Physics-Aware Downsampling with Deep Learning for Scalable Flood Modeling

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Introduction

- Hydraulic water flow simulations rely on accurate terrain elevation maps.
- Such simulations, based on solving PDEs, are computationally prohibitive on a large scale.
- This scalability issue is commonly alleviated using a coarse grid representation of the elevation map.
- Coarse grid representation may distort crucial terrain details, leading to significant inaccuracies in the simulation.

\[
\frac{\partial h}{\partial t} + \nabla \cdot \mathbf{q} = 0
\]

Coarse graining by a factor of \( n \)
- Speedup of \( n^3 \)
- Terrain detail loss

Goal - Similar hydraulic solution of fine & coarse grid terrain maps

We optimize the coarse grid representation of the terrain maps, so that the flood prediction will match the fine grid solution.

Contributions:
- A novel configured dataset for 2D water flow estimation, with accessible code for reproduction.
- A new framework for learning how to coarse-grain a PDE together with its external environment.
- A demonstration of our approach with X16 coarsening factor, which entails a X4096 speedup.

Method

\[
W^* = \arg \min_W E_{z,c}[\ell(S(z,c), S(f_W(z),c)]
\]

\[
h = S(z,c), \tilde{h} = S(\tilde{z},c)
\]

Training Data:
- Real elevation maps (USGS 3DEP)
- 1 meter x 1 meter cell size (LiDAR)
- 5183 samples

Each sample consists:
- Initial conditions
- Boundary conditions
- Elevation map (4 km\(^2\))
- Simulation time
- Inundation map (ground truth)

Backpropagation through PDEs identifies hydraulically important details
- 6 hours of simulated flow, with differentiation through more than 10,000 iterations

1. A modified elevation map with a few pixels of an embankment flattened
2. Difference between the solutions calculated on the modified and the non-modified elevation maps
3. Gradient magnitude of the modified elevation map

Generalization over boundary conditions
- DNN trained on a single elevation map
- Different boundary conditions

\[
W^*(z) = \arg \min_W E_{z,c}[\ell(S(z,c), S(f_W(z),c) | z)]
\]

Generalization over elevation maps
- DNN trained on different elevation maps and boundary conditions

Results

- Code for reproduction of dataset & results -  
  www.github.com/tech-submissions/physics-aware-downsampling