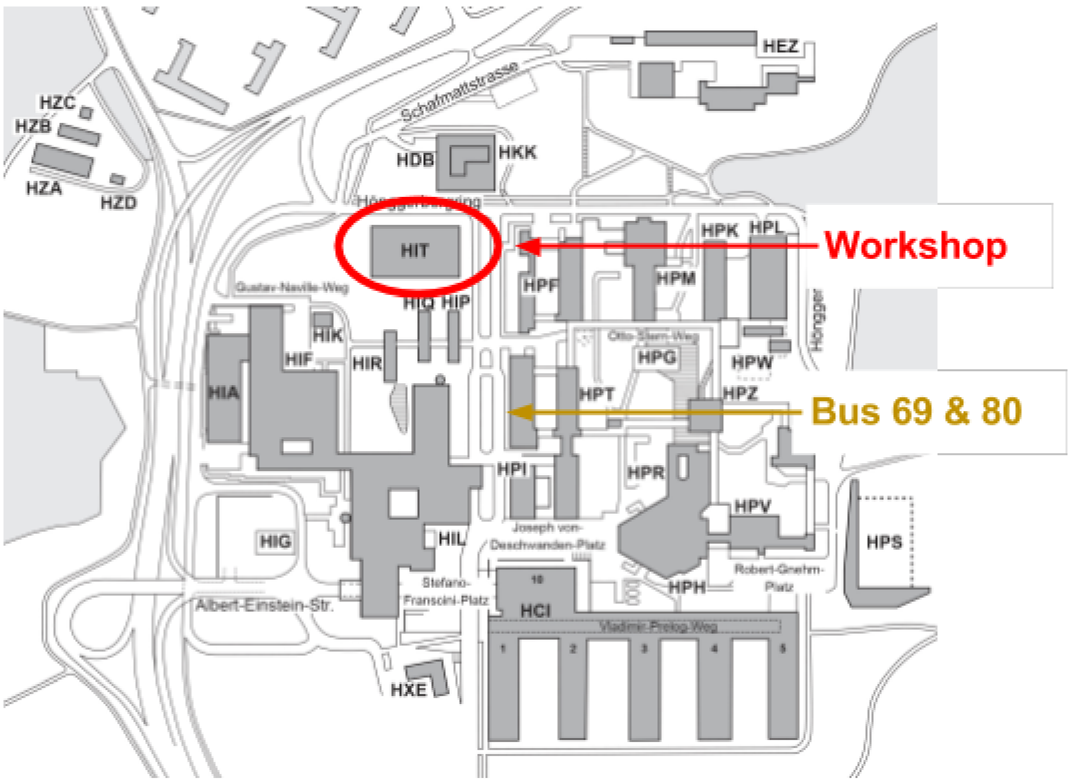
Practical information

The workshop takes place in the HIT building at ETH-Honggerberg, Wolfgang-Pauli-Str. 27 in room HIT E51. From the Zurich HB, you can take tram 11 to Bucheggplatz and then change to bus 69 which takes you to ETH. Once you arrive at ETH, you will need to find the HIT building:



Using public transportation
Please make sure you buy a valid ticket for public transportation (before boarding). This can be bought either at the ticket machine at the tram and bus stops or at the railway stations. We advice you to buy a "Tageskarte". It is valid 24 hours and can be used all over Zurich (Zone 110), be it for trams, buses or even ships. Please note that zone 110 does not include Zurich airport (you have to buy a ticket for 3 zones).

Campus ETH Hoenggerberg
https://www.ethz.ch/en/campus/locations/zurich-region/hoenggerberg.html

Site plans for ETH Zurich
https://www.ethz.ch/en/campus/locations.html

Programme for Workshop on Classical and Quantum optimization

Day 1, 20.08.2014
Morning chair: Helmut Katzgraber
Afternoon chair: Layla Hormozi

Time	**Title** **Speaker**
9:00	Coffee & registration
9:55	Welcome & introduction
10:00	Alan Middleton (Syracuse) *What can we learn from glassy problems with polynomial time solutions?*
10:45	Alexander Hartmann (Oldenburg) *Vertex-cover problem: algorithms and phase transitions*
11:30	Jonathan Machta (UMass Amherst) *Population annealing: An effective algorithm for rough free energy landscapes*
12:15	Lunch
14:00	Alex Selby *Methods for classical optimisation and simulation of frustrated Ising models*
14:45	Andrew Lucas (Harvard) *NP-hard combinatorial problems as Ising spin glasses*
15:30	Coffee break
16:00	Stefan Boettcher (Emory) *Extremal Optimization Heuristic for the Quadratic Unconstrained Binary Optimization (QUBO) Problem*
16:45	Greg Tallant (Lockheed Martin) *TBA*

Day 2, 21.08.2014
Morning chair: A. Jamie Kerman
Afternoon chair: William D. Oliver

Time	**Title** **Speaker**
9:00	Giuseppe Santoro (SISSA) *Quantum Annealing: old work and recent thoughts*
9:45	Sergio Boixo (Google) *TBA*
10:30	Coffee break
11:00	Karl Roenigk, Ph.D. (IARPA CSQ Program Manager) *Qubits for Robust, Fast Quantum Annealing: Extending Advances from the IARPA CSQ Program*
11:45	Lunch
14:00	Bryan Jacobs *Quantum Annealing: Near Term Prospects*
14:45	Itay Hen (ISI) *Quantum versus thermal annealing: seeking a fair comparison*
15:30	Coffee break
16:00	Vadim Smelyanskiy (NASA) *Bottlenecks of quantum annealing*
16:45	Martin Weigel (Coventry) *Some exact and heuristic optimisation algorithms for spin glasses*
20.00	Workshop dinner

Day 3, 22.08.2014
Morning chair: Firas Hamze
Afternoon chair: Sergei V. Isakov

Time	**Title** **Speaker**
9:00	Ilia Zintchenko (ETH) *Hierarchical search*
9:45	Ruben Andrist (Santa Fe) *TBA*
10:30	Coffee break
11:00	Bettina Heim (ETH) *Classical vs. quantum annealing - A numerical study on Ising spin glasses*
11:45	Lunch
13:30	Robert Lucas (ISI) *TBA*
14:15	Discussion
16:00	Farewell

Abstracts
Workshop on Classical and Quantum optimization

What can we learn from glassy problems with polynomial time solutions?

Alan Middleton (Syracuse University)

I will review some results and problems in disordered models in finite dimensions. Using primarily the two-dimensional spin glass as a model, I will stress the difference between problems represented by finite-dimensional graphs and those represented by high-dimensional graphs. Problems in finite dimensions seem to lend themselves to heuristic methods. It is possible that the perspective gained by exhaustive study of polynomial time problems can provide “physical” insight into NP-hard problems, as the physics can be very similar, though the computational complexity is not.

Vertex-cover problem: algorithms and phase transitions

Alexander Hartmann (Oldenburg University)

We study the vertex-cover problem which is an NP-hard optimization problem and a prototypical model exhibiting phase transitions on random graphs, e.g., Erdoes-Renyi (ER) random graphs. These phase transitions coincide with changes of the solution space structure, e.g, for the ER ensemble at connectivity c=e=2.7183 from replica symmetric toreplica-symmetry broken. We study several types of algorithms: Heuristics, exact branch-and-bound algorithms, and linear programming with cutting planes:

For the vertex-cover problem, also the typical complexity of exact branch-and-bound algorithms, which proceed by exploring the landscape of feasible configurations, augmented by the leaf-removal heuristics, change close to this phase transition from ``easy'' to ``hard''.Such an algorithm proceeds by exploring the space of feasible configurations. Furthermore, we consider an algorithm which has a completely different strategy: The problem is mapped onto a linear programming problem augmented by a cutting-plane approach, hence the algorithm operates in a space outside the space of feasible configurations until the final step, where a solution is found. Here we show that this type of algorithm also exhibits an easy--hard transition around c=e, which strongly indicates that the typical hardness of a problem is fundamental to the problem and not due to a specific representation of the problem.

Population annealing: An effective algorithm for rough free energy landscapes

Jonathan Machta (University of Massachusetts Amherst)

Population annealing Monte Carlo is a general purpose algorithm for sampling thermal states and finding ground states of systems withrough free energy landscapes such as spin glasses. Population annealing is an example of a sequential Monte Carlo algorithm. It is closely related to simulated annealing but with an additional resampling step in which replicas of the system are differentially reproduced. In this talk I will explain the algorithm, describe some of its useful features, and compare it to both simulated annealing and parallel tempering in the context of three dimensional spin glasses. Population annealing substantially outperforms simulated annealing and is comparable to parallel tempering for finding ground states. It has several advantages over parallel tempering, for example, it is well-suited to massive parallelization and it provides an accurate estimator of the free energy.

Collaborators:
Wenlong Wang, U. Massachusetts Amherst
Helmut Katzgraber, Texas A&M University

Methods for classical optimisation and simulation of frustrated Ising models

Alex Selby

There has recently been some interest in classical algorithms to find the minimum energy configuration of Ising spin-glass models, and of other models with frustration. In addition to finding ground states ("optimisation"), there is also a closely related problem of simulating these systems at a non-zero temperature ("simulation"). Two methods are considered here that appear to be useful for these tasks. One is the method of Exchange Monte Carlo ("EMC") and the other is subgraph-based sampling ("SGS"), where non-local updates are performed using sets of tractable subgraphs instead of updating each spin according only to its immediate neighbours. EMC has a successful track record for simulation, but also functions as a replacement for simulated annealing in the case of pure optimisation. The methods EMC and SGS are kinds of meta-methods, in that they can be combined with other methods and with each other. Each method appears to be useful in isolation, but it is not obvious how much these advantages "overlap", i.e., whether or not the combination EMC+SGS is significantly better than either SMC or SGS individually. This talk attempts to evaluate the performance of these methods, also comparing these with the current D-Wave device.

NP-hard combinatorial problems as Ising spin glasses

Andrew Lucas (Harvard University)

Recent experimental progress suggests the possibility of using adiabatic quantum optimization (AQO) to solve hard combinatorial optimization problems in the not-too-distant future. Arguably the most important step in this process is to find a good reduction of the problem of interest to an Ising spin glass: it has been found recently that the performance of AQO is highly sensitive to this choice. I will discuss some simple tricks and methods for mapping famous combinatorial optimization problems from computer science to Ising spin glasses with a "reasonable" number of spins, and discuss directions for further improvements.

Extremal Optimization Heuristic for the Quadratic Unconstrained Binary Optimization (QUBO) Problem

Stefan Boettcher (Emory University)

Extremal Optimization (EO), introduced in PRL 86, 5211 (2001), is a general-purpose heuristic for hard combinatorial problems that has provided many new results for the ground states and low-energy excitations of spin glasses models on lattices and random networks, a well-known NP-hard problem in statistical physics. We will discuss the properties of EO for a few simple examples and highlight some of the significant successes as well as its pitfalls. Mainly, we will focus on our recent attempts to implement EO for QUBO, and demonstrate its potential in comparison with some of the existing studies in the literature.

TBA

Greg Tallant (Lockheed Martin)

TBA

Quantum Annealing: old work and recent thoughts

Giuseppe Santoro (SISSA)

TBA

TBA

Sergio Boixo (Google)

TBA

Qubits for Robust, Fast Quantum Annealing: Extending Advances from the IARPA CSQ Program

Karl Roenigk, Ph.D. (IARPA CSQ Program Manager)

Five years of advances in the IARPA Coherent Superconducting Qubit (CSQ) Program are reviewed for their significance to the future of quantum annealing. Extended capability from CSQ offers prospects for advanced annealing architectures and performance employing highly-connected, reproducible, and high-performance qubits. Emphasis is given to historical progression of temporal variability and noise for charge and flux qubits. Novel, coherent connectivity offers a path forward to further reduce coupling to temporal, stochastic defects, and subsequent sensitivity to variability from factors of design and fabrication. Ten-fold advances in coherence are described, and recent results promise additional, imminent advances in T1, T2, temporal stability and reproducibility. New silicon materials processing now raises the possibility of millisecond coherence, but also presents new loss and noise behavior at low temperature. New temperature-dependence of loss has also been observed as a function of magnetic field during cool-down. Recent discovery of quasiparticle-limited loss reveals correlated noise dynamics. These and other results suggest a near future of qubits possessing upwards of 100-microsecond coherence, coupled to finite, two-level systems, and exhibiting on/off, temporal behavior. IARPA is now building from CSQ toward the systematic discovery and harnessing of quantum fluctuations enabling quantum enhanced optimization.

Quantum Annealing: Near Term Prospects

Bryan Jacobs

Although the theoretical benefits of gate-based quantum computing are well established, the hardware precision required to outperform classical processors for relevant problems is so challenging that this approach may never be practical. Alternatively, the less stringent conditions required to implement quantum annealing are well within reach of current technologies, and the benchmarking of potential hardware solutions and algorithms has already begun. Unfortunately, the same question of practical relevance remains, partially due to the increased complexity of mapping (and embedding) real-world problems onto a limited connectivity quantum annealing machine. This talk describes two real-world applications that could be used to demonstrate two different forms of “quantum enhancement” that may be possible with an annealing machine. A structured scheduling problem is presented that, if embedded on an appropriate architecture, could demonstrate resource reduction, or “quantum speedup”. Additionally, a new application of random k-SAT is presented that could demonstrate the ability of a quantum annealer to find “better solutions” than classical solvers, which could still be of value on a relatively slow/limited machine.

Quantum versus thermal annealing: seeking a fair comparison

Itay Hen (ISI)

The D-Wave Two chip presumably exploits quantum annealing effects to solve optimization problems. Whether D-wave’s quantum annealing is capable of achieving a real speedup as compared to classical (thermal) annealing is still a matter of investigation. In that context, specifically of importance is the question of how well quantum annealing performs on instances with rugged free-energy landscapes for which simulated annealing methods are expected to fail. In this talk I will describe attempts to identify very hard D-Wave-specific instances exhibiting "temperature chaos" by means of state-of-the-art methods (multi spin coding, parallel tempering simulations and the related stochastic time-series analysis), and present preliminary results pertaining to the performance of classical algorithms and the D-wave Two chip on these. This is a joint work with Victor Martin-Mayor.

Bottlenecks of quantum annealing

Vadim Smelyanskiy (NASA)

TBA

Some exact and heuristic optimisation algorithms for spin glasses

Martin Weigel (University of Coventry)

In general, finding ground states of spin glass Hamiltonians is an NP hard optimisation problem. A notable, non-trivial exception is the nearest-neighbor Ising spin glass on two-dimensional lattices. A mapping of this model to a polynomial minimum-weight perfect matching problem has long been used for efficient ground states computations. Based on a recent suggestion for a modified mapping, we are able to study large systems of up to 10^8 spins. While the matching approach itself is restricted to planar graphs, a windowing technique allows to treat fully periodic boundaries, i.e., toroidal geometries. Using a cluster decomposition of the ground-state manifold for discrete coupling distributions that feature degeneracies, we propose a uniform sampling algorithm for degenerate ground states.

For systems in three dimensions and/or spins with more degrees of freedom, no exact algorithms that are better than exact enumeration are available. For continuous spins, even enumeration is not an option. For such systems in two dimensions, an embedding of Ising spins into the continuous degrees of freedom allows to apply the matching approach as a partial solution. Combining this approach with a suitably tailored genetic algorithm allows to reliably find ground states of 2D continuous spin systems for lattices of the order of 40^2 spins. For samples in three dimensions, the embedded matching can be replaced by spin quenches augmented by over-relaxation moves. For the case of Ising spins, similar approaches based on genetic optimisation are feasible. Instead of developing these further, however, we here here introduce an alternative technique based on the removal of barriers by an augmentation of the dimensionality of phase space.

Hierarchical search

Ilia Zintchenko (ETH Zurich)

Finding ground states of Ising spin glasses is a notoriously hard problem for which there is to date no known efficient algorithm. We present a heuristic, general-purpose hierarchical approach as a way to potentially improve the performance of a given algorithm or special purpose classical or quantum hardware device. For all our benchmark problems, including chimera graphs and lattices in two and three dimensions this approach shows significantly better scaling performance than simulated annealing.

TBA

Ruben Andrist (Santa Fe Institute)

TBA

Classical vs. quantum annealing - A numerical study on Ising spin glasses

Bettina Heim (ETH Zurich)

In recent years, the emergence of hardware-based quantum devices has sparked the interest in quantum annealing algorithms. Whereas previous results suggest a superiority of simulated quantum annealing over simulated classical annealing, in recent simulations on a D-Wave Two device, no evidence of quantum speedup has been detected. We discuss how these seemingly contradictory results fit together and analyze the role of the Trotter error based on a numerical study of Ising spin glasses with uniform couplings. Differences between quantum annealing as an optimizer and quantum annealing of a physical system are identified and the results of our numerical study are compared to those of simulated classical annealing for both cases.

TBA

Robert Lucas (ISI)

TBA