Stochastic Geometry Days 2024
Schedule and Abstracts

Monday, May 27th

10h Welcome
10h30-12h Céline Duval - *Excursion sets: from geometry to estimation (1/4)*
Lunch Break
14h-15h30 Mathew Penrose - *Coverage and connectivity of spatial point processes (1/4)*
Coffee Break
16h-17h30 Céline Duval - *Excursion sets: from geometry to estimation (2/4)*

Tuesday, May 28th

9h-10h30 Mathew Penrose - *Coverage and connectivity of spatial point processes (2/4)*
Coffee Break
11h-12h30 Céline Duval - *Excursion sets: from geometry to estimation (3/4)*
Lunch Break
14h15-15h45 Mathew Penrose - *Coverage and connectivity of spatial point processes (3/4)*
Coffee Break
16h15-17h45 Céline Duval - *Excursion sets: from geometry to estimation (4/4)*

Wednesday, May 29th

9h-10h30 Mathew Penrose - *Coverage and connectivity of spatial point processes (4/4)*
Coffee Break
11h-11h45 Franco Severo - *Level set percolation of smooth Gaussian fields*
11h50-12h20 Antonin Jacquet - *Patterns crossed by geodesics in first-passage percolation*
Lunch Break
14h20-15h05 Christophe Biscio - *Non-parametric intensity estimation of spatial point processes by random forests*
15h10-15h55 Elena Villa - *Mean boundary and perimeter density of inhomogeneous germ-grain models*
Coffee Break
16h30-17h Sayeh Khaniha - *Hierarchical thinning nearest neighbor algorithm*
17h05-17h50 Arnaud Poinas - *Attractive coupling of determinantal point processes using nonsymmetric kernels*

Thursday, May 30th

9h-9h45 Nathanaël Enriquez - *Poisson-Voronoi mosaic on the hyperbolic space: what remains when the Poisson has disappeared?*
9h50-10h20 Thibaut Duboux - *Maximal Entropic Random Walks (MERWs) on infinite graph and scaling limit*
Coffee Break
10h50-11h35 Alice Contat - *Critical core percolation on random graphs*
11h40-12h10 Ludovic Morin - *Probability that n points are in convex position in a convex polygon: asymptotic results*
Lunch Break
14h-14h45 Pierre Chainais - *Plug-and-play split Gibbs sampler: embedding deep generative priors in Bayesian inference*
14h50-15h35 Vytaute Pilipauskaite - *Fractional operators and fractionally integrated random fields on $\mathbb{Z}^\nu$*
Coffee Break
16h10-16h40 Alexandre Makhlouf - *Interpolation for random fields*
16h45-17h30 Xiaochuan Yang - *Boundary effects in some stochastic geometric models*
17h35-18h RT Meeting

19h30 *Conference dinner*

Friday, May 31th in honour of Anne Estrade

9h-9h45 Yimin Xiao - *Some geometric properties of anisotropic Gaussian random fields*
9h50-10h35 Elena di Bernardino - *The story of how Anne took me on a excursion set: some theoretical and computational developments*
Coffee Break
11h00-11h45 Jose Leon - *On a general Kac-Rice formula for the measure of a level set*
11h50-12h35 Pierre Calka - *Fractal Anne*
Lunch Break
14h00-16h00 *A festive afternoon with Anne Estrade*

NON-PARAMETRIC INTENSITY ESTIMATION OF SPATIAL POINT PROCESSES BY RANDOM FORESTS

CHRISTOPHE BISCIO
University of Aalborg, Denmark

FRÉDÉRIC LAVANCIER
ENSAI, Rennes, France

The intensity of a spatial point process is one of the first quantity of interest to estimate in presence of real-data. When no covariate is observed, non-parametric kernel estimation is routinely used, but comes with some drawbacks: it adapts poorly to non-convex domain, and the estimation is not consistent in an increasing domain asymptotic regime. When the intensity depends on observed covariates, most estimation methods are parametric. Non-parametric kernel estimation has been extended to this situation, but it appears to be efficient only for a few numbers of covariates, and provides no indication on the importance of each covariate, which is crucial for interpretation.

In this talk, we show how to adapt random forest regression to circumvent these drawbacks and estimate non-parametrically the intensity of a spatial point process with or without covariates, while measuring the importance of each variable in the latter case. Our approach allows to handle non-convex domain together with a large number of covariates. From a theoretical side, we prove that in the case of purely random forests, our method is consistent in both infill and increasing domain asymptotic regime, and may achieve a minimax rate of convergence.

FRACTAL ANNE

PIERRE CALKA
Université de Rouen Normandie

YANN DEMICHEL
Université Paris Nanterre

Throughout her career, Anne Estrade has developed and used tools from fractal geometry for studying different kinds of random sets with notable applications to medicine. This talk is intended as a tribute to her and to her body of work in this particular field. At the heart of the presentation is the mysterious notion of Fractal Anne that we unveil and study. The material is based on a joint work with Yann Demichel.

PLUG-AND-PLAY SPLIT GIBBS SAMPLER: EMBEDDING DEEP GENERATIVE PRIORS IN BAYESIAN INFERENCE.

PIERRE CHAINAIS
Centrale Lille Institut, France

This work introduces a stochastic plug-and-play (PnP) sampling algorithm that leverages variable splitting to efficiently sample from a posterior distribution. The algorithm based on split Gibbs sampling (SGS) draws inspiration from the half quadratic splitting method (HQS) and the alternating direction method of multipliers (ADMM) in optimization. It divides the challenging task of posterior sampling into two simpler sampling problems. The first problem depends on the likelihood function, while the second is interpreted as a Bayesian denoising problem that can be readily carried out by a deep generative model. Specifically, for an illustrative purpose, the proposed method is implemented in this paper using state-of-the-art diffusion-based generative models. Akin to its deterministic PnP-based counterparts, the proposed method exhibits the great advantage of not requiring an explicit choice of the prior distribution, which is rather encoded into a pre-trained generative model. However, unlike optimization methods (e.g., PnP-ADMM and PnP-HQS) which generally provide only point estimates, the proposed approach allows conventional Bayesian estimators to be accompanied by confidence intervals at a reasonable additional computational cost. Experiments on commonly studied image processing problems illustrate the efficiency of the proposed sampling strategy. Its performance is compared to recent state-of-the-art optimization and sampling methods.

CRITICAL CORE PERCOLATION ON RANDOM GRAPHS.

ALICE CONTAT
Université Paris 13, France

Motivated by the desire to construct large independent sets in random graphs, Karp and Sipser modified the usual greedy construction to yield an algorithm that outputs an independent set with a large cardinal. When run on the Erdös-Rényi $G(n,c/n)$ random graph, this algorithm is optimal as long as $c < \mathrm{e}$. We will present the proof of a physics conjecture of Bauer and Golinelli (2002) stating that at criticality, the size of the remaining subgraph is of order $n^{3/5}$. Along the way we shall highlight the similarities and differences with the usual greedy algorithm and the k-core algorithm.

Based on a joint work with Nicolas Curien and Thomas Budzinski.

THE STORY OF HOW ANNE TOOK ME ON A EXCURSION SET: SOME THEORETICAL AND COMPUTATIONAL DEVELOPMENTS.

L'histoire de comment Anne m'a emmené dans un ensemble d'excursion : quelques développements théoriques et computationnels.

ELENA DI BERNARDINO
Laboratoire J.A. Dieudonné, Université Côte d'Azur, France

joint works with: M. Abaach, H. Biermé, R. Cotsakis, C. Duval, A. Estrade, J. R. Léon, T. Opitz

The excursion set of a smooth random field carries relevant information in its various geometric measures. Geometric properties of these exceedance regions above a given level provide meaningful theoretical and statistical characterizations for random fields defined on Euclidean domains. Many theoretical results have been obtained for excursions of Gaussian processes and include expected values of the so-called LipschitzKilling curvatures (LKCs), such as the area, perimeter and Euler characteristic in two-dimensional Euclidean space. In this talk we will describe a recent series of theoretical and computational contributions in this field. Our aim is to provide answers to questions like:

- How the geometric measures of an excursion set can be inferred from a discrete sample of the excursion set;
- How these measures can be related back to the distributional properties of the random field from which the excursion set was obtained;
- How the excursion set geometry can be used to infer the extremal behavior of random fields

MAXIMAL ENTROPIC RANDOM WALKS (MERWS) ON INFINITE GRAPH AND SCALING LIMIT

THIBAUT DUBOUX
Institut de Mathmatiques de Bourgogne, France

The aim is to maximize entropy globally on a given graph, i.e. on all possible trajectories. When the graph is finite, it's easy to show that such a process is uniquely defined: it's called the "maximal entropic random walk". However, it is very difficult to specify, even numerically, the transition probabilities and invariant measure of this Markov chain. Indeed, these quantities depend on the spectrum of the adjacency matrix A of the graph and, more precisely, on the spectral radius ρ and the normalized eigenvector ψ associated with it. It turns out that the square of this vector is nothing other than the invariant probability π of the MERW. MERWs can be a tool for studying and modeling complex networks. This concept has found applications in various scientific fields, such as community detection, link prediction and even biology (neutral quasispecies evolution).
In this talk, we will define this walk in the context of an infinite graph, giving existence and uniqueness criteria. On the basis of these criteria, we will naturally be able to carry out scale limits of this random walk and recognize classical limit processes. The aim is to highlight localization and diffusion properties of this walk, which are essential for applications in other disciplines, in particular on periodic networks (crystal lattices, etc.).

EXCURSION SETS: FROM GEOMETRY TO ESTIMATION

CÉLINE DUVAL
University of Lille, Laboratoire Paul Painlevé, France

In this mini-course we indent to show how the geometry of excursion sets of a random field, successfully exploited in many applications, can be used to built statistical procedures. For random field $X : \mathbb{R}^d \mapsto \mathbb{R}$ and a level $u \in \mathbb{R}$, the excursion set of X above u is $\{t \in \mathbb{R}^d, X(t) \geq u\} \cap T$, where $T \subset \mathbb{R}^d$ is the observation window. In dimension $d = 2$, it is a black and white image which indicates whether the field is above or below u (center and right Figures).

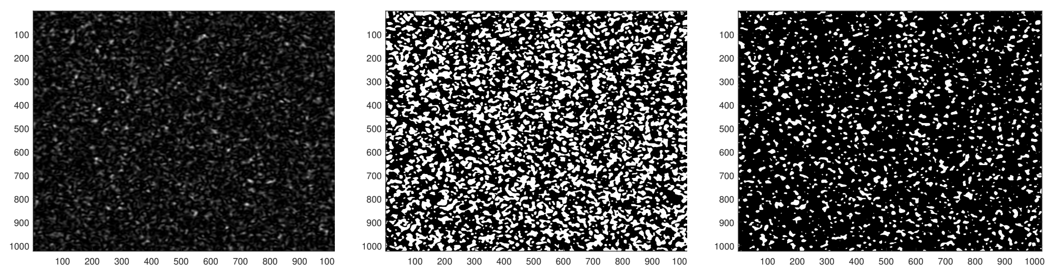

Fig. 0.1 χ^2 field with 2 degrees of freedom observed on a T domain of size $2^{10} \times 2^{10}$ pixels. A realisation of the field (left) and two sets of excursions at $u = 0$ (centre) and $u = 1$ (right).

The geometrical tools considered to study these excursion sets are the Lipschitz Killing curvatures (also called Minkowski functionals or intrinsic volumes). In dimension 2, they correspond to the area, the perimeter and the Euler characteristic, each offering a different point of view on the set. The aim of this mini-course is to introduce these functionals and to show how they can be related to specific parameters or properties of the field and allowing to build statistical procedures (estimation and/or testing). We will discuss some main challenges (e.g. the difficulty of establishing theoretical guarantees or numerical discretization issues) and show they can be addressed.

POISSON-VORONOI MOSAIC ON THE HYPERBOLIC SPACE: WHAT REMAINS WHEN THE POISSON HAS DISAPPEARED?

NATHANAËL ENRIQUEZ
Université Paris-Saclay, France

I'll try to convince you that, unlike the Euclidean case, the Poisson-Voronoi mosaic on the Hyperbolic space does not converge to the vacuum when the density of the Poisson process tends to 0. I will describe the law of this limit and some of its properties. (Joint work with M. d'Achille, N. Curien, R. Lyons and M. Ünel)

PATTERNS CROSSED BY GEODESICS IN FIRST-PASSAGE PERCOLATION.

ANTONIN JACQUET
Université de Tours – Institut Denis Poisson, France

In first-passage percolation, we consider a family of nonnegative, independent and identically distributed random variables indexed by the set of edges of the graph $\mathbb{Z}^d$, called passage times. The time of a finite path is defined as the sum of the passage times of each of its edges. Geodesics are then the paths with minimal time. A pattern is a local property of the time environment. We fix a pattern and are interested in the number of translates of this pattern crossed by geodesics. The aim is to present a result guaranteeing, under mild conditions, that apart from an event with exponentially small probability, for any geodesic, this number is linear in the distance between the endpoints of the geodesics.

HIERARCHICAL THINNING NEAREST NEIGHBOR ALGORITHM

FRANCOIS BACCELLI
INRIA Paris, France

SAYEH KHANIHA
INRIA Paris, France

Clustering is a widely used technique in unsupervised learning to identify groups within a dataset based on the similarities of its elements. This talk introduces a novel hierarchical clustering model, specifically designed for datasets with a countably infinite number of points. The proposed algorithm employs various levels of clustering and constructs clusters at each level using nearest-neighbor chains of points or clusters. We apply this algorithm to the Poisson point process. We prove that the clustering algorithm defines a phylogenetic forest on the Poisson point process, which is a factor of the point process and is hence unimodular. Various properties of this random forest, such as the mean sizes of clusters at each level or the mean size of the cluster of a typical node, follow.

ON A GENERAL KAC-RICE FORMULA FOR THE MEASURE OF A LEVEL SET

DIEGO ARMENTANO
Universidad de la República. Uruguay

JEAN-MARC AZAÏS
Université de Toulouse, France

JOSÉ LEÓN
Universidad de la República. Uruguay

Let $X(\cdot)$ be a random field from $\mathbb{R}^D$ to $\mathbb{R}^d$, $D \geq d$. We first studied the level set $X^{-1}(u)$, $u \in \mathbb{R}^d$. In particular we gave a weak condition for this level set to be rectifiable. Then, we established a Kac-Rice formula to compute the $(D-d)$ Hausdorff measure. Our results extend known results, particularly in the non-Gaussian case where we obtained a very general result. We conclude with several extensions and examples of application, including functions of Gaussian random field, zeroes of the likelihood, gravitational microlensing, shot-noise.

INTERPOLATION FOR RANDOM FIELDS

ALEXANDRE MAKHLOUF
Laboratoire de Mathmatiques d'Avignon, France

In this talk we will present the construction of a piecewise polynomial random field that interpolates a second-order random field X on $[0;1]^2$. By observing X on a uniform grid, we will be able to locally construct a polynomial interpolator of prescribed degree. The interpolation error is studied using the integrated mean square error and assuming some mean square regularity. One of the statements can be considered as a generalisation of Bermans definition of local stationarity, for mean square derivative fields of X. The rate of convergence obtained for this method is at least as good as the optimal rate for L^2-approximation affine method with random fields satisfying Hölder conditions. Finally, we will conclude by giving some examples of random fields that satisfy our assumptions, notably including fractional Brownian fields and Mat ern fields.

References:

1. Berman, S.M., 1992. Sojourns and extremes of stochastic processes. The Wadsworth & Brooks/Cole Statistics/Probability Series, Wadsworth & Brooks/Cole Advanced Books & Software, Pacific Grove, CA.
2. Blanke, D., Vial, C., 2011. Estimating the order of mean-square derivatives with quadratic variations. Stat. Inference Stoch. Process. 14, 8599.
3. Ritter, K., 2000. Average-case analysis of numerical problems. volume 1733 of Lecture Notes in Mathematics. Springer-Verlag, Berlin.

PROBABILITY THAT *n* POINTS ARE IN CONVEX POSITION IN A CONVEX POLYGON : ASYMPTOTIC RESULTS

LUDOVIC MORIN
LaBRI, Université de Bordeaux, France

The study of the probability that n points drawn uniformly and independently in a convex domain of area 1 (in the plane) are in convex position, meaning, they form the vertex set of a convex polygon, is quite an age-old question. The matter was risen at the end of the 19^{th} century with Sylvester's conjecture for $n = 4$ points, solved by Blaschke in 1917. Since then, general results for n points came one after the other in the square, the triangle or the disk, as well as other asymptotic results.

In this talk I will give an equivalent of the probability $\mathbb{P}_n$ that n points are in convex position in a regular convex polygon to deduce an analogous result for any convex polygon; so far, the most precise formula was due to Bárány and identified the limit $n^2(\mathbb{P}_n)^{1/n}$ (though Bárány's formula holds for general convex domains).

Bárány also proved that a convex n-gon drawn uniformly in a fixed convex domain K converges to a deterministic domain. Still working in the case where K is a polygon, we present second order results for the fluctuations of the n-gon around this domain.

COVERAGE AND CONNECTIVITY OF SPATIAL POINT PROCESSES

MATHEW PENROSE
University of Bath, UK

Suppose A is a bounded domain with smooth boundary in $\mathbf{R}^d$, where $d \geq 2$, and n points are placed uniformly at random in A. Let $Z(n,r)$ be the union of Euclidean balls of radius r centred on these points (a Boolean model with parameters $n \in \mathbf{N}$ and $r > 0$).

The *coverage threshold* T_n is the smallest r such that $A \subset Z(n,r)$, while the *connectivity threshold* K_n is twice the smallest r such that $Z(n,r)$ is a connected set. The random variables K_n and T_n are of interest, for example, in wireless communications and topological data analysis.

In this mini-course we shall describe how to determine the limiting distributions of K_n and T_n, suitably scaled and centred, in the large-n limit. Along the way, we shall investigate some related quantities, and explore some mathematical techniques, that are of interest in their own right. Some parts of the work we shall describe are published (see below) but others are work in progress with Xiaochuan Yang and Frankie Higgs. A provisional plan for the four talks is:

1. Limiting distribution (for large λ) of T'_λ, defined as the furthest distance from any point of A to a homogeneous Poisson process of intensity λ in the whole of $\mathbf{R}^d$ (note that T_n is the furthest distance from any point of A to a binomial point process of of points *within* A). This result dates back to [**?**, **?**] but we may add some refinements if time permits.

2. Limiting distribution of T_n and its Poissonized version. This work was done in [**?**].

3. Limiting distribution of the *largest nearest neighbour link* L_n, defined to be the smallest r such that each of the n random points is contained in at least one other ball of $Z(n,r)$, besides its own ball. Some of the work for this talk appears in [**?**].

4. Relating K_n to L_n to complete the description of asymptotics for K_n.

The recent and ongoing work described in this mini-course was supported by EPSRC Grant EP/T028653/1.

References:

1. Hall, P. (1985) Distribution of size, structure and number of vacant regions in a high intensity mosaic. Z. Warsch. Verw. gebiete **70**, 237–261.
2. Higgs, Penrose, M.D. and Yang, X. (2024) Covering one point process with another. arXiv:2401.03832
3. Janson, S. (1986) Random coverings in several dimensions. *Acta Math.* **156**, 83–118.
4. Penrose, M.D. (2023) Random Euclidean coverage from within. *Probab. Th. Related Fields* **185**, 747–814.

FRACTIONAL OPERATORS AND FRACTIONALLY INTEGRATED RANDOM FIELDS ON $\mathbb{Z}^\nu$

VYTAUTĖ PILIPAUSKAITĖ
Aalborg University, Denmark

DONATAS SURGAILIS
Vilnius University, Lithuania

We consider fractional integral operators $(I-T)^d$, $d \in (-1,1)$, acting on functions $g: \mathbb{Z}^\nu \to \mathbb{R}$, where T is the transition operator of a random walk on $\mathbb{Z}^\nu$, $\nu \in \mathbb{N}$. We obtain sufficient and necessary conditions for the existence, invertibility and square summability of kernels $\tau(s;d)$, $s \in \mathbb{Z}^\nu$, of $(I-T)^d$. Asymptotic behavior of $\tau(s;d)$ as $|s| \to \infty$ is identified following local limit theorem for random walk. A class of fractionally integrated random fields X on $\mathbb{Z}^\nu$ solving the difference equation $(I-T)^d X = \varepsilon$ with white noise on the right-hand side is discussed, and their scaling limits. Several examples including fractional lattice Laplace and heat operators are studied in detail.

ATTRACTIVE COUPLING OF DETERMINANTAL POINT PROCESSES USING NONSYMMETRIC KERNELS

ARNAUD POINAS
Université de Poitiers, France

Determinantal point processes (DPPs for short) are a common class of point processes that model repulsiveness between points. They are defined through a symmetric function called their kernel. From this kernel, we can deduce most of their properties (correlation functions, likelihood, various summary statistics, method of simulation, etc.). DPPs can also be defined using a nonsymmetric kernel, but this case has been rarely studied in the literature since most of the good properties of DPPs require the symmetry of the kernel. In this talk, we will discuss what kinds of properties are satisfied by these more general DPPs and what kinds of assumptions is needed by their kernel to be well-defined. In particular, compared to DPPs with symetric kernels, general DPPs can model attraction between points, and we will show how to use these DPPs in order to create an attractive coupling of DPPs with symmetrical kernels. This would allow us to model marked point processes with repulsion between points of the same marks and attraction between points of different marks.

LEVEL SET PERCOLATION OF SMOOTH GAUSSIAN FIELDS

FRANCO SEVERO
ETH Zurich, Switzerland

Given a centered, stationary, smooth Gaussian field f on $\mathbb{R}^d$, we are interested in the geometry of the excursion sets $\{f \leq \ell\} := \{x \in \mathbb{R}^d : f(x) \leq \ell\}$, for $\ell \in \mathbb{R}$. As ℓ varies, these random sets naturally define a percolation model, whose critical point is denoted by ℓ_c. Important examples of such models are the Bargman-Fock field and the Monochromatic Random Wave, which arise as the local limits of random homogeneous polynomials of high degree and random Laplace eigenfunctions of high frequency, respectively. Most of the available literature is devoted to the case $d = 2$, where a special duality property implies, in particular, that $\ell_c = 0$ for basically any planar field. In higher dimensions on the other hand, the lack of duality makes the study more difficult and relatively fewer results are known. In this talk, we shall discuss some of these results, including the sharpness of phase transition in arbitrary dimensions. The latter serves as a crucial step towards a detailed description of the large scale geometry of level sets in the whole off-critical regime $\ell \neq \ell_c$.

MEAN BOUNDARY AND PERIMETER DENSITY OF INHOMOGENEOUS GERM-GRAIN MODELS

ELENA VILLA
Università degli Studi di Milano, Italy

We consider random germ-grain models in $\mathbb{R}^d$ having integer Hausdorff dimension less than d. The mean density, say λ_{Θ_n}, of a random closed set Θ_n with Hasudorff dimension n, is defined to be the density of the measure $\mathbb{E}[\mathscr{H}^n(\Theta_n \cap \cdot)]$ with respect to $\mathscr{H}^d$, whenever it exists. Crucial problems are the evaluation and the pointwise estimation of λ_{Θ_n} in the inhomogeneous setting.

In the first part of the talk, we give sufficient conditions for the existence of $\lambda_{\Theta_n}(x)$. Whenever its theoretical expression is not computable, suitable rectifiability assumptions on the grains allow to provide a local approximation of λ_{Θ_n}, based on a stochastic version of the so-called *n-dimensional Minkowski content* of Θ_n. Such approximation leads to the definition of an estimator of $\lambda_{\Theta_n}(x)$, whose good statistical properties will be also discussed.

In the second part of the talk we will focus on the boundary of full dimensional germ-grain models. Actually, we shall distinguish between the *topological* boundary and the *essential* boundary. The $\mathscr{H}^{d-1}$-measure of the essential boundary coincides with the so-called *perimeter* of the involved set in geometric measure theory. Since the perimeter of a set is invariant under modification of a set of Lebesgue measure zero, the difference between the measure of the topological boundary and the perimeter might be of interest in detecting negligible parts of the set under consideration. The computation of the mean perimeter density and the mean boundary density can be carried out by means of the notion of mean *covariogram* and of mean *outer Minkowski content*, respectively. We will relate these two notions when the perimeter and the $\mathscr{H}^{d-1}$-measure of the topological boundary coincide.

SOME GEOMETRIC PROPERTIES OF ANISOTROPIC GAUSSIAN RANDOM FIELDS

YIMIN XIAO
Michigan State University, East Lansing, USA

This talk is concerned with geometric properties of anisotropic Gaussian random fields. We will present some recent results on the hitting probabilities of Gaussian random fields and their applications in studying the existence and Hausdorff dimensions of intersections. If time permits, we will show that, by employing the properties of strong local nondeterminism, one can prove precise results on the local times and level sets of multivariate anisotropic Gaussian random fields.

BOUNDARY EFFECTS IN SOME STOCHASTIC GEOMETRIC MODELS

XIAOCHUAN YANG
Brunel University London, UK

Abstract. Coverage and connectivity of Boolean models are classical problems in stochastic geometry. In this talk, I will present some interesting findings concerning connectivity threshold and coverage threshold in the large n limit, where n is the number of balls in the Boolean model. In most cases, boundary effects play a dominant role in deriving limit theorems for these thresholds. Based on joint works with Frankie Higgs and Mathew Penrose.

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