Multi-dimensional Spatial Data Structures

Lecture delivered by:

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Session Objectives

• To understand the requirement and areas of application for multi-dimensional spatial data structures
• To understand methods of dividing spacial data structures
• To understand the construction of Quad Trees and R-Trees
• To know the basic operations performed on Quad Trees and R-Trees
Multi-dimensional Data Structures

Definition
– The most common definition of multi-dimensional data is a collection of points in a higher dimension
– Records
  • Heterogeneous
    – For example: Database of employee details
  • Homogeneous
    – For example: Location
      » X,Y,Z
    – Special case of spatial data
      » Spans a continuous physical space
      » Roads (linear), Lakes (Regions), Buildings on maps (Rectangular), Terrains (surfaces)
Buckets and Bucketing Method

• Buckets
  – Region of space containing more than one elements
  – An area of interest in space

• Grids
  • Divide space into chunks based on attribute values
    • Uniform period of attributes
      • Called “Uniform Grid”
  • Divide based on point density
Quad Tree

- Represents 2-D spacial data
- Recursively splitting space
  - Based on node element
  - Four quadrants
    - South Weast
    - North Weast
    - South East
    - North East
- For 8 way split
  - Octree
- For 3D: Hyperoctree
Building a Point Quad Tree

- Insert in the order of input nodes
- Based on the direction of inserted node on the grid from current node, insert in that quadrent
Operations on Point Quad Tree

• Insert a point
  – Conduct search
  – Insert at null leaf

• Delete a point
  – Find a point that can take it's place
    • This involves a lot of effort
  – Find the point to be deleted
  – Delete the node by replacing the selected vertex

• As these trees are inefficient when compared with other data structures such as k-d trees, they are not used much
Building a Region Quad Tree

- Surround the area into square cells
- Divide the cell into quadrants
- Check if all points are in separate quadrant or if empty
- If not, repeat steps 1-3 till all points are in separate quadrants
Building a Region Quad Tree

- Map the points from origin of first rectangle
Operations on Region Quad Tree

• A point can be considered as a zero area cell
• Operations
  – Query for a cell
    • Search by traversal
  – Insertion of a cell
    • Find if the area of cell is represented in the quad tree
    • Traverse from root to null leaf
    • If parent is cell and leaf present, split parent cell and insert else insert as a leaf
Operations on Region Quad Tree

• Operations
  – Deletion of a cell
    • Only done on leaf nodes
    • Find the cell in the quad tree
    • Remove the cell
    • If parent has only one child, remove parent and replace it with remaining child
Operations on Region Quad Tree

• Operations
  – Range query
    • (Databases – query with multiple key ranges)
  • Method
    – Start with empty set as answer
    – If node in quad tree is completely within the range
      » Copy to answer set
    – If it is completely outside, discard it
    – If it is overlapping, evaluate it's children
Operations on Region Quad Tree

• Operations
  – Group Query (Spherical region query as example)
    • Find all points that are in 10kms of bangalore
    • Start at root node, for every cell
      – Move down if part of the node is within the range (UNKNOWN)
      – Add entire tree of points rooted at current node if all the points satisfy (PROCESSED)
        » Farthest and Closest distances within cell are in range
      – Discard node if no point is in range
Building an R Tree
Building an R Tree

- Start by covering the entire area in one rectangle
- Now, try to encompass maximum sub regions (lines) and refine until leaves can contain the objects
- Remember each node can contain \((m<=\text{Ceil}(M/2), M)\) elements
- Here \(m=2\) and \(M=3\). Hence, it is \((2,3)\) R tree
Operations on R Tree

- **Insertion**
  - Add to leaf node
  - If there is a overflow, split and propagate split up to root node if needed

- **Deletion**
  - Delete node
  - Move leaf nodes to balance requirements

- **Query**
  - Bounds of region are known
  - Search as per matching limits
Areas of Application

- Computer Graphics
  - For Example: 3D model representation
- Data Bases
  - For Example: Oralce
- Image Processing
  - For Example: Face Recognition
- Geographic Information Systems
  - For Example: Highway Construction Planning
Summary

• Multi-dimensional spatial data structures are used in many areas ranging from databases to robotics

• Dividing space into regions based on attribute ranges is known as bucketing

• Buckets are collections of points in a higher dimension

• Space can be divided into uniform grid of cells or set of overlapping regions
Summary

• There are two types of Quad Trees: Point Quad Tree and Region Quad Tree
• Quad trees can help in operations such as range queries and group queries such as in databases
• R-Trees attempt to fit spatial points in best fitting rectangle