The Value of Information in Spatial Decision Making

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Abstract Experiments performed over spatially correlated domains, if poorly chosen, may not be worth their cost of acquisition. In this paper, we integrate the decision-analytic notion of value of information with spatial statistical models. We formulate methods to evaluate monetary values associated with experiments performed in the spatial decision making context, including the prior value, the value of perfect information, and the value of the experiment, providing imperfect information. The prior for the spatial distinction of interest is assumed to be a categorical Markov random field whereas the likelihood distribution can take any form depending on the experiment under consideration. We demonstrate how to efficiently compute the value of an experiment for Markov random fields of moderate size, with the aid of two examples. The first is a motivating example with presence-absence data, while the second application is inspired by seismic exploration in the petroleum industry. We discuss insights from the two examples, relating the value of an experiment with its accuracy, the cost and revenue from downstream decisions, and the design of the experiment.

Keywords Value of information · Value of experiment · Markov random field · Spatial decision making · Decision analysis · Recursive computation

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1 Introduction

Gathering the right kind and right amount of information is crucial for any decision making process. Auxiliary decisions regarding information gathering often arise when an important decision is to be made in the future. This downstream decision may have a lot at stake, and it may be worthwhile to obtain more information before an irrevocable allocation of resources. A crucial question—how much information should one purchase?—is related to the well-established concept of value of information in decision analysis (Howard 1966; Raiffa 1968; Lindley 1971; Matheson 1990). The value of information for a particular information gathering scheme is the maximum monetary amount that a decision maker should be willing to pay to acquire it. The value of information depends on several factors, including the prior probabilities, the quality of the test and the decision maker’s utility curve. In this paper, we present models that compute the value of information for experiments performed in the context of spatial decision making. We use the phrase spatial decision making to refer to decision problems with two important characteristics: that the decision generally involves a choice of alternatives over space and that the distinction of interest is spatially correlated. There are several applications that are relevant within this context. Petroleum exploration and production is a natural contender as a possible application, here the distinction of interest is the presence or absence of economic accumulations of oil within a reservoir. The subsurface distribution of hydrocarbons is spatially correlated, and the decision maker must decide where to drill wells to recover oil and maximize profits. Information about the latent distinction of interest may be acquired (at a cost) in the form of seismic data, measured with noise. While seismic data are usually continuous variables, other applications use binary data acquired in the form of presence–absence, again possibly measured with noise through observation. We illustrate our methods with examples from both cases.

The value of information is a powerful tool in many decision making scenarios including medical sciences (e.g., Yokota and Thompson 2004; Welton et al. 2008) and geosciences, particularly in the oil and gas industry, where it is used for the analysis of large decision problems involving reservoir appraisal and depletion (Begg et al. 2002; Cunningham and Begg 2008). Usually the application of value of information in medical decisions does not involve spatial dependence. In many geoscience applications at the global level, spatial dependence is usually not modeled directly. Our focus blends a local view with the global level, in the sense that the value of information is computed for a particular reservoir using a modeling approach that works at a finer granularity. We briefly discuss some recent literature for computing the value of information in spatial decision making, and compare their approach to the general framework adopted in the current paper. Polasky and Solow (2001) present issues regarding the value of information in conservation biology, indicating that inferences about value of information can often be counter-intuitive. They assume that the distinction of interest is independent in the spatial domain. Houck and Pavlov (2006) estimate the value of information for electromagnetic surveys using a decision tree formulation. Bickel et al. (2006) use a Gaussian model to estimate the value of seismic attributes, but do not model spatial dependence between the target drilling sites. In Eidsvik et al. (2008), the value of information is computed for a spatially correlated continuous variable using a Gaussian model.