Virtually Unrolling the Herculaneum Papyri by Diffeomorphic Spiral Fitting

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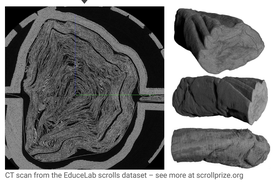
Code

Data & Competition

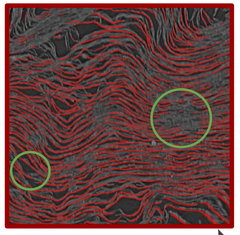
- **AD79:** papyrus scrolls charred & buried by Mount Vesuvius
- excavated starting c1752
- many are **impossible** to unroll physically
- solution: μCT scans + **virtual unrolling**
  - seek a 2D mesh representation of where the original papyrus surface passes in 3D

PHerc Paris 4
Photo: Vesuvius Challenge



CT scan from the EduceLab scrolls dataset – see more at scrollprize.org

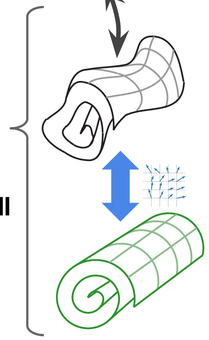
- **but:** CTs look like *this* 😱
  - very dense
  - very distorted
  - some wraps broken / missing
- neural networks can *kinda* localise the sheet – but many gaps & false joins



- cannot easily 'read off' a 2D surface mesh

Idea

- the physical scroll is a rectangular sheet, rolled up, then badly distorted following the eruption
- our aim: **invert** this process, *i.e.* **find a 'good' rolled sheet + deformation that explains the observed scan data**
- the deformation is a **diffeomorphism** that distorts an **ideal scroll** into the shape in the scans
- very different to existing bottom-up methods!



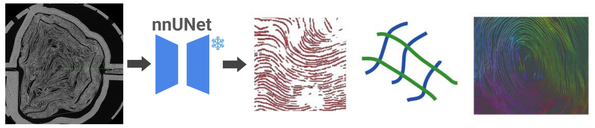
Model

- ideal scroll: extruded archimedean spiral $s(\theta, z; \omega) = \begin{pmatrix} \frac{\theta}{\omega}\cos\theta \\ -\frac{\theta}{\omega}\sin\theta \\ z \end{pmatrix}$
  - free parameter: winding rate ω
- deformation: three **diffeomorphic** stages
  - z-dependent global xy-scale
  - integrated constant velocity field
  - local scaling of winding gaps

$$\begin{cases} \frac{d}{dt}\phi^{(t)}(\mathbf{x}) = \mathbf{u}\left(\phi^{(t)}(\mathbf{x})\right) \\ T_{\text{flow}}(\mathbf{x}) = \phi^{(1)}(\mathbf{x}) \\ \phi^{(0)}(\mathbf{x}) = \mathbf{x} \end{cases}$$

Fitting

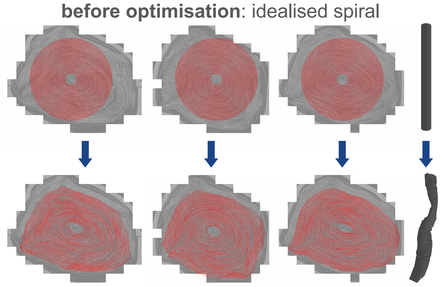
- **targets:** use pre-trained nnUNet to extract (imperfect) **surfaces**, **papyrus fibers**, and **normals**



- optimise **winding density** & **diffeomorphism** jointly to match these
- **losses:** – (deformed) spiral normals match predictions
  – points on the same predicted surface (connected component) lie on the same deformed spiral winding
  – average spacing of deformed spiral windings matches that of predicted surfaces
  – each predicted surface/fiber is near one spiral winding

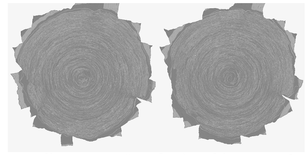
Results

- validated on two Herculaneum papyri
- quantitative results better *ThaumatoAnakalyptor*, the only other fully-automated approach that can tackle large portions of these scrolls

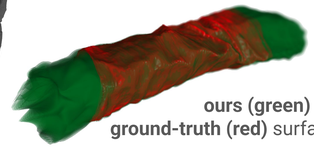


before optimisation: idealised spiral

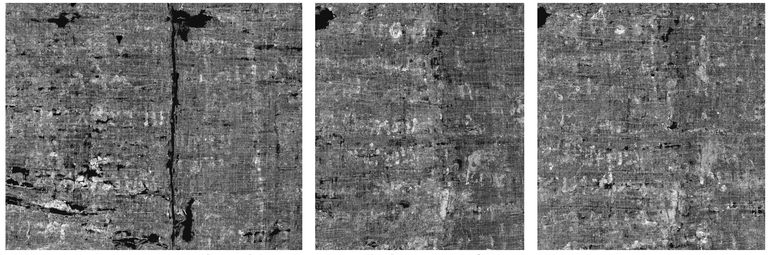
after optimisation: spiral conforms to scroll



scroll wraps **circularised** by passing through the inverse diffeomorphism



ours (green) and **ground-truth (red)** surfaces



Ink visible in our unrolled version of PHerc 0172

Ink detected in our unrolled version of PHerc Paris 4