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# 3-D Hamiltonian Monte Carlo Traveltime Tomography

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As a step forward from traditional deterministic tomography, we propose here a methodology to perform three-dimensional (3-D) probabilistic traveltime tomography capable of producing not only a set of possibly different plausible solutions, all compatible with the observed data, but also uncertainty estimation on the unknown parameters. In the probabilistic framework, in fact, the aim is not to obtain a single solution, but to characterise the so-called posterior probability distribution, which contains information about which Earth models are plausible and the relative uncertainty of the inferred parameters. The posterior distribution results from a combination of prior information (independent of the observed data) and the likelihood probability density function, measuring the degree of fit between observed and calculated traveltime seismic data.

The work we present is based on the Hamiltonian Monte Carlo (HMC) algorithm, a probabilistic method which, in addition to more classic Markov chain Monte Carlo approaches, exploits the valuable information obtained from calculating the gradient of the misfit function (the negative logarithm of the posterior) to propose candidate models. The advantage of the HMC over traditional Monte Carlo strategies is the use of derivatives, which provide additional information to explore the posterior, allowing for long distance moves in the model space and updating of all model parameters at once at each iteration.

The forward model, i.e. the computation of the arrival time given a velocity model, is based on the solution of the eikonal equation. The gradient of the misfit function is calculated using the adjoint state technique, which has a cost of about two forward simulations and low memory requirements. This strategy allows us to address the nonlinearity of the problem by avoiding the linearisation of the forward modelling so that "fat rays" are obtained when calculating the gradient.

Both traveltimes for 3-D velocity models and the adjoint calculations for the gradient of the misfit function are obtained by a finite difference approach which uses a fast marching method.

We show an application of the methodology described above on 3-D synthetic tests using a Fortran code parallelized using OpenMPI. Application of the algorithm to a real data set is currently under study.