I. Introduction
In recent years laser scanning and terrestrial imaging have enabled the collection of large amounts of LiDAR (Light Detection and Ranging) data. New laser scanning equipment made it easier to acquire 3-D representations of real world entities as high-density point clouds, which may then be generalized to compact forms such as TINs, meshes, surfaces and solids. Increasing LiDAR densities bring new data management challenges for large volumes of point data. Lag time from acquisition to analysis, metadata access and management, fusion with other geospatial and attribute data, multi-user access and security are some of the challenges in managing large scale LiDAR data. Scaling to the sizes of such large point data sets is becoming increasingly impossible for desktop applications. This paper focuses on the high-performance storage, loading and visualization of SDO_PC (Point Cloud) type in 3-D Spatial Engine.

II. Storage model of SDO_PC Type
Oracle Spatial introduces a new data type called SDO_PC to manage very large volumes of data generated by LiDAR scans. The data generated from LiDAR scans is usually called Point Cloud data and SDO_PC type is designed to efficiently manage such point cloud data. Users can store up to $4 \cdot 10^{18}$ points in a single point cloud object in Oracle. Partitioning the points into fixed-size blocks and storing the blocks as rows in a separate block table achieves this scalable storage. Figure 1 shows the storage schematic for the point cloud.

As shown in Figure 1, only the metadata, such as the block capacity, the total number of dimensions (at least 3: x, y, z and usually more, e.g., color), and the block table information is stored in the SDO_PC column. The data points themselves are partitioned into subsets (using spatial partitioning techniques), each subset being stored in the points column of the associated block table. Note that the blk_extent column stores the extent of each subset and is spatially indexed. This blk_extent column allows for efficient query processing in a 2-stage filter processing as discussed in Section III. The Max_res, Min_res columns allow point clouds to be stored in multiple resolutions. Such multi-resolution point clouds are useful in some applications that need to access them based on proximity to a viewpoint (closer for higher resolution and farther for less detail). This partitioned or blocked storage of a point cloud ensures scalability.
**III. Queries on SDO_PC Objects**

Oracle provides a clip PL/SQL query on the SDO_PC type. This query takes a *spatial window* (specified as an SDO_GEOMETRY) and identifies all points that have any interaction with the spatial window. In addition to the spatial window, the query also takes a resolution range to identify only those blocks that satisfy the resolution range. This type of query is typically called a resolution-based visibility query and we refer to this as the clip operation. To restrict the scope of the discussion, we refer to the spatial window as the “query” in the rest of the section, ignoring any resolution range portions of the query. As shown earlier in Figure 1, a point cloud is stored as multiple rows in an associated block table, each row containing a *blk_extent* column of type SDO_GEOMETRY to represent the extent of the points in that row. This *blk_extent* is implicitly indexed with an Oracle R-tree index. Using such an index, the CLIP query on an SDO_PC is processed in 2-stages as shown in Figure 2.

![Fig. 2. 2-Stage Query Processing on a Point Cloud.](image)

1. **First-stage**: Using the spatial index on the *blk_extent*, the query identifies all the relevant blocks of a point cloud.
2. **Second-stage**: For each relevant block for the query (identified in first-stage), the associated points are retrieved. Typically the number of such points in a block is of the order of thousands or tens of thousands (typical block capacity). These points are compared with the query geometry using the *anyinteract* function. The intersecting points (and/or triangles) are returned as part of the result of the CLIP routine.

**IV. Visualization of SDO_PC Objects**

For the purpose of visualization, we use pyramiding, to focus on just a representative subset of points. The entire set of points intersecting with a view frustum may be excessive, and visually redundant.

**V. Pyramiding**

Originally, the entire point set in a point cloud is spatially clustered and indexed, using the Oracle R-tree. We may consider these “original blocks” a single “level of detail”. Any spatial query on the original blocks will return all intersecting points, usually many millions.

To add pyramiding, we generate additional levels of detail $1, \cdots, n$, with level 1 being least-detailed. To avoid repetition, the “pyramid blocks” store each point from the original blocks, exactly once. Thus, the pyramid blocks repeat points from the original blocks, but there is no internal repetition, within the pyramid. A visualization app will only read pyramid blocks of the appropriate level of detail, but never the original blocks.

Generally, any block at level $i$ “summarizes” multiple blocks at level $i + 1$, thus covering their spatial extent union. There is, thus, an implicit tree structure, within the pyramid.

The generation of the pyramid can be massively parallel: at any level of detail $i$, the blocks can be generated, independently from its neighbors, contingent only on its child nodes.
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