LINKÖPING UNIVERSITY

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PhD student in Statistics (Ref IDA–2019–00064)

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The Division of Statistics and Machine Learning (STIMA) at Linköping University is expanding. In this call we are looking for a new PhD student who wants to join us in our effort of strengthening our research in the direction of developing and mathematically studying statistical inference methods for stochastic processes (in particular continuous–time–continuous–space) in phylogenetics. This document briefly presents the research at the division and the background of the PI (Section 1). This is followed by a few concrete suggestions for research topics for the PhD position (Section 2). Some administrative details are:

- **Application deadline:** May 6, 2019
- **Application procedure:** All applications are to be submitted via Linköping University's online application system, available via this link:
  `https://liu.se/en/work-at-liu/vacancies?rmpage=job&rmjob=10890&rmlang=UK` (English)
  `https://liu.se/jobba-pa-liu/lediga-jobb?rmpage=job&rmjob=10885&rmlang=SE` (Swedish)
- **Questions:** If you have any questions do not hesitate to contact Krzysztof via e–mail.

1 The Division of Statistics and Machine Learning

STIMA—The Division of Statistics and Machine Learning belongs to the Department of Computer Science at Linköping University. This fact makes us unique in Sweden, and we like to view ourselves as Sweden's most modern division of Statistics with a clear focus on state–of–the–art data analysis, prediction and decision making in complex systems. We are engaged in basic methodological research motivated by a wide range of problems in areas that span from journalism and psychology to computational biology and climatology.

Krzysztof Bartoszek, who will be the main supervisor for the PhD students recruited in this call, is a Docent and Senior Lecturer (Universitetslektor) in Statistics at STIMA. His research background is in stochastic processes with a special focus on phylogenetic comparative methods and other applications of probabilistic modelling in life science problems. In particular, his research has focused on probabilistic models and the development of computational algorithms for learning and reasoning about these models. Using probability theory, probabilistic models are able to systematically represent and cope with the uncertainty that is inherent to most data. This is of central importance in many applications of machine learning.

The group at STIMA has a wide network of strong international collaborators all around the world. The intended project work will give the student direct possibilities of working with scientists from the Łódź University, Medical University of Gdańsk, University of Alabama, University of Gdańsk, University of Oslo, University of Toruń and Uppsala University. Other members of the Division have joint projects with researchers for example at Berkeley, University of British Columbia (Vancouver), University of California, and the University of New South Wales (Sydney). We strive for all PhD students to get a solid international experience during their PhD studies.

2 Potential Research Topics

The research projects for the advertised position will be in the area of "Inference for branching Markov process models—the mathematics and computations of phylogenetic comparative methods", Krzysztof Bartoszek's Swedish Research Council Starting Grant that partially funds the PhD position. A few examples of potential research topics are briefly outlined below. In brief the high–level description is that one has a tree structure and top of this tree, i.e. along the tree's branches some stochastic processes evolves. The values of the process are observed only at the tips of the tree and based on such a sample (and the tree) one is to make inference about the data generating stochastic process. The approach has as its goal to model the evolution of traits, e.g. body size, on a between–species level. In the scope of the project the focus will be on methods for modelling evolution of both univariate and multivariate interacting traits.

As an applicant you are not required to specify a specific research topic in your application, but you are of course welcome to do so if you want. The topics below are provided mainly to make the advertised positions more concrete. We do welcome your own initiatives and the precise research topic of each PhD student will be decided in a dialog between the student and the supervisor after a successful appointment. Depending on the interests of the students the topics can be approached from either a mathematical perspective, a software development/computational one or a mixture of the two. Apart from the main methods development work the PhD student will have the opportunity to interact with biological researchers from various backgrounds and institutions, testing the methods and contributing to the analyses of real data.

Markov processes on trees: The vast majority of modelling and inference approaches for phylogenetic comparative methods require an explicit form of the transition density along a given length of time and also the ability to integrate out analytically the unobserved internal node stats. This allows for effective estimation schemes but severely restricts the family of permissible models of evolution. From a practical point of view, only Gaussian transitions seem possible today.

A potential PhD project is to change the modelling approach and to focus on a different description of a Markov process. A process defined by a stochastic differential equation (SDE) can be described through its generator. Solving the associated partial differential equation on top of a tree will allow one to obtain the likelihood and hence do parameter inference for all SDE models of evolution.

Punctuated equilibrium models of evolution: While most modelling approaches assume gradual evolution, i.e. the trajectory of the traits is continuous, biological theory and the fossil record point to the possibility of jumps (i.e. punctuated equilibrium). Due to computational difficulties including jumps is an area of promising research. It is clear from current studies that inference methods for and development of Lévy process models is desired.

In this project we will try to develop software for traits that can jump at speciation points. A possible starting point for accomplishing this goal is to use currently available models and software, and modify them with a jump possibility.

Evolution with interactions: Just as with punctuated equilibrium models due to computational difficulties only now is development of models with after speciation, between lineage interactions (e.g. hybridization or migration) taking place. A third possible PhD project is to study the mathematical properties of and develop inference software for branching Markov processes with interactions. This project can be done in close collaboration with biological groups who have well curated data sets and clear hypotheses between which species did mixing events take place.

Properties of branching stochastic processes: For a theoretically minded student there is the possibility to explore the mathematical properties of the above described branching stochastic processes. Possible problems include central limit theorems, law of the iterated logarithm or the maximum processes. One can couple this with branching process models for the tree, including trait dependent speciation. Despite being formulated in an abstract way such results are of utmost importance for statistical estimation method development. They provide theoretically justified initial states for iterative inference methods and indicate what is estimable i.e. what are our possibilities and limitations.