Calculation of multivalued ray–theory travel times at nodes of 3-D grids

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Summary

Controlled initial–value ray tracing, able to accurately determine the boundaries between ray histories and to cover the model volume with a sufficiently dense system of rays forming ray tubes, is a by–product of the development of the shooting algorithm for boundary–value ray tracing. Considerable attention has thus been paid to the development of a new method for the computation of multivalued travel times at nodes of 3-D grids in complex 3-D structures based on the controlled initial–value ray tracing. The method is an alternative to the wavefront tracing method. It is based on construction of ray tubes, composed of ray cells, through the model volume, followed by interpolation inside individual ray cells. In contradiction to the wavefront tracing method, in which the rays are traced by parts, and interpolation is performed as soon as the wavefront reaches a gridpoint of the receiver grid, all the rays are traced during the first step and interpolation is done during the second step of the proposed method.

Introduction

This brief paper would like to illustrate controlled initial–value ray tracing (performed by program `crt.for`), followed by the interpolation of ray–theory travel times within ray cells (performed by program `mtt.for`). The example in the model with a lenticular inclusion (Klimeš 1995) has been presented at Bulant's (1997a) poster at the EAGE conference. The data for this computation may be found in the subdirectory `len` of the `CRT` package. To perform the computation and to calculate multivalued ray–theory travel times at the nodes of a given 3-D grid, run program `crt.for` with main input data file `len-crt.dat`, and then program `mtt.for` with main input data file `len-mtt.dat`.

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Brief description of the algorithm

The two–point ray tracing algorithm by Bulant (1996a,b; 1997a,b) is based on the demarcation of the boundaries between individual ray–parameter regions of the same ray history relevant to the elementary wave under consideration, and on the triangularization of these regions. Once the individual regions of ray–parameter domain are triangularized, we can use the triangles to construct the ray tubes through the model volume (Figure 1). Each ray tube is then bounded by three rays, representing the vertices of the corresponding triangle in the ray–parameter domain. Each ray tube can be divided into ray cells. Each ray cell corresponds to the space in the ray tube, limited by two consecutive wavefronts (with time step Δt) or structural interfaces. The gridpoints situated inside each ray cell of a ray tube are determined (Figure 2). A ray cell situated inside smooth complex blocks is limited by two wavefronts and is determined by 6 points located on the corresponding three rays, whereas a ray cell touching a structural interface is limited by the interface and a wavefront (or sometimes even another structural interface), and may have 4, 5 or 6 vertices situated on the corresponding three rays. Travel times and other quantities may then be interpolated inside individual ray cells, like in the wavefront tracing method.

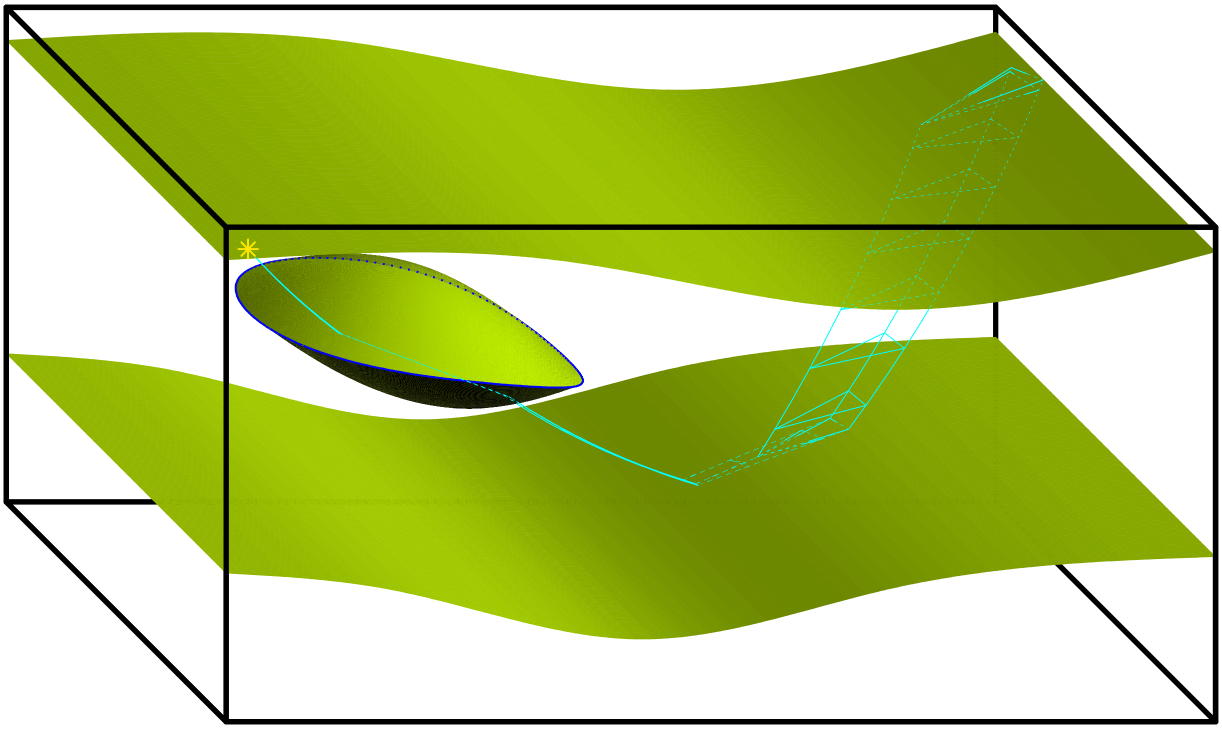

Figure 1. Each homogeneous triangle determined during boundary–value ray tracing corresponds to a ray tube. The ray tube, limited by three rays, is composed of ray cells. Each ray cell is located inside a single complex block, and is bounded by 4 to 6 points situated on the rays. The displayed ray tube corresponds to the refracted wave in the model with a lenticular inclusion.

The proposed interpolation method thus reduces into a reasonable organization of the loop over the ray cells and a proper decision, which gridpoints of the target grid are located in the ray cell being examined. The interpolation of the travel time and other quantities is straightforward once the gridpoint is identified to be located in the ray cell, because the interpolation formula for individual gridpoints uses quantities computed by

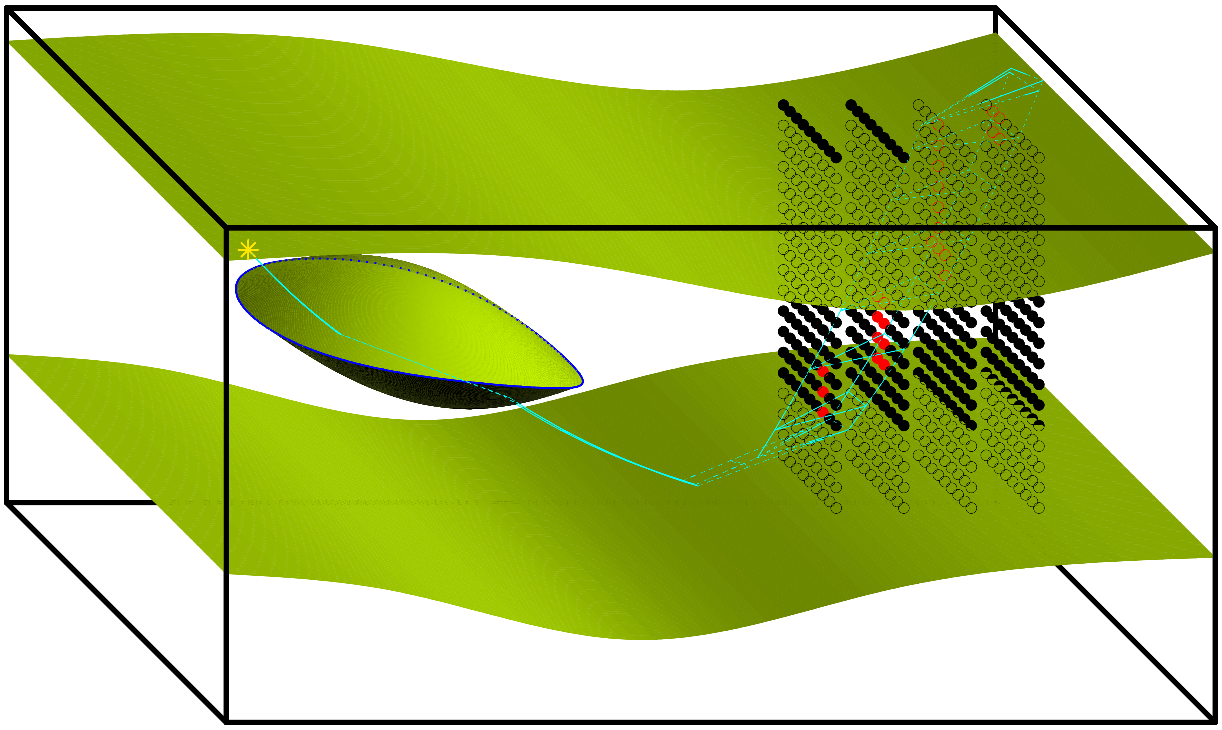

Figure 2. The 3-D grid is located inside the model. Black dots represent the gridpoints located outside the ray tube. Red dots represent the gridpoints located inside the ray cells of the ray tube. The travel times are interpolated at all gridpoints located inside each ray cell of the ray tube. This is repeated for the ray tubes corresponding all homogeneous triangles in the ray–parameter domain in order to determine all multivalued ray–theory travel times at all gridpoints.

the system of equations for the decision whether a gridpoint is located inside a ray cell.

The described method for the computation of multivalued travel times was suggested by Bulant (1996a,b), and the first numerical experiments were performed by Bulant (1997a,b). Recently the method is coded in Fortran 77 as a post–processing program `MTT` (Multivalued Travel Times) to the `CRT` program.

Conclusions

The proposed method is a useful extension of two–point ray tracing programs based on a triangularization of the ray–parameter domain. It provides interpolated values of ray–theory travel times and other quantities at nodes of 3-D grids located in the seismic model, including quantities corresponding to multiple arrivals. This is of interest in many applications, e.g., in ray–theory based migrations or seismic hypocentre determination methods.

References

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