PhD Thesis

Title:

Joint analysis of eye-movements and EEGs using coupled hidden Markov and topic models

Doctoral School:

Mathematics, Information Sciences and Technologies, and Computer Science, University of Grenoble (MSTII).

Supervisors:

Anne Guérin-Dugué[(1)], Marianne Clausel[(2a)] and Jean-Baptiste Durand[(2b)]
E-mail: Anne.Guerin@gipsa-lab.grenoble-inp.fr, [Marianne.Clausel|Jean-Baptiste.Durand]@imag.fr
Location of PhD: GIPSA-lab or Laboratoire Jean Kuntzmann

(1) GIPSA-lab / Dépt. DIS, 11 rue des Mathématiques, Saint Martin d'Hères. +33 (0)4 76 57 43 73
(2) Laboratoire Jean Kuntzmann, Saint Martin d'Hères. (a) +33(0)4 76 63 56 93 / (b) +33(0)4 76 63 57 09

Scientific background:

Recently, GIPSA-lab has developed computational models of information search in web-like materials, using data from both eye-tracking to get eye movements during the search and electroencephalograms (EEGs) to analyze the related neural activities. These joint datasets were obtained from experiments, in which subjects had to make some kinds of press reviews (Frey e*t al.*, 2013). In such information seeking tasks, reading process and decision making are closely related. Two kinds of decision are expected: A positive decision if the meaning of the text matches with the goal of information search, and a negative decision otherwise. Statistical analysis of such data aims at: deciphering underlying cognitive phases in the cognitive process, characterize these phases with eye movements and EEG properties, explain the phase changes by the local text properties and quantify the individual variability of the phase properties, as well as the variability due to different texts. Hidden Markov models (HMMs) have been used on eye movement series to infer phases in the reading process that can be interpreted as steps in the cognitive processes leading to decision – see for example Simola *et al.* (2008). In HMMs, each phase is associated with a state of the Markov chain. The states are observed indirectly through eye-movements.
However, the characteristics of eye movements within each phase tend to be poorly discriminated. As a result, high uncertainty in the phase changes arises, and it can be difficult to relate phases to known patterns in EEGs. HMMs were also used for the analysis of EEGs (Obermaier *et al.*, 2001) but coupling eye movements, EEGs and text properties in a coherent model is an unaddressed challenge.

Tasks:

The aim of the PhD is to develop an integrated model coupling EEG and eye movements within one single HMM for better identification of the phases. Coupled HMMs are based on several dependent Markov chains such that at each time *t*, observations only depend on the states at time *t* (Zhong & Ghosh, 2001). Here, the coupling should incorporate some delay between the transitions in both chains, since EEG patterns associated to cognitive processes may occur with some delay with respect to eye-movement phases.
To better relate the human reading process to some intrinsic characteristics of the reviewed text, we propose an interpretation of our two experimental models based on a well-known hierarchical generative model, called LDA, used in the data mining context (Blei *et al.*, 2003) and thereafter extending to the image setting (Fei-Fei & Perona, 2005). We want to model "human data mining" for text or image as a variant of LDA, modifying in a convenient way the generative process and involving a random choice of the cognitive phase. The main goal is to take into account the fact that, in a text, a given word can be either read or not. The same question can also be raised in the image setting since a region of interest corresponding to a specific visual word can be explored or not. For this, a joint database with eye movements and EEG signals has been also recording during a visual search task according to a similar design as the information seeking task.

References:

D. Blei, A. Ng, and M. Jordan. Latent Dirichlet allocation. *Journal of Machine Learning Research*, 3, 993–1022 (January 2003).

L. Fei-Fei and P. Perona. A Bayesian hierarchical model for learning natural scene categories. *IEEE Computer vision and Pattern Recognition* (2005)

A. Frey, G. Ionescu, B. Lemaire, F. Lopez Orozco, T. Baccino and A. Guérin-Dugué. Decision-making in information seeking on texts: an Eye-Fixation-Related Potentials investigation. *Frontiers in Systems Neuroscience*, 7, pp.Article 39 (2013).

B. Obermaier, C. Guger, C. Neuper and G. Pfurtscheller. Hidden Markov models for online classification of single trial EEG data. *Pattern Recognition Letters*, 22, 1299-1309 (2001).

J. Simola, J. Salojärvi and I. Kojo. Using hidden Markov model to uncover processing states from eye movements in information search tasks. *Cognitive Systems Research* 9(4), 237-251 (October 2008)

S. Zhong and J. Ghosh. A New Formulation of Coupled Hidden Markov Models, *Technical report, Dept. of Electrical and Computer Eng.*, Univ. of Texas at Austin (2001)