Micromagnetic Modeling

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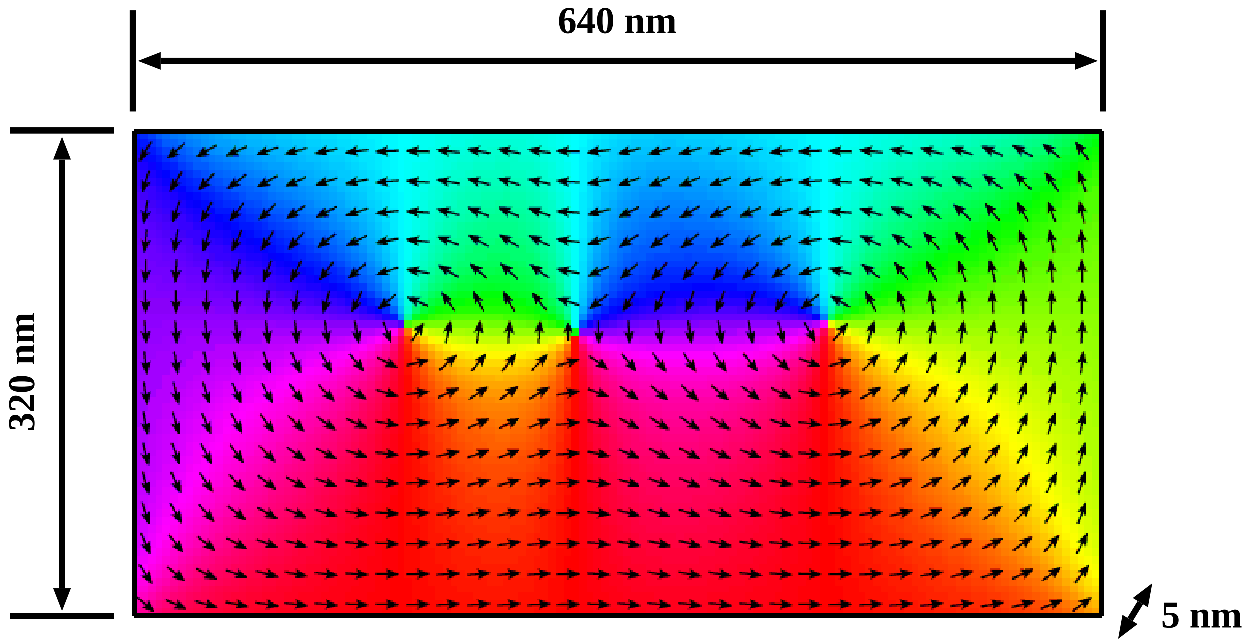
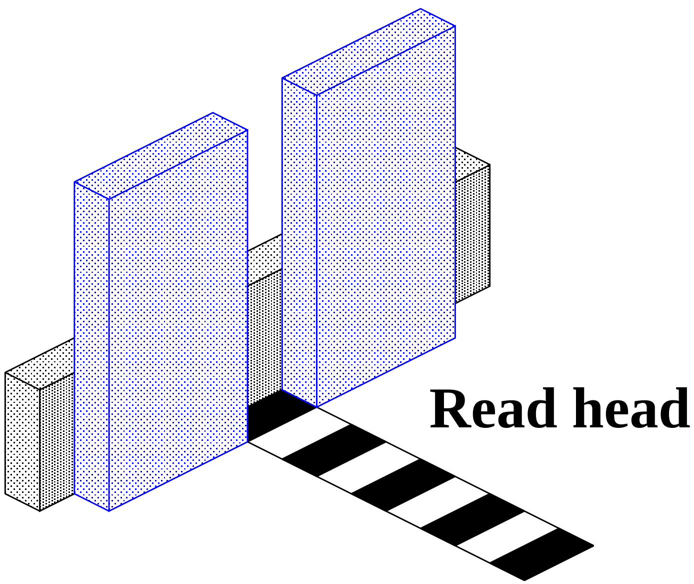
Micromagnetics. . .

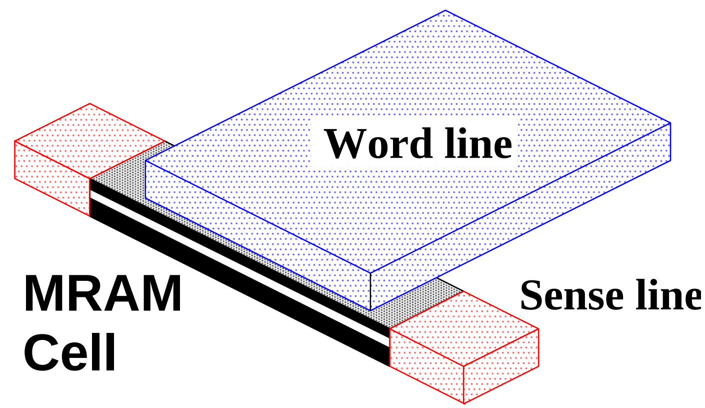


. . . is the study, modeling and simulation of magnetic materials and their behavior at the nanometer scale.

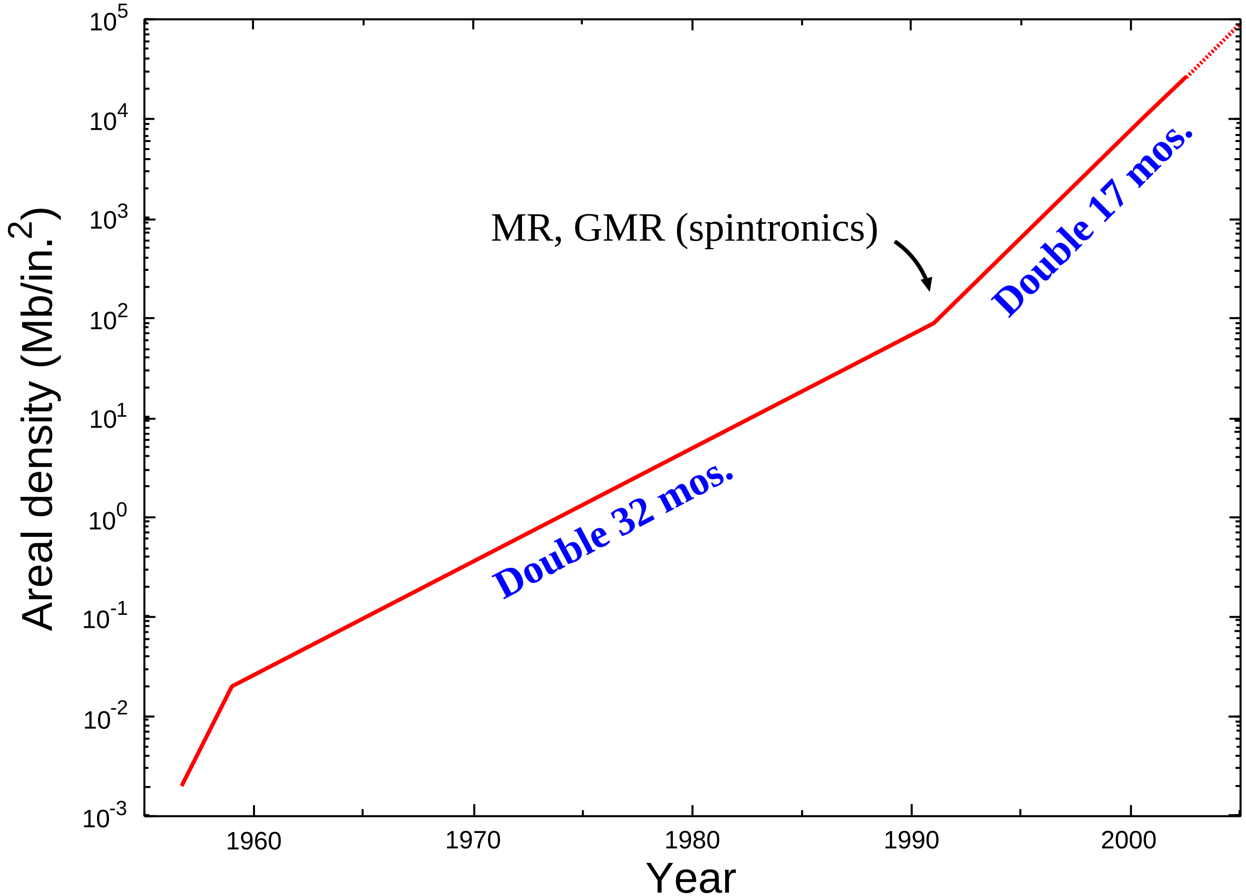
Why Computational Micromagnetics?

- Disk Drives
- Sensors
- Nonvolatile Memory
- Spintronics

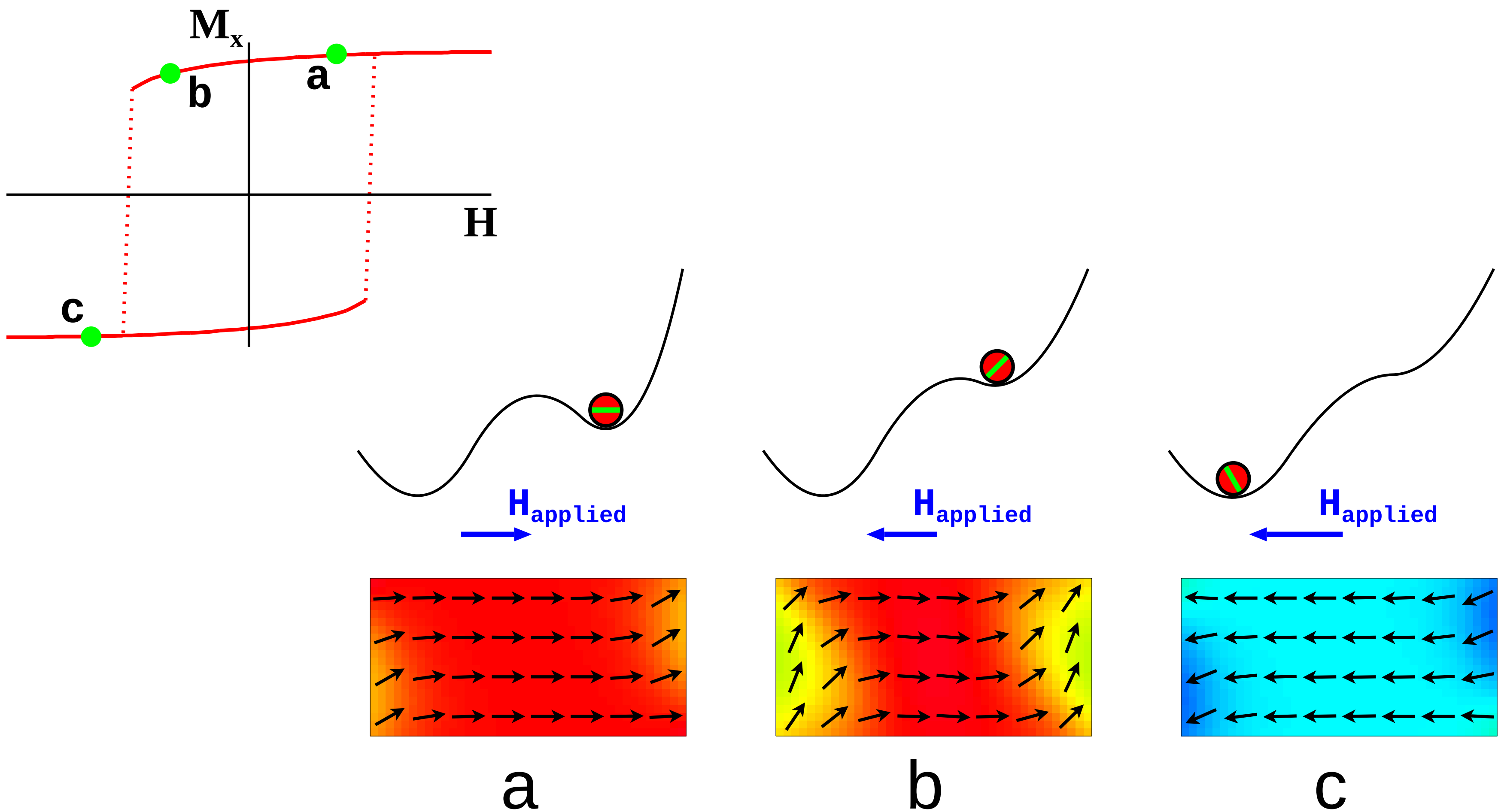




Magnetic Disk Storage



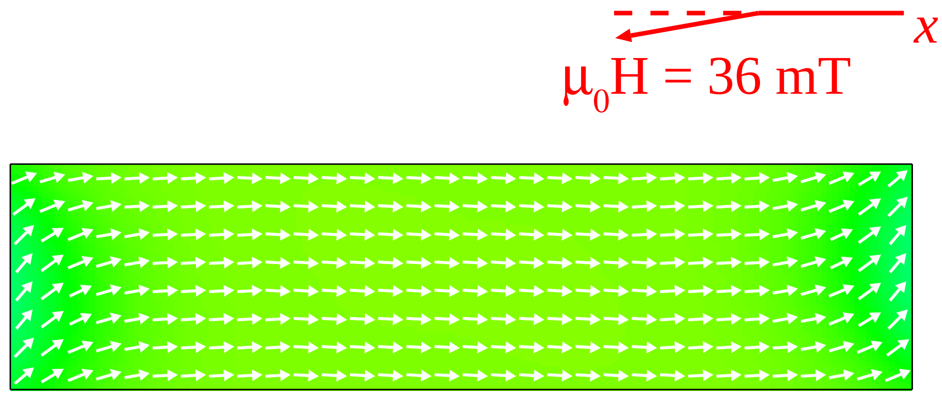
Quasi-Static Micromagnetics



Magnetization Dynamics

Time

0 ps

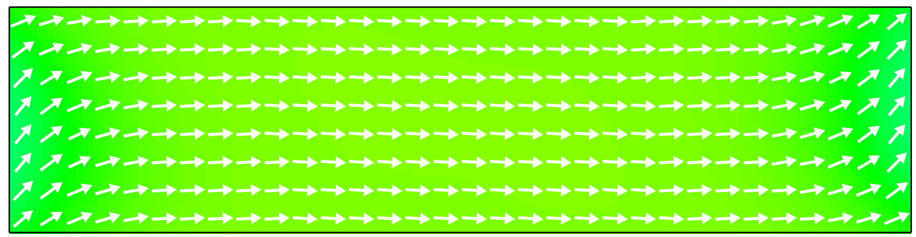


Magnetization Dynamics

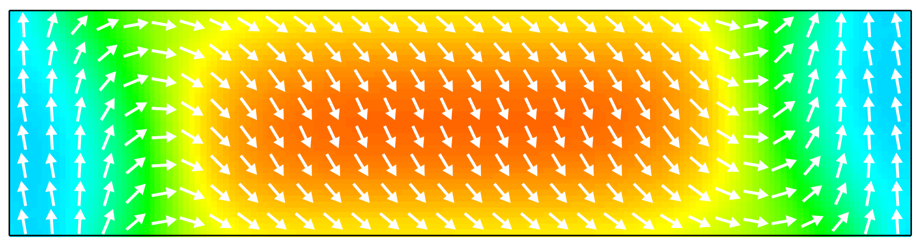
Time

$\mu_0 H = 36$ mT

0 ps



100 ps

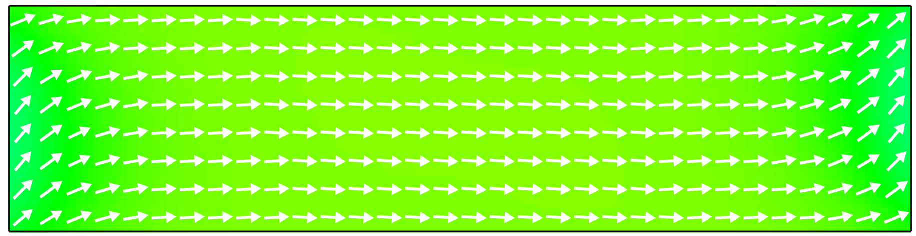


Magnetization Dynamics

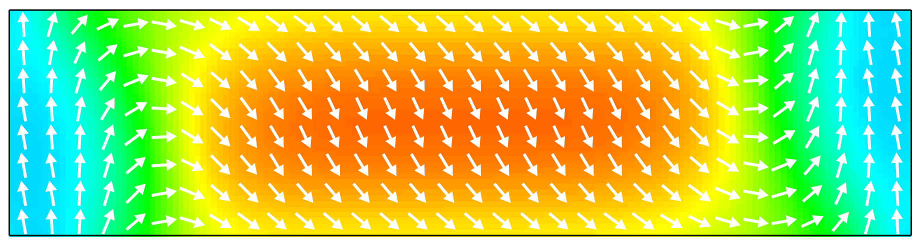
$\mu_0 H = 36$ mT

Time

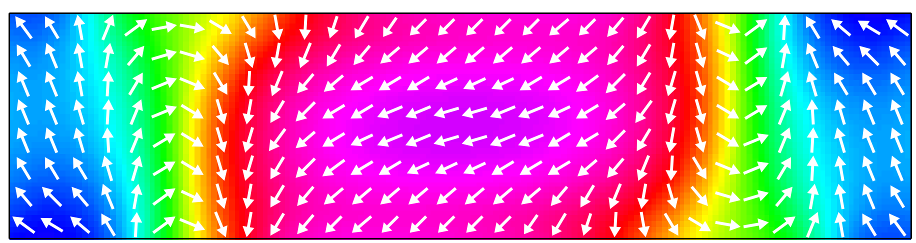
0 ps



100 ps

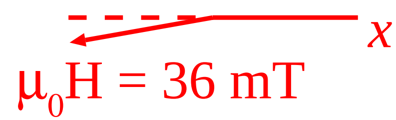


150 ps

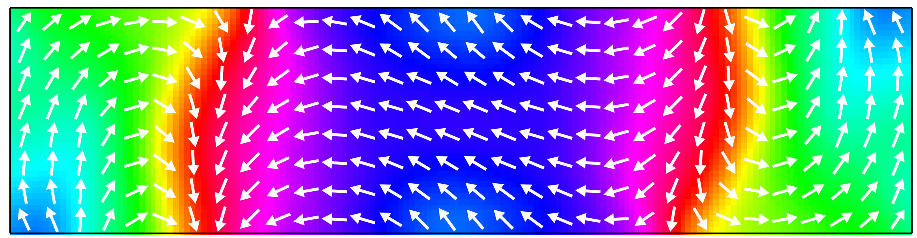


Magnetization Dynamics

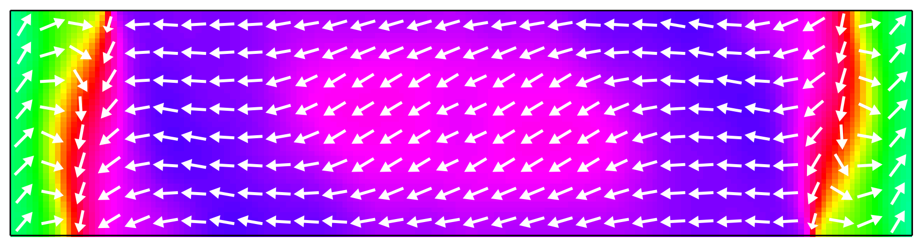
Time



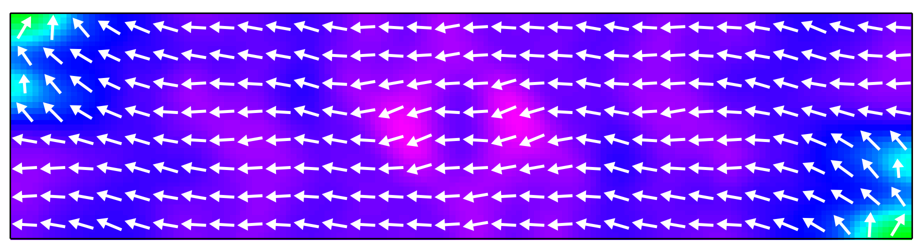
350 ps

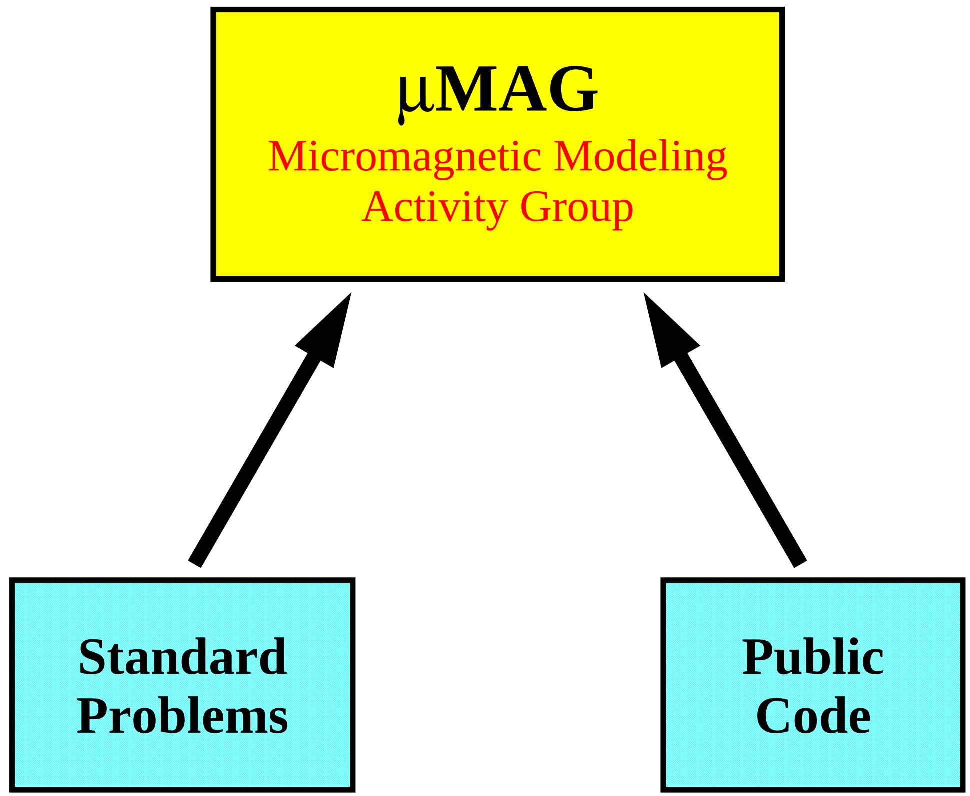


450 ps



750 ps





Center for Theoretical and Computational Materials Science

http://www.ctcms.nist.gov/

Standard Problems

µMAG

Micromagnetic Modeling Activity Group

Four Standard Problems for micromagnetics

`http://www.ctcms.nist.gov/~rdm/mumag.html`

Check computed outputs against contributed solutions:

- Verify algorithms
- Compare methods
- Optimize parameters

Standard Problems

μMAG

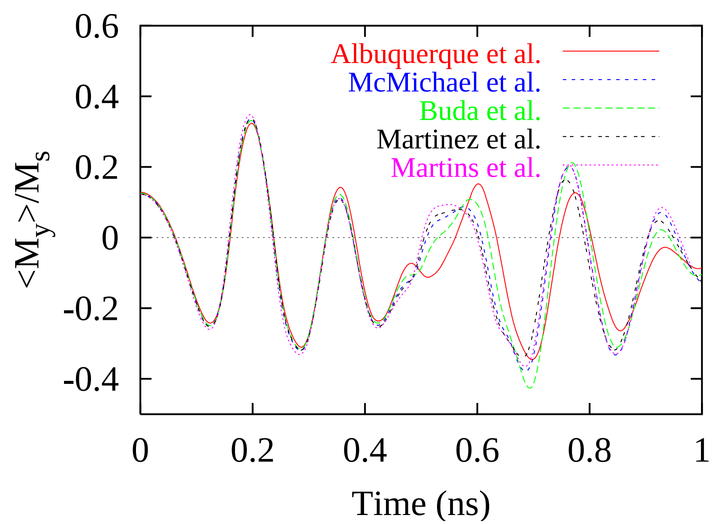
Micromagnetic Modeling Activity Group

Four Standard Problems for micromagnetics

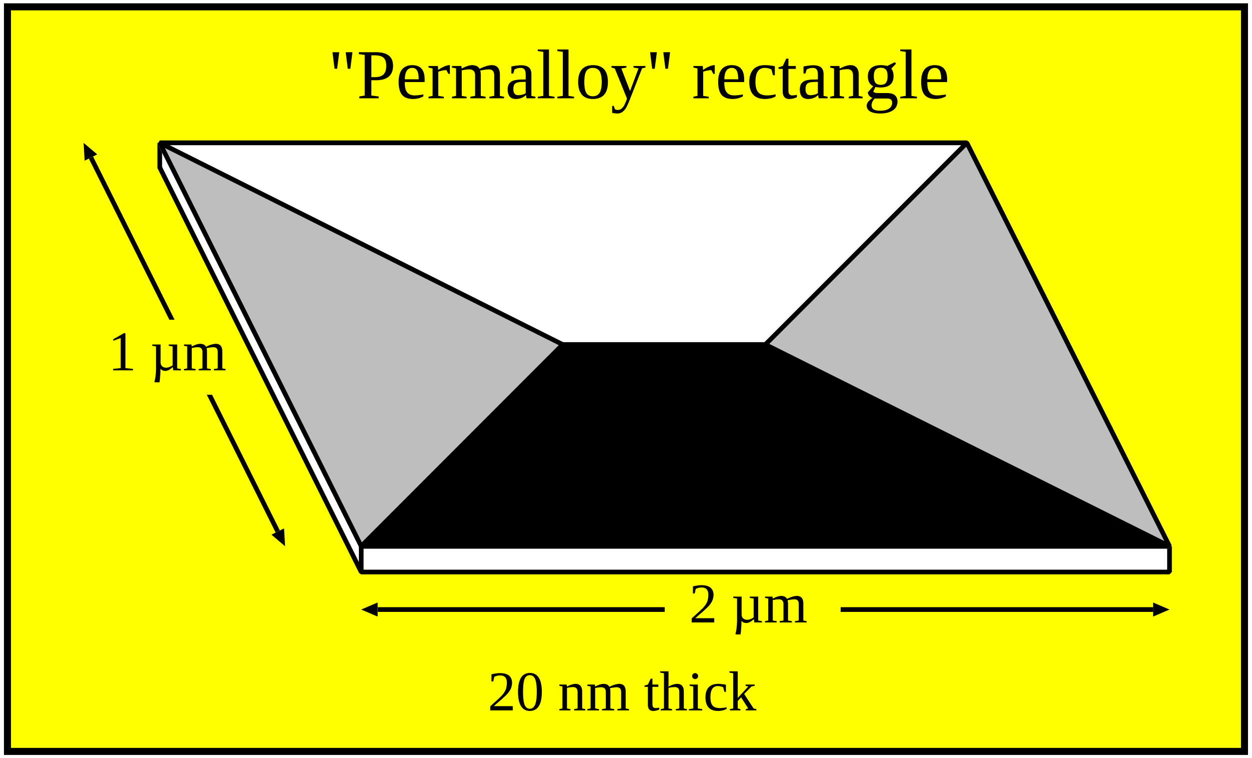
http://www.ctcms.nist.gov/~rdm/mumag.html

Example #4,

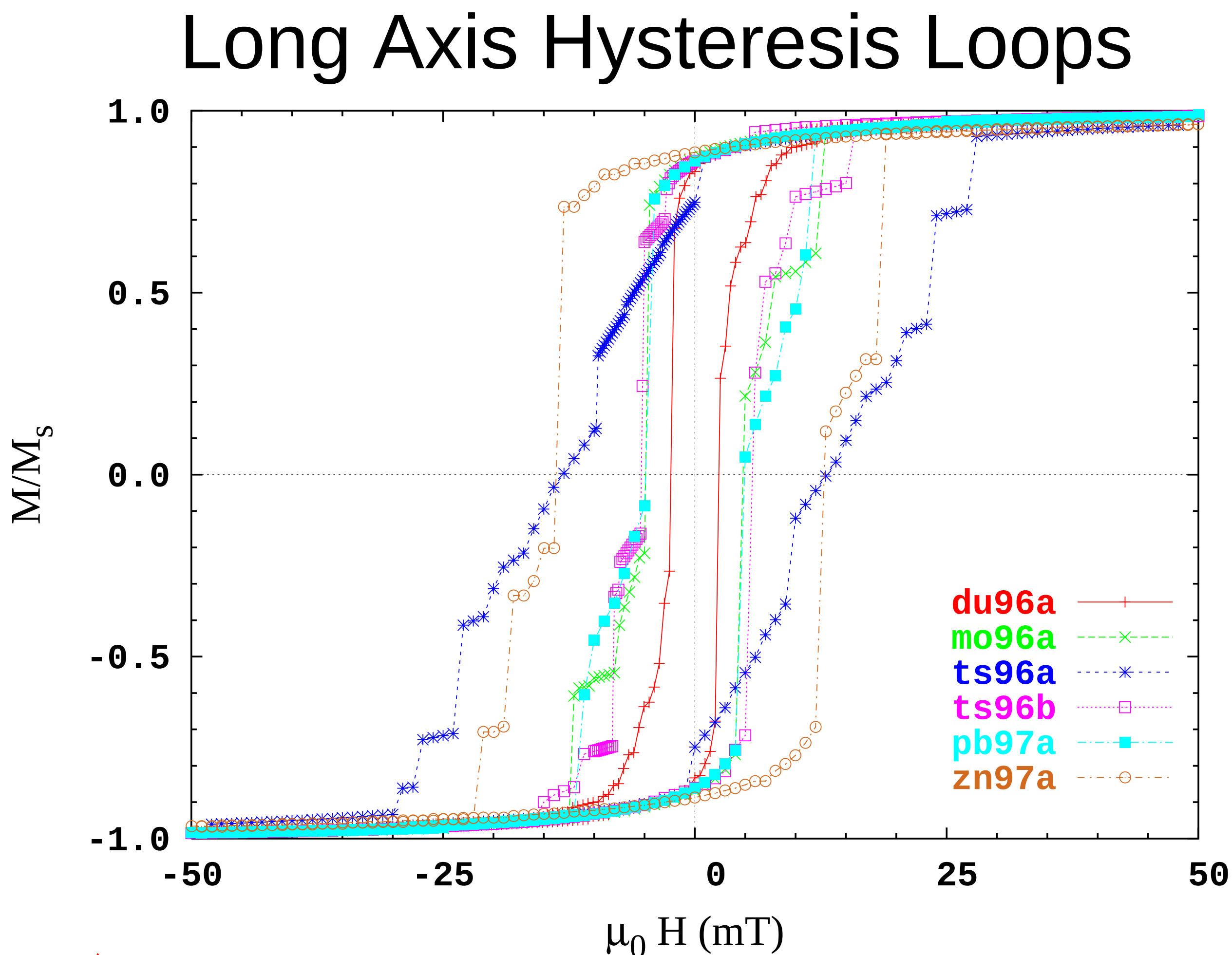
Switching dynamics:



μMAG Standard Problem #1



μMAG Standard Problem #1



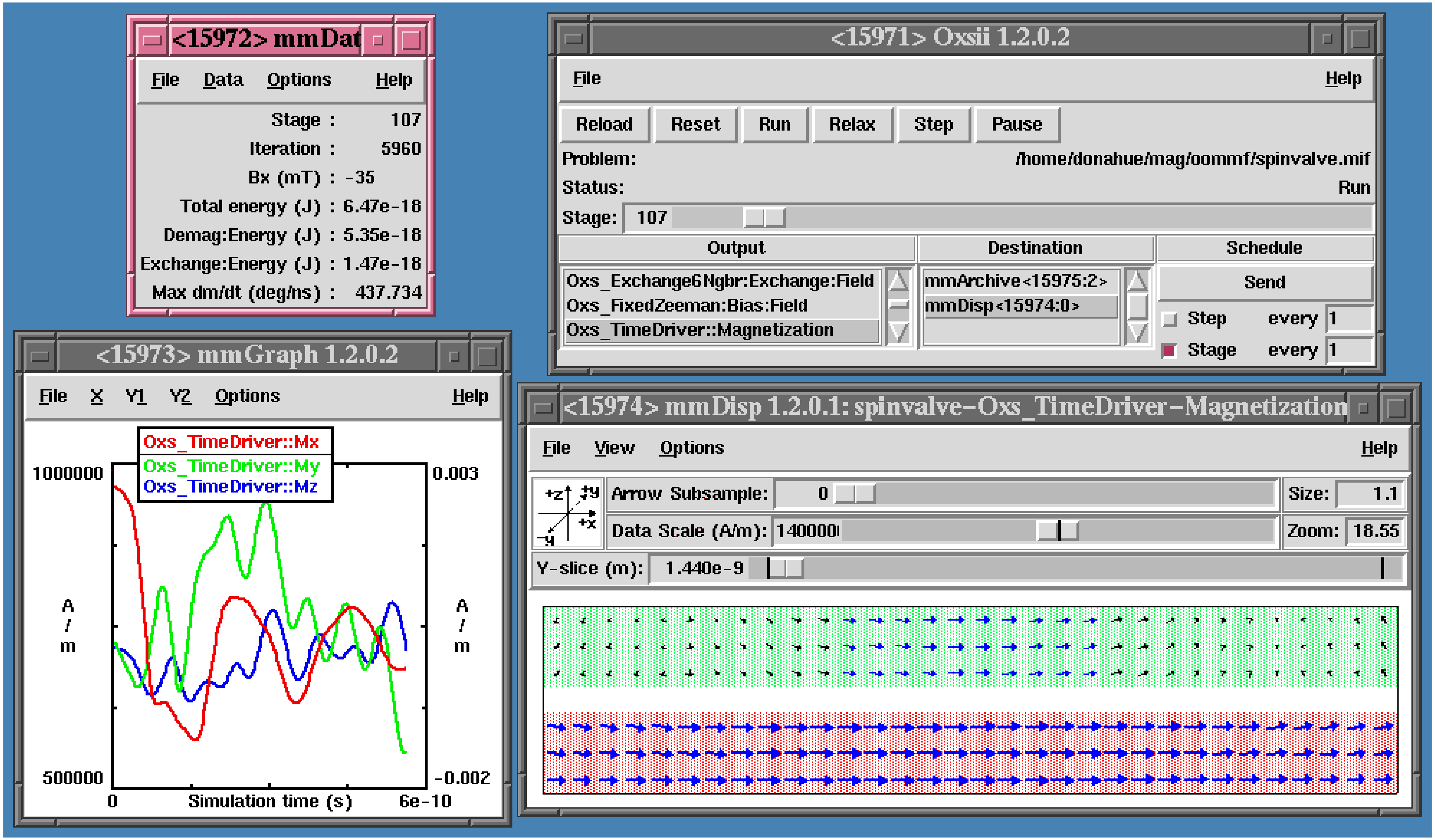
Public Code

Portable, extensible,
public domain
programs & tools
for micromagnetics

`http://math.nist.gov/oommf`

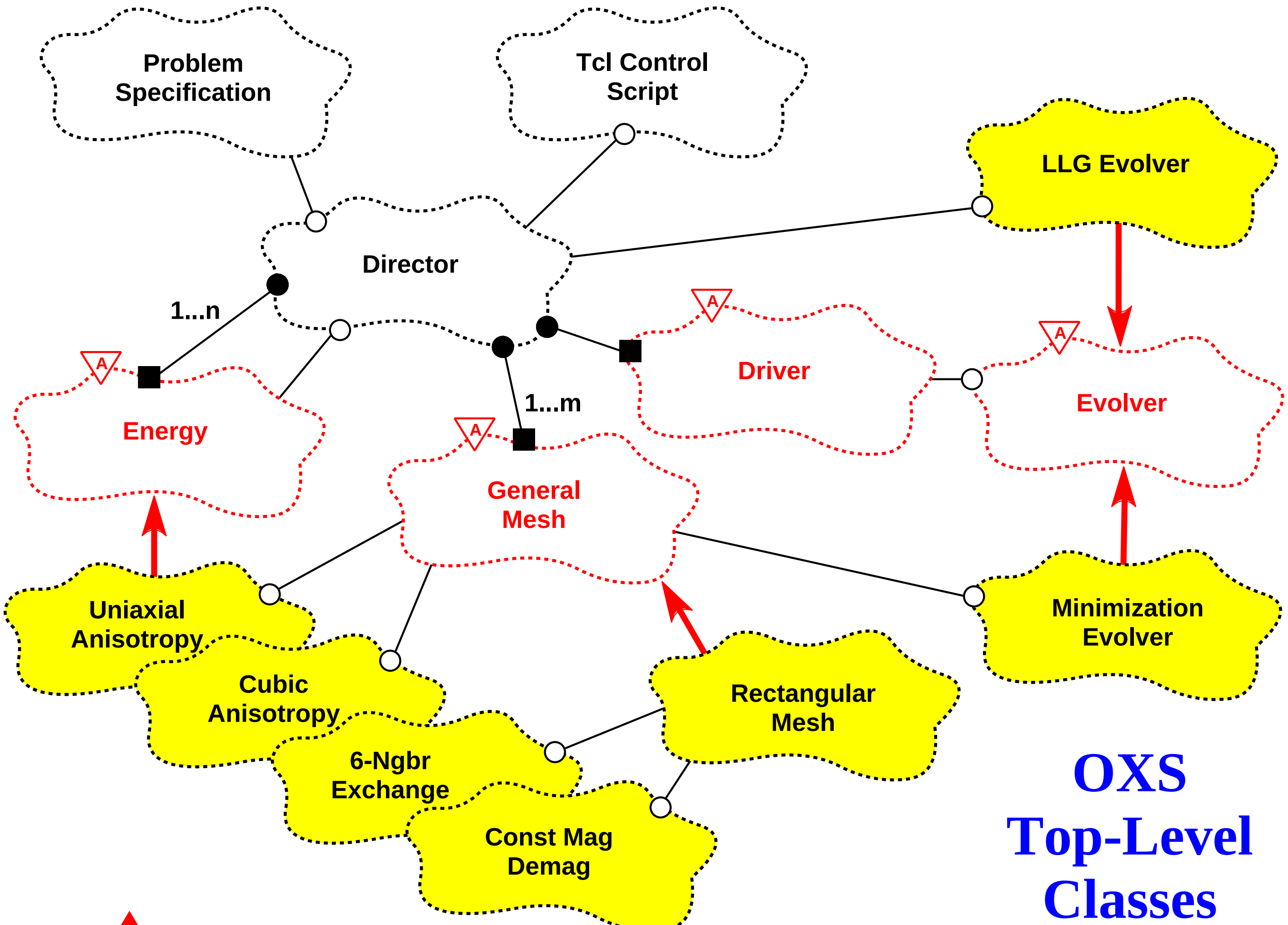
- Graphical User Interface
- Windows and Unix
- 150 page user's manual
- Binaries and source code
- Tcl/Tk and C++ based modular architecture
- 1000+ downloads in 2001

Public Code



<15972> mmDat
File Data Options Help
Stage : 107
Iteration : 5960
Bx (mT) : -35
Total energy (J) : 6.47e-18
Demag:Energy (J) : 5.35e-18
Exchange:Energy (J) : 1.47e-18
Max dm/dt (deg/ns) : 437.734
<15971> Oxsii 1.2.0.2
File Help
Reload Reset Run Relax Step Pause
Problem: /home/donahue/mag/oommf/spinvalve.mif
Status: Run
Stage: 107
Output Destination Schedule
Oxs_Exchange6Ngbr:Exchange:Field
Oxs_FixedZeeman:Bias:Field
Oxs_TimeDriver::Magnetization
mmArchive<15975:2>
mmDisp<15974:0>
Send
Step every 1
Stage every 1
<15973> mmGraph 1.2.0.2
File X Y1 Y2 Options Help
Oxs_TimeDriver::Mx
Oxs_TimeDriver::My
Oxs_TimeDriver::Mz
1000000
500000
A/m
0.003
-0.002
0
Simulation time (s)
6e-10
<15974> mmDisp 1.2.0.1: spinvalve-Oxs_TimeDriver-Magnetization
File View Options Help
Arrow Subsample: 0
Size: 1.1
Data Scale (A/m): 140000
Zoom: 18.55
Y-slice (m): 1.440e-9

OOMMF eXtensible Solver



OXS Top-Level Classes

References

- CTCMS:
  http://www.ctcms.nist.gov/
- μMAG:
  http://www.ctcms.nist.gov/˜rdm/mumag.org.html
- OOMMF:
  http://math.nist.gov/oommf/
- OOMMF User's Guide, Version 1.0
  M. J. Donahue and D. G. Porter, **NISTIR 6376**, NIST, Gaithersburg, MD (Sept 1999).

Brown's Equations

Energies:

$$
\begin{aligned}
E_{\text{exchange}} &= \frac{A}{M_s^2}\left(|\nabla M_x|^2 + |\nabla M_y|^2 + |\nabla M_z|^2\right) \\
E_{\text{anis}} &= \frac{K_1}{M_s^2}(\mathbf{M}\cdot\mathbf{u})^2 \\
E_{\text{demag}} &= \frac{\mu_0}{8\pi}\mathbf{M}(r)\cdot\left[\int_V \nabla\cdot\mathbf{M}(\mathbf{r}')\frac{\mathbf{r}-\mathbf{r}'}{|\mathbf{r}-\mathbf{r}'|^3}\,d^3r'\right. \\
&\qquad\left. - \int_S \hat{\mathbf{n}}\cdot\mathbf{M}(\mathbf{r}')\frac{\mathbf{r}-\mathbf{r}'}{|\mathbf{r}-\mathbf{r}'|^3}\,d^2r'\right] \\
E_{\text{Zeeman}} &= -\mu_0\mathbf{M}\cdot\mathbf{H}_{\text{ext}}
\end{aligned}
$$

Magnetization Dynamics

Landau-Lifshitz-Gilbert:

$$\frac{d\mathbf{M}}{dt} = \frac{-\omega}{1+\lambda^2}\mathbf{M}\times\mathbf{H}_{\mathrm{eff}} - \frac{\lambda\,\omega}{(1+\lambda^2)M_{\mathrm{s}}}\mathbf{M}\times(\mathbf{M}\times\mathbf{H}_{\mathrm{eff}})$$

where

$$\begin{aligned}\mathbf{H}_{\mathrm{eff}} &= -\frac{1}{\mu_0}\frac{\partial E}{\partial \mathbf{M}} \\ \omega &= \text{gyromagnetic ratio} \\ \lambda &= \text{damping coefficient}\end{aligned}$$