Proposed internship topic

Coupled Markov chain modeling of the joint dynamics of earthquake occurrences

Context. The internship concerns the spatio-temporal modeling of earthquake occurrence, within the framework of Hidden Markov Models (HMM) for the temporal dynamics, coupled between different locations of the same geological province for the spatial aspect. The aim is to formalize one or more models, infer parameters of interest on real data, and interpret the results. HMM modelling of the dynamics of earthquake occurrence in a geographical location has already been considered in the following articles: [2] and [3]. Observations are earthquake occurrences with their magnitude. The hidden chain is used to model the different regimes through which the level of seismic stress in the lithosphere passes over time, and which are not observed. When stress is too high, the probability of an earthquake occurring is high, leading to a relaxation of stress and therefore a change of regime. However, these models do not take into account the influence of stress levels in neighboring regions on local stress levels. This is what we propose to model in this course, by coupling the HMM dynamics of each site within the Coupled HMM framework (CHMM, [1]).

Project layout. The course comprises three main stages: modeling, exploration and selection of algorithms for model inference, and application to real data.

1. **Modeling**. Following a literature review of existing work on HMM modeling of earthquake dynamics, we'll be making a choice about the nature of the hidden variables and observations. Direct use of the raw data is not possible, as several earthquakes can occur in a single time step. The next step is to propose how to summarize this information into one or more variables for which it will be simple to model the distribution conditionally on the regime. The next step will be to build a CHMM model integrating the coupling between the two locations (coupled chains), as well as the feedback loops between observed earthquakes and changes in stress state. In particular, it will be necessary to propose a parametric model for the transition probability of the hidden regime of one chain knowing that of the other chain.

2. **Inference**. For inference of CHMM model parameters and hidden regimes, Bayesian approaches will be favored as they provide not only parameter values, but an a posteriori distribution. The student will explore several options (Metropolis-Hasting, Gibbs Sampling, Hamiltonian methods, Langevin algorithms on Riemannian Varieties). Algorithms have already been proposed for CHMM applied to infectious disease modeling, and could be a starting point. It will be a matter of implementing the method that seems best suited to the complexity of the model. The behavior of the inference algorithm will be tested on simulated data. It will also be possible to test whether the CHMM model improves the

quality of prediction of observations and latent regimes, as well as parameter inference, compared with an HMM.

3. **Application.** The CHMM model will be applied to real earthquake occurrence data from two different locations in Greece. This will make it possible, for example, to quantify the importance of coupling both in the evolution of local stress and in the occurrence of earthquakes.

Profile. Second year Master's student with a) a specialization in statistics, probability, data science; b) a solid grounding in R programming; c) an interest in life and earth science applications.

Supervision. The course will be supervised by Sébastien Coube and Nathalie Peyrard (MIAT -INRAE Toulouse), Irène Votsi (LIEC, Université de Lorraine) and Alain Franc (BioGeCo, INRAE Bordeaux).

Location and duration. The internship will take place in the Mathematics and Informatics unit of INRAE's Occitanie-Toulouse center (MIAT, https://miat.inrae.fr/). The internship can start on April 1 and will last 5 to 6 months.

Contact. Please send your application, including CV, to sebastien.coube@inrae.fr, nathalie.peyrard@inrae.fr, Eirini.Votsi@univ-lorraine.fr and alain.franc@inrae.fr.

References

[1] M. Brand. Coupled hidden Markov models for modeling interacting processes. Technical Report 405, MIT Media Laboratory, Cambridge, 1997.

[2] K. Orfanogiannaki, D. Karlis, and G. A. Papadopoulos. Identifying seismicity levels via poisson hidden markov models. *Pure and Applied Geophysics*, 167(8):919–931, 2010.

[3] I. Votsi, N. Limnios, G. Tsaklidis, and E. Papadimitriou. Hidden markov models revealing the stress field underlying the earthquake generation. *Physica A: Statistical Mechanics and its Applications*, 392(13):2868–2885, 2013.