Combinatorial optimization using networks of optical parametric oscillators with measurement feedback

Peter L. McMahon1,2,3,* , Alireza Marandi4,* , Ryan Hamerly5, Yoshitaka Haribara6,7, Takahiro Inagaki8, Davide Venturelli9,10, Tatsushi Onodera1, Edwin Ng1, Carsten Langrock1, Kensuke Inaba8, Toshimori Honjo9, Koji Enbutsu10, Takeshi Umeki11, Ryoiich Kasahara12, Shoko Utsunomiya13, Satoshi Kako14, Kenichi Kawarabayashi15, Dirk Englund16, K. Aihara6,7, Eleanor Rieffel9, Hiroki Takesue8, Robert L. Byer1, Martin M. Fejer1, Hideo Mabuchi1, Yoshihisa Yamamoto1,11

1 E. L. Ginzton Laboratory, Stanford University (USA), 2 National Institute of Informatics (Japan), 3 School of Applied and Engineering Physics, Cornell University (USA), 4 Department of Electrical Engineering, California Institute of Technology (USA), 5 Research Laboratory of Electronics, Massachusetts Institute of Technology (USA), 6 Department of Mathematical Informatics, University of Tokyo (Japan), 7 Institute of Industrial Science, University of Tokyo (Japan), 8 NTT (Japan), 9 NASA Ames Research Center (USA), 10 USRA Research Institute for Advanced Computer Science (USA), 11 ImpACT Program, Japan Science and Technology Agency (Japan)

* These authors contributed equally to this work.

Combinatorial optimization problems, including many nondeterministic polynomial-time–hard (NP-hard) problems, are central in numerous important application areas, including operations and scheduling, drug discovery, finance, circuit design, sensing, and manufacturing. Despite large advances in both algorithms and digital computer technology, even typical instances of NP-hard problems that arise in practice may be very difficult to solve on conventional computers. There is a long history of attempts to find alternatives to current von Neumann–computer–based methods for solving such problems, including use of neural networks realized with analog electronic circuits and by using molecular computing. A major topic of contemporary interest is the study of adiabatic quantum computation (AQC) and quantum annealing (QA). Sophisticated AQC/QA devices are already under study, but providing dense connectivity between qubits remains a major challenge, with important implications for the efficiency of AQC/QA systems.

Networks of coupled optical parametric oscillators (OPOs) are an alternative physical system, with an unconventional operating mechanism, for solving the Ising problem and by extension many other combinatorial optimization problems. We have realized a fully-programmable 100-spin Ising machine using a network of OPOs and measurement feedback, and with it can solve many different Ising problems. In cases in which exact solutions are not easy to obtain, we can find good approximate solutions.

In this talk we will provide an overview of our work on constructing a coherent Ising machine and highlight the results we have obtained in benchmarking the performance of our prototype system.