PEPO cluster expansion of tensor exponential

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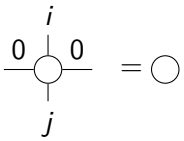
Intoduction

Statistical Quantum mechanics

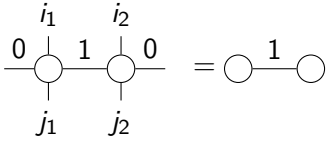
$$\hat{\rho} = \frac{e^{-\beta \hat{H}}}{Z} \tag{1}$$

$$\begin{aligned} Z &= \mathrm{Tr}\left(e^{-\beta \hat{H}}\right) \\ \langle X \rangle &= \mathrm{Tr}\left(\rho \hat{X}\right) \end{aligned} \tag{2}$$

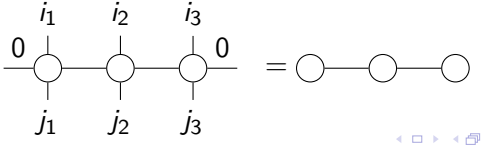
Graphical notation



$$= \quad (3)$$



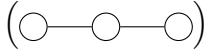
$$= \quad (4)$$



$$= \quad (5)$$

Graphical notation

$$\hat{H} = \left(\sum_{<ij>} H_2^i H_2^j + \sum_i H_1^i \right) \tag{6}$$

H 

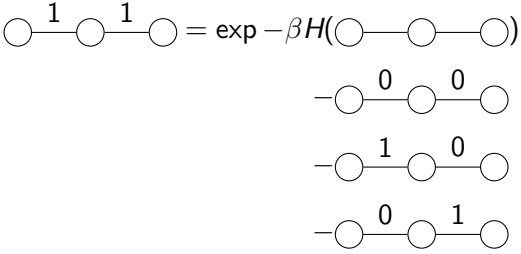
$$\begin{aligned} &= H_1 \otimes 1 \otimes 1 \\ &+ 1 \otimes H_1 \otimes 1 \\ &+ 1 \otimes 1 \otimes H_1 \\ &+ H_2 \otimes H_2 \otimes 1 \\ &+ 1 \otimes H_2 \otimes H_2 \end{aligned} \tag{7}$$

General idea

$$\bigcirc = \exp\left(-\beta H(\bigcirc)\right) \tag{8}$$

$$\bigcirc\!\!\overset{1}{-}\!\!\bigcirc = \exp -\beta H(\bigcirc\!\!-\!\!\bigcirc) - \bigcirc\!\!\overset{0}{-}\!\!\bigcirc \tag{9}$$

General idea



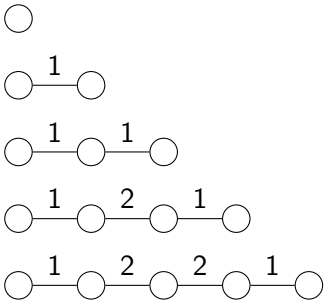
(10)

Advantages

- size extensive
- symmetry
- fast

Construction 1D

Variant A



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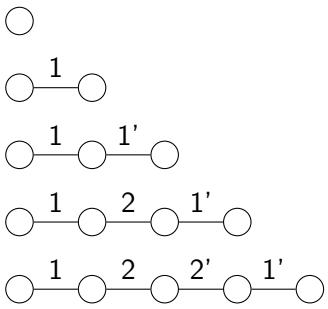
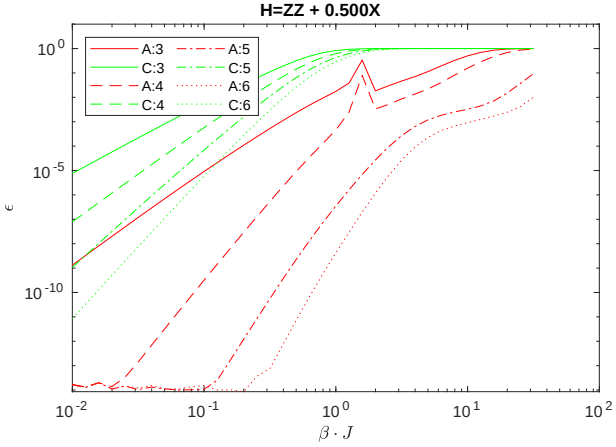
Variant C

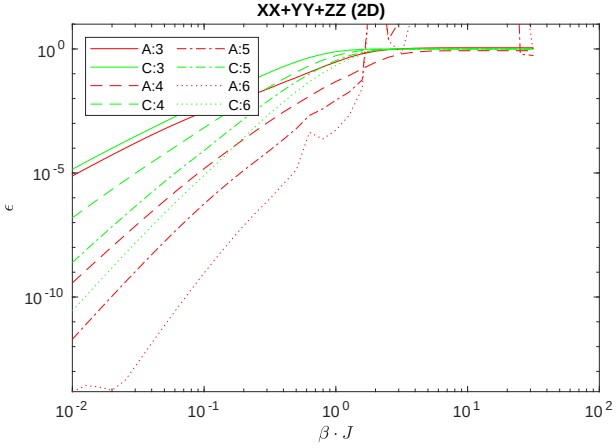


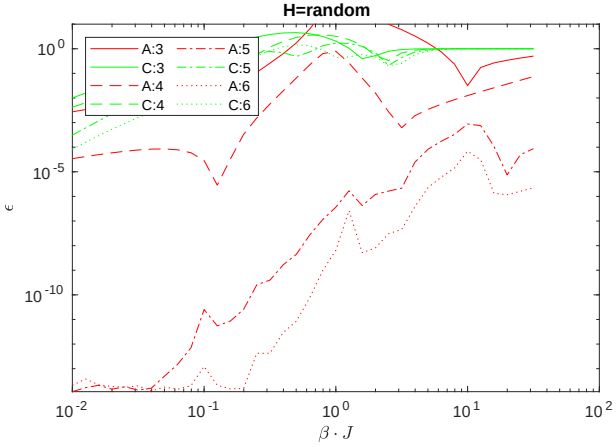
(12)

Error measure

$$\epsilon(\text{map}) = \frac{||\exp -\beta H(\text{map}) - \text{MPO}(\text{map})||}{||\exp -\beta H(\text{map})||} \tag{13}$$

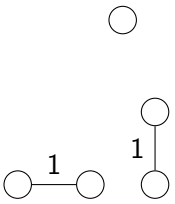






Construction 2D

Construction 2D: Linear blocks



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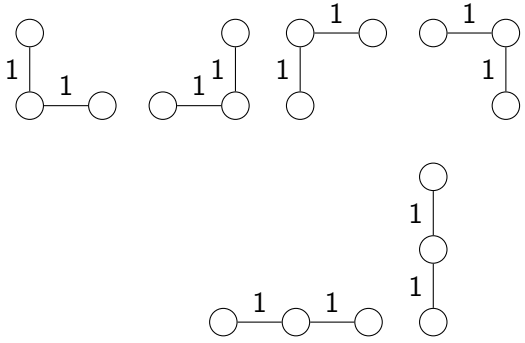
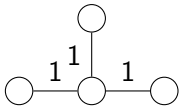
Construction 2D: Linear blocks

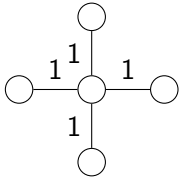


(16)

Construction 2D: Linear blocks

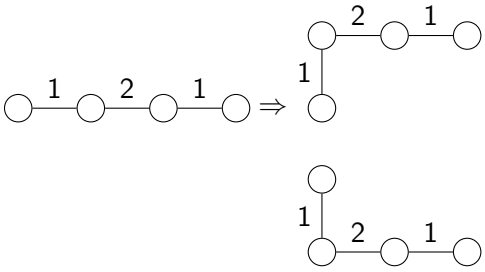


(17)



(18)

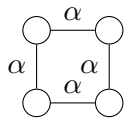
Construction 2D: Linear blocks



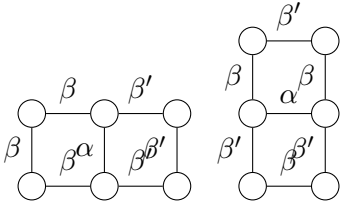
(19)

And many more "linear" blocks

Loops



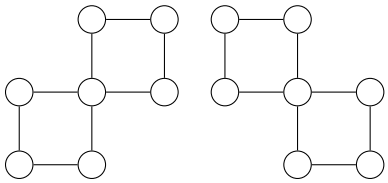
(20)



(21)

- bond dim
- solver: see later

Unsolved



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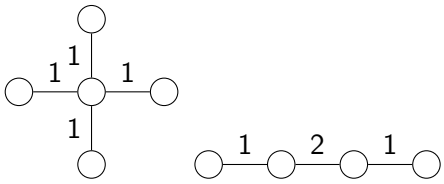
Easy to solve on finite lattice, difficult in thermodynamic limit...

Solvers

Linear solver

- pseudoinverse
- optimisation for tree graphs
- implemented for any shape



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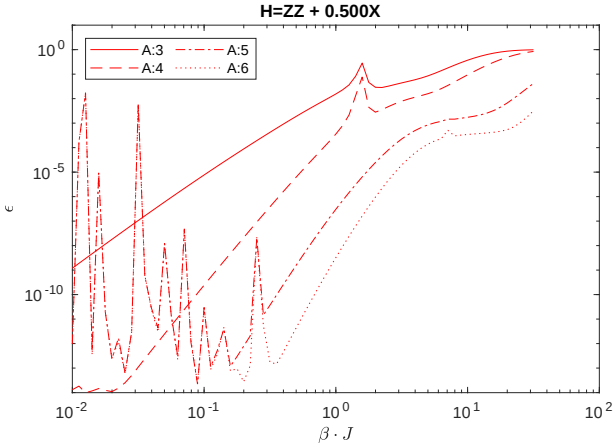
```
[map, ~] = create_map([0, 0, 5, 0;
                       0, 0, 6, 0;
                       1, 2, 3, 4;
                       0, 0, 7, 0], obj.numopts);
pattern = {[2, 2, 1, 1]};
[obj, ~, ~, ln_prefact, ~] = solve_lin_and_assign(obj, map, pattern, ln_prefact);
```



sequential linear

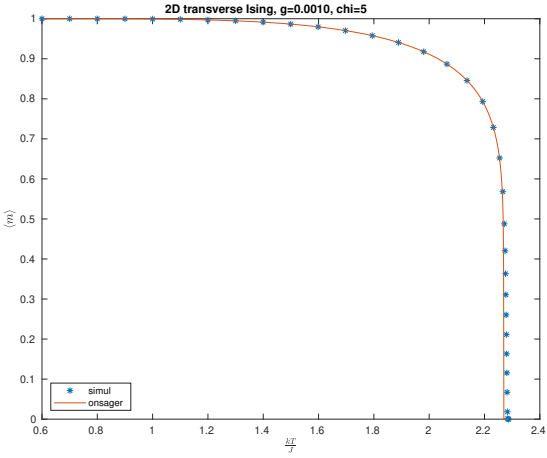
- initialize randomly
- use linear sovler for 1 tensor
- fast

true non-linear solver

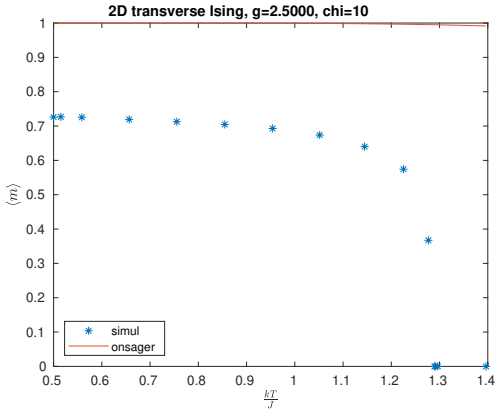
- Matlab fsolve
- exact jocobian
- multiple patterns
- multiple maps

2D Transversal Ising Model

First results



First results



Conclusion and outlook

Conclusion

- Working code for 1D and 2D
- General solvers
- Promising first results in 2D

Outlook: short term

- Accurate estimate transversal Ising quantum critical point
- Improve blocks for loops
- continuous improvements framework

Outlook: long term

- Incorporate symmetries of Hamiltonians
- Look at other (types of) Hamiltonians
- Generalize for other lattice geometries
- Generalize to 3D

References I