

TN: Tensor Networks, SS2019

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Lectures: Mo+We, Tutorials: Th

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Nr.	Date	Topic
	22.04.19	Easter Monday
L01	24.04.19	Tensor network basics 1. Why tensor networks? 2. Iterative Diagonalization. 3. Entanglement entropy and area laws. 4. Tensor network diagrams. 5. Singular-value decomposition. 6. Schmidt decomposition.
T01	Th 25.04.19	Tutorial: MATLAB basics 1. MATLAB basics. 2. Tensor contraction. 3. Singular-value decomposition.
L02	Mo 29.04.19	MPS I: Matrix Product States 1. Canonical MPS forms (left, right, site, bond). 2. Overlaps and normalization. 3. Matrix elements, expectation values.
	We 01.05.19	Labor Day
T02	02.05.19	Tutorial: MPS I 1. Canonical forms of MPS. 2. Expectation values.
L03	06.05.19	MPS II: Diagonalization 4. Iterative diagonalization of short spin chain. 5. Fermionic chain, fermion signs: Jordan-Wigner transformation.
L04	08.05.19	NRG I: Numerical Renormalization Group - Wilson chain 1. Single-impurity Anderson model. 2. Logarithmic discretization. 3. Wilson chain. 4. Iterative diagonalization.
T03	09.05.19	Tutorial: NRG I 1. Iterative diagonalization. 2. Energy flow diagram. 3. Logarithmic discretization.
L05	13.05.19	NRG II: RG flow 5. RG flow of Kondo model, SIAM. 6. Thermodynamic observables.
L06	15.05.19	NRG III: Spectral functions 7. Complete basis. 8. Spectral functions (fdmNRG).
T04	16.05.19	Tutorial: NRG II (1. Energy level flow. 2. Thermodynamic properties, Wilson ratio.) 3. Expectation values. 4. Spectral function.
L07	20.05.19	MPS III: Transfer operators 6. Transfer operators, normalization. 7. Correlation functions.
L08	22.05.19	AKLT model Model, spin projectors, ground state.
T05	23.05.19	Tutorial: AKLT Model 1. Left-normalization. 2. Transfer operator. 3. Spin transfer operators. 4. Spin correlators, string order parameter.
L09	27.05.19	MPS IV: Matrix product operators 7. Definition of MPO; applying MPO to MPS; need for truncation.
L10	29.05.19	DMRG I: Density Matrix Renormalization Group - ground state search 1. Single-site optimization. 2. Lancos method. 3. Excited states. 4. Two-site optimization.
	Thu 30.05.19	Ascension Day
T06	Mo! 03.06.19	Tutorial: DMRG 1. Ground state search. 2. 1st excited state search. 3. Correlation function.
L11	05.06.19	MPS V: Vidal's Gamma-Lambda notation iTEBD: Infinite Time-Evolving Block Decimation 1. Basic iTBD algorithm. 2. Hasting's method (no division by singular values). 3. Mixed-canonical form.
T07	Th! 06.06.19	Tutorial: iTEBD

1. iTEBD for ground state search.
- L12 10.06.19 **Pentecost Monday**
 12.06.19 **DMRG II: Relation to traditional DMRG. tDMRT**
 5. Infinite-size DMRG. 6. Finite-size DMRG. 7. iDMRG in Gamma-Lambda notation. 8. Time-dependent DMRG.
- L13 **Th!** 13.06.19 **DMRG III: purification. Time-dependent variational principle**
 9. Time evolution: purification. 10. Time-dependent variational principle (TVP)
- T08 **Mo!** 17.06.19 **Tutorial: tDMRG, purification, TVP**
 1. tDMRG for real time evolution. 2. Purification. 3. TVP
- L14 19.06.19 **Symmetries I: Abelian**
 1. Example: spin 1/2 XXZ-chain. 2. Iterative diagonalization. 3. Qspace bookkeeping for unit matrices.
- Thu 20.06.19 **Corpus Christi**
- L15 24.06.19 **Symmetries II: Non-Abelian. Qspace**
 4. SU(2) basics. 5. Example: Heisenberg chain. 6. Qspace bookeping for unit matrices.
- T09 **We!** 26.06.19 **Tutorial: Symmetries & Qspace**
- T10 27.06.19 **Tutorial: Symmetries & Qspace (continued)**
- L16 01.07.19 **PEPS I: Projected entangled-pair states**
 1. Definition: PEPS. 2. Example: RVB state.
- L17 03.07.19 **PEPS I (continued): Examples**
 3. Kitaev's toric code (continued). 4. General remarks about PEPS.
- T11 04.07.19 **Tutorial: PEPS I - exact contraction on a strip**
- L18 08.07.19 **PEPS II: Tensor-entanglement renormalization group (TERG)**
Tensor renormalization group (TRG)
 5. TERG. 6. TRG for classical spin systems. 7. TRG for quantum ground states.
 8. Second TRG (SRG).
- L19 10.07.19 **PEPS III: contractions via MPS techniques**
 6. PEPS via MPO-MPS. 7. iPEPS via iMPO-MPS (iTEBD)
- T12 11.07.19 **Tutorial: TERG, TRG**
- L20 15.07.19 **Fourier transform and spectral tensor networks**
- L21 17.07.19 **MERA: Multiscale Entanglement Renormalization Ansatz**
 1. Entanglement renormalization. 2. Technical details. 3. Tensor network renormalization (TNR). 4. MERA and wavelets.
- T13 18.07.19 **Tutorial: PEPS II - simple update method**
 1. Ground state search for 2D Heisenberg model
 (2. Corner transfer method. 3. Environmental gauge fixing. 4. Fermionic PEPS.)
- L22 22.07.19 **Entanglement Renormalization and Wavelets**
- L23 24.07.19 **Machine learning**
 1. Neural networks. 2. Supervised learning with tensor networks.
- T14 25.07.19 **Tutorial: MERA, Machine learning**
 1. MERA and wavelets. 2. Machine learning: handwriting recognition