What students (and professors) can learn about physics using a computer

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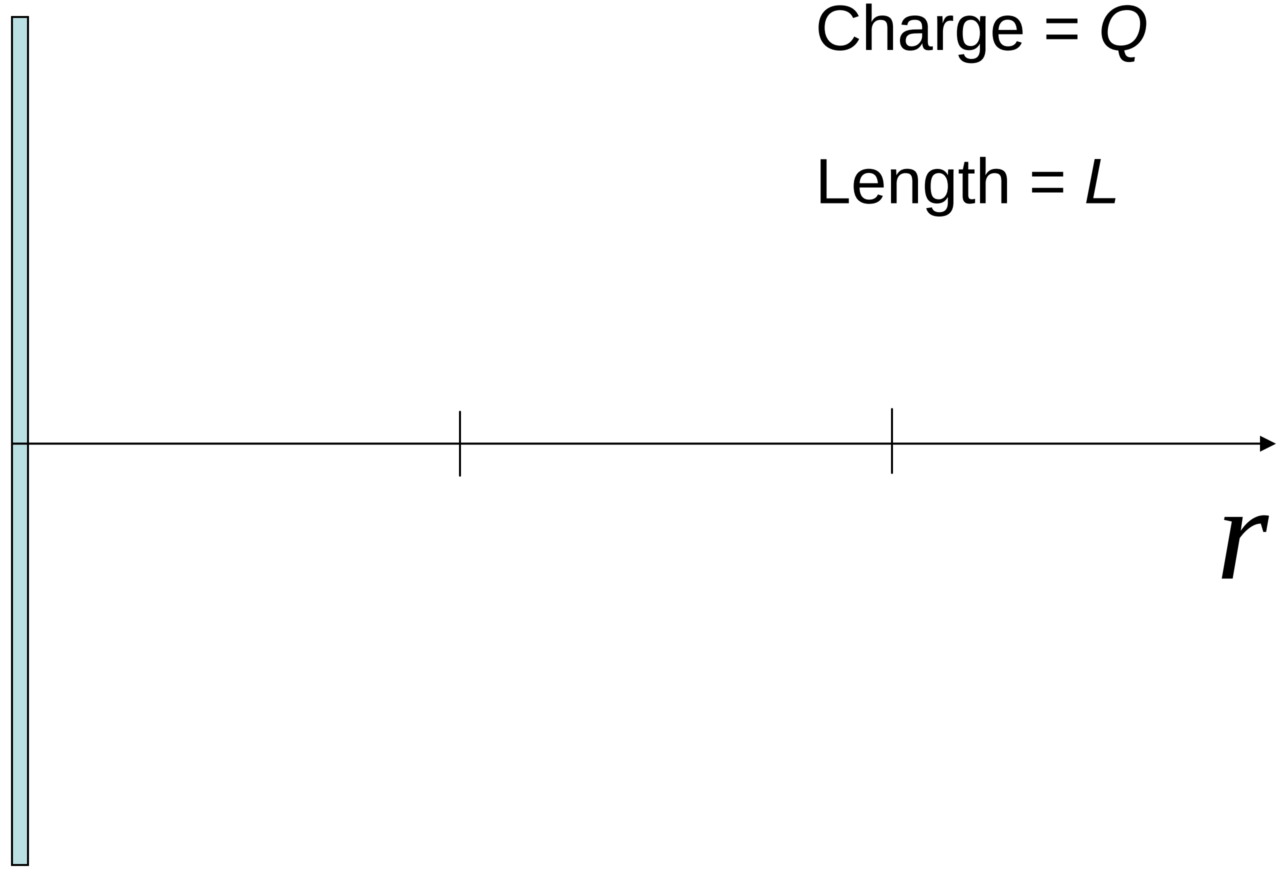
How we can use computation to teach students physics

Electric field of a finite rod

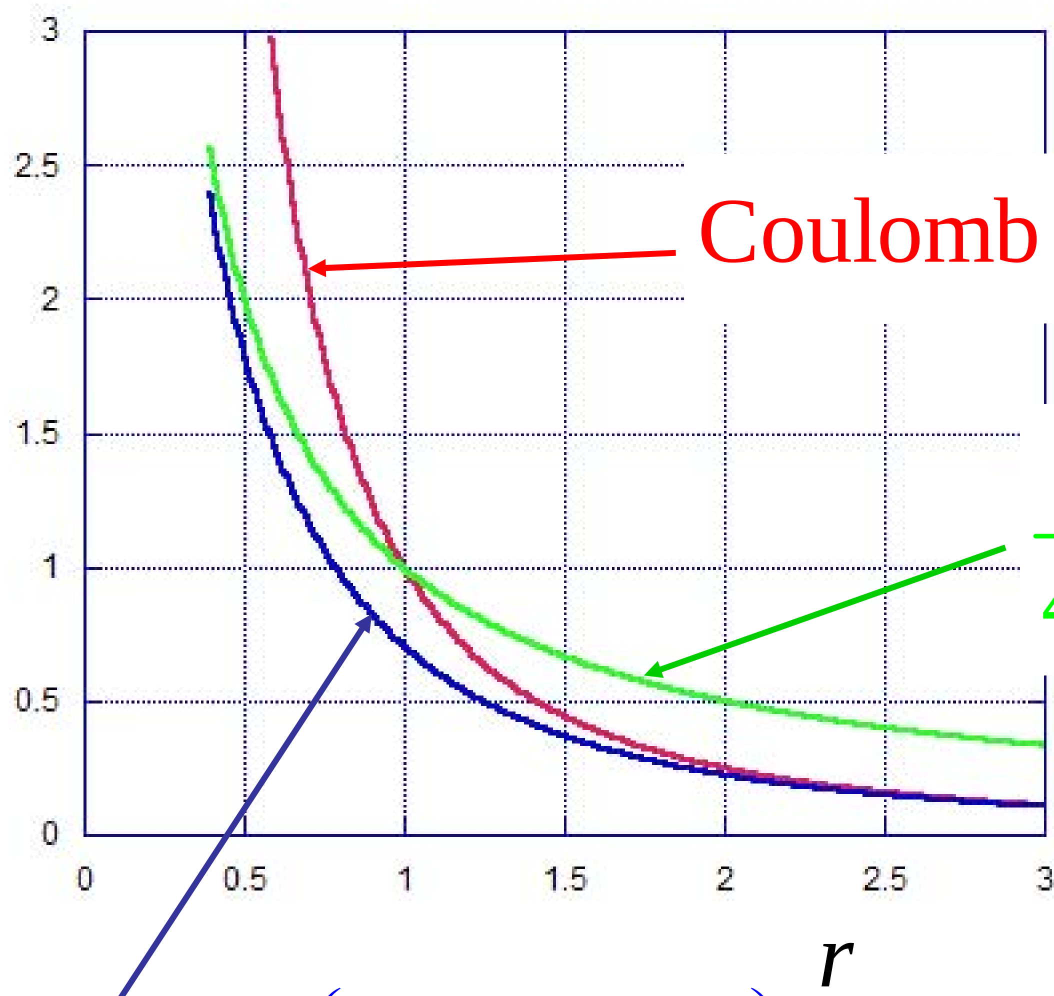
Uniformly charged rod

Charge = *Q*

Length = *L*



FINITE ROD L=2



$$\frac{1}{4\pi\varepsilon_o}\left(\frac{2Q/L}{r}\right)$$

$$E_r = \frac{1}{4\pi\varepsilon_o}\left(\frac{Q}{r\sqrt{r^2+(L/2)^2}}\right)$$

Electric field of a finite rod

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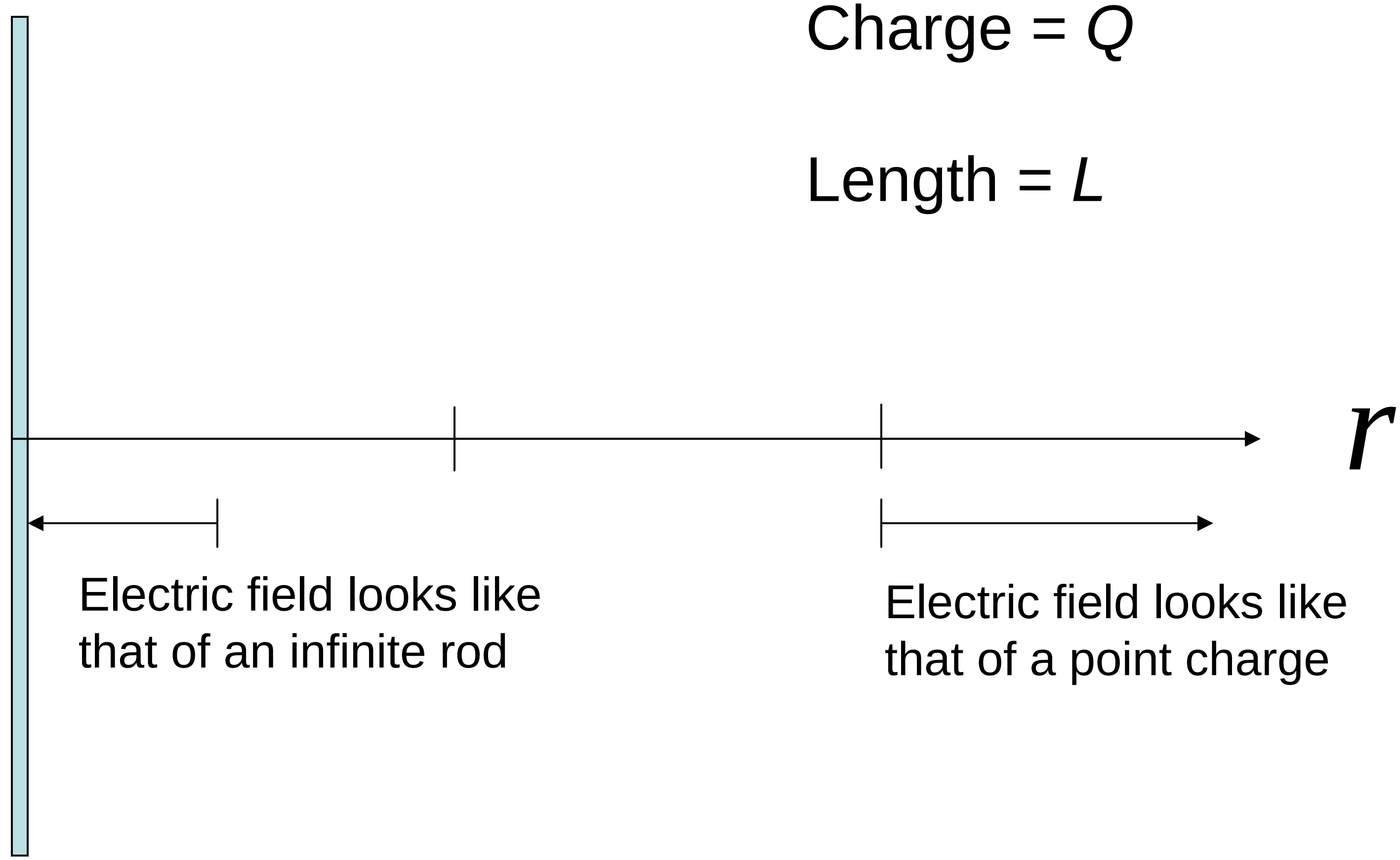
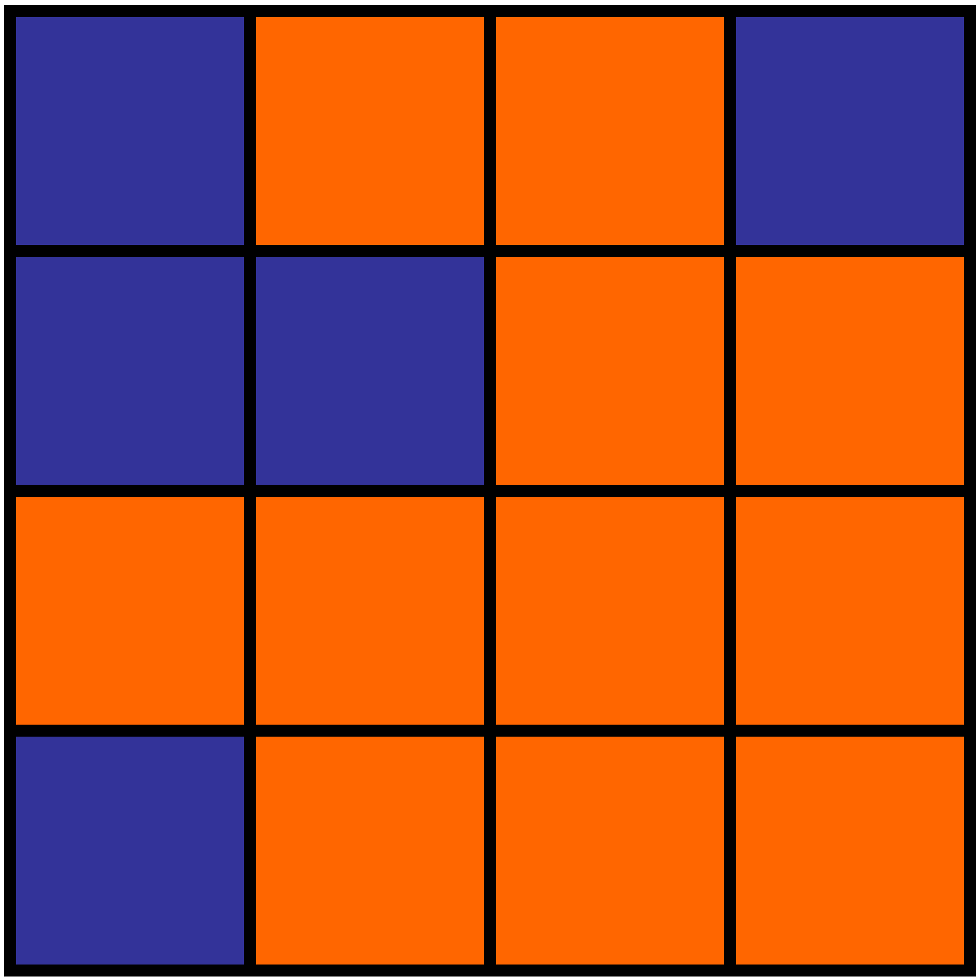


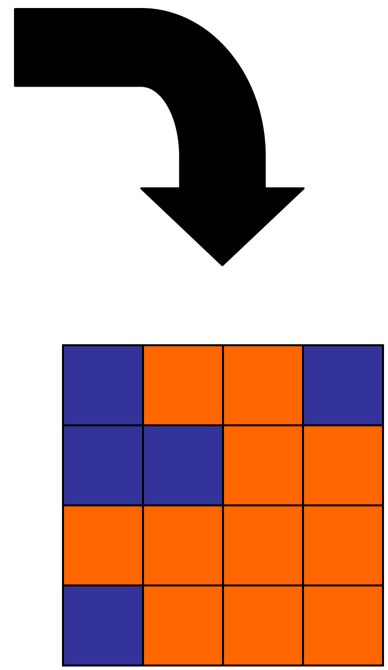
Real-space
Renormalization group

Show the explicit effect of RG transformations

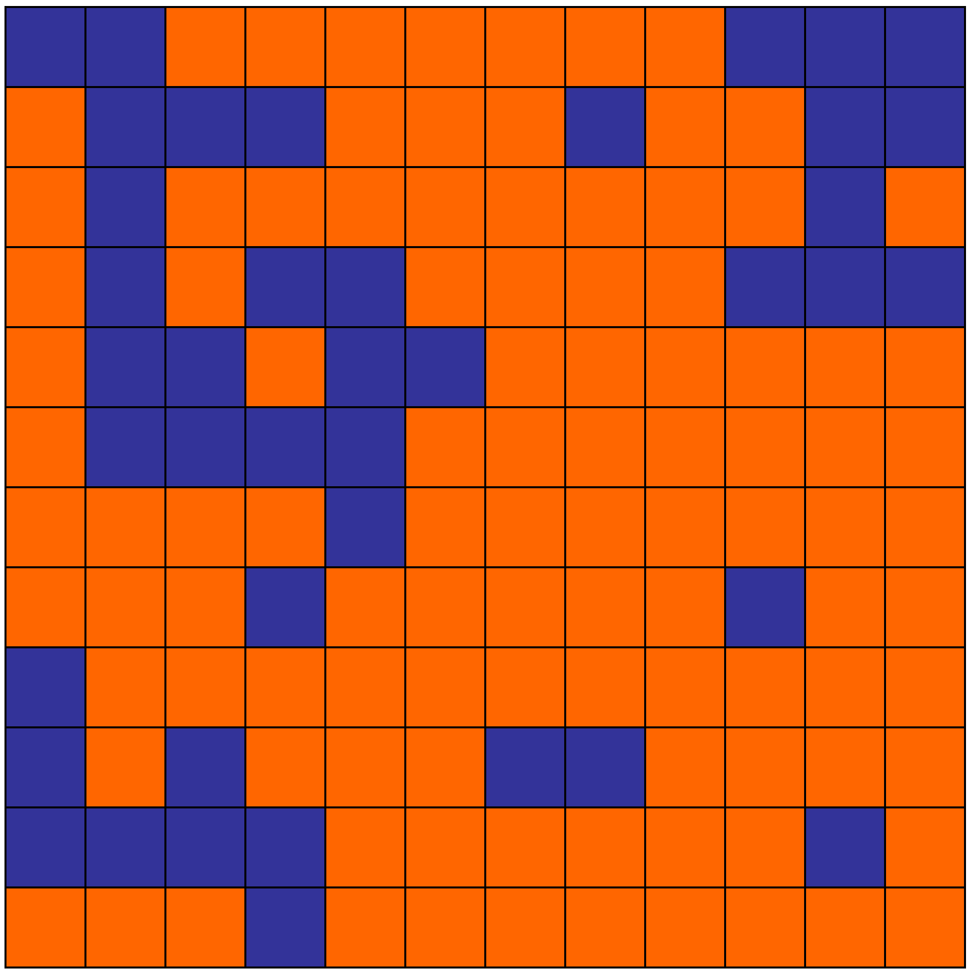
3 by 3 block spins
with “majority rule”



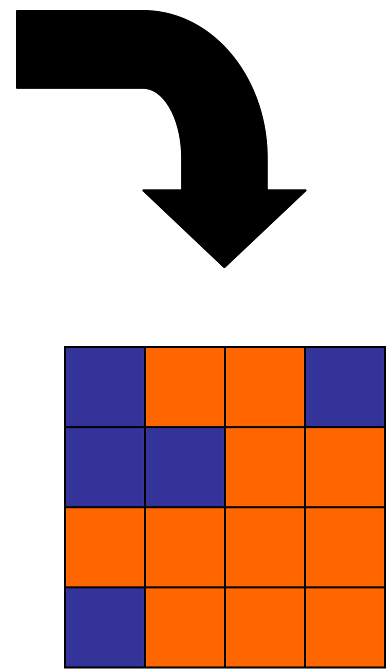
Now shrink the lattice
by a factor of 3



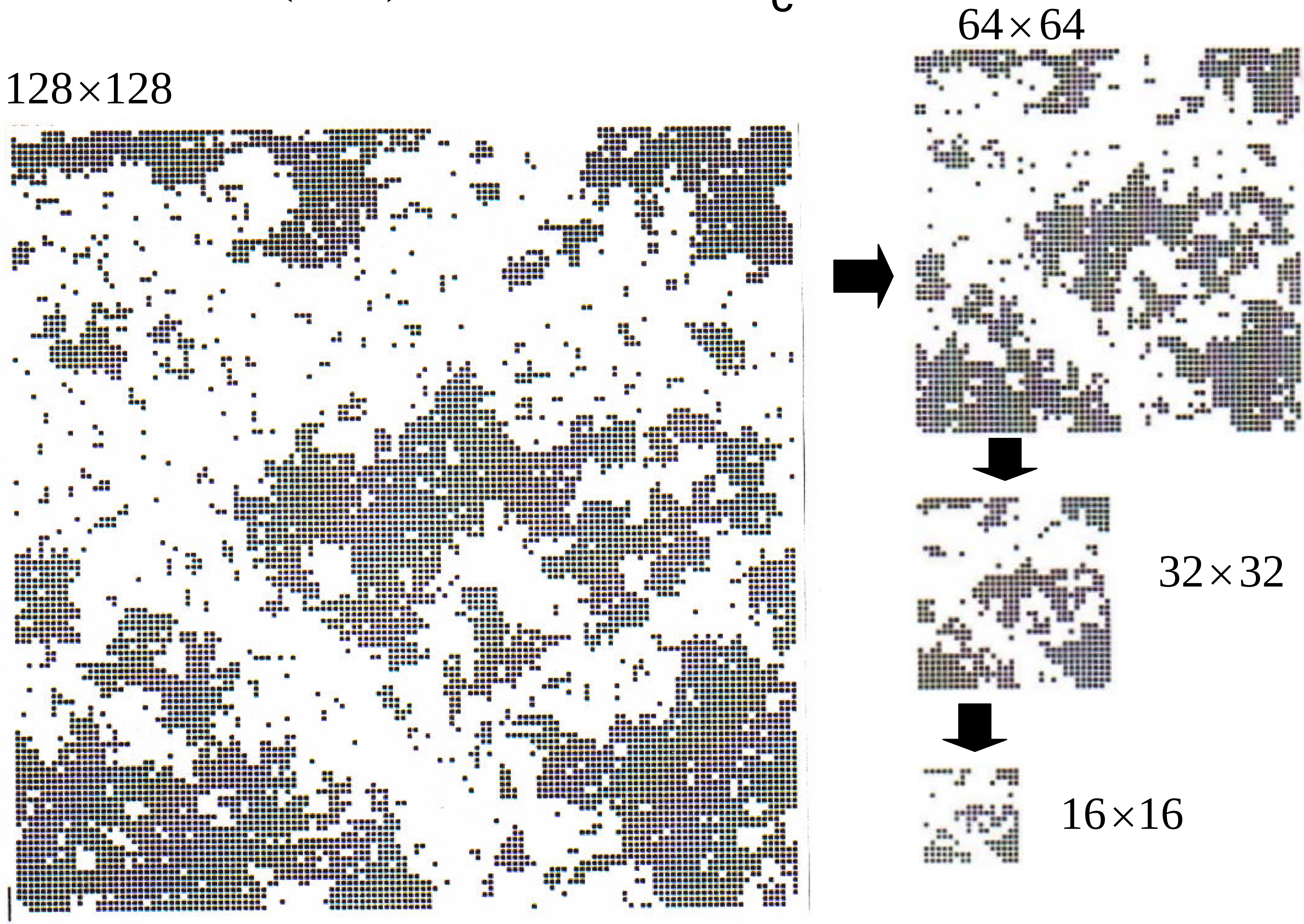
3 by 3 block spins with “majority rule”



Compare the original spins with the renormalized spins.



2×2 blocks ($b = 2$) $T = 1.0 T_c$



How students can use computation to learn physics

Examples

VPython programs

orbit for inverse-square force

orbit for non-inverse-square force

VPython program for a gravitational orbit

```
from visual import *

planet = sphere(pos=(50.,0.,0.),radius=1.0,color=(1,0,0),mass=1.0)
sun = sphere(pos=(0.,0.,0.),radius=1.0,color=(1,1,1),mass=10^9)
G=1.0

trail = curve(pos=planet.pos,color=planet.color, radius=0.2*planet.radius)

planet.momentum = vector(0.,0.1,0.)
dt = 0.01
force = vector(0.,0.,0.)

while 1==1:
    planet.pos = planet.pos + (planet.momentum/planet.mass)*dt
    r = planet.pos
    rNorm = norm(r)
    r2 = dot(r,r)
    r2 = pow(r2,0.99)
    force = -(G * planet.mass *sun.mass / r2) * rNorm
    planet.momentum = planet.momentum + force * dt
    trail.append( pos = planet.pos )
```

Ising model tutorial
(since ~1980)

Professors

Post-docs

Graduate students

Undergraduates

Successful completion of Ising model tutorial

1. Undergraduates

2. Graduate students

3. Post-docs

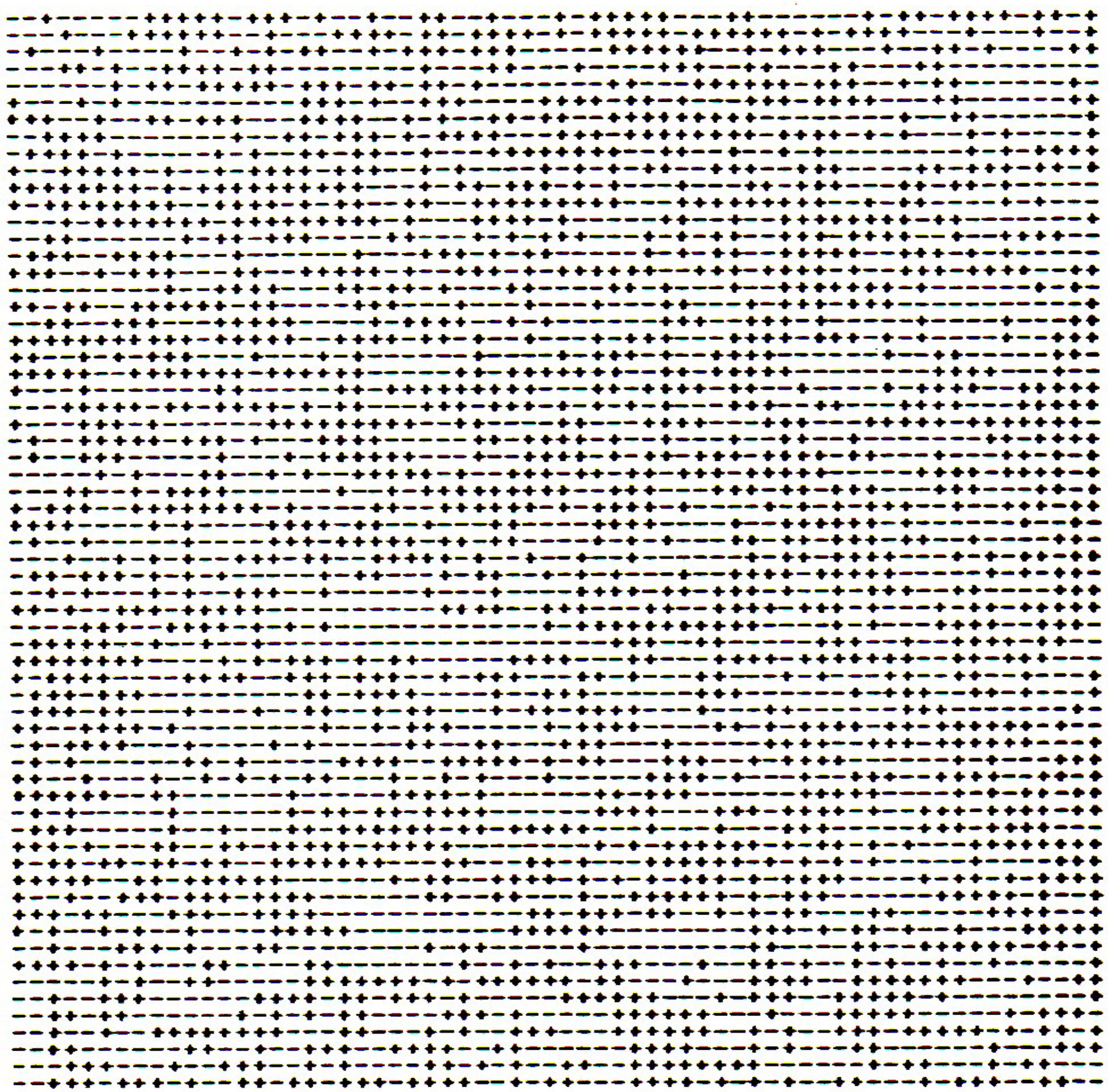
4. Professors

Ising model tutorial

MC program for Ising model

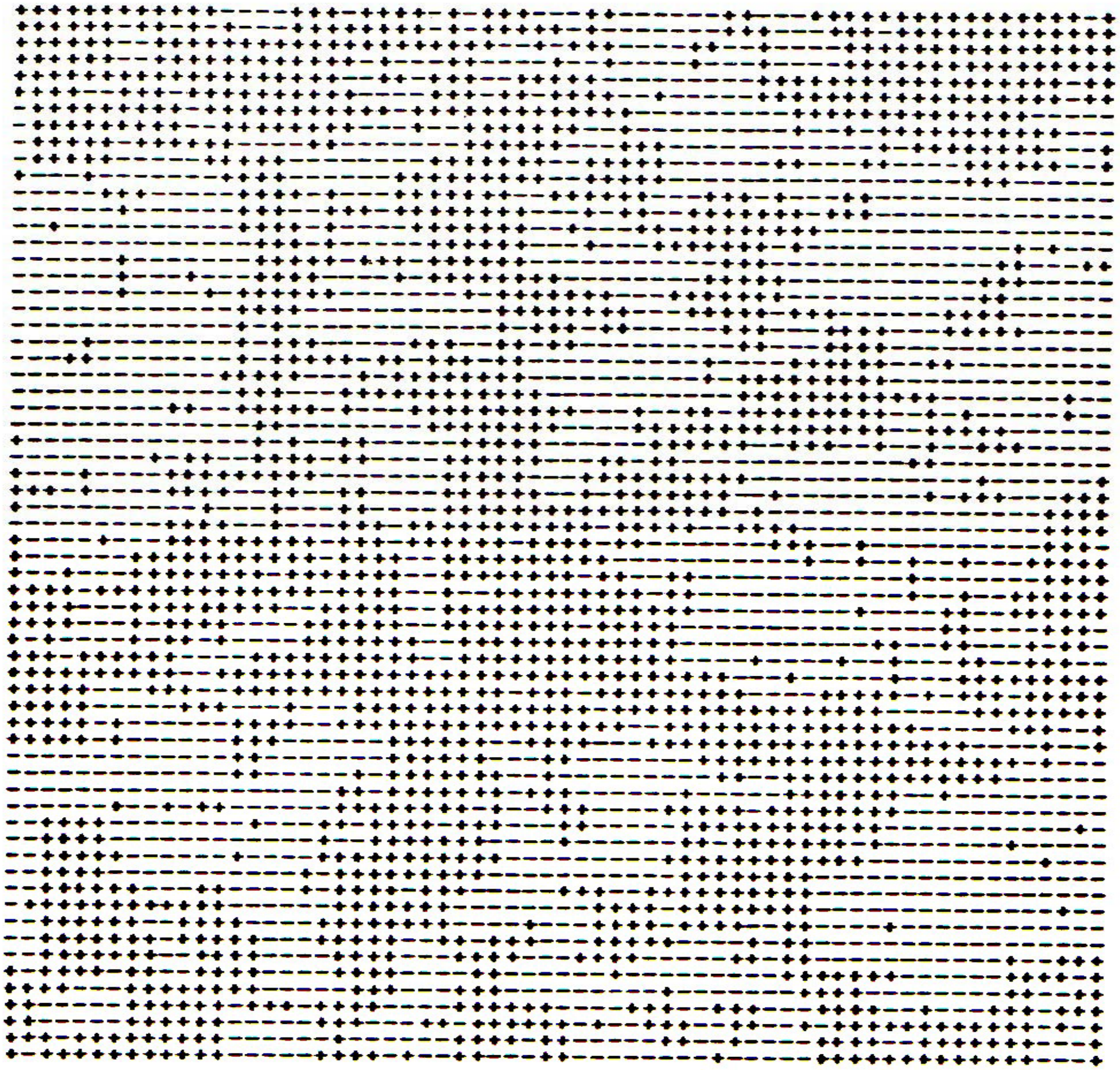
Pictures of Ising spin configurations

High-temperature configuration



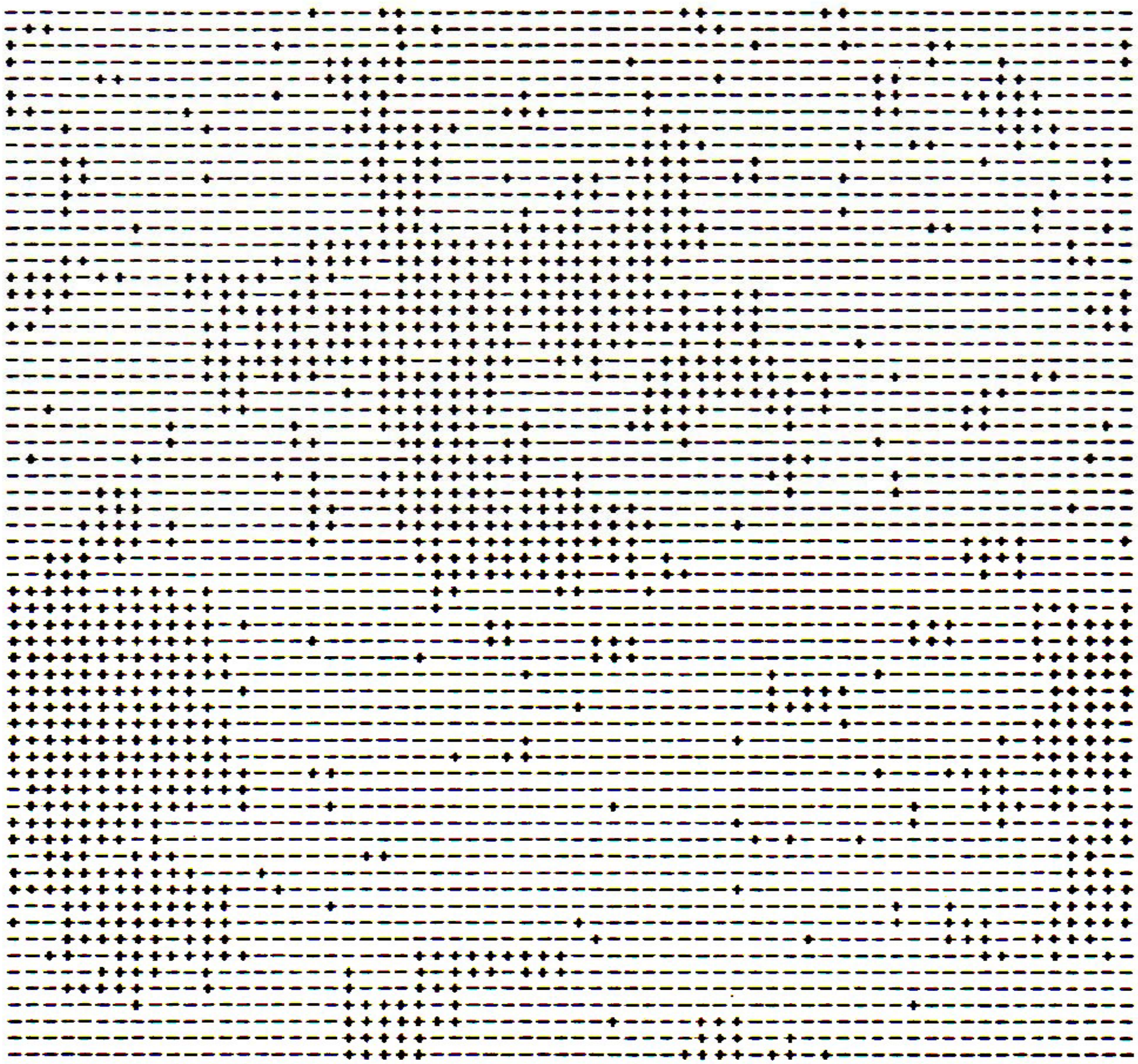
$$T = 5T_c$$

Ten percent above T_c



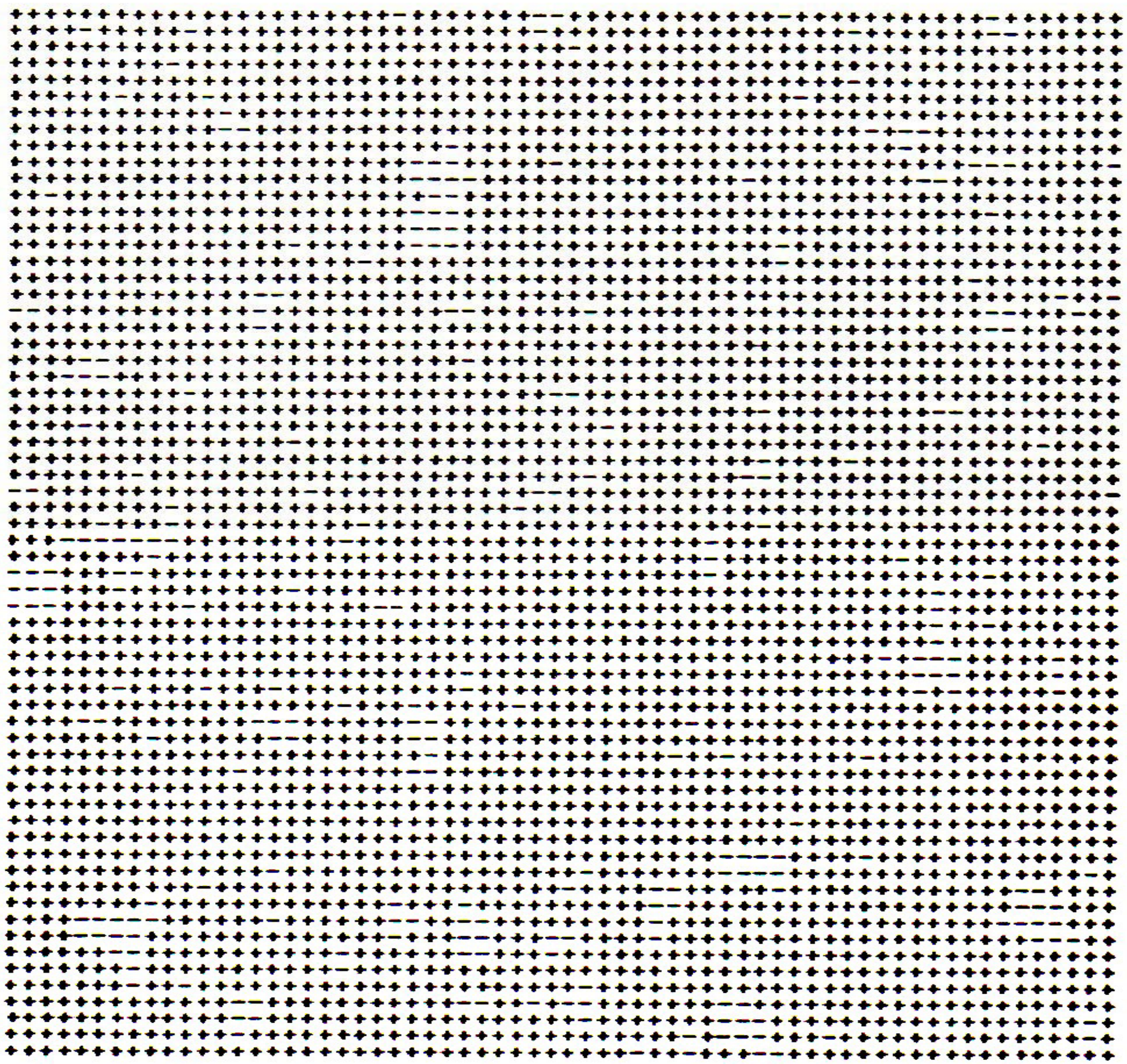
$$T = 1.1T_c$$

At T_c



$$T = T_c$$

Ten percent below T_c



$T = 0.9T_c$

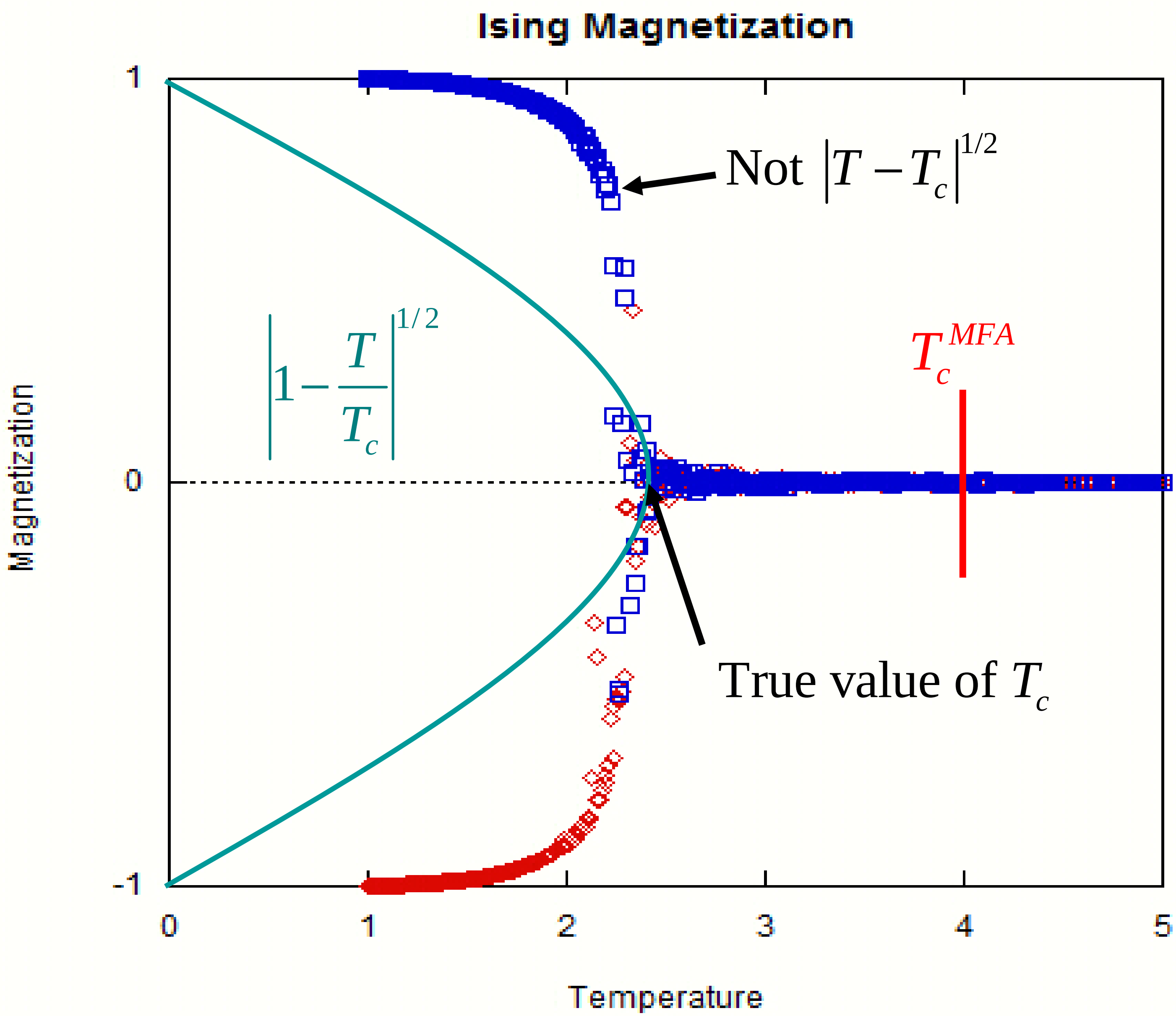
Ising model tutorial

MC program for Ising model

Pictures of Ising spin configurations

Scans of temperature

Magnetization vs. temperature



True value

is $\beta = \frac{1}{8}$

$$\langle m \rangle = \left\langle \frac{1}{N} \sum_{j=1}^{N} \sigma_j \right\rangle$$

Ising model tutorial

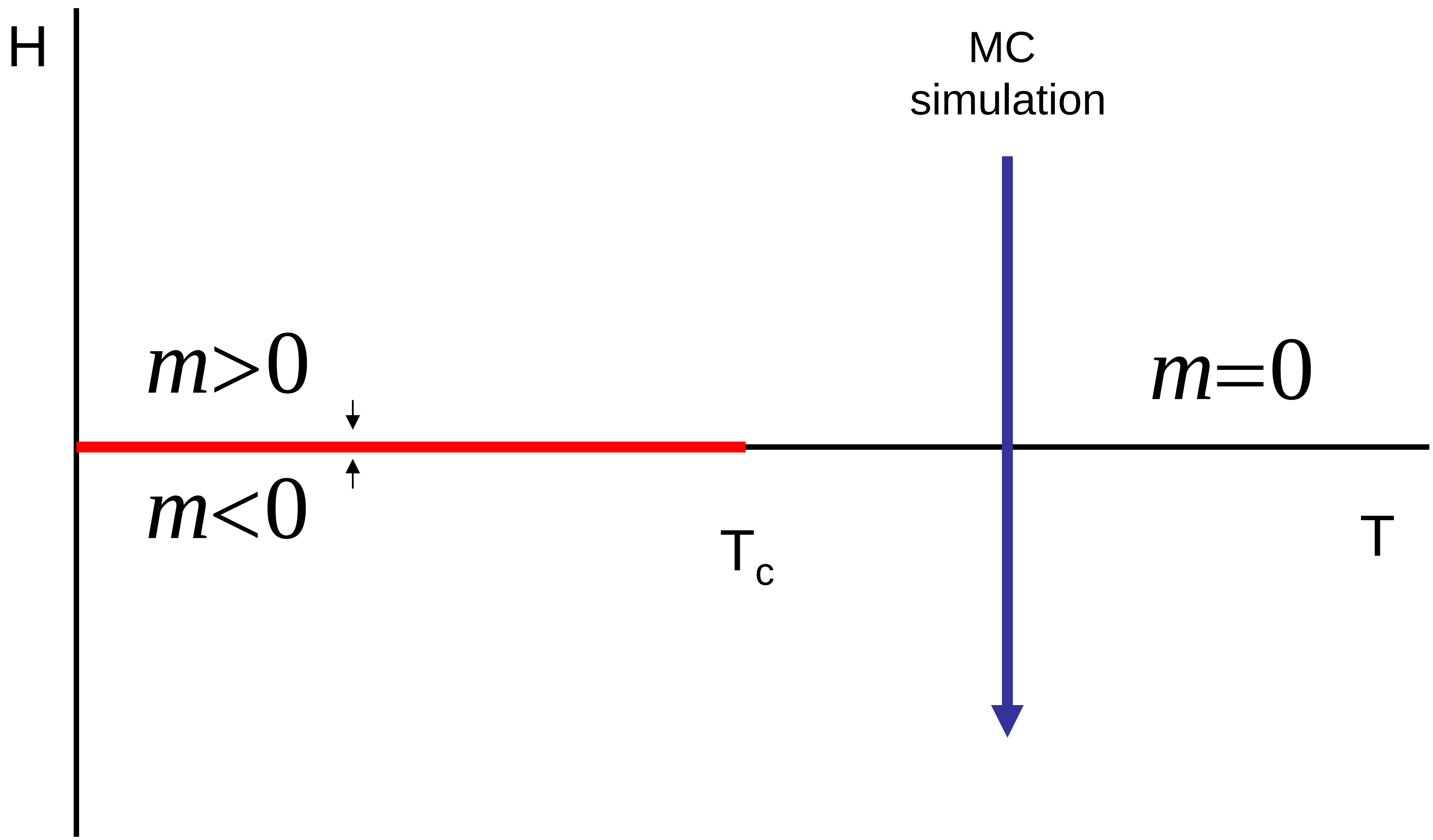
MC program for Ising model

Pictures of Ising spin configurations

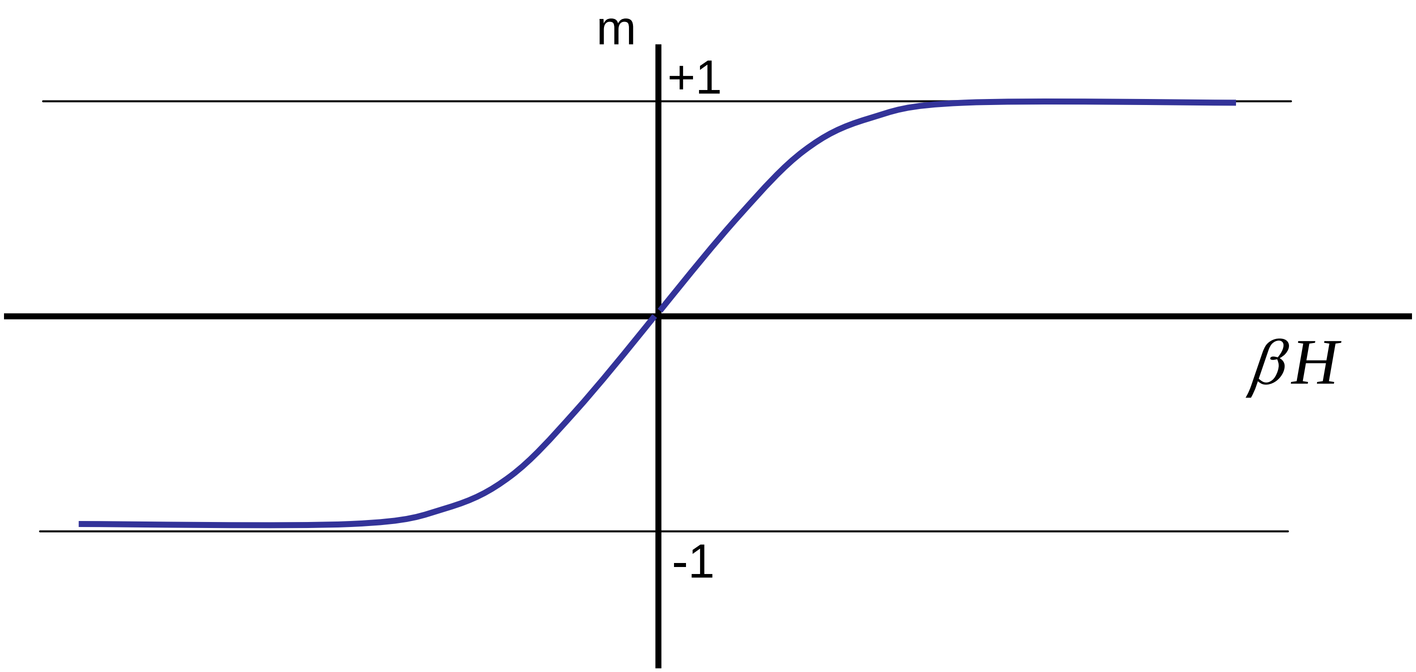
Scans of temperature

Scans of magnetic field

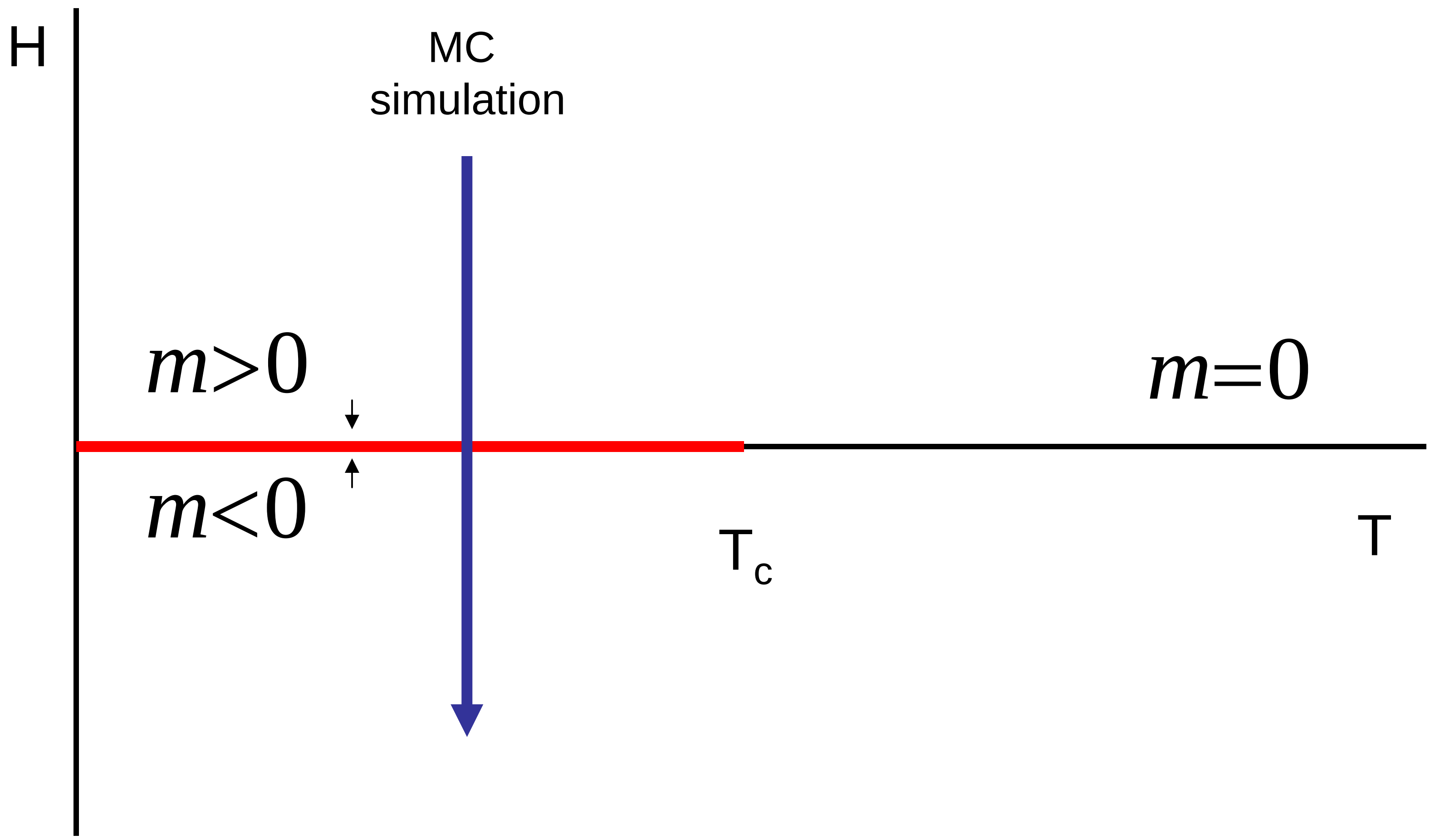
Phase diagram of a ferromagnet



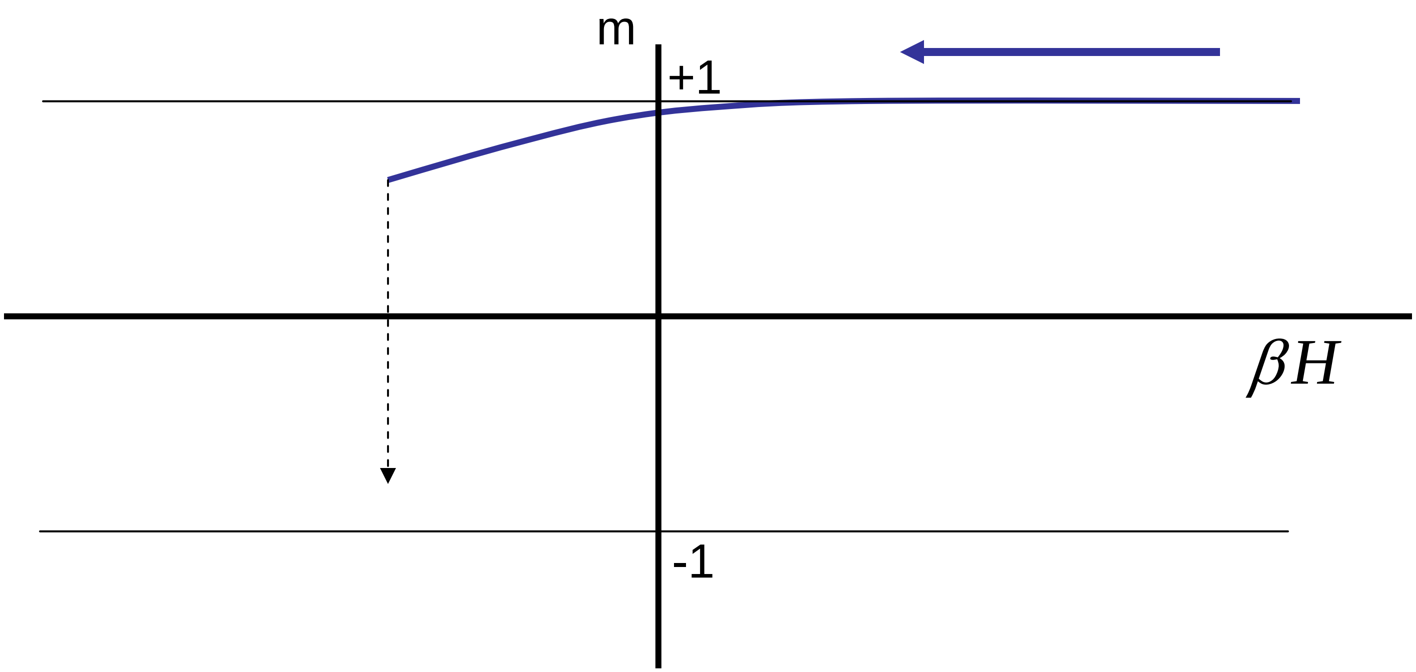
Above the critical temperature



Phase diagram of a ferromagnet

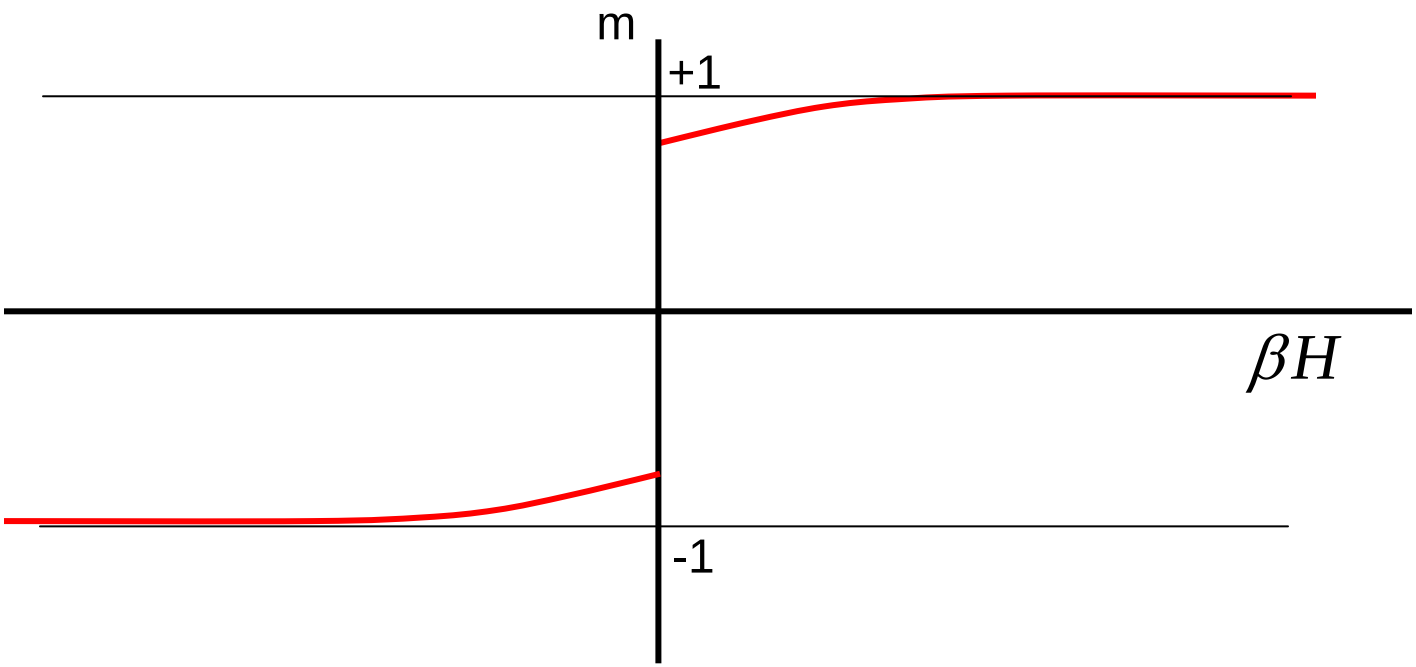


Below the critical temperature

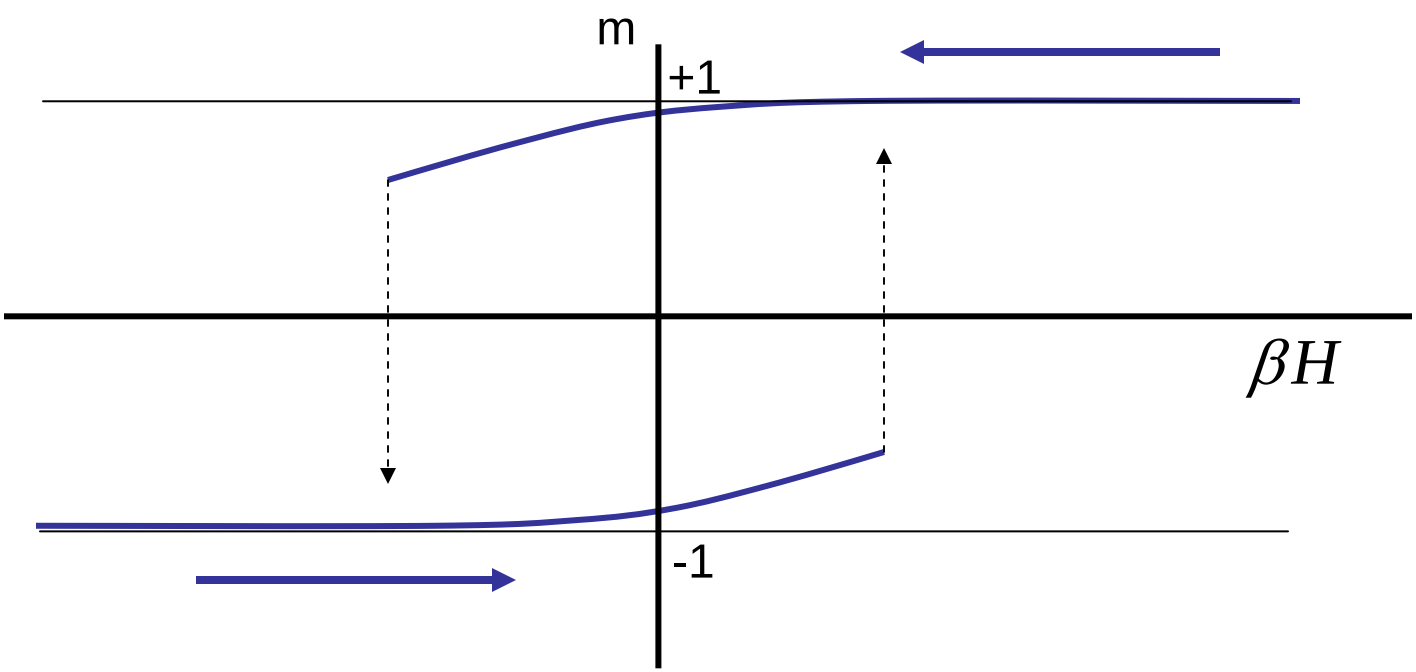


Below the critical temperature

Professors' expectations:



Below the critical temperature



Hysteresis

Are we preparing students to benefit from computational physics?

What are we doing now to teach computational physics?

Computational Physics Report Card

Undergraduate Physics Education

Analytic methods	A
Classical mechanics	A
Classical E&M	A
Thermodynamics	B+
Quantum mechanics	B
Statistical Mechanics	C+
Computational physics	D

CMU Undergraduate Curriculum

- Six required physics courses deal mainly with analytic solution methods
- Required Introduction to Computer Science
- Two computational physics electives
- No computational physics requirement

Curriculum is determined by history

Change is **SLOW**!

“Modern Physics”

is the physics of the 1920’s

Curriculum is determined by history

Professors' attitudes toward computing when I was a student:

Very negative!

"Use computers **ONLY**
if you're not very good at math"

Anachronisms

- Printed tables of functions
- “Reduction to quadrature”
- Long analytic calculations by hand
- Study of “important special functions”
- Name: “Modern Physics”
  [i.e.: physics of the 1920’s]

Computation will be the basis of scientific progress in the 21st century

This opinion is not necessarily that of the rest of our profession,

but it should be.

Generals tend to prepare to fight the previous war.

Are we still preparing our students to solve the physics problems of the 1960's?