Gigantic Deformable Surfaces

Ben Houston[1*] Michael B. Nielsen[2] Christopher Batty[1] Ola Nilsson[3] Ken Museth[2,3]
[1]Frantic Films [2]University of Århus [3]Linköping Institute of Technology

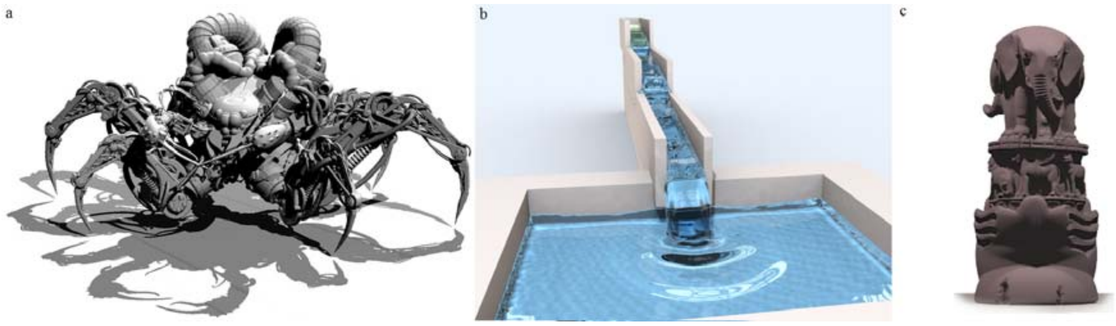

Figure 1: a) A massive level set model, b) a fully sparse particle level set fluid simulation. c) a partial level set metamorphosis

In this sketch, we introduce the Compact RLE Level Set. This representation is new structure that combines the benefits of the two previously presented sparse regular level set representations: the versatile RLE Sparse Level set of [Houston et al. 2004] and the near-optimally efficient DT-Grid of [Nielsen and Museth 2005]. We then present many important applications for computer graphics.

1 Data Structure and Algorithms

From the RLE Sparse Level Set, the Compact RLE Level Set employs a run-length encoding (RLE) scheme that denoted the values of sequential grid points outside of the narrow band by signed runs. The level set values of narrow band grid points are stored explicitly. Taking inspiration from the DT-Grid, the Compact RLE Level Set applies the RLE encoding hierarchically first to the level set values along the x-axis, then to the resulting run codes along the y-axis, and then again to the resulting run codes along the z-axis. Unlike the DT-Grid, our new structure requires the specification of the current maximal bounding box (which can grow arbitrarily as needed to retain the out-of-boxness property.) It is important to note that the Compact RLE Level Set explicitly denotes undefined regions using run codes (which simplifies inside/outside tests in undefined regions), where the DT-Grid only implicitly delineates the undefined regions. Where as the RLE Sparse Level Set requires $O(n^2+D)$ space, where n is the side length of the bounding box and D is the number of defined grid points, our fusion structure only requires $O(D)$ space.

Encoding of Compact RLE Level Sets requires $O(D)$ space and time. Sequential iteration over the defined narrow band is an $O(1)$ per element operation (compared to $O(1+n^2/D)$ required by the RLE Sparse Level Set.) Fixed stencil iteration, useful when applying finite difference methods, can be optimally achieved via the use of properly advanced multiple concurrent sequential iterators. Random access, because of the hierarchical encoding scheme, is an $O(\sum_{i=1..k} \log_2 r_i)$ operation, where k is the dimensionality of the level set and r_i is the number of runs in the relevant cross section. The rebuilding of the defined narrow band, via dilation, requires an optimal $O(D)$.

2 Applications

Massive Deformable Models Both the efficient polygon to distance field conversion method of [Mauch 2000] and a more robust method of [Houston et al. 2004] can be adapted to the Compact RLE Level Set such that $O(n^3)$ space is never required during scan conversion. By scan converting 724 unclosed tri-mesh components at a minimal bounding resolution of $1691 \times 1223 \times 839$ (1.74 billion voxel volume) we were able to create the spider mech level set depicted in figure 1a. The resulting defined interface of the level set consists of 44.7 million voxels. Total memory requirement is 229.6 MB. An intermediate result of a gigantic level set metamorphosis is depicted in figure 1c.

Direct Ray Tracing The availability of fast random access combined with sign information in undefined regions, enables efficient direct ray tracing of the zero-level set. For a grid width of n and a defined narrow bandwidth of β, approximately n/β random accesses are required. This makes tracing of R rays $O((n/\beta)R\log_2 r)$. Figure 1a was rendered at a speed of 3600 rays / second.

Fluid Simulation We have implemented a fully sparse fluid simulation system based upon RLE level sets. Unlike the level set, the fluid velocities are required to be defined within the volume, not just within the interface narrow band. This is possible via the flexibility offered by the RLE encoding scheme. We represent the velocities of the MAC grid as three appropriately offset Compact RLE grids, each storing one of the three velocity components. The improvement in memory usage from our fully sparse scheme for the scene depicted in figure 1b is 77% as compared to a dense fluid simulation.

3 Conclusion

The Compact RLE Level Set offers a favorable combination of efficiency, scalability and versatility that is suited to the needs of level set researchers and practitioners. In the advection of massive level set surfaces, the Compact RLE Level Set required 50% less space and was 50% faster than the Octree level set method. Our methods are also more efficient than the full grid Peng method.

*ben@exocortex.org, bang@daimi.au.dk, cbatty@franticfilms.com, olani@itn.liu.se, museth@acm.org

References

HOUSTON, B., WIEBE, M., AND BATTY, C. 2004. RLE sparse level sets. In *Proc. SIGGRAPH 2004 on Sketches & Applications*, ACM Press, ACM.

MAUCH, S. 2000. A fast algorithm for computing the closest point and distance transform. *http://www.acm.caltech.edu/ seanm/software/cpt/cpt.pdf*.

NIELSEN, M. B., AND MUSETH, K. 2005. Dynamic Tubular Grid: An efficient data structure and algorithms for high resolution level sets. *Journal of Scientific Computing*.