Human-Competitive Lens System Design with Evolution Strategies

Christian Gagné, Julie Beaulieu,
Marc Parizeau, and Simon Thibault

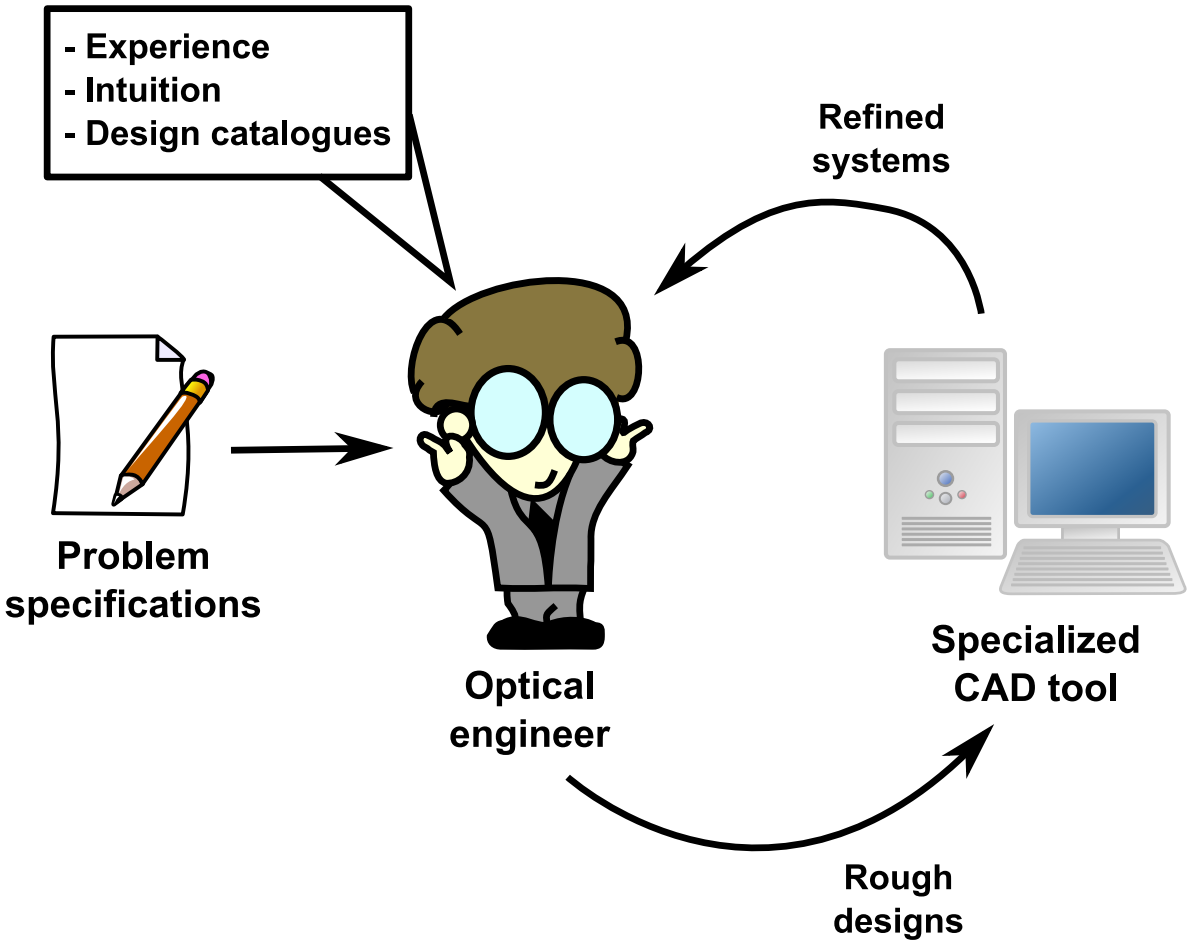
2007 Humies at the GECCO, London (UK)
9 July 2007

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

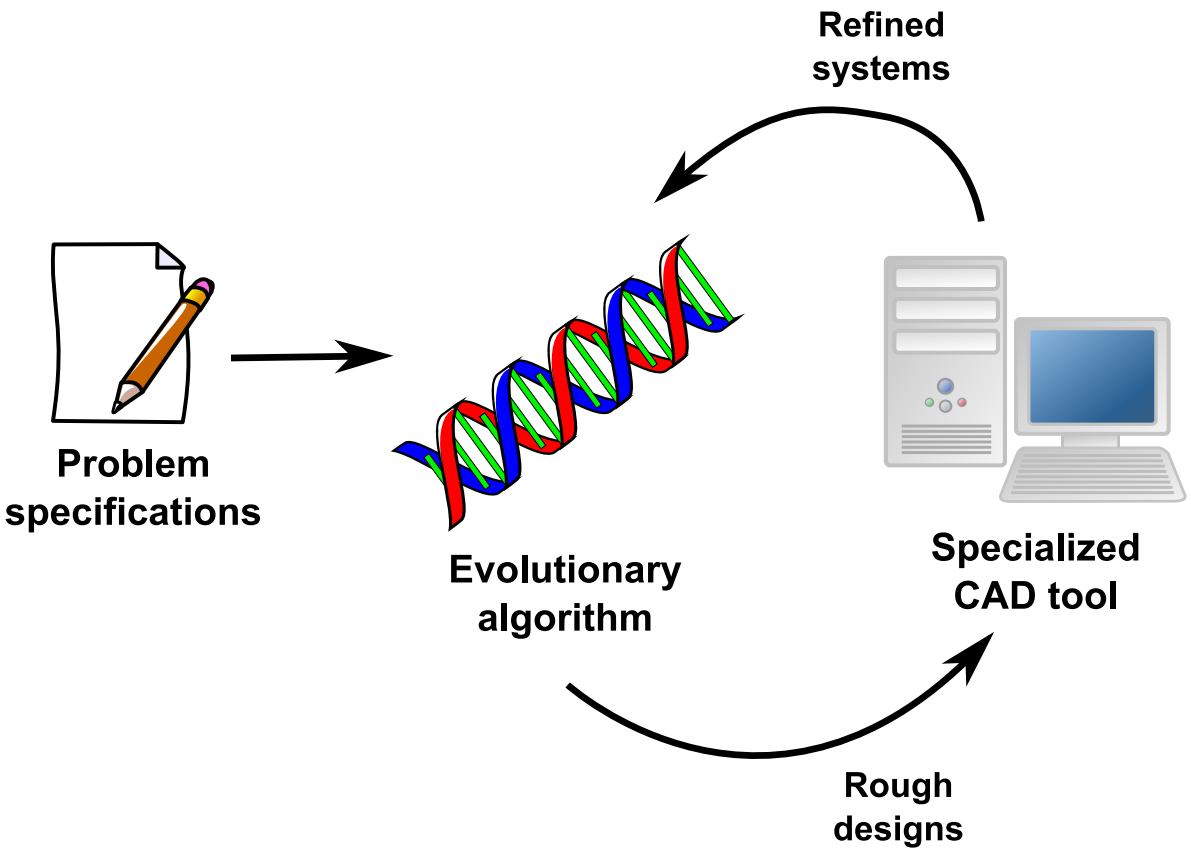
Modern Lens Design Process

- Complex engineering task not achievable analytically

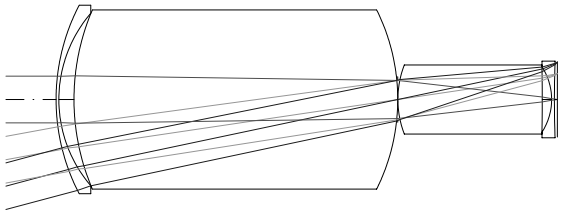


Lens Design Process with EA

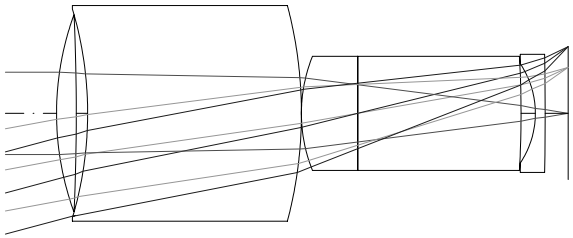
- Replace human expert in the loop by an evolutionary algorithm



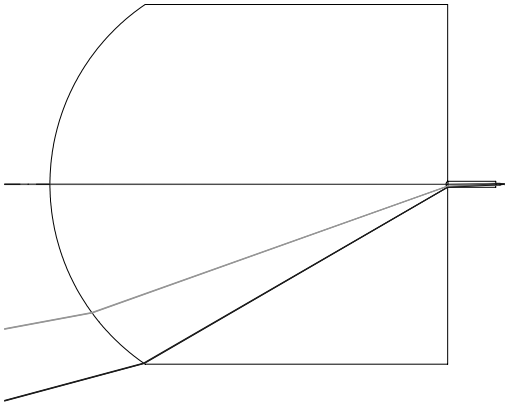
Monochromatic Quartet



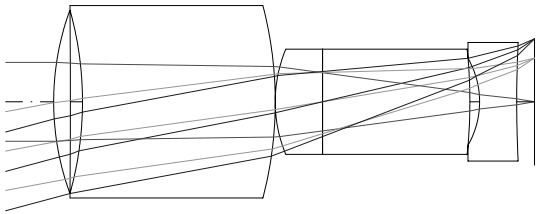
ILDC 1990 #14
RMS blur spot = 0.00218 mm
Best proposed solution



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

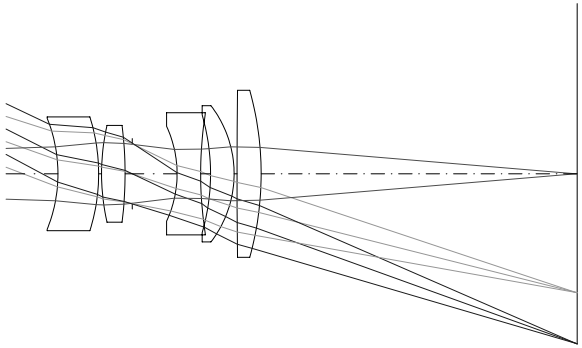


Best design with SA-ES
RMS blur spot = 0.00167 mm
23% smaller than ILDC #14, 23 meters long!

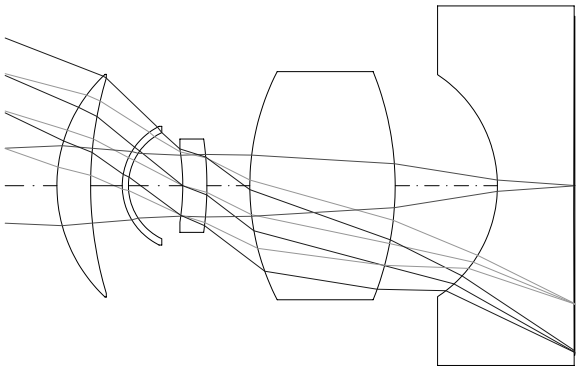


Best design with CMA-ES
RMS blur spot = 0.00393 mm
Mid-rank at ILDC 1990

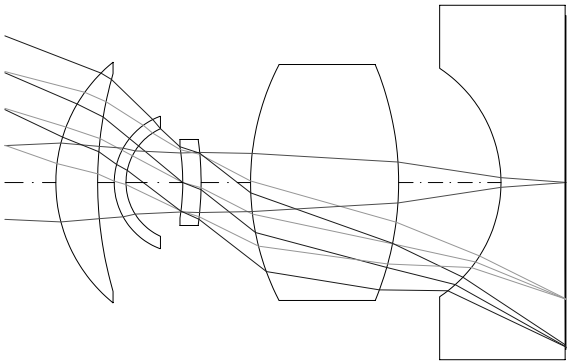
Imaging Lens System



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

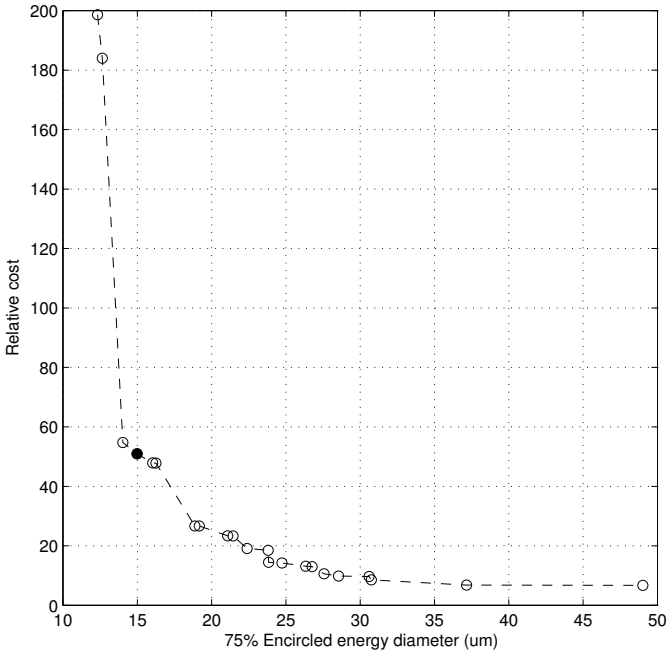


SA-ES
Max. 75%-EED = 11.68 μm

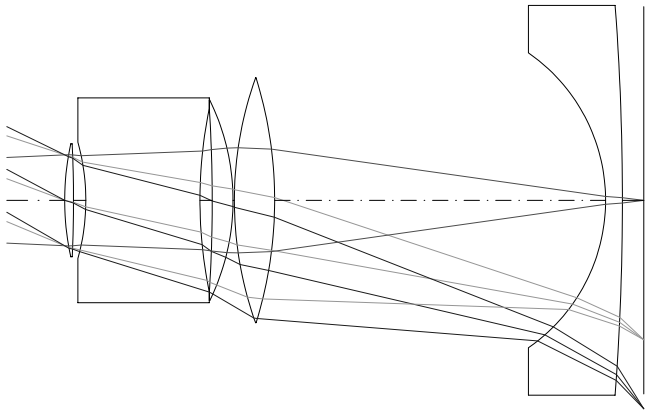


CMA-ES
Max. 75%-EED = 12.05 μm

Multiobjective Optimization



Pareto front for NSGA-II SA-ES



NSGA-II SA-ES
Max. 75%-EED $= 15.0\ \mu$m
Relative cost $= 50.96$

New Scientific Results

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

Problems of Indisputable Difficulty

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!

Christian Gagné, Julie Beaulieu, Marc Parizeau, and Simon Thibault, **Human-Competitive Lens System Design with Evolution Strategies**, Technical report RT-LVSN-2007-01, Laboratoire de Vision et Systèmes Numériques, Université Laval, Québec (Quebec), Canada, May 22, 2007, 25 pages, `http://vision.gel.ulaval.ca/Publications/PublDetails.php?Id=674`.

Simon Thibault, Christian Gagné, Julie Beaulieu, and Marc Parizeau, **Evolutionary Algorithms Applied to Lens Design: Case Study and Analysis**, Proc. of the SPIE International Symposium on Optical Systems Design (EOD 2005), Jena, Germany, September 12-16, 2005.

Julie Beaulieu, Christian Gagné, and Marc Parizeau, **Lens System Design and Re-Engineering with Evolutionary Algorithms**, Proc. of the Genetic and Evolutionary Computation Conference (GECCO 2002), New York (NY), USA, July 9-13, 2002, p. 155-162.