Individual Tree Mapping from LiDAR point clouds based on topological tools

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Mapping individual tree structures from a LiDAR point cloud

- Problems
  - Forest understructure
  - Partial occlusions
  - Noise
- Methods focusing on geometry fit well on specific types of trees only

**Proposed approach**
1. Input – point cloud
2. Infer a topology to the point cloud by means of a VR complex
3. Compute a morphological representation by means of a Forman gradient
4. Simplify the Forman gradient for identifying relevant features

**Vietoris Rips (VR) complex**
- A VR complex is a simplicial complex obtained by connecting with an edge all the points closer than a specific distance and by computing the maximal cliques or the resulting 1-skeleton.

- Objective – infer a topology to the point cloud
- After creating the 1-skeleton from the point cloud we compute the cliques limiting their expansion to dimension three. (i.e., our simplicial complex will be composed by vertices, edges, triangles and tetrahedra)

**Discrete Morse Theory [Forman 1997]**
- Let $\Sigma$ a simplicial complex and $F$ a scalar function defined on its simplices.
- $F$ is a Forman function if, for every $i$-simplex $\sigma$ of $\Sigma$:
  - all the $(i-1)$-simplices $\tau$, faces of $\sigma$, $F(\tau) < F(\sigma)$, and
  - all the $(i+1)$-simplices $\delta$, cofaces of $\sigma$, $F(\delta) > F(\sigma)$

- V-path, is a sequence of simplices $[\sigma_0, \tau_0, \sigma_1, \tau_1, ..., \sigma_n, \tau_n]$ such that:
  - $\sigma_i$ and $\sigma_{i+1}$ are faces of $\tau_i$, and
  - $[\sigma_i, \tau_i]$ are gradient pairs.

- The collection of all the gradient pairs $V$ is a Forman gradient if all the V-paths are acyclic.

- Starting from a scalar function defined on the vertices of $\Sigma$ (i.e., the height function) we compute a Forman gradient by extending $F$ to the remaining simplices.

**Topological features and simplification**
- The Forman gradient provides a combinatorial representation for studying the evolution of the VR complex.
- Critical simplices identify the topological features of our dataset.
  - Minimum – point where the trunk connects to the ground
  - Saddle – point where a branch connects with the tree or two crowns overlap
  - Maximum – heights point reached by a tree
- By applying persistence based simplifications [Edelsbrunner et al. 2002] we remove the low level features (pair of critical points close in terms of function values) keeping only higher level features.

**Results**
- The proposed approach has been tested on a broadleaf dominated experimental forest in Maryland managed by the Smithsonian Environmental Research Center (http://www.sigeo.si.edu).
- Our preliminary implementation works on different subsets of the dataset independently. Approximately 90% of the trees are correctly split.
- The approach can be generalized to other types of forest by modifying the function values to find the most characteristics features.

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