SBA: Generic sparse bundle adjustment

Given a set of images depicting a number of 3D points from different viewpoints, *Bundle Adjustment* (BA) is the problem of simultaneously refining the 3D coordinates of these points as well as the parameters of the relative motion and the optical characteristics of the camera(s) employed to acquire the images, according to an optimality criterion involving the corresponding image projections of all points. BA amounts to a large-scale non-linear optimization problem on the 3D structure and viewing parameters (i.e., camera pose and possibly intrinsic calibration and radial distortion). It is used as the last step of most feature-based 3D reconstruction vision algorithms, since its solution yields a reconstruction which is optimal under certain assumptions regarding the noise pertaining to the observed image features: If the image error is zero-mean Gaussian, then BA provides the Maximum Likelihood Estimator. Owing to the large number of the variables involved, general-purpose numerical optimization codes incur high computational and storage costs when applied to BA.

BA boils down to minimizing the reprojection error between the image locations of observed and predicted image points, which is expressed as the sum of squares of a large number of nonlinear, real-valued functions. Thus, the minimization is achieved using nonlinear least-squares algorithms, of which Levenberg-Marquardt has proven to be of the most successful. By iteratively linearizing the function to be minimized in the neighborhood of the current estimate, the Levenberg-Marquardt algorithm involves the solution of linear systems known as the normal equations.

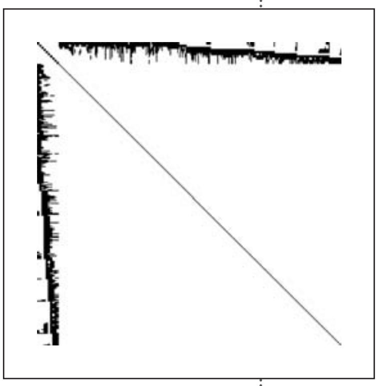
When solving the minimization problems arising in the context of BA, the underlying normal equations have a sparse block structure owing to the lack of interaction among parameters for different 3D points and cameras. This can be exploited to gain tremendous computational benefits by employing a sparse variant of the Levenberg-Marquardt algorithm, which explicitly takes advantage of the normal equations zeros pattern, avoiding storing and operating on zero elements.

SBA is a C/C++ software package for generic sparse BA that is based on a sparse variant of the Levenberg-Marquardt algorithm tailored to the zero pattern of the normal equations arising in BA. It is generic in the sense that it grants the user full control over the choice of coordinate systems, parameters and functional relations describing cameras, 3D structure and image projections. SBA can be invaluable to researchers and practitioners in the fields of computational vision, robotics, image-based graphics, photogrammetry, surveying, cartography, etc. It is being used in several laboratories around the globe and is currently the only such software worldwide to be offered in source under the GNU General Public License (GPL) with the option of commercial licensing.

More details and the source code can be found at http://www.ics.forth.gr/~lourakis/sba.

Contact Person:

Dr. Manolis Lourakis
Principal Researcher
lourakis@ics.forth.gr



Sparsity pattern of the approximate 992x992 Hessian corresponding to a modestly sized BA problem. Black regions correspond to nonzero blocks

FORTH
ICS

COMPUTATIONAL VISION AND ROBOTICS LABORATORY (CVRL)

The Computational Vision and Robotics Laboratory (CVRL) of FORTH-ICS was established in 1985. The research and development efforts at CVRL focus on the areas of computational vision and autonomous mobile robots that perceive their environment and exhibit intelligent behaviours.

Research in this field has theoretical interest because it leads to the computational and mathematical modelling of perception and action, and contributes to a better understanding of the mechanisms involved in the corresponding capabilities of biological organisms. Furthermore, this research is of practical interest because it forms the basis for the development of interesting and often significant robotic systems, such as robotic wheelchairs for people with disability, tour-guide robots in museums and other exhibitions, robots performing routine tasks such as cleaning and surveillance. Moreover, by-products of this research prove extremely useful in other application areas that are not directly related to robotics, such as virtual and augmented reality, 3D modelling and environmental monitoring, event detection, and content-based image retrieval. Efforts at CVRL are balanced between basic and applied research, resulting in the construction of robust vision and robotic systems for various application domains.

Contact Person:

Panos Trahanias
Professor of Computer Science
Head of CVRL
trahania@ics.forth.gr

FORTH
ICS

Foundation for Research and Technology - Hellas (FORTH) ● Institute of Computer Science (ICS)
N. Plastira 100, Vassilika Vouton, GR-70013 Heraklion, Crete, Greece ● TEL: +30.2810391600 ● FAX: +30.2810391601 ● www.ics.forth.gr