Examining Hausdorff dimension and Scaling behaviour with Worm algorithm

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Scaling Mass

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Algorithms Used For Generating Graph Patterns

Worm Algorithm

Idea is to sample non-zero contributions of the partition function at $T = T_c$. Express them in a way as to form 'loops'.

Hoshen Kopelman Labeling and Graph Dividing

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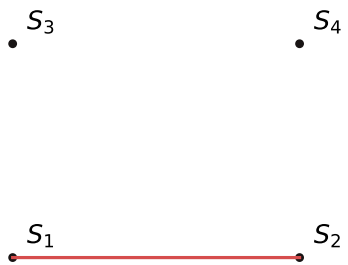
Ising Model

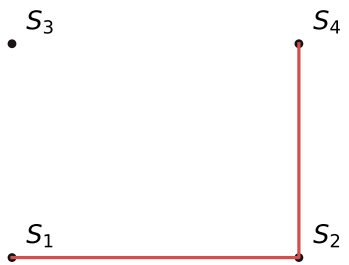
Ising Loop Expansion

$$Z \propto \sum_{\{S\}} \left(1 + \tanh(K) \sum_{l=1} S_i S_j + \tanh^2(K) \sum_{l=2} (S_i S_j)(S_{i'} S_{j'}) + \dots \right)$$

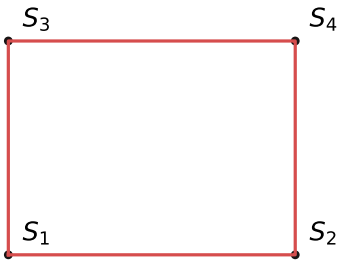
Ising Loop Expansion



a: $(S_1 S_2),\ L = 1$

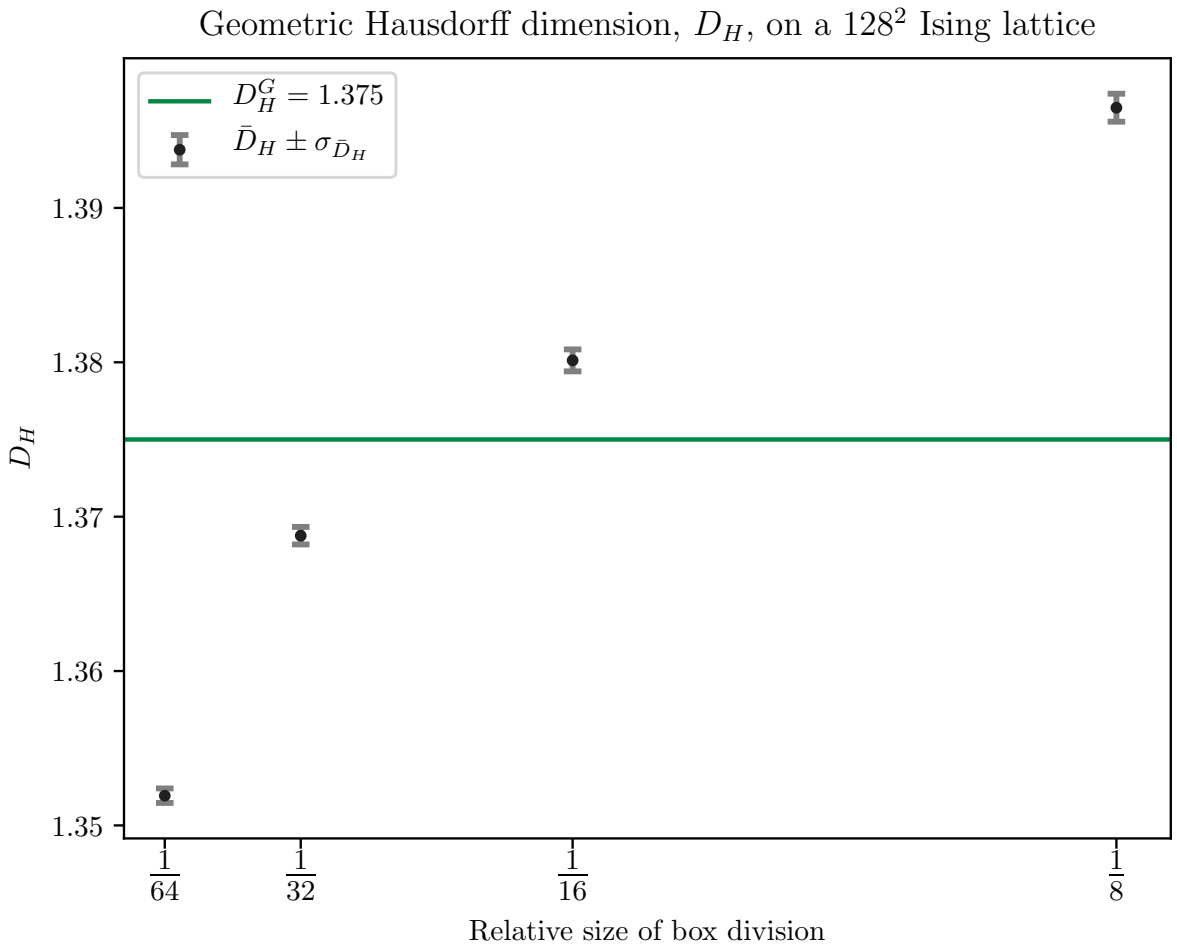


b: $(S_1 S_2)(S_2 S_4),\ L = 2$

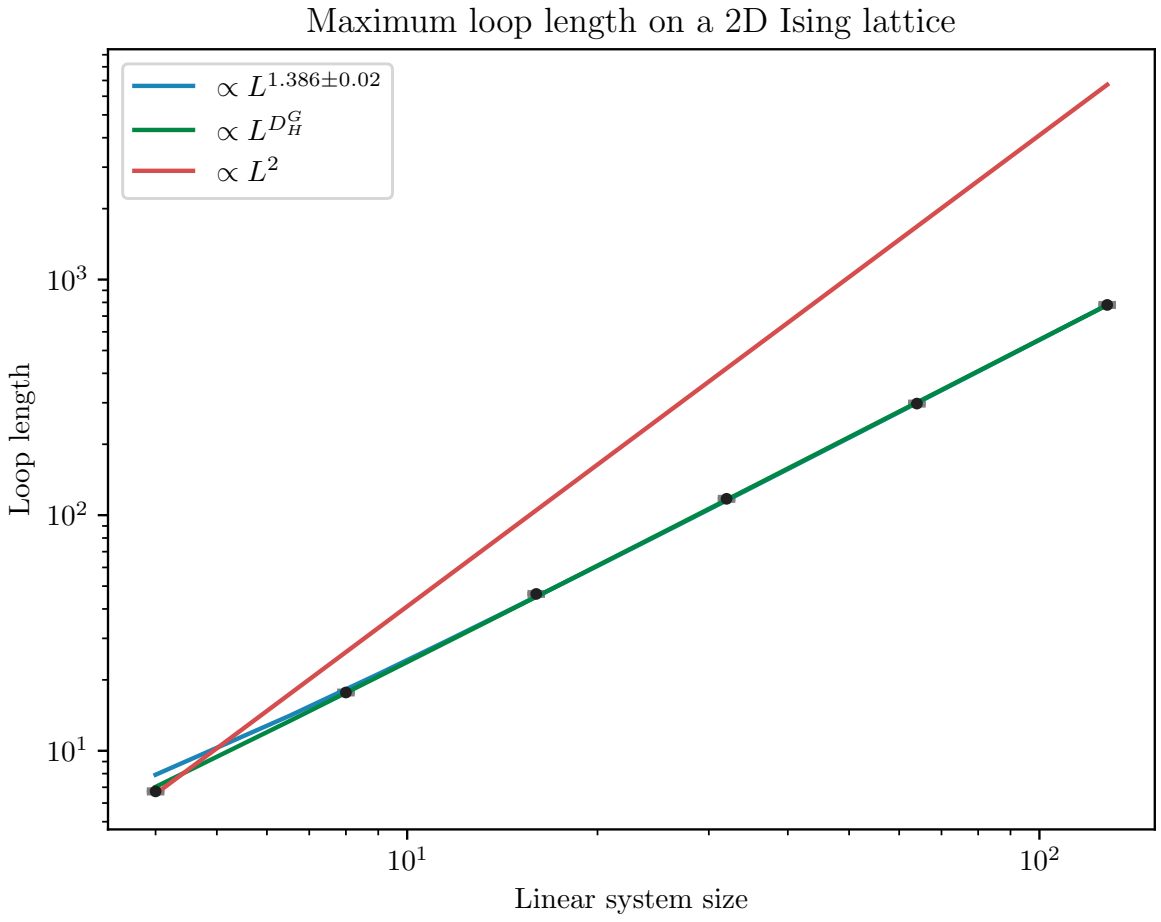


c: $(S_1 S_2)(S_2 S_4)(S_4 S_3)(S_3 S_1),\ L = 4$

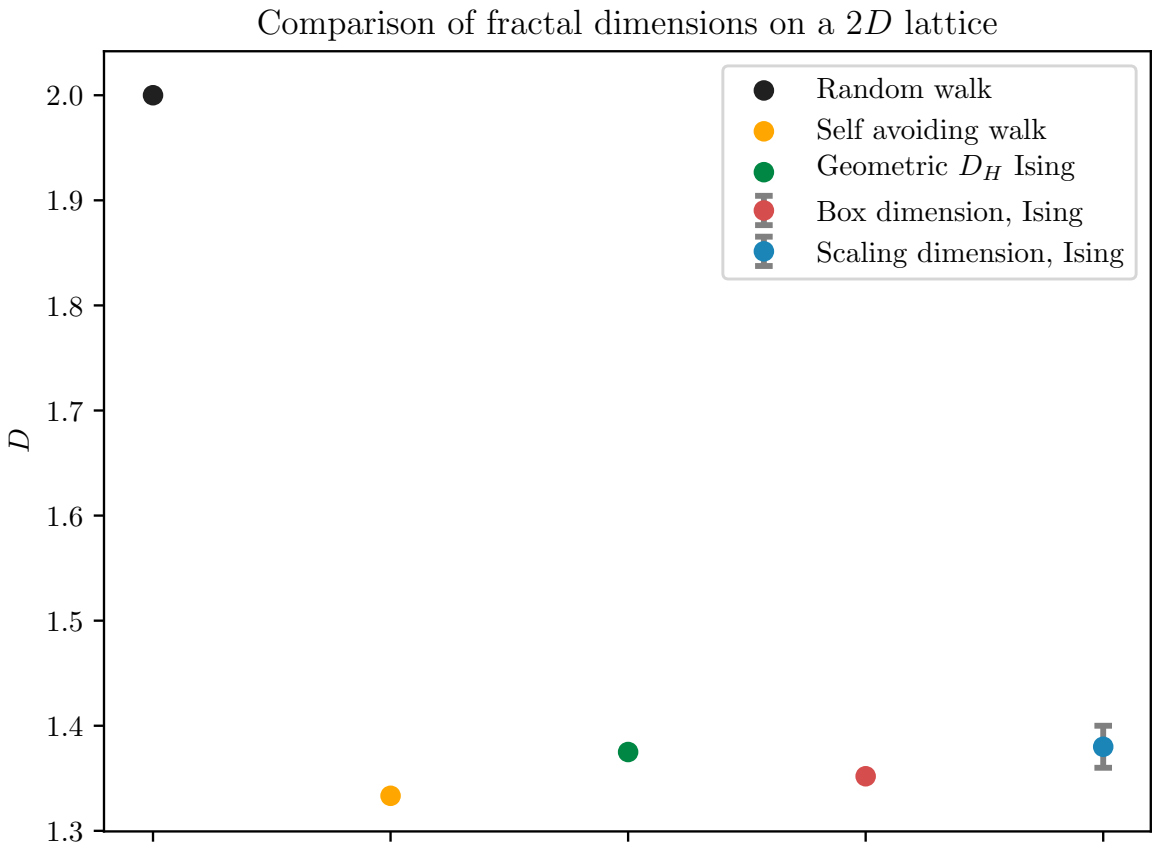
Box Dimension



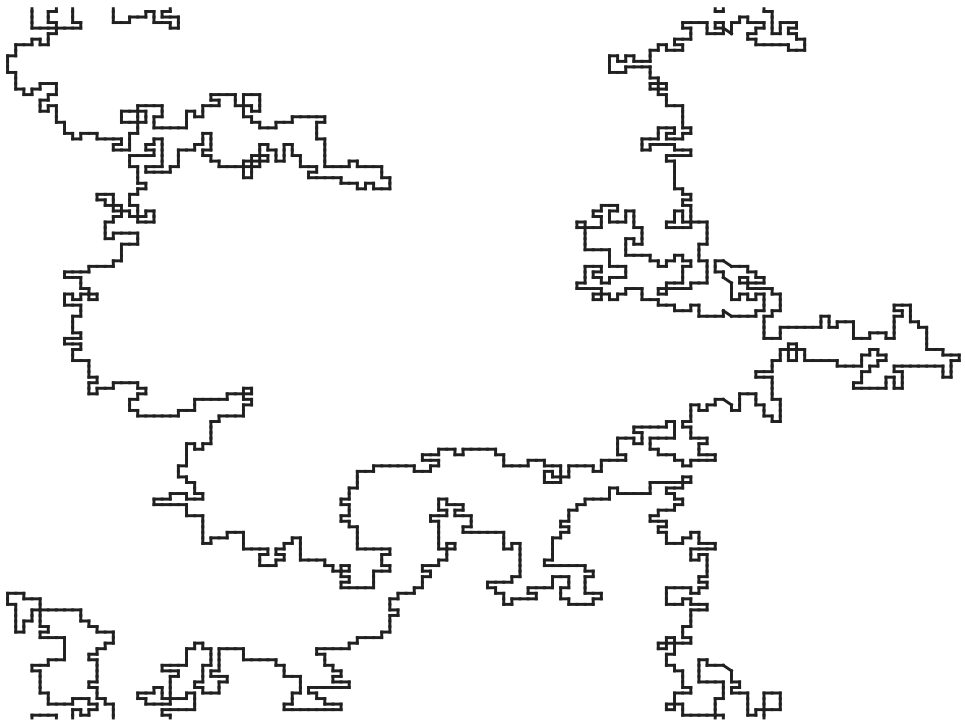
Scaling Dimension



Comparison of Dimensions $2D$ Ising



Largest Ising Loop on a 128^2 Lattice



$2D$ Ising Animation

XY Model

XY Loop Expansion

$$H = -J \sum_{\langle ij \rangle} \cos(\theta_i - \theta_j)$$

$$Z = \prod_i \int \frac{\mathrm{d}\theta_i}{2\pi} \prod_{\langle ij \rangle} e^{K \cos(\theta_i - \theta_j)}$$

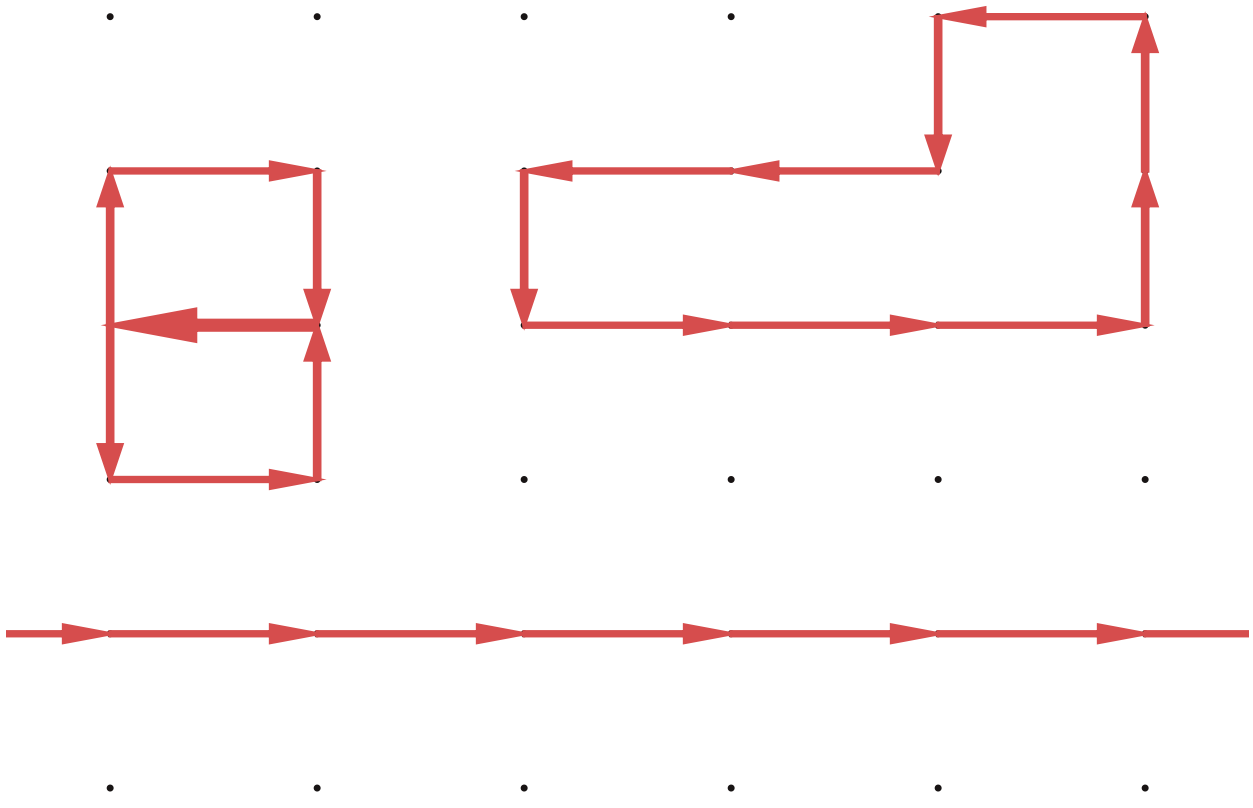
XY Loop Expansion

$$Z \sim \int \frac{\mathrm{d}\theta_i}{2\pi} e^{i \sum_{\langle ij \rangle} j_{\langle ij \rangle} (\theta_i - \theta_j)}$$

XY Loop Expansion

$$
\begin{aligned}
Z &\sim \int \frac{\mathrm{d}\theta_i}{2\pi} e^{i \sum_{\langle ij \rangle} j_{\langle ij \rangle} (\theta_i - \theta_j)} \\
&\sim \delta_{0, \sum_{\langle ij \rangle} j_{\langle ij \rangle}}
\end{aligned}
$$

XY Loop expansion



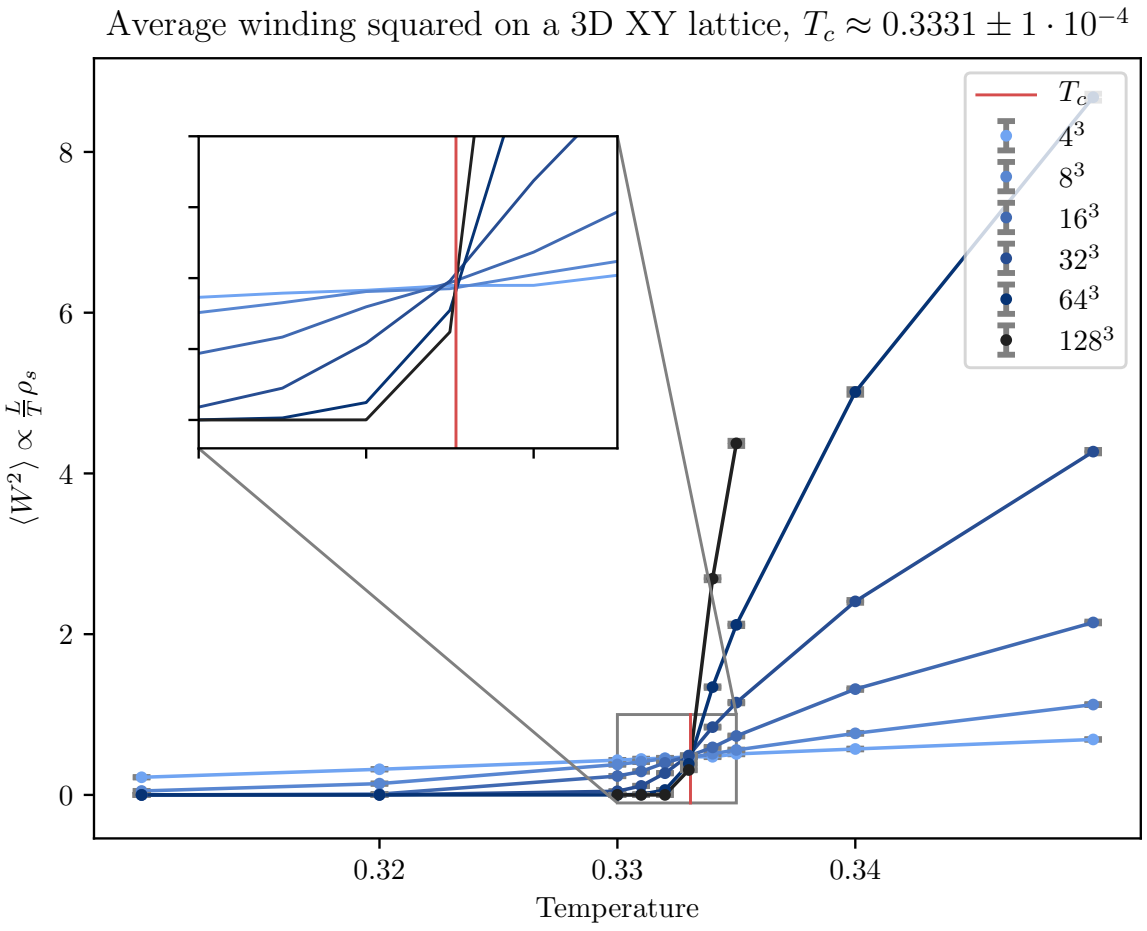
Villain Approximation

$$E = \frac{1}{2} \sum_i j_i^2$$

Winding Number

$$\rho_s = L^{2-d} T \langle W_\mu^2 \rangle$$

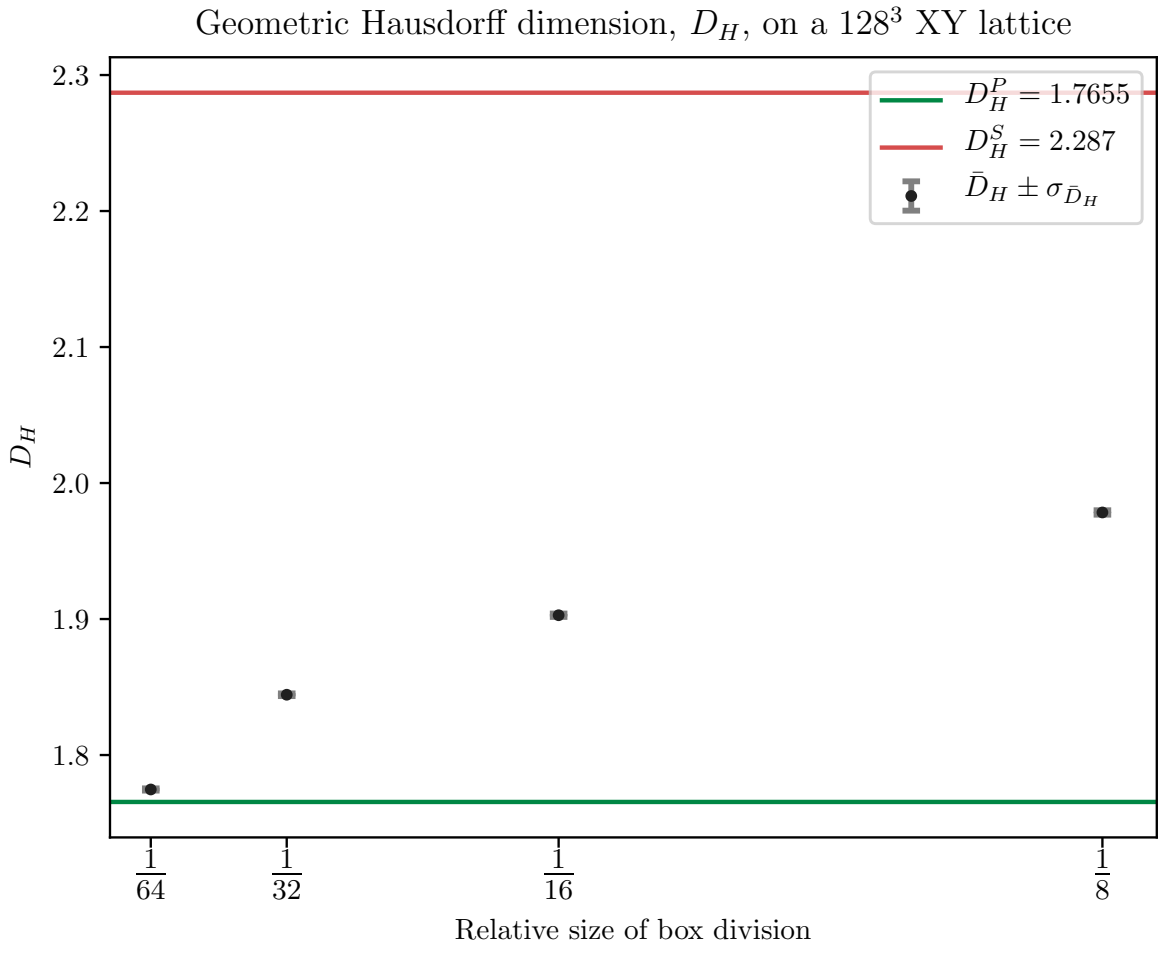
Winding Number



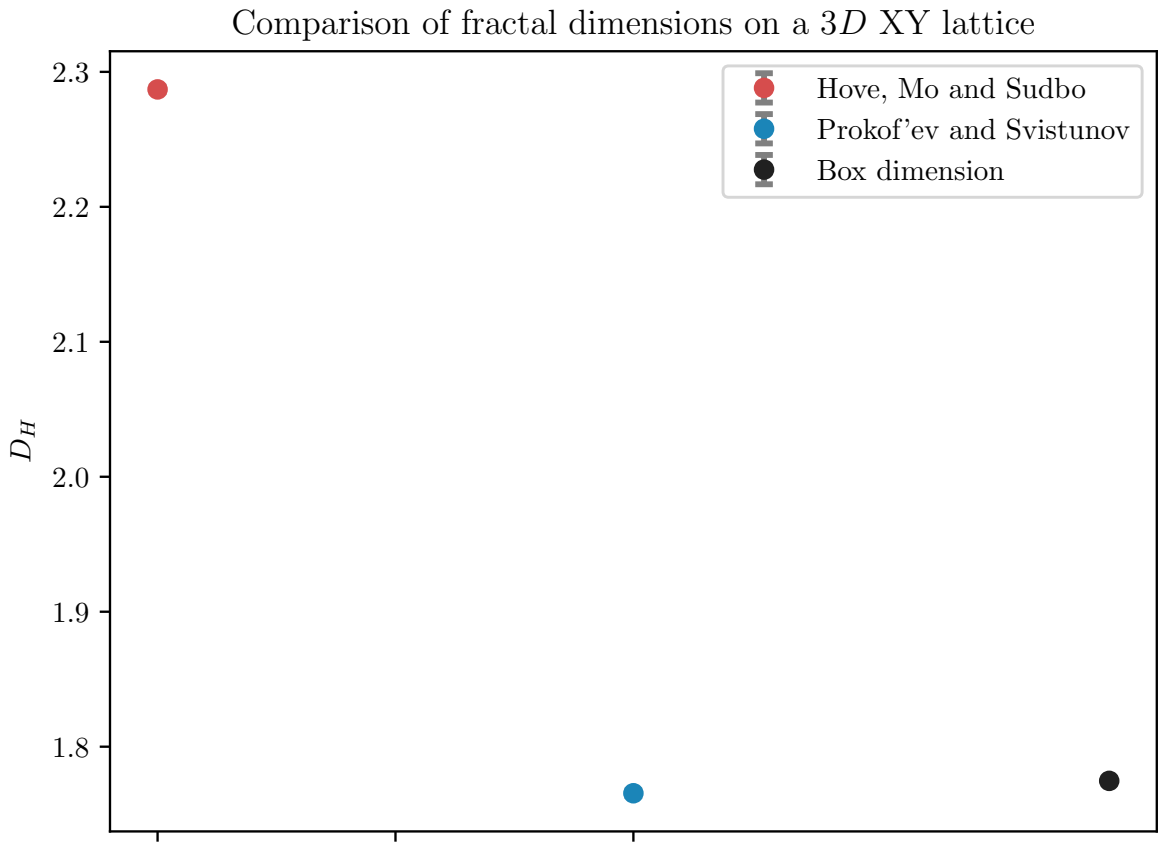
$3D$ **XY Model Hausdorff Dimension**

- Hove, Mo and Sudbo: $D_H = 2.287 \pm 4 \cdot 10^{-3}$
- Prokof'ev and Svistunov Comment: $D_H = 1.7655 \pm 2 \cdot 10^{-3}$

Box Counting Method $3D$ XY



Comparison of Dimensions $3D$ XY



$3D$ **XY Animation - 4^3 system**

$3D$ **XY Animation - Largest cluster**

Summary

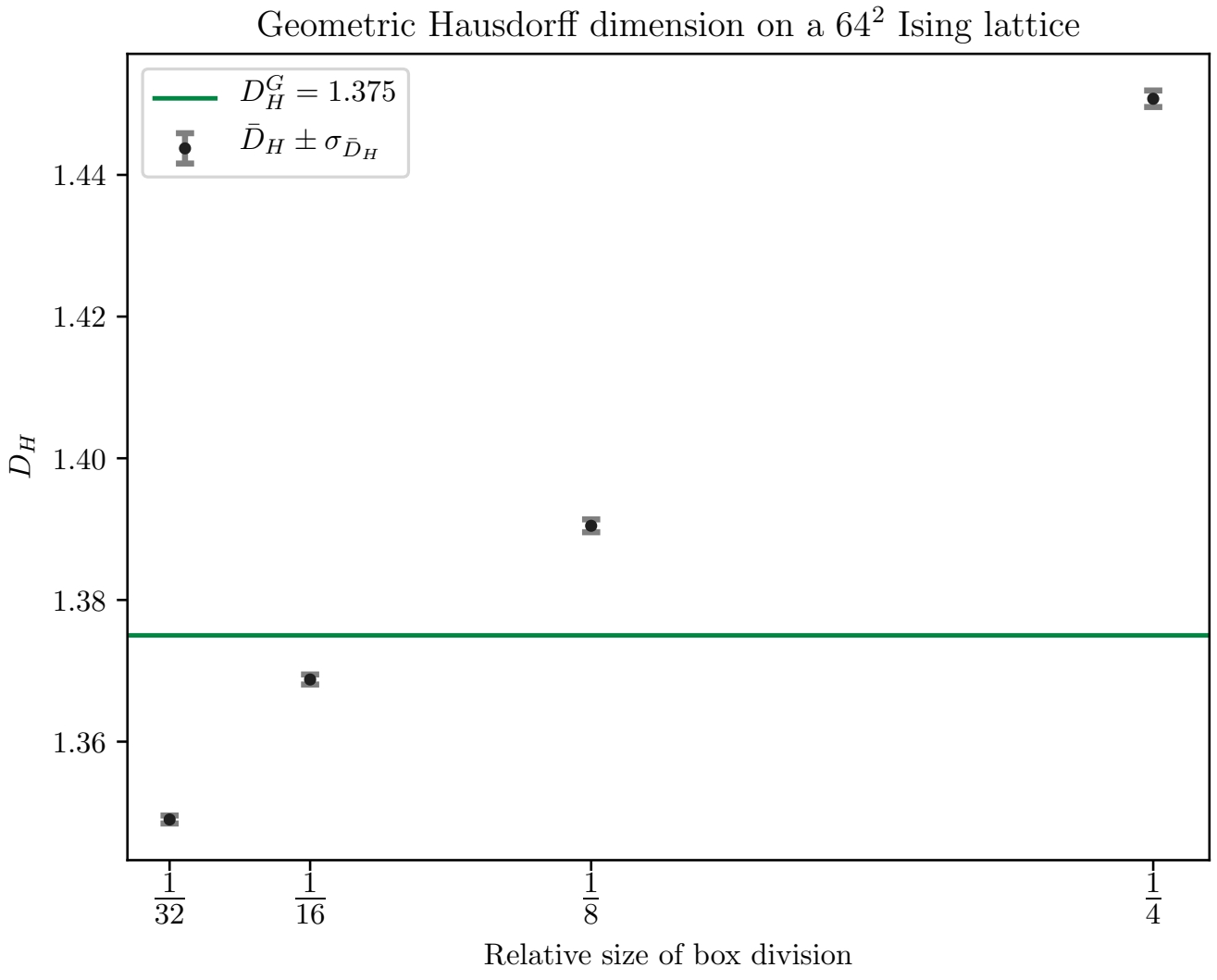
	D_H
Box	1.35193(5)
Scaling	1.38(2)
D_H^G	1.375
SAW	1.33
Random Walk	2

Table 1: $2D$ Ising

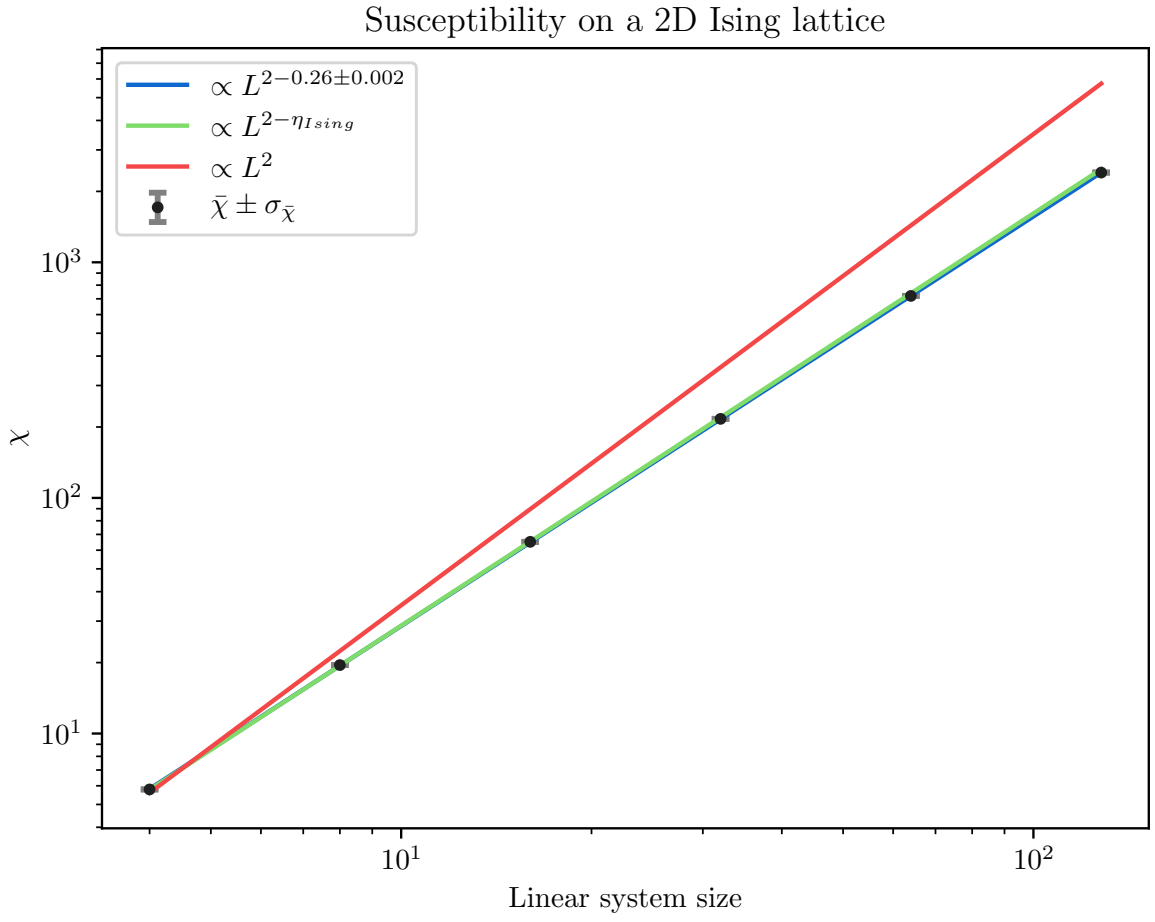
	D_H
Box	1.77468(4)
Prokof'ev	1.765(2)
Sudbo	2.287(2)

Table 2: $3D$ XY

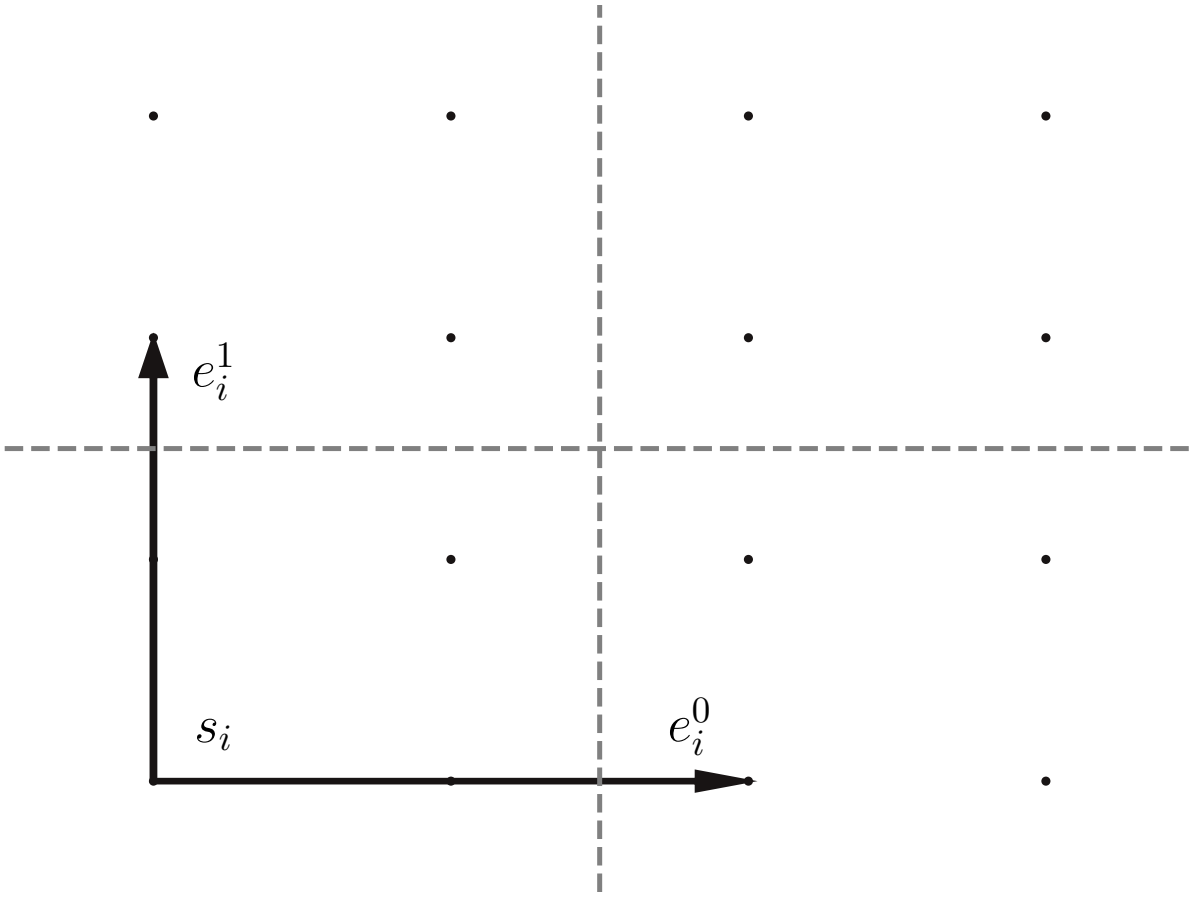
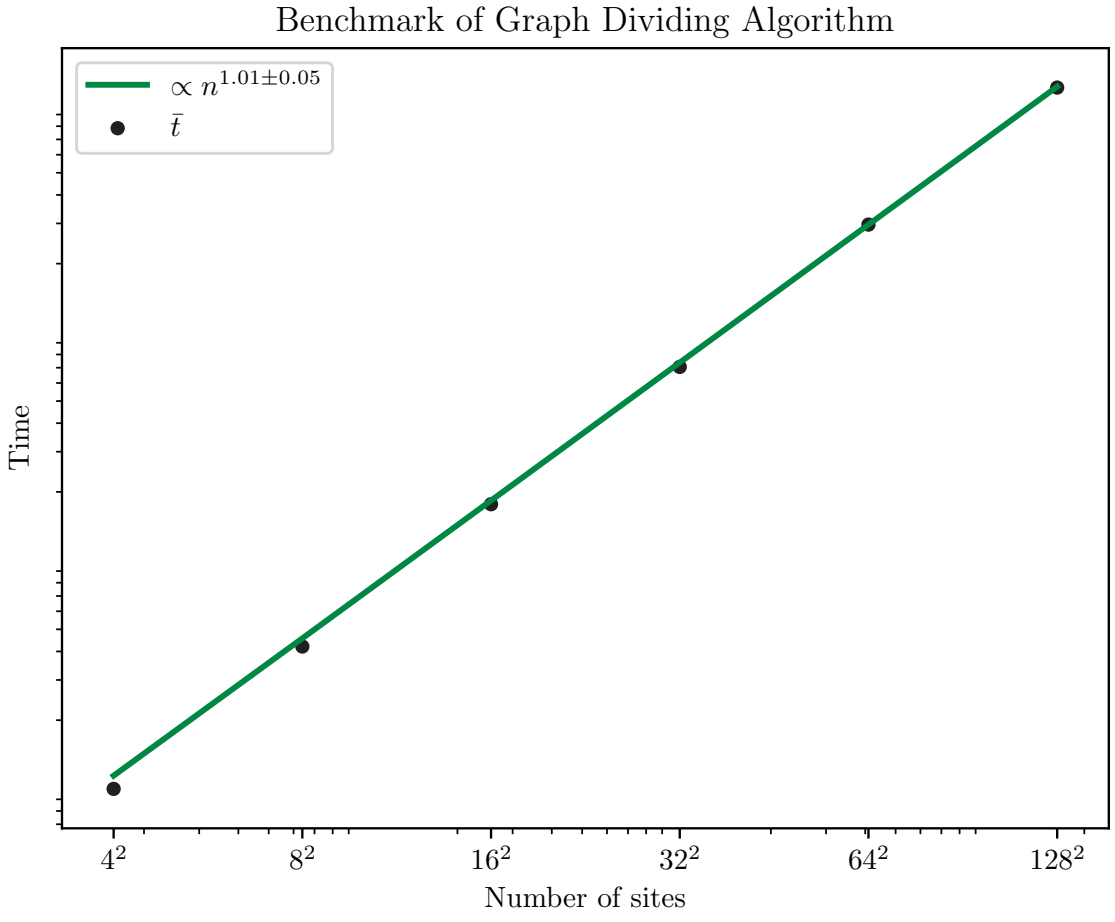
Extra slides: Box Dimension 64^2 Ising



Extra slides: Susceptibility $2D$ Ising



Extra slides: Graph Dividing Algorithm



Extra slides: Graph Dividing Algorithm