One Professor's Experience on the Classroom use of Tesseral2d and Tesseral Pro

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A sound understanding of wave propagation and scattering phenomena is critical to both seismic processing and seismic interpretation. We wish to enhance diffractions in order to better image faults, fractures, and channel edges. We wish to suppress Rayleigh waves, Love waves, head waves, and multiples that interfere with scattered energy from deeper targets. Prestack impedance inversion as well as multicomponent data analysis requires an understanding of mode conversion. Imaging in many parts of the world are strongly affected by shale anisotropy, while natural fractures and azimuthally variable horizontal stresses give rise to azimuthal anisotropy and shear wave splitting.

40 years ago, students learned about wave propagation by writing their own ray tracing algorithms. More mathematically talented students may have solved the wave equation using contour integration techniques. Today's students are quite different. First, as educators we require them to know much more geology, petrophysics, and petroleum engineering than in the past, so they have less time for a rigorous theoretical or programming studies. Second, and more important, they are "hands-on" learners who learn by doing, with a great deal of comfort playing with commercial software.

I have taught seismic modelling and migration for all of my 20 years of teaching. While there will always be a need for some small group of geophysicists to write modelling and migration codes, there is a larger need for geophysicists to know how to effectively use such algorithms and an even greater need in understanding wave phenomena. Whether they are undergraduate or Ph.D. students, geologists or geophysicists, the simplest way for students to understand diffractions and multiples is to have them compute a suite of numerical snapshots. Almost all other wave phenomena, from shear wave splitting in an anisotropic media to tunnelling through a thin high velocity zone can be rendered clearly in a similar manner.

I have proudly written both finite difference and finite element codes myself. However, without a user interface, the time spent teaching students to use such codes carries considerable cost. For this reason, in 1999 I adopted first GX-II, and then in 2007, Tesseral as the primary lab component of my course on seismic modelling and migration. With Tesseral's purchase of GX-II, students can directly examine the approximations inherent in ray-tracing, eikonal travel time solutions, wave equation solutions. Running these solutions backwards, one quickly realizes the limitations (and computational cost) of Kirchhoff migration vs. reverse time migration.

I break my course into didactic and laboratory components that complement each other. My lectures last year are summarized in the following box, where I use a mix of published papers, and the SEG books by Ikelle & Amundsen and by Biondi as references:

LECTURES

Introduction

1. The value of seismic modeling
2. Review of vector and tensor notation

Alternative solutions of the wave equation

3. Ray theory and traveltime calculation
    a. Direct ray tracing
    b. Huygens Principle
    c. Computing first arrival travel times on a grid
    d. Wave front continuation methods
    e. Subsurface illumination case studies
    f. Kirchhoff modeling
4. The Reflectivity Method
    a. Formulation of the reflectivity method
    b. Reflectivity method artifacts
5. Grid-based methods
    a. The Finite Differences Method
        i. FD from derivatives of polynomials fit and Taylor Series expansions
        ii. Finite differences solution of the 1D advection equation
        iii. Finite differences and pseudospectral solutions of the scalar wave equation
        iv. Finite difference and pseudospectral solutions of the elastic wave equations
        v. Wave equation finite difference calculations in Tesseral
        vi. Software snippets – pseudospectral code implementation
    b. Introduction to Finite Elements
        i. Boundary conditions
        ii. The weighted residual method
    c. Wavefield theory – Tesseral implementation

Forward modeling applications

6. Subsurface illumination understood through scalar modeling
    a. Reverberating refractions
    b. Multiples
    c. Diffractions
    d. Weathering zones
    e. Topography
    f. High velocity zones
    g. Rugosity
    h. Tunneling
    i. Turning (or diving) waves
    j. Attenuation
7. Understanding elastic wave phenomena through modeling
    a. Sensitivity of Rayleigh waves to source and receiver depth
    b. Elastic wave propagation movies
        i. Reflections and diffractions
        ii. Converted waves
        iii. Head waves and diving waves
        iv. Ground roll and other interface waves
            1. Backscattered ground roll
        v. Multiples, reverberating refractions, and friendly multiples
        vi. S-star
        vii. Effects of topography and weathering zones
        viii. Effects of intrinsic vs. geometrical attenuation
    c. Marmousi2
    d. Anisotropy
        i. Vertical transverse isotropy (VTI) models of shales and thin layering
        ii. Horizontal transverse isotropy (HTI) models of vertical fractures and lateral stresses
        iii. Orthorhombic anisotropy models of shales subject to lateral stresses

Inverse Modeling Applications

8. Seismic imaging (migration)
    a. Time vs. depth migration
    b. Ray-based methods
        i. Kirchhoff migration
        ii. Gaussian-beam migration
        iii. A modeling and migration case study using Tesseral software
    c. Wave equation based methods
        i. One-way wave equations
        ii. Paraxial equations – Finite differences time migration
        iii. Phase screen methods
        iv. Phase shift and interpolate
        v. Reverse time migration
    d. 2D preconditioned least-squares depth migration
    e. Diffraction imaging
9. Seismic velocity analysis (Tomography)
10. Full waveform inversion (FWI)

My classes are typically comprised of about five senior geophysics students, 10-15 graduate geophysics students and 5 geology students. I require very little math from them other than their being able to follow the derivation and appreciate the limitations of each method, such as numerical anisotropy and grid dispersion, lack of later arrivals for eikonal solvers, and the complexity of multi-arrival ray tracers and hence multi-arrival Kirchhoff migration algorithms. I start with a suite of 15-20 cross-section models. The first several weeks involve ray tracing. This is followed by Kirchhoff modelling using the eikonal solver. Next comes the finite difference solution of the scalar wave equation, and finally of the elastic wave equations. Each student is required to identify key events (head wave, converted waves, diffractions, guided waves, head waves…) on snapshots and common shot gathers. The results of each model are shared with the rest of the class, comprising a library.

Midway through the semester, the students are provided a final project. Students working on research projects in seismic processing and interpretation are encouraged to formulate a project that complements this effort. I commonly pair students together, geologists with geophysicists, interpreters with processors, graduate students with undergraduates. Almost all final projects are carried through prestack migration, again using the Tesseral software. A suite of shot gathers are computed along a 2D line, and then processed and migrated. Exceptions are projects that may be geared more towards processing and quantitative analysis rather than structural or stratigraphic illumination and interpretation, such as the appearance of interbed multiples and groundroll on velocity analysis panels, or the effect of thin bed tuning on prestack seismic inversion.

Grading can become a large headache in such an endeavour. I require the students to write their final report in the four-page SEG Expanded Abstract format. This has several advantages. First, there is simply less for me to read - four pages times 25 students equals 100 pages total. Second, the bulk of the grade depends on clarity and format – proper statement of the problem and testing of a hypothesis, to the appropriate use of color bars, scale bars, citation of references, and formatting of equations (if any). Using such a rubric makes the final project easier to grade. Most important, by April 1 of the spring semester, many students have an SEG formatted Expanded Abstract ready for submission. Last year’s class resulted in three acceptances – two for graduate and one for an undergraduate student – attached to this document.

In summary, I have found the use of Tesseral software to be extremely beneficial in both teaching and supporting student research. When confronted with a difficult problem, these students are now empowered to “go model it” and determine whether their hypothesis or proposed processing and imaging workflow makes sense.

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