A Python Toolbox for Shape Detection and Analysis in Images

Günay Doğan
Theiss Research, National Institute of Standards and Technology (NIST)
gunay.dogan@nist.gov

We present a Python toolbox for shape detection, image segmentation, and shape analysis. The basis of our approach is to express the shape detection or segmentation problem as a shape optimization problem, in which the sought unknowns are shapes, such as 2d curves or 3d surfaces outlining the boundaries of objects or regions in images. For this, we work with specialized shape energies corresponding to the detection or segmentation problem. We then iteratively compute the optimal shapes Γ minimizing these energies. The energies typically have the following form:
$E(\Gamma) = Data(\Gamma, I(x)) + Prior(\Gamma) + Regular(\Gamma)$,
where $I(x)$ is the image data, $Data(\Gamma, I(x))$ is a data fidelity term based on the image data, $Prior(\Gamma)$ encodes prior knowledge on the statistical distribution of the shapes, and $Regular(\Gamma)$ is a geometric regularization term to enforce smoothness of the shapes. Many such energies have been proposed in the image processing community. Some examples are the Geodesic Active Contour energy [1], the two-phase Chan-Vese energy [2], and a recent piecewise constant multiphase segmentation energy [3].

We have developed efficient and robust numerical algorithms to perform minimization of the energy, and to compute its minimizers. We provide these algorithms packaged as a free, open-source Python module to the research community. Using Python as the development language makes it easy to combine modules in Fortran and C. Moreover, it easily interfaces with other image processing and machine learning packages, e.g. SciPy, scikit-image, scikit-learn, CellProfiler, OpenCV, ITK, etc. We have built on the NumPy and SciPy packages to enable Matlab-like interactivity with advanced scripting capabilities. Our implementation integrates the following key algorithmic ideas to enable an effective solution of the problem:

- The shapes (currently curves) have explicit Lagrangian representations, which are compact and efficient (no parameterization or level sets or involved).
- The differential equations to be solved at each update iteration of the curve moves are discretized with the finite element method. This results in linear time computation per iteration with respect to number of nodes of the curve.
- The geometry is discretized adaptively. Fewer nodes are used where the geometry and data are smooth, whereas more nodes are added to resolve highly varying geometry and data.
- Fast Newton-type iterations are used to converge to the solution in fewer iterations [4].
- Stable time discretizations and intelligent step size controls are used to take large steps without destroying the quality of the curve representation [3].

We are currently working on expanding the collection of segmentation energies available for the user, refining the optimization results using estimated errors and uncertainty, and quantifying shape dissimilarity with elastic shape distance formulation [5, 6]. We will also extend to 3d shape analysis using triangulated surfaces.

References

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