TN: Tensor Networks, SS2021

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Lectures: We+Th, Tutorials: Tu (except in first week: Lectures: Tu+We, Tutorial: Th)

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Nr.	Date	Topic [topics typeset in green are new relative to 2020 course]
L01	13.04.21	**Tensor network basics I** 1. Notation for generic quantum lattice systems. 2. Entanglement and area laws. 3. Tensor network diagrams. 4. Covariant notation.
L02	14.04.21	**Tensor network basics II** 1. Singular value decomposition. 2. Schmidt decomposition. 3. Iterative diagonalization (conceptual). 4. Rewriting any tensor as MPS.
T01	15.04.21	**MATLAB 101**
T02	20.04.21	**Tensor Network Basics** 1. Tensor contraction. 2. Singular-value decomposition. 3. Tensor decomposition, entanglement entropy
L03	21.04.21	**MPS I: Basic Properties of matrix product states** 1. Overlaps, matrix elements. 2. Left- and right-normalized states. 3. Matrix elements of local operators. 4. Canonical MPS forms (left, right, site, bond).
L04	22.04.21	**MPS II: Canonical forms, fermionic signs** 1. Basis change. 2. Iterative diagonalization of short spin chain. 3. Spinless fermions. 4. Spinful fermions.
T03	27.04.21	**Tutorial: MPS, Iterative diagonalization** 1. Canonical forms of MPS. 2. Expectation values. 3. Iterative diagonalization of fermionic chain.
L05	28.04.21	**MPS III: Translationally invariant MPS, AKLT model** 1. Transfer matrix and correlation functions. 2. AKLT model. 3. AKLT ground state. 4. Transfer operator and string order parameter.
L06	29.04.21	**MPS IV: Matrix product operators** 1. Applying MPO to MPS yields MPS. 2. MPO for Heisenberg Hamiltonian. 3. Applying MPO to mixed-canonical MPS. 4. MPS representation of Fermi sea.
T04	04.05.21	**Tutorial: AKLT Model** (pen & paper), **MPO methodology** 1. Left-normalization. Transfer operator. Spin transfer operators. Spin correlators, string order parameter. 2. Appying MPO to MPS. 3. Parton treatment of Haldane-Shastry model.
L07	05.05.21	**Symmetries I: Abelian** 1. Example: spin 1/2 XXZ-chain. 2. Iterative diagonalization. 3. QSpace bookkeeping for unit
L08	06.05.21	**Symmetries II: Non-Abelian.** 1. Motivation, SU(2) basics. 2. Tensor product decomposition. 3. Tensor operators. 4. A-matrix factorizes. 5. Example: two spin 1/2s. 6. Example: 3 spin-1/2s. 7. Bookkeeping for unit matrices.
T05	11.05.21	**Tutorial: Symmetries & Qspace I** 1. Introduction to QSpace.
L10	12.05.21	**DMRG I: Density Matrix Renormalization Group -- ground state search** 1. Single-site optimization. 2. Lanczos method. 3. Excited states. 4. Two-site update
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T06	18.05.21	**Tutorial: Symmetries & Qspace II** 1. Iterative diagonalization (optional). 2 Canonical form (optional).
T07	19.05.21	**Tutorial: DMRG** 1. Ground state search. Spin-spin correlator. 1st excited state search. Majumdar-Gosh model. 2. Two-site update.
L11	20.05.21	**iTEBD: Infinite Time-Evolving Block Decimation** 1. Vidal's Gamma-Lambda notation. 2. Basic iTEBD algorithm. 3. iTEBD in Gamma-Lambda notation. 4. iTEBD: Hasting's method. 5. Orthogonalization.
T08	25.05.21	**Tutorial: iTEBD. Qspace DMRG (optional)** 1. iTEBD for ground state search. Hastings' method. Correlation length of spin-1 Heisenberg chain. Orthogonalization. 2. QSpace: ground state DMRG (optional).

L12	26.05.21	**DMRG II: original, subspace expansion, error estimates** 1. Relation to original DMRG. 2. One-site update with subspace expansion. 3. Error estimates.
L13	27.05.21	**DMRG III: tDMRG, finite temperature (purification, XTRG)** 1. tDMRG. 2. Error analysis. 3. Purification. 4. Exponential tensor renormalization group (XTRG).
T09	01.06.21	**Tutorial: tDMRG, subspace expansion, error estimates** 1. tDMRG. XY chain - domain wall. Entanglement growth. Error analysis. Local excitation. 2. Subspace expansion.
L14	02.06.21	**Tangent space methods (TDVP)** 1. MPS and canonical forms. 2. Tangent space. 3. Tangent space projector. 4. Time evolution.
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T10	08.06.21	**Tutorial: Finite temperature. TDVP. Qspace tDMRG (optional)** 1a. Purification. 1b. XTRG (optional). 2. Error estimates. 3. TDVP. 4. QSpace tDMRG (optional).
L15	09.06.21	**NRG I: Numerical Renormalization Group - Wilson chain** 1. Single-impurity Anderson model. 2. Logarithmic discretization. 3. Wilson chain. 4. Iterative diagonalization.
L16	10.06.21	**NRG II: RG flow, fixed points** 1. General RG concepts. 2. NRG iteration scheme from RG perspective. 3. Uncoupled bath Hamiltonian: fixed points. 4. Kondo model: fixed points and RG flow. 5. Anderson model: fixed
T11	15.06.21	**Tutorial: NRG I** 1. Iterative diagonalization. 2. Energy flow diagram.
L17	16.06.21	**NRG III: Thermodynamics, Lehmann** 1. Thermodynamics. 2. Wilson ratio. 3. Lehmann representation of spectral function. 4. Single-shell and patching schemes
L18	17.06.21	**NRG IV: Spectral function, fdm-NRG** 1. MPS notation for discarded/kept states. 2. Complete many-body basis. 3. Full- density-matrix NRG (fdmNRG). 4. Spectral functions of SIAM
T12	22.06.21	**Tutorial: NRG II** 1. Thermodynamic properties. 2. Spectral function.
L19	23.06.21	**PEPS I: Projected entangled-pair states** 1. Motivation and definition. 2. Example: RVB state. 3. Example: Kitaev's Toric Code. 4. Example: Resonating AKLT state
L20	24.05.21	**PEPS II: contractions techniques** 1. Infinite-size PEPS (iTEBD). 2. Corner transfer matrix (CTM).
T13	29.06.21	**Tutorial: Finite PEPS** 1. RVB state. 2. Kitaev's Toric code. 3. Resonating AKLT loop state.
L21	30.06.21	**Tensor renormalization group (TRG)** 1. TRG for 2D classical lattice models. 2. TRG for quantum lattice models. 3. Second ternormalization (SRG) of tensor network states.
L22	01.07.21	**TRG-II: Graph-independent local truncations (Gilt)** 1. Motivation. 2. Why is TRG insufficient. 3. Environment spectrum.
T14	06.07.21	**Tutorial: TRG, simple update** 1. TRG to compute correlation functions. 2. Simple update to find ground states
L23	07.07.21	**TNR: Tensor network renormalization** 1. Motivation. 2. TNR idea. 3. Projective truncation. 4. TNR details. 5. TNR results in MERA. 6.TNR benchmark results.
L24	08.07.21	**2D Canonical Forms, Isometric PEPS** 1. Canonical form for bond in 2D tensor network. 2 Full environment truncation. 3. Isometric PEPS: Moses move. 3. Isometric PEPS: Applications
T15	13.07.21	**Tutorial: GILT, FET** 1. Graph-independent local trunction (GILT). 2. Full environment truncation (FET)
L25	14.07.21	**Fermionic PEPS** 1. Parity conservation. 2. Fermionic signs. 3. Jump move. 4. Examples.
L26	15.07.21	**Machine learning** 1. Neural networks. 2. Supervised learning with tensor networks.
T16	20.07.21	**Tutorial: MPS-based machine learning (optional)** 1. Handwritten digit (MNIST) recognition