

# Human-Competitive Lens System Design with Evolution Strategies

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



UNIVERSITÉ  
**LAVAL**



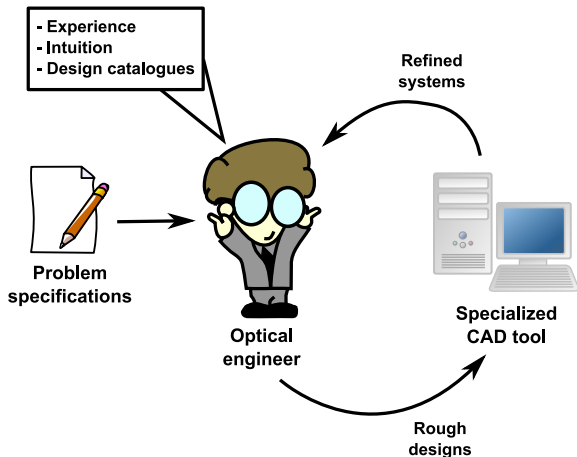
2007 Humies at the GECCO, London (UK)  
9 July 2007

# 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

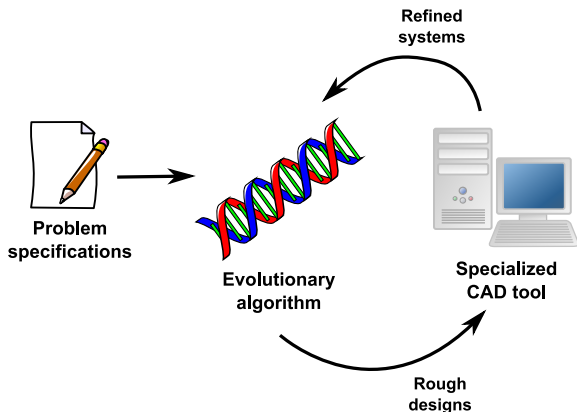
# Modern Lens Design Process

- ▶ Complex engineering task not achievable analytically

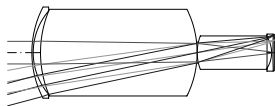


## Lens Design Process with EA

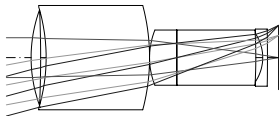
- ▶ Replace human expert in the loop by an evolutionary algorithm



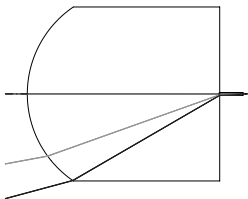
# Monochromatic Quartet



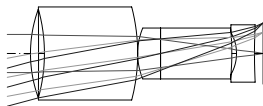
ILDC 1990 #14  
RMS blur spot = 0.00218 mm  
Best proposed solution



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

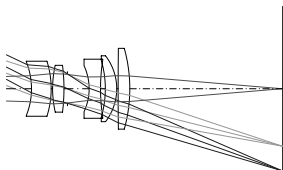


Best design with SA-ES  
RMS blur spot = 0.00167 mm  
23% smaller than ILDC #14, 23 meters long!

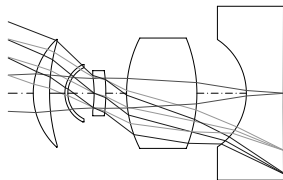


Best design with CMA-ES  
RMS blur spot = 0.00393 mm  
Mid-rank at ILDC 1990

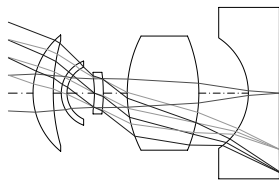
# Imaging Lens System



Best design proposed by INO experts  
Max. 75%-EED = 33.3  $\mu\text{m}$

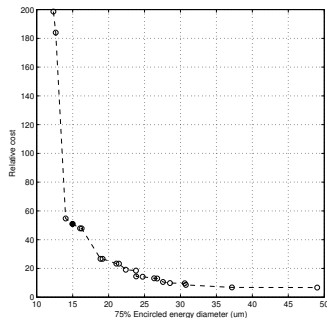


SA-ES  
Max. 75%-EED = 11.68  $\mu\text{m}$

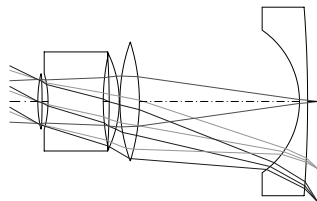


CMA-ES  
Max. 75%-EED = 12.05  $\mu\text{m}$

# Multiobjective Optimization



Pareto front for NSGA-II SA-ES



NSGA-II SA-ES  
Max. 75%-EED = 15.0  $\mu\text{m}$   
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
  - ▶ Experienced 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.