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Application of cosine similarity for updating velocity model in seismic inversion

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Seismic waveform inversion is a challenging and promising method to give us a high-resolution velocity model and imaging from the seismic data. Waveform inversion has inherently a highly nonlinear nature and so the model should be updated iteratively by solving a nonlinear optimization problem. Because a full Newton method inverting full Hessian matrix to normalize steepest descent direction is still computationally expensive, we commonly follow Gauss-Newton or Newton method using the pseudo-Hessian or approximate Hessian. In these methods, a proper step length needs to be estimated and a line search method is often used. This however is a little time consuming because of additional modelling required for evaluation of misfit function. Instead, a small fixed step length could be used throughout the inversion process. However, it is difficult to consider the decrease of model update length which is expected at the late iteration step.

In this presentation we propose an application of cosine similarity to adjust the fixed step length in each iteration step. The cosine similarity is defined as a similarity measure between previous gradient vector and new gradient vector and should be between -1 and 1. In the early inversion step where steepest descent directions would be similar, the cosine similarity would be close to 1 and the step length can be increased accordingly. In the late inversion step where the velocity model would be converged a little and steepest descent vectors and misfit function would show oscillating or zigzagging natures, the cosine similarity might be close to -1, and therefore the step length can be decreased. We apply the proposed method in various waveform inversion techniques such as Laplace-, Laplace-Fourier-, and conventional frequency-domain waveform inversion and investigate its effect on the data misfit function and convergence rate. From the numerical experiments, we find that the step length can be simply adjusted using cosine similarity and the convergence rate of the waveform inversion might be improved.