GiST: A Generalized Search Tree for Database Systems

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Road Map

- Motivation
- Intuition on Generalized Search Trees
- Overview of GiST ADT
- Example indices: integers, polygons & sets
- Implementation challenges
- Open problems in indexing research

Indexing in OO/OR Systems

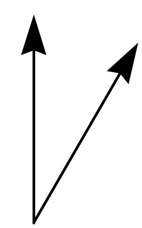
- Quick access to user-defined objects
- Support queries natural to the objects
- Two previous approaches
  - Specialized Indices ("ABCDEFG-trees")
    - » redundant code: most trees are very similar
    - » concurrency control, etc. tricky!
  - Extensible B-trees & R-trees (Postgres/Illustra)
    - » B-tree or R-tree lookups only!
    - » E.g. 'WHERE movie.video < 'Terminator 2'

A Third Approach

- A generalized search tree. Must be:
- Extensible in terms of queries
- General (B+-tree, R-tree, etc.)
- Easy to extend
- Efficient (match specialized trees)
- Highly concurrent, recoverable, etc.

Uses for GiSTs

- New indexes needed for new apps...
  - find all supersets of *S*
  - find all molecules that bind to *M*
  - your favorite query here (multimedia?)
- ...and for new queries over old domains:
  - find all points in region from 12 to 2 o'clock
  - find all strings that match R. E.



Database Search Trees from 50,000 feet

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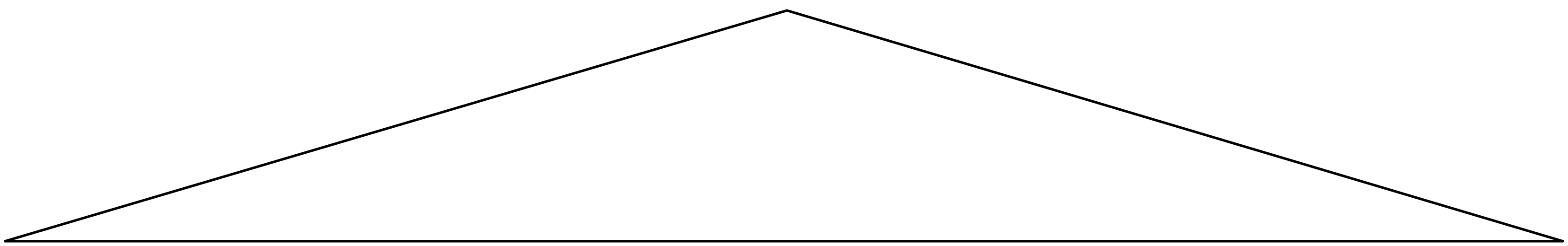
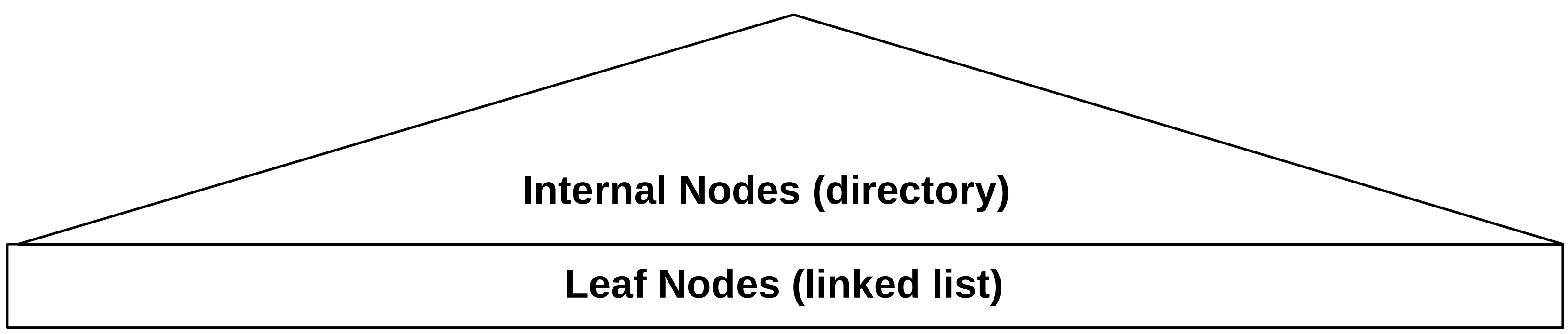
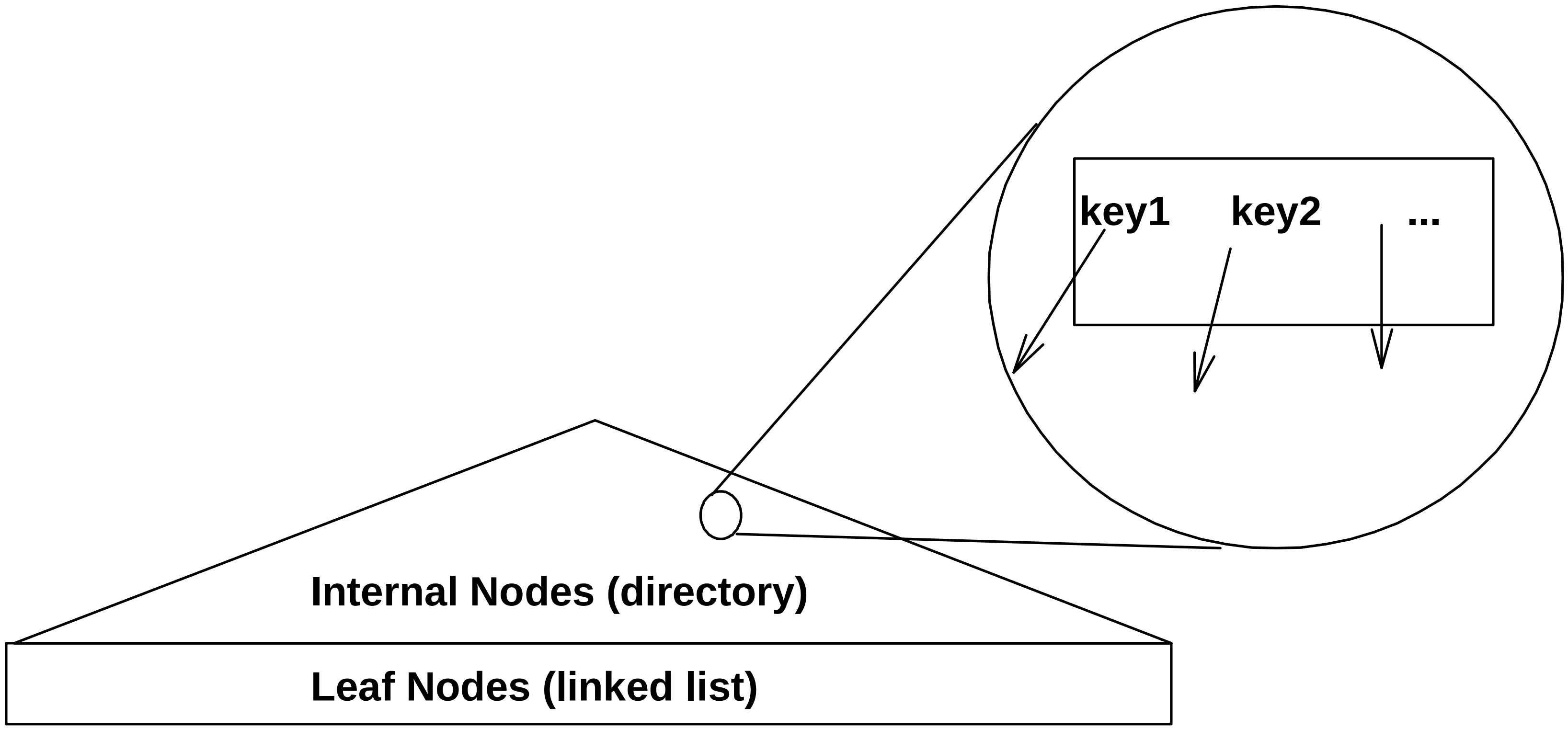


Database Search Trees from 40,000 feet



Database Search Trees from 30,000 feet



GiST: Generalized Search Tree

- Structure: balanced tree of (*p*, ptr) pairs
  - *p* is a key “predicate”
  - *p* holds for all objects below ptr
  - keys on a page may overlap
- Key predicates: a user-defined class
  - This is the only extensibility required!

Key Methods

- Search:
  - **Consistent**(E,q): $E.p \wedge q$? (no/maybe)
- Characterization
  - **Union**(P): new key that holds for all tuples in P
- Categorization
  - **Penalty**(E_1,E_2):
    penalty of inserting E_2 in subtree E_1
  - **PickSplit**(P): split P into two groups of entries

Search

- General technique:
  - traverse tree where **Consistent** is TRUE
- For range predicates on ordered domain:
  - user specifies **IsOrdered**
  - user registers **Compare**(p_1, p_2) operator
  - methods ensure ordered, non-overlapping keys
  - traverse leftmost **Consistent** branch
  - scan right across bottom.

Insert

- descend tree along least increase in **Penalty**
- if there's room at leaf, insert there
- else split according to **PickSplit**
- propagate changes using **Union**

- Notes:
  - on overflow, can do R*-tree style reinsert
  - for ordered keys, **Penalty** needs to keep order

Delete

- find the entry via **Search**, and delete it
- propagate changes using **Union**
- on underflow:
  - if ordered keys, do B+-tree style borrow/coalesce
  - else reinsert stuff on page and delete page

GiSTS over $\mathbb{Z}$ (B+-trees)

- Logically, keys represent ranges $[x,y)$
- Queries: **Contains**($[a,b)$, v)
- **Consistent**(E,q): $(x<b) \wedge (y > a)$
- **Union**(P): $[\mathrm{MIN}(x_i), \mathrm{MAX}(y_i))$
- **Penalty**(E_1, E_2):
  - return $\mathrm{MAX}(y_2 - y_1, 0) + \mathrm{MAX}(x_1 - x_2, 0)$
  - if E_1 is leftmost or rightmost, drop a term
- **PickSplit**(P): split evenly in order

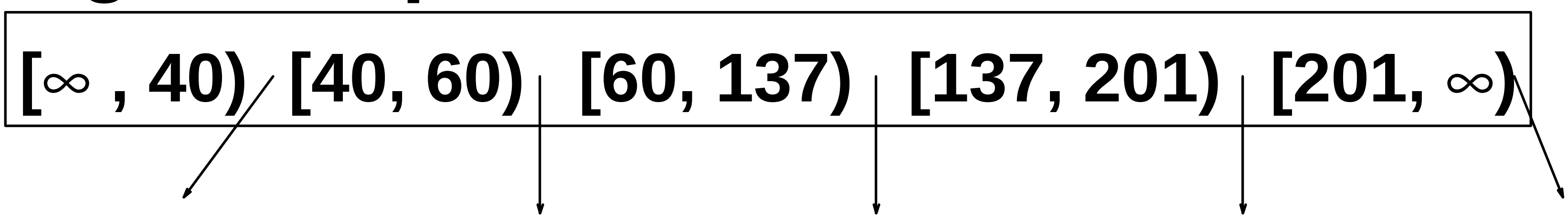
Key Compression

- Keys may take up too much room on a page
- Two extra key methods:
  - **Compress**(*E*)/**Decompress**(*E*)
- Compression can be lossy:

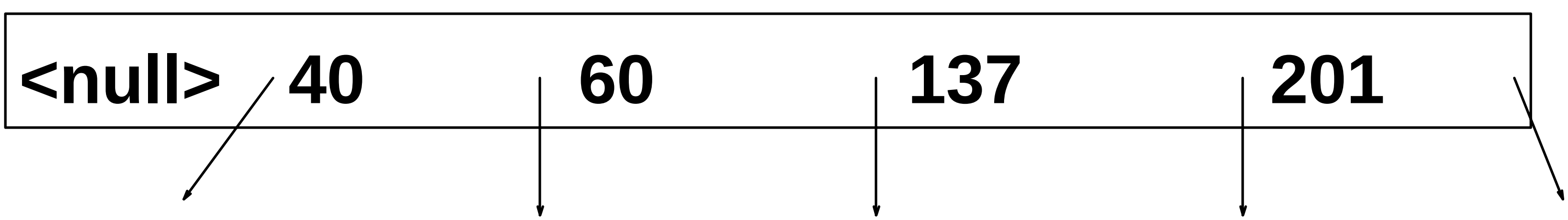
  over-generalization OK

A B+-tree Page

Logical Representation:



Physical Representation (compressed):



B+-tree Compression

- **Compress**(E=([x,y), ptr)):
  – if E is leftmost return NULL, else return x
- **Decompress**(E=(π, ptr)):
  – if E is leftmost, let $x = -\infty$, else let $x = \pi$.
  – if E is rightmost, let $y = \infty$, else let y be the value stored in the next key on the right.
  – if E is rightmost on a leaf page, let $y = x+1$.

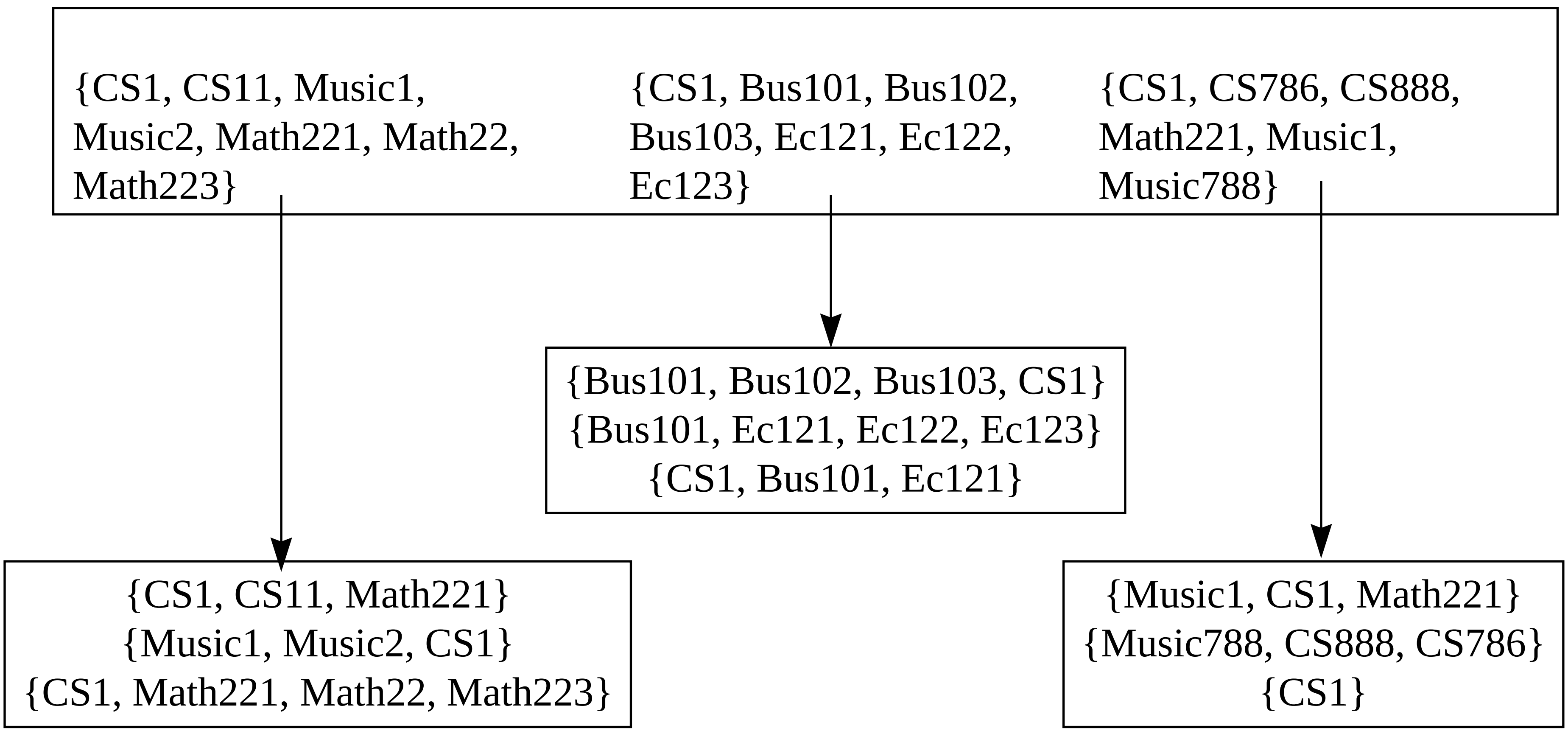
GiSTs over $\boldsymbol{R}^2$ (R-tree)

- Logically, keys represent bounding boxes
- Queries: **Contains, Overlaps, Equals**
- **Consistent**(*E*,*q*): does *E.p* overlap *q*?
- **Union**(*P*): bounding box of all entries
- **Compress**(*E*): form bounding box
- **Decompress**(*E*): identity function
- **Penalty**(*E*,*F*): size(Union({*E*,*F*}) - size(*E*)
- **PickSplit**(*P*): R-tree or R*-tree methods

GiSTs over $P(\mathbb{Z})$ (RD-tree)

- Logically, keys represent bounding sets
- Queries: **Contains, Overlaps, Equals**
- **Consistent**(E,q): does $E.p \cap q = \emptyset$?
- **Union**(P): set-union of keys
- **Compress**(E): Bloom filters, rangesets, etc.
- **Decompress**(E): match compress
- **Penalty**(E,F): $|E.p \cup F.p| - |E.p|$
- **PickSplit**(P): R-tree algorithms

An RD-tree


{CS1, CS11, Music1, Music2, Math221, Math22, Math223}
{CS1, Bus101, Bus102, Bus103, Ec121, Ec122, Ec123}
{CS1, CS786, CS888, Math221, Music1, Music788}
{Bus101, Bus102, Bus103, CS1}
{Bus101, Ec121, Ec122, Ec123}
{CS1, Bus101, Ec121}
{CS1, CS11, Math221}
{Music1, Music2, CS1}
{CS1, Math221, Math22, Math223}
{Music1, CS1, Math221}
{Music788, CS888, CS786}
{CS1}

Implementation Issues

- In-memory efficiency: Node subclass
- Concurrency, Recovery, Consistency
  - Kornacker & Banks, VLDB95
- Variable-Length Keys
- Bulk Loading
- Optimizer Integration
- Extensibility & Efficiency

GiST Performance

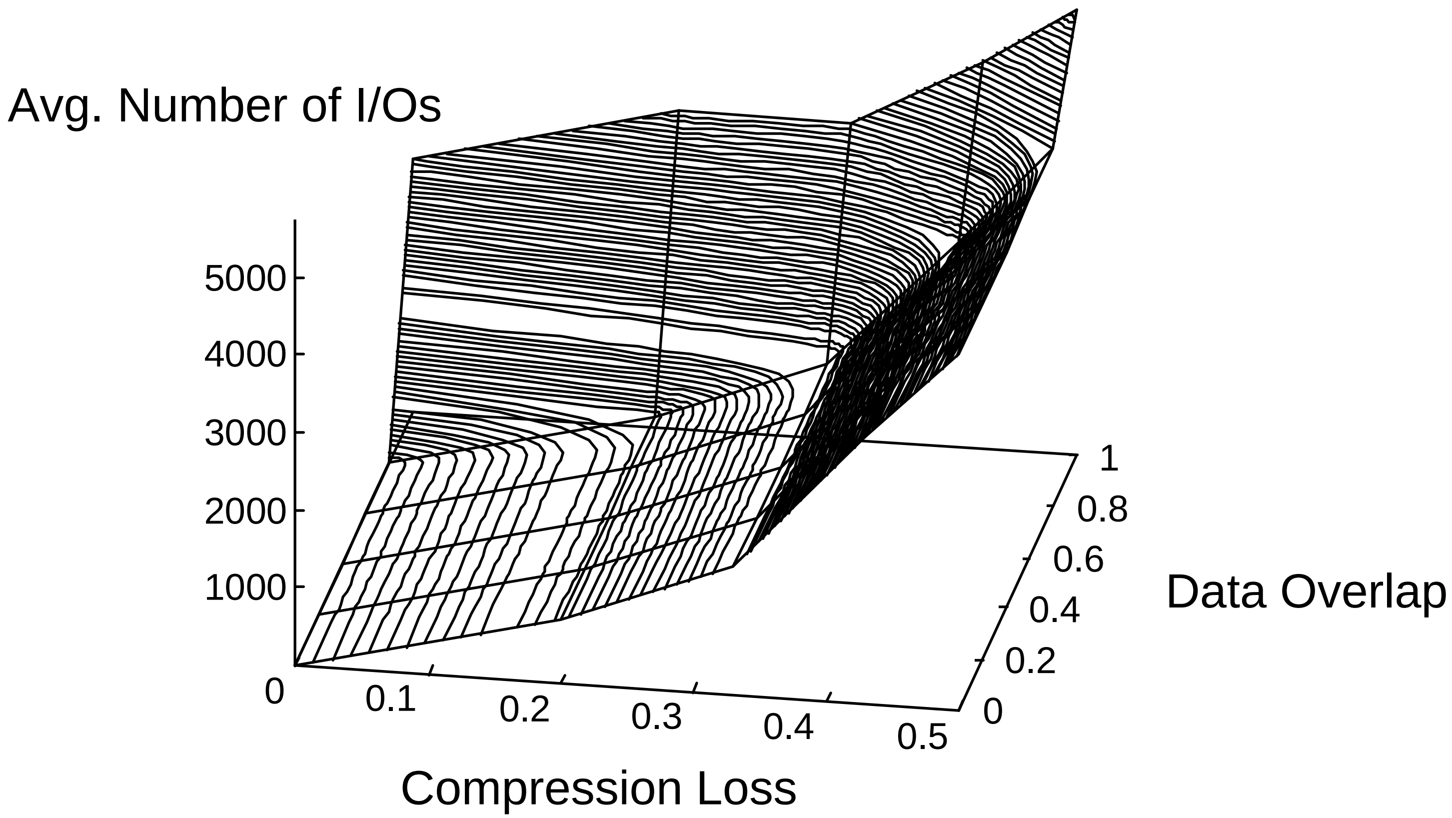
- B+-trees have O(log *n*) performance
- R-trees, RD-trees have no such guarantee
  - search may have to traverse multiple paths
  - worst-case O(2*n*) to traverse entire tree
  - aggravated by random I/O: much worse than scan!

SO: when does it pay to build/use an index?

GiST Performance, cont.

- As a first cut, look at 2 parameters:
  - data overlap & compression loss
- Experiment with Illustra's R-trees
  - Comb sets: {[1,10], [10001,10010], ...}
  - 30 data sets, each of 10,000 combs
  - vary data overlap, numranges (compression)
  - 5 queries per dataset, searching for comb teeth

GiST Performance, cont.



Future Directions in Indexing

- Indexability theory:
  - when is an index useful? Papadimitriou?
- New things to index! Queries over:
  - sets, sequences/text (REs), graphs, multimedia, molecular structures...
- Lossy compression techniques
- Algorithmic improvements?
  - (R*-tree techniques?)

The Gist of the GiST

- Boil search trees down to their essence.
- Unify B+-tree, R-tree, etc. in one ADT.
- Extensible in terms of data and queries.
- Opens research on indexability.

Status

- Prototype implementation in Postgres95
  - currently no variable-length keys, concurrency
- Illustra/Informix port?
- General purpose C++ library planned
- Papers, etc. at:
  - http://www.cs.berkeley.edu/~jmh/