High-performance multiphysics FEM simulations in the Sparselizard open source library

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Sparselizard

Funding

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Thanks

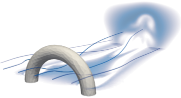
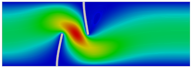
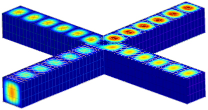
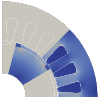
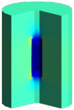
Kindly provided the Feather M2 magnet dimensions.

Oh, yet another open source FEM software!

Yes, but unlike others!

- High-performance
- Strongly multiphysics
- Concise to write

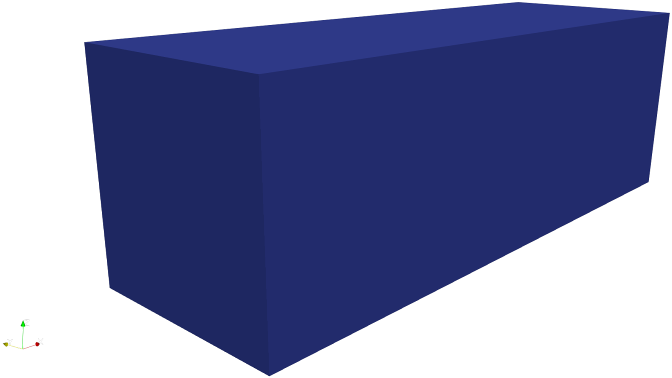
sparselizard.org

Feather M2 magnet geometry

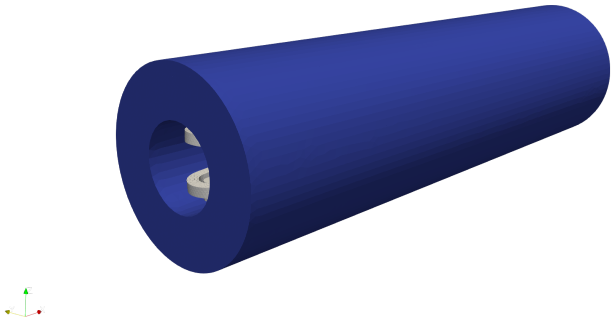
Created by J. Ruuskanen

Air



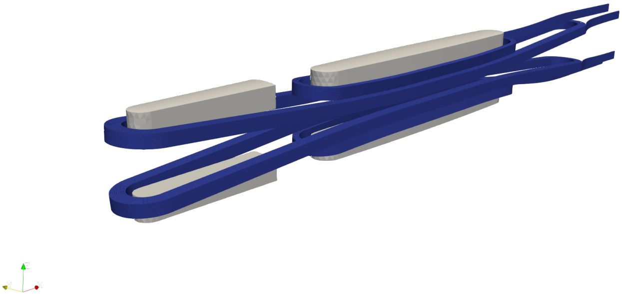
Feather M2 magnet geometry

Magnetic shell



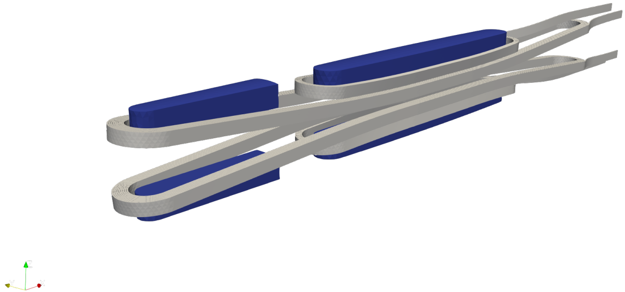
Feather M2 magnet geometry

Top and bottom coils



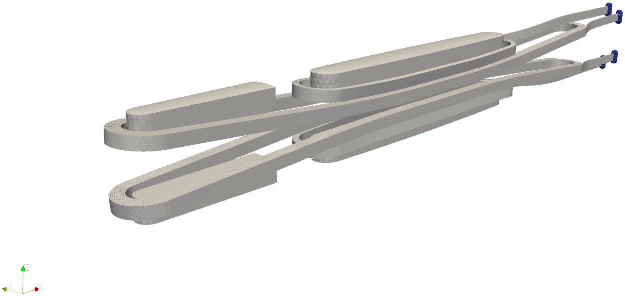
Feather M2 magnet geometry

Irons



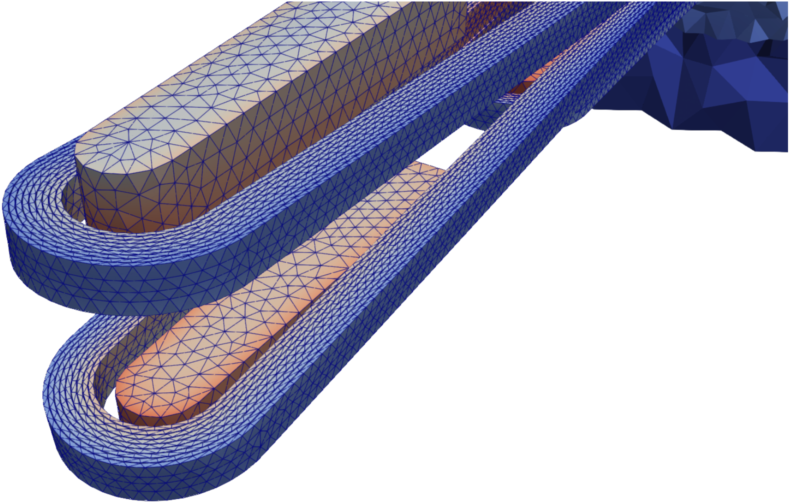
Feather M2 magnet geometry

Electric supply



Feather M2 magnet geometry

Mesh it with gmsh (1.1 million tetrahedra, few mins on my laptop)



Sparselizard demos - Region tags

- Download the static library or compile it
- Create a text file main.cpp
- Define region tags

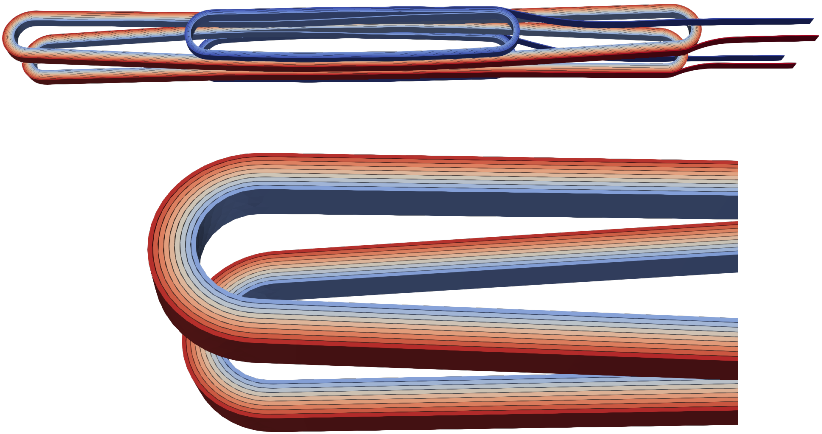
```cpp
#include "sparselizard.h"

using namespace sl;

void createmesh(void);

int main(void)
{
    int air = 3000, topcoil = 3100, botcoil = 3200, topiron = 4100, botiron = 4200, lefttopiron = 4300;
    int leftbotiron = 4400, coreiron = 5000, bnd = 1, vintop = 2200, vouttop = 2300, vinbot = 2400, voutbot = 2500;

    mesh mymesh;
    mymesh.selectskin(bnd);
    mymesh.load("fm2.msh");

    int coils = selectunion({topcoil, botcoil});
    int irons = selectunion({topiron, botiron, lefttopiron, leftbotiron, coreiron});
    int vins = selectunion({vintop, vinbot});
    int vouts = selectunion({vouttop, voutbot});
    int solid = selectunion({coils, irons});
    int notmagnetic = selectunion({air, coils});
    int all = selectall();
  }
```

Sparselizard demos - DC current flow

- Ports feature added for KiCAD
- Solve $\nabla \cdot (\sigma \nabla v) = 0$ with 8 kA supply
- Takes 1.6 sec on my laptop

```
    field v("h1");
    v.setorder(all, 1);

    port Vt, It, Vb, Ib;

    v.setport(vintop, Vt, It);
    v.setport(vinbot, Vb, Ib);

    v.setconstraint(vouts);

    double sigma = 1e8;
    expression j = sigma * -grad(v);

    formulation elec;

    elec += It - 8000.0;
    elec += Ib - 8000.0;

    elec += integral(coils, -sigma * grad(dof(v)) * grad(tf(v)));

    elec.solve();

    //v.write(coils, "v.vtu", 1);
    //j.write(coils, "j.vtu", 1);
```

Unsurprisingly this is the electric potential profile:

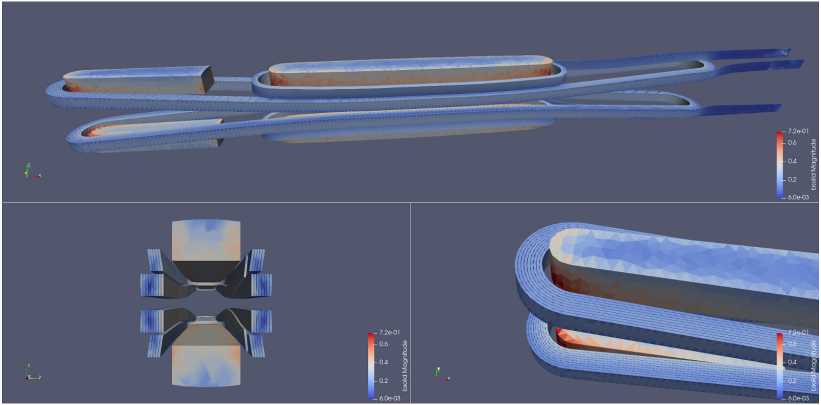


Sparselizard demos - Static magnetic field

- Saturation is taken into account (see online)
- Use A-v formulation (for a H-phi example see online)
- Takes 57 sec on my laptop (+- 1.2 M unknowns)

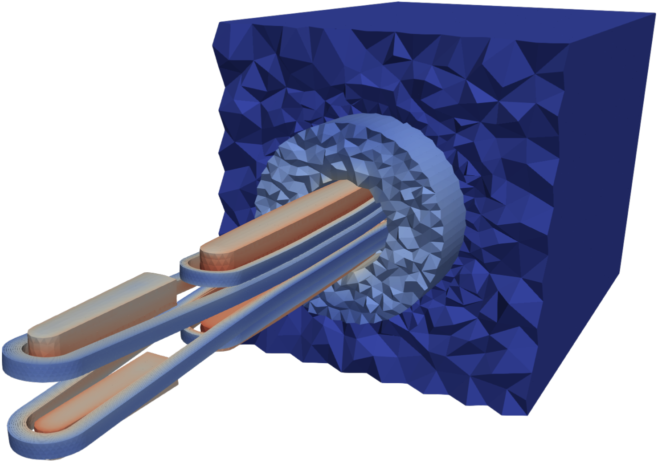
```
double mu0 = 4*getpi()*1e-7;

parameter mu;

mu|all = mu0;
mu|irons = 1000 * mu0;

spanningtree spantree({bnd});

field a("hcurl", spantree);

a.setgauge(all);
a.setorder(all, 0);
a.setconstraint(bnd);

formulation magnetostatics;

magnetostatics += integral(all, 1/mu * curl(dof(a)) * curl(tf(a)));
magnetostatics += integral(coils, -j * tf(a));

magnetostatics.solve();

std::cout << "B center is " << norm(curl(a)).interpolate(all, {0,0,0})[0] << " T" << std::endl;
```

- With saturation (B center = 4.1 T): 3 min run time (3 NL its)
- B center is already very accurate here!

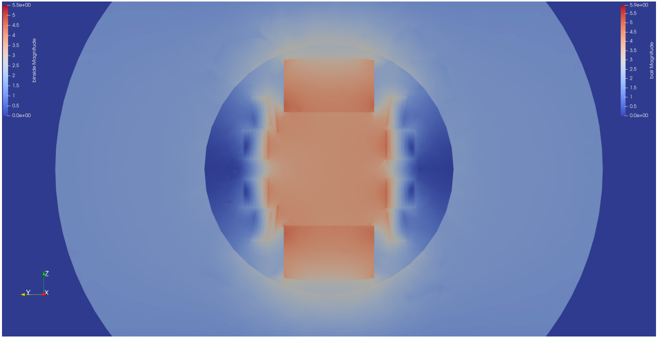


Sparselizard demos - Static magnetic field

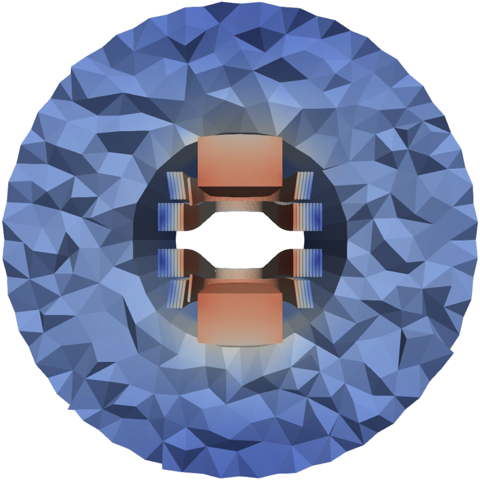
- Now use a.setorder(all, 2): 10+ million unknowns
- 30 min for 3 NL its on 16 core CPU



Sparselizard demos - Static magnetic field



Sparselizard demos - Static magnetic field



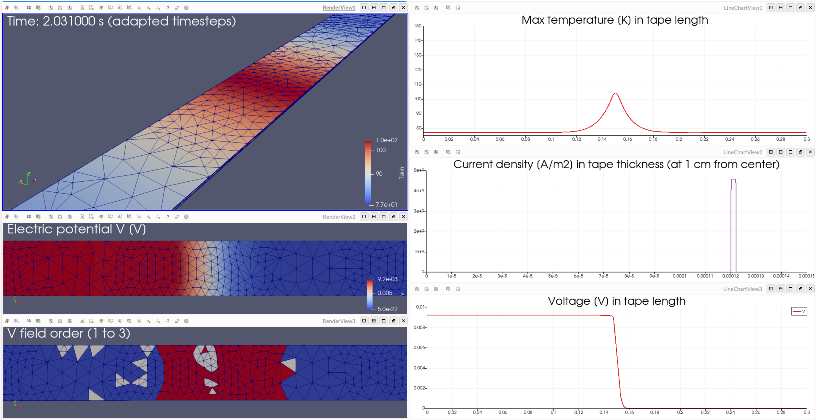
Sparselizard demos - Mechanical stresses

- See magnetostriction and mag. force sandbox examples online
- Include prestress + geometric nonlinearity in one line change
- Need plasticity? See H. Milanchian's talk
- In the unsaturated case simply:

```
field u("h1xyz");
u.setorder(coils, 2);

u.setconstraint(vins);
u.setconstraint(vouts);

expression b = curl(a);

formulation elasticity;

elasticity += integral(coils, predefinedelasticity(dof(u), tf(u), 150e9, 0.3));
// Magnetostatic Maxwell stresses:
elasticity += integral(all, predefinedmagnetostaticforce(tf(u, coils), b/mu, mu) );

elasticity.solve();

u.write(coils, "u.vtu", 2);
```

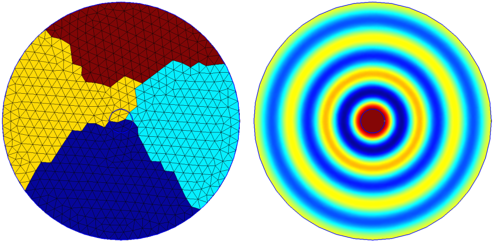
Sparselizard demos - hp-adaptive 3D tape quench

- See video



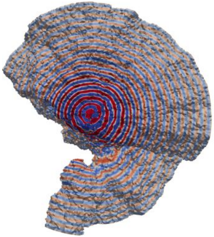
Sparselizard demos - DDM and beyond

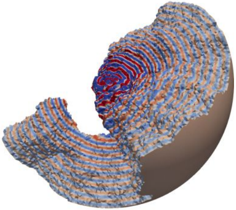
- Need to run larger problems? DDM is available for any physic.

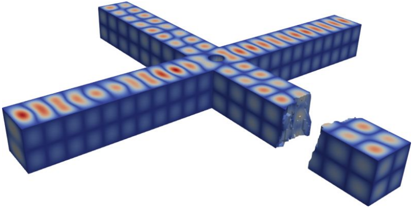


Sparselizard demos - DDM and beyond

- 100 M dofs 3D acoustic freq. analysis: 40 min/100 CPUs







Thank you

Thank you for your attention! See you at www.sparselizard.org

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