TN: Tensor Networks, SS2020

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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
L01	21.04.20	**Tensor network basics I** 1. Why tensor networks? 2. Iterative Diagonalization (conceptual). 3. Covariant index notation.
L02	22.04.20	Tensor network basics II 1. Entanglement entropy and area laws. 2. Tensor network diagrams. 3. Singular-value decomposition.
T01	23.04.20	**MATLAB basics**
T02	28.04.20	**Tensor Network Basics** 1. Tensor contraction. 2. Singular-value decomposition.
L03	29.04.20	**MPS I: Matrix Product States** 1. Overlaps and normalization. 2. Canonical MPS forms (left, right, site, bond).
L04	30.04.20	**MPS II: Expectation values** 1. Matrix elements, expectation values. 2. Schmidt decomposition.
T03	05.05.20	**Tutorial: MPS I** 1. Canonical forms of MPS. 2. Expectation values.
L05	06.05.20	**MPS III: Diagonalization, fermionic signs** 1. Basis change. 2. Iterative diagonalization of short spin chain. 3. Spinless fermions. 4. Spinful fermions.
L06	07.05.20	**MPS IV: Translationally invariant MPS, AKLT model** 1. Transfer matrix. 2. Eigenvalues of transfer matrix. 3. Correlation functions. 4. AKLT model - general remarks.
T04	12.05.20	**Tutorial: MPS II** 1. Iterative diagonalization of fermionic chain. **Tutorial: AKLT Model** (pen & paper) 1. Left-normalization. 2. Transfer operator. 3. Spin transfer operators. 4. Spin correlators, string order parameter.
L07	13.05.20	**Symmetries I: Abelian** 1. Example: spin 1/2 XXZ-chain. 2. Iterative diagonalization. 3. Qspace bookkeeping for unit matrices.
L08	14.05.20	**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	19.05.20	**Tutorial: Symmetries & Qspace I** 1. Introdution to Qspace library. 2. Complete set of local operators.
L09	20.05.20	**Symmetries III: Further details** 1. Building local state space.
---	21.05.20	**Ascension Day [Symmetries IV*]**
T06	26.05.20	**Tutorial: Symmetries & Qspace II**
L10	27.05.20	**MPS V: Matrix product operators** 1. Applying MPO to MPS yields MPS. 2 MPO for Heisenberg Hamiltonian. 3. Applying MPO to mixed-canonical MPS.
L11	28.05.20	**DMRG I: Density Matrix Renormalization Group - ground state search** 1. Single-site optimization. 2. Lancos method. 3. Excited states. 4.Two-site update.
T07	02.06.20	**Tutorial: DMRG** 1. Ground state search. 2. 1st excited state search. 3. Correlation function.
L12	03.06.20	**MPS VI: Vidal's Gamma-Lambda notation** **iTEBD: Infinite Time-Evolving Block Decimation** 1. Basic iTEBD algorithm. 2. iTEBD in Gamma-Lambda notation. 3. iTEBD: Hasting's method. 4. Orthogonalization.
L13	04.06.20	**DMRG II: Traditional DMRG, tDMRT, purification**
	04.06.20	1. Relation to traditional DMRG. 2. tDMRG. 3. Finite temperature: purification

T08	09.06.20	**Tutorial: iTEBD** 1. iTEBD for ground state search. 2. Hastings' method. 3. Correlation function. 4. Orthogonalization.
L14	10.06.20	**Tangent space methods (TDVP)** 1. MPS and canonical forms. 2. Tangent space. 3. Tangent space projector. 4. Time evolution.
---	11.06.20	**Corpus Christi**
T09	16.06.20	**Tutorial: tDMRG. Tangent space methods** 1. tDMRG. 2. Entanglement growth, Trotter error. 3. TDVP
L15	17.06.20	**NRG I: Numerical Renormalization Group - Wilson chain** 1. Single-impurity Anderson model. 2. Logarithmic discretization. 3. Wilson chain. 4. Iterative
L16	18.06.20	**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 points and RG flow.
T10	23.06.20	**Tutorial: NRG I** 1. Iterative diagonalization. 2. Energy flow diagram.
L17	24.06.20	**NRG III: Thermodynamics, Lehmann** 1. Thermodynamics. 2. Wilson ratio. 3. Lehmann representation of spectral function. 4. Single-shell and patching schemes
L18	25.06.20	**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
T11	30.06.20	**Tutorial: NRG II** 1. Thermodynamic properties. 2. Spectral function.
L19	01.07.20	**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	02.07.20	**PEPS II: contractions techniques** 1. PEPS via finite-size MPS. 2. Infinite-size PEPS (iTEBD). 3. Corner transfer matrix (CTM).
T12	07.07.20	**Tutorial: Finite PEPS** 1. Contraction of finite PEPS on a strip. 2. RVB state. 3. Kitaev's Toric code. 4. Resonating AKLT loop state
L21	08.07.20	**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	09.07.20	**TRG-II: Graph-independent local truncations (Gilt)** 1. Motivation. 2. Why is TRG insufficient. 3. Environment spectrum.
T13	14.07.20	**Tutorial: TRG, simple update** 1. TRG to compute correlation functions. 2. Simple update to find ground states
L23	15.07.20	**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	16.07.20	**2D Canonical Forms, Isometric PEPS** move. 3. Isometric PEPS: Applications
T14	21.07.20	**Tutorial: GILT, FET** 1. Graph-independent local trunction (GILT). 2. Full environment truncation (FET)
L25	22.07.20	**Fermionic PEPS** 1. Parity conservation. 2. Fermionic signs. 3. Jump move. 4. Examples.
L26	23.07.20	**Machine learning** 1. Neural networks. 2. Supervised learning with tensor networks.
T15	28.07.20	**Tutorial: MPS-based machine learning (optional)** 1. Handwritten digit (MNIST) recognition