Human-Competitive Lens System Design with Evolution Strategies

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Optics

- Optics is ubiquitous in science:
  - Astronomy
  - Life sciences
  - Computer vision
  - Remote sensing
  - Optical telecommunication

- Optics is a *hot* topic
  - In a close future, computing devices might be based on light and optical material
Modern Lens Design Process

- Complex engineering task not achievable analytically

- Experience
- Intuition
- Design catalogues

Problem specifications

Optical engineer

Refined systems

Specialized CAD tool

Rough designs
Lens Design Process with EA

- Replace human expert in the loop by an evolutionary algorithm
Monochromatic Quartet

ILDC 1990 #14
RMS blur spot = 0.00218 mm
Best proposed solution

ILDC 1990 #7
RMS blur spot = 0.00250 mm
Best of second family of designs

Best design with SA-ES
RMS blur spot = 0.00167 mm
23% smaller than ILDC #14, 23 meters long!

Best design with CMA-ES
RMS blur spot = 0.00393 mm
Mid-rank at ILDC 1990
Imaging Lens System

Best design proposed by INO experts
Max. 75%-EED = 33.3 μm

SA-ES
Max. 75%-EED = 11.68 μm

CMA-ES
Max. 75%-EED = 12.05 μm
Multiobjective Optimization

Pareto front for NSGA-II SA-ES

Max. 75%-EED = 15.0 µm
Relative cost = 50.96
Criteria D: *The result is publishable in its own right as a new scientific result - independent of the fact that the result was mechanically created.*

- Better results for the monochromatic quartet
  - Believed that global optimum was found at ILDC 1990
- Imaging lens system results are by themselves of great interests
  - Design special sensors with difficult physical constraints
  - Set of non-dominated solutions, nice to select good trade-off
Criteria G: The result solves a problem of indisputable difficulty in its field.

- Monochromatic quartet is a benchmark for global optimization
  - Designed for not being solvable automatically with local optimization
- Imaging problem is a real-world application
  - First presented as a consultancy contract to INO experts
  - INO experts did their best to solve it in a real-life setting (allowed budget of 5 man-days)
- Hundreds of optical designers worldwide are earning their wages doing this kind of job
Wins Human-Machine Competitions

Criteria H: The result holds its own or wins a regulated competition involving human contestants (in the form of either live human players or human-written computer programs).

- Monochromatic quartet first proposed in a friendly competition between human experts
  - Intentions very similar to the Humies, but for optical design, see (O’Shea, 1990)
- Imaging system design is a competition between INO human experts against ES
  - INO is a world-class research center in optical science
  - Consulting for industrial (e.g. telecommunication) and governmental (e.g. defence) organizations
Why it Matters

- Optical design is an important engineering discipline
  - Specialized CAD tools with local optimization used since a long time
  - Experimented and skilled optical engineers are rare
  - Global optimization is not (yet) working well in CAD tools
- Efficient approach mimics modern design process
  - Replace human experts by Evolutionary Computation (EC)
  - Successful applications to synthetic and real-world problems
- First step to include EC-based optimization in the optical designer’s toolbox
Thanks!

