Oracle Spatial and Graph: Advanced Data Management
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Introduction

Oracle Spatial and Graph, an option for Oracle Database 12c Enterprise Edition, includes advanced features for geospatial, location-based and graph data management and analysis. Formerly known as Oracle Spatial option, Oracle Spatial and Graph underlines its existing graph capabilities, which comprise the most robust, mature database graph technologies available in the industry.

The geospatial data features are designed to support the most complex requirements found in Geographic Information Systems (GIS), enterprise applications and in location-enabled business and web applications. It extends the Locator spatial query and analysis features in Oracle Database with more advanced spatial analysis and processing capabilities. These geospatial data features include native support for advanced models and types such as georaster (for geo-referenced imagery and gridded data), topology, 3D, including triangulated irregular networks (TINs) and point clouds (supporting LIDAR data), and linear referencing. Geocoding, a routing engine, and spatial web services conformant with Open Geospatial Consortium (OGC) and ISO standards are also included. These advanced features provide a complete platform for geospatial applications in many domains, including defense, land management retail, insurance, and finance.

Oracle Spatial and Graph provides two graph data models: Network Data Model graph (NDM), and RDF Semantic Graph. NDM is a property graph model used to model and analyze physical and logical networks used in industries such as transportation, logistics, and utilities. NDM persistently manages the network connectivity in the database, while a Java API provides fast in-memory graph analytics, including: shortest path, nearest neighbors, within cost, and reachability. RDF Semantic Graph supports the World Wide Web Consortium (W3C) Resource Description Framework (RDF) standards. It provides RDF data management, querying and inferencing that are commonly used in a variety of applications ranging from semantic data integration to social network analysis and linked open data applications. Oracle Spatial and Graph RDF support has become the industry’s leading open, scalable, and secure RDF database.

Oracle Spatial and Graph spatial capabilities are part of the database kernel and geospatial and graph deployments natively harness Oracle Database features for scalability, security,
partitioning, and parallelism. They exploit the processing power and bandwidth of Oracle Exadata Database Machine and realize extreme performance capabilities that are orders of magnitude over what was previously possible.

Oracle Spatial and Graph 12c delivers dramatic spatial performance improvements though Vector Performance Acceleration that can achieve 50 times performance improvements for the most common spatial functions and operations. The GeoRaster feature of Oracle Spatial and Graph has parallel raster capabilities that can make raster operations from 3 to 100s of times faster than the previous release.

Additionally, Oracle Spatial and Graph 12c adds features for applications across several different domains, reducing application logic and supporting real world analysis by moving complex spatial and graph logic into the database. Parametric or free form curves are supported. The routing engine supports advanced truck routing. The Network Data Model automatically associates real-world features with graph elements, and supports time based attributes, and multimodal fastest path calculations. GeoRaster adds virtual mosaics, more analytics and image processing, more complete Java support, and a GDAL-Based ETL wizard. RDF Semantic Graph includes RDF views on relational data, more extensive inferencing capabilities, the latest SPARQL support, spatial RDF data support, and graph analytics and statistics support. The appendix provides a list of major new features in Oracle Spatial and Graph.

This white paper provides an overview of the features in Oracle Spatial and Graph 12c. Please refer to the Oracle Spatial and Graph Spatial Developer's Guide, Appendix B for the list of spatial features found in Oracle Database and in Oracle Spatial and Graph.

Oracle Spatial and Graph is completely integrated with the performance, scalability, and security of Oracle Database, making it the most advanced spatial and graph database platform available for enterprise class deployments.
Spatial Features Overview

Vector Performance Acceleration

Vectors are 2-dimensional and 3-dimensional sets of vertices, for instance latitude, longitude and height that describe geometries, such as points, lines, polygons, surfaces and solids. Geometries often represent real world objects. Vector operations evaluate spatial relationships between geometries, including within-distance, nearest-neighbor, and geometry interactions, such as touch, overlaps, contains, covers, distance, and buffer zone generation around geometries.

Oracle Spatial and Graph 12c vector acceleration capabilities substantially improve the performance of vector operations. Vector acceleration provides enhanced computational algorithms along with CPU and memory enhancements that improve the performance of spatial index creation, geometric computations in functions and spatial operator secondary filter operations. Oracle Spatial and Graph vector performance acceleration builds on general improvements in Locator described the section below "Locator Operator and Function Improvements."

Parametric Curve Support

Oracle Spatial and Graph 12c supports 2-dimension and 3-dimension parametric curves, also called non-uniform rational B-splines (NURBs). The Oracle Database spatial type, SDO_GEOMETRY now supports mathematically precise representation of freeform curves that can be reproduced exactly. NURBs are used to simplify the design and modeling of roads, highways, and rail.

Locator Operator and Function Improvements

Oracle Database 12c Locator feature includes the following functions in the SDO_GEOM package that were part of Oracle Spatial and Graph: RELATE, DIFFERENCE, INTERSECTION, UNION, VOLUME, and XOR. The spatial aggregate function, SDO_AGGR_UNION is also included with Locator.

Oracle Database 12c performance for most commonly used location operations is up to forty times faster than previous releases for ANYINTERACT, INSIDE, DISTANCE, WITHINDISTANCE, and VALIDATEGEOMETRY operators. Algorithms for geospatial functions relate and validate are four to five times faster than previous releases.

Oracle Spatial and Graph 12c vector performance acceleration builds on general improvements in Oracle Database available to all SDO_GEOMETRY operations in these areas: caching of index metadata, concurrent update mechanisms, and optimized spatial predicate selectivity and cost functions.

These optimizations enable more efficient use of CPU, memory, and partitioning, resulting in substantial query performance improvements. For example, internal test results show up to 100 times faster query performance than with the previous release for non-geodetic point data and a polygon query window.

Vector Geometry Functions

Oracle Spatial and Graph provides over 400 functions, in addition to those found in Locator, to perform calculations on geometries, such as area of a polygon, length or perimeter. These functions are used, for example, to determine the total area of all counties around a given county, the length of an interstate highway, or the length of a provincial border.
Other functions generate new geometries such as buffers, unions, intersections, and much more. They can be used, for example, to define sales regions by creating a 5 mile buffer around all sales offices, identify the new geometry representing the union of two sales regions, or find the intersection between two sales regions.

Other functions include interior point, concave hull, and generation of triangulated irregular networks through Delaunay triangulation. Cross-endian operations for transportable tablespaces are also supported.

Whole Earth Geometry Model for Geodetic Coordinate Support

The Whole Earth geometry model takes into account the curvature of the Earth’s surface when performing calculations on geodetic data. Thus, Oracle Spatial and Graph functions return accurate lengths and areas for both projected and geodetic data. It supports over 30 of the most commonly used distance and area units, including foot/square foot, meter/square meter, kilometer/square kilometer.

Projections and Coordinate Systems

Oracle Spatial and Graph provides comprehensive tools for managing coordinate systems and projections to represent and integrate spatial information effectively and accurately. Over 4000 commonly used mapping coordinate systems are supported; users can also define new coordinate systems. Oracle Spatial and Graph also provides support for implicitly and explicitly transforming data between different coordinate systems – it enables explicit map projection transformations of vector objects from one coordinate system to another. These transformations can be on a geometry-level basis or an entire layer at a time.

Coordinate systems support is based on the European Petroleum Survey Group (EPSG) data model and data set. Although created by the oil and gas industry, this industry model provides benefits of standardization, expanded support, and flexibility for all industries, georaster data vendors, and GIS users in general.

Oracle Spatial and Graph supports 3D coordinate systems, which include height or a “z” coordinate, in addition to longitude and latitude or projected x, y coordinates as appropriate; reprojection of rasters is also supported.

Spatial Aggregates

SQL has long had aggregate functions, which are used to aggregate the results of a SQL query. Oracle Spatial and Graph aggregate functions perform a specified aggregate operation on a set of input geometries, and return a single geometry object. For example, the following statement returns the state boundary of Tennessee generated from all of the counties in Tennessee:

```sql
select sdo_aggr_union(sdoaggrtype(geom,0.5)) state
from geod_counties
where state_abrv='TN';
```

Other supported aggregate functions include, union, centroid, and convex hull; users can also define other aggregate functions. The use of spatial aggregates improves performance and simplifies coding.
Linear Referencing Support

Oracle Spatial and Graph can store and associate attributes and events with a specified segment on a linear geometry. Attributes and events are stored in tables separately from the geometry, and the geometry does not have to be duplicated in the attribute tables. Linear referencing is often used in the transportation, utilities, and telecommunication industries.

Functions to manipulate linear referenced geometries are also included, such as locating points along a linear feature, clipping a piece of a linear feature (dynamic segmentation), snapping to the closest point of a linear feature of a given point, and conversion between standard and linear referenced geometries. Oracle Spatial and Graph 12c Linear Referencing System functions support 3D geodetic data.

GeoRaster Support

Geometries can be represented by vectors or rasters, or both. Image processing systems typically refer to raster data as images, for instance in satellite imagery and airborne photographs. Raster data used in GIS is normally called gridded data. Oracle Spatial and Graph GeoRaster can store, index, query, analyze, and deliver raster image and gridded data and its associated metadata. GeoRaster associates location with the geometries in a raster by assigning location values to a matrix of cells that cover the raster and storing the cells as an array.

GeoRaster stores multidimensional grid layers and digital images that can be referenced to positions on the Earth's surface (georeferenced) or to a local coordinate system. If the data is georeferenced, users can find the location on Earth for a cell in an image and vice-versa. GeoRaster has data types and an object-relational schema to support raster processing and analysis for a variety of industries, including environmental monitoring and assessment, geological engineering and exploration, natural resource management, defense, emergency response, telecommunications, transportation, urban planning, and homeland security.

GeoRaster loading and native storage is flexible, cost-effective and performant. The file formats GeoTiff, JPEG 2000, and Digital Globe RPC are supported for loading and exporting GeoRaster objects. JPEG files can be loaded without decompression. Oracle SecureFiles provides transparent lossless compression. Alternatively, GeoRaster-specific industry standard image compression techniques, including JPEG baseline (lossy) and DEFLATE (lossless) can be used and an open plug-in architecture allows additional third party compression techniques. Automatic blocking size optimization chooses a block size for georasters that minimizes storage while optimizing retrieval and processing. GeoRaster supports raster image and raster data at differing sizes and degrees of resolution through pyramiding, and very large images with tiling. Three types of interleaving are supported to optimize access to the data in the raster.

GeoRaster has fast, sophisticated image processing. Parallelism accelerates the execution of SQL and GeoRaster procedures. GeoRaster uses industry standard resampling and interpolation methods for image and raster transformations and operations. Raster re-projections to over 4,000 coordinate systems are supported. Transformations between 2D or 3D ground coordinates and 2D cell coordinates, and vice-versa are supported. Non-rectified images (not geometrically corrected for uniform scale) can be georeferenced with GeoRaster’s flexible functional fitting polynomial georeferencing model. Ground Control Point-based georeferencing establishes coordinates in the raster based on a point for which the coordinates are known. Irregular polygon-based clipping in queries returns a precise subset of a
GeoRaster object. Grid point interpolations infer values at spatial positions between or within cells. Irregularly shaped regions inside an image can be defined with bitmap masks.

GeoRaster provides ease of development, ease of use, and manageability. GeoRaster DML triggers are created and monitored by the system automatically. Users can monitor resource-intensive operations on GeoRaster system data. Partial raster updates are supported. GeoRaster templates are supported to develop GeoRaster applications, such as extraction, transformation, and loading (ETL) tools and image processing systems that work with GeoRaster objects. Statistical analysis functions can dynamically compute complete statistical values for a GeoRaster object or individual statistical values. Image classification, time series analysis, and raster GIS modeling are supported with the capability to merge multiple bands or layers of different GeoRaster objects into a single GeoRaster object. Raster data versioning with the Workspace Manager feature of Oracle Database, and raster data row-level security with Oracle Label Security are supported.

A Java API supports query, manipulation, and raster management. It also supports the development of ETL tools, Web applications, and raster processing applications—simplifying the development of Java applications that use, access, and manipulate raster and gridded data sets stored in Oracle Database.

The GeoRaster data type is supported by all the leading third party GIS and image processing tool vendors. This data type is also supported by Geospatial Data Abstraction Layer (GDAL), the leading open source geospatial ETL tool and API available for raster data. GDAL natively supports importing and exporting over 50 raster formats to and from SDO_GEORASTER. GDAL is a high performance C++ tool that supports large file sizes. It includes C/C++, Java, and Python APIs to access GeoRaster; and utilities to translate raster formats, warp rasters, generate contours from DEM rasters, and many other raster operations.

GeoRaster Enhancements
Oracle Spatial and Graph 12c GeoRaster capabilities have been significantly enhanced with substantial performance, data manageability, usability, and security features.

Virtual Mosaic Support
Oracle Spatial and Graph 12c includes virtual mosaic support. A virtual mosaic is defined as any large collection of georeferenced GeoRaster objects, rectified or un-rectified, from one or more GeoRaster tables or views that is treated as if it is a single GeoRaster object. A virtual mosaic can be one or a list of GeoRaster tables, a database view with a GeoRaster column, or a CURSOR for a SQL query statement that results in a collection of GeoRaster objects. A virtual mosaic can contain unlimited number of images, and a whole GeoRaster database can be treated as a virtual mosaic. Users can issue a single call to query the virtual mosaic based on an area-of-interest (that is, subsetting or cropping) and request the cropped images be in a different coordinate system with different resolutions. A spatial query can request different images from different tables of the virtual mosaic that can be rectified and stitched together, or mosaicked, on the fly, without producing a physical image to be persisted. This flexible model eliminates the need for preprocessing of imagery before querying it, simplifies the delivery for visualization, and can save disk space.

Raster Algebra and Analytics
Oracle Spatial and Graph 12c supports raster algebra operations that work on individual raster cells, or pixels to generate new maps from two or more raster layers. Raster algebra operations enable
applications to implement sophisticated analytical algorithms, such as a Normalized Difference
Vegetation Index (NDVI), and Tasseled Cap Transformation (TCT). Raster operation performance is
also substantially faster and can be parallelized to scale up to 100s of times faster for large data sets.

**Enhanced Image Processing**

Oracle Spatial and Graph 12c has additional image processing capabilities. These include image
rectification, orthorectification, image stretching, image segmentation, image update and appending,
advanced mosaicking, large scale virtual mosaic, and on-the-fly spatial queries.

More image processing can now be handled in the server instead of the client, and some processing is
parallelized. This enables improved performance of image processing on a much larger scale, with larger
data sets, which are increasingly being used in government and commercial applications as more raster
data becomes available.

**Java API Enhancements**

Oracle Spatial and Graph 12c GeoRaster Java API supports features such as ground control point (GCP)
storage and manipulation, GCP georeferencing, reprojection, grid interpolations, and getCellValue.
These features were previously supported by the PL/SQL API.

With these enhancements, Java developers have more access to Oracle Spatial and Graph GeoRaster
data management features.

**Metadata Content**

Oracle Spatial and Graph 12c supports relational raster data tables (RDTs) to allow users to specify
default alpha channel and pyramid level in its metadata. It includes a resampling algorithm that supports
resolution unit specification and parallel processing in many operations, and adds additional loading and
exporting capabilities.

For more information about GeoRaster, please refer to separate white paper on the Oracle Technology
Network, Oracle Spatial and Graph page.

**GDAL-Based ETL Wizard for Concurrent Batch Loading and Exporting**

Oracle Spatial and Graph 12c includes GDAL libraries that are installed with the database.

An ETL wizard tool is included to automate and enable concurrent batch loading and exporting of various
image and raster files using GDAL. The tool can load and export large numbers of raster and image files
in batches, and do so concurrently. It defines an XML schema and provides a graphical user interface to
create loading and exporting description files in XML. Each description file describes how to load or
export a series of raster files into or from GeoRaster in a batch. After the XML description files are
created, the tool can be used to invoke multiple description files to concurrently load and export raster
files in batches. Any runtime failures are caught and logged, but they do not stop the batch loading or
exporting process. This tool supports all raster formats supported by GDAL.
3D Data Type Support

Oracle Spatial and Graph provides native storage, querying, and retrieval for 3-dimensional (3D) data, including points, lines, surfaces, triangulated irregular networks (TINs), an alternative to rasters, and point clouds. Spatial R-tree indexing and SQL operators and analysis functions for 3D data are also provided.

Very large 3D datasets such as urban models, point clouds, and terrain models can be stored and managed in the open Oracle 3D data types, with security, scalability, and high performance. 3D datasets are often found in urban planning and design, government, homeland security, military, oil and gas exploration, transportation engineering, gaming and simulation, geo-engineering, medical applications, business intelligence (for example, real estate and advertising), and LIDAR-based map production.

Oracle Spatial and Graph provides a modeling, visualization and simulation infrastructure for 3D data. A set of metadata tables describes themes, scenes, textures, viewpoints, light sources, non-geographic data, and other elements used to visualize 3D content. This metadata support enables a consistent way to combine all 3D, raster, vector, and non-geometric data into a unified visualization framework. Information may be logically grouped into themes to simplify the development, analysis, use, and maintenance of 3D applications.

3D Enhancements

Oracle Spatial and Graph 12c has richer 3D and Point Cloud analysis and visualization. As described earlier, 3D parametric (freeform) curves are supported. The Java API in-memory functions support 3D projected and geodetic geometry types. The distance between two 3D points approximates and accounts for the height of those points in the calculation. 3D visualization and analytical tools can take advantage of metadata views for 3D themes, scenes, and viewframes. Pyramiding is supported for Point clouds and TINS to support visualization at different levels of granularity. Contour lines can be generated from point clouds. 2D points can be projected onto a TIN to determine point heights. Linear Referencing System functions support 3D geodetic data.

Topology Data Model

Oracle Spatial and Graph includes a data model and schema that persistently stores topology in Oracle Database. This is useful when there is a high degree of feature editing and a strong requirement for data integrity across maps and map layers. Topology-based queries typically perform faster than the alternative for relationships such as adjacency, connectivity, and containment. Land management (cadastral) systems and spatial data providers benefit from these capabilities.

Application developers and DBAs can version topologies stored in the Oracle Spatial and Graph topology data model using Workspace Manager, a feature of Oracle Database. Feature level spatial transactions against a persistent topology in the database are supported. A feature insert or update occurs as a single operation, simplifying the process of updating and maintaining topology datasets, and simplify application logic.

Spatial Analytic Functions

Oracle Spatial supports spatial analysis and mining in Oracle Data Mining (ODM), a component of Oracle Advanced Analytics. ODM allows automatic discovery of knowledge from a database, such as discovering hidden associations between various data attributes, classification of data based on some samples, and clustering to identify intrinsic patterns.
Spatial data can be materialized for inclusion in data mining applications. Data at a specific location is often influenced by data in the neighborhood. The spatial analysis and mining features in Oracle Spatial and Graph let users exploit such spatial correlation in the following ways:

- Binning data into regions – determine if southeastern US customers in a certain age or income category are more likely to prefer regular or diet soda
- Materializing spatial correlation (neighborhood influence) – examine the values of similar houses in a neighborhood when assessing the value of a house
- Colocation mining – determine if locating a pizza restaurant franchise with a video store results in higher sales
- Spatial clustering – determine the regions where crime rates are high, decide where to deploy additional police
- Location prospecting – identify the best locations for opening new hospitals based on the population of patients who live in each neighborhood

For more information about spatial analytic functions, please refer to the white paper on the Oracle Technology Network, Oracle Spatial and Graph page.

Geocoding

Geocoding is the process of associating geographic references, such as addresses and postal codes, with location coordinates (longitude and latitude). Oracle Spatial and Graph offers full geocoding capabilities. It provides international address standardization, geocoding points of interest (POI) and matching them to geocoded data stored in Oracle Database, reverse geocoding, batch geocoding, and other geocoding capabilities. Its unique unparsed address support adds great flexibility and convenience to customer applications. SQL, Java, and XML APIs for geocoding are provided, and it can be deployed either at the middle tier (Oracle Fusion Middleware) or at the database server tier.

Sample data is available online. Data sets in the format supporting Oracle Spatial and Graph are also available from leading data providers. For more information, please visit the Oracle Technology Network for Oracle Spatial and Graph and navigate to the Partners tab.

Oracle Spatial and Graph geocoding supports standard address geocoding based on interpolation and point-based geocoding where data sets include the exact location of addresses, intersections, and points of interest. Point-based geocoding is becoming increasingly popular because it allows for more accurate results and can be used in situations where interpolation is not possible.

Geocoding Enhancements

Oracle Spatial and Graph 12c geocoding includes point address geocoding support for countries that don't have address ranges and language support for countries that have addresses in multiple languages. Reverse geocoding can be performed without specifying a country code.

Routing Engine

A routing engine provides driving distances, times, and directions between addresses or between locations that have been geocoded in advance. The Oracle Spatial and Graph routing engine is provided as a Java client library that can be easily deployed in J2EE servlet containers. It supports preference for either fastest or shortest routes, and provides summary and detailed driving directions, and the time and distance along a street network from a location to multiple destinations. It also provides driving distances, times, and directions between addresses for over a dozen Western European countries,
including Germany, United Kingdom, and France to support logistics, transportation, and location-based services applications.

Sample data is available online. Data sets in the format supporting Oracle Spatial and Graph are also available from leading data providers. For more information, please visit the Oracle Technology Network, Oracle Spatial and Graph page and navigate to the Partners tab.

The routing engine provides driving directions in Western European languages, including German, French, Spanish, and Italian. Turn-specific geometries can be generated for location services applications that require turn-specific point of interest data. Computed routes can be returned as a set of relationships between points that can be used for further analysis.

Routing Enhancements

The Oracle Spatial and Graph 12c routing engine supports restrictions and conditions that are required for advanced routing applications, such as truck-specific routing. It can provide truck-specific routing based on roads, weight, height, time of day, and other conditions applied to commercial and logistics applications and logical turn restrictions. It can compute the drive times based on truck speed limits, which often differ from car speed limits. It can also provide information on truck services, such as weigh stations and truck stops along a route. Finally, it can handle logical turn restrictions involving more than two way points in the route geometry. These enhancements yield more accurate results for logistics and truck routing applications.

Spatial Web Services

Oracle Spatial and Graph provides a web services platform to access, incorporate, publish, and deploy geospatial services, including services for geocoding, routing, mapping, business directory, catalog, and geospatial feature transactions. Oracle Spatial and Graph is tightly integrated with Oracle Database and Oracle Fusion Middleware to provide a transactional service-oriented architecture platform with enterprise-class security. They provide security, including authorization, authentication, and transport confidentiality and integrity.

Oracle Spatial and Graph has supported the Open Geospatial Consortium (OGC) and ISO TC211 standards for many releases. It supports these XML-based geospatial web services standards: OGC OpenLS 1.1, Web Feature Service – Transactional (WFS-T) 1.0, Web Feature Service 1.0, and Catalogue Service 2.0, on a variety of client technologies and platforms.

Oracle Spatial and Graph includes full support for database transactions on WFS-T feature tables through SQL without restriction. It also supports Workspace Manager versioning and WFS feature tables. Java and PL/SQL client APIs are provided.

Spatial Web Services Enhancements

Oracle Spatial and Graph 12c provides a Web-based administrative console for Web Feature Server 1.1. It is a menu-driven user interface that simplifies registration of spatial layers with Web Feature Server 1.1. It allows users to browse existing spatial layers, eliminating the need for a DBA to run PL/SQL scripts to publish spatial layers. It includes a tutorial on configuring and using WFS, and includes sample request and response page for WFS queries. The user interface can also be used as a client to other WFS servers.
Network Data Model Graph Features Overview

Oracle Spatial and Graph Network Data Model (NDM) stores general network or property graph data structures persistently in Oracle Database. It explicitly stores and maintains network connectivity and provides network analysis capability, including shortest path, nearest neighbors, within cost, and reachability. Applications requiring network solutions include transportation, utilities, and oil and gas.

NDM has a PL/SQL API for managing network data in the database, and a Java API for performing network analysis and creating and applying network constraints.

Oracle Spatial and Graph NDM users can benefit from the speed of in-memory analytics with networks that are larger than available memory. NDM supports partitioning large networks into manageable sub-networks and can automatically load network partitions into memory as needed for efficient in-memory analysis. Partitioning utilities are also available.

NDM is integrated with Oracle Spatial and Graph geocoding and the routing engine; applications using these features can perform analysis using NDM functions. NDM supports commercial street network data from Nokia (Navteq), in Oracle Delivery Format (ODF).

NDM includes a number of modeling and analysis features that meet the requirements for utility networks, logistics, transportation, and other network-based applications.

Modeling features:

» Model and represent any point along a link for all analysis functions, such as specific addresses in street networks with any number of properties on the nodes and links.
» Model partial-link paths (subpaths).
  » Customize link and node properties: e.g., costs.
  » Perform path analysis with multiple link and node properties (e.g., distance/time/hops costs).
» Perform partitioning of logical networks, for example social and biochemical pathway networks, based on metrics appropriate to the application.

Network analysis features:

» Compute the shortest route connecting a given set of nodes.
» Generate a polygon representing the region that can be reached from a given node with a specific cost. A typical application is the generation of drive-time and drive-distance polygons.
» Generate the shortest path on a hierarchical network, where links are prioritized by property (e.g., highways, local roads), to support queries such as finding the route between two addresses that favors highways over local roads as much as possible.
  » Compute a buffer based on network cost; the buffer representation contains coverage and cost information.
  » Compute K shortest paths between two nodes.

NDM includes an example with JSP and Java files for application developers to quickly and easily deploy routing and other network analysis using data stored in NDM. Users can visualize analysis results in a web browser. The example works with Nokia ODF network data, and uses the NDM load on demand API, Oracle Fusion Middleware MapViewer, and the Oracle Spatial and Graph geocoding engine.
Download the example from the Oracle Technology Network at oracle.com/technetwork/database/options/spatialandgraph/spatial.

NDM Enhancements

Oracle Spatial and Graph 12c NDM feature and time modeling enhancements simplify application development and support real-world analysis by moving complex spatial logic into the database.

Feature Modeling and Analysis

Oracle Spatial and Graph 12c NDM simplifies feature editing and analysis by providing a feature analysis function that associates feature representations with network elements. Feature modeling bridges the gap between concrete objects of interest in real world and abstract network elements.

Feature modeling simplifies application development by associating real world objects with network elements. For example, if a utility network application needs to find affected households when a substation experiences a power failure, it is necessary to associate the application features (substations, power lines and transformers) with network elements (links and nodes). Feature modeling maintains these relationships through feature metadata, simplifying application development and maintenance.

Network Modeling with Time; Multimodal Transportation Routing

Oracle Spatial and Graph 12c adds support for modeling networks having a time dimension. Users may associate time properties with nodes and links, and specify temporal inputs in network analysis queries.

Most real-world networks have a time element. Travel times on road segments vary with the time of day. Utility networks experience different demand loads based on seasonal demand and the time of day. Analytic and planning applications can benefit from more accurate representation of real-world conditions. NDM supports queries such as finding the fastest travel route for a specified time of day.

NDM supports modeling and analysis of multimodal transportation networks, and computing the fastest paths on multimodal transportation networks.

For more information about Oracle Spatial and Graph Network Data Model, please refer to the white paper on the Oracle Technology Network, Oracle Spatial and Graph page.

RDF Semantic Graph Features Overview

The RDF Semantic Graph feature of Oracle Spatial and Graph (formerly Semantic Technologies) provides advanced semantic data management. With native support for world wide web consortium standards RDF and OWL are standards for representing and defining complex, semantically related data and SPARQL is a query language designed specifically for graph analysis. Application developers benefit from the industry’s leading open, scalable graph data platform integrated with Oracle Database for scalability, security, performance and high availability. Graphs are becoming central to a new category of social network and linked data applications common in health sciences, finance, media and intelligence communities. RDF Semantic Graph includes: storing and loading RDF/OWL data and ontologies; inference using OWL 2 and user-defined rules; and SPARQL 1.1 query and update.

Storing, Loading, and Data Manipulation

RDF Semantic Graph has proven scalability to over 54 billion triples (LUBM 200K benchmark) and can scale up to 8 petabytes of triples. It supports all standard database loading, storing, and data
manipulation operations on RDF/OWL models. Each RDF model contains a set of subject – object – relationship triples organized as a graph of directed, labeled edges. The edge is the link (or relationship) that connects a subject node to an object node and is labeled by a predicate (property). Space-efficient storage saves up to 60% disk space for scalable and performant loading, querying, and inferencing.

Native Inferencing
RDF Semantic Graph has native, forward-chaining, persistent inferencing using any combination of RDF, RDFS, and OWL 2 RL and EL profiles, as well as user-defined rules for specialized inference capabilities. It also provides a plug-in framework to support third party specialty reasoners. Optimizations include optimized large owl:sameAs sets, incremental inference to update entailments after triple inserts, and parallel inference on multi-core or multi-CPU architectures.

Oracle Spatial and Graph 12c supports ladder-based inferencing that ensures newly inferred triples are labeled with the proper security and user-defined inferencing has been added.

Querying RDF Graphs in Oracle Database
RDF Semantic Graph provides SPARQL 1.1 endpoint web services and Java APIs via open source Apache Jena / Joseki and Sesame. RDF/OWL data can also be queried using SQL; the Oracle SQL SEM_MATCH table function embeds SPARQL graph pattern queries in a SQL query. A virtual model capability provides a view-like feature to combine models for querying.

The SEM_MATCH table function in Oracle Spatial and Graph 12c supports SPARQL 1.1. The OGC GeoSPARQL standard is supported for storing and querying spatial data in an RDF graph.

Viewing Relational Data as RDF Triples
RDF views can be created on relational tables, views and SQL query results in Oracle Spatial and Graph 12c. The W3C specifications for automatic mapping (called Direct Mapping), custom mapping (using the W3C R2RML language) and materializing views are supported. RDF views present relational data in RDF triple format so it can be queried using SPARQL and connected with other linked data and RDF graphs to relate and facilitate enterprise data integration.

RDF, XML, JXON and Relational Interoperability
Ontology-assisted SQL querying allows SQL queries to extract more semantically complete results from table data by associating relational data with ontologies that organize the domain knowledge of the data.

Oracle Spatial and Graph 12c provides a SPARQL Gateway feature that presents SPARQL query results in XML format for visualization tools that support XML data sources, such as Oracle Business Intelligence (OBIEE). RDF query results can be returned in the JXON interoperability format.

Fine-grained Security
Model-level access control is the default for RDF graph data. Triple-level security using the Oracle Label Security Option is also supported for the most stringent security levels. Sensitivity labels can be defined on individual triples and users to conditionally restrict a user’s access to individual triples stored in an RDF model.
Graph Analytics

Oracle Spatial and Graph 12c supports SPARQL 1.1 property path expressions to find graph patterns across any length path and integration with Network Data Model property graph in-memory graph analytics, including shortest path, reachability, within-cost, and nearest-neighbor. Results from graph queries can be used with Oracle Advanced Analytics Data Mining and Oracle R Enterprise.

Semantic Indexing for Documents

Semantic indexing for documents provides an index type to semantically index information in unstructured documents, table data and URLs extracted by third party natural language processors and annotators. Semantically indexed documents can be searched using SEM_CONTAINS operator within a standard SQL query. The search criteria for these documents are expressed using SPARQL query patterns that operate on the information extracted from the documents.

Advanced Performance and Scalability

RDF Semantic Graph supports parallelism, compression, partitioning, Oracle Real Applications Clusters (RAC) and Oracle Exadata Database Machine for enterprise-level performance and scalability. Required licensing for this functionality is: Oracle Database Enterprise Edition, Oracle Spatial and Graph option, and the Oracle Partitioning option.

Oracle Exadata Database Machine

Engineered systems provide high performance, high bandwidth, and massive parallelism with enormous capacity to address the challenges faced by high volume workloads. Combining Oracle Spatial and Graph advanced analysis with Oracle Exadata Database Machine performance and scalability delivers an ideal platform for the most demanding applications.

Oracle Spatial and Graph fully uses the balanced hardware and highly parallelized architecture of Oracle Exadata. It can achieve performance results over 150x faster than other spatial database machines and solutions. Real customer scenarios, test results, and strategies have maximized performance for massive spatial and graph computations and data ingest.

Oracle Spatial and Graph features are engineered to natively leverage the parallelism, partitioning, indexing and the scalability features of Oracle Exadata without application changes. The fully-parallelized joins and aggregations of Oracle Exadata coupled with the extreme I/O bandwidth and high performance of Exadata Storage server provide Oracle Spatial and Graph with the processing power needed for server-based geo-processing and graph applications. OLTP index compression improves query performance by compressing and increasing memory residence for spatial and graph indexes. Exadata Hybrid Columnar Compression increases memory residence for large spatial and graph data sets as well as the rule sets used in inferencing.

For more information, including customer scenarios, test results, and strategies with Oracle Exadata and Oracle Spatial and Graph, please refer to Oracle Technology Network, Oracle Spatial and Graph page.
Enterprise Features Supported in Oracle Database 12c

Oracle Database 12c provides powerful, reliable support for an organization’s mission-critical applications. These enterprise features enrich Oracle Spatial and Graph capabilities via a flexible Internet deployment architecture, object capabilities, and robust data management utilities that ensure data integrity, data recovery, and data security. This level of support can only exist in the homogenous environment of an enterprise database solution, and cannot be effectively replicated in a hybrid solution that marries an external location-based solution with a traditional enterprise solution, no matter how tightly integrated the two components may appear.

Oracle Spatial and Graph takes full advantage of expanded database size limits, high-performance VLDB maintenance, utilities, replication, versioning of geospatial data (Workspace Manager), faster backup and recovery, and partitioning. Only users of the native geospatial and graph data types in Oracle Database can take full advantage of features such as partitioning, replication, parallel spatial index builds and queries, and geospatial and graph-driven multi-level security. The full range of Oracle utilities (e.g. SQL*Loader) are also available to ease migration and help upgrade applications that use the spatial features. Some of these key enterprise features are described below.

Partitioning Support for Spatial Indexes

The Oracle Database architecture includes partitioning, in which a single logical table and its indexes are broken up into one or more physical tables, each with its own index. Spatial indexes associated with partitioned tables can be partitioned; range partitioning is the partitioning scheme supported for spatial indexes. A graph in Oracle Database is subdivided into models that reside in separate partitions. Partitioning offers significant performance, scalability, and manageability benefits, including the following:

» Reduced response times for long-running queries; partitioning can reduce disk I/O operations.
» Reduced response times for concurrent queries; I/O operations run concurrently on each partition.
» Easier index maintenance because of partition-level create and rebuild operations.
» Ability to rebuild indexes on partitions without affecting the queries on other partitions.
» Ability to change storage parameters for each local index independent of other partitions.
» Partitions that can be split, merged, and exchanged.

Parallel Index Creation

Spatial and graph indexes and index partitions can be created in parallel. Geospatial R-tree index and graph B-tree index creation can be subdivided into smaller tasks that can be performed in parallel, making use of unused hardware (CPU) resources. For certain spatial data sets and index types and parameters, parallel index creation can substantially increase index build performance and provide a significant time savings. Large non-point datasets (commonly used in many standard GIS applications) can show dramatic performance improvements.

Parallel Load, Query and Inference

Spatial queries can run in parallel on partitioned spatial indexes, improving the performance of "within distance", "nearest neighbor", and "relate" queries. Performance scales with the number of CPUs used to execute a query. This helps location service and land management applications, which need to execute
high volumes of spatial queries quickly. RDF graph data loading, graph queries and inferencing operations are also fully parallelised.

Replication

Oracle GoldenGate can replicate data in the native geospatial data types. It supports SDO_GEOMETRY, SDO_GEORASTER, SDO_TOPO_GEOMETRY. Distributed systems that involve geographically dispersed yet logically replicated web sites, can take advantage of synchronized replication of spatial data objects across multiple databases.

Note: Oracle Database Advanced Replication multimaster configuration is supported but deprecated in Oracle Database 12c Release 1 and will be desupported in release 2. It is available with Oracle Database Enterprise Edition only. Refer to the Oracle Database Advanced Replication manual for more information about Advanced Replication features. Use Oracle GoldenGate going forward to replace all features of Advanced Replication, including multimaster replication, updatable materialized views, multitier materialized views, and deployment templates.

Database Workspaces and Long Transactions

Workspace Manager, a feature of Oracle Database, provides a virtual environment (workspaces) that allows current, proposed and historical spatial data values to be managed in the same database. Workspaces can be shared and used to: isolate a collection of changes to production data until they are approved and merged into production; keep a long term history of changes to data; and create multiple data scenarios based on a common data set for "what if" analysis. Workspace Manager is supported by most GIS vendors.

Support for Oracle Multitenant

Oracle Multitenant is an option for Oracle Database 12c that enables database consolidation without changes to applications. Designed for the Cloud, it allows many databases to be managed as one, while retaining the isolation and resource prioritization of separate databases. The multitenant architecture consolidates multiple Oracle Databases (each referred to as a pluggable database) to run under a single occurrence of Oracle Database software (referred to as a multitenant container database). Architectural separation is enforced between each pluggable database (user data and metadata) and its multitenant container database (Oracle metadata). Pluggable databases are compatible with traditional Oracle Databases not in a multitenant container database.

Oracle Spatial and Graph functions transparently in a multitenant architecture; spatial and graph applications benefit from the efficient administration of one multitenant container database, and the separation and resource prioritization allowed by multiple pluggable databases.

Open Standards

Oracle consistently works to help shape, drive, implement and support the latest open standards in the spatial, location services, and graph database areas. Oracle is a founding, Principal Member of the Open Geospatial Consortium (OGC). Oracle is a World Wide Web Consortium (W3C) member and active contributor and/or editor in various technical working groups, such as the W3C RDF, SPARQL, OWL and RDB2RDF working groups and the OGC GeoSPARQL Working Group.
Multiple versions of Oracle Spatial and Graph comply with the OGC Simple Features Specification for SQL, Revision 1.1, Types and Functions Alternative; OGC OpenLS 1.1, Web Feature Service – Transactional 1.0, Web Feature Service 1.0, and Catalogue Service 2.0. Oracle Spatial and Graph also supports the SQL/MM types and operators, as specified in ISO 13249-3, Information technology - Database languages - SQL Multimedia and Application Packages - Part 3: Spatial. Oracle Spatial and Graph operators corresponding to those defined in this standard, as well as the SDO_NN and SDO_WITHIN_DISTANCE operators, can be used on data stored in the SQL Multimedia root type.

RDF Semantic Graph supports the W3C semantic and OGC GeoSPARQL standards. Supported W3C specifications include: RDF, RDF Schema (RDFS), SPARQL 1.1 query language, OWL 2 (RL and EL profiles) knowledge representation languages for authoring ontologies, the Simple Knowledge Organization System (SKOS) and the RDB2RDF specifications for creating RDF views on relational tables - Direct Mapping (DM) and Mapping Language (R2RML). The OGC GeoSPARQL 1.0 – A Geographic Query Language for RDF Data standard is supported for queries and analysis of geospatial data stored in an RDF graph.

Standards compliance testing for Oracle Spatial and Graph is ongoing, and compliance with more recent versions of standards or with new standards might be announced at any time. For current information about compliance with standards, visit the Oracle Technology Network, Oracle Spatial and Graph page.

Oracle Spatial and Graph Partners

Oracle builds and maintains active partnerships with the leading data providers; systems integrators; and geospatial and graph tool, application, and service providers. Oracle’s longstanding commitment to depth and breadth of partnerships provides users flexibility and the widest possible choices. Developers and IT managers can select best of breed tools and applications to meet their industry and organization-specific requirements and rapidly deploy scalable, secure enterprise geospatial and location service solutions. Support from leading data providers and systems integrators, both from the geospatial and enterprise IT domains, provides customers with choices for fast deployment of customized solutions to meet their needs.

All of the most widely used GIS software technologies available in the industry support Oracle Spatial and Graph. The leading geospatial data vendors provide data products in Oracle’s spatial format with worldwide coverage, and integrators around the globe provide expertise and experience at delivering Oracle spatial solutions.

RDF Semantic Graph features are directly integrated with the leading third party graph tools and applications as well as Oracle Business Intelligence and Oracle Advanced Analytics products. RDF Semantic Graph also supports the leading open source application development frameworks, Apache Jena and Seseme, and associated open source tools as well as linked open data ontologies.

For a complete list of partners and links to sample data, free downloads, and other resources, visit the Oracle Technology Network, Oracle Spatial and Graph page.
Conclusion

Oracle Spatial and Graph provides advanced capabilities for Oracle Database 12c Enterprise Edition. It addresses the business-critical needs of customers in traditional geospatial domains such as defense and intelligence, homeland security, land management, transportation, as well as a broad range of business domains requiring location and/or graph technologies, including finance, retail, life sciences, publishing and media companies. Oracle Spatial and Graph users include several of the largest organizations in the world that use mission-critical, location-enabled enterprise systems. Customers and partners rely on Oracle to deliver performance, scalability, security, and ease of use for their spatial and graph applications. Oracle Spatial and Graph is supported by all the leading geospatial and location services vendors and systems integrators.

Oracle Spatial and Graph is the solution for users who have geospatial or graph applications requiring advanced server-side analysis and processing. Oracle Spatial and Graph provides storage and management of urban models, point clouds, and terrain models found in domains such as urban planning, homeland security, or LiDAR-based map production. It is also a geospatially-enabled web services platform, supporting major XML-based standards from OGC. An open GeoRaster format supports geo-referenced image storage and management requirements from the public sector, defense, and energy exploration domains. Network and topology data models meet the needs of applications in transportation, utilities, land management, life sciences, and location services. A server-side geocoder and routing engine support the deployment of location-based services, and spatial analysis functions enhance business applications.

Graphs are fundamental to a new category of social network and linked data applications common in health sciences, finance, media and intelligence communities. The RDF Semantic Graph model provides an open, scalable graph data platform for representing and defining complex, semantically related data commonly found in metadata integration, social network analysis, and text mining and entity analytics applications. It is integrated with the partitioning, parallelism, fine-grained security and high availability of Oracle Database for enterprise-scale graph applications. It enables storing and loading RDF/OWL data and ontologies; inferencing using OWL 2, SKOS and user-defined rules; and SPARQL graph pattern queries and updates in Oracle Database.

Oracle Database 12c, includes Oracle Spatial and Graph enhancements that support more completely a wider range of customer requirements, simplify application development, and boost performance. Explosive performance improvements in the Oracle Spatial and Graph 12c Vector Performance Acceleration feature speed up common spatial functions and operations over 50 times faster. Core spatial function performance has also been improved. GeoRaster parallel capabilities can speed up raster operations from 3 to 100s of times.

Oracle Spatial and Graph 12c features such as Network Data Model real-world feature modeling, parametric curve support, raster algebra, and 3D and Point Cloud analysis and visualization enhancements provide more complete support for a wide range of GIS applications. GeoRaster virtual mosaic support provides management flexibility for querying and working with raster data sets. These capabilities reduce application logic and support real world analysis by moving complex spatial logic into the database. RDF views on relational data enable integration and discovery across disparate data sets. Additional support for W3C OWL inferencing language, user defined inferencing and integration with
Network Data Model, Oracle Data Mining and Oracle R Enterprise provide unmatched discovery and advance analytics for complex interrelated data.

With every release since its introduction over ten years ago, Oracle Spatial and Graph has delivered the most advanced spatial and graph data management capabilities to database management systems. With the unmatched enterprise data management capabilities of Oracle Database 12c, it continues to be the world’s leading database management platform for geospatial enterprise spatial and graph systems.

Appendix: Oracle Spatial and Graph 12c New Features

Oracle Database 12c Location Features

» More operators: DIFFERENCE, INTERSECTION, RELATE UNION, VOLUME, XOR

» Forty times faster operators: ANYINTERACT, INSIDE, DISTANCE, WITHINDISTANCE, and VALIDATEGEOMETRY

» Faster functions: RELATE is up to five times faster, VALIDATE is up to four times faster

Spatial Features

» Vector Performance Acceleration: Substantially faster querying and more efficient use of CPU, memory, and partitioning

» Parametric Curves (NURBs): mathematically precise representation of free form curves that can be reproduced exactly for 2D and 3D data.

» GeoRaster virtual mosaic: a large collection of GeoRaster objects, rectified or not, from one or more GeoRaster tables or views can be treated as a single GeoRaster object

» GeoRaster raster algebra: new analytical algorithms and faster, parallel raster operations

» GeoRaster image processing: More processing capabilities, more server-side and parallel processing

» GeoRaster Java APIs: more APIs that were previously supported only in the PL/SQL API

» GeoRaster metadata content: specify default alpha channel and pyramid level, resampling supports resolution unit and parallel processing, additional loading and exporting options

» GeoRaster GDAL-Based ETL Wizard: The ETL wizard tool automates and enables concurrent batch loading and exporting of various image and raster files using GDAL

» 3D: accounts for height when calculating distance between two 3D points

» 3D: metadata views for 3D themes, scenes, and viewframes for visualization and analytics

» 3D: pyramiding is supported for Point clouds and TINS

» 3D: Contour lines can be generated from point clouds

» 3D: geodetic data supported in Linear Referencing System functions

» Geocoding: supports point address geocoding for countries that don’t have address ranges and language support for countries that have addresses in multiple languages.

» Routing engine: advanced routing restrictions and conditions, such as truck-specific routes

» Spatial Web Services: A Web-based Administrative Console for Web Feature Server 1.1

Network Data Model Graph (NDM) Features

» Feature modeling: automatic mapping of application objects to network elements
Network time modeling: Time attributes can be associated with nodes and links, and specified in network analysis queries

Multimodal transportation modeling: fastest paths can be computed

RDF Semantic Graph Features

RDF views: present relational data in RDF format for SPARQL queries and connect with other linked data and RDF graphs to relate and facilitate enterprise data integration.

SPARQL 1.1 in the Database: SPARQL 1.1 supported by SEM_MATCH table function

Store/query spatial data in RDF: The OGC GeoSPARQL standard is supported

Security on inferencing: Ladder-based inferencing ensures inferred triples are labeled with the proper triple-level security.

More inferencing support: User-defined inferencing and full OWL 2 EL profile support

Graph analytics: SPARQL 1.1 property path expressions find graph patterns across any length path

In-memory graph analytics: shortest path, reachability, within-cost, and nearest-neighbor.

Graph mining and statistics: Oracle Advanced Analytics Data Mining and Oracle R Enterprise are supported

SPARQL Gateway: SPARQL query results can be presented for visualization in tools that support XML data sources, such as Oracle Business Intelligence (OBIEE)