Flexible & Probabilistic Topology Tracking Using Partial Optimal Transport

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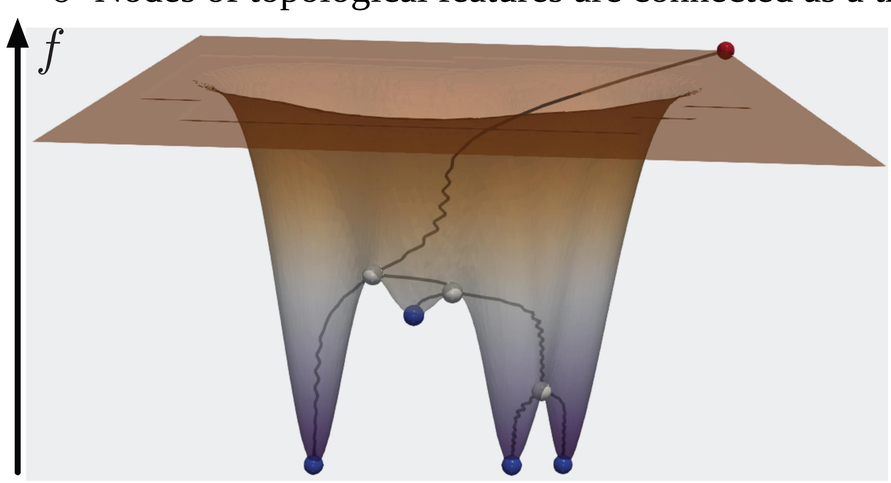
Overview

- Our goal is to track topological features (i.e., maxima, minima, saddles) in time-varying scalar fields using *Merge Trees*
- Our framework preserves both geometric and topological information
- We use probabilistic tracking graph for probabilistic visualization

What is a Merge Tree?

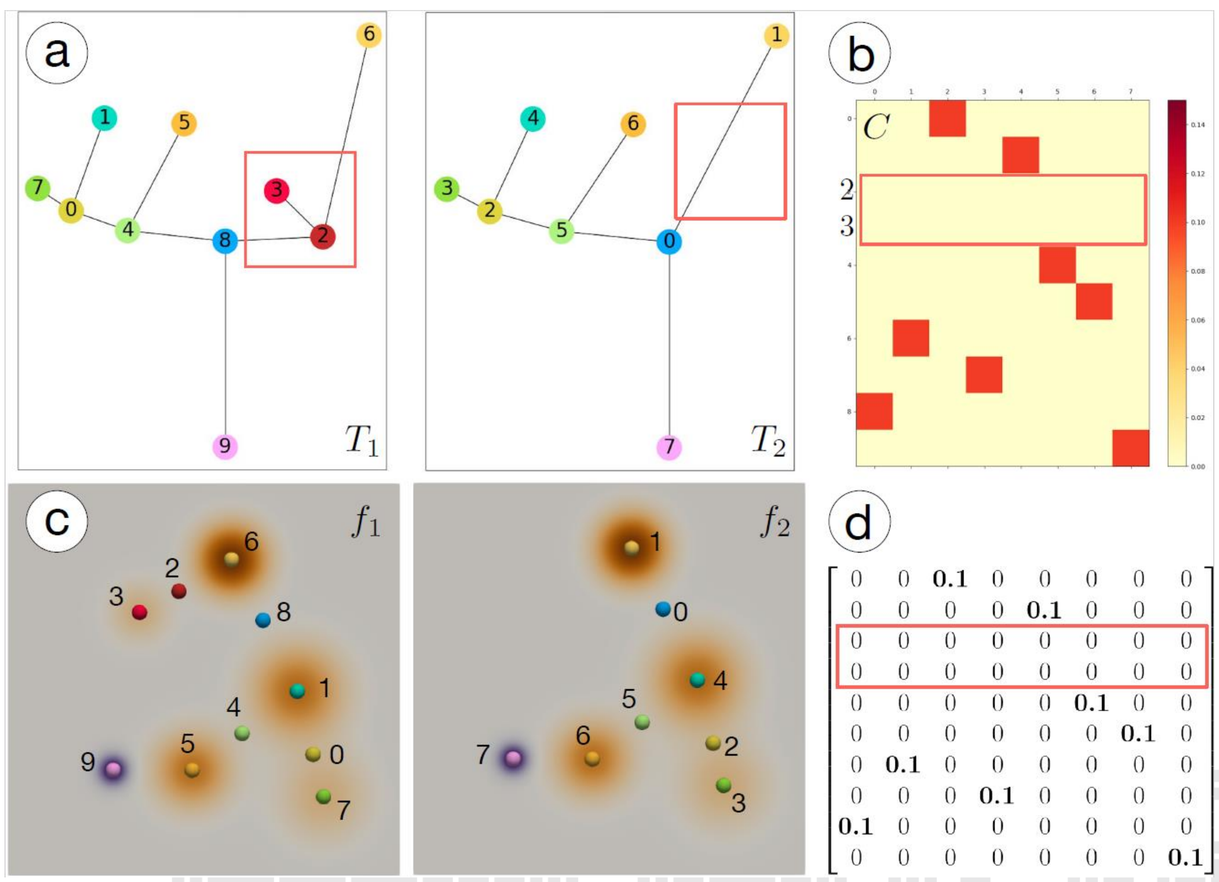
- Data Type: scalar field $f: M \rightarrow R$, defined on the domain of interest M
- Merge trees capture the connectivity among sublevel sets of f
- Example:
  - Topological features: red – maxima, white – saddle, blue – minima
  - Scalar function f shown as the height of the terrain
  - Nodes of topological features are connected as a tree



Merge tree embedded in the terrain of f | Merge tree of f

Optimal Transport for Tracking

- Target: compute the probability of matching between nodes in two trees
  - We consider the location of topological features & the tree structure
  - We allow certain nodes to be matched to nothing in the solution
- Example:
  - (a) shows merge trees that arise from the scalar fields in (c)
  - (b) and (d): optimal matching solution between nodes in T_1 and T_2
  - Red boxes: two nodes disappear in T_2, leading to empty matching

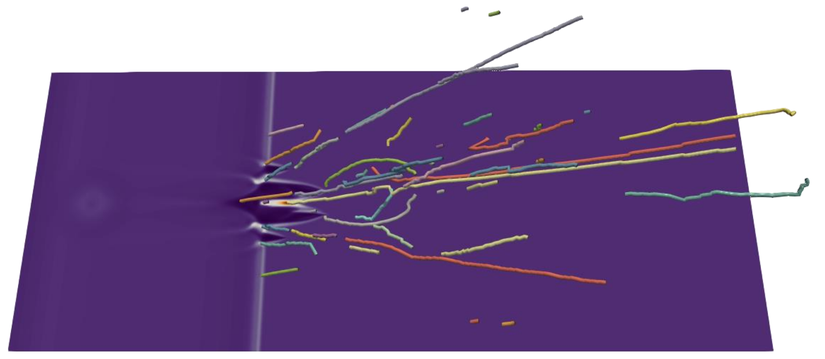


$$\begin{bmatrix} 0 & 0 & \mathbf{0.1} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \mathbf{0.1} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \mathbf{0.1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0.1} & 0 \\ 0 & \mathbf{0.1} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \mathbf{0.1} & 0 & 0 & 0 & 0 \\ \mathbf{0.1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0.1} \end{bmatrix}$$

Results

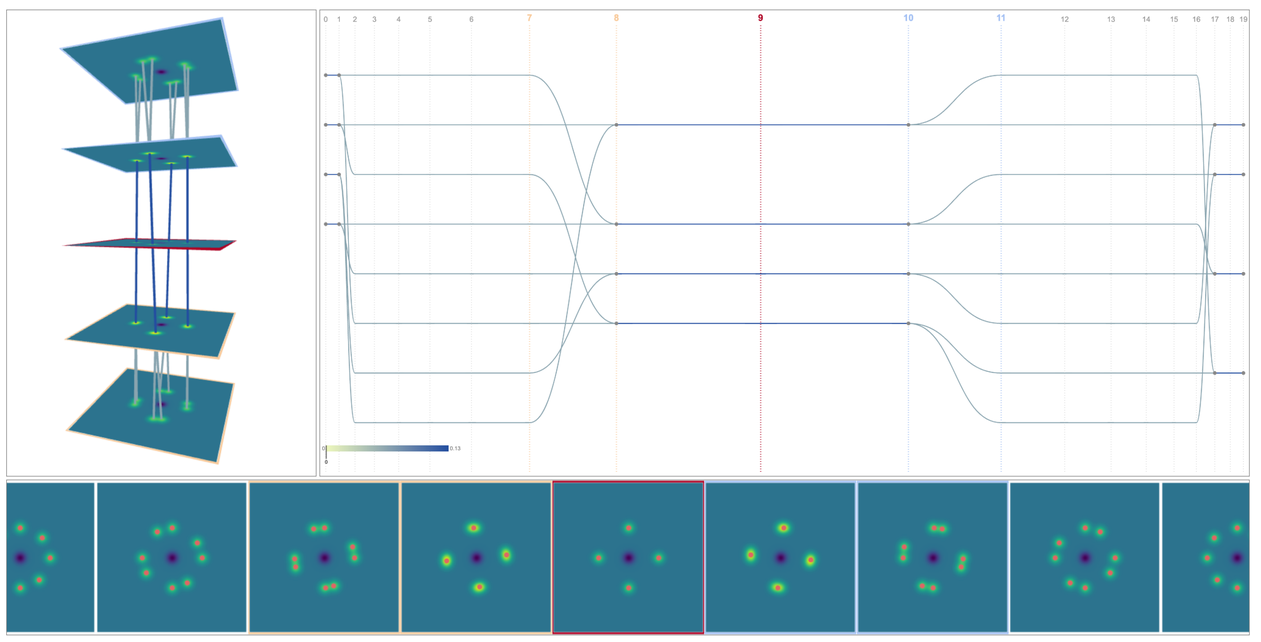
- Feature trajectories for scientific datasets

Tracking high density in ionization front[1]



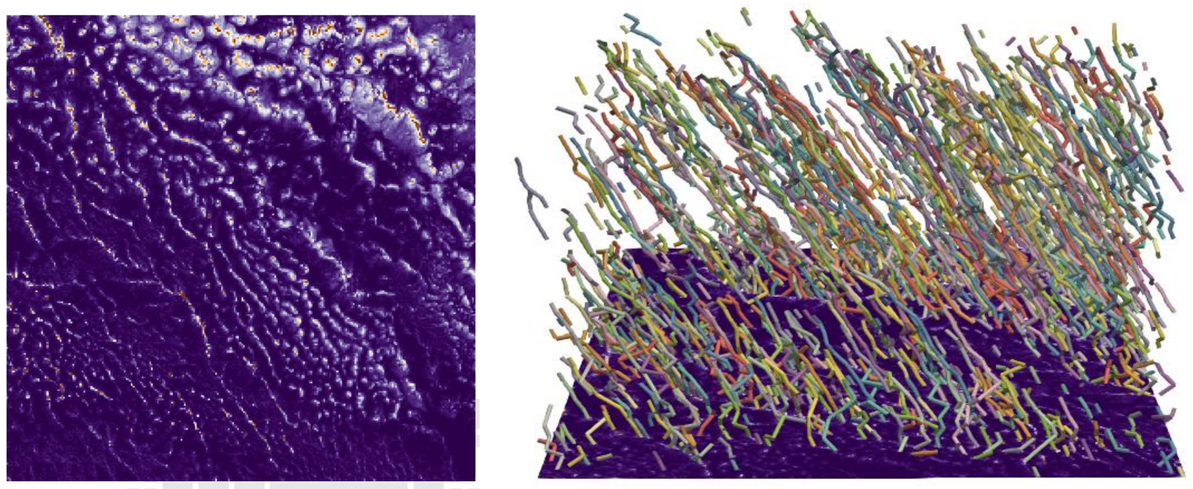
Tracking high vorticity in flow simulation[2]

- Probabilistic tracking graphs: a visualization tool
  - 3D View for feature trajectories in domain
  - tracking graphs for feature lifetime
  - probability of matching as the edge thickness

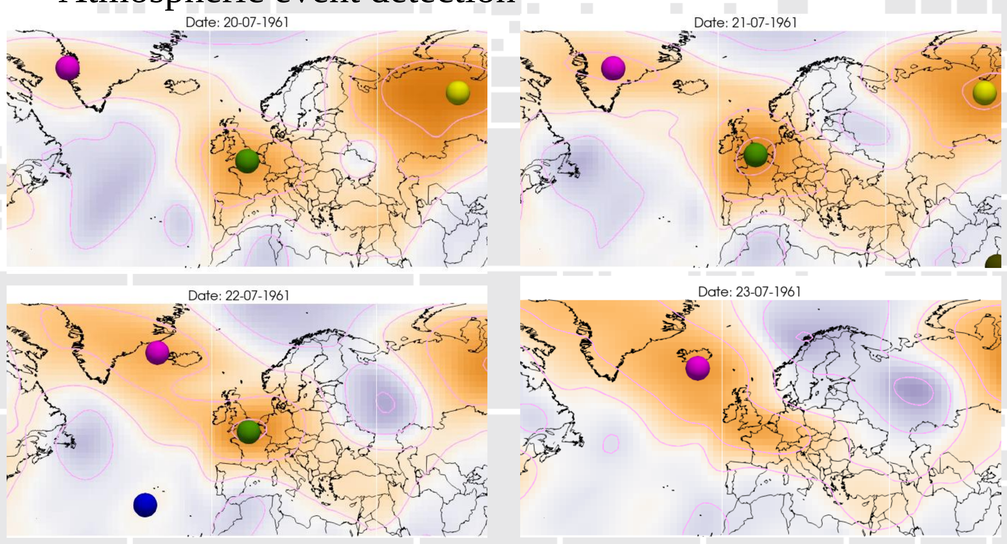


Applications

- Cloud tracking[3]



- Atmospheric event detection[4]



References

[1]. D. Whalen and M. L. Norman, "The IEEE SciVis Contest," http://vis.computer.org/VisWeek2008/vis/contests.html, 2008.
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[3]. A. Walther and A. Heidinger, "Implementation of the daytime cloud optical and microphysical properties algorithm (DCOMP) in PATMOS-x," Journal of Applied Meteorology and Climatology, vol. 51, pp. 1371–1390, 07 2012.
[4]. Sellar, A. A., Jones, C. G., Mulcahy, J. P., Tang, Y., Yool, A., Wiltshire, A., et al. (2019). UKESM1: Description and evaluation of the U.K. Earth System Model. Journal of Advances in Modeling Earth Systems, 11, 4513–4558. https://doi.org/10.1029/2019MS001739

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