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POLARIZATION-DEPENDENT OPTOELECTRONIC OSCILLATOR-BASED COHERENT ISING MACHINE FOR OPTIMIZATION PROBLEMS

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Introduction. The advent of hybrid opto-electronic systems, particularly Coherent Ising Machines (CIMs), is pushing the boundaries of computational capabilities beyond the traditional von Neumann architecture. These systems, which merge the high-speed processing of optical components with the precision of electronic controls, are particularly adept at addressing complex combinatorial optimization problems [1]. Among the innovative approaches in this domain, the concept of Polarization-dependent Optoelectronic Oscillator (OEO)-based CIMs stands out as a novel idea. By utilizing the polarization state of light to encode information within optical parametric oscillators (OPOs), our approach introduces a new dimension to optical computing. It leverages the intrinsic properties of light, such as polarization, to enhance the system's computational efficiency and solution exploration for challenges like the Max-Cut problem. While the exploration of polarization dependence in optical computing presents unforeseen challenges, including system stability and scalability, it opens up exciting possibilities for advancing computational technology. This new paradigm underscores a significant step towards realizing scalable, efficient optical computing systems capable of surpassing current computational limits [2].

Main part. Our proposed model of Coherent Ising Machine (CIM) utilizing changes in light polarization for computation. We start with an unpolarized light passing through a 45 degree polarizer, then one component of the polarization undergoes phase retardation via an Electro-Optic Modulator (EOM) influenced by Field Programmable Gate Array (FPGA)/Central Processing Unit (CPU) voltage changes which is directly proportional to the phase shift. This process encodes binary states through polarization changes after passage of modulated light via second 45 degree polarizer. A feedback loop involving a photodiode (PD) and FPGA/CPU dynamically adjusts the light's phase, steering the system to finding the most effective or functional solution of the mapped problem within a given set of parameters or constraints. This process of optimizing solution is performed by translating optical information into digital signals for computational via feedback mechanism.

The system architecture encompasses initial polarization state preparation, electro-optic modulation for phase manipulation, and a feedback mechanism for dynamic control. This method establishes a feedback loop where the photodiode's output informs FPGA processing, iterating towards optimization. The nonlinear iteration map of the nodes/oscillators is modelled as in [1,3].

The system's dynamics can be described using stochastic differential equations (SDEs) with the Euler-Maruyama method to account for stochastic fluctuations in the EOM's phase shift. This approach models the system's evolution under random influences, essential for understanding its behaviour in real-world conditions.

Results. The two node undirected graph is simulated with the coupling between the nodes to be unity. In a noise-free simulation, voltage generated in FPGA computational element or logic gates representing nodes increases corresponding to the phase change and saturates, indicating the system's progression to a stable equilibrium. This dynamic, where the system converges towards attractor states irrespective of initial conditions, showcases its resilience and the inherent robustness against varying initial voltages.

Introducing noise directly into the feedback voltage simulates the effect of random fluctuations impacting the immediate system output (intensity at PD) or state variable (light's phase or feedback voltage). Here, the noise term alters the argument of the output function, thereby affecting the resultant intensity directly and deterministically based on the current voltage and noise realization leading to a result similar to the noiseless case.

In simulating the stochastic dynamics of our model, the stochastic element in Euler-Maruyama equation influence state variable trajectories over time, introduces impact of random processes (representing inherent uncertainties) on the system's evolution. Thus, leading to occasional alignment or crossing of node voltages due to noise-induced deviations but preserving the overall trend of the trajectories. Such intersections demonstrate the system's adaptive response to uncertainty, blending deterministic convergence with stochastic variability to reflect real-world noisy environments. This nuanced approach to noise integration highlights the system's resilience to initial conditions and its adeptness at reaching equilibrium, crucial for computational efficacy amidst deterministic and stochastic variables.

The polarization-dependent CIM showcases a unique computational feedback mechanism, with preliminary simulations validating the theoretical model's effectiveness. The system's resilience to noise and its dynamic control mechanism highlight its applicability in solving NP-hard problems, with further research needed to optimize performance and scalability.

References:

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