

Spatial and Graph Analytics with Oracle Database 12c Release 2

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Introduction

Oracle Spatial and Graph, part of Oracle Cloud and an option for Oracle Database 12c Enterprise Edition provides the industry's leading spatial and graph database management platform. It includes advanced features for management and analysis of spatial data, social (property) graphs, and RDF linked data applications. Support for the general-purpose property graph model is introduced in the Oracle Database 12c Release 2 (12.2) on Oracle Cloud.

Spatial and graph analysis is about understanding relationships. As applications and infrastructure evolve, as new technologies and platforms emerge, we find new ways to incorporate and exploit social and location information into business and analytic workflows. The emergence of Internet of Things, Cloud services, mobile tracking, social media, and real time systems create new challenges to manage the volume of data, but more importantly, to discover patterns, connections, and relationships.

To address these opportunities, Oracle Database 12c includes a wide range of spatial analysis functions and services to evaluate data based on how near or far something is to another, whether something falls within a boundary or region, or to visualize geospatial patterns on maps and imagery. With Oracle Database 12c Release 2 on Oracle Cloud, Oracle introduces a powerful new property graph analysis feature to address graph use cases, including making recommendations, finding communities and influencers, pattern matching, and identifying fraud and other anomalies.

A unique, general-purpose property graph capability is introduced in Oracle Spatial and Graph 12c Release 2 on Oracle Cloud. Current industry offerings tend to focus on providing either analytics or a graph database. Oracle Spatial and Graph is unique in that it has both: a powerful in-memory analyst with many more built-in analytics (40) than other offerings and a scalable graph database. This is a game-changing feature because much of the Big Data generated these days contains inherent relationships between the collected data entities. These relationships can be easily structured as a property graph – a set of connected entities, and analyzed to find opportunities and make better business decisions. The property graph models entities as vertices, relationships as edges, and stores associated properties or attributes as key-value pairs for both.

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 geocoding, a routing engine, and spatial web services conformant with Open Geospatial Consortium (OGC) and ISO standards. Support for advanced spatial models and types



include a network data model, georaster (for geo-referenced imagery and gridded data), topology, 3D, including triangulated irregular networks (TINs) and point clouds (supporting LIDAR data), and linear referencing. These advanced features provide a complete platform for geospatial applications in many domains, including defense, land management retail, insurance, and finance.

With Oracle Database 12c Release 2 on Oracle Cloud, spatial operations are faster, cloud-ready and more developer friendly. With GeoJSON support, a location tracking service to track millions of objects against thousands of regions, more accelerated spatial functions, and an interactive HTML5 map visualization component, it is the most advanced spatial platform Oracle has ever offered.

Oracle Spatial and Graph also provides a mature, special purpose RDF graph conforming to World Wide Web Consortium standards. It provides parallelized RDF data storage, querying and inferencing that is used in a semantic data integration and linked open data applications. Oracle Spatial and Graph RDF support has become the industry's leading open, scalable, and secure RDF database. New features include SPARQL 1.1 Update operations, an RDF ORDER BY query option, property graph integration, a function that translates a SPARQL query to SQL, more SPARQL Query functions and Oracle Flashback Query support.

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 reduce application logic and support real world analysis by moving complex spatial and graph logic into the database. The processing power and bandwidth of Oracle Exadata Database Machine is exploited, realizing extreme performance capabilities that are orders of magnitude over what was previously possible.

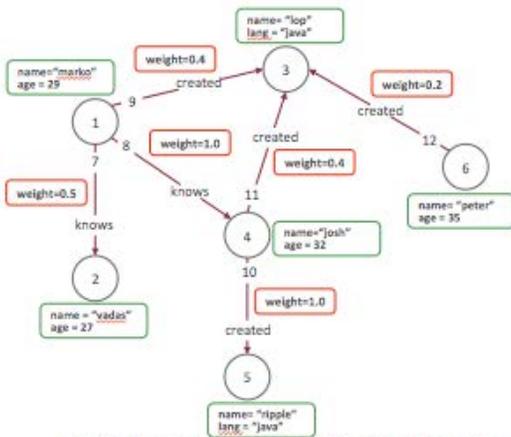
This white paper provides an overview of the features in Oracle Spatial and Graph. The appendices list major and new features. Please refer to the Oracle Spatial and Graph Spatial Developer's Guide, Appendix B for the list of spatial features found in Oracle Database and in the Oracle Spatial and Graph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

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.

Property Graph Overview

General-purpose property graph support is introduced in Oracle Spatial and Graph 12c Release 2 on Oracle Cloud. Much of the Big Data generated these days contains inherent relationships between the collected data entities. These relationships can be easily structured as a property graph – a set of connected entities. The property graph vertices denote entities, the edges denote relationships, and the associated properties or attributes are stored as key-value pairs for both.

The Property Graph Data Model

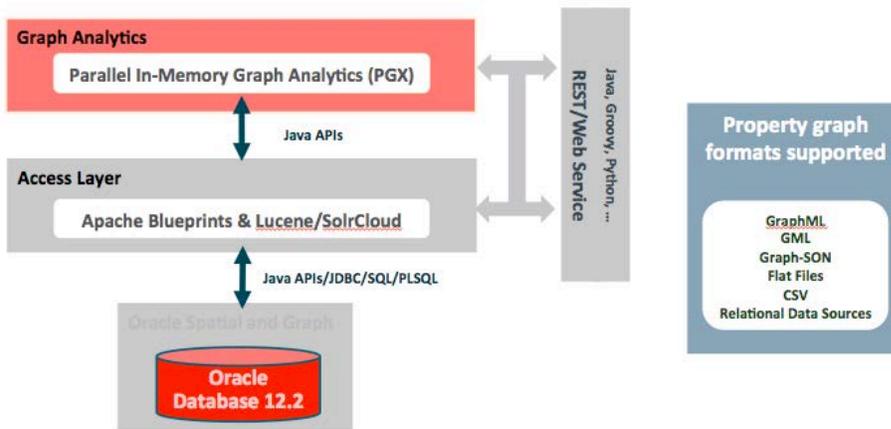


<https://github.com/tinkerpop/blueprints/wiki/Property-Graph-Model>

- A set of vertices (or nodes)
 - each vertex has a unique identifier.
 - each vertex has a set of in/out edges.
 - each vertex has a collection of **key-value** properties.
- A set of edges (or links)
 - each edge has a unique identifier.
 - each edge has a head/tail vertex.
 - each edge has a label denoting type of relationship between two vertices.
 - each edge has a collection of **key-value** properties.

Property graph data model

The major capabilities are the in-memory analyst and the data access layer. The in-memory analyst (PGX) is the engine for 40 built-in, powerful, parallel graph analytics. The graph database data access layer includes a Groovy-based console, Java APIs, fast search through text indexing, fast, parallel bulk loading, spatial filtering in graph queries and multi-level security.

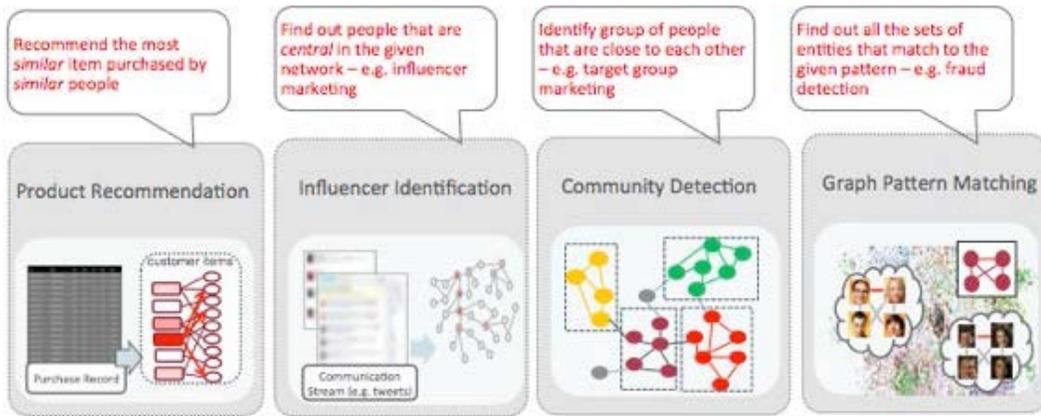


Property graph architecture

Graph analytics

Graph analytics are powered by the in-memory analyst (PGX) with 40 built-in, powerful, parallel, in-memory analytics, including ranking, centrality, recommendation, community detection, and path finding for social network analysis.

Graph Analysis in Business



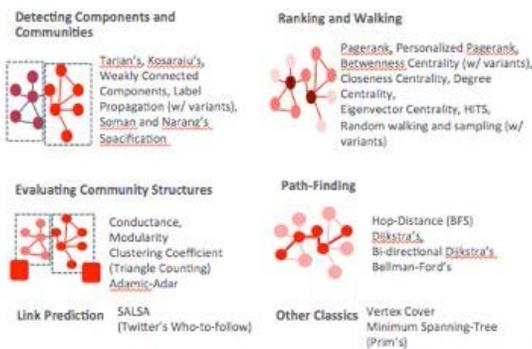
Example property graph use cases

The in-memory analyst takes advantage of modern server architecture that parallelizes computation using multiple cores and sizeable memory configurations that enable fast non-sequential data access across a larger portion of a graph read into memory. A parallelized filter query on the database reads a subgraph of interest into memory.

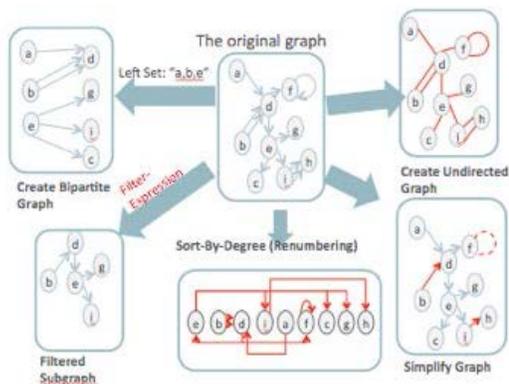
The analytics can either be executed within a Java application or executed in the multi-user, multi-graph in-memory analyst server environment on Oracle WebLogic Server, Apache Tomcat or Eclipse Jetty. The output of graph analysis can be another graph, such as a bipartite, filtered, undirected, sorted or simplified edges graph.

Computational Analytics: Built-in Package

Rich set of built-in parallel graph algorithms



... and parallel graph mutation operations



Categories of analytics and types of output graphs

Ease of development and management

Ease of development and management is facilitated through a Groovy-based console and a set of Java APIs. The built-in Groovy shell provides graph database access and in-memory analyst operations. With this command-line shell interface, you can explore the feature's Java APIs to create and drop property graphs, add and remove vertices and edges, search for vertices and edges using key-value pairs, create text indexes, and perform other manipulations. The Java APIs include an implementation of the Apache TinkerPop interfaces. Support for scripting languages, such as Groovy and Python is included. Groovy scripts allow developers to test Java code snippets more easily without defining objects or compilation.

Fast and flexible querying

The property graph can be queried using Java APIs that implement Tinkerpop Gremlin APIs. The Java APIs perform parallel scans on vertices and edges. Parallel retrieval takes advantage of the distribution of the data across table partitions, so each partition is queried using a separate database connection.

A property graph can also be queried through SQL. Here is an example of querying for a vertex using a vertex ID.

This example find the vertex with vertex ID 1 in the connections graph.

```
SQL> select vid, k, v, vn, vt
      from connectionsVT$
      where vid=1;
```

The output might be as follows:

```
1 country      United States
1 name         Barack Obama
1 occupation   44th president of United States of America
...
```

Example of querying for a vertex using a vertex ID

Fast search with text indexing

Fast search is enabled through Apache Lucene and optionally Apache SolrCloud. They provide text indexing on properties for fast retrieval of vertices and edges. Native Oracle Text indexing is supported; text queries are automatically translated into SQL SELECT statements with a "contains" clause.

Apache Lucene

Text searching and indexing is enabled through Apache Lucene for queries on property graph elements. For example, if you have Twitter feeds you can query for tweets containing the word "Oracle" using usual search syntax. Both manual (selective) and auto indexing of graph elements are supported. A limitation of Apache Lucene is that its indexes can't be shared directly among users and applications.

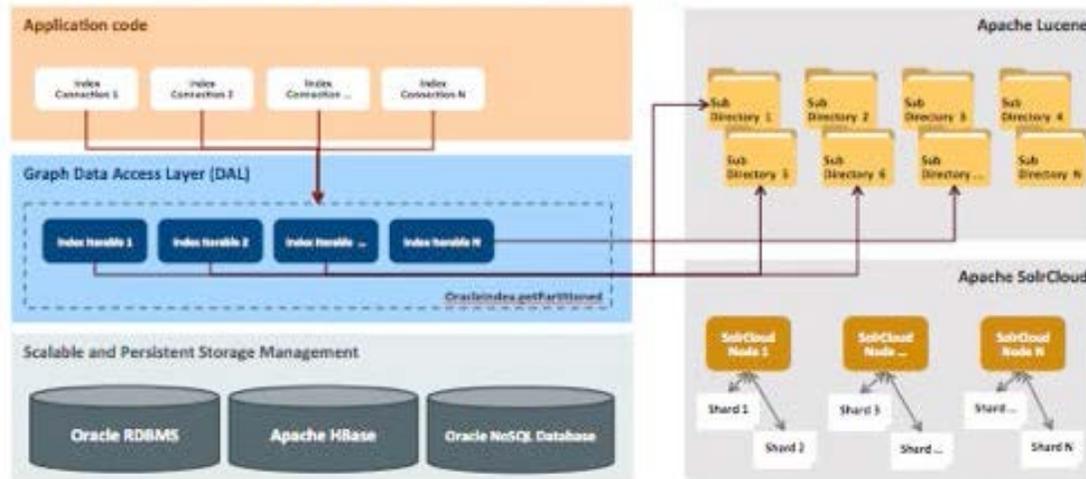
Auto index is easy to use. It is a b-tree index that is created by specifying the index name and what to index, vertices or edges. It is automatically updated as graph elements are changed.

Manual (selective) index is a more flexible manual process. Index content is determined and loaded by the developer. This provides the flexibility to choose what graph elements will be indexed, making the index more focused.

Apache SolrCloud

Faceted search is a powerful capability of SolrCloud. Multiple users and applications can share a SolrCloud index. SolrCloud is implemented with Lucene. The SolrCloud load balancer enables multiple shards on different servers with index replication. Documents are sent to the HTTP interface, sharded, and the index is replicated if that is enabled. The query coordinator transparently queries the shards and assembles the final results.

Parallel Text Query using Text Indexes



Using Apache Lucene and Apache SolrCloud

Oracle Text indexing and search

Automatic text indexing using Oracle Text is supported. Oracle Text uses standard SQL to index, search, and analyze text values stored in the property columns of the vertices and edges tables. Oracle Text indexes all the existing K/V pairs in the property graph.

Fast, parallel bulk loading

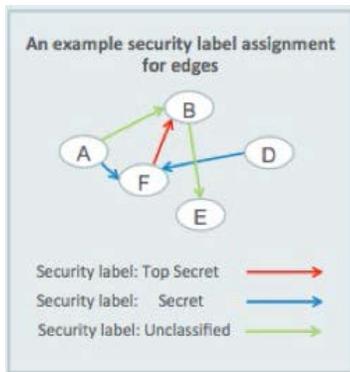
Fast, parallel bulk loading of very large graphs is accomplished with an easy to use, data type-rich Oracle flat file format and Oracle SQL*Loader. The data can be loaded into multiple database partitions. A utility is provided to easily convert Oracle tables and comma separated values (CSV) files into flat file format. The open source graph file formats GraphSON, GraphML and GML are also supported.

Spatial filtering to enhance graph analysis

Spatial filtering in graph queries can enhance graph analysis. A spatial geometry, such as coordinates for an address can be stored as a property and analyzed; for example, a “within distance” query can determine whether to consider the associated entity in further analysis. Support for point, line and polygon geometries and function-based spatial indexing, and access to spatial analytic functions make this a powerful feature.

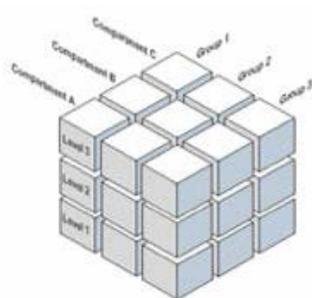
Multi-level security

Multi-level security can be enforced with graph level access control as well as optional use of the Oracle Label Security option for fine-grained access control to individual vertices and edges



Label Components:

- **Levels** – Determine the vertical sensitivity of data and the highest classification level a user can access.
- **Compartments** – Facilitate compartmentalization of data. Users need membership to a compartment to access its data.
- **Groups** – Allow hierarchical categorization of data. A user with authorization to a parent group can access data in any of its child groups.



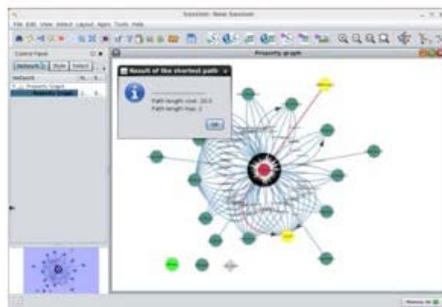
Row Label → CONF : NAVY , MILITARY : NY , DC
 User Access Label → HIGHCONF : MILITARY , NAVY , SPCLOPS : US , UK
User Access Label dominates the row label

Applying Oracle Label Security to graph elements

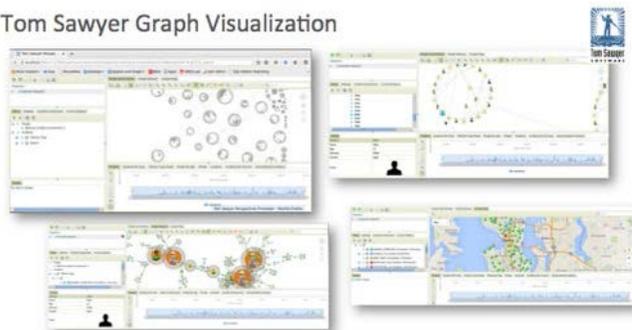
Graph visualization

The property graph feature supports open source and commercial graph visualization through Cytoscape and Tom Sawyer Perspectives, respectively.

Cytoscape Open Source Visualization



Tom Sawyer Graph Visualization



Graph visualization using Cytoscape and Tom Sawyer Perspectives

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:

```
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 leading third party GIS and image processing tool vendors. Geospatial Data Abstraction Layer (GDAL), the leading open source geospatial ETL tool and API available for raster data also supports it. GDAL natively supports importing and exporting over 50 raster formats to and from SDO_GEOASTER. 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.

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

Virtual Mosaic Support 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.

GeoRaster Enhancements for 12.2 on Oracle Cloud

In 12.2 on Oracle Cloud, GeoRaster capabilities provide further enhancements for data manageability, analytics, usability, and performance.

Native JPEG 2000 compression provides significantly better compression ratios and higher image quality. Mosaicking has been enhanced with advanced color balancing approaches; and a new set of image processing and transformations, including image dodging, filtering, warping, and affine transformation, is added. For Raster Algebra, over 25 new operators and functions enable more complex logical, mathematical, and statistical analytics. New GeoRaster core functions include faster single cell queries and DEM-based 3D surface area computation. GeoRaster performance has significantly improved with new algorithms, customizable memory control and



parallelism. GeoRaster Java API supports all server-side functions and procedures and provides a new Virtual Mosaic API. The GeoRaster ETL and the GeoRaster Viewer are now integrated into one tool for ease of deployment and use.

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.

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 view frames. 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.

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 JEE 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.

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.

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.

Oracle Spatial and Graph 12c supports additional Open Geospatial Consortium (OGC) standards. It provides an implementation of the Web Coverage Service Interface Standard (WCS), for retrieval of coverages Version 2.0.1 of WCS and many of its extensions are supported.

Catalog Services for the Web (CSW), Version 2.0.2, is also now supported. The DCMI record type is supported in this release. The previous implementation of CSW is deprecated.

A unified WFS, WCS and CSW framework and consolidated administration console are provided for easy deployment, administration, and diagnosing.

Network Data Model Graph Features Overview

Network Data Model (NDM) stores physical and logical network data structures commonly used in transportation, utilities, and oil and gas. It explicitly stores and maintains network connectivity and provides network analysis capability, including shortest path, nearest neighbors, within cost, and reachability.



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.

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.

NDM Enhancements for 12.2 on Oracle Cloud

Network Feature Editing

Network feature editing (NFE) lets you create and manage an NFE model. An NFE model extends the feature modeling capabilities by enabling you to visualize and manipulate features using Java Swing components and a PL/SQL API. You can also define features on the top of an existing network.

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.

New Spatial Features in Oracle Database 12c Release 2 on Oracle Cloud

GeoJSON Support

Oracle Spatial and Graph supports the use of GeoJSON objects to store, index, and manage geographic data that is in JSON (JavaScript Object Notation) format, directly in Oracle Database. You can convert data from JSON objects to Oracle Spatial SDO_GEOMETRY objects, and from SDO_GEOMETRY objects to JSON objects. You can use spatial operators, functions, and a special SDO_GEOMETRY method to work with GeoJSON data. If the application requires a JSON data store, GeoJSON data can be embedded into that JSON store; these JSON documents can then be spatially indexed and used in spatial queries. The GeoJSON features leverage capabilities in Oracle Database 12c to store, manage, and index JSON documents. Developers can access JSON through REST services or other APIs, and use SQL to query JSON documents, providing flexible application development and powerful SQL analytics for modern development environments.

Location Data Enrichment

Oracle Spatial and Graph includes a place name data set, with hierarchical geographical data from HERE, that you can load into the database and search using the new SDO_UTIL.GEO_SEARCH function. The data set includes commonly used textual location data such as place names, addresses and partial addresses, and latitude and longitude information.

Location tags are extracted from customer text data, matched with well known place names using Oracle Text, and enhanced with other geographic information associated with the well known place names. The results can be stored as additional attributes with the original data. This feature enables you to process less structured geographic and location data so that the information can be categorized, compared, filtered, and associated with other data. For example, data with only partial names can be enriched to include city, county, state, and country, allowing it to be



joined or analyzed with other data sets that may have state level information. This is especially useful when comparing Big Data results with structured information in operational systems and data warehouses.

Spatial Index Improvements

Spatial indexes now support all partitioning methods, including list, interval, and hash partitioning; previously, this was restricted to range partitioning. This enables improved performance.

Additionally, Spatial indexes can be system-managed. The main benefit is simplified spatial index management. This is most beneficial in cases of partitioning, because this new index type eliminates the need for most, if not all, index partitioning management operations. Full support is provided for almost all Oracle Database base table partitioning models. Customers are strongly encouraged to use this index type for all new spatial indexes created, regardless of whether the spatial table or the spatial index is partitioned.

Index Type Optimized for Point Data

Point only data sets commonly used for location services, such as moving objects, point of interest, and yellow page data, can be massive, and applications often require fast update and query performance. Performance using R-tree indexes can be challenging when large numbers of concurrent DMLs are performed on spatial tables.

A new index type, the composite B-tree index, can significantly improve the performance of spatial index creation and DML operations for large volumes of updates for point only data sets, with 20 – 30 times faster index creation, and 10 times faster updates.

Map Visualization of Geographic Data

The spatial visualization feature is an HTML5-based mash up component that allows developers who are familiar with SQL and JavaScript to incorporate a wide variety of map styles and spatial analysis into business applications. Its mapping engine visualizes data in Oracle Spatial and Graph, and allows developers to combine this data with external web services such as WMS, WFS, GeoRSS streams, and WMTS. Developers can define their own third party map tile layer using a plug-in interface, and there is support for third party GeoJSON files. Dynamic tile layers enable large data sets to be visualized in an interactive manner, with the ability to explore individual features if needed.

These capabilities, previously available in Oracle Fusion Middleware MapViewer, are now also available to Oracle Spatial and Graph users. The map visualization feature must be deployed in a JEE container or in Oracle Java Cloud Service.

Location Tracking Server

The new Oracle Spatial and Graph location tracking server enables you to define regions of interest, track the movement of objects into or out of those regions, and receive notifications when certain movements occur. As location becomes an increasingly important aspect of our lives, and as location-sensing devices become ubiquitous, there is an increasing demand for applications to be able to monitor subscriber location data continuously. The monitoring of the location data may translate into alerts being generated in the system.

For example, a trucking company may want to monitor its network of 10,000 trucks as they move along their specified routes towards their destinations. They may want to track the movement of trucks within a specified range of the route and expect notifications to be generated to detect undesirable deviations the vehicles from their desired routes. Proactive location-based services (LBSs) generalize such applications that track locations of subscribers inside or outside a specified region of interest for various purposes, such as location-based advertising and notifications about friends nearby.



The Oracle Spatial and Graph location tracking server provides a simple framework for setting up a location tracking network within the database through a PL/SQL interface. An API is provided for continuous location monitoring of objects within a tracking network. A queuing mechanism handles incoming location updates and tracking requests and for outgoing relevant notifications, using Oracle Advanced Queuing. This delivers efficient, continuous location monitoring for thousands of relevant objects within the database.

RDF Semantic Graph Features Overview

The RDF Semantic Graph feature of Oracle Spatial and Graph is a special purpose graph for linked data and semantic web applications conforming to 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.

Storing, Loading, and Data Manipulation

RDF Semantic Graph has proven scalability to over one trillion triples (LUBM benchmark). 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. 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.

RDF Semantic Graph Enhancements for 12.2 on Oracle Cloud

You can now perform SPARQL Update operations on a semantic model. The W3C SPARQL 1.1 Update is supported in Oracle Database semantic technologies through the new SEM_APIS.UPDATE_MODEL procedure. Integration with property graphs is enabled by RDF views on property graph data for SPARQL queries and property graph views on RDF data for property graph social network analytics. Queries on RDF data that use SPARQL ORDER BY semantics can use the ORDER_TYPE, ORDER_NUM, and ORDER_DATE columns in the MDSYS.RDF_VALUE\$ metadata table for more efficient operations. Specifying the DISABLE_ORDER_COL option in the SEM_MATCH query can disable this capability. A New SEM_APIS.SPARQL_TO_SQL function enables SQL translation and execution of a SPARQL query. New SPARQL Query functions are provided: orardf:like, orardf:sameCanonTerm, orardf:textScore. Integration with Oracle Flashback Query is now supported.



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.

Property Graph supports multiple open source Apache projects, including Tinkerpop, Lucene, SolrCloud, Groovy and Tomcat, as well as other open source, such as Eclipse Jetty, Python, and file formats GraphSON, GraphML and GML.

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 framework, Apache Jena, 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

Spatial and graph analysis is about understanding relationships. The emergence of Internet of Things, Cloud services, mobile tracking, social media, and real time systems create new challenges to manage the volume of data, but more importantly, to discover patterns, connections, and relationships. To address these opportunities, the Oracle Spatial and Graph option for Oracle Database 12c includes a wide range of spatial analysis functions and services to evaluate data based on distance, and proximity, and to visualize geospatial patterns on maps and imagery. Also, with Oracle Database 12c Release 2 on Oracle Cloud, a powerful new general purpose property graph feature is available to analyze inherent relationships between collected data entities for a variety of graph use cases, including making recommendations, finding communities and influencers, pattern matching, and identifying fraud and other anomalies.

Oracle Spatial and Graph provides advanced capabilities for Oracle Cloud and 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 graph and location 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.

New spatial features include support for GeoJSON objects to store, index, and manage geographic data that is in JSON (JavaScript Object Notation) format, directly in Oracle Database. Location data can be enriched using location tags extracted from customer text data and hierarchical geographical data from HERE. Spatial visualization using is an HTML5-based mash up component allows developers who are familiar with SQL and JavaScript to incorporate a wide variety of map styles and spatial analysis into business applications.



The special purpose RDF Semantic Graph model has new features that include supporting SPARQL Update operations, integration with property graph analytics and with Oracle Flashback Query.

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, on premises and in the cloud.

Appendix 1: Oracle Spatial and Graph 12c 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 feature modeling: automatic mapping of application objects to network elements
- » Network Data Model time modeling: Time attributes can be associated with nodes and links, and specified in network analysis queries
- » Network Data Model 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)

Appendix 2: New Features in Oracle Database 12c Release 2 on Oracle Cloud

Property Graph New Features

- » Optimized schema for storage of vertices, edges and k/v properties
- » Ease of development with Java and Tinkerpop APIs, Groovy and Python scripting, SQL queries on graph data
- » 40 powerful parallel, in-memory analytics for social network analysis
- » Analytics execute in Java or in a multi-user, multi-graph in-memory analyst server on WebLogic, Tomcat or Jetty
- » Analysis results can flow into a bipartite, filtered, undirected, sorted or simplified edge output graph
- » Fast retrieval of vertices and edges using text indexing of properties with Oracle Text, Apache Lucene, or optionally SolrCloud
- » Spatial filtering, indexing and analytic functions on spatial data in properties
- » Property graph analysis of RDF graphs using property graph views
- » Parallel bulk load with optimized Oracle flat file format, rich data types and from relational and CSV data
- » Open source formats GraphSON, GraphML and GML supported
- » Groovy management console
- » Security for graphs and graph elements

Spatial New Features

- » GeoJSON support and REST APIs: spatial data access for modern development environments
- » Location data enrichment services: API with bundled geographic hierarchy and place names data set, to search and categorize large collections of unstructured text records with location tags for analysis
- » Spatial index optimization for point data: composite B-tree indexes for improved performance on index update and creation for point only data
- » Spatial index improvements: support for all index partitioning methods and system managed indexes for improved performance and simplified management
- » Map visualization: HTML5-based mash up component for spatial visualization of geographic data in Oracle Spatial and Graph or from external services. (Must be deployed in a JEE container or in Oracle Java Cloud Service)
- » Location tracking server tracks the movement of objects in and out of regions of interest on a massive scale for logistics and IOT

- 
- » Spatial Web Services supports OGC Web Coverage Service (WCS) 2.0.1 and Catalog Services for the Web (CSW) 2.0.2
 - » Spatial Web Services: provides a unified WFS, WCS and CSW framework and consolidated administration console
 - » GeoRaster compression: native JPEG 2000 compression support
 - » GeoRaster mosaic: advanced color balancing for mosaicking
 - » GeoRaster image processing: more processing and transformation operations
 - » GeoRaster raster algebra: over 25 new operators and functions
 - » GeoRaster Java APIs: all new server-side functions and procedures.
 - » GeoRaster improved performance with new algorithms, customizable memory control and parallelism
 - » GeoRaster ETL wizard and the GeoRaster Viewer are enhanced and integrated into one tool
 - » Network Data Model feature editing model: extends feature modeling capabilities – visualize and manipulate features using Java Swing components and a PL/SQL API, and define features on top of an existing network

RDF Semantic Graph New Features

- » SPARQL 1.1 Update operations and RDF ORDER BY query option
- » RDF views on property graph data and Property graph views on RDF data
- » SEM_APIS.SPARQL_TO_SQL function for SQL translation of a SPARQL query
- » SPARQL Query orardf functions like, sameCanonTerm, textScore
- » Oracle Flashback Query support



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Integrated Cloud Applications & Platform Services

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