Scale transitions in magnetisation dynamics

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Multi-scale modelling of spin dynamics

- Materials Theory (Department of Physics and Astronomy)
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Introduction

- variety of applications
  - magnetic storage media
  - magnetic RAM
  - nanowires
  - etc.
- continuum modelling: micromagnetics
  - can handle relatively large spatial and time scales
- atomistic modelling: spin dynamics
  - precise treatment of singularities
  - material defects
- combine advantages – multi-scale approach
Multi-scale modelling

1. “information passing”

2. “direct coupling”

2a:

2b:
Multi-scale modelling

1. “information passing”
2. “direct coupling”

- static and dynamic methods
- wave reflections at the interface
  - not an issue of coupling methods
- approach: stadium damping region
  - wave-absorbing layer
  - thermostatting
Micromagnetics

- magnetisation – density of magnetic dipole moments

- Landau-Lifshitz equation
  \[
  \frac{\partial \mathbf{m}}{\partial t} = -\beta \mathbf{m} \times \Delta \mathbf{m} - \alpha \mathbf{m} \times \mathbf{m} \times \Delta \mathbf{m}
  \]
Damping band

- atomistic and continuum descriptions are based on LL equation
- modify LL equation, test in continuum case

\[
\frac{\partial \vec{m}}{\partial t} = -\beta \vec{m} \times \Delta \vec{m} - \alpha \vec{m} \times \vec{m} \times \Delta \vec{m} - \vec{m} \times \vec{m} \times \vec{f}
\]

- 1D case
- choice of parameters?
- possible issues:
  - wave damping
  - influence of the boundary
  - size dependence
  - temperature stability
Spin waves

1D wave propagation analysis (small amplitudes):

• damping strength should be proportional to time derivative of magnetisation
• width of damping band determines scale of reflections from it
• average magnetisation
Amplitude–frequency

- uniform fine scale
- attenuation of small wave lengths
- finite error due to reflection from damping band
- size of averaging window determines cutoff wave length
Spin waves, example
Spin waves in 2D (preliminary results)

issues in 2D:
- local timestepping in case of implicit numerical methods
- large angle between wave front and interface: relatively high reflections

approach in 2D:
- borrow idea from damping of acoustic waves, perfectly matched layer
Conclusions

• damping zone at the interface eliminates wave reflections
• finite width (depends on desired accuracy)
• optimal values of damping parameters can be obtained numerically

Future work

• further investigation of damping in 1D continuum case
  – finite temperature (stochastic terms in LL eq.)
• further investigation of 2D continuum case
  – extensive testing of PML concept
  – domain wall motion
• transition form continuum fine scale to atomistic