Using Approximate Bucket Structures And The Pape-Levit Algorithm In High Performance Shortest Path Raytracing

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Shortest Path Raytracing (SPR) is a graph-theoretic approach to modeling P-wave propagation offering guaranteed convergence to global minimum traveltime values. Most investigations of the SPR method have relied upon relatively slow techniques for shortest-path calculation: implementations of Dijkstra's algorithm using the binary heap data structure are common. These implementations have an asymptotic complexity of $O(E \log N)$, E and N being the number of edges and nodes in the graph representation of the velocity model. Use of faster data structures within Dijkstra's algorithm, such as bucket arrays, can lead to a $O(E + NC)$ shortest path algorithm with C being a constant factor related to available memory. We examine four different implementations of Dijkstra's algorithm using variations of the bucket array data structure and two incremental graph algorithms; performance comparisons are made against existing SPR packages using binary heaps, fibonacci heaps, and linear arrays.

The SPR algorithms were tested on 2D crustal models from the Fiji-Tonga region provided by members of the Southwest Pacific Seismic Experiment (SPASE) as well as smaller models from the Chilean margin. The dimensions of the velocity models ranged from 26x26 to 400x400 cells: the corresponding graph representations included between 1404 and 641,600 nodes. A finite-difference eikonal solver package provided an accuracy and speed benchmark for the various SPR methods.

The newer algorithms using buckets performed, on average, twice as fast as the implementations using heaps and several orders of magnitude faster then the naive implementations that searched linear arrays. Surprisingly, two incremental graph methods, the Pape-Levit algorithm and Pallentino's algorithm, outperformed every version of Dijkstra's algorithm on the test suite, usually by a factor of two or greater. Despite extremely poor asymptotic worst-case bounds, experimental results suggest that inexpensive update operations within both algorithms and the regular connectivity of the graphs allowed this increased performance. The Pape-Levit algorithm computed the complete traveltime table for a 400x400 model with 2 nodes per cell boundary (641,600 nodes and 7,680,000 edges) in 2.58 seconds of CPU time, more than twice as fast as Dijkstra's Algorithm using Approximate Buckets (5.67 sec.). The Pape-Levit algorithm has an exponential worst-case bound of $n2^n$.

Accuracy comparisons between SPR traveltime tables and finite-difference solutions showed only a 0.02% average relative error for the SPR algorithm using graphs with 2 nodes per cell edge. Use of SPR algorithms on large anisotropic models is also being investigated.

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