Other Use of Triangle Inequality

Algorithms for Nearest Neighbor Search: Lecture 2

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Outline

1. Nearest Neighbors via Walking
2. Matrix-Based Techniques
3. Basic Techniques for Euclidean Space

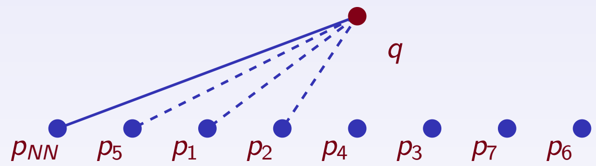
Chapter VI

Nearest Neighbors via Walking

Orchard's Algorithm

Preprocessing: Orchard'91

For every object $p_i \in S$ construct a list $L(p_i)$ of all other objects sorted by their similarity to p_i



Query processing:

- Start from some random p_{NN}
- Inspect members of $L(P_{NN})$ from left to right
- Whenever meet p' having $d(p', q) < d(p_{NN}, q)$, set $p_{NN} := p'$
- Stopping condition: we reached p' having $d(p', q) \geq 2d(p_{NN}, q)$

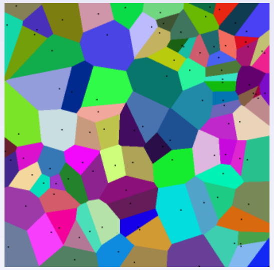
Hierarchical Orchard's Algorithm

- Randomly choose $S_1 \subset S_2 \subset \dots S_k = S$ with $|S_i|/|S_{i-1}| \approx \alpha > 1$
- Start with Orchard algorithm on S_1
- For every i from 2 to k apply Orchard's algorithm for S_i using result of the previous step as a starting point

Inspired by classic skip list technique Pugh'90

Delaunay Graph Algorithm

Delaunay Graph:
Construct Voronoi diagram for set in Euclidean space. Draw an edge between every two points whose Voronoi cells are adjacent



Search algorithm:

- Start from a random point
- Check all Delaunay neighbors of current object p
- If some p' is closer to q, move to p' and repeat
- Otherwise return p

Delaunay Graph in General

Exercise: prove correctness of the above algorithm

Assume we have general metric space and full matrix of pairwise distances. How Delaunay graph should be defined?

Navarro, 2002: for any distance matrix any two objects can be adjacent :-(

Spatial Approximation Tree: Construction

Navarro'99:

- Set a random object p to be root
- Partitioning technique:
  - Inspect all other object in order by their similarity to p
  - Whenever some p' is closer to p than to any of already chosen children $Ch(p)$ add p' to children set
  - Put every other object p'' to the subtree of closet member of $Ch(p)$
- Recursively repeat

Exercise: prove that covering radius for children subtree is never exceeding covering radius of parent subtree

SA-Tree: Search

- Start from the root p
- For every node to be inspected:

  keep global candidate p_{NN}

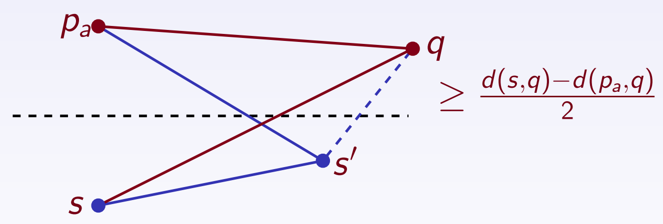
  (closest object to query visited so far)

  and p_a — closest to q among

  all ancestors and brothers of current node
- Use usual depth-first or best-first tree traversal
- Processing current node t:
  - Compute distances from q to all children of t
  - Go to child s whenever $d(q,s) < d(q,p_a(s)) + 2r_{NN}$

SA-Tree: Correctness

Observation: fix node s, let p_a be its ancestor/brother and s' be some objected in its subtree. Then s' is closer to s than to p_a



If there exists s' such that $d(s',q) < r_{NN}$ then $d(s,q) < d(p_a,q) + 2r_{NN}$

Chapter VII

Matrix-Based Techniques

Approximating and Eliminating Search Algorithm

Preprocessing: Vidal'86

Compute $n \times n$ matrix of pairwise distances in S

Query processing:

- Maintain a set C of candidate objects, initially $C := S$
- For every $p \in C$ keep the lower bound $d_l(q,p)$
- Main loop:
  - Choose $p \in C$ with smallest lower bound, compute $d(q,p)$, update $p_{NN}, r_{NN} = d(q,p_{NN})$ if necessary
  - Approximating: update lower bounds in C using $d(q,p') \geq d(q,p) + d(p,p')$ inequality
  - Eliminating: delete all elements in C whose lower bounds exceeded r_{NN}

Linear AESA

Advantage of AESA: small number of distance computations
Disadvantages: large storage and non-distance computation

Linear AESA: Micó, Oncina, Vidal'94
Compute $n \times m$ matrix choosing m objects as pivots

Range search:

- Compute all query-pivot distances
- Compute lower bounds for all non-pivot objects
- Eliminate objects with lower bound exceeding search range
- Explicitly check remaining non-pivots

TLAESA

A combination of bisector tree and LAESA

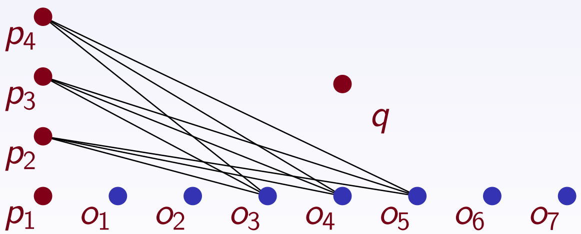
Data structure: Micó, Oncina, Carrasco'96
Usual bisector tree
Additionally, m pivots
Distances from pivots to all objects are precomputed

Query processing
Compute distances from query to pivots
Depth-first/Best-first search in bisector tree
Additional condition to prune subtree of some object s:

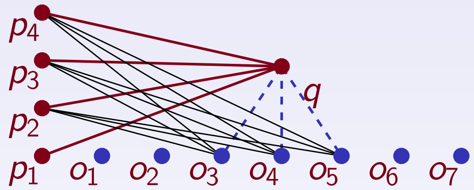
$$\exists i : \quad |d(p_i, s) - d(p_i, q)| \geq r_c(s) + r_{NN}$$

Shapiro's Algorithm (1/2)

Data structure: Shapiro'77
$n \times m$ distance matrix (pivots $p_1, \ldots, p_m$)
Non-pivot objects are sorted by there distances
to first pivot $p_1 : o_1, \ldots, o_n$



Shapiro's Algorithm (2/2)



Query processing
Compute distances from query to pivots
Start with o_i having $d(p_1, o_i) \approx d(p_1, q)$
Inspect other objects in order $i-1, i+1, i-2, i+2, \ldots$
Whenever meet better candidate change the center of inspection
Use flags to avoid double-check
Use all pivots to skip some objects (similar to AESA)
Stopping condition: $|d(p_1, o_i) - d(p_1, q)| \geq r_{NN}$

Actually, it's a mixture of LAESA and Orchard
But published before both: 1977 vs 1991 and 1992!

Chapter VIII

Basic Techniques for Euclidean Space

Advantages of Euclidean Space

- Rich mathematical formalisms for defining a boundary of any set

  Examples: rectangles, hyperplanes, polynomial curves

- Easy computation of lower bound on distance between query point and any set boundary

- (Tomorrow) Easy definable mappings to smaller spaces

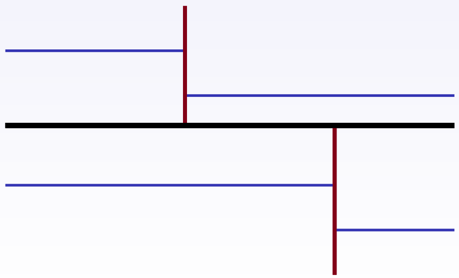
k-d Tree

Preprocessing: Bentley, 1975

Top-down partitioning
On level l: split the current set
by hyperplane orthogonal to $l \bmod k$ axis

Query processing:

Standard branch and bound



R-Tree

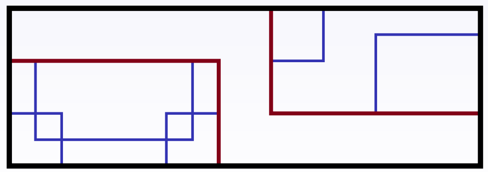
Preprocessing: Guttman, 1984

Bottom-up partitioning
Keep bounding rectangles
Every time: merge current rectangles
and compute bounding rectangle for every group

Query processing:

Standard branch and bound

Insertions/delitions: similar to M-tree, B-tree



Exercises

Prove correctness of Delaunay graph stopping condition

Prove monotonicity of covering radii in SA-tree

Highlights

- Orchard: use local search around the current candidate, move whenever meet better option
- Spatial tree approximation: emulating Delaunay graph in general metric space
- AESA: use every inter-object distance to get a lower bound on unchecked distances
- Euclid space: use explicit boundaries in metric trees

Thanks for your attention! Questions?

References

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Y. Lifshits
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