# Summer Academy 2011

# Stochastic Analysis, Modelling and Simulation of Complex Structures

September 11-24, 2011
Söllerhaus, Hirschegg/Kleinwalsertal

ulm university universität uulm

Lomonosov Moscow State University МГУ

DAAD Deutscher Akademischer Austausch Dienst
German Academic Exchange Service

# Contents

Dear colleagues,

it is our pleasure to welcome you to the Summer Academy 2011, which is held at the alpine conference center "Söllerhaus" in Hirschegg/Kleinwalsertal during the two weeks of September 11-24, 2011.

The Summer Academy 2011 has 14 lecturers and 44 participants from eight countries. It is part of a whole series of international summer academies on various aspects of probability, statistics and their applications, which have recently been organized by members of the Faculty of Mathematics and Economics of Ulm University. Previous summer academies of this series were dealing with Stochastic Geometry, Spatial Statistics and Random Fields (2009), and Stochastic Finance (2010). A subsequent summer academy, to be organized in 2012, will be devoted to Advanced Stochastic Methods to Model Risk.

The aim of the present Summer Academy 2011 is to give an introduction into methods, models and results of spatial stochastics. The focus is put on applications of stochastic geometry and spatial statistics to quantitative, model-based description of microstructures which are investigated in science and engineering (e.g. the stochastic 3D modelling of transportation paths of charges, gases or liquids in complex structured materials). In particular, the quantitative analysis, modelling and simulation of geometrically complex structures such as irregular point patterns, fibre systems, geometric graphs and particle systems are covered.

During the Summer Academy 2011, leading international experts in the fields of spatial stochastic modelling and its applications to science and engineering will share their knowledge with advanced students, graduates and PhD students as well as young researchers. There are several cycles of lectures given by the international experts. Additionally, the Summer Academy 2011 provides a forum for an active exchange of ideas and new joint research projects. Participants are invited to actively contribute to the scientific program by presenting short talks and posters on their current research subjects.

The financial support of German Academic Exchange Service (DAAD) and Ulm University is gratefully acknowledged. It allowed us to reimburse accommodation and travel expenses of lecturers and participants from abroad.

The organization of this summer academy would not have been possible without the great support of Mrs. Renate Jäger, the secretary of our institute. Last but not least, many other members of our institute (Gerd Gaiselmann, Christian Hirsch, Sebastian Lück, Martin Meinhardt, David Neuhäuser, Aaron Spettl, Ole Stenzel) contributed substantially to the preparation and realization of this summer academy. We sincerely thank them for their very helpful work.

Volker Schmidt
Coordinator of the Summer Academy 2011

## Conference Information

The Summer Academy 2011 on Stochastic Analysis, Modelling and Simulation of Complex Structures is held at the alpine conference center Söllerhaus in Hirschegg/Kleinwalsertal during the two weeks of September 11-24, 2011.

| | |
|---|---|
| Lecturers | Viktor Beneš, Bartek Błaszczyszyn, Alexander Bulinski, Lorenz Holzer, Dominique Jeulin, Eva Vedel Jensen, Zakhar Kabluchko, Wilfrid Kendall, Dirk P. Kroese, Jesper Møller, Claudia Redenbach, Volker Schmidt, Evgeny Spodarev, Ulrich Stadtmüller |
| Coordinator | Volker Schmidt |
| Contact | renate.jaeger@uni-ulm.de |
| Conference Web-Page | http://www.uni-ulm.de/mawi/summer-academy-2011/ |

### Accommodation, Conference fee, etc.

The total costs for participation are 750 € covering the conference fee of 250 € and the costs for accommodation and full board, i.e. breakfast, lunch, and dinner, starting with dinner on Sunday, September 11, and ending with breakfast on Saturday, September 24. Beverages have to be paid for individually. On the excursion days, free box lunchs may be prepared at the Söllerhaus.

### Conference venue

The Summer Academy 2011 will take place at the Söllerhaus in Hirschegg/Kleinwalsertal , which is a mountain lodge in the Alps that has been turned into a modern conference center. The Söllerhaus offers conference rooms, internet access and lodging (in single- and shared rooms). Located at an elevation of 1320 m, it is surrounded by a gorgeous mountain scenery which does not only create an inspiring atmosphere for academic work but also offers great opportunities for hiking and outdoor activities.

### Travel information

**By car.** Take the motorways A7/A98/B19 (Ulm–Kempten–Immenstadt–Sonthofen–Oberstdorf). Just before reaching Oberstdorf, in the traffic circle take a turn to Kleinwalsertal (B19–201). Follow the federal road B19–201 towards Riezlern. After crossing the Breitach bridge in Riezlern, turn right into Schwarzwassertalstraße which leads to Ifen. Follow Schwarzwassertalstraße until you reach a T-shaped crossroad. Take a turn to the left and follow the road for 1100 m to Café Walserblick. Immediately after Café Walserblick take a sharp turn to the left into Rohrweg. Turn right into Schöntalweg. Follow the road until you reach the Söllerhaus.
**Navigation system.** Please choose as destination Österreich 6992 Mittelberg, Schöntalweg 10.

**By train.** Take the train to Oberstdorf/Allgäu. For further information, please visit www.bahn.de. From the train station Oberstdorf/Allgäu take the bus line 1 in direction Baad/Mittelberg. Get off the bus at the bus stop Riezlern Post (Hauptlinie). Change to the bus line 5 in direction Ifen and leave the bus at the bus stop Fuchsfarm. From the bus stop Fuchsfarm, turn into Rohrweg, and shortly after that turn right into Schöntalweg and follow it until you reach the Söllerhaus (200 m). Note that the bus line 5 only operates until 17:25.
If you would like to take a taxi from the train station, we recommend you to call +43 5517 5460 (please call this phone number at least 1h in advance). The taxi fare from the train station Oberstdorf/Allgäu to the Söllerhaus should be approx. 24 € per taxi (1-4 persons) or approx. 6 € per person for big taxis (5-8 persons).

### Internet access

During the conference, there will be LAN and WLAN access to the internet in the seminar rooms.

### Social Program

- On Wednesday, September 14, there will be a bus excursion to Ulm, including a visit to Ulm University. Departure time is 8:00. After a welcome address by Prof. Dr. Paul Wentges, the Dean of the Faculty for Mathematics and Economics, at 11:00, there will be a short campus tour followed by a lunch at the University canteen (self-pay). At 13:00 the program will proceed with a presentation by Prof. Dr. Paul Walther (Electron Microscopy Facility of Ulm University) in the multimedia lab of Ulm University. The talk is entitled "On electron tomographic image acquisition of life science samples" and will feature advanced imaging technologies at Ulm University. Afterwards, we will visit the city center of Ulm including the picturesque Fischerviertel with its beautiful historical buildings and small streams flowing into the Danube river. There will also be the opportunity to visit Ulm's cathedral, which is famous for its elaborately carved choir chairs and the highest historical steeple, whose 768 steps may be climbed to be rewarded by a magnificent view over the city. The bus back to Hirschegg is scheduled to leave Ulm at 16:00. Dinner will be served at 18:45 at the traditional mountain lodge Sonna Alp in Mittelberg.

- On Sunday, September 18, there will be a bus excursion to the Bavarian royal castle Neuschwanstein near Schwangau. Alternatively to a tour inside the castle there will be the opportunity to go on a hiking trip in the surrounding mountains. Please take good mountain shoes and outdoor/rain wear with you for hiking. Departure time is 9:00 and the return to Söllerhaus in the evening is scheduled for approximately 18:00.

- On Wednesday, September 21, there will be a bus excursion to Lindau (Lake Konstanz) with some time to walk through the city. The departure time is 9:00. The bus will leave Lindau again at 13:15 for Friedrichshafen, where will be a guided tour through the Zeppelin museum starting at 14:15. At 16:00 the bus will depart from Friedrichshafen for the drive back to Hirschegg. Dinner will be served starting at 19:30 at the mountain lodge Walserblick, which is located within short walking distance to the Söllerhaus.

# Program

## Sunday, September 11, 2011

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|---|---|
| 14:00 - 18:00 | Arrival & Registration |
| 18:30 - 20:00 | Dinner |
| 20:00 - 22:00 | Coming together |

## Monday, September 12, 2011

| | | |
|---|---|---|
| 8:00 - 9:00 | | Breakfast |
| 9:00 - 12:00 | | Lectures |
| | 9:00 | Dominique Jeulin<br>Introduction to fundamental classes of models in stochastic geometry (p. 23) |
| | 10:15 | *Coffee break* |
| | 10:45 | Claudia Redenbach<br>Random tessellations and their application to the modeling of cellular materials (p. 28) |
| 12:30 - 14:00 | | Lunch |
| 14:00 - 17:00 | | Lectures |
| | 14:00 | Lorenz Holzer<br>Quantitative microstructure analysis in materials science with special emphasis on 3D-aspects and FIB imaging (p. 21) |
| | 15:15 | *Coffee break* |
| | 15:45 | Evgeny Spodarev<br>Introduction to the extrapolation of stationary random fields (p. 30) |
| 17:15 - 18:30 | | Talks |
| | 17:15 | Yang Yuxin<br>Clark-Ocone formula: applications and generalisations (p. 45) |
| | 17:55 | Oleg Butkovskiy<br>Coupling method for strongly ergodic Markov processes (p. 32) |
| 18:30 - 20:00 | | Dinner |

## Tuesday, September 13, 2011

| | | |
|---|---|---|
| 8:00 - 9:00 | | Breakfast |
| 9:00 - 12:00 | | Lectures |
| | 9:00 | Dominique Jeulin<br>Introduction to fundamental classes of models in stochastic geometry (p. 23) |
| | 10:15 | *Coffee break* |
| | 10:45 | Claudia Redenbach<br>Random tessellations and their application to the modeling<br>of cellular materials (p. 28) |
| 12:30 - 14:00 | | Lunch |
| 14:00 - 17:00 | | Lectures |
| | 14:00 | Lorenz Holzer<br>Quantitative microstructure analysis in materials science with special emphasis<br>on 3D-aspects and FIB imaging (p. 21) |
| | 15:15 | *Coffee break* |
| | 15:45 | Evgeny Spodarev<br>Introduction to the extrapolation of stationary random fields (p. 30) |
| 17:15 - 18:30 | | Talks |
| | 17:15 | Pascal Martin<br>Point pattern analysis in articular cartilage (p. 38) |
| | 17:55 | Martin Meinhardt<br>Modeling chondrocyte patterns by elliptical cluster processes (p. 39) |
| 18:30 - 20:00 | | Dinner |

## Wednesday, September 14, 2011

| | |
|---|---|
| 7:00 - 7:30 | Breakfast |
| 8:00 - 18:45 | Excursion |

On Wednesday, September 14, there will be a bus excursion to Ulm, including a visit to Ulm University. Departure time is 8:00. After a welcome address by Prof. Dr. Paul Wentges, the Dean of the Faculty for Mathematics and Economics, at 11:00, there will be a short campus tour followed by a lunch at the University canteen (self-pay). At 13:00 the program will proceed with a presentation by Prof. Dr. Paul Walther (Electron Microscopy Facility of Ulm University) in the multimedia lab of Ulm University. The talk is entitled "On electron tomographic image acquisition of life science samples" and will feature advanced imaging technologies at Ulm University. Afterwards, we will visit the city center of Ulm including the picturesque Fischerviertel with its beautiful historical buildings and small streams flowing into the Danube river. There will also be the opportunity to visit Ulm's cathedral, which is famous for its elaborately carved choir chairs and the highest historical steeple, whose 768 steps may be climbed to be rewarded by a magnificent view over the city. The bus back to Hirschegg is scheduled to leave Ulm at 16:00. Dinner will be served at 18:45 at the traditional mountain lodge Sonna Alp in Mittelberg.

## Thursday, September 15, 2011

| | | |
|---|---|---|
| 8:00 - 9:00 | | Breakfast |
| 9:00 - 12:00 | | Lectures |
| | 9:00 | Dominique Jeulin<br>Introduction to fundamental classes of models in stochastic geometry (p. 23) |
| | 10:15 | *Coffee break* |
| | 10:45 | Jesper Møller<br>Introduction to spatial point processes and simulation-based inference (p. 27) |
| 12:30 - 14:00 | | Lunch |
| 14:00 - 17:00 | | Lectures |
| | 14:00 | Alexander Bulinski<br>Introduction to stochastic genetics and its applications (p. 20) |
| | 15:15 | *Coffee break* |
| | 15:45 | Evgeny Spodarev<br>Introduction to the extrapolation of stationary random fields (p. 30) |

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|---|---|
| 17:15 - 18:00 | Introduction to Poster Session |

Eva-Maria Didden
The stochastic puzzle process: A Bayesian point process model for the analysis of texture images (p. 32)
Julia Hörrmann
Random mosaics in high dimensions (p. 36)
Jan-Otto Hooghoudt
Computation of FRET efficiency using spatial point process modeling for protein alignment (p. 36)
Wolfgang Karcher
Spatial modeling in storm insurance (p. 37)
Mayukh Samanta
Bootstrapping for highly unbalanced clustered data (p. 41)
Ondřej Šedivý
Use of electron backscatter diffraction for crystallographic mapping (p. 42)
Malte Spiess
Asymptotic properties of the approximate inverse estimator for directional distributions (p. 43)
Irene Vecchio
3d geometric characterization of particles for technical cleanliness (p. 44)

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| 18:30 - 20:00 | Dinner |
| 20:00 - 21:00 | Poster presentations |

## Friday, September 16, 2011

| | | |
|---|---|---|
| 8:00 - 9:00 | | Breakfast |
| 9:00 - 12:00 | | Lectures |
| | 9:00 | Viktor Benes<br>Random marked sets and space-time models (p. 18) |
| | 10:15 | *Coffee break* |
| | 10:45 | Jesper Møller<br>Introduction to spatial point processes and simulation-based inference (p. 27) |
| 12:30 - 14:00 | | Lunch |

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|---|---|---|
| 14:00 - 17:00 | | Lectures |
| | 14:00 | Alexander Bulinski<br>Introduction to stochastic genetics and its applications (p. 20) |
| | 15:15 | *Coffee break* |
| | 15:45 | Volker Schmidt<br>Stochastic segmentation and 3D modeling of microstructures (p. 29) |
| 17:15 - 18:30 | | Talks |
| | 17:15 | Andreas Häffelin, Andreas Messner<br>3D finite element model for porous electrode microstructures (p. 33) |
| | 17:55 | Gerd Gaiselmann<br>Stochastic 3D modeling of velt-type GDL in PEM fuel cells (p. 33) |
| 18:30 - 20:00 | | Dinner |

## Saturday, September 17, 2011

| | | |
|---|---|---|
| 8:00 - 9:00 | | Breakfast |
| 9:00 - 12:00 | | Lectures |
| | 9:00 | Viktor Benes<br>Random marked sets and space-time models (p. 18) |
| | 10:15 | *Coffee break* |
| | 10:45 | Jesper Møller<br>Introduction to spatial point processes and simulation-based inference (p. 27) |
| 12:30 - 14:00 | | Lunch |
| 14:00 - 17:00 | | Lectures |
| | 14:00 | Alexander Bulinski<br>Introduction to stochastic genetics and its applications (p. 20) |
| | 15:15 | *Coffee break* |
| | 15:45 | Volker Schmidt<br>Stochastic segmentation and 3D modeling of microstructures (p. 29) |

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|---|---|---|
| 17:15 - 18:30 | | Talks |
| | 17:15 | Peter Stanley Jørgensen<br>Three dimensional microstructure analysis of solid oxide electrode microstructure by focused ion beam tomography (p. 36) |
| | 17:55 | Martin Salzer<br>Segmentation of FIB-SEM images of highly porous material (p. 41) |
| 18:30 - 20:00 | | Dinner |

## Sunday, September 18, 2011

| | |
|---|---|
| 7:30 - 8:30 | Breakfast |
| 9:00 - 18:00 | Excursion<br>On Sunday, September 18, there will be a bus excursion to the Bavarian royal castle Neuschwanstein near Schwangau. Alternatively to a tour inside the castle there will be the opportunity to go on a hiking trip in the surrounding mountains. Please take good mountain shoes and outdoor/rain wear with you for hiking. Departure time is 9:00 and the return to Söllerhaus in the evening is scheduled for approximately 18:00. |
| 18:30 - 20:00 | Dinner |

## Monday, September 19, 2011

| | | |
|---|---|---|
| 8:00 - 9:00 | | Breakfast |
| 9:00 - 12:00 | | Lectures |
| | 9:00 | Wilfrid Kendall<br>Perfect simulation with applications in stochastic geometry (p. 25) |
| | 10:15 | *Coffee break* |
| | 10:45 | Ulrich Stadtmüller<br>Introduction to functional data analysis and its applications (p. 31) |
| 12:30 - 14:00 | | Lunch |

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|---|---|---|
| 14:00 - 17:00 | | Lectures |
| | 14:00 | Bartek Błaszczyszyn<br>Clustering, percolation and directionally convex ordering of point processes (p. 19) |
| | 15:15 | *Coffee break* |
| | 15:45 | Zakhar Kabluchko<br>Max-stable random fields and modeling of extremal spatial phenomena (p. 24) |
| 17:15 - 18:30 | | Talks |
| | 17:15 | Ole Stenzel<br>Stochastic modeling of the 3D morphology in polymer-ZnO solar cells (p. 43) |
| | 17:55 | Christian Hirsch<br>Euclidean first-passage percolation on creek-crossing graphs (p. 35) |
| 18:30 - 20:00 | | Dinner |

## Tuesday, September 20, 2011

| | | |
|---|---|---|
| 8:00 - 9:00 | | Breakfast |
| 9:00 - 12:00 | | Lectures |
| | 9:00 | Wilfrid Kendall<br>Perfect simulation with applications in stochastic geometry (p. 25) |
| | 10:15 | *Coffee break* |
| | 10:45 | Ulrich Stadtmüller<br>Introduction to functional data analysis and its applications (p. 31) |
| 12:30 - 14:00 | | Lunch |
| 14:00 - 17:00 | | Lectures |
| | 14:00 | Bartek Błaszczyszyn<br>Clustering, percolation and directionally convex ordering of point processes (p. 19) |
| | 15:15 | *Coffee break* |
| | 15:45 | Zakhar Kabluchko<br>Max-stable random fields and modeling of extremal spatial phenomena (p. 24) |

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|---|---|---|
| 17:15 - 18:30 | | Talks |
| | 17:15 | Kaspar Stucki<br>Stationary particle systems (p. 44) |
| | 17:55 | David Neuhäuser<br>On the distribution of typical shortest–path lengths<br>in connected random geometric graphs (p. 40) |
| 18:30 - 20:00 | | Dinner |

## Wednesday, September 21, 2011

7:30 - 8:30 Breakfast

9:00 - 18:30 Excursion

On Wednesday, September 21, there will be a bus excursion to Lindau (Lake Konstanz) with some time to walk through the city. The departure time is 9:00. The bus will leave Lindau again at 13:15 for Friedrichshafen, where will be a guided tour through the Zeppelin museum starting at 14:15. At 16:00 the bus will depart from Friedrichshafen for the drive back to Hirschegg. Dinner will be served starting at 19:30 at the mountain lodge Walserblick, which is located within short walking distance to the Söllerhaus.

## Thursday, September 22, 2011

| | | |
|---|---|---|
| 8:00 - 9:00 | | Breakfast |
| 9:00 - 12:00 | | Lectures |
| | 9:00 | Wilfrid Kendall<br>Perfect simulation with applications in stochastic geometry (p. 25) |
| | 10:15 | *Coffee break* |
| | 10:45 | Ulrich Stadtmüller<br>Introduction to functional data analysis and its applications (p. 31) |
| 12:30 - 14:00 | | Lunch |

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|---|---|---|
| 14:00 - 17:00 | | Lectures |
| | 14:00 | Eva Vedel Jensen<br>Applications of automatic image analysis in stereology and spatial statistics (p. 22) |
| | 15:15 | *Coffee break* |
| | 15:45 | Dirk P. Kroese<br>Stochastic process generation (p. 26) |
| 17:15 - 18:30 | | Talks |
| | 17:15 | Alexey Shashkin<br>A central limit theorem for the surface area of excursion sets (p. 42) |
| | 17:55 | Sebastian Lück<br>Statistical comparison of tomographic reconstruction algorithms<br>with respect to missing wedge artifacts (p. 38) |
| 18:30 - 20:00 | | Dinner |

## Friday, September 23, 2011

| | | |
|---|---|---|
| 8:00 - 9:00 | | Breakfast |
| 9:00 - 12:00 | | Lectures |
| | 9:00 | Eva Vedel Jensen<br>Applications of automatic image analysis in stereology and spatial statistics (p. 22) |
| | 10:15 | *Coffee break* |
| | 10:45 | Dirk P. Kroese<br>Stochastic process generation (p. 26) |
| 12:30 - 14:00 | | Lunch |
| 14:00 - 17:00 | | Talks |
| | 14:00 | Dominic Schuhmacher<br>Stein's method for approximating complex distributions (p. 42) |
| | 15:15 | *Coffee break* |
| | 15:45 | Tim Brereton<br>Efficient quantile estimation (p. 32) |
| | 16:25 | Markéta Zikmundová<br>Spatio-temporal model for a random set given by a union of interacting discs (p. 45) |
| 18:30 - 20:00 | | Dinner |

## Saturday, September 24, 2011

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|---|---|
| 8:00 - 9:00 | Breakfast |
| 9:00 | Departure |

# Lectures

Viktor Benes, Charles University Prague

**Random marked sets and space-time models**

Random marked sets present generalizations of marked point processes. We are interested mostly in marked fibre and surface processes and show their relation to weighted random measures. Geostatistical characteristics as well as moment measures and distance methods are available for a statistical evaluation. Random-field models can be tested in various ways. For multivariate marks we consider the problem of dimension reduction. Results of simulations are presented for the 3D Poisson-Voronoi tessellation and for a curve in a bounded planar domain being a solution of a SDE, both marked by a Gaussian random field. In applications the 3D grain microstructure of metals with crystallographic orientations of cells induces a marked surface process of cell faces with disorientation marks of neighbouring cells. In a neurophysiological experiment the track (a random fibre) of a rat is monitored together with occurrences of action potentials of a hippocampal neuron, the planar intensity function of spiking activity being a mark. A track of the rat elongates in time, therefore it can be viewed as a spatio-temporal random set. Parametric models are used to describe the development of firing fields. Filtering enables to quantify the evolution of parameters in discrete time, sequential Monte Carlo algorithms are used to speed up the calculations and relax traditional Gaussian assumptions on the posterior. Another model presented is a spatio-temporal random set based on the union of interacting discs simulated by MCMC. Besides growth models here all quermassintegrals may have a temporal trend. The particle filter is compared with the maximum-likelihood estimation of parameters.

Lecture 1. Random marked sets

- Section 1.1. Models of integer Hausdorff dimension
- Section 1.2. Statistical characteristics and simulations
- Section 1.3. Applications in materials research and neurophysiology

Lecture 2. Stochastic geometry in space and time

- Section 2.1. From spatial to spatio-temporal random sets
- Section 2.2. Sequential Monte-Carlo
- Section 2.3. Filtering and statistical methods

Bartek Błaszczyszyn, INRIA & ENS, Paris

**Clustering, percolation and directionally convex ordering of point processes**

Heuristics indicate that point processes exhibiting clustering of points have larger critical radius for the percolation of their continuum percolation models than spatially more homogeneous point processes. It has already been shown, and we reaffirm it in this presentation, that the dcx-ordering of point processes is suitable to compare their clustering tendencies. Hence, it is tempting to conjecture that the critical percolation radius is increasing in dcx-order. Some numerical evidences support this conjecture for a special class of point processes, called perturbed lattices, which are "toy models" for determinantal and permanental point processes. However the conjecture is not true in full generality, since one can construct a Cox point process with degenerate critical radius being equal to zero, that is dcx-larger than a given homogeneous Poisson point process, for which this radius is known to be strictly positive. Nevertheless, the aforementioned monotonicity in dcx-order can be proved, for a nonstandard critical radius, related to Peierls argument. Furthermore, we show the reverse monotonicity for another nonstandard critical radius. This gives uniform lower and upper bounds on the standard critical percolation radius for all point processes being dcx-smaller than some given point process. Moreover, we show that point processes which are dcx-smaller than a homogeneous Poisson point process admit uniformly non-degenerate lower and upper bounds on the standard critical percolation radius. In fact, all the above results hold under weaker assumption on the ordering of void probabilities or factorial moment measures only. Examples of point processes comparable to Poisson point processes in this weaker sense include determinantal and permanental point processes with trace-class integral kernels. More generally, we show that point processes dcx-smaller than a homogeneous Poisson point processes exhibit phase transitions in certain percolation models based on the level-sets of additive shot-noise fields of these point process. Examples of such models are k-percolation and SINR-percolation.

Lecture 1. Directional ordering and clustering

- Section 1.1. Definitons, examples and properties
- Section 1.2. Statistical descriptors of spatial (non-) homogeneity
- Section 1.3. Examples (Super- and Sub-Poisson, perturbed-lattice, determinantal and permanental point processes)

Lecture 2. Directional ordering and continuum percolation

- Section 2.1. Upper and lower critical percolation radius
- Section 2.2. Sandwich inequality and phase transition
- Section 2.3. Phase transitions in sub-Poisson models

Alexander Bulinski, Lomonosov Moscow State University

**Introduction to stochastic genetics and its applications**

The goal of these lectures is to give an introduction to modern stochastic models in genetics. Such models are used in studying the complex risks of diseases. The challenging problem here is to identify the collection of single nucleotide polymorphisms (SNP) increasing the risk of diseases. There exist various approaches to this problem involving different probabilistic techniques. We will employ ideas of random trees and forests, spatial Markov processes and Bayesian networks. New statistical methods will be also discussed, including exemplary results of data analysis.

Lecture 1. Biological background

- Section 1.1. DNA, genes, SNP: Heredity theory; gene-gene and gene-environment interactions
- Section 1.2. Complex diseases and the risk-factors; identification of interactions
- Section 1.3. Measures of importance of interactions

Lecture 2. Model selection and genome-wide association study (GWAS)

- Section 2.1. Multifactor dimensionality reduction (MDR) method and its modifications
- Section 2.2. Logic regression and simulated annealing
- Section 2.3. Random trees and forests

Lecture 3. Statistical inference and spatial analysis of DNA

- Section 3.1. Spatial Markov processes
- Section 3.2. Bayesian networks
- Section 3.3. Simulation techniques

Lorenz Holzer, Zurich University for Applied Sciences

**Quantitative microstructure analysis in materials science with special emphasis on 3D-aspects and FIB-imaging**

This lecture intends to highlight the materials scientists approach in elaborating the relationships between microstructure parameters and materials properties. Based on the fundamental understanding of these relationships it will be possible to improve specific material properties such as permeability, effective conductivity, electrochemical activity or durability. The typical methodologies which are used in the work flow for microstructure analysis are discussed and illustrated. These methodologies include image acquisition, basic image processing procedures, extraction of quantitative parameters and finally the elaboration of relationships with experimental results. Practical applications of these methods will be illustrated with some examples which include a) hydration kinetics (crystallization/precipitation) in cement suspensions, b) transport properties of porous media (electrolysis membranes, concrete, clay stones), c) degradation kinetics of nickel based electrodes and d) microstructure-property relationships (i.e. electrochemical activity) of fuel cell electrodes.

Lecture 1: Work flow from image acquisition to microstructure quantification

- Section 1.1. Image acquisition: Overview of 2D- and 3D-methods
- Section 1.2. Practical aspects of image processing: Correction of image imperfections, stack alignment, feature recognition, boundary truncation problem
- Section 1.3. Two different concepts for size distributions: Discrete and continuous PSDs

Lecture 2: Discussion of some microstructure-property relationships

- Section 2.1. Basic concepts of microstructure - property relationships in materials science
- Section 2.2. Porous media: Discussion of transport properties with a special focus on tortuosity
- Section 2.3. Microstructure effects on the performance of solid oxide fuel cells: degradation kinetics and electrode activity

Eva Vedel Jensen, Aarhus University

**Applications of automatic image analysis in stereology and spatial statistics**

The aim of these lectures is to give a number of recent examples where computerized image analysis has been combined with non-uniform sampling to increase the efficiency of estimators in stereology and spatial statistics. In Lecture 1, we focus on estimation of intensities of point processes based on observation in non-uniformly placed sampling windows. The distribution of the windows is determined by a rough estimate of the realized point pattern. For this reason, the technique is called image-based empirical importance sampling. Methods of constructing optimal estimators of the intensity of a point process based on such data are discussed. Lecture 2 deals primarily with applications of automatic image analysis in local stereology. It will be shown that measurements along lines and in planes can be combined in an intelligent way to increase the efficiency of local stereological estimators in common use.

Lecture 1. Image-based empirical importance sampling

- Section 1.1. Importance sampling
- Section 1.2. Efficiency for homogeneous point processes
- Section 1.3. Design- and model-based inference

Lecture 2. Automatic image analysis in local stereology

- Section 2.1. Local stereological estimators
- Section 2.2. Efficiency of estimators of particle size
- Section 2.3. A comparative study

Dominique Jeulin, MINES ParisTech

**Introduction to fundamental classes of models in stochastic geometry**

The aim of these lectures is to give an introduction to some theroretical models developed in mathematical morphology and to simulation of random sets and functions (scalar and multivariate). These models are useful in many physical situations with heterogeneous media, for which a probabilistic approach is required. We can mention for instance problems of fracture statistics of materials, the composition of permeabilities in porous media, scanning or transmission electron microscopy images (including multispectral images), rough surfaces or multicomponent composites, but also some biological textures. We will detail the construction and probabilistic properties of Boolean random function models, originally proposed to simulate random rough surfaces, and various types of dead leaves models, well suited to the simulation of multi-component random sets, as well as to simulate perspective views.

Lecture 1. Introduction to random sets and functions. The Boolean random function

- Section 1.1. Random closed sets and the Choquet capacity
- Section 1.2. Semi-continuous random functions
- Section 1.3. The Boolean random function

Lecture 2. Dead leaves random sets

- Section 2.1. The dead leaves random tesselation
- Section 2.2. Color dead leaves: construction and main probabilistic properties
- Section 2.3. Color dead leaves: properties and simulations

Lecture 3. Dead leaves random functions

- Section 3.1. Construction and general properties
- Section 3.2. Bivariate distribution and distribution of the minimum on a compact

Zakhar Kabluchko, Ulm University

**Max-stable random fields and modeling of extremal spatial phenomena**

Max-stable random fields are natural models for extremal spatial random phenomena like extreme rainfalls, extreme floods, large insurance losses, etc. Max-stable random fields appear as limits of pointwise maxima of independent copies of a random field as the number of copies goes to infinity. Starting with the classical one-dimensional extreme-value theory we will proceed to multivariate extreme-value distributions and then to max-stable random fields. We will discuss basic properties of max-stable fields, their representations, simulation, define basic classes of max-stable fields and discuss their statistical estimation.

Lecture 1. Classical extreme-value theory

- Section 1.1. Motivating examples; the classical extreme-value theorem; max-stable distributions and their domains of attraction
- Section 1.2. Multivariate extreme-value theory; spectral representations
- Section 1.3. Example: Hüsler-Reiss distributions

Lecture 2. Max-stable random fields

- Section 2.1. Definition of max-stable random fields and their basic properties; spectral representations of max-stable random fields
- Section 2.2. Basic classes: mixed moving maxima, positive recurrent max-stable fields, Brown-Resnick fields; simulation of max-stable random fields
- Section 2.3. Dependence measures and statistical estimation

Wilfrid Kendall, University of Warwick

**Perfect simulation with applications in stochastic geometry**

The aim of these lectures is to present a clear introduction to the notion of perfect simulation and related mathematical ideas, with a strong emphasis on applications to stochastic geometry. Lecture 1 begins with the original finite-state-space context of Propp and Wilson (1996), and illustrate it by developing a coupling-from-the-past (CFTP) algorithm for a simple problem in elementary image analysis. Lecture 2 continues by describing ways in which one can generalize the CFTP algorithm to suitable infinite-state-space contexts (for example as in Kendall and Moeller, 2000), together with work on how far one might be able to go in this direction (Kendall 2004, Connor and Kendall 2007a,b). This will be illustrated by discussion of CFTP for point processes and other object processes. Finally Lecture 3 discusses the use of perfect simulation ideas in other contexts, such as in dealing with boundary effects.

Lecture 1. Classic coupling from the past

- Section 1.1. Simplest possible instances: flip-flops, simple random walks, Ising models
- Section 1.2. Mathematical precursors and general theorems
- Section 1.3. Case studies: seeking out monotonicity

Lecture 2. Dominated coupling from the past

- Section 2.1. Birth-death processes and point processes
- Section 2.2. Theoretical limits
- Section 2.3. Case studies: perpetuation and interaction

Lecture 3. Complements

- Section 3.1. Dealing with boundaries
- Section 3.2. Further refinements
- Section 3.3. Other variants of perfect simulation

Dirk P. Kroese, The University of Queensland, Brisbane

**Stochastic process generation**

Many numerical problems in science, engineering, finance, and statistics are solved nowadays through Monte Carlo methods; that is, through random experiments on a computer. The most basic use of Monte Carlo simulation is to generate realisations of a random (or stochastic) process from a given probabilistic model, in order to observe its behaviour. In these lectures we discuss how to efficiently generate a range of well-known one- and multi-dimensional random processes, including those used in spatial statistics. The theory will be illustrated with working code in Matlab, which can be downloaded from www.montecarlohandbook.org

Lecture 1. Fundamental stochastic processes

- Section 1.1. Gaussian Processes
- Section 1.2. Markov Processes and Markov Random Fields
- Section 1.3. Random Point Processes and Poisson Random Measures

Lecture 2. Other stochastic processes

- Section 2.1. Stochastic Differential Equations
- Section 2.2. Fractional Brownian Motion and the Brownian Sheet
- Section 2.3. Levy Processes

Jesper Møller, Aalborg University

**Introduction to spatial point processes and simulation-based inference**

Spatial point pattern data occur frequently in a wide variety of scientific disciplines, including seismology, ecology, forestry, geography, spatial epidemiology and material science. In recent years, fast computers and advances in computational statistics, particularly Markov chain Monte Carlo (MCMC) methods, have had a major impact on the development of statistics for spatial point processes. The focus has now changed to likelihood-based inference for flexible parametric models, often depending on covariates, and liberated from restrictive assumptions of stationarity. We summarize and discuss the current state of spatial point process theory and directions for future research, making an analogy with generalized linear models and random effect models, and illustrating the theory with various examples of applications. In particular, we consider Poisson, Gibbs and Cox process models, diagnostic tools and model checking, MCMC algorithms, computational methods for likelihood-based inference, and quick non-likelihood approaches to inference.

Lecture 1. Fundamental concepts and tools

- Section 1.1. Introduction
- Section 1.2. Poisson processes
- Section 1.3. Summary statistics

Lecture 2. Two main classes of spatial point process models

- Section 2.1. Cox processes
- Section 2.2. Markov point processes

Lecture 3. Simulation and inference procedures

- Section 3.1. Markov chain Monte Carl
- methods
- Section 3.2. Likelihood and moment-based estimation procedures
- Section 3.3. Overview and concluding remarks

Claudia Redenbach, University of Kaiserslautern

**Random tessellations and their application to the modeling of cellular materials**

Cellular materials are nowadays used in a wide range of application areas including shock absorption, thermal insulation or filtration. The macroscopic properties of a material, e.g., elasticity, thermal conductivity or permeability, are highly affected by its microstructure. Models from stochastic geometry combined with finite element simulations are important tools for studying these complex structure-property relations. Random tessellations, i.e., space-filling systems of convex, non-overlapping polytopes, are widely used as models for cellular or polycrystalline materials. Foam structures, for instance, are modelled by the systems of edges (open-cell foam) or facets (closed-cell foam) of the tessellation. Random Laguerre tessellations (a weighted form of the well-known Voronoi tessellations) generated by systems of non-overlapping spheres are particularly promising models for foam structures. In our lectures, we will introduce random tessellation models, in particular Voronoi and Laguerre tessellations, together with their geometric characteristics. We will discuss how to estimate these characteristics from 3D images of cellular materials obtained by microcomputed tomography. Using these characteristics, we will fit random tessellation models to the materials. These models are then used to study the dependence of macroscopic properties on the geometric microstructure.

Lecture 1. Geometric characterisation of cellular materials

- Section 1.1. Cellular materials: Properties and applications
- Section 1.2. Random tessellations, in particular tessellations of Laguerre type
- Section 1.3. Characteristics of tessellation and their estimation from image data

Lecture 2. Stochastic modeling of cellular materials

- Section 2.1. Model fitting procedure
- Section 2.2. Examples of application
- Section 2.3. Prediction of macroscopic properties

Volker Schmidt, Ulm University

**Stochastic segmentation and 3D modeling of microstructures**

We will discuss various techniques of stochastic segmentation and modeling of 3D images, which show complex microstructures of composite and porous materials reconstructed by electron and synchrotron tomography. Using a multiscale approach, it is possible to decompose complex microstructures into several (less complex) components. In particular, a macroscale component is determined by morphological smoothing. It can be represented by unions of overlapping spheres, where a certain maximum-likelihood principle is used. This leads to an enormous reduction of complexity and allows us to model the macroscale component by random marked point processes, which is one of the most fundamental classes of models in stochastic geometry. On the other hand, by the morphological smoothing, a small fraction of voxels is misspecified. The set of these misspecified voxels is interpreted as the microscale component of the microstructure. It is modeled separately, using random particle systems of Cox type. Furthermore, stochastic network models are considered which describe the 3D morphology of percolation paths in composite or porous materials. They have the form of random geometric graphs, where the vertex set is modelled by random point processes and the edges are put using tools from graph theory and MCMC simulation. The network models can be applied to analyse transport processes of charges, gases, or fluids, e.g., in polymer solar cells, Li-ion batteries, and fuel cells.

Lecture 1. Multi-scale approach to stochastic 3D modeling

- Section 1.1. Representation by unions of overlapping spheres
- Section 1.2. Random particle systems of Cox type
- Section 1.3. Model fitting, model validation, and virtual material design

Lecture 2. Modeling the 3D morphology of percolation paths

- Section 2.1. Stochastic network models via random geometric graphs
- Section 2.2. Model fitting based on tools from graph theory and MCMC simulation
- Section 2.3. Applications to polymer solar cells, Li-ion batteries, and fuel cells

Evgeny Spodarev, Ulm University

**Introduction to the extrapolation of stationary random fields**

For stationary random fields with finite second moments, the theory of mean square optimal linear extrapolation exists since 1960s due to D. Krige and G. Matheron. In practice however (e.g. in storm insurance) there is also a need to extrapolate heavy-tailed spatial data without finite second moments. These data can often be reasonably modelled by stable random fields given as integrals of a non-random kernel function with respect to a random stable noise. In our lectures, we give an overview of classical and new results in this area. We study the existence and uniqueness properties of the extrapolation methods which are realised as (non-) linear optimisation problems with constraints.

Lecture 1. Extrapolation of second order stationary random fields

- Section 1.1. Stationary random fields, covariance, and variogram
- Section 1.2. Estimation of the covariance structure
- Section 1.3. Ordinary kriging and its properties, kriging with drift

Lecture 2. Stable random laws

- Section 2.1. Normalisation: Box–Cox transform, stable distributions
- Section 2.2. Random measures, stochastic integration
- Section 2.3. Stable random fields and their properties, stability and association

Lecture 3. Extrapolation of stable random fields

- Section 3.1. Predictors and their properties
- Section 3.2. Maximization of covariation
- Section 3.3. Examples, open problems

Ulrich Stadtmüller, Ulm University

**Introduction to functional data analysis and its applications**

In many modern statistical questions the data are not just copies of a random variable or a random vector but copies of ininitely dimensional objects as random processes or random fields. If we want to do statistical analysis based on finitely many data and do not have some parametric model in mind, we have to use approaches using a dimension reduction. These lectures give an introduction into the topics of functional data analysis including functional principal component analysis providing appropriate tools. The lectures will include basic modeling, tools and methods together with some theoretical results. Exemplary applications will illustrate the methods.

Lecture 1. Introduction and basics

- Section 1.1. Examples of functional data
- Section 1.2. Basic tools
- Section 1.3. Representing functional data

Lecture 2. Functional principle component analysis

- Section 2.1. Classical principle component analysis
- Section 2.2. Functional PCA
- Section 2.3. Consisteny results for functional PCA

Lecture 3. Linear models with functional data

- Section 3.1. Scalar response
- Section 3.2. Functional response
- Section 3.3. Classification

# Contributed Talks/Posters

Tim Brereton, University of Queensland

**Efficient quantile estimation**

Joint work with Joshua Chan and Dirk Kroese.

In practice, one often wishes to estimate certain quantiles of a random variable. These could describe the risk associated with a financial portfolio, the critical values of a test statistic, or the typical length of a path through a stochastic network. These quantiles often need to be calculated using potentially expensive Monte Carlo methods. In this talk, I describe how variance reduction methods - in particular, importance sampling - can be applied to the problem of quantile estimation. The methods used incorporate a number of key techniques in simulation, including Markov Chain Monte Carlo, splitting and the Cross-Entropy method.

Oleg Butkovskiy, Moscow State University

**Coupling method for strongly ergodic Markov processes**

Joint work with A. Yu. Veretennikov.

The coupling method is a powerful tool for proving ergodicity results. It dates back to Doeblin and was later developed by Vaserstein, Pitman, Griffeath, Goldstein and others (see [1]). We prove that strong ergodicity of Markov process is linked with a spectral radius of a certain "associated" semigroup operator, although, not a "natural" one. We also give sufficient conditions for weak ergodicity and provide explicit estimates of convergence rate. To establish these results we construct a modification of Vaserstein coupling [2]. Some applications including mixing properties are also discussed.

References:

[1] Thorisson, H. (2000): Coupling, Stationarity, and Regeneration. Probability and its Applications, Springer-Verlag, New York.

[2] Vaserstein, L.N. (1969): Markov processes on countable product spaces describing large systems of automata, Problemy Peredaci Informacii, 3, 64–72

Eva-Maria Didden, University of Heidelberg

**The stochastic puzzle process: A Bayesian point process model for the analysis of texture images**

Joint work with Thordis L. Thorarinsdottir, Alexander F. Lenkoski, and Christoph Schnörr

Texture synthesis and the recovery of the 3D structures of objects from 2D images are typical tasks in computer science and image processing. In spatial statistics, marked point process

models serve as a well-established tool to characterize global structures and local pecularities. We want to establish a connection beween both disciplines and propose a Bayesian point process model to identify and quantify relevant patterns as well as geometric structures in textures.
To this end, we apply a marked point process where the marks are based on a predefined codebook of small distinctive patches from the image itself, a representative image section, or an image of the same class. Rather than aiming for an exact image reconstruction, we focus on the estimation of posterior parameters describing mark allocations and compositions, local and global orientations, and background attributes of the underlying texture. The assessment of inhomogeneities and irregularities is also included.
We describe our model and provide first results for the analysis of photographs of brick walls.

Gerd Gaiselmann, University of Ulm

**Stochastic 3D modeling of velt-type GDL in PEM fuel cells**

In this talk a parameterized stochastic 3D multi-layer model is presented which describes the microstructure of (strongly) curved fiber-based materials. The multi-layer model consists of independent random layers which are stacked together. Each of these layers is modeled by a 2D germ-grain model dilated in 3D. The germs form a 2D Poisson point process and the grains, representing random 2D polygonal tracks, are modeled by multivariate time series. Exemplarily, the multi-layer model is fitted to the microstructure of velt-type GDL in PEM fuel cells. For this type of materials it is reasonable to assume that the GDL can be decomposed in thin disjoint and independent layers. In this way, it is possible to fit the 3D multi-layer model just on the basis of information about the fiber courses of 2D SEM images from velt-type GDL. Therefore, an algorithm is presented which extracts the required information from 2D images. Finally, the fitted multi-layer model is validated by comparing structural characteristics extracted from 3D X-ray synchrotron data and realizations of the model.

References:

[1] Thiedmann, R., Fleischer, F., Lehnert, W. and Schmidt, V. (2008). Stochastic 3D modelling of the GDL structure in PEM fuel cells, based on thin section detection. Journal of the Electrochemical Society, 155, B391-B399.

[2] Gaiselmann, G., Thiedmann, R., Manke, I., Lehnert, W. and Schmidt, V. (2011). Stochastic 3D modeling of velt-type GDL in PEM fuel cells. (Preprint)

Andreas Häffelin, Andreas Messner, Karlsruhe Institute of Technology (KIT)

**3D finite element model for porous electrode microstructures**

The performance of solid oxide fuel cells and lithium ion batteries is strongly affected by the polarization resistance of the cell, which is determined by the composition and the microstructure of the porous electrodes. Therefore it is essential to know the microstructure as accurate as possible in order to separate the influence of material composition and microstructure.

Focused ion beam (FIB)-tomography as a high-resolution three-dimensional (3D) technique has already proven potential in studying the morphology of porous electrodes in SOFC research

[1-3]. With this technique a detailed analysis, which includes the quantification of critical parameters such as volume fractions, active surface area, grain sizes and tortuosity can be derived [1-4]. These parameters can be used in homogeneous models to predict the cell performance [5]. Moreover, presumed that an adequate model is available, the achieved reconstruction can be used as a detailed model-geometry in space resolved 3D microstructure models.

To consider material and microstructural parameters, a 3D finite element model was developed for a mixed ionic-electronic conducting (MIEC) cathode. FIB-tomography was applied for providing a detailed and accurate model-geometry of the porous microstructure. In this model diffusion (described by the oxygen ion diffusion coefficient $D^\delta$) and electrochemical reactions (described by the surface exchange parameter $k^\delta$) of the involved species are simulated within the reconstructed porous electrode structure.

On the one hand a static model enabled us to compute the area specific resistance (ASR) of an electrode as a performance index [2]. Additionally a dynamic time-dependent model is able to predict the impedance spectrum of a MIEC-cathode (Figure 1) from a simulation of the current response due to a sinusoidal voltage stimulus at different frequencies or an appropriate voltage step. By disabling the loss contribution of individual processes in the model, their impact on the impedance spectra can be evaluated for various MIEC cathodes differing in microstructure.

Although this detailed analysis of the microstructure was performed for a SOFC-electrode, this method can be applied to different types of porous media, including e.g., battery electrodes [4].

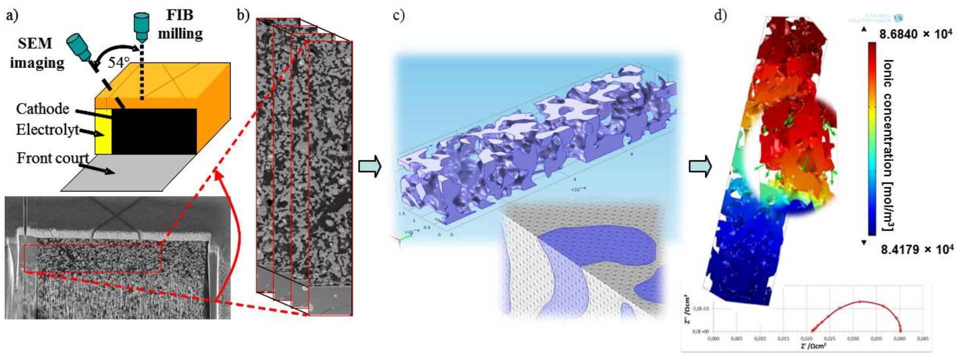


Figure 1: Schematic design of a FIB/SEM-setup (a). The consecutive SEM images were stacked and aligned (b) to obtain a 3D reconstruction of the electrode (c). This reconstruction can be used directly as model-geometry in COMSOL to calculate the tortuosity and the area specific resistance and the impedance spectrum of the electrode. The simulation result shows the oxygen ion distribution and oxygen flux in the reconstructed electrode (d).

References:
[1] J. R. Wilson, W. Kobsiriphat, R. Mendoza, H. Y. Chen, J. M. Hiller, D. J. Miller, K. Thornton, P. W. Voorhees, S. B. Adler and S. A. Barnett, Nature Mater., 5 (7), p. 541 (2006).

[2] B. Rüger, J. Joos, T. Carraro, A. Weber and E. Ivers-Tiffée, ECS Trans., 25 (2), p. 1211 (2009).

[3] L. Holzer, B. Münch, B. Iwanschitz, M. Cantoni, Th. Hocker, Th. Graule, J. Power Sources 196 p. 7076 (2011).

[4] M. Ender, J. Joos, T. Carraro, E. Ivers-Tiffée, Electrochem. Comm. p. 166 (2011)

[5] S. B. Adler, J. A. Lane and B. C. H. Steele, J. Electrochem. Soc. 143, p. 3554 (1996).

Christian Hirsch, Ulm University

**Euclidean first-passage percolation on creek-crossing graphs**

In [3] Hammersley and Welsh introduced first-passage percolation as a simple model for the spread of fluid in a random medium. While many results have been proven for first-passage percolation on the lattice $\mathbb{Z}^d$, more recently mathematicians also have begun to consider first-passage models on structures determined by point processes (see e.g. [2], [6]). In particular, we shall be interested in the model described by Aldous in [1].

Aldous considers certain connected random geometric networks defined on the vertex set of a homogeneous $2$-dimensional Poisson point process. He goes on to state and prove a sufficient criterion implying that for all $k \geq 1$ the $k$-th moments of shortest path-lengths on these graphs behave asymptotically as some multiple of the $k$-th power of the Euclidean distance. In this talk we will show how to extend his methods to prove similar results for the creek-crossing graphs introduced in [4]. In particular, we will allow more general point processes and show how to remove the restriction on the dimension.

We give two possible applications of this result: the a.s. boundedness of cells induced by $2$-dimensional creek-crossing graph, as well as a continuous analog of Kesten's classical shape theorem [5,Theorem 1.7].

References:

[1] Aldous, D. J. (2009): Which connected spatial networks on random points have linear route-lengths?, Arxiv preprint arXiv:0911.5296

[2] Baccelli, F. and Błaszczyszyn, B. and Haji-Mirsadeghi, M.O. (2011): Optimal paths on the space-time SINR random graph, Advances in Applied Probability,43, 131-150

[3] Hammersley, J. M. and Welsh, D. J. A. (1965): First-passage percolation, subadditive processes, stochastic networks, and generalized renewal theory, Bernoulli-Bayes-Laplace Anniversary Volume, 61–110

[4] Hirsch, C., Neuhäuser, D. and Schmidt,V. (2011): Connectivity of random geometric graphs related to minimal spanning forests, preprint

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Julia Hörrmann, Karlsruhe Institute of Technology (KIT)

**Random mosaics in high dimensions**

Joint work with Daniel Hug

A mosaic is a collection of non-overlapping cells covering the $d$-dimensional space. The cell containing the origin is called zero cell. We consider a family of random mosaics generated by a special isotropic hyperplane process X depending on two parameters $r$ and $\gamma$. What is the asymptotic behavior of the characteristics of the zero cell as the dimension goes to infinity?

Jan-Otto Hooghoudt, Aalborg University

**Computation of FRET efficiency using spatial point process modeling for protein alignment**

My research concerns introducing spatial statistics in the field of Fluorescence Resonance Energy Transfer. In this field Monte-Carlo simulations are done, where randomly chosen spatial configurations of proteins (represented by balls) are used to calculate the FRET-efficiency. Instead of using only random protein configurations and/or naively created clustered protein configurations, we will generate spatial protein patterns using Cox and Markov point processes. We will carefully examine the effect the spatial distribution of proteins has on the FRET-efficiency. We expect that, by making a catalog linking the FRET-efficiencies to the spatial alignment of the proteins, in the future we will be able to extract information regarding the alignment of proteins on an inner pixel level. The poster will give an outline of the basic theory concerning Fluorescence Resonance Energy Transfer. The FRET efficiency will be defined in the single-donor-single-acceptor case as well as in the case of multiple donors and multiple acceptors. Further, it is explained how the FRET efficiency depends on the spatial configurations of the proteins.

Peter Stanley Jørgensen, Technical University of Denmark

**Three dimensional microstructure analysis of solid oxide electrode microstructure by focused ion beam tomography**

Joint work with Jacob R. Bowen.

The performance of high temperature solid oxide cell electrodes used as fuel cells for heat and power generation or as electrolysers for the production of hydrogen or carbon monoxide is dictated by the materials and the morphology of the electrode microstructure. These electrodes consist of porous metallic and or ceramic composites. Three phases are required:porosity for gas transport, an electronic conducting phase and an ion conducting phase to complete the electrochemical circuit. In these structures important parameters include: the interfaces between phases, (two phase boundaries), the line loops at the intersection of all phases (triple phase boundary - TPB) and the connectivity (percolation) of each phase to gas, electron and ion sources. The ability to accurately quantify these parameters, amongst others is therefore required.

Electrode structures, due to the fabrication process, have a stochastic nature in 3D and therefore require 3D characterisation methods for accurate quantification. The current characterisation state of the art uses conventional focused ion beam tomography (FIB) to make serial sections in sequence with scanning electron microscopy.

This talk gives an overview of FIB tomography, the segmentation of the image data through a level set method [1] and various methods of quantifying key microstructural parameters from the image data such as TPB length [2] and network characteristics [3].

References:

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Wolfgang Karcher, Ulm University

**Spatial modeling in storm insurance**

For a long time, there has been an ongoing discussion on the impact of the climate change on losses due to natural disasters. The past years have demonstrated that natural disasters can cause losses in the billions so that insurance companies have to raise enormous sums to cover them (e.g. after the hundred year flood in August 2002 or after Hurricane Katrina in August 2005). Experts assume that both the intensity and the frequency of natural disasters continue to increase resulting in even larger and more frequent insurance claims.

In contrast to classical (one-dimensional) risk theory, we use $\alpha$-stable random fields to spatially model the claim sizes of a storm insurance portfolio of an Austrian insurance company. We show how one can fit such random fields to real data and calculate the spatialized insurance premiums based on Monte-Carlo simulation. It turns out that the premiums significantly differ from the ones determined by the collective model in classical risk theory. Furthermore, we use extrapolation methods – in particular for $\alpha$-stable random fields – to produce risk maps with which we can assess the spatial risk situation in the metropolitan area of Vienna, Austria.

References:

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Sebastian Lück, Ulm University

### Statistical comparison of tomographic reconstruction algorithms with respect to missing wedge artifacts

In computed tomography reconstructions frequently need to be generated from input data which is in complete due to a missing wedge of rotation angles. This situation is especially relevant for electron tomography, where projection images of the sample can typically only be taken in a range of $+-75^{\circ}$. Under standard reconstruction algorithms this missing wedge causes severe elongation, streak and blurring artifacts in the tomograms posing major challenges for a quantitative analysis of tomographic image data. We compare reconstructions of standard techniques such as filtered backprojection to results of the innovative algorithm DIRECTT (Direct Iterative Reconstruction of Computed Tomography Trajectories) [1], which has recently been developed at the Federal Institute of Materials Research and Testing (BAM) in Berlin [1]. This comparison is based on virtual phantom images and their tomographic reconstructions from simulated projections. A focus of the talk will be on statistical issues related to the analysis of reconstruction quality. In particular, we will illustrate how novel statistical tests for the Palm mark distribution in point processes with correlated marks [2] may be applied to investigate missing wedge artifacts based on appropriate marked point patterns extracted from reconstruction data. By means of these techniques and descriptive statistical tools we explore the capability of DIRECTT to reduce missing wedge artifacts in comparison to standard algorithms. This is done under various degrees of imperfections in the virtual projections of the phantoms such as noise and the size of the missing wedge.

References:

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Pascal Martin, University of Tübingen

### Point pattern analysis in articular cartilage

Human articular cartilage consists of 1-10 % by volume of cells, which are called chondrocytes. These chondrocytes produce and maintain the rest of the volume, the so-called matrix. On the surface of articular cartilage, where it is in contact with the opposite cartilage of a joint, the tissue has to respond to different, complex and high biomechanical forces. It was found out that chondrocytes in this superficial level of cartilage show a distinct spatial organization.

The chondrocytes are organized as single cells, pairs, clusters of three or more cells or as strings of three or more cells in a row (see Figure 2). It may be assumed that each pattern has special biomechanical qualities corresponding to the requirements in the different joints.

Degeneration of cartilage leads to changes in the cellular organization. In early stages of arthritis, a fifth form of cellular pattern appears: Double strings, consisting of two parallely ordered strings. They seem to be a sign of indication, before clinical symptoms arise. With further degeneration the chondrocytes lose their organization of cellular patterns. The function of the cartilage fades according to the architecture of the cellular structure.

By analysis of 2-dimensional microscopical images we were already able to show by statistical means distinct angles and distances between chondrocytes. Similar to the changes of the patterns in cartilage undergoing degeneration, the angles show significant changes before clinical symptoms.

By means of a particular type of microscopy it was possible to create 3-dimensional images of cartilage. Using the nearest neighbor method and the pair correlation function for statistical analysis we could show up the vertical organization of chondrocytes in healthy human cartilage. Furthermore we analyzed artificial cartilage produced in a laboratory for replacement of focal damages in knee joints. We could show up the existing difference in cellular organization between healthy human cartilage and artificial cartilage. These data are essential on the way to engineer artificial cartilage that is supposed to have similar biomechanical characteristics as the original one.

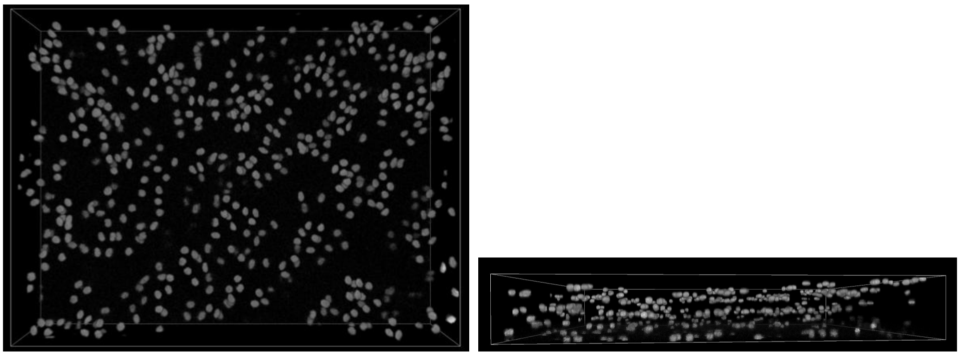

Figure 2: Chondrocytes in human articular cartilage;top view (left) and cross section (right)

Martin Meinhardt, Ulm University

### Modeling chondrocyte patterns by elliptical cluster processes

Superficial zone chondrocytes (CHs) of human joints are spatially organized in distinct horizontal patterns. The type of spatial CH organization within a given articular surface depends on whether the cartilage has been derived from an intact joint or the joint is affected by osteoarthritis (OA). Furthermore, specific variations of the type of spatial organization are associated with particular states of OA [1]. This association may prove relevant for early disease recognition based on a quantitative structural characterization of CH patterns. Therefore, we present a point process model describing the distinct morphology of CH patterns within the articular surface of intact human cartilage. This reference model for intact CH organization can be seen as a first step towards a model-based statistical diagnostic tool. Model parameters are fitted to fluorescence microscopy data by a novel statistical methodology utilizing tools from cluster and principal component analysis. This way, the complex morphology of surface CH patters is represented by a relatively small number of model parameters. We validate the point process model by comparing biologically relevant structural characteristics between the fitted model and data derived from photomicrographs of the human articular surface using techniques from spatial statistics.

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David Neuhäuser, Ulm University

**On the distribution of typical shortest–path lengths in connected random geometric graphs**

Stationary point processes in $\mathbb{R}^2$ with two different types of points, say $H$ and $L$, are considered where the points are located on the edge set $G$ of a random geometric graph, which is assumed to be stationary and connected (see [4]). Examples include the classical Poisson–Voronoi tessellation with bounded and convex cells, aggregate Voronoi tessellations induced by two (or more) independent Poisson processes whose cells can be non–convex (see [3]), and so–called $\beta$-skeletons being subgraphs of Poisson–Delaunay triangulations (see [2],[5]). The length of the shortest path along $G$ from a point of type $H$ to its closest neighbor of type $L$ is investigated. Two different meanings of 'closeness' are considered: either with respect to the Euclidean distance (e-closeness), or in a graph–theoretic sense, i.e., along the edges of $G$ (g-closeness). For both scenarios, comparability and monotonicity properties of the corresponding typical shortest–path lengths $C^{e*}$ and $C^{g*}$ are analyzed. Furthermore, extending the results which have recently been derived for $C^{e*}$ (see [1]), we show that the distribution of $C^{g*}$ converges to simple parametric limit distributions if the edge set $G$ becomes unboundedly sparse or dense, i.e., a scaling factor $\kappa$ converges to zero and infinity, respectively.

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Martin Salzer, Ulm University

**Segmentation of FIB-SEM images of highly porous material**

Image processing is a crucial step in statistical analysis of real-world data which itself often is a prerequisite for later modeling. Due to the specific nature of FIB-SEM data, image segmentation is a special matter. Especially when imaging highly porous material, it is often not sufficient to consider usual properties like the absolute gray intensities of voxels. We therefore developed a new algorithm that detects appearances and disappearances of solid structures based on variation of gray values in $z$-direction, rather than on absolute gray values. This approach already yields results better than common thresholding approaches, but still has potential for further improvement. We gain such improvement by considering the gray values of neighbouring voxels in the $x$-$y$-plane. This can be done in two different ways, either directly or iteratively by applying a framework introduced by Jørgensen *et. al.* [1]. Both approaches behave differently in certain situations and their pros and cons are discussed.

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Mayukh Samanta, University of Queensland

**Bootstrapping for highly unbalanced clustered data**

Joint work with A.H.Welsh

We apply the generalized cluster bootstrap to both Gaussian quasi likelihood and robust estimates in the context of highly unbalanced clustered data. We compare it with the transformation bootstrap where the data are gener- ated by the random effect and transformation models and all the random vari- ables have different distributions. We also develop a fast approach (proposed by Salibian-Barrera *et. al.* (2008)) and show that it produces some encourag- ing results. We show that the generalized boostrap performs better than the transformation bootstrap for highly unbalanced clustered data. We apply the generalized cluster bootstrap to a sample of income data for Australian workers.

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Ondřej Šedivý, Charles University Prague

**Use of electron backscatter diffraction for crystallographic mapping**

Electron backscatter diffraction (EBSD) is a modern method of microstructural research which produces detailed crystal orientation maps of grains recognized at the surface of the sample. It is well known that physical properties of crystalline materials are closely connected with the grains' morphology and the distribution of disorientation angles of grain boundaries. The poster presents selected results of research of pure metals processed by equal-channel angular pressing (ECAP) being a mechanical deformation with a major effect on homogeneity of the microstructure.

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Dominic Schuhmacher, University of Bern

**Stein's method for approximating complex distributions**

Since its first publication in 1972, Charles Stein's method for obtaining *"A bound for the error in the normal approximation to the distribution of a sum of dependent random variables"* has been generalized to a host of different approximation problems and approximating distributions on (reasonably) complex spaces. I give an elementary introduction to the general philosophy and techniques of Stein's method, and illustrate them for the special case of point process distributions. Some concrete results of distance estimates for Poisson process approximation in classical settings, such as under thinning and superposition transformations of point process distributions, are also given.

Alexey Shashkin, Lomonosov Moscow State University

**A central limit theorem for the surface area of excursion sets**

We consider random excursion sets of a stationary isotropic Gaussian field and study its surface area in the domain of observation. A central limit theorem for this functional is obtained. To that end we apply the Bernstein sectioning method together with covariance inequalities known in the association theory, as well as some geometrical considerations. Possible generalizations to other Minkowsky functionals, including the Euler characteristics of an excursion set, are also discussed.

Malte Spiess, Ulm University

**Asymptotic properties of the approximate inverse estimator for directional distributions**

Joint work with M. Riplinger.

We consider the estimator for the directional distribution $\varphi$ of stationary fiber processes which was introduced in the recent article [1]. The estimation approach is based on the well-known stereological idea of counting the intersection points of the process with test hyperplanes in a bounded observation window. To derive the directional distribution from this information, it is necessary to invert the cosine transform. Since in practice only finitely many test hyperplanes can be considered, we use the method of the approximate inverse to ensure the numerical stability of the operation.

In this poster, we consider Poisson line processes and show the strong convergence of the estimator in the supremum norm. Finally, we derive Berry-Esseen bounds and large deviation results for the pointwise convergence.

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Ole Stenzel, Ulm University

**Stochastic modeling of the 3D morphology in polymer-ZnO solar cells**

A spatial stochastic model is considered, which describes the 3D nanomorphology of blends of two different (organic and inorganic) solid phases as used in bulk heterojunction solar cells. The paramterized model has been fitted to a number of solar cell morphologies fabricated with different production parameters (here: varying spin coating velocities) $\omega_i,\ i = 1, \ldots, n$. We interpret the vector $\vec{\lambda}$ of model parameters as a function of $\omega$ determining the solar cell morphology and fit analytical formulae to the parameters obtained from the experimental data. Thereby, solar cell morphologies can be simulated for arbitrary spin coating velocity. This allows to make predictions beyond the previous chemical and physical experiments (inter- and extrapolation). The model is used for virtual materials design. More precisely, a scenario analysis is performed where 3D morphologies are simulated for different spin coating velocities to elucidate the correlation between processing conditions, morphology, and efficiency of hybrid P3HT-ZnO solar cells. The simulated morphologies are analyzed quantitatively in terms of structural and physical characteristics. In particular, the quenching efficiency is calculated by numerically solving a corresponding diffusion equation which takes the real 3D morphology into account. Also, the mobility is determined by numerically solving the steady-steady Pauli master equation.

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Kaspar Stucki, University of Bern

**Stationary particle systems**

Joint work with I. Molchanov.

Z. Kabluchko described all stationary Gaussian particle systems, i.e. particles on the real line starting at the points of a Poisson process and moving independently of each other according to the law of some Gaussian process. This talk is about a (somehow partial) multivariate generalisation of his results. We emphasize the connection to some analysis problems and give some conditions under which a characterisation of stationary particle systems is possible.

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Irene Vecchio, Fraunhofer ITWM, Kaiserslautern

**3d geometric characterization of particles for technical cleanliness**

Joint work with Katja Schladitz, Michael Godehardt, Markus J. Heneka.

During the production of mechanical components, residual particles collect on the surface, thus creating a contamination that might affect the expected durability and performance of the assembled products. Therefore the dirt particles have to be analyzed in order to intervene in the production line. The common methodology is until now based on 2d images, see [1]. However, as the required accuracy in production grows, analysis methods must become more sophisticated, too. Micro computed tomography opens the door to a new quality of cleanliness analysis by capturing the complex spatial geometry of thousands of particles simultaneously. Our goal is to characterize particles according to their three dimensional shape and classify them as fibers, chips or granules. We will define unambiguously indicative characteristics combining methods from classical geometry, mathematical morphology and integral geometry. Among them, volume, surface area, isoperimetric shape factors [3], size of the minimum volume bounding box [2], elongation index [4], to mention but some. Moreover it will be outlined how they can be exploited to perform a reliable classification.

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Yang Yuxin, University of Warwick

**Clark-Ocone formula: applications and generalisations**

Joint work with David Elworthy.

The classical Clark-Ocone formula has many important consequences including the log-Sobolev inequality [1] and spectral gap inequality [2]. It can also be used to prove the Hodge decomposition on the Wiener space, as an alternative to Shigekawa's original proof [3] of the same result; this approach has the extra advantage of being adaptable to more general settings, including the based path spaces over a compact Riemannian manifold. In an attempt to prove similar results in greater generality, we explore a few generalisations of the Clark-Ocone formula involving resolutions of the identity [4] and isometries [5].

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Markéta Zikmundová, Charles University Prague

**Spatio-temporal model for a random set given by a union of interacting discs**

Joint work with Kateřina Staňková Helisová and Viktor Beneš

We define a spatio-temporal random set model based on the union of interaction discs. A state space model is used for the temporal change of parameters corresponding to integral–geometric variables of the random set. The evolution of parameters of the state space model is estimated using sequential Monte Carlo. The aim is to compare the particle filter (MCMC particle filter respectively) and MCMC maximum likelihood estimation of the parameters.

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