Multisource data fusion and super-resolution from astronomical images

A. Jalobeanu

LSIIT (UMR 7005 CNRS-ULP) @ ENSPS, Illkirch – France

Abstract. The goal is to combine multiple astronomical images of the same field of view into a single model, within the Virtual Observatory framework where the huge amounts of data often exhibit some redundancy. To achieve this goal, we propose to develop a multi-source data fusion method using probability theory. We want to infer an image from several blurred and noisy observations, possibly from different sensors and instruments under various conditions. We aim at the recovery of a compound object "image+uncertainties" that contains a maximum of useful information from the initial data set. In some cases, conserving information may require achieving super-resolution. We propose to use a Bayesian inference scheme to invert a generative model that explains the image formation for each observation while taking into account a priori knowledge. Understanding the image formation process is crucial. The originality of the work is in devising a new technique of multi-image data fusion that also addresses spatial super-resolution and recursive model updating. This involves both automatic registration and resampling, which are difficult inverse problems that are treated within a probabilistic framework. Our contribution outperforms state of the art methods in astronomy since it can handle different instrument characteristics for each input and provide uncertainty estimates as well.

1. Probabilistic data fusion

Multi-source data fusion can be viewed from three different perspectives: data enhancement, decision making and optimal data reduction. Although the first two are the most popular, we choose the third category, wishing to reconstruct an object that reduces the complexity of the data set while conserving the maximum amount of information. The goal is to embed all measurements in a single model, free of instrumental effects, while minimizing the information loss, the noise contribution and the redundancy. This should help any subsequent data analysis, which would be greatly simplified through the use of a single object instead of multiple, heterogeneous sources.

Here we focus on astronomical images observed through multiple instruments, and we aim at reconstructing such images through a probabilistic framework, with sampling theory, geometry and noise modeling as basic ingredients.

To avoid losing information, it is necessary to fuse the data into a multivariate probability distribution, since the observations are realizations of random variables. Restricting to an image-like, deterministic object would imply an obvious loss not only of local uncertainties, but also of correlations between variables in the reconstructed object. Indeed, initial uncertainties originating from the noise process (photon counting, thermal and readout noise) propagate through to the very final stage of the processing. Source observations are redistributed into the new object so that final variables become entangled. The uneven contri-
butions of the observations to each final variable, as well as the possible spatial dependence of the noise, are strong evidence that model uncertainties are useful information that ought to be retained during the fusion. We adopt a Bayesian framework as in Gelman et al. to devise a general method for band-limited signal reconstruction (Jalobeanu and Gutiérrez); we aim at a critically sampled image where point sources are shifted B-Splines. It can be interpreted as a generalization of Spline interpolation/reconstruction to blurred, noisy, arbitrarily sampled and multiple observations, where we use a priori knowledge such as image smoothness to deal with underdetermination.

2. Fusion and super-resolution in astronomy

The figure below shows the results of a 2x super-resolution experiment from 4 simulated astronomical images corrupted by Gaussian noise. The observations were generated from a known ground truth (background and 6 point sources) using shift, blur and sampling, in such a way that they were undersampled by a factor 2. Notice the fluctuations in the star photometry. The shifts (pointing pattern) are far from ideal such that a simple interlacing can not solve the problem. Super-resolution and uncertainties are necessary in order to conserve the information. For sake of clarity only a subset of the diagonal elements of the inverse covariance matrix (uncertainties) are displayed, showing strong spatial variations due to the different contributions of input to output pixels. Covariance terms (not shown) are also part of the results. Drizzling (Fruchter and Hook) was also applied; some artifacts are obvious (texturing and star shear).

References

