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Guest Editorial JMIV Special Issue SSVM'23

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This Special Issue explores the exciting new developments shaping the field of computer vision and image analysis. It emphasizes the collaboration between cutting-edge mathematical techniques (including optimization, variational methods, statistics, inverse problems, multiscale analysis, and partial differential equations) and machine learning towards the solutions of various challenging problems in image processing and computer vision. This Special Issue is related to the 9th edition of the International Conference on Scale Space and Variational Methods in Computer Vision (SSVM 2023) which took place from May 21–25, 2023 in the small town of Santa Margherita di Pula, on the Sardinian coast in Italy. This selected research collection features twelve papers covering the main topics presented at SSVM2023 related to computer vision and image analysis, including diverse themes such as 3D-vision, convex and non-convex variational modeling, image analysis, inverse problems in imaging, optimization methods in imaging, machine learning in imaging, PDEs in image processing, registration, restoration and reconstruction, scale-space methods, and segmentation.

In the following we provide a short overview of the topics covered by the scientific contributions in this special issue.

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1 Topics of the Special Issue

1.1 Inverse Problems in Imaging

Inverse problems in imaging tackle the challenge of recovering the original scene or object from the often indirect and incomplete data captured by imaging devices. Recent approaches rely on the use of advanced non-convex regularization models, density-estimation/sampling approaches.

The paper by E. Chouzenoux, M. C. Corbineau, J. C. Pesquet, and G. Scrivanti presents a variational model for joint image restoration and feature-extraction. The non-smooth and non-convex variational formulation introduced is equipped by a space-variant generalised Gaussian prior. The optimization problem is efficiently solved by an alternating proximal-based algorithm.

In the paper by the authors M. Zach, E. Kobler, A. Chambolle and T. Pock a novel product-of-experts model is proposed by using Gaussian mixture experts for density estimation via diffusion processes, particularly applied to image processing tasks like denoising. The model, which is analytically tractable and interpretable, demonstrates competitive performance with few learnable parameters and can also reliably estimate noise levels for blind denoising of images affected by varying noise intensities.

E. Gofer and G. Gilboa in their contribution to the SI generalize some known concepts of inverses of linear operators of the case of general nonlinear operators. The first part discusses generalizations of the Moore-Penrose generalized inverse, while the second part deals with the Drazin inverse using algebraic techniques.

1.2 Machine and Deep Learning in Imaging

Neural networks have gained significant traction as a method for solving inverse problems in imaging in recent years. However, despite the development of numerous empirical methods, a clear and rigorous theoretical understanding of their guarantees remains elusive.

A promising step forward for this research direction is provided in the paper by N. Buskulic et al. where rigorous results on both convergence for the network and recovery of the solution are proved for a broad class of loss functions verifying the Kurdyka–Łojasewiecz inequality.

In the paper by Z. Lambert and C. Le Guyader, a hybrid Deep-learning/variational framework is proposed for image registration and segmentation using a loss function that incorporates topological knowledge in a 2D-CNN training. This ensures topology preservation and guarantees area conservation.

1.3 Optimization for Imaging: Theory and Methods

Optimization methods play a crucial role in imaging science, and its combination with the deep learning realm has provided tremendous boosting in both areas.

H. Shi, Y. Traonmilin and J.-F. Aujol, in their contribution to the SI, proposed a regularizer parametrized with a neural network is learned within a compressive learning framework, by means of a suitable stochastic gradient descent algorithm. Applications of the approach in denoising tasks on synthetic 2-D and 3-D audio data, and real images show good computational efficiency and quality of the trained regularizers.

A framework for the estimation of off-the-grid curves, with a piecewise affine practical estimation method is introduced by B. Laville, L. Blanc-Féraud and G. Aubert. This is based on a novel Frank–Wolfe algorithm for reconstructing vector measures regularized with their total variation and the total variation of their divergence. The paper presents numerical experiments as well as a Γ-convergence result of the discretized surrogate functional towards the continuous energy.

In the paper by S. Hurault, A. Chambolle, A. Leclaire and N. Papadakis the authors propose a framework for convergent plug & play optimization algorithms such as Douglas–Rachford and Forward–Backward splitting which overcomes the unitary step-size restriction required by standard analyses. Several numerical results on some exemplar image restoration problems show outperformance in comparison to standard approaches.

1.4 Scale Space, PDEs, Flow, Motion and Registration

Within image processing literature, the concept of scale-space is typically formalized as the solution to an initial value problem described by a partial differential equation (PDE), such as a diffusion equation, which can be either linear or nonlinear. Alternatively, scale-spaces can be defined in an axiomatic way starting from a fixed-scale image operator (e.g. a linear convolution or a morphological erosion) and a group of scalings.

A new PDE-based inpainting method is proposed by K. Schaefer and J. Weickert. They applied a regularised diffusion-shock model to the image inpainting problem, which combines homogeneous diffusion and coherence-enhancing shock filtering.

P. Peter deals with diffusion probabilistic models for sampling new images from learned distributions. The author proposes a generalised scale-space theory for diffusion probabilistic models showing conceptual and empirical connections to diffusion and osmosis filters.

A multi-metric approach to analyze and process objects in 3D is presented by D. Bensaïd and R. Kimmel, which is achieved by the spectral decomposition of Laplace-Beltrami operators defined with various metric tensors. This multi-spectra characterization of a smooth surface allows each metric to provide a distinct perspective of the shape.

In the paper by A. Fazeny, D. Tenbrinck, K. Lukin, and M. Burger the authors revisit the definition of differential operators on hypergraphs focusing on the definition of Laplacian and p-Laplace operators for oriented and unoriented hypergraphs, their basic properties, variational structure, and their scale-spaces. It also illustrates different applications on social networks or image processing.

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