SPATIAL INDEXING

Vaibhav Bajpai

Contents

Overview

* What is a Spatial Data?
* Who requires Spatial Data?
* What are types of Spatial Data?
* What are types of Spatial Data Queries?
* Spatial Databases and their Applications

Overview

What is Spatial Data?

* Information representing geometry - location - topology
* 2d - Planar | Surface
* 3D - Volumetric
* 4D - Spatio-Temporal

```
CREATE TABLE CITY (
   NAME         VARCHAR(30),
   POPULATION    INTEGER,
   CITY_PARKS    VARCHAR(30) ARRAY[10],
   LOCATION     ST_GEOMETRY )
```

We can determine the area of San Francisco by executing a query like this:

```
SELECT location.area
FROM CITY
WHERE name = 'San Francisco'
```

Overview

Who requires Spatial Data?

* Local Governments: City Planning | Traffic Management | Accident Investigation
* State | Provincial Governments: Highway Planning | Natural Resource Management
* National Governments: Defense | Border Control
* Extractive Industries: Mineral | Water Location
* Farming: Plot Allocation

Overview

What are types of Spatial Data?

* Point Data
    * Points in m-Dimensional space.
    * No Space | No Area | No Volume.
    * Raster Point Data: Each Pixel with added measured value
* Region Data
    * Objects having a spatial extent.
    * Location: A fixed point [Centroid]
    * Boundary: A geometric approximation [Vector Data] constructed using Polygons

Overview

What are types of Spatial Data Queries?

* Point Queries
* Spatial-Range Queries
* Nearest-Neighbor Queries
* Spatial-Join Queries *expensive*
* Similarity Queries

Overview

Spatial Databases

* normal databases understand numeric | character types.
* need to make them understand geometry and features
* *SimpleFeatures* specification by OGC
    * Point | LineString | Polygon | Multipoint | Multipolygon

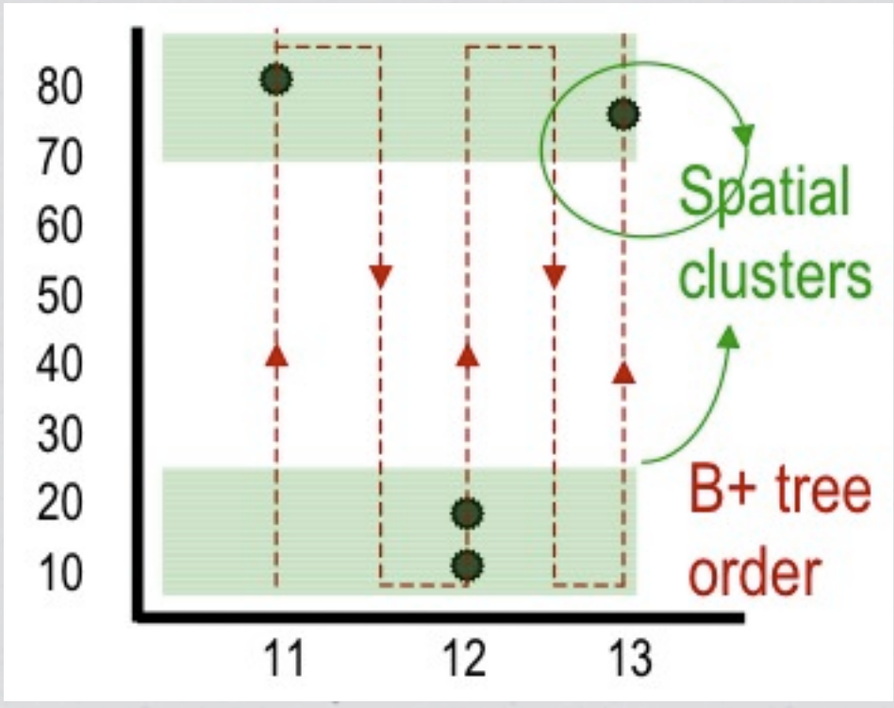
Problem with B+ Trees in Spatial Domain

* Approaches to Adapt to Spatial Domain -
    * Composite B+ Trees
    * Multiple B+ Trees

Problem with B+ Trees in Spatial Domain

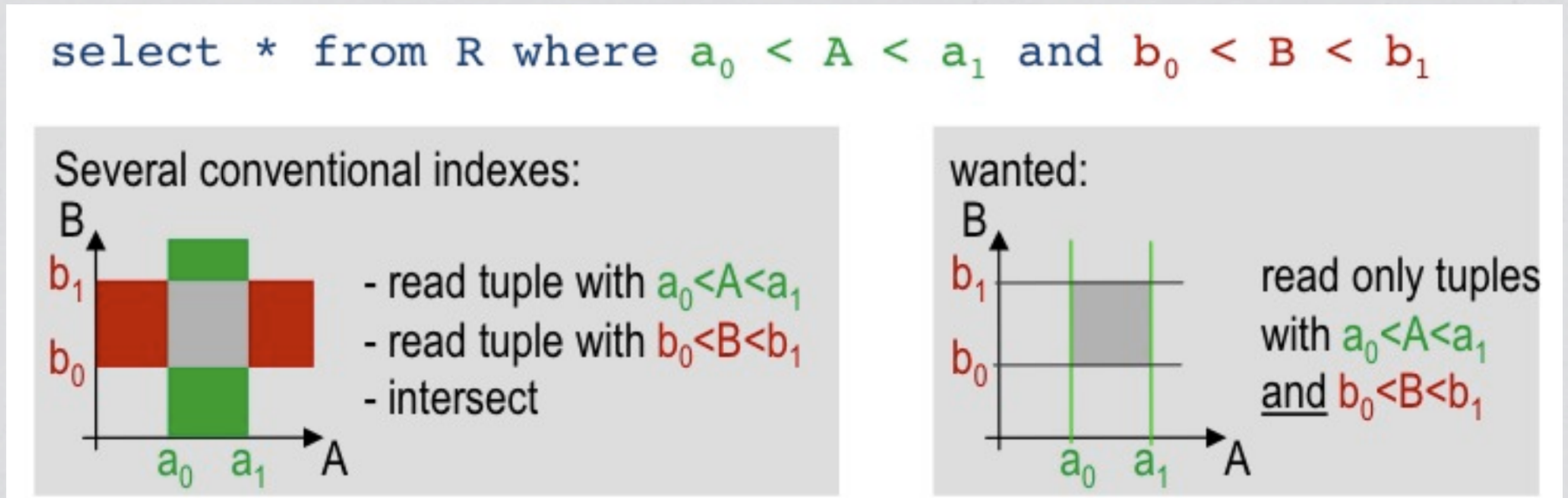
Composite B+ Trees

* It linearizes 2D space
* [-] Spatial Proximity is lost.
  * Close in nature => Close on Disk



Problem with B+ Trees in Spatial Domain

Multiple B+ Trees



* [-] Selects too much un-needed data
* [-] Index space grows with increasing dimensions

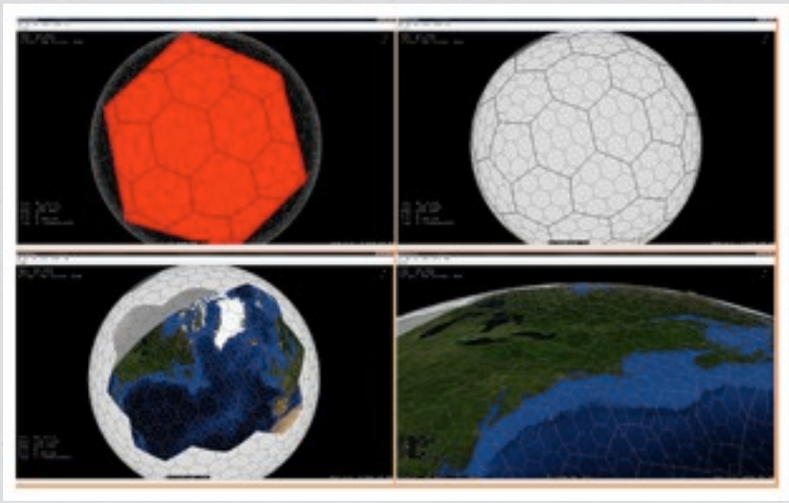
Requirements from a Spatial Indexing Structure

* Should be scalable to n-Dimensions
* Should have symmetric behavior in all Dimensions
* Should support Insert | Delete gracefully
* Should support non-point data

Approaches

* GRIDs
* Quad Trees
* Z-Curves
* X-Trees
* GiST
* R-Trees *popular*

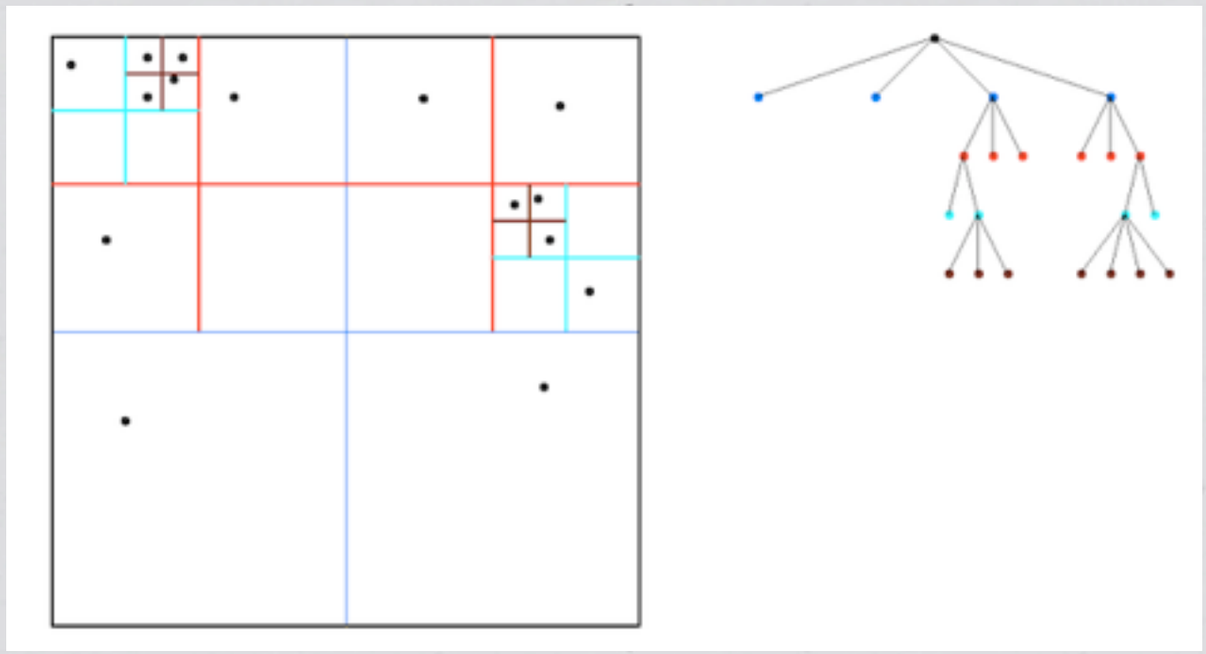
Approaches
GRIDs



* 2D surface divided into contiguous cells
* each cell is assigned unique ID and used for indexing
* *Equal Angle GRIDs*
* *Equal Area GRIDs*
* based on *Space Driven Indexing Method*

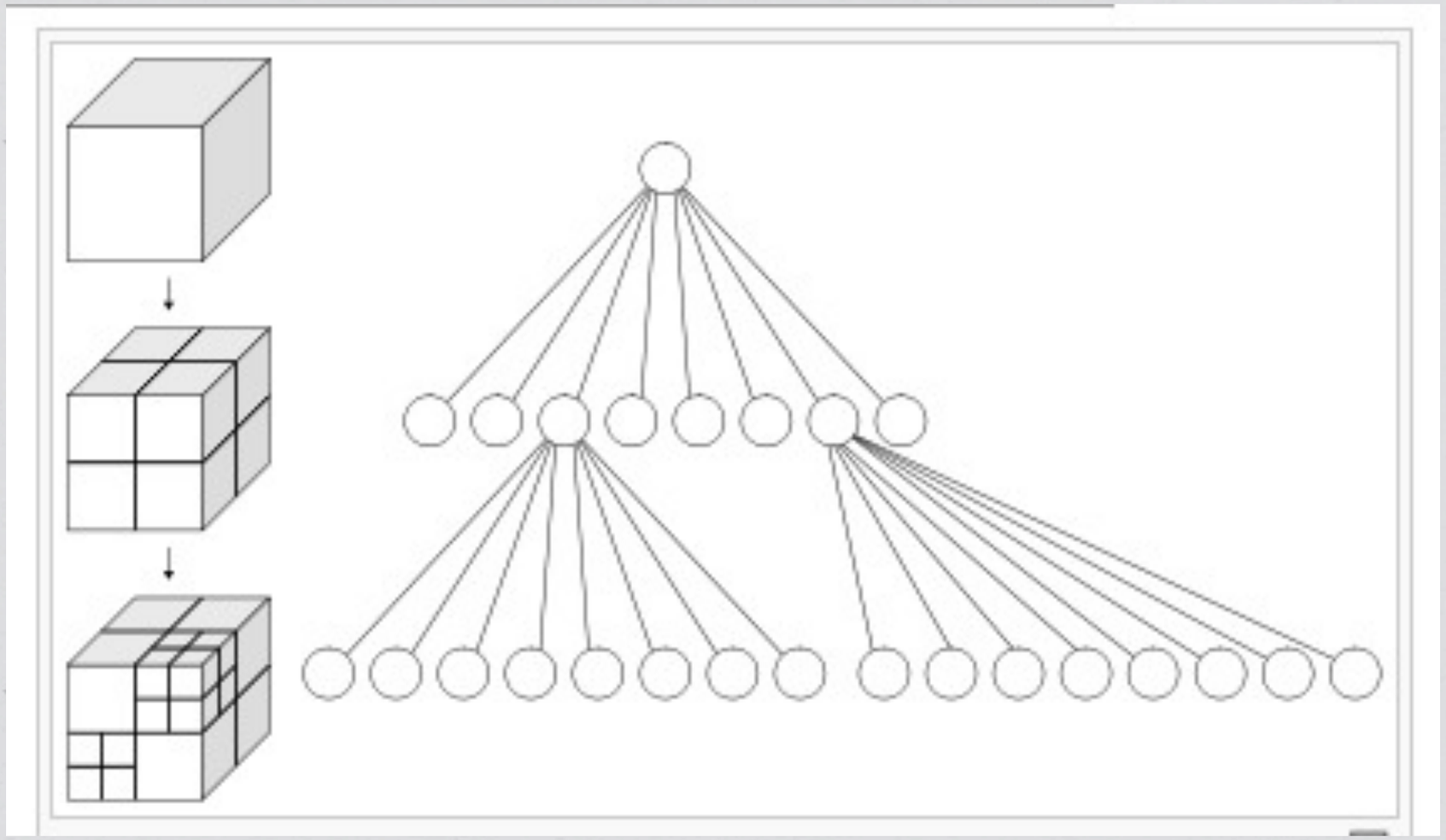
Approaches
Quad Trees

* Region-Based Quad Trees
* Point-Based Quad Trees



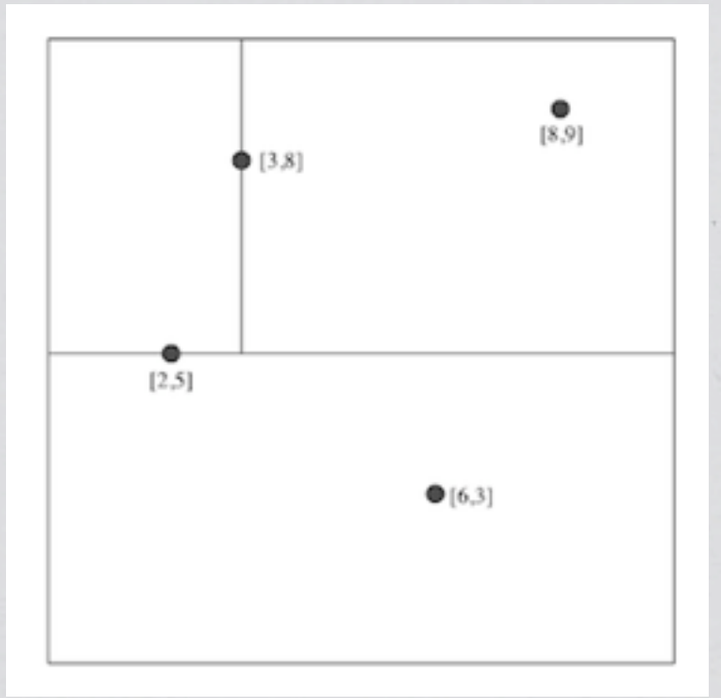
Approaches

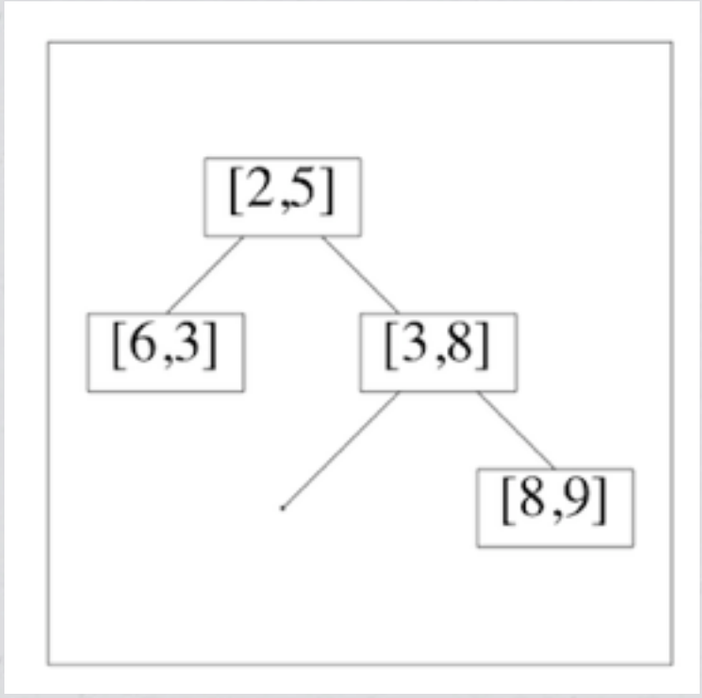
Quad Trees: Oct Trees



Approaches

Quad Trees: kD Trees





* Always Binary
* Always split along a point

Approaches
Z-Curves

y: \ x:	0 000	1 001	2 010	3 011	4 100	5 101	6 110	7 111
0 000	000000	000001	000100	000101	010000	010001	010100	010101
1 001	000010	000011	000110	000111	010010	010011	010110	010111
2 010	001000	001001	001100	001101	011000	011001	011100	011101
3 011	001010	001011	001110	001111	011010	011011	011110	011111
4 100	100000	100001	100100	100101	110000	110001	110100	110101
5 101	100010	100011	100110	100111	110010	110011	110110	110111
6 110	101000	101001	101100	101101	111000	111001	111100	111101
7 111	101010	101011	101110	101111	111010	111011	111110	111111

* A space-filling curve
* Good locality-preserving behavior
* Z-value is interleaved the binary representation of coord values
* UB-Tree: B+Tree with records stored in Z-Order

Approaches
X-Trees

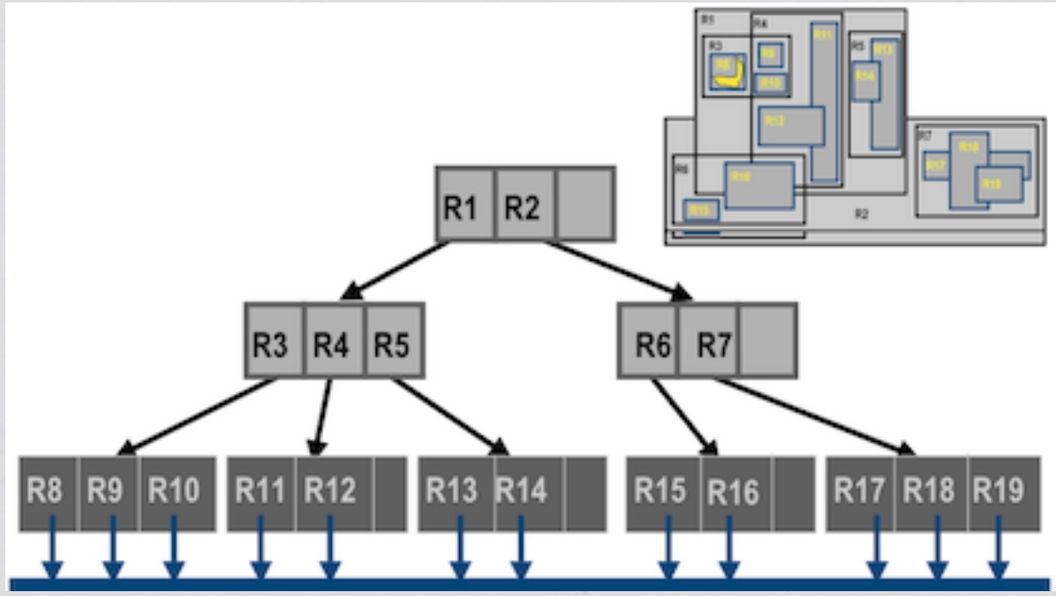
* Improves upon the R* Tree

* Provides a *overlap free* split and *supernode* mechanism

Approaches
GiST

* Generalized Search Tree
* is both a data structure and an API to build upon.
* R-Trees and X-Trees are built upon using GiST.
* PostgreSQL has an off-the-shelf GiST implementation.

Approaches
R-Trees



* leaf: <n-Dim box, RID>

* non-leaf: <n-Dim box, Ptr to Child>

Approaches
R-Trees | Search

```
Current nod := root;
1.  If current node is non-leaf:
        for each entry <E, ptr>:
            if box E overlaps Q
            then search subtree identified by ptr;
2.  If current node is leaf:
        for each entry <E, rid>:
            if E overlaps Q
            then
                rid identifies an object that might overlap Q.
```

Approaches
R-Trees | Insert

```
Current node := root;
1. go down to "best-fit" leaf L
        find child whose box needs least enlargement to cover B; resolve
        ties by going to smallest-area child
2. If  best-fit leaf L has space,
   then insert entry and stop;
   Otherwise,
        split L into L1 and L2
        Adjust entry for L in its parent so that box now covers (only) L1
        Add entry (in the parent node of L) for L2
                // this step could cause parent node to recursively split
```

* Node Splitting Heuristic: min [area(L1) + area(L2)]

Approaches

R-Trees | Delete

1 search entry to be deleted

2 remove it

3 if node becomes under-full
then
delete node
re-insert remaining entries

Approaches

R-Trees | Properties

* The tree is balanced!
* Inexact Match is a good thing!
    * Match bounding boxes and exact match later.
* Good on Average-Case
* Poor in Worst-Case | Use Priority R-Tree

Approaches

R-Trees | Optimizations

* Store boxes as *Approximate Regions*
    * compact boxes
        * fast interval checking
* use *Convex Polygons*
    * reduces overlap
    * reduces complexity

Approaches

R-Trees | Variants

* R* Tree
    * minimize *box perimeter* than *box area*
        * *forced re-inserts*
* R+ Tree
    * insert objects in multiple leaves | reduces overlap
    * search now takes place a single path to leaves.

SQL/MM

* defines how to store, retrieve and process spatial data using SQL
* defines functions to convert, compare, and process this data.
* only supports up to 2D data
* commercial implementations
  * IBM DB2 Spatial Extender
  * IBM Informix Dynamic Server
  * Oracle9 Spatial Product

- SQL/MM Part 1: Framework
- SQL/MM Part 2: Full Text
- SQL/MM Part 3: Spatial
- SQL/MM Part 5: Still image
- SQL/MM Part 6: Data mining

SQL/MM

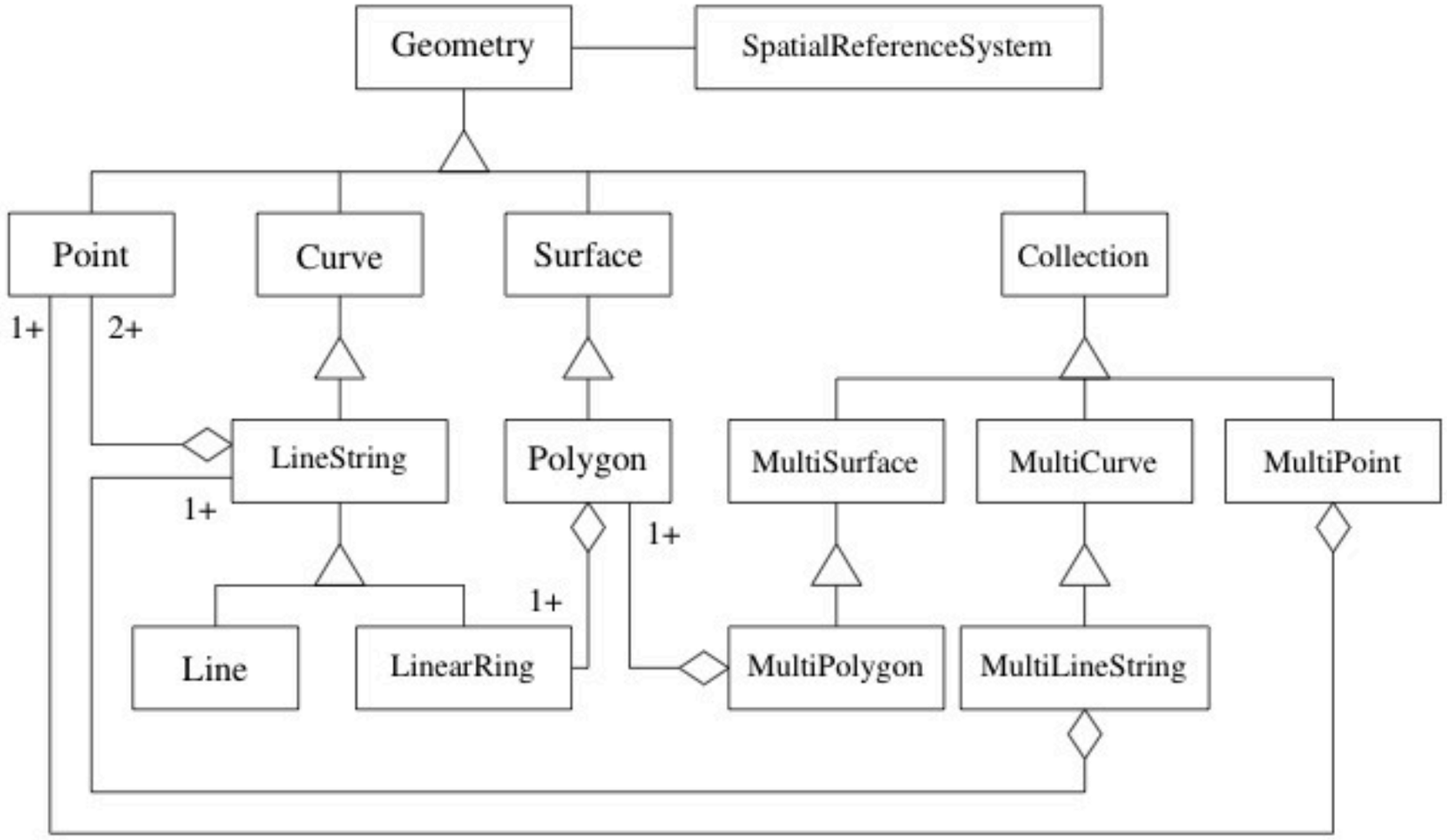


Figure 1: OpenGIS Geometry Class Hierarchy

Current Issues

* Sequential Scan > R-Tree when Dimension > 12

* Nearest Neighbor Queries are meaningful only at Low Contrast

  * need to empirically test the database