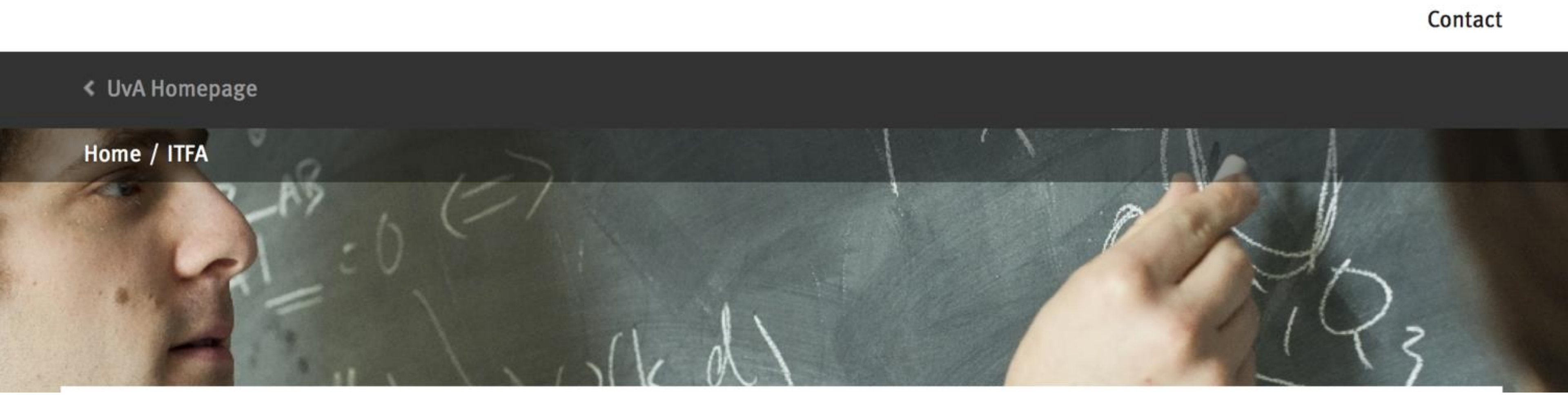
Bachelor Projecten ITFA 2018



De natuur is van iedereen,
pluk je geluk uit je stuk!

Presentatie/coordinatie: Theo Nieuwenhuizen

- **Random tensor networks and geometry**

- Networks of random tensors have "holographic" features -- i.e., the geometry of the network is reflected in the properties of the quantum state described by the network. In this project, you will study these features numerically for different geometries using the stabilizer formalism and discover the onset of the famous Ryu-Takayanagi entropy law. We will also try to address some open questions, time permitting.

- **2. Decoupling quantum information**

- The “no cloning” theorem states that, in general, it is impossible to copy the state of, say, a quantum bit (in contrast to ordinary bits, such as the ones in your computer). It follows that if we want to send a quantum bit from a sender to a receiver, we’d better not leak too much information to the environment! In this project, you will learn how to turn this logic around and send quantum information by making sure that the environment does not learn anything about the message.

Michael
Walter

- Chaos, attractors and the dynamics of random neural networks

Greg Stephens

Models of neural networks with random, Gaussian-distributed connections exhibit a sharp transition to chaotic dynamics as a function of the variance and may explain irregular patterns commonly observed in brain activity.
However, real networks are structured in their connectivity.

In this student project we will explore the dynamics of model neural networks with connections reflective of real neural systems.

Tensor network simulations in statistical physics

Philippe Corboz

- **Corner Transfer Matrix method applied to classical spin systems**
- The partition function of a two-dimensional classical spin system with nearest-neighbor interactions can be represented as a network of rank-4 tensors. The corner-transfer matrix method is an efficient approach to contract this network (i.e. to compute the partition function). This method will be used to investigate the thermodynamic properties and phase transitions in classical spin systems. (Requirements: Knowledge in statistical physics and good programming skills).

Simple hyperspherical models

Edan Lerner

The spectral properties of disordered system are a subject of much focus in condensed matter. One route to explain spectral properties [1] is via investigation of the statistics of random functions.

Consider a random function given by an expansion

$$f(x) = \sum_{q=1}^{n} c_q x^q \,, \tag{4}$$

where the coefficients c_q are random numbers given by some joint probability distrubution $P(c_1, c_2, \ldots, c_n)$, and $n \geq 4$.

(a) Assume first that the random numbers c_q are **independent**. Imagine that our random function represents a potential energy, and investigate the distribution (over minima and realizations) of vibrational frequencies about the minima of such randomly-generated functions.

(b) for each function you generate, find the **global** minimum, and consider the distribution of vibrational frequencies only around the global minima.

(c) how do your findings depend on the order n?

(d) what if the c_q's are no longer independent? think about a way to induce correlations between them, and observe their effect on the vibrational frequencies.

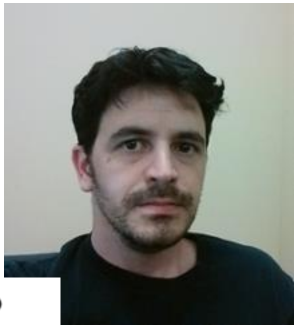
(e) repeat the analysis for higher dimensions, then the observable of interest is the distribution of eigenfrequencies of the Hessian of your random functions. Do you find the same statistics as in the 1D case?

references:

[1] V. Gurarie and J. T. Chalker, *Bosonic excitations in random media*, Phys. Rev. B **68**, 134207 (2003).

[2] E. Lerner and E. Bouchbinder, *Effect of instantaneous and continuous quenches on the density of vibrational modes in model glasses*, Phys. Rev. E 96, 020104(R) (2017).

Statistics of local minima of random functions



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Topological Defect Dynamics

Jasper van Wezel

In this project we will consider the dynamics of topological defects (kinks, or solitons) in various one-dimensional systems.

We will consider both the classical and idealized phi^4 theory, and a specific implementation of the dynamics in terms of charge density wave materials.

The outcomes of this project should be applicable in the description of real, ongoing condensed matter experiments.

- Colored torus knots (no more available)

Vladimir Gritsev

The idea of the project is to understand a connection between Witten's Chern-Simons theory on one side, Turaev-Reshetikhin knot's invariants on the other side and the matrix models a-la Vafa et al and topological recursion from the third side.

High energy physics

Juan
Rojo

A three-dimensional imaging of the proton with Artificial Neural Networks

Our understanding of the transverse momentum dependence of the quarksand gluons in the proton is still much less understood that the corresponding longitudinal case. TMD PDFs encode non-perturbative information on hadron structure, including transverse momentum transverse momentum and polarization degrees of freedom, and are essential in the context of QCD factorization theorems for multi scale, non-inclusive collider observables.
In this project, a first attempt to a three-dimensional imaging of the proton by means of machine learning tools such as artificial neural networks will be carried out.

Heavy quarks production at neutrino telescopes

The charm, beauty and top quarks are among the heaviest of the known fundamental particles of nature. Due to their large mass, the production of these particles requires large amounts of input energy, such as that provided through the collision of high energy protons. Such a process occurs naturally as high energy cosmic rays bombard the Earth’s upper atmosphere as well at high energy colliders such as the Large Hadron Collider (LHC). In this project we will study charm quark production and fragmentation at the LHC and at neutrino telescopes such as IceCube and KM3NET, where they represent the dominant background to the detection of astrophysical neutrinos.

Effective field theory as guide to new physics

Wouter Waalewijn

In the absence of a direct discovery of a new particle at the Large Hadron Collider, one can search for new physics by parametrizing the effects it has on existing measurements in terms of so-called Wilson coefficients in an effective field theory. Discrepancies between theoretical predictions and experimental measurements correspond to non-zero values of the coefficients, signaling the presence of physics beyond the standard model.
The main goal of the project is to develop understanding of the techniques of effective theories and calculate which Wilson coefficients are present in a given process. Time permitting, a subset of quantum corrections could also be included, to expose potentially important coefficients which only arise through quantum effects.

Topological effects in quantum field theory

In quantum field theory there are field configurations characterized by a non-trivial topology. These can therefore not be described as a small perturbation around the standard vacuum, which is independent of space and time. The goal would be to learn about solitons and instantons, first in some toy model and then in a real life example, such as the vacuum of QCD.

- **Monte Carlo event generators in high energy physics**

Wouter Waalewijn

Monte Carlo event generators are powerful and essential simulation tools that underpin the study of the interactions of elementary particles. They are ubiquitously used at collider experiments such as the CERN Large Hadron Collider (LHC). Using Monte Carlos, one can obtain precise predictions of LHC events and put the Standard Model of particle physics to the test. The goal of this project would be to learn the basics of Monte Carlos and explore their use in a specific example from collider experiments.

- **Axes as allies**

Collisions at the Large Hadron Collider result in collimated sprays of hadrons, called jets. Recently there have been several new proposals for axes to describe the directions of these jets. In particular, certain axes are insensitive to low-energy radiation, making them useful for the noisy environment of LHC collisions. The goal of this project would be to investigate properties of these axes, explore new definitions and ideally obtain a classification. This project is phenomenology-oriented and could potentially contribute to ongoing experimental efforts.

- **Borel summation in physics**

  In physics, one often cannot analytically solve a problem of interest. One solution is to solve such a problem using a perturbation series in some small parameter - a procedure made famous by Feynman for the example of quantum field theory. However, perturbative solutions, also for simpler models, generally run into a serious mathematical problem: the perturbation series is often asymptotic, and hence divergent.

  In this mathematically oriented project, you will investigate how techniques like Borel summation and resurgence can cure divergent perturbative approaches, and how such mathematical "tricks" may teach us about non-perturbative physics that the perturbative solution misses altogether.

Marcel Vonk

Eric Laenen

Renormalization proofs

Renormalization in quantum field theory involves subtraction the ultraviolet divergences in Feynman graphs with loops. The possibility to do this, and maintain predictive power requires all-order proofs.
In this project the student will look at different types of proofs, including the BPH program and the Zimmerman forest formula. There are some new developments of applying this to infrared divergences as well, and this can be part of the project.

The strong CP problem, symmetry breaking and axions

In this project we look at the strong CP problem: a term in the Quantum chromodynamics Lagrangian that is (i) topological in character, (ii) violates parity, and (iii) has an unexplicably small coefficient. The term is also related to the so-called theta-vacuum. Axions are related to a possible mechanism to explain this smallness, and maybe a source of Dark Matter.

- **Quantum entanglement for bipartite and tripartite states.**

Piet Mulders

In the EPR experiment one has an entangled bipartite state, actually a two-particle state. For bipartite states, there is only a single class of entangled states. In contrast for tripartite states one has two classes of entangled states, the GHZ and W-states. The goal of the project is to understand the equivalence between states that underlies this distinction and to study some applications.

Basic literature:
(1) Multipartite entanglement, M. Walter et al,, arXiv: 1612.02437 (2016)
(2) Three qubits can be entangled in two inequivalent ways,
W. Dur, G.Vidal and J. I. Cirac, arXiv: quant-ph/0005115 (2000).

- **Instant and front form of quantum mechanics**

We start with the classic paper of Dirac on forms of quantum mechanics and then look at the equivalence for free particles, followed by applications in particle physics, in particular for particle distribution (and fragmentation) functions used to connect the worlds of quarks and gluons to the world of hadrons.

- Forms of relativistic dynamics, P.A.M. Dirac, Rev. Mod. Phys. 21, 392 (1949)

1) Aspects of the ergodic theorem.

Ben Freivogel

Depending on the interests of the student, we will investigate which systems are ergodic. One possible direction is to understand the transfer of energy to short wavelengths in fluids. Another is to investigate the effect of quantum mechanics, and the eigenvalue thermalization hypothesis

2) Structure of axion dark matter.

One possibility is that the dark matter is made up of very light particles called axions. It is not yet clear in what ways axion dark matter behaves differently then other dark matter candidates. We will look into this issue. Reference: http://arxiv.org/abs/1412.5930

3) Complexity of quantum states.

For various reasons relating to quantum computation and black holes, we would like to know how to define the complexity of a quantum state. We will examine various definitions, apply them to simple examples, and perhaps propose a new definition.

Probing dark matter with dwarf spheroidal galaxies

Christoph Weniger

- One of the big challenges of contemporary cosmology, theoretical physics and astronomy is to understand the origin of the dark matter phenomenon.

  So-called cold dark matter consistently explains a large range of phenomena in the Universe, including the angular power spectrum of the cosmic microwave background, the large scale distributions of galaxies, the power spectrum of the Lyman alpha forest, hierarchical structure formation and the rotation curves of spiral galaxies.

  Dwarf spheroidal galaxies, which are satellite galaxies of the Milky Way, have very high mass-to-light ratios, M/L ~1000, and are thought to be dark matter dominated.

  You will study how stellar kinematics can be used to infer the amount of dark matter in dwarf spheroidal galaxies, and compare this with predictions from modified Newtonian gravity (MOND).

  You will furthermore study how astronomical multi-wavelength observations can be used to test the hypothesis that dark matter is made of new fundamental particles, and/or how stellar kinematics can be used to probe the hypothesis that dark matter is made of primordial black holes.

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Project (no longer available)

The interface of quantum information, condensed matter theory and topology.
For example on topological error correcting codes based on Majorana fermions.

Kareljan Schoutens

Cluster vorming

Bernard Nienhuis

- Granulaire deeltjes worden onderscheiden van moleculaire deeltjes doordat ze bij wisselwerkingen aan interne vrijheidsgraden steeds energie verliezen.
  Deze wordt in warmte omgezet. Deze omzetting is onomkeerbaar.
  Het gevolg is dat granulaire deeltjes clusteren: een homogene verdeling is onstabiel voor dichtheidsfluctuaties.
  Een kleine locale verhoging van de dichtheid versterkt zichzelf, en trekt steeds meer deeltjes naar zich toe.
  In dit project wordt gepoogd om dit verschijnsel in een eenvoudig model inzichtelijk te maken.

Quantum thermodynamica

Wat blijft er van thermodynamica over voor *kleine systemen*,
gekoppeld aan een macroscopisch bad en dito werkbron?

Theo Nieuwenhuizen

Quantum meetprobleem

Metingen geven richting aan de interpretatie van quantum mechanica.
Bestudeer een realistisch model voor een meting met een apparaat.
Uiteindelijk kom je bij het *meetprobleem:* hoe verklaart QM individuele metingen?
Die kennen we uit de praktijk, maar theoretisch alleen d.m.v. postulaten.

Neutrino donkere materie – neutrino massa

Als donkere materie van neutrino's komt, wat is dan hun massa ?
Zijn het Dirac of Majorana fermionen ?
Bestudeer de lenswerking data van een cluster van melkwegstelsels.

Quantum meetprobleem

Theo Nieuwenhuizen

- Leerboeken: meting beschreven door *postulaten* Instorten van de golffunctie, Born regel
- *Een meetapparaat is ook een fysisch systeem*
- Kun je een quantummeting beschrijven door het meetapparaat te modeleren?
- Meetprobleem: Kun je verklaren dat je bij een quantummeting een enkele waarde meet?
- Wat is de *minimale* interpretatie van de QM?