MoltenFAC: A Tiled Flow Accumulation Algorithm for Large-Scale, Massively Parallel, and Memory-Efficient CPU/GPU Processing

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Abstract

Recent improvements in the resolution of Digital Elevation Models (DEMs) have highlighted the need for fast, memory efficient algorithms for terrain processing operations. One such operation that is key to hydrology is Flow Accumulation (FAC). While many FAC algorithms with a time complexity of O(N) exist, most of these implementations require loading the full dataset into memory. **We propose an FAC algorithm that performs a global analysis by first processing the dataset as individual tiles, then solving for the accumulated flow at the tile boundaries, and finally seeding the correct boundary values into each tile to obtain the final result**. Using this approach offers several benefits: only **the tile boundaries and one full tile per thread are required to be loaded into memory at any given time**, the **independence of each tile enables parallelization without synchronization primitives, and the relatively small and contiguous tile memory footprint results in good cache locality**. This method achieves results identical to a global analysis while requiring only a fraction of the memory of traditional approaches. Preliminary results indicate this implementation uses 3 GB of RAM for an 18.6 GB output dataset, compared with Memory-Efficient Flow Accumulation (MEFA)'s 22 GB of RAM for the same task. **This work, together with a GPU-accelerated implementation of Flow Direction (FDR) and a base implementation of Wang and Liu's Fill Sinks algorithm, will be made available online as a geoprocessing package called MoltenDEM**.

Acknowledgements

1: Significant portions of this work are derived from Huidae Cho's MEFA [Huidae Cho .(2023). *Memory-efficient flow accumulation using a look-around approach and its OpenMP parallelization*. https://doi.org/10.1016/j.envsoft.2023.105771]

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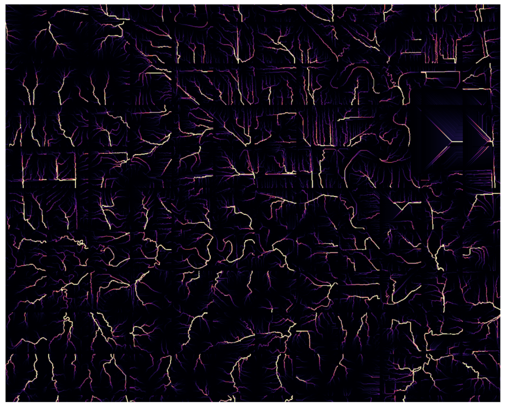
In the Real World

	State of Alabama-All Watersheds (10m)		Verdigris River (5m)		Republican River (5m)		Smoky River (5m)		Neosho River (5m)		Osage River (5m)		Big Blue River (5m)	
	Exec Time (s)	Peak Mem (GB)	Exec Time (s)	Peak Mem (GB)	Exec Time (s)	Peak Mem (GB)	Exec Time (s)	Peak Mem (GB)	Exec Time (s)	Peak Mem (GB)	Exec Time (s)	Peak Mem (GB)	Exec Time (s)	Peak Mem (GB)
MEFA/8 threads	11.621	22.6	2.292	4.9	3.214	8.9	5.066	11.9	4.682	14.2	2.610	6.7	1.968	5.2
MoltenFAC/8 threads [RAM, 2048x]	9.948	18.3	2.500	4.8	3.392	8.1	5.632	10.7	3.009	12.9	1.692	6.0	2.338	5.0
MoltenFAC/8 threads [RAM, 512x]	11.613	17.9	2.967	4.6	4.181	7.7	6.759	10.5	6.590	12.7	3.485	5.8	2.720	4.8
MoltenFAC/8 threads [DISK, 2048x]	14.093	1.4	3.887	1.2	5.389	1.2	7.979	1.3	8.734	1.2	5.331	1.2	3.493	1.2
MoltenFAC/8 threads [DISK, 512x]	14.066	1.2	4.230	0.5	5.885	0.6	7.992	0.8	9.398	0.8	4.393	0.6	3.996	0.5



Flow Accumulaton calculated per-tile

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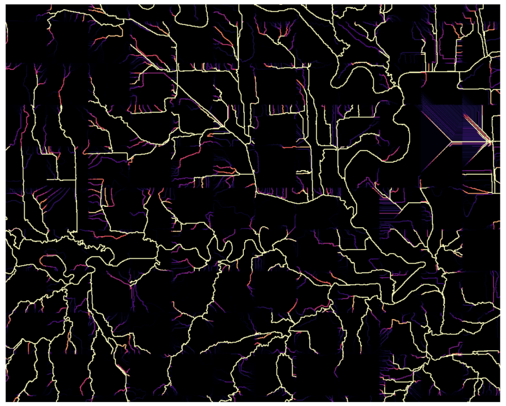

Sparse inter-tile routing

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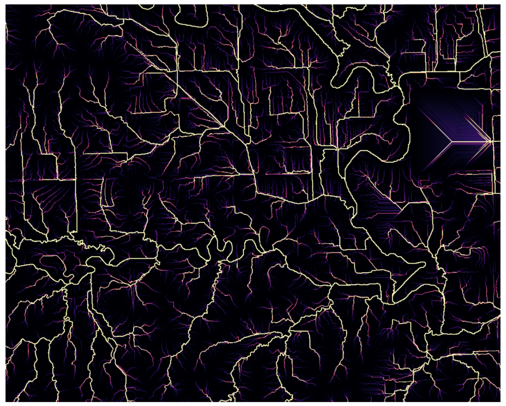
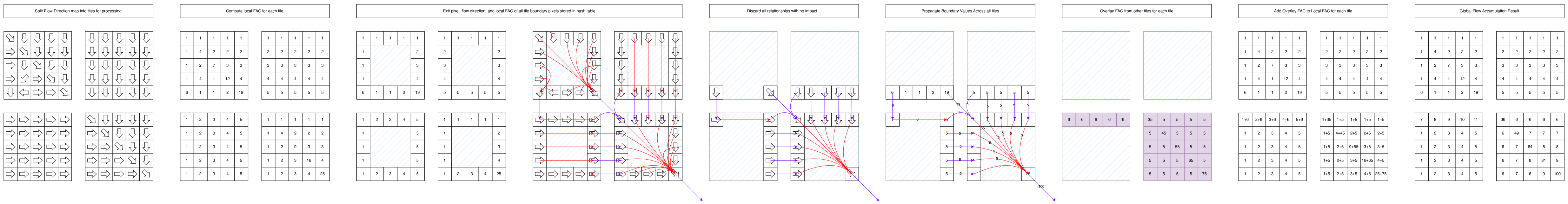


Global Flow Accumulation result

From Start to Finish



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