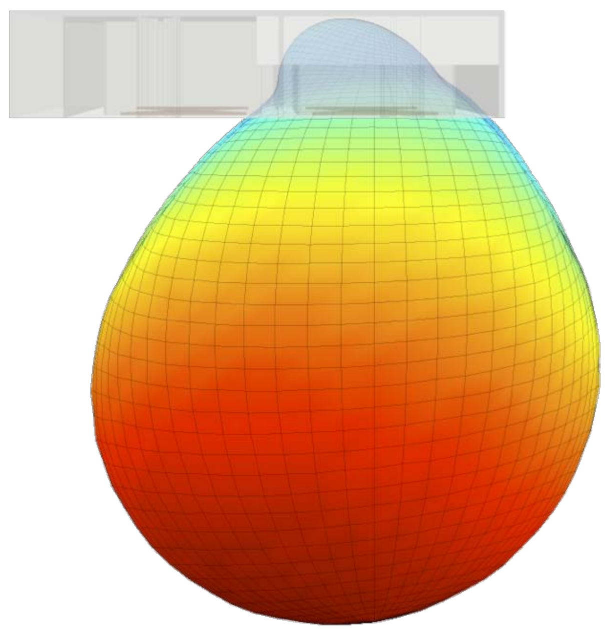
gprMax

Finite-Difference Time-Domain Electromagnetic modelling software



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Background

Detecting buried objects – electromagnetic wave propagation from a GPR

What is gprMax?

gprMax is free software that simulates electromagnetic wave propagation. It uses Yee's algorithm to solve Maxwell's equations using a Finite-Difference Time-Domain (FDTD) scheme.

It is one of the most widely used simulation tools in the **Ground Penetrating Radar** (GPR) community, and has been successfully utilised for a diverse range of applications in industry and academia.

GPR applications

- Infrastructure assessment of bridges, roads and railways
- Locating buried utilities
- Ice profiling and glaciology
- Groundwater and soil contaminant mapping
- Landmine and UXO detection

Why is it useful?

Predicting how electromagnetic (EM) waves propagate through naturally occurring or man-made heterogeneous environments is a challenging problem. Many such scenarios exist, in areas of **engineering**, **geophysics**, **archaeology** and **medicine**, that would benefit from improved understanding of this phenomenon.

Software design

Aims

- To move from original C code to a modern and flexible set of tools
- To facilitate the implementation of new advanced modelling features
- To lay foundations for future developments

Open source formats

HDF5 - to manage larger and more complex data sets for EM field output files.

Visualization Toolkit (VTK) - for improved handling and viewing of detailed 3D FDTD geometry meshes.

Tools

Python - for ease, readability, extensibility, object-orientation, dynamic typing and automatic memory management.

Cython (with OpenMP) - used for the computationally intensive elements, e.g. FDTD update loops.

NumPy - to efficiently handle many operations on large array-based data sets, e.g. 3D Fast Fourier Transform (FFT) functions.

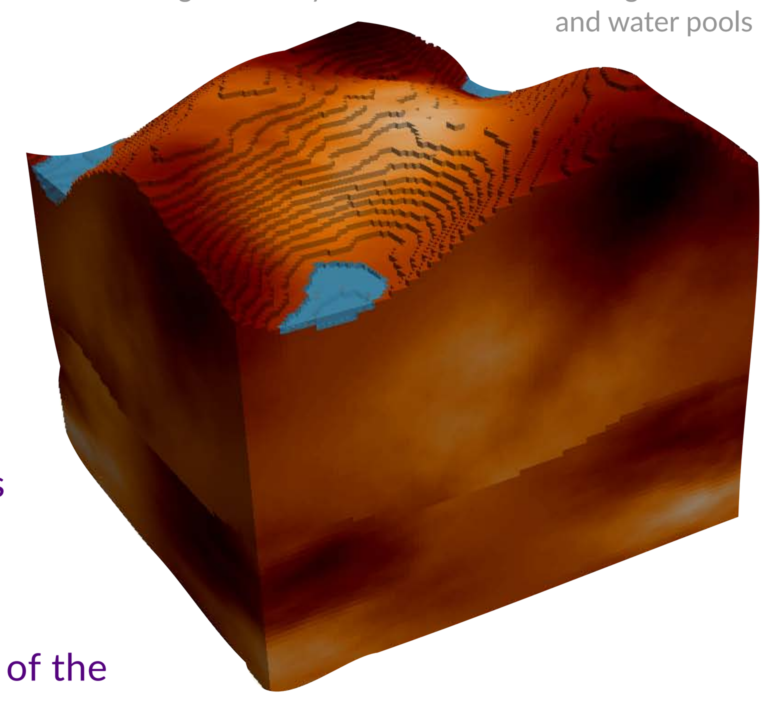
Advanced modelling features

Realistic soil & rough surface modelling

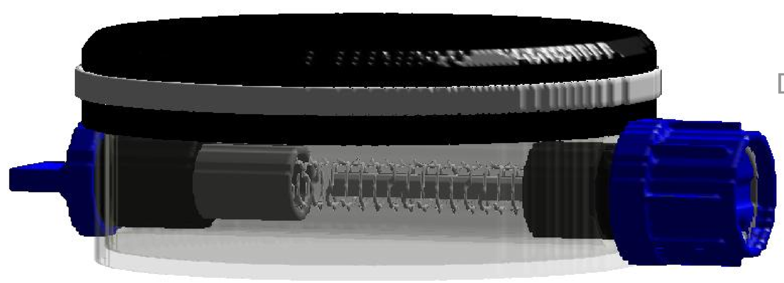
Soil models are important for many geotechnical and archaeological GPR simulations. gprMax can now create soils with more realistic dielectric and geometrical properties. A semi-empirical model, relates relative permittivity of the soil to bulk density, sand particle density, sand fraction, clay fraction and water volumetric fraction. Using this approach, a more realistic soil with a stochastic distribution of the aforementioned parameters can be modelled.

Fractals are used to represent the topography of the soil. Increasing the fractal dimension increases the roughness of the surface of the soil.

Heterogeneous layered soil model with rough surface and water pools



Giannakis, I., Giannopoulos, A., Warren, C. & Davidson N. (2015), "An Accurate FDTD Numerical Modelling Framework of Ground Penetrating Radar for Landmine Detection", IEEE Journal Of Selected Topics In Applied Earth Observations And Remote Sensing

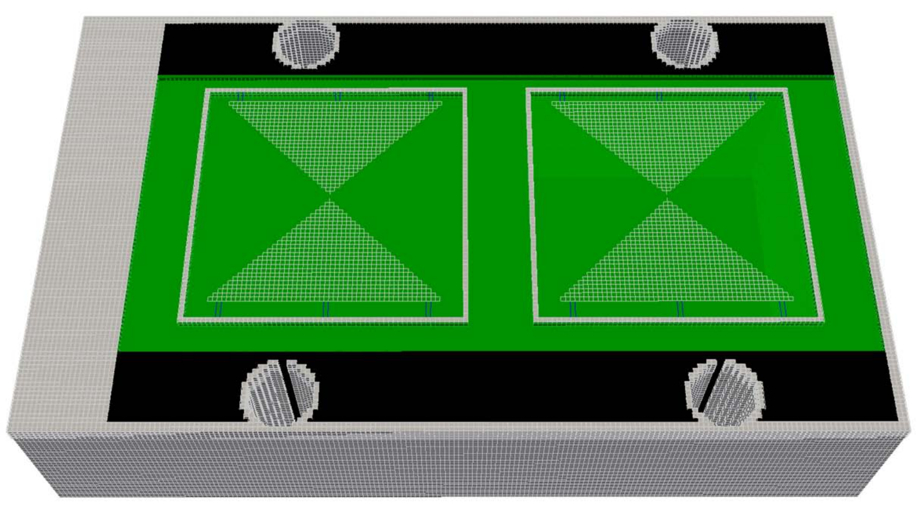


Detailed 3D FDTD mesh of a complex object

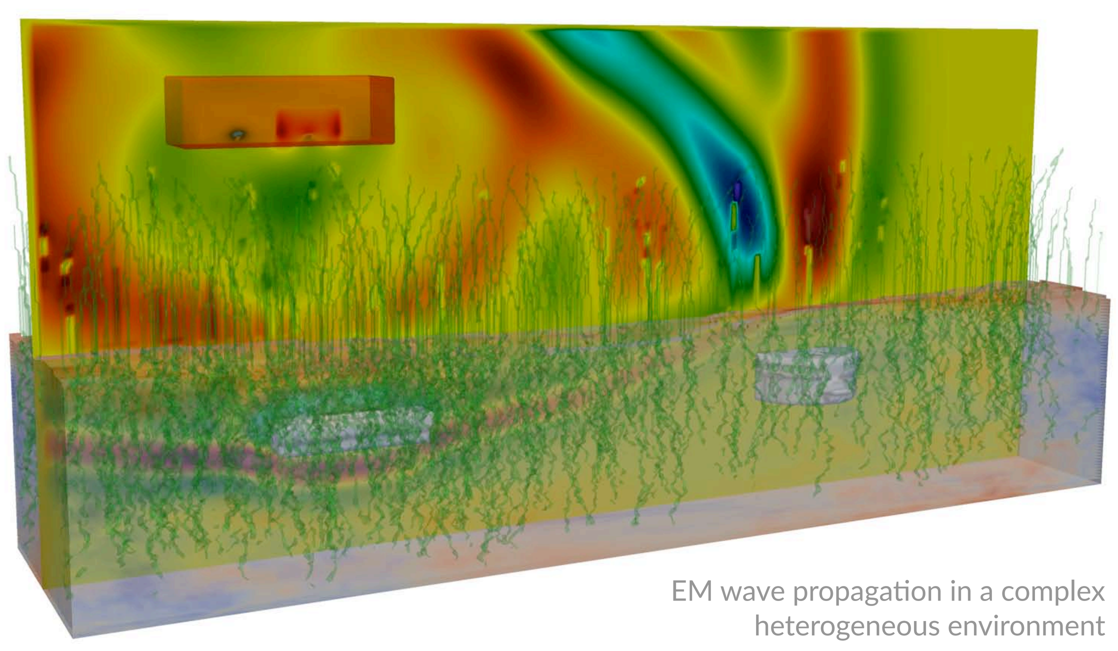
Builtin modules of complex objects

Python modules with pre-defined libraries of complex objects such as GPR antennas can be easily loaded into a simulation.

Warren, C. & Giannopoulos, A. (2011), "Creating FDTD models of commercial GPR antennas using Taguchi's optimisation method", Geophysics, 76(37)



Detailed 3D FDTD mesh of a GPR antenna



EM wave propagation in a complex heterogeneous environment

Anisotropic & dispersive materials

Every volumetric geometry object can specify up to three materials identifiers and therefore have uniaxial anisotropy. This allows materials such as wood and fibre-reinforced composites, which are often imaged with GPR, to be more accurately modelled.

Dispersive materials have dielectric properties that vary with frequency. Multi-pole Debye, Drude and Lorenz functions can now be used to simulate the electric susceptibility of materials such as water, human tissue, cold plasma, gold, and soils.

Giannakis, I. & Giannopoulos, A. (2014), "A Novel Piecewise Linear Recursive Convolution Approach for Dispersive Media Using the Finite-Difference Time-Domain Method", IEEE Transactions on Antennas and Propagation, 62(5)

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