Computer Vision in R: Enabling Flyby Science at Comets and Asteroids

Thomas J. Fuchs*, David R. Thompson, Brian D. Bue, Julie Castillo-Rogez, Kiri L. Wagstaff

Jet Propulsion Laboratory, California Institute of Technology
*Contact author: thomas.fuchs@jpl.nasa.gov

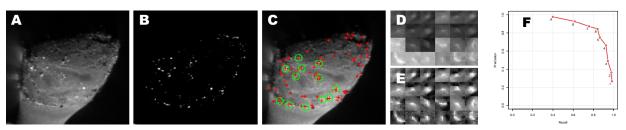
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Computer Vision is a vast field of research and integral part of scientific inquiry from biology and medicine to earth science and space exploration. While *R* provides an exceptional portfolio of statistical packages it has historically been very weak in computer vision. Some packages provide wrappers to external software like GDAL, ImageJ or ImageMagick but an *R* -specific computer vision framework is still missing to date. To close this gap we are developing **visionaRy**. The purpose is to provide an *R* package which allows for fast prototyping of image intensive algorithms in *R* with standard *R* data structures and standard *R* syntax. We are convinced that the benefit of directly manipulating images and easily using the complete statistical machinery of *R* outweighs the loss of processing speed for a wide range of scientific scenarios. Furthermore, since this implementation is based on standard *R* structures replacing specific methods in **Rcpp** is straightforward.

While the package is intended for a general computer vision and image processing audience some methods are tailored towards applications in space exploration. To this end **visionaRy** contains methods for retrieving imagery from NASA's Planetary Data System (PDS: pds.nasa.gov) and for decoding raw data from space missions stored in JPL . IMG format.

Specifically, we represent images as arrays within a Reference Class which allows for image manipulation in place without unnecessary copying of data. Based on that we can provide an extensive set of *drawing* methods for geometric primitives like lines, circles, or rectangles which enables image annotation by modifying pixel intensities in the array itself. Compared to classic *R* plotting operation on some output device, *drawing* yields precise annotations in the same coordinate frame in which all algorithms operate.

visionaRy provides a unified interface for reading and writing a broad range of file formats, image processing functionality such as color conversion, image overlays, and scaling as well as display functions on single and multiple panels, tiling and patch extraction. Furthermore **visionaRy** implements several computer vision algorithms ranging from integral images, 3D color histograms, and edge preserving median filters to binary and intensity weighted mean shift clustering in image space. Since the underlying data structure is a standard *R* array we can employ the full breath of *R* 's statistical tool chest for feature extraction and classification.



We demonstrate the capabilities of **visionaRy** with an application for flyby science at small bodies from JPL (cf. Fig.): **A:** First we retrieve images of comet Hartley 2 taken by the framing camera of the Deep Impact probe during the EPOXI mission from PDS. **B:** The difference of the grayscale and median filtered image is renormalized. **C:** Set of possible surface features as a result of weighted mean shift clustering (red crosses) and ground truth labels from a domain expert (green circles). **D:** Patches of labeled surface features from 9P/Tempel. **E:** Locally normalized patches, constituting the positive class for training. **F:** Finally we train a random forest classifier to differentiate surface features from background and report precission and recall on the test set.