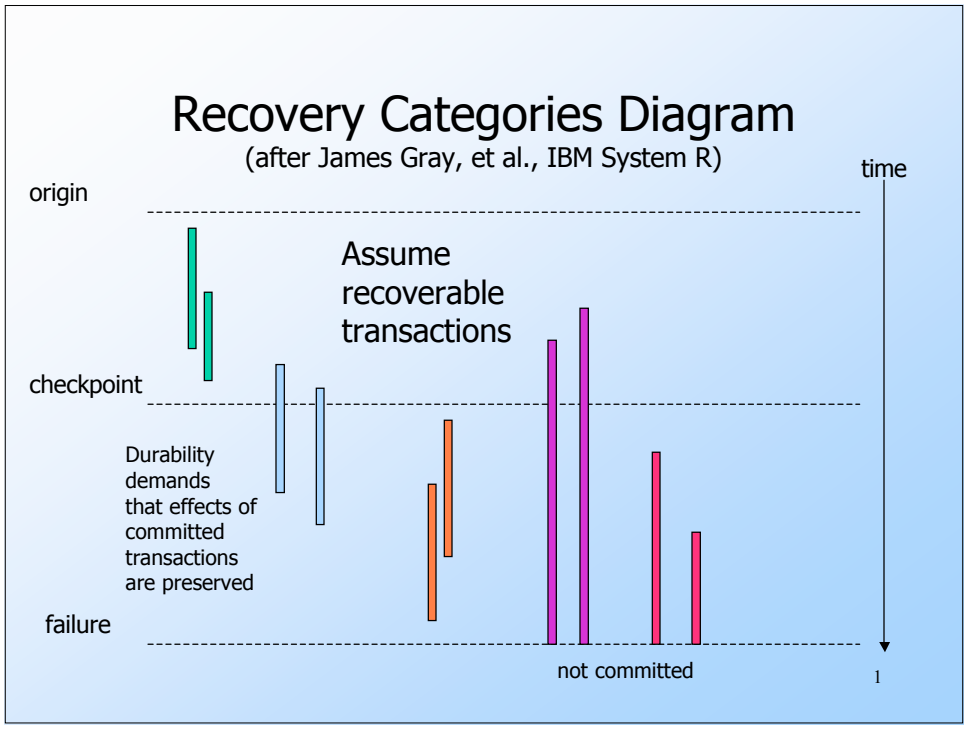
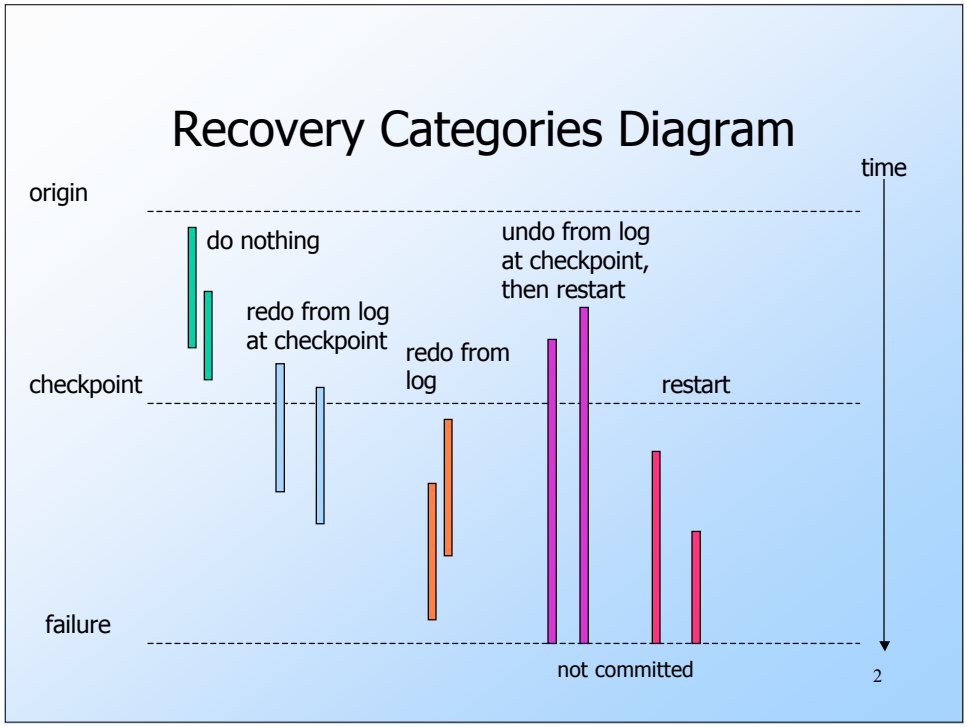
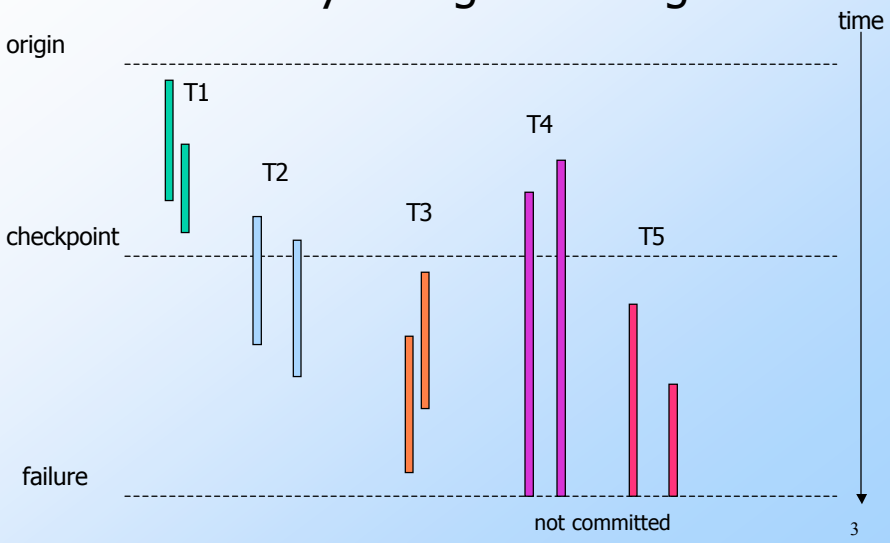

Recovery Categories Diagram
(after James Gray, et al., IBM System R)
time
origin
Assume
recoverable
transactions
checkpoint
Durability
demands
that effects of
committed
transactions
are preserved
failure
not committed
1


Recovery Categories Diagram
time
origin
do nothing
undo from log
at checkpoint,
then restart
redo from log
at checkpoint
redo from
log
checkpoint
restart
failure
not committed
2

Recovery Categories Diagram



3

From Gray, et al.

- "Restart uses the log as follows:
- It reads the most recent checkpoint record and assumes that all transactions active at the time of the checkpoint are of type T4.
- It then **reads the log in the forward direction**, starting from the checkpoint record.
  - If it encounters a BEGIN record, it notes that this is a transaction of type T5.
  - If it encounters the COMMIT record of a T4 transaction, it reclassifies the transaction to T2.
  - Similarly, T5 transactions are reclassified as T3 if a COMMIT record is encountered.
  - When it reaches the end of the log, all T2, T3, T4, and T5 transactions are known.
  - T4 and T5 are the "losers" and T2 and T3 are the "winners".

4

Gray, et al., continued

- Restart **reads the log backward** from the checkpoint, **undoing** all actions of losers.
- It then **reads the log forward** from the checkpoint, **redoing** all actions of winners.
- Once this is done, a new checkpoint is written so that the restart work will not be lost."

5

Note

- The System R approach is but one of several possibilities.
- For an anthology of papers on recovery, see:

  Kumar and Hsu, Recovery mechanisms in database systems, Prentice-Hall, 1998.

6

Spatial, Temporal, and Spatio-Temporal Databases

Robert M. Keller
Harvey Mudd College
April 2004

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Motivation

- Endowing DBMS with more application capabilities when space or time are involved.
- Can suggest a logical view of data in such applications.
- Can provide flexible querying similar to what query languages do for other data.

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Contrasts

- Databases (so far) have focused on discrete relations (e.g. the domain values and tuples are enumerable).
- Spatial and temporal databases attempt to integrate properties of space and time with discrete data.

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Contrasts

- Traditional Query:
  Who is the representative for Claremont, California?
- Spatial Query:
  Who are the representatives living west of Reno, Nevada?
- Temporal Query:
  Which representatives served during the tenure of President Clinton?

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Example of a Spatial DB Application

- Vehicular Navigation Sytem
  - Receives current position via GPS
  - Can plan a route from current position to destination, identified in a variety of different ways:
    - Enter address
    - Enter place name
    - Point to on map
    - Query database of place types, then select
  - Can display and enunciate (by voice response) directions for each intersection en route
  - Can computing remaining distance and estimated driving time

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Other Spatial Applications

- Computers: Distributed network of mobile agents
- Medicine: Human body mapped to 3-D space, for medical diagnoses
- Astronomy: Relate spatial distances to astrophysical features
- Urban planning: Relate metrics of usage areas to demographic data (which is temporal)
- Military: Battelfield management
- Politics: (detection of) Gerrymandering

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Spatial Types

- Point
- Line
- Polyline (series of points connected by lines)
- Curve (e.g. determined by equation)
- Spline (series of curves with smooth transitions
- 2-D shapes, e.g. rectangle, ellipse
- 3-D shapes, e.g. prism, polyhedron, ellipsoid
- Composite shapes
- Shapes from operators (union, intersection, subtraction)

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Spatial Relationships

- Touching, parallel
- Within (e.g. point, line, or shape within another shape)
- Relative location between items
- Distance between items
- Shortest path including certain items

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Ties with Other Areas

- Operations Research (Routing algorithms, Flow algorithms)
- Computational Geometry (Algorithms)
- AI: Constraint networks

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Early Demo Example: Chat
(Warren and Pereira)

- Implemented in Prolog
- Illustrates natural language processing as well as geographic information:
  - prolog (Quintus)
  - :- ensure_loaded(demo(chat)).
  - :- demo(_). or :- hi.

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Chat Demo

| ?- hi.
Question: Which countries border mexico?
belize, guatemala and united_states.

Question: which countries are bordered by two seas ?
egypt, iran, israel, saudi_arabia and turkey.

Question: what is the total area of countries south of the equator and not in australasia ?
10228 ksqmiles.

Question: what are the countries from which a river flows into the black_sea ?
romania and soviet_union.

Question: which country bordering the mediterranean borders a country that is bordered by a country whose population exceeds the population of india ?
turkey.

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Open Geodata Interoperability Specification (OGIS) Standard

- Consists of base-class Geometry and four sub-classes:
  - Point, Curve, Surface and GeometryCollection
- Operations fall into three categories:
  - Apply to all geometry types
    - SpatialReference, Envelope, Export,IsSimple, Boundary
  - Predicates for Topological relationships
    - Equal, Disjoint, Intersect, Touch, Cross, Within, Contains
  - Spatial Data Analysis
    - Distance,Buffer,Union, Intersection, ConvexHull, SymDiff

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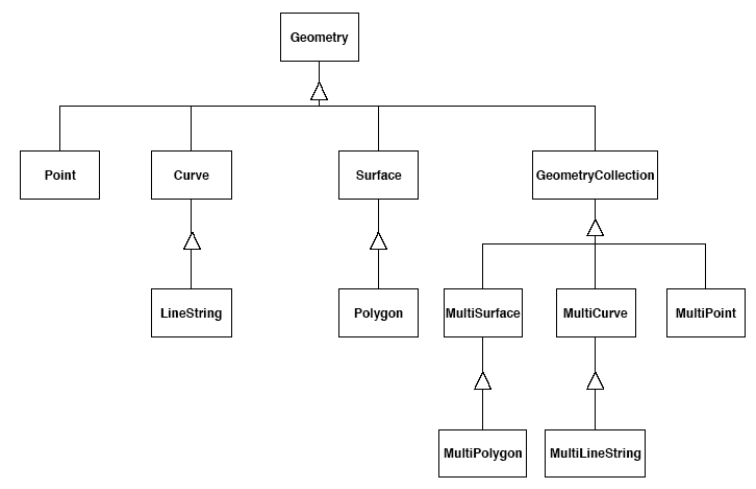
SQL/OGIS Data Type Hierarchy



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SQL/OGIS Data Examples

Geometry Type	SQL Text Literal Representation	Comment
Point	`'POINT (10 10)'`	a `Point`
LineString	`'LINESTRING ( 10 10, 20 20, 30 40)'`	a `LineString` with 3 points
Polygon	`'POLYGON ((10 10, 10 20, 20 20, 20 15, 10 10))'`	a `Polygon` with 1 exterior ring and 0 interior rings
Multipoint	`'MULTIPOINT (10 10, 20 20)'`	a `MultiPoint` with 2 point
MultiLineString	`'MULTILINESTRING ((10 10, 20 20), (15 15, 30 15))'`	a `MultiLineString` with 2 linestrings
MultiPolygon	`'MULTIPOLYGON ( ((10 10, 10 20, 20 20, 20 15, 10 10)), ((60 60, 70 70, 80 60, 60 60 ) ))'`	a `MultiPolygon` with 2 polygons
GeomCollection	`'GEOMETRYCOLLECTION (POINT (10 10), POINT (30 30), LINESTRING (15 15, 20 20))'`	a `GeometryCollection` consisting of 2 `Point` values and a `LineString` value

SQL/OGIS Functions (Examples)

`Disjoint(g1 Geometry, g2 Geometry) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. `TRUE` if the intersection of `g1` and `g2` is the empty set.
`Touches(g1 Geometry, g2 Geometry) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. `TRUE` if the only points in common between `g1` and `g2` lie in the union of the boundaries of `g1` and `g2`.
`Within(g1 Geometry, g2 Geometry) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. `TRUE` if `g1` is completely contained in `g2`.
`Overlaps(g1 Geometry, g2 Geometry) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. `TRUE` if the intersection of `g1` and `g2` results in a value of the same dimension as `g1` and `g2` that is different from both `g1` and `g2`.

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SQL/OGIS Query

(from "Spatial Databases -- A Tour")

Query: List the GDP and the distance of a country's capital city to the equator for all countries.

SELECT Co.GDP, **`Distance`**(Point(0,Ci.Shape.y),Ci.Shape) AS "Distance"
FROM Country Co,City Ci
WHERE Co.Name = Ci.Country
AND Ci.Capital ='Y '

Note: The spatial operator **`Touch`**() is used in the WHERE clause to join the Country table with itself. This query is an example of **spatial self join** operation.

Co. Name	Co. GDP	Dist-to-Eq (in Km).
Havana	16.9	2562
Washington, D.C.	8003	4324
Brasilia	1004	1756
Ottawa	658	5005
Mexico City	694.3	2161
Buenos Aires	348.2	3854

SQL/OGIS Query

(from "Spatial Databases -- A Tour")

Query: Find the names of all countries that are neighbors of the United States (USA) in the Country table.

```
SELECT C1.Name AS "Neighbors of USA"
FROM Country C1,Country C2
WHERE Touches(C1.Shape,C2.Shape)=1
AND C2.Name ='USA '
```

Note: Spatial operator **`Touches`**() is used in the WHERE clause to join the Country table with itself. This query is an example of **spatial self join** operation.

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Major Issues

- Euclidean geometry is continuous, whereas computers (and databases) are discrete.
- Simple questions, such as "Is point P on line L?" may be difficult to answer.
- The answer may depend on the approach to discretization.

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An Approach: "Realms"

(Ralf Hartmut Güting, Tutorial Spatial Database Systems)

- *Realm*
- (intuitive notion): Complete description of the geometry (all points and lines) of an application.
- *Realm*
- (formally): A finite set of points and line segments defined over a grid such that:
  - (i) each point or end point of a segment is a grid point
  - (ii) each end point of a segment is also a point of the realm
  - (iii) **no realm point lies *within* a segment**
  - (iv) any two distinct segments do neither intersect nor overlap

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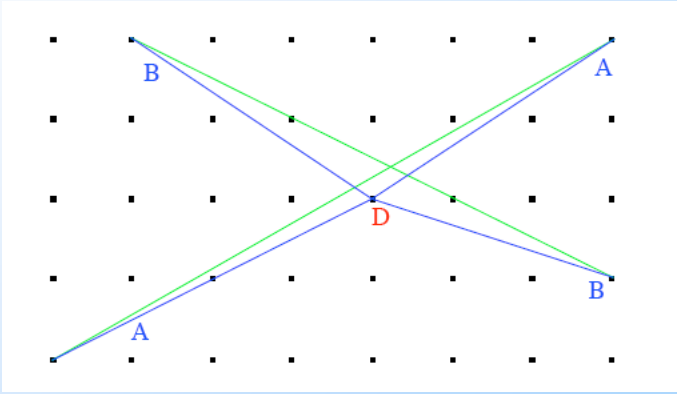
"Bending truth" to fit the Realm model

(Ralf Hartmut Güting, Tutorial Spatial Database Systems)



can lead to some anomalies.

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Disk File Organization: General (prior to refining for spatial DBs)

- Database data is typically stored on disk
- Meta-data (data describing the data is there too)
- Data stored on disk in blocks (or "sectors")
- Each block has a physical **address**
- Some blocks used for indexing other blocks
- Purpose of indexing: organize data by particular attribute (e.g. numerical attribute ⇒ index can be searched to find range of blocks of interest without looking at *all* blocks)

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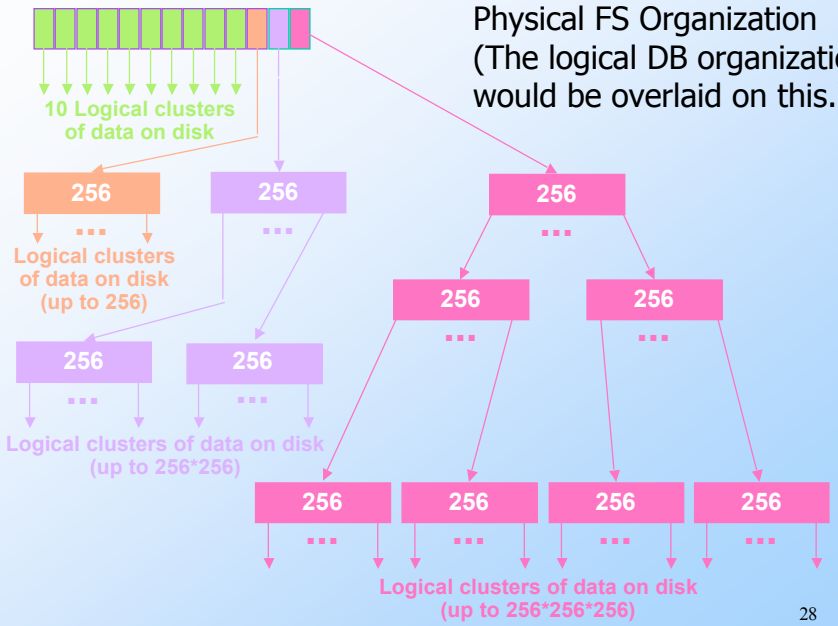
Example: UNIX Physical FS Organization (The logical DB organization would be overlaid on this.)



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Logical → Physical Indexing

- Example: Index on an integer attribute
- The index could be a table giving ranges of values and pointing to blocks where those values can be found:
  - 0-5: block 15392
  - 6: blocks 1421, 21537, 126
  - 7-100: block 17
  - 101-999: block 32174
- Given a query that requires data values in range 200-300, we would know to confine the search to block 32174
- The index itself would be stored on some block or blocks on the disk.

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Using Indexes for Joining, etc.

- For operations such as join on indexed relations, can compute the set of blocks to be examined based on commonality of indexed values.
- This is much faster than examining the entire content of each relation.

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Disk Organization for Spatial DBs

- Quad trees, oct trees, KD trees
- R trees
- Grid files
- Space-filling curves

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Quad Trees, Oct Trees

- Extension of "trie" concept
- Common in graphics, physical simulation

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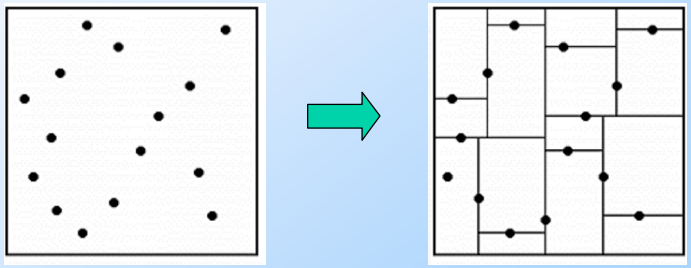
KD Trees (K = # dimensions)

- Extension of binary search tree
- Recursively bisect set of points (based on median) until each subdivision is one point.
- Useful in nearest-neighbor search and others.



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Grid Files

(Jürg Nievergelt, Hans Hinterberger, Kenneth C. Sevcik)

- Extends integer indexing idea to multiple dimensions.
- Therefore could be used for spatial data.
- Divides space non-uniformly, depending on **occupation density.**
- **Buckets** oriented toward ***physical*** implementation.
- Several **sub-divisions** may map to one bucket.

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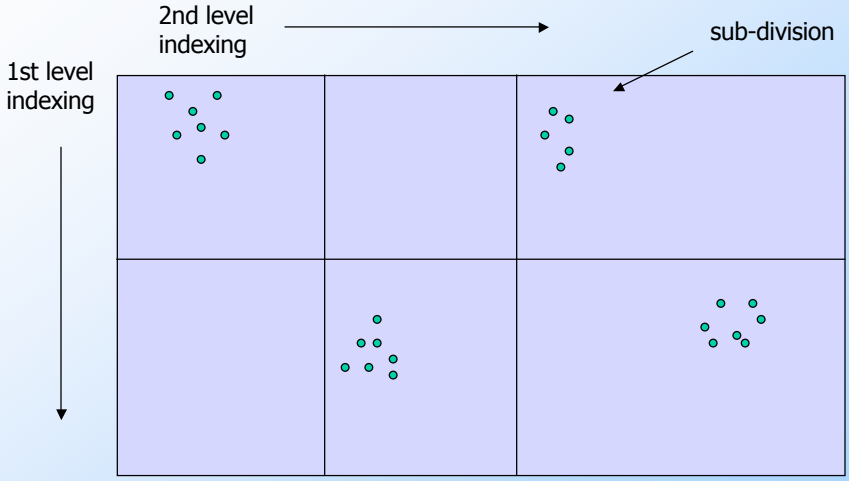
Grid File Example: 2-space



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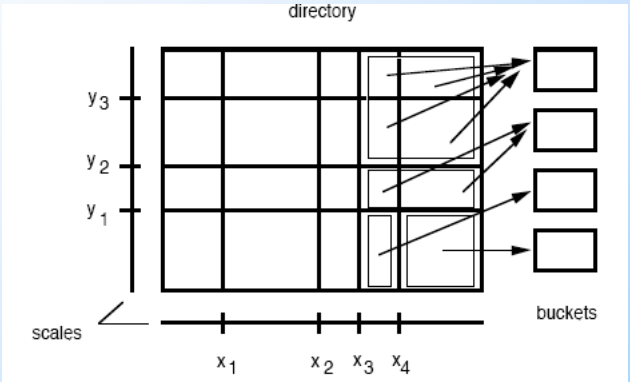
Buckets vs. Sub-Divisions



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Sub-Dividing Grid File

- Buckets depend on how many points (records/tuples) will fit in a block, not to do with the spatial distribution of records.
- When a bucket gets too large:
  - The bucket is split
  - The points are redistributed in indices

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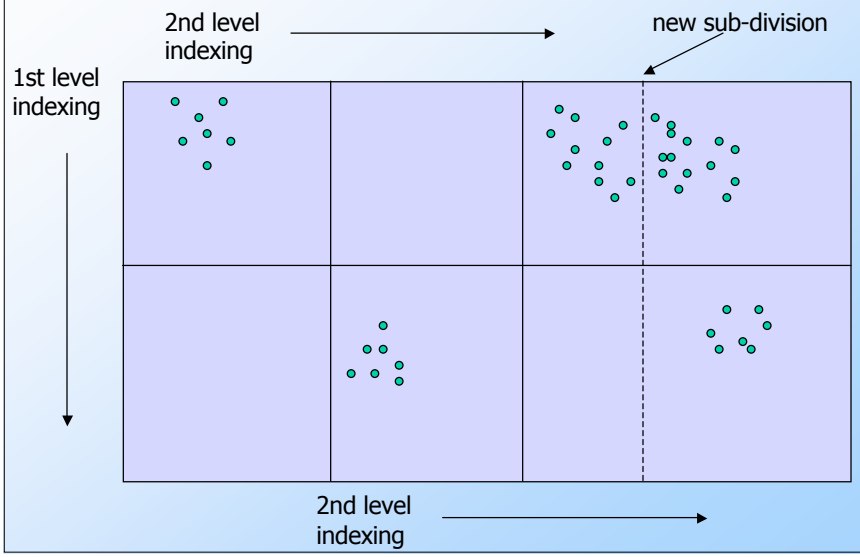
Grid File Example: Expansion



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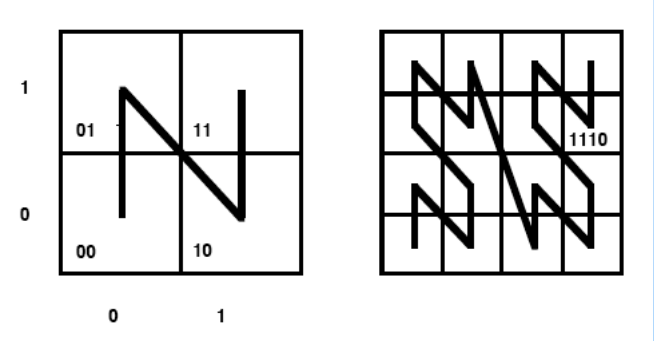
Space-Filling Curves

An application for a Mathematical Curiosity

(Ralf Hartmut Güting, Tutorial Spatial Database Systems)



"Z" model of space organization and addressing

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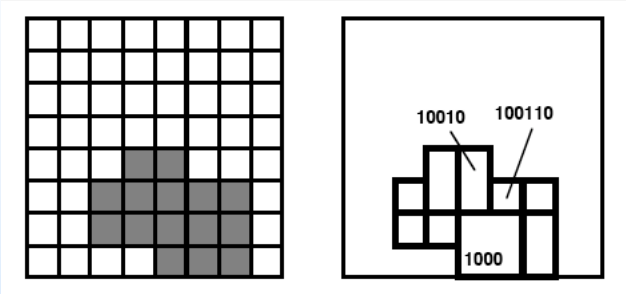
Any Shape Representable



as a string of Z indices

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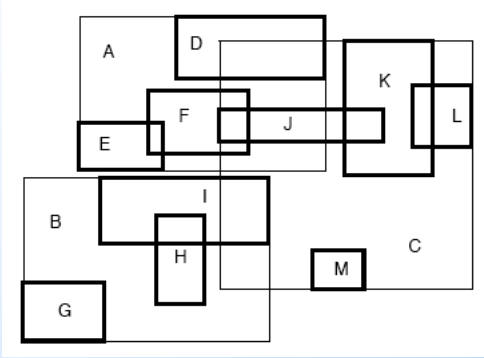
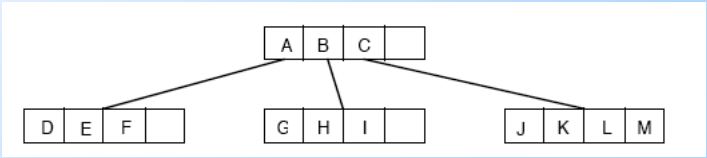
R-Trees (Region Trees)



Keep single object in one sub-tree.



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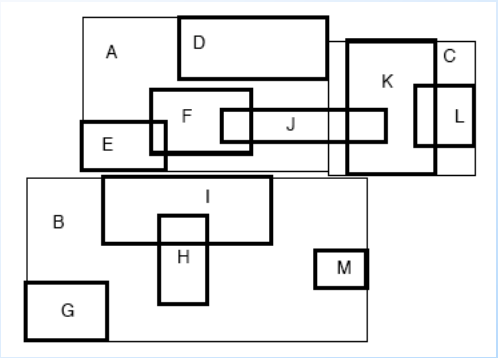
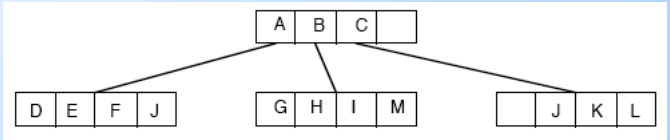
R+-Trees



Keep leaf regions disjoint.

Split similar to B-trees, as necessary.



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Geometric Operations

- Tree structure can play a role in operations such as intersection, union, difference.
- Generalized Search Trees (GiST; Hellerstein, Naughton & Pfeffer '95) generalize B trees, R trees, etc. and can implement numerous operations

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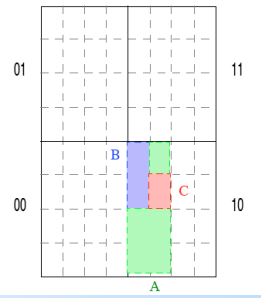
Filter&Refine Example

- Suppose using Z representation
- To find whether two objects intersect, compare Z indices



0110, 10, 10010, 100110, 10110, ..

0111, 100, 1010, 1011, 1101

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