Optimization in optical systems revisited
Beyond genetic algorithms
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Optimization in physics
Optimization problems are ubiquitous in physics. Notable instances include
- Design of integrated optical devices
- Design of injectors and magnets in accelerator design
- Topological solitons in nonlinear classical field theories
- Ring models in condensed matter physics

Most real-life optimization problems cannot be solved analytically and are NP-hard. The most common approach is to use metaheuristics, algorithms based on empirical rules for exploring large solution spaces.

Two key concepts for metaheuristics
1. Diversification: Global exploration of the solution space in order to identify regions containing “fit” solutions
2. Intensification: More thorough investigation of “promising” solution regions [1].

Genetic algorithm
Developed by J. Holland in the 1970s. Commonly used in photonics research, for instance integrated waveguide design [2].

- Stochastic, population-based, nature-inspired algorithm
- Memoryless method. The escape from local minima relies on random mutations
- Best suited for diversification. This stems from the population-based nature of the algorithm
- 3 adjustable parameters to specify: Population size, mutation, and crossover rates

Application to single-objective optimization

Parallel tabu search
First proposed by F. Glover in the 1980s. More commonly used in scheduling and networking problems.

- Deterministic, local, non-nature inspired algorithm [1]
- Uses a short-term memory to escape from local minima
- Best suited for intensification of search. Parallel implementation allows to combine exploration and intensification
- Initialization of solutions is the only random process
- Only 1 adjustable parameter: Number of entries in the Tabu list

Laser beam shaping problem

Goal: To find a photonic lattice configuration which produces a scattered wavefunction that matches a desired profile in a given plane [2].

- Binary encoding
- Vertical symmetry
- Fitness function (scattered field) computed via generalised Lorenz-Mie theory

Multiobjective optimization (amplitude and phase control)

Outlook
Engineering of non-diffracting beams
Non-diffracting beams can be used in many applications, like atom guiding and microscopy. Various generation methods have been proposed.

- Phase plates optimized via GA [P. A. Sanchez-Serrano et al., Opt. Lett. 37, 5040 (2012)]
- Hyugens’ surfaces, composed of 2D arrays of polarizable particles [C. Pfeiffer and A. Grbic, PRS 110, 157401 (2013)]

Optimization of random laser action
Recent studies have shown that optimizing the pump shape allows control of laser thresholds and emission directivity. This optimization process implies the computation of a special kind of eigenstate, the constant-flux state [5].

Summary
1. Since parallel tabu search combines search diversification and intensification, it outperforms the SGA in the case of our model problem of beam shaping.
2. The performance gain associated with PTS allows for multi-objective optimization in photonic designs.
3. Optimization of random lasers and engineering non-diffracting beams are potential applications of our algorithms in optics and photonics.

References

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