Cost distance analysis of historical pilgrimage routes in Google Earth Engine

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BACKGROUND

- Least cost path (LCP) is a spatial analysis method used to identify the most cost-effective path between two locations.
- LCPs have many applications: planning for industrial pipelines, wildlife corridors, and printed circuit board layouts.
- In archeology and history, LCP is used to reconstruct most likely travel paths.
- LCP is implemented as a dynamic programming algorithm using cumulative cost surfaces as input.
- The cost is determined by the distance and slope, and relies on digital elevation models.

OUR GOAL

- Implement LCP in Google Earth Engine (GEE) to find historical pilgrimage routes because path-finding analysis does not exist in GEE at the time of writing.
- Run our algorithm with test data being the Camino de Santiago.

CHALLENGES

- GEE is built to be highly parallelizable but is poor at iterative algorithms like ones used in LCP, by nature of it being cloud-based.
- While GEE has a built-in cumulative cost function, which is used in LCP, iterative backlinking to determine a path needs to be done manually.

APPROACH

- Least cost corridor (LCC), a non-iterative path-finding algorithm, is used.
- While LCP identifies a precise one-pixel wide path, alternative paths with similar costs might exist, which LCC includes.[1]
- A slope-based hiking cost function is used to form cost surfaces, assigning each pixel with a value representing the effort required to hike across it, seen in Figure 3.
- While Tobler's Hiking Cost function is the most well-known, the Anaya Hernandez method appears to work better in mountainous environments, like the terrain in our test data.[2]

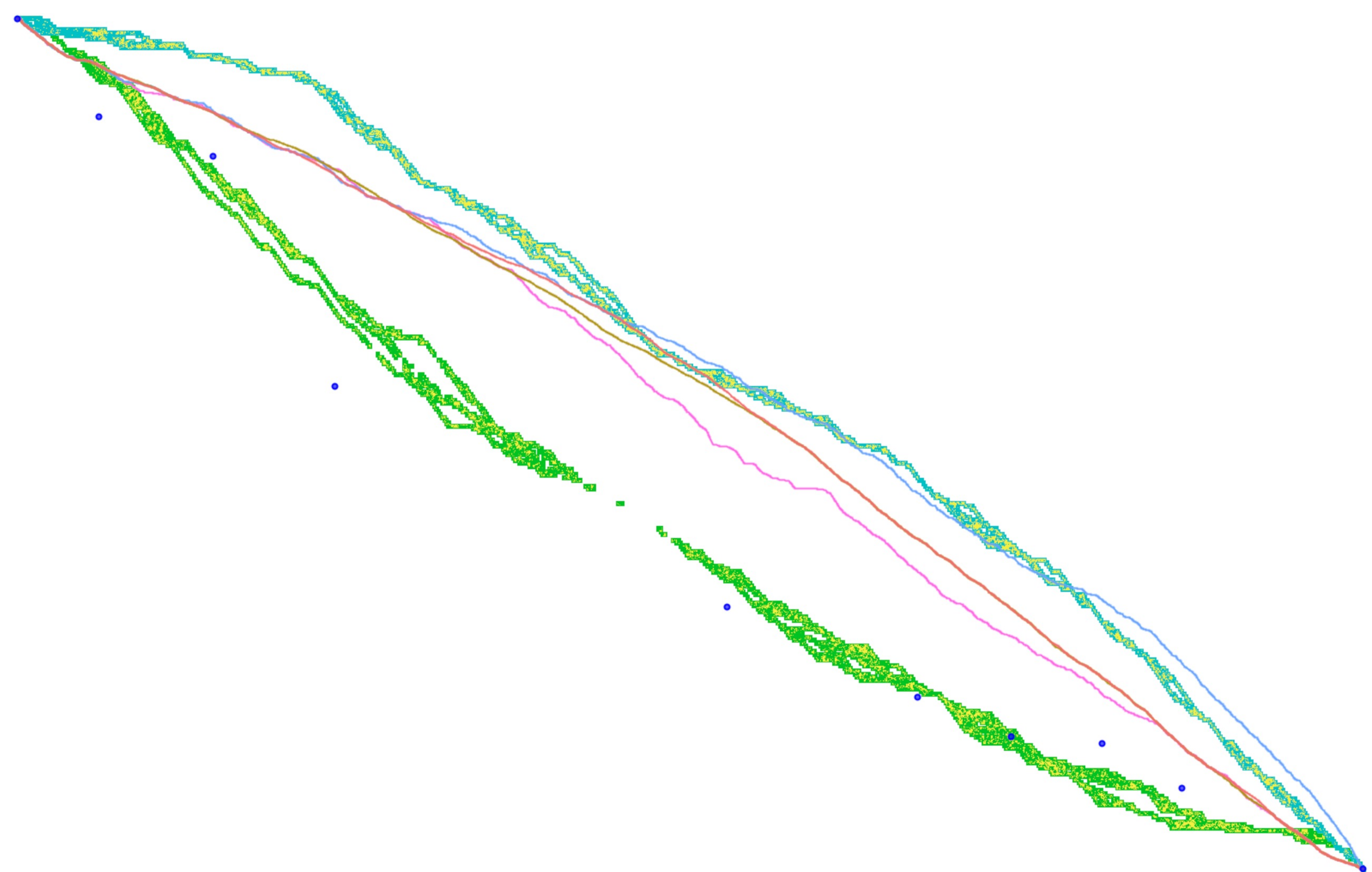

Figure 1. LCCs and LCPs between two furthest points with different software applications and cost functions

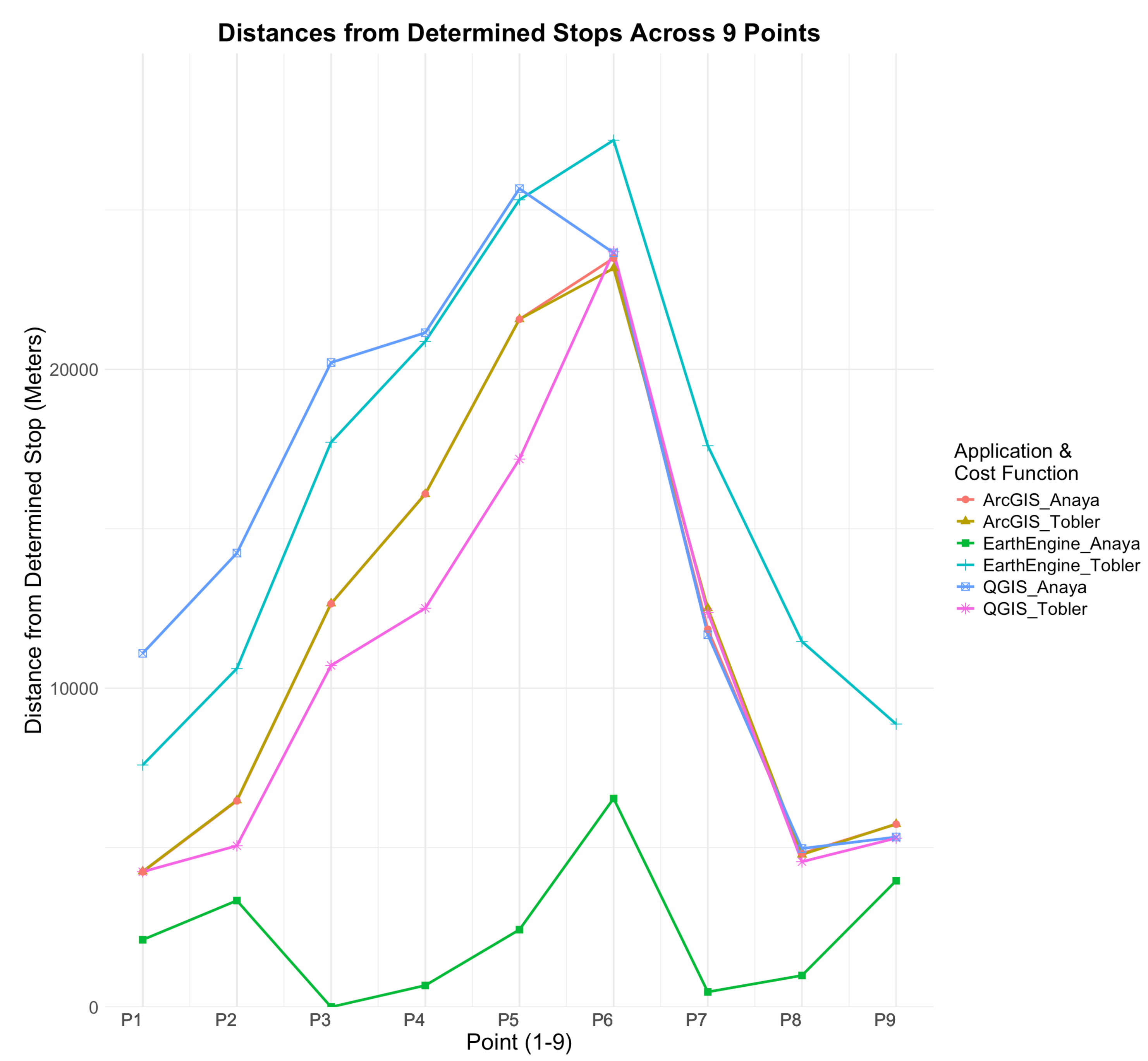

Figure 2. Chart of distances of LCCs and LCPs from known points

<u>Tobler's Hiking Cost</u>

Walking velocity (taken as cost) = $6e^{-3.5|\tan\theta + 0.05|}$

<u>Anaya Hernandez method</u>[3]

Cost = $0.031\theta^2 + (-0.025\theta + 1)$

Figure 3. Hiking cost functions, where θ is the slope

SOLUTION

- A multi-resolution cost surface model was adopted, which helps improve computational performance where the original cost raster is progressively downsampled.[4]
- LCC is determined on a low-resolution raster before gradually narrowing down to a final LCC on a high-resolution raster.
- Convolution edge detection with a Laplacian kernel is used to identify regions with low slope gradients, allowing for further narrowing of LCCs.
- Our LCC algorithm is particularly effective in mountainous terrain, covering the exact regions as LCP analysis for the two furthest points in traditional GIS tools as seen in Figure 4.

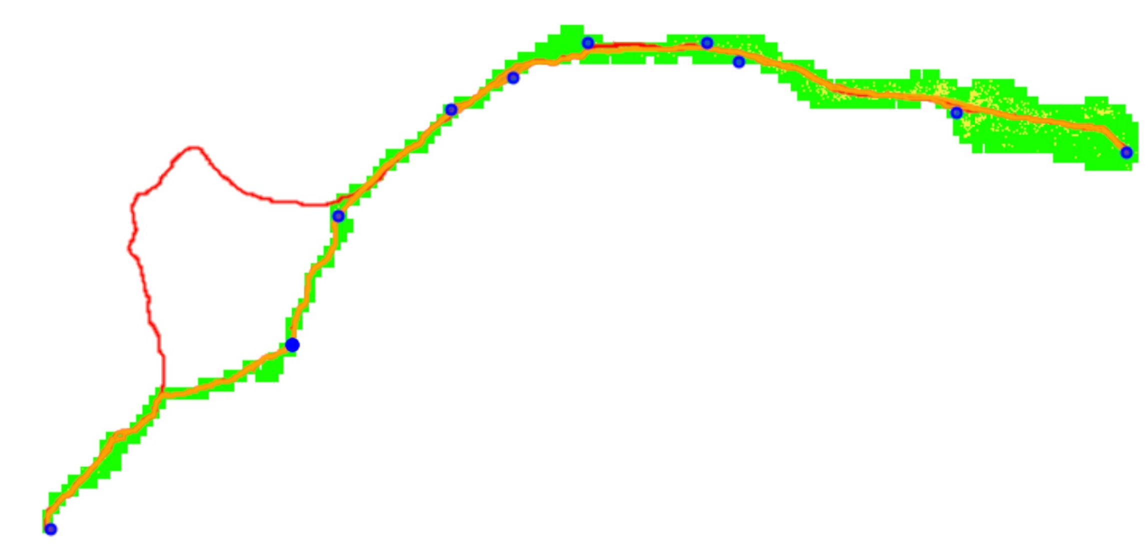

Figure 4. LCC and LCPs between two furthest points in mountainous region between France and Italy

DISCUSSION

- A major assumption and point for future improvement is the use of isotropic cost surfaces, where direction of travel is not considered.[5]
- This disregards how downhill movement can be more cost-effective than moving across flat surface, which can result in distortions from the actual LCC/LCP.
- Despite this, the algorithm remains useful in allowing historians to have a better idea of likely pilgrimage routes that considers hiking cost, including movement between all known points as seen in Figure 5.

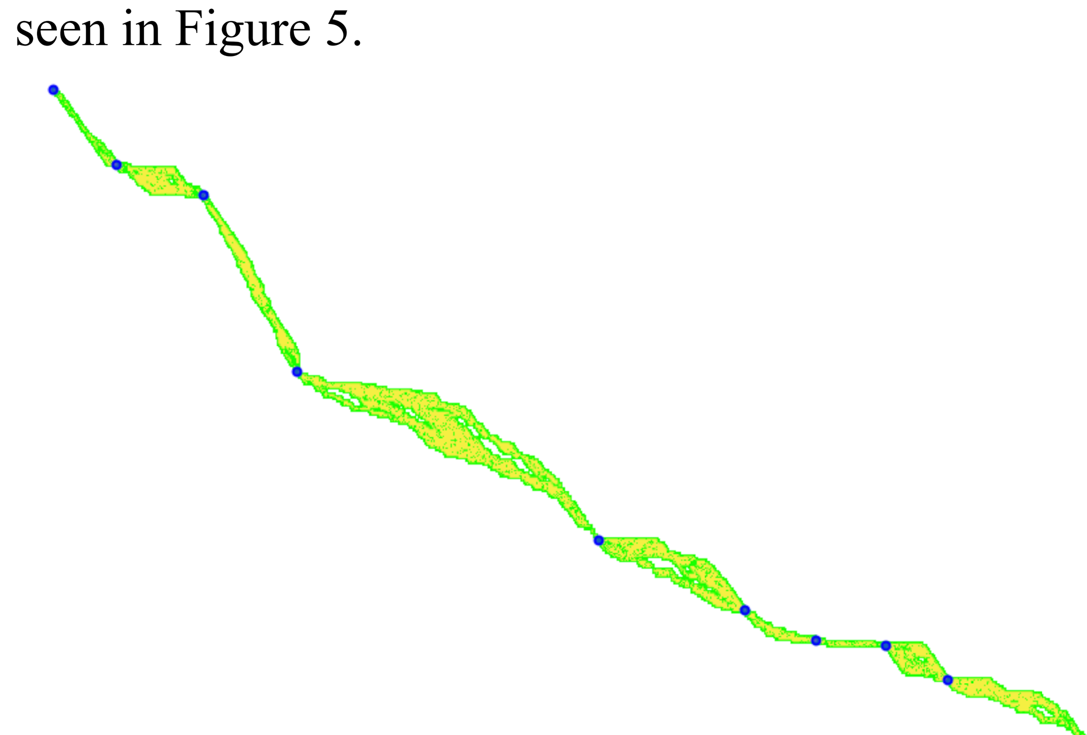

Figure 5. LCC between all known points

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