CUDA Accelerated Sparse Field Level Set Segmentation of Large Medical Data Sets

Mike Roberts, Jeff Packer, J Ross Mitchell, Mario Costa Sousa
University of Calgary, Calgary, Alberta, Canada

UNIVERSITY OF CALGARY

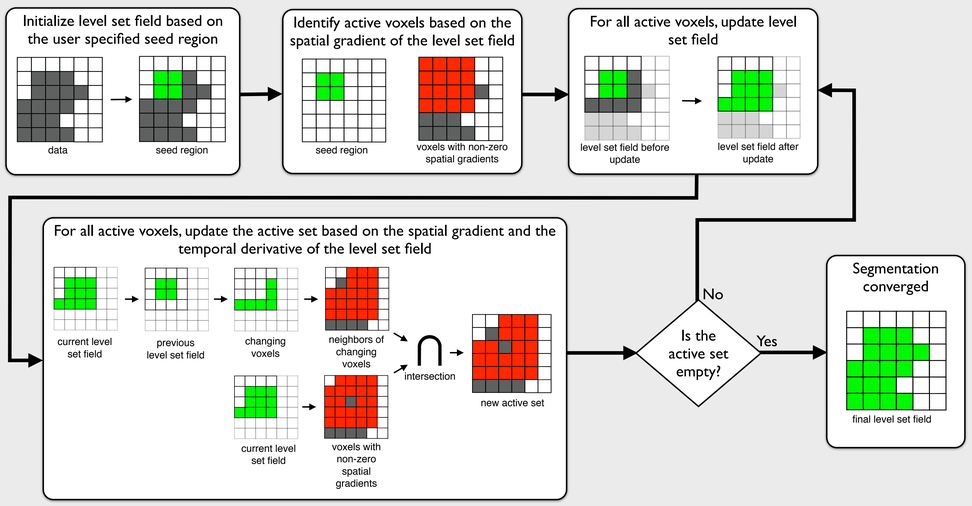
1 Introduction

- Image segmentation is an important task in diagnostic medicine
- Level set segmentation techniques have been shown to improve the accuracy of difficult segmentation tasks
- Previous level set segmentation techniques are computationally expensive even when running on the GPU
- Long computation times limit clinical utility

We present a novel CUDA accelerated level set segmentation algorithm with significantly improved performance over previous algorithms.

- 360x speedup compared to previous CPU algorithms
- 16x reduction in the size of the computational domain compared to previous GPU algorithms
- 9x speedup compared to previous GPU algorithms
- No reduction in segmentation accuracy

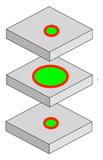
2 Sparse Field Algorithm



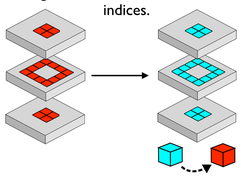
- Processes the minimal set of voxels at each time step
- Number of active voxels approaches 0 as the segmentation converges
- Tracks the active computational domain at the granularity of individual voxels instead of in large tiles

3 CUDA Implementation

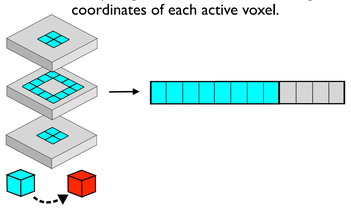
Iterate in parallel over every voxel in a level set field buffer. Initialize every voxel based on the user specified seed region.



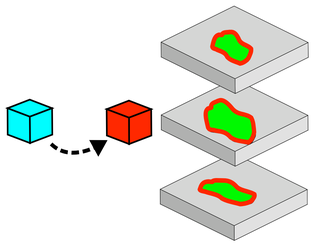
Iterate in parallel over every voxel in the level set field buffer to identify active voxels. If a voxel is deemed active, write its coordinates to an auxiliary buffer using the coordinates themselves as array indices.



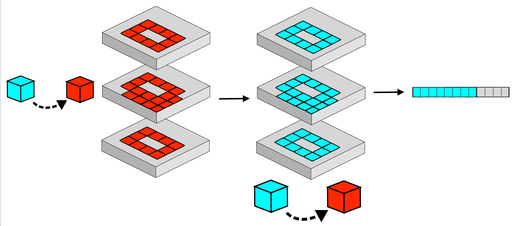
Compact the auxiliary buffer in parallel using Nvidia's CUDPP library to get a dense buffer containing the coordinates of each active voxel.



During each time step, iterate in parallel over the dense buffer of active voxel coordinates. Update the level set field at those coordinates.



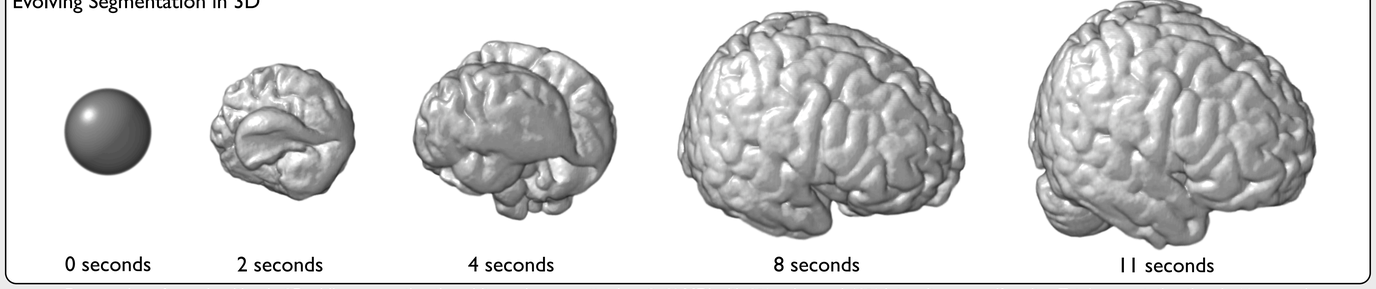
During each time step, iterate in parallel over the dense list of active voxel coordinates again to identify new active voxels. Write the coordinates of all the new active voxels to the auxiliary buffer. Compact the auxiliary buffer as above to get a dense buffer of active voxel coordinates for the next time step.



- Performed entirely on the GPU without requiring costly GPU-to-CPU message passing

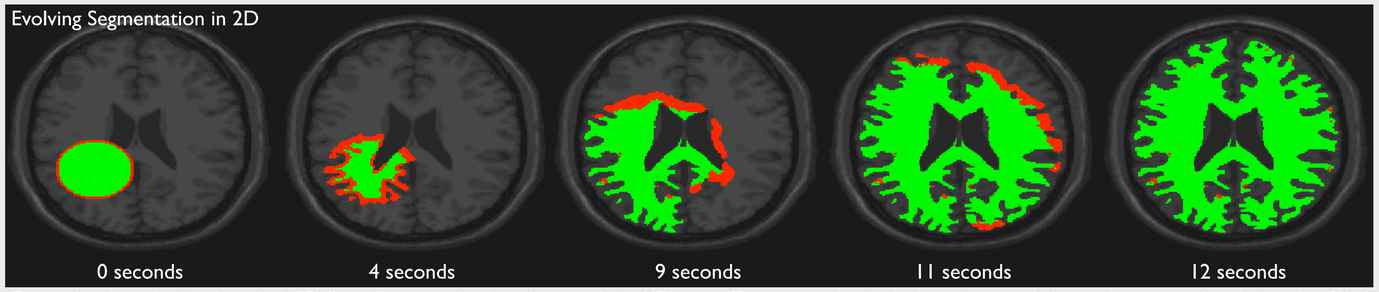
4 Results

Evolving Segmentation in 3D



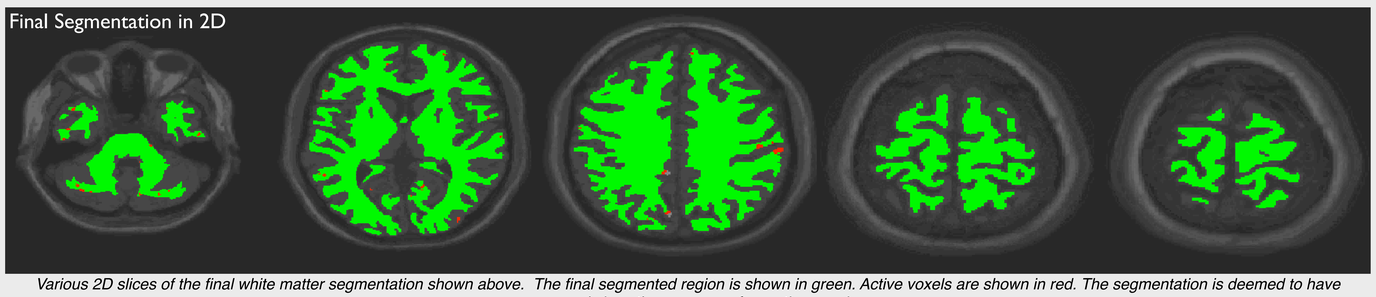
Progression of our algorithm in 3D while segmenting the white and grey matter in a 256³ MRI with 9% noise and 40% intensity non-uniformity. Total computation time is 11 seconds.

Evolving Segmentation in 2D

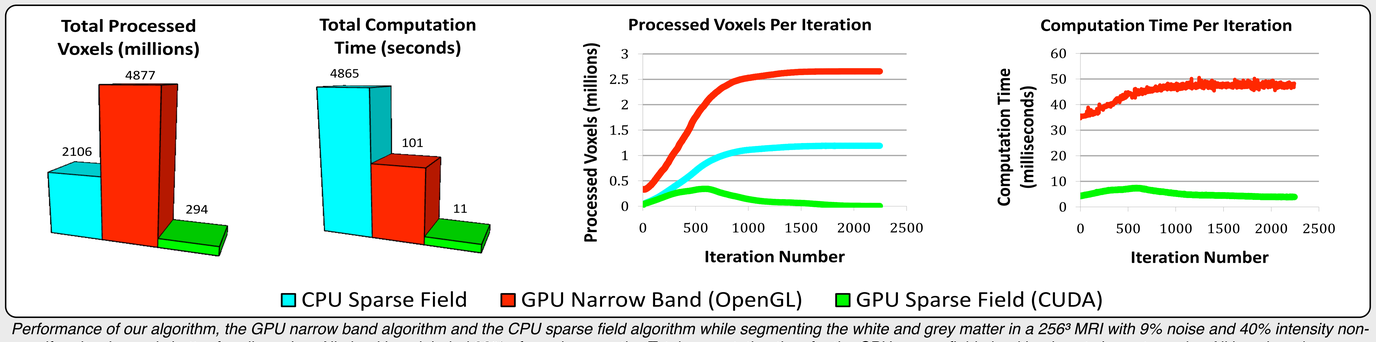


Progression of our algorithm for a single 2D slice while segmenting the white matter in the MRI above. The segmented region is shown in green. Active voxels are shown in red. Less than 3% of voxels are active at any time during the segmentation.

Final Segmentation in 2D



Various 2D slices of the final white matter segmentation shown above. The final segmented region is shown in green. Active voxels are shown in red. The segmentation is deemed to have converged since there are very few active voxels.



Performance of our algorithm, the GPU narrow band algorithm and the CPU sparse field algorithm while segmenting the white and grey matter in a 256³ MRI with 9% noise and 40% intensity non-uniformity. Lower is better for all graphs. All algorithms labeled 98% of voxels correctly. Total computation time for the CPU sparse field algorithm is not shown to scale. All benchmarks were performed using an Intel 2.5 GHz Xeon CPU and an Nvidia GTX 280 GPU.

5 Conclusions

- 9x speedup compared to previous GPU algorithms
- 16x fewer computations compared to previous GPU algorithms
- No reduction in segmentation accuracy
- Performed entirely on the GPU without requiring costly GPU-to-CPU message passing
- Number of active voxels approaches 0 as the segmentation converges

6 References

1. Shattuck D W, Prasad G, Mirza M, Narr K L, Toga A W (2009) Online Resource for Validation of Brain Segmentation Methods. NeuroImage 45(2), 2009. 431-439
2. Whitaker R T (1994) Volumetric Deformable Models: Active Blobs. Visualization in Biomedical Computing 1994. 122–134
3. Lefohn A E, Cates J E, Whitaker R E (2003) Interactive, GPU-Based Level Sets for 3D Segmentation. MICCAI 2003. 564–572
4. Cates J E, Lefohn A E, Whitaker R T (2004) GIST: An Interactive, GPU-Based Level Set Segmentation Tool for 3D Medical Images. Medical Image Analysis 8(3), 2004. 217-231
5. Lefohn A E, Kniss J E, Hansen, Whitaker R E (2003) Interactive Deformation and Visualization of Level Set Surfaces Using Graphics Hardware. IEEE Visualization 2003. 75-82
6. Sethian J A (1999) Level Set Methods and Fast Marching Methods: Evolving Interfaces in Computational Geometry, Fluid Mechanics, Computer Vision, and Materials Science. Cambridge University Press, New York
7. Adalsteinsson D, Sethian J A (1995) A Fast Level Set Method for Propagating Interfaces. Journal of Computational Physics 8(2), 1995. 269–277
8. Lefohn A E, Kniss J E, Hansen, Whitaker R E (2004) A Streaming Narrow-Band Algorithm: Interactive Computation and Visualization of Level Sets. IEEE Transactions on Visualization and Computer Graphics 10(4), 2004. 422-433
9. Park S J, Hong H, Shin Y G (2007) Interactive Segmentation and Visualization using Level-Set Method based on Graphics Hardware. IFMBE Proc. 14(4), 2007. 2603-2606
10. Klar O (2007) Interactive GPU based Segmentation of Large Medical Volume Data with Level-Sets. 11th Central European Seminar on Computer Graphics 2007.
11. Whitaker, R (1998) A Level-Set Approach to 3D Reconstruction from Range Data. International Journal of Computer Vision 29(3), 1998. 203–231
12. Peng, D, Merriman, B, Osher, S, Zhao, H, and Kang, M (1999). A PDE Based Fast Local Level Set Method. Journal of Computational Physics. 155(2), 1999. 410–438
13. CUDPP: CUDA Data Parallel Primitives Library, http://www.gpgpu.org/developer/cudpp/
14. BrainWeb: Simulated Brain Database, http://www.bic.mni.mcgill.ca/brainweb/
15. Cocosco C A, Kollokian V, Kwan R K-S, Evans A C (1997) BrainWeb: Online Interface to a 3D MRI Simulated Brain Database. NeuroImage 5(4), 1997. 425

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calgary SCIENTIFIC MEDICAL GROUP
IMAGING INFORMATICS .CA

mroberts@ucalgary.ca 2009