PhD in Physics

Research Title: Reconstruction problems and tomography

Funded by	Interdepartmental Centre for SmartData (SmartData@PoliTo) Politecnico di Torino

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Context of the research activity	Linear estimation problems are ubiquitous in computer science, life science, and physics. In brief, these problems can be posed as finding solutions to an under-determined linear system of equations for which infinitely many solutions exist. Important examples are compressed sensing problems [1], and tomographic reconstruction [2], the inference of brain activity from EEG and fMRI recordings [3], problems related to the inference in flow networks, including those arising on the modelling of cell metabolism [4-6] and some neural network learning problems [7]. In a Bayesian framework, the space of solutions is weighted by a prior distribution, and the problem consists in finding a maximum a posteriori point or some other statistical observables. Prior distributions of interest in applications are typically highly non-linear, and depend on a specific datasets of sub-problems, rendering the exact relevant computations intractable. Classical approaches employ linear or quadratic terms as a proxy for non-linearities (see e.g. basis pursuit methods [8], Loretta priors [9], l_1-norm [10]). In the last years, several Statistical Physics computational techniques, including advanced mean-field methods (e.g. GAMP, adaptive TAP), that were originally devised to approximate complex probability distribution arising in models of many interacting bodies or agents, were shown to be applicable to non-linear problems of this type with large success. The methods lead naturally to algorithmic solutions that are typically very simple and iterative, qualities that render them extremely interesting in applications. *The research activity fits in the SmartData@PoliTo interdepartmental center, that brings together competences from different fields, ranging from modeling to computer programming, from communications to statistics. The candidate will join this interdisciplinary team of experts and collaborate with them.*

	References [1] Baraniuk, R.G., Cevher, V., Duarte, M.F., Hegde, C., 2010. Model-Based Compressive Sensing. IEEE Transactions on Information Theory 56, 1982–2001. doi:10.1109/TIT.2010.2040894 [2] Gouillart, E., Krzakala, F., Mézard, M., Zdeborová, L., 2013. Belief-propagation reconstruction for discrete tomography. Inverse Problems 29, 35003. doi:10.1088/0266-5611/29/3/035003 [3] Martínez-Montes, E., Valdés-Sosa, P.A., Miwakeichi, F., Goldman, R.I., Cohen, M.S., 2004. Concurrent EEG/fMRI analysis by multiway Partial Least Squares. NeuroImage 22, 1023–1034. doi:10.1016/j.neuroimage.2004.03.038 [4] Braunstein, A., Mulet, R., Pagnani, A., 2008. Estimating the size of the solution space of metabolic networks. BMC Bioinformatics 9, 240. doi:10.1186/1471-2105-9-240 [5] Braunstein, A., Muntoni, A.P., Pagnani, A., 2017. An analytic approximation of the feasible space of metabolic networks. Nature Communications 8, 14915. doi:10.1038/ncomms14915 [6] De Martino, D., Figliuzzi, M., De Martino, A., Marinari, E., 2012. A Scalable Algorithm to Explore the Gibbs Energy Landscape of Genome-Scale Metabolic Networks. PLoS Comput Biol 8, e1002562. doi:10.1371/journal.pcbi.1002562 [7] Braunstein, A., Zecchina, R., 2006. Learning by Message Passing in Networks of Discrete Synapses. Phys. Rev. Lett. 96, 30201. doi:10.1103/PhysRevLett.96.030201 [8] Tibshirani, R. (1996). *Regression shrinkage and selection via the lasso*. J. Royal. Statist. Soc B., Vol. 58, No. 1, pages 267-288. [9] Pascual-Marqui R. *Standardized low resolution brain electromagnetic tomography (sLORETA):* technical details. Methods Find. Exp. Clin. Pharmacol. 2002;24:5–24. [10] Donoho, David L and Maleki, A and Montanari, A, Message-passing algorithms for compressed sensing, Proceedings of the National Academy of Sciences, 106:45, 18914, 2009.

Objectives	This Ph.d. position will be devoted to theoretical aspects of reconstruction problems, with special emphasis in the adaptive TAP method for the analysis of Bayesian problems with non-linear prior information coming from real datasets. This will involve successfully modelling distributions of real data in some subdomain (e.g. natural and tomographic images), and the development of methods to solve approximately the resulting Bayesian problem.