NEXD: A Software Package for Seismic Wave Simulation in Complex Geological Media – New Developments

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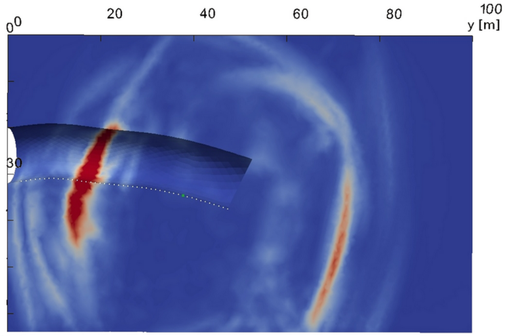
NEXD is an open source software package for the simulation of seismic waves in complex geological media. This includes elastic, viscoelastic, porous and fractured media with complex geometries. For the computation of the wave fields, the nodal discontinuous Galerkin approach (NDG) is used. The NDG approach combines unstructured tetrahedral meshes with an element-wise, high-order spatial interpolation of the wave field based on Lagrange polynomials. NEXD offers capabilities for modeling wave propagation in one-, two- and three-dimensional settings of very different spatial scale with little logistical overhead. It allows the import of external triangular (2D) and tetrahedral (3D) meshes provided by independent meshing software and can be run in a parallel computing environment. The computation of adjoint wavefields and an interface for the computation of waveform sensitivity kernels are offered. The method is verified by means of symmetry tests and the method of exact solutions. The capabilities of NEXD are demonstrated through, for example, a 2D synthetic survey of a geological carbon storage site. The most recent developments have been the inclusion of porous media in 2D and the inversion capabilities to the latest release versions of the 2D and 3D codes as well as the release of the 1D code.
NEXD is available on GitHub:
https://github.com/seismology-RUB

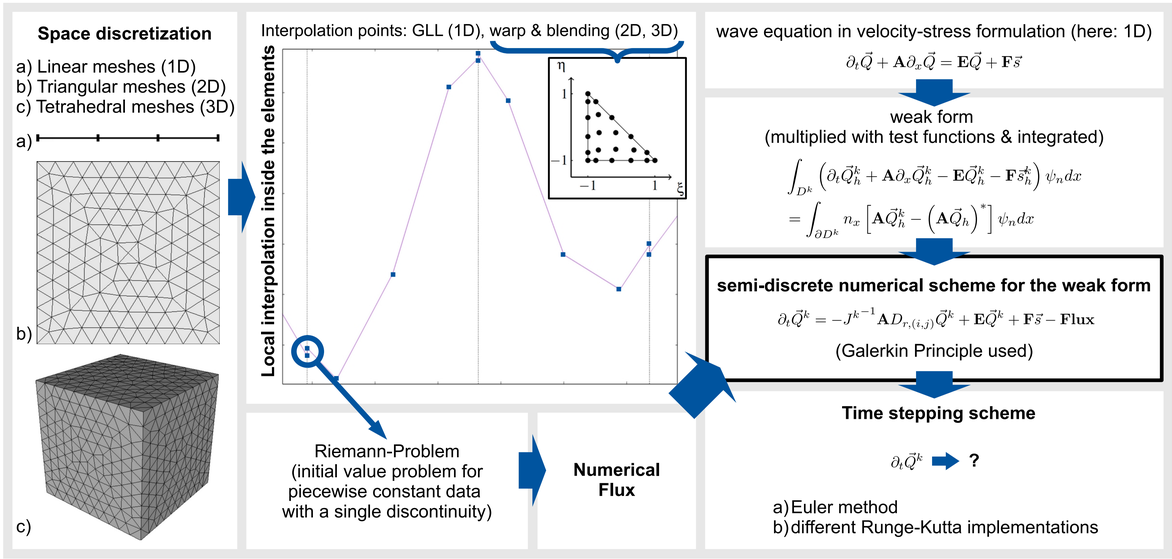


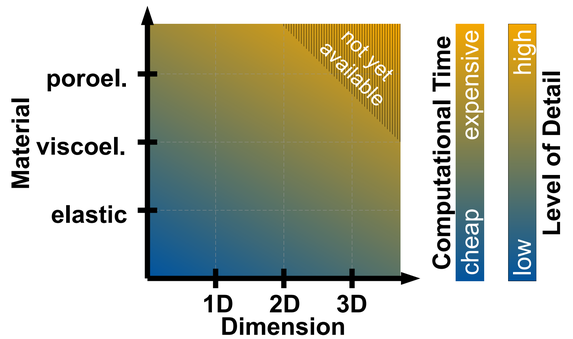
▲ **Fig. 1:** Snapshot from a simulation in complex media (here: tunnel reconnaissance)

	NEXD 1D	NEXD 2D	NEXD 3D
Latest release version	0.1	0.4	0.1.2
Parallelized	✗	✓	✓
Material: elastic, viscoel., poroel., fractures	✓, ✗, ✓[2], ✓[1]	✓, ✓[1,2,3], ✓[2,3], ✓[1,3]	✓, ✓[3], ✗, ✗
Boundary conditions: reflecting, periodic, absorbing, PML	✓, ✓, ✓, ✗	✓, ✗, ✓, ✓[1]	✓, ✗, ✓, ✓
Inversion: adjoint, scattering-integral (with ASKI)	✗, ✗	✓, ✗	(✓), (✓)
Fluxes: Godunov, Rosanov, exact Riemann	✓, ✓, ✓[1]	✓, ✗, ✓[1]	✓, ✗, ✗
Time: Euler, TVD-RK 2, TVD-RK 3, LSERK 3	✓, ✗, ✗, ✓	✓, ✓, ✓, ✓	✓, ✓, ✓, ✗

▲ **Tab. 1:** Overview over the features of the different programs of the NEXD software package.
✓: implemented, (✓): implemented but not yet included in the latest release, ✗: not yet implemented
[1] Not (yet) available in combination with poroelasticity
[2] Not (yet) available in combination with fractures
[3] In combination with adjoint methods, only available in the forward simulation. It is not possible to invert for specific parameters related to viscoelasticity, poroelasticity or fractures.

▼ **Fig. 2:** The nodal discontinuous Galerkin method (as used in NEXD) in a nutshell.





▲ **Fig. 3:** Model hierarchies involved in NEXD schematically visualized in terms of required computational time and level of detail. A model hierarchy is a purposeful, transitive collection of models, that can account for material / wave equation used, dimension, grid size, method alternatives (FD, FV, FEM, SEM, DG, …), and more.

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