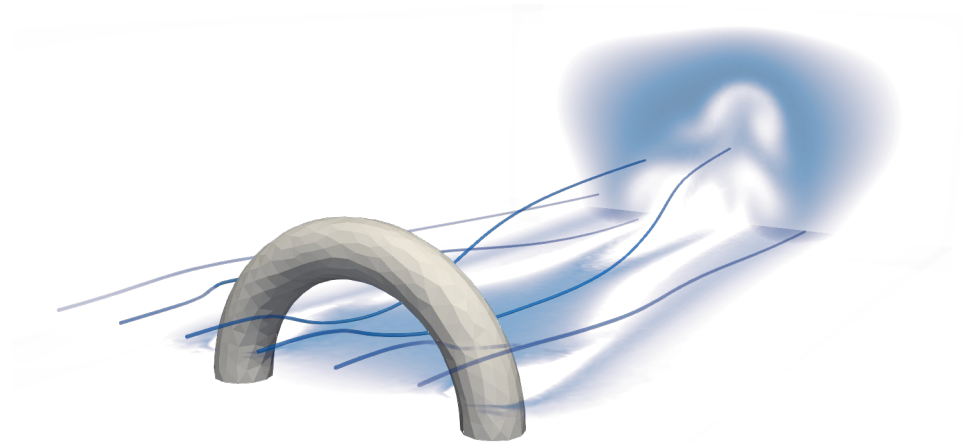


# Sparselizard: a general purpose multiphysics FEM c++ library

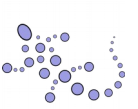
[sparselizard.org](http://sparselizard.org)





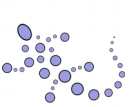
## Some history

- 2014-2016: first line of precursor Matlab FEM code @ University of Liege
- 2017: first sparselizard c++ line, starting from scratch @ University of Liege
- 2018-2019: free-time development @ IMEC (nanoelectronics, MEMS research centre)
- 2020-2024: academy of Finland grant @ Tampere University  
→ particle accelerator magnet design in collaboration with CERN



## What's special to sparselizard?

- Natively designed to be highly multiphysics
- Large demonstrated capabilities
- Support of advanced FEM and extra tools
- Concise and user-friendly (even for a c++ library)
- Carefully validated and debugged
- Clearly documented
- Efficient, highly multi-threaded
- Rapidly expanding



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# Natively designed to be highly multiphysics.

Sparselizard

UNSTEADY FLUID FLOW PAST AN OBSTACLE




The fluid flow past an obstacle is simulated in time for an increasing inlet velocity. A von Karman vortex street appears at a high enough inlet velocity. The flow can be visualized in time [here](#) in 3D and [here](#) in 2D.

[SEE EXAMPLE](#)

Sparselizard

MAGNETIC INDUCTION, SKIN EFFECT




An AC voltage is applied to a coil surrounding an aluminium tube in which currents are induced. In the current density image displayed the skin effect in the thick copper wire of the coil is also visible.

[SEE EXAMPLE](#)

Sparselizard

SYNCHRONOUS ELECTRIC MOTOR

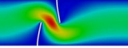


The induction field and the motor torque of a permanent magnet synchronous electric motor are calculated for an increasing mechanical angle. Only 1/8 of the geometry has to be simulated (anti-periodicity). Follow [this link](#) for a visualization video.

[SEE EXAMPLE](#)

Sparselizard

FLUID-STRUCTURE INTERACTION

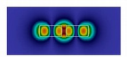


A pair of micropillars placed in a microchannel bend due to a forced inlet water velocity. This strong fluid-structure interaction is solved in a monolithic way and a Laplace formulation is used to smooth the deformed fluid mesh.

[SEE EXAMPLE](#)

Sparselizard

OPTICAL WAVEGUIDE COUPLING MODES




The coupling (eigen)modes between two photonic SiN waveguides in a SiO2 cladding are calculated. The waveguide is designed for optical frequencies.

[SEE EXAMPLE](#)

Sparselizard

FLUID COUPLED PIEZO ACTUATED MEMS




A piezoelectric actuated micromembrane (PMUT) outputs ultrasound pressure waves in air. The simulation is performed in 2D using axisymmetry. Follow [this link](#) for a time visualization video of a similar device (CMUT).

[SEE EXAMPLE](#)

Sparselizard

THERMOACOUSTICS IN A DEFORMABLE CAVITY

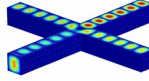


The transient thermoacoustic response to a 0.1 us laser pulse in a 500 um deformable cavity with ambient air on top is simulated. The fields displayed are the fluid pressure, velocity, temperature and membrane deformation. Follow [this link](#) for a time visualization video.

[SEE EXAMPLE](#)

Sparselizard

ELECTROMAGNETIC WAVEGUIDE

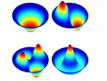


A cross shaped perfectly conducting 3D waveguide is excited with an imposed electric field at one end. Follow [this link](#) for a transient time resolution video.

[SEE EXAMPLE](#)

Sparselizard

DAMPED MECHANICAL RESONANCE MODES



The damped eigenmodes and eigenfrequencies are obtained for a 3D disk clamped at its side. A proportional damping is used to model losses.

[SEE EXAMPLE](#)

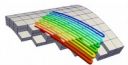
Fluids | Magnetics | Electricity | Mechanics | Rotating machines | Acoustics | Thermal



# Demonstrated capabilities through validated examples.

Sparselizard

**PIEZORESISTOR, NON MATCHING MESHES**




The deflection of a monocrystalline silicon cantilever causes a change in the resistance of the doped (piezoresistive) conducting track in it. The cantilever and track meshes do not match, field interpolation has to be used.

[SEE EXAMPLE](#)

Sparselizard

**PERMANENT MAGNETS, MAGNETIC FORCE**




The static magnetic field created by an array of permanent magnets is simulated using the scalar magnetic potential formulation. The Halbach configuration shows as expected a magnetic field strength increase. The potential and the magnetic field lines are illustrated.

[SEE EXAMPLE](#)

Sparselizard

**HIGH TEMPERATURE SUPERCONDUCTOR**




A thin superconducting tube is subject to an applied magnetic field that increases over time. As the magnetic field is increased it progressively penetrates in the tube until the tube is not able to perfectly shield its interior volume anymore. The time solution can be visualized here.

[SEE 2D EXAMPLE](#)

[SEE 3D EXAMPLE](#)

Sparselizard

**HALF-WAVE DIPOLE ANTENNA**

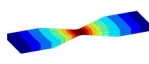


The 1 GHz electromagnetic wave radiation of a half-wave dipole antenna is simulated. The electric field, magnetic field and Poynting vector are computed and can be visualized in time. The electric field can be visualized here.

[SEE EXAMPLE](#)

Sparselizard

**CONDUCTOR HEATING DUE TO DC CURRENT**

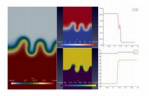


A voltage is applied across a 3D tungsten conductor in vacuum. The (strong) DC current flow as well as the induced thermal heating (displayed) is simulated. The influence of the temperature on the material properties is taken into account with a nonlinear loop.

[SEE EXAMPLE](#)

Sparselizard


**DOUBLE DIFFUSION OF SALT FINGERS**



A coupled thermal-salt concentration advection-diffusion problem is simulated in time in presence of a gravity force. The picture shows the appearing salt fingers as well as the density inversion phenomenon.

Sparselizard


**NATURAL CONVECTION IN AIR**



The natural convection created by a human hand in a colder air environment is simulated without major simplifying assumptions: the fully compressible flow is considered and solved in time. Follow [this link](#) for a time visualization video.

Sparselizard

**BUCKLING, GEOMETRIC NONLINEARITY**




A prestressed 3D bilayer micromembrane is pushed downwards by the atmospheric pressure. The static deflection and resonance frequency shil is simulated thanks to a small-strain geometric nonlinearity formulation. This example can be adapted to simulate buckling in time, as shown in this video.

[SEE EXAMPLE](#)

Sparselizard

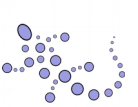
**STABILIZED ADVECTION DIFFUSION**



This is a sandbox example for stabilized (advection dominated) advection-diffusion problems. The isotropic, streamline anisotropic, SPG, SUPG, crosswind and crosswind-shockwave stabilization methods are predefined.

[SEE EXAMPLE](#)

Transient | Harmonic | Harmonic balance | Eigenmodes | Predefined physics



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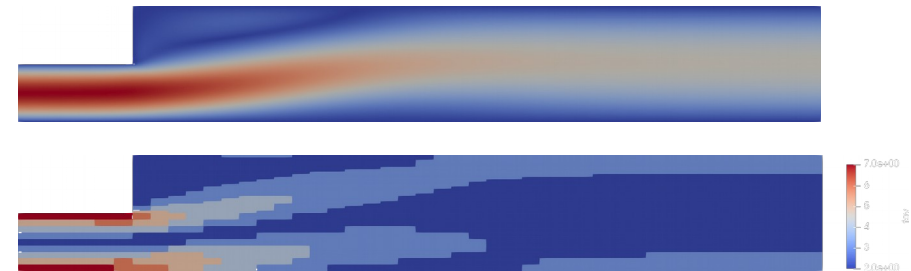


## Support of advanced FEM and extra tools.

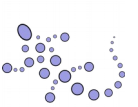
- Native support of harmonic balance FEM → nonlinear harmonic analysis
- Fast 3D unstructured mesh to mesh interpolation
- General 3D mortar FEM
- True p-adaptivity pFEM (to be officially released next week)
- Ultra compact .slz file format (x4 to x8 more compact than usual formats)
- One-liner probes, max, average,... functionalities
- ParaView output format
- Gmsh, Nastran,... mesh input format
- Curved meshes allowed

<https://youtu.be/rdKATF6aBSw>

P-adaptivity in pipe flow (order 2 → 7):

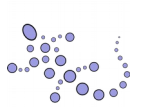






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## Concise. User-friendly.

- No advanced knowledge of c++ required
- No hacks
- High readability

### Working 3D electrostatic example:

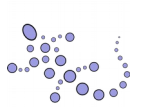
```
int vol = 1, sur = 2;           // Disk volume and boundary as set in 'disk.geo'
mesh mymesh("disk.msh");

field v("h1");                  // Nodal shape functions for the electric potential
v.setorder(vol, 2);             // Interpolation order 2 on the whole domain
v.setconstraint(sur, 0);        // Force 0 V on the disk boundary

formulation elec;               // Electrostatics with 1 nC/m^3 charge density
elec += integral(vol, -8.85e-12 * grad(dof(v)) * grad(tf(v)) + 1e-9 * tf(v));

solve(elec);                    // Generate, solve and save solution to field v

(-grad(v)).write(vol, "E.vtk"); // Write the electric field to ParaView format
```



## Documented. For humans.

- All functions/predefined physics are clearly documented
- A working example gets you started

Functions are illustrated with simple working examples.

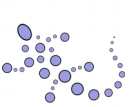
---

```
double integrate(int physreg, int integrationorder)

mesh mymesh("disk.msh");
int vol = 1;
expression myexpression = 12.0;
// Mesh with curved elements at order 3 to accurately
// capture the cylinder geometry and get value 3.7699!
double integralvalue = myexpression.integrate(vol, 4);
```

This integrates the expression over the geometric region 1. The integration is exact for up to 4th order polynomials.

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sparselizard.org  
[github.com/halbux/sparselizard](https://github.com/halbux/sparselizard)

