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Bayesian Inference and Maximum Entropy Methods in Science and Engineering (MaxEnt 2014)

Clos Lucé, Amboise, France

21–26 September 2014

Editors

Ali Mohammad-Djafari and Frederic Barbaresco

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POSTER SESSIONS

Preface: Bayesian Inference and Maximum Entropy Methods in Science and Engineering (MaxEnt 2014)

On behalf of both organizing and scientific committees, it was a great pleasure to welcome all delegates, representatives and participants from around the world to MAXENT 2014 conference. The thirty-fourth International Workshop on Bayesian Inference and Maximum Entropy Methods in Science and Engineering was held in France, organized by SEE (https://www.see.asso.fr/en), under the auspices of Centre national de la recherche scientifique (CNRS), École supérieure d'électricité (SUPÉLEC) and Université Paris Sud (UPS), Orsay. MAXENT 2014 benefited from scientific support of SMF (Société Mathématique de France: http://smf.emath.fr/), and financial sponsoring from Jaynes foundation.

MaxEnt 2014 took place in the Château Le Clos Lucé (http://www.vinci-closluce.com/en/), the last residence of Leonardo Da Vinci, in Amboise at the heart of Loire Valley Castles, labeled by UNESCO as World heritage. Le Clos Lucé is at proximity of King Francis the First Amboise Castle, apex of the French Renaissance and of Vouvray wines vineyards and cellars. We express all our thanks to the Clos Lucé Castle and Saint Bris Family for hosting this event in this historical place.

MaxEnt 2014, as usual, strived to present Bayesian inference and Maximum Entropy methods in data analysis, signal and image processing, information processing and inverse problems from a broad range of diverse disciplines: Astronomy and Astrophysics, Geophysics, Medical and Molecular Imaging, Non Destructive Evaluation, Particle and Quantum Physics, Physical and Chemical Measurement Techniques, Economics and Econometrics.

MaxEnt 2014's special interest was Geometrical Sciences of Information/ Information Geometry and their link with classical subjects of MaxEnt workshops which are Entropy, Maximum Entropy and Bayesian inference in sciences and engineering. The focus was more on using these concepts in generic Inverse problems, multidimensional and multi components Time Series Analysis and Spectral Estimation, Deconvolution and Source Separation, Segmentation, Classification and Pattern Recognition, X-ray, Diffractive, Diffusive and Quantum Tomographic Imaging.

Bayesian Inference and Maximum Entropy Methods in Science and Engineering (MaxEnt 2014)
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Specifically, MaxEnt 2014’s technical program had covered topics and highlights in the domain of “Geometric Science of Information” including Information Geometry Manifolds of structured data/information and their advanced applications. These topics addressed inter-relations between different mathematical domains like shape spaces (geometric statistics on manifolds and Lie groups, deformations in shape space), probability/optimization and algorithms on manifolds (structured matrix manifold, structured data/Information), relational and discrete metric spaces (graph metrics, distance geometry, relational analysis), computational and hessian information geometry, algebraic/infinite dimensional/Banach information manifolds, divergence geometry, tensor-valued morphology, optimal transport theory, manifold & topology learning.

In MaxEnt 2014, we had 8 Tutorials:

- Modern Probability Theory by Kevin H. Knuth
- The Basics of Information Geometry by Ariel Caticha
- Voronoi diagrams in information geometry by Franck Nielsen
- Foundations and Geometry by John Skilling
- Uncertainty quantification for computer model by Udo V. Toussaint
- Geometric Structures Induced From Divergence Functions by Jun Zhang
- Koszul Information Geometry and Souriau Lie Group Thermodynamics by Frédéric Barbaresco
- Bayesian and Information Geometry in signal processing by Ali Mohammad-Djafari,

and 4 keynote presentations:

- On the Structure of Entropy by Prof. Mikhail GROMOV (Abel Prize, IHES, Bures-sur-Yvette, France);
- Topological forms of information by Prof. Daniel BENNEQUIN (member of l'Institut Mathématique de Jussieu, Denis Diderot University, Paris, France);
- *The entropy-based quantum metric*” by Prof. Roger BALIAN (Member of French Academy of Sciences, Scientific Consultant of CEA, France)
- *Duhem’s abstract thermodynamics*” by Prof. Stefano BORDONI (associate professor of logic, philosophy and history of science, Bologna University, Italy).

We would like to acknowledge all the Scientific Committee members, all the local organizing committee members, all the chairmen and participants for their hard work in evaluating submissions. We also give our thanks to the authors and co-authors, for their tremendous effort and scientific contribution. Thanks to Flore Manier who insured the secretariat of the workshop. We would like to thank in particular Mircea Dumitru for all his efforts during the workshop for helping the participants, for co-organizing with Nicolas Gac the reviewing process and for his editorial and proceedings edition works after the workshop.

General chairs of MaxEnt 2014
Ali Mohammad-Djafari
Frédéric Barbaresco

General chairs of MaxEnt 2014

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Aymé Poirson Prize 2014 from French Academy of Sciences
Senior Scientist & Advanced Studies Manager, Thales Air Systems

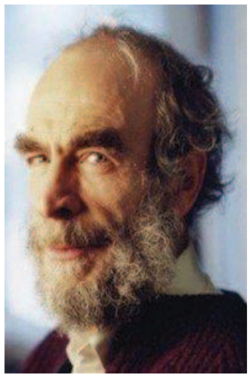
ABOUT SEE

SEE (Société de l'Electricité, de l'Electronique et des TIC – Society for Electricity, Electronics and ICT) is a nonprofit scientific and technical organization mainly active in France and by extension in French-speaking countries. It aims at gathering and animating a community of persons and organizations concerned by Science and Technologies in the fields of Energy, Electronics and Communications to foster the progress of both theoretical approaches in these fields and new applications in the main sectors of Economy (Energetic transition, new Transportation challenges, Health and silver Economy, Digital life, etc.). The two main vectors of action of SEE are the organization of S&T events (like MAXENT) and the publication of 2 periodic reviews (REE and 3EI). SEE has strong actions shared with "sister" Societies like IEEE.

Alain BRENAC
SEE General Secretary
SEE Emeritus Member

MaxEnt 2014 keynote speakers

Prof. Mikhail Gromov
Abel Prize, IHES,
Bures-sur-Yvette, France



On the Structure of Entropy

Abstract: Mathematics is about "interesting structures". What make a structure interesting is an abundance of interesting problems; we study a structure by solving these problems. The worlds of science, as well as of mathematics itself, is abundant with gems (germs?) of simple beautiful ideas. When and how may such an idea direct you toward beautiful mathematics? I present in this talk a 20th century mathematician's perspective on Boltzmann's idea of entropy.

Biography: Mikhail Leonidovich Gromov. A French–Russian mathematician. He studied in Leningrad University where he was a student of Vladimir Rokhlin. He has been working on the Riemannian Geometry, Geometric PDE, Symplectic Geometry, Geometric Theory of Groups and also on mathematical formalizations of ideas coming from biology, psychology and linguistic.

Prof. Daniel Bennequin

Denis Diderot University,
Paris, France

Topological forms of information

Abstract: This talk will present recent joint works with Pierre Baudot, where we propose a general definition of categories of informations, and study a natural cohomology for associated information quantities, and homotopical derived notions. Entropies of Shannon, Kullback and Von Neumann, appear as first fundamental classes for classical and quantum setting respectively. The decomposition of entropy in higher mutual information functions appears as an homotopical structure, and generates a new kind

of topology. Possible applications to the study of large statistical data and dynamics of neuronal systems will be mentioned

Biography: Born 3 January 1952. Graduated from Ecole Normale Supérieure, he has defended his PhD in 1982 with Alain Chenciner at Paris VII University (Doctorat d'Etat, Entrelacements et équations de Pfaff). He was Professor at Strasbourg University and was member of Bourbaki. He is currently a Professor at Denis Diderot University and a member of l'Institut Mathématique de Jussieu. He has made many major contributions to contact geometry during the 1980's and was initiator of Contact Topology with Yakov Eliashberg. During the years 1990, he worked with his students and colleagues in Strasbourg, on integrable systems and geometrical structures of Mathematical Physics. Since 2000 he has been working in Neuroscience (mainly in LPPA directed by A.Berthoz, C-d-F, Paris); he made contributions to the study of geometrical invariance in human movements duration, dynamical structure of vestibular end sensors, organization of vestibular information flow, eye movements preparation, and gaze functions during locomotion.

Prof. Roger Balian

French Academy of Sciences Member,
Scientific Consultant of CEA

<u>The entropy-based quantum metric</u>

Abstract: The von Neumann entropy S(^D) generates in the space of quantum density matrices ^D the Riemannian metric $ds^2 = - d^2S$(^D), which is physically founded and which characterizes the amount of quantum information lost by mixing ^D and ^D + d^D. A rich geometric structure is thereby implemented in quantum mechanics. It includes a canonical mapping between the spaces of states and of observables, which involves the Legendre transform of S(^D). The Kubo scalar product is recovered within the space of observables. Applications are given to equilibrium and non-equilibrium quantum statistical mechanics. There the formalism is specialized to the relevant space of observables and to the associated reduced states issued from the maximum entropy criterion, which result from the exact states through an orthogonal projection. Von Neumann's entropy specializes into a relevant entropy. Comparison is made with other metrics. The Riemannian properties of the metric $ds^2 = - d^2S$(^D) are derived. The curvature arises from the non-Abelian nature of quantum mechanics; its general expression and its explicit form for q-bits are given.

Biography: Roger Balian has been working at the "Institut de Physique Théorique" of Saclay (CEA), which he has directed (1979-1987). He was also Professor of Statistical Physics at Ecole Polytechnique (1972-1998), and Director of the "Ecole d'Eté de Physique Théorique des Houches" (1972-1980). His research works have addressed various topics, often related to statistical physics: superfluid Helium 3, signal theory, information/entropy, waves and complex trajectories, foundations of quantum mechanics, Casimir effect, quantum liquids, nuclear structure, gauge theories, distribution of galaxies.

Dr. Stefano Bordoni

Bologna University, Italy

<u>Duhem's abstract thermodynamics.</u>

Abstract: In the second half of the 19th century, two different traditions of research emerged from Clausius' thermodynamics. Maxwell and Boltzmann pursued the integration of thermodynamics with the kinetic theory of gases, whereas others relied on a macroscopic and more abstract approach, which set aside specific mechanical models. Massieu, Gibbs, and Helmholtz exploited the structural analogy between mechanics and thermodynamics, the young Planck and J.J. Thomson aimed at filling the gap between thermodynamics and the theory of elasticity, and Oettingen developed a dual mathematical structure for heat and work. Starting from 1891, Pierre Duhem put forward the most original and systematic reinterpretation of abstract thermodynamics, and at the same time the boldest upgrade of Analytical mechanics. He developed and transformed the second tradition: his design of a generalized mechanics based on thermodynamics led to an astonishing mathematical unification between physics and chemistry. Purely mechanical phenomena and chemical reactions represented the opposite poles in Duhem's *Energetics*.

Biography: He graduated in physics and received a PhD in History of science and then a PhD in Philosophy. He has recently gained a qualification as associate professor of Logic, philosophy and history of science. He has published papers and books on the history of science, and in particular history of physics. He has given seminars and lectures in some Italian universities and at the Max-Planck-Institut für Wissenschaftsgeschichte in Berlin. He has lectured in History of physics, History of science, and Mathematics.

Tutorial abstracts

1. Modern Probability Theory - Kevin H. Knuth

A theory of logical inference should be all-encompassing, applying to any subject about which inferences are to be made. This includes problems ranging from the early applications of games of chance, to modern applications involving astronomy, biology, chemistry, geology, jurisprudence, physics, signal processing, sociology, and even quantum mechanics. This paper focuses on how the theory of inference has evolved in recent history: expanding in scope, solidifying its foundations, deepening its insights, and growing in calculational power.

2. The Basics of Information Geometry - Ariel Caticha

A main concern of any theory of inference is to pick a probability distribution from a set of candidates and this immediately raises many questions. What if we had picked a neighboring distribution? What difference would it make? What makes two distributions similar? To what extent can we distinguish one distribution from another? Are there quantitative measures of distinguishability? The goal of this tutorial is to address such questions by introducing methods of geometry. More specifically the goal will be to introduce a notion of "distance" between two probability distributions.

A parametric family of probability distributions forms a statistical manifold, namely, a space in which each point represents a probability distribution. Generic manifolds do not come with a pre-installed notion of distance; such additional structure has to be purchased separately in the form of a metric tensor. Statistical manifolds are, however, an exception: a theorem due to N. Čencov (1981) states that up to an overall scale factor there is only one metric that takes into account the fact that these are not distances between simple structureless dots but distances between probability distributions.

To educate our intuition I will briefly sketch a couple of derivations of the information metric and provide a couple of examples. I will not develop the subject in all its possibilities but I will emphasize one specific result. Having a notion of distance means we have a notion of volume and this in turn implies that there is a unique and objective notion of a distribution that is uniform over the space of parameters—equal volumes are assigned equal probabilities. Whether such uniform distributions are maximally non-informative, or whether they define ignorance, or whether they reflect the actual prior beliefs of any rational agent, are all important issues but they are quite beside the specific point to be made here: that these distributions are uniform and this is not a matter of subjective judgment but of objective mathematical proof.

3. Voronoi diagrams in information geometry - Franck Nielsen

Divergence functions, which are traditionally viewed as a bi-variate function on some manifold M, are here viewed as functions on the cross-manifold MxM which generate a statistical structure (a Riemannian metric plus a pair of torsion-free conjugate connections) along its diagonal manifold. Imposing compatibility conditions allow us to define a divergence function that is “proper”. Further conditions can be imposed so that the cross-manifold may admit a complex representation, linking the divergence function to the “potential” on MxM. For the family of divergence functions induced by a convex function (Zhang, 2004), it is shown that they are proper and their Kahler potentials are given exactly by the inducing convex function. These results highlight the “reference-representational biduality” in Information Geometry.

4. Foundations and Geometry - John Skilling

Probability theory has a solid foundation based on elementary symmetries, nowadays refined to associativity augmented with either commutativity or order. Few workers now contest the sum and product rules of standard probability calculus (often called "Bayesian" although there's no rational alternative and a unique form needs no adjective). The practice of inference is understood and agreed. Yet pure inference is not the end of the story. We may wish to simplify a distribution, or aggregate several into a single representative, in a minimally damaging way. For such purposes, we wish to know how far one probability distribution is from another, so that we can define what we mean by minimal damage.

Over the years, many candidate distances have been proposed, used, and generalised to cover measures (distributions that can have any total) and even to positive matrices. On these distances, geometries have been constructed. Their very multiplicity, though, to say nothing of their ad hoc production, indicates that none has been found wholly satisfactory. There is a reason for that.

The reason is that there is only one connection that allows data from arbitrary partitions of the coordinate space to be combined consistently. That connection is the unique information

H(p; q) = pi log pi/qi

known to statisticians as the Kullback-Leibler. And H is asymmetric,

H(p; q) not= H(q; p).

The asymmetry is both central and obvious. It can't be evaded. To pass from distribution q = (1/2 ; 1/2) to p = (1; 0) takes one bit of information (which might tell us that a coin was "heads"). But the reverse passage from (1; 0) representing a coin known to be "heads" to (1/2 ; 1/2) is impossible because "tails" is supposedly known to be false. It follows that probability distributions do not form a metric space. Consequently, all geometries must fail. More precisely, any proposal based on a symmetric distance l(p; q) = l(q; p) must be opposed to the uniqueness of H and will fall foul of elementary criteria, thereby being open to counter-example. Specifically, the popular claim that the Fisher metric g = \nabla\nabla H defines generally applicable geodesic paths and lengths, with associated density \sqrt{p |g|}, is to be resisted because it contradicts the foundation of H itself. 150 years ago, Riemann ditched Euclid. Perhaps it is time to ditch Riemann.

5. Uncertainty quantification for computer model - Udo V. Toussaint

The quantification of uncertainty for complex simulations is of increasing importance as well as a significant challenge. Bayesian and non-Bayesian probabilistic uncertainty quantification methods like polynomial chaos (PC) expansion methods or Gaussian processes have found increasing use over the recent years. This contribution describes the use of Gaussian processes and collocation methods for the propagation of uncertainty in computational models using illustrative examples as well as real-world problems. In addition the existing challenges like phase-transitions are outlined.

6. Geometric Structures Induced From Divergence Functions - Jun Zhang

Divergence functions are generalizations of cross-entropy; they characterize (non-symmetric) proximity of pairs of points of a vector space or smooth manifold in general. As surrogate to the symmetric metric function, divergence functions play important roles in statistical inference, machine learning, image processing, optimization, etc. This talk will review the various geometric structures induced from a divergence function defined on a manifold. Most importantly, a Riemannian metric with a pair of torsion-free affine connections can be induced on the manifold; this is the so-called "statistical structure" in Information Geometry. Additional structures may emerge depending on the functional form of the divergence. A general family of divergence functions can be constructed based on a smooth and strictly convex function, which unifies the various known families. Such divergence functions results in a manifold equipped with a pair of bi-orthogonal coordinates, and therefore Hessian structure, reflecting "reference-representation biduality", and an equiaffine structure such that parallel volume forms exist. Computational advantages of this convex-based divergence functions will be discussed.

7. Koszul Information Geometry and Souriau Lie Group Thermodynamics

Frédéric Barbaresco

The Koszul-Vinberg Characteristic Function (KVCF) is a dense knot in important mathematical fields such as Hessian Geometry, Kählerian Geometry, Affine Differential Geometry. This paper develops KVCF as the foundation of Information Geometry, transverse concept in Thermodynamics, in Statistical Physics and in Probability. From general KVCF definition, the paper defines Koszul Entropy, that coincides with the Legendre transform of minus the logarithm of KVCF (their gradients defining mutually inverse diffeomorphisms). These dual functions are compared by analogy in thermodynamic with dual Massieu-Duhem potentials. Hessian of minus the KVCF logarithm provides a non-arbitrary Riemannian metric for Information Geometry. We will observe the fundamental property that barycenter of Koszul Entropy is equal to Koszul entropy of barycenter. We present then a generalization of the characteristic function by physicist Jean-Marie Souriau in statistical physics, introducing the concept of co-adjoint action of a group on its momentum space, defining physical observables like energy, heat and momentum as pure geometrical objects. We will compare moment map with the dual coordinate in Koszul model (barycenter where entropy is maximum) and give a vector valued definition of Maximum Entropy. In covariant Souriau model, Gibbs equilibriums states are indexed by a geometric parameter, the Geometric Temperature, with values in the Lie algebra of the dynamical group, interpreted as a space-time vector (a vector valued temperature of Planck), giving to the metric tensor a null Lie derivative. Information Fisher metric appears as the opposite of the derivative of Moment map by geometric temperature, equivalent to a Geometric Capacity. We will synthetize the analogies between Koszul and Souriau models where Information Geometry is considered as a particular case of Koszul Hessian Geometry. Information Geometry metric is then characterized by invariances, by automorphisms of the convex cone or by Dynamic groups. We conclude, interpreting Legendre transform as Fourier transform in (Min,+) algebra, with new definition of Entropy given by the following relation: Entropy = -Fourier(Min,+) ° Log ° Laplace(+,X) .

8. Bayesian and Information Geometry in signal processing

Ali Mohammad-Djafari

The main object of this tutorial article is first to review the main inference tools using Bayesian approach, Entropy, Information theory and their corresponding geometries.

This review is focused mainly on the ways these tools have been used in signal and image processing.

After a short introduction of different quantities related to the Bayes rule, the entropy and the maximum entropy principle, we will study their use in different fields of data and signal processing such as: source separation, model order selection, spectral estimation and, finally, general linear inverse problems.

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