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Optimizing Spatio-Temporal Sampling Designs of Synchronous, Static, or Clustered Measurements

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When sampling spatio-temporal random variables, the cost of a measurement may differ according to the setup of the whole sampling design: static measurements, i.e. repeated measurements at the same location, synchronous measurements or clustered measurements may be cheaper per measurement than completely individual sampling. Such "grouped" measurements may however not be as good as individually chosen ones because of redundancy. Often, the overall cost rather than the total number of measurements is fixed. A sampling design with grouped measurements may allow for a larger number of measurements thus outweighing the drawback of redundancy. The focus of this paper is to include the tradeoff between the number of measurements and the freedom of their location in sampling design optimisation.

For simple cases, optimal sampling designs may be fully determined. To predict e.g. the mean over a spatio-temporal field having known covariance, the optimal sampling design often is a grid with density determined by the sampling costs [1, Ch. 15]. For arbitrary objective functions sampling designs can be optimised relocating single measurements, e.g. by Spatial Simulated Annealing [2]. However, this does not allow to take advantage of lower costs when using grouped measurements.

We introduce a heuristic that optimises an arbitrary objective function of sampling designs, including static, synchronous, or clustered measurements, to obtain better results at a given sampling budget. Given the cost for a measurement, either within a group or individually, the algorithm first computes affordable sampling design configurations. The number of individual measurements as well as kind and number of grouped measurements are determined. Random locations and dates are assigned to the measurements. Spatial Simulated Annealing is used on each of these initial sampling designs (in parallel) to improve them. In grouped measurements either the whole group is moved or single measurements within the group, e.g. static measurements may be moved to another location or the sampling times may be rearranged. After several optimisation steps, the objective functions of the sampling designs are compared. Only for the best ones optimisation is pursued. After several iterations the sampling designs are selected again. Thus more and more of the low performing sampling designs are deleted and computational effort is concentrated on the most promising candidates.

The use case is optimisation of a monitoring sampling design for a river. We use a flow model to simulate the spread of a pollutant that enters the system at different locations with known, location-dependent probabilities and at random times. The objective function to be minimised is the amount of pollution that is not detected.

Keywords: spatio-temporal sampling design, static sample, synchronous sample, spatial simulated annealing, cost function

References

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