CDO: An extremely high-throughput solution, e.g., 7 million computations per second, for shortest road network distance or ETA computations using the $\epsilon$-distance oracle on a city road network.

Motivation:
1) Spatial analytic queries typically perform millions of shortest distance computations in applications such as delivery, smart city analysis, local advertisement, spatial business intelligence, etc.
2) Spatial concentration property: in most applications, making use of such spatial analytic queries is typically concentrated in a small local region rather than an entire continental region.
3) Approximate shortest distance/time results are acceptable in these cases.

Distance Oracles

A Well-Separated Pair Decomposition (WSPD) on a road network consists of $O(n/\epsilon^2)$ well-separated pairs, where $n$ is the number of vertices, and $\epsilon$ is an error tolerance.

Well-Separated Pair (WSP) example:

$$\forall s \in A, t \in B, (1 - \epsilon)d_G(p_A, p_B) \leq d_G(s, t) \leq (1 + \epsilon)d_G(p_A, p_B)$$

Each WSP is a key-value pair where the key is the pair of two sets of vertices, $A$ and $B$, satisfying the above inequalities, and the value is $d_G(p_A, p_B)$.

Storing & Querying

Key Representation:
1) Each WSP is $(A, B, d_G(p_A, p_B))$. Both $A$ and $B$ are PR quadtree blocks.
2) $Z_2(A)$, denoted as the Morton code of quadtree block $A$.
3) $Z_4(A, B)$, similar to $Z_2(Z_2(A), Z_2(B))$, but interleaving two bits at a time
4) $Z_8(A, B)$, padding $Z_4(A, B)$ with zeros to the same length

Example:
1) $Z_2(01, 10) = 0110$ $Z_2(01, 10) = 01110000$
2) $Z_4(0000, 1111) = Z_2^2(0000, 1111) = 00110011$

Query:
1. Load all WSPs in memory, and sort them by key, $Z_2^2(A, B)$
2. Given a source-target query $(s, t)$, compute $Z_2^2(s, t)$
3. Binary search on all WSPs to find the WSP that max key $\leq Z_2^2(s, t)$

Uniqueness Property: For any source-target query $(s, t)$, there is exactly one WSP $(A, B)$ that contains $(s, t)$, i.e., $A$ contains $s$ and $B$ contains $t$.

Multi-threads improvements: only read-only operations for searching.

Comparisons: HLDB in memory and Contraction hierarchies (CH)

Datasets: Bay Area road network with 781K vertices and New York City road network with 407K vertices from OpenStreetMap.

CDO Size:
1) The number of WSPs for the Bay Area road network is 392M with $\epsilon = 0.1$, which uses 4.3GB of memory.
2) The number of WSPs for the New York City road network is 629M with $\epsilon = 0.05$, which uses 7.1GB of memory

Showing the time consumption for one million random source-target pairs on the Bay Area road network, varying with number of threads.

CDO achieves 0.16 seconds with 8 threads for one million distance computations.