixel spacing units). This operation might be combined with item 2.

4. Convert Variance to LE. The inputs would include the Variance (in squared units) and the desired confidence Probability. The outputs would include the Linear Error (LE) (in un-squared units).

5. Convert CE and LE to Ground Covariances. The inputs would include the Horizontal CE and Vertical LE (in meter units) and the corresponding confidence Probability. The outputs would include the 3 by 3 Ground Position Covariance Matrix (in meters squared units), with all the off-diagonal matrix elements being either omitted or having null values. In addition, the two horizontal coordinate variances would be the same in the output covariance matrix.

6. Convert CE to Horizontal Covariances. The inputs would include the Horizontal CE (in meter units) and the corresponding confidence Probability. The outputs would include the 2 by 2 Horizontal Ground Position Covariance Matrix (in meters squared units), with the off-diagonal matrix elements being either omitted or having null values. In addition, the two horizontal coordinate variances would be the same in the output covariance matrix.

7. Convert CE to Image Covariances. The inputs would include the Image Position CE (in pixel spacing units) and the corresponding confidence Probability. The outputs would include the 2 by 2 Image Position Covariance Matrix (in pixel spacing squared units), with the off-diagonal matrix elements being either omitted or having null values. In addition, the two image coordinate variances would be the same in the output covariance matrix. This operation might be combined with item 6.

8. Convert LE to Variance. The inputs would include the Linear Error (LE) and the corresponding confidence Probability. The outputs would include the Variance (in the same units squared).

All the operations listed above might assume a normal probability distribution for the errors in each position coordinate. Alternately, these operations might use an additional input specifying the probability distribution to be used.

3.13. References for Section 3

[1] OpenGIS™ Abstract Specification, OpenGIS™ Project Documents 99-100 through 99-116, available through www as <http://www.opengis.org/techno/specs.htm>.

4. Future Work

The classes, attributes, and interface functions proposed here probably need to be further refined. We hope that recommended and possible refinements will result from discussion of this proposal by an OpenGIS™ group. For example, specific objects or operations might be specified for converting between different error probabilities (assuming normal distributions).

This work clearly needs to be extended to define a way to describe the accuracy of transformations between coordinate systems, datums, etc. Furthermore, mechanisms are needed to ensure that accuracy descriptions are updated when transformations are used (preferably updated behind the scenes, without human interaction).

We do not yet understand how available coordinate transformations would be recorded and exercised. Attaching accuracy data to transformations clearly depends on how the transformations are recorded. Perhaps the accuracy of transformations could be recorded using Metadata Set objects containing Metadata Entity objects similar to the "Absolute Position Accuracy" and "Relative Position Accuracy" objects.

Ideally, the same object operations that perform transformations would also automatically generate combined accuracy data. If this is not practical, operations of the appropriate Metadata Entity subtypes could generate combined accuracy data. This might be done using operations similar to "Compute Total Errors," that have input parameters for the ground position errors before the corresponding transformation is performed.

5. Appendix A. Well Known Structures

The WKS needed to carry the Accuracy Information specified in this Topic are tbd.