# Delta ITP - Advanced Topics in Theoretical Physics I
# Module 2: Tensor Networks

Philippe Corboz (UvA), p.r.corboz@uva.nl, April/May 2017

## General

- Lectures (11:15-13:00) and exercises (13:45-end) Mar 27, Apr 3, 10, 24
- Exam: May 1
- Room: HL214

## Description

Tensor networks are among the most powerful tools to study quantum many-body systems. One can even see them as a new language to think and talk about many-body physics. They have been developed by combining ideas from quantum information theory and condensed matter physics, where the notion of entanglement plays a central role. The main idea is to efficiently represent many-body states (or operators) by a trace over a product of tensors, with an accuracy that can be systematically controlled by the size of the tensors. A well-known example are matrix product states (MPS) - an efficient ansatz for ground states in one dimension - which has become the state-of-the-art approach to study low-dimensional systems. Progress in understanding the structure of entanglement in many-body systems has led to the generalization of this idea to higher dimensions (PEPS) and critical systems (MERA), offering a very promising route to solve challenging open problems for which previous approaches failed. This module provides a practical introduction to this fast-developing field, with topics covering the diagrammatic notation, the area law of the entanglement entropy, discussion of different tensor network ansaetze and algorithms, and more.

## Exercise sessions

Some of the exercises will involve programming. We will use Matlab as programming language since there exist useful tools for tensor network calculations. Thus, **please bring your laptop with Matlab installed**. You should be able to get a Matlab license from your university.

Don't worry if you are new to Matlab. It's easy to learn and shares many similarities, e.g. with Python (Numpy/Scipy) or Fortran. We will go through some useful language features at the beginning of the exercise session. If you would like to check out Matlab beforehand, you can find many basic introductions online, e.g.:

- A short Matlab Primer: `http://faculty.olin.edu/bstorey/Notes/matlab.pdf`
- An even more compact overview: `http://www4.ncsu.edu/~pfackler/MPRIMER.htm`
- The official Matlab Primer: `https://www.mathworks.com/help/pdf_doc/matlab/getstart.pdf`

## Course material

All material for this lecture (including this document) will be in the following Dropbox folder: `http://tinyurl.com/jzz92zr` which will be updated on a regular basis.

## Useful references on tensor networks


- U. Schollwöck, *The density-matrix renormalization group in the age of matrix product states*, Annals of Physics 326, 96192 (2011).
  Open-access version: `http://arxiv.org/abs/1008.3477`

- F. Verstraete, V. Murg, and J. I. Cirac, *Matrix product states, projected entangled pair states, and variational renormalization group methods for quantum spin systems*, Advances in Physics 57, 143 (2008).
  `https://arxiv.org/abs/0907.2796`

- G. Vidal, *Entanglement Renormalization: an introduction*, see `https://arxiv.org/abs/0912.1651v2`

- R. Orus, *A Practical Introduction to Tensor Networks: Matrix Product States and Projected Entangled Pair States*, Annals of Physics 349, 117158 (2014).
  `https://arxiv.org/abs/1306.2164v3`