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Numerical Optimization for Parallel Computing

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General structure of generation based optimizers

Loop over Ni individuals

  Initialize individual (randomly)

  Evaluate fitness (time consuming)

End initialization loop

Loop over Ng generations (PSO: Ng time steps)

  Loop over Ni individuals

    Create/modify individuals (smart)

    Evaluate fitness (time consuming)

  End inner loop

End outer loop

Parallelization of generation based optimizers

Parallelize loops over Ni individuals!

Seems to be trivial if Ni=multiple of Np (Np=number of processors)

BUT:

- Optimal value of Ni depends on problem
- Reasonable Ni may be smaller than Np
- Processors with unequal speed or load
- Fitness evaluation time may strongly depend on the properties of the individual (examples follow!)

Generation-based is not well-adapted to parallelization!

Populations in nature are often also not generation-based!

Generation-free optimization

- Optimization process should continuously generate individuals based on the knowledge available
- Never wait for knowledge currently being gained (running fitness evaluations)
- Population size may be dynamic but can be static as soon as the desired size is obtained
- Good individuals may survive for ever (why not?)
- Selection mechanisms may be the same as for generation-based optimizers
- Stop after Ne fitness evaluations (Ne=Ng*Ni)

Generation-free evolutionary strategy (ES)

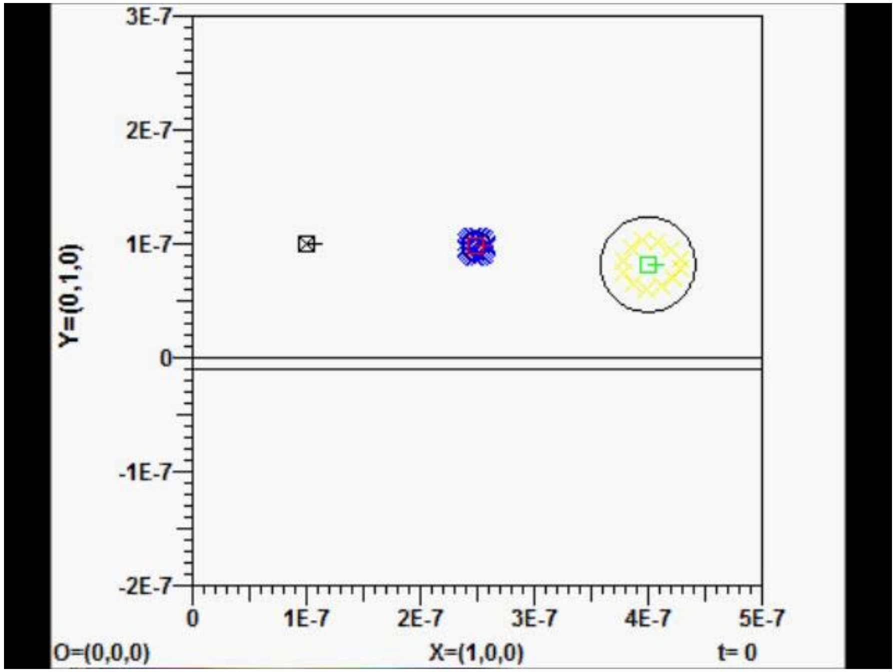
While some processor is free and N<Ne: generate individual and submit it to a free processor

As soon as a fitness has been evaluated: Insert data in table T and sort individuals in T according to fitness)

Generate individual:

- Create randomly if T shorter than Nmin
- Otherwise:
  - select 2 parents out of T (prefer good ones, different possibilities)
  - Apply crossover and mutate (as for generation-based ES)

Example: Excitation of surface wave by 2 particles I

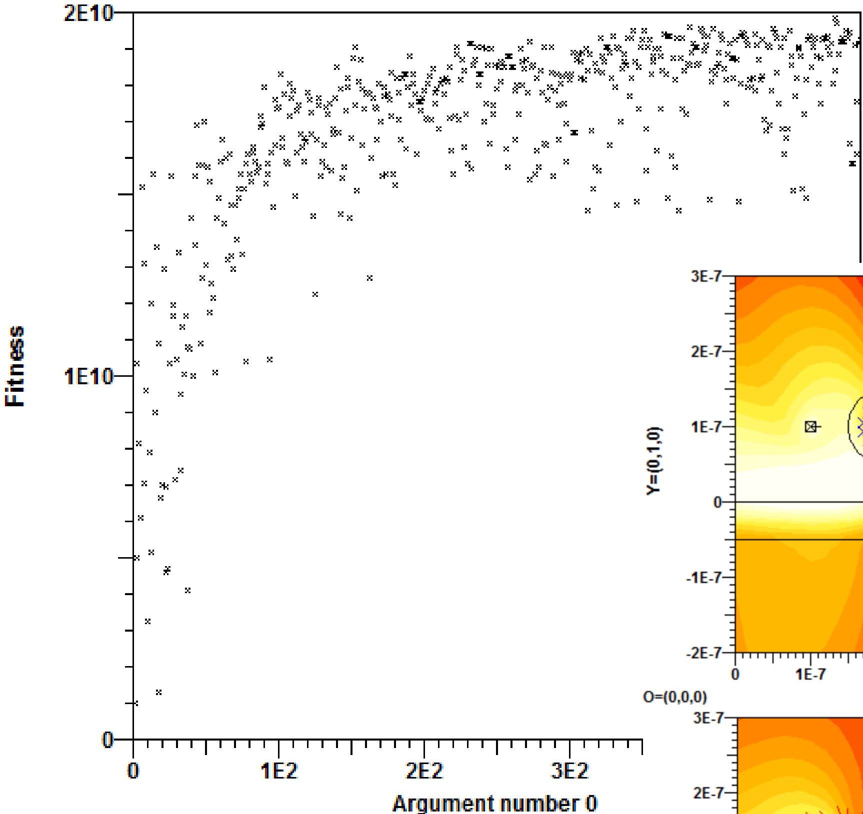


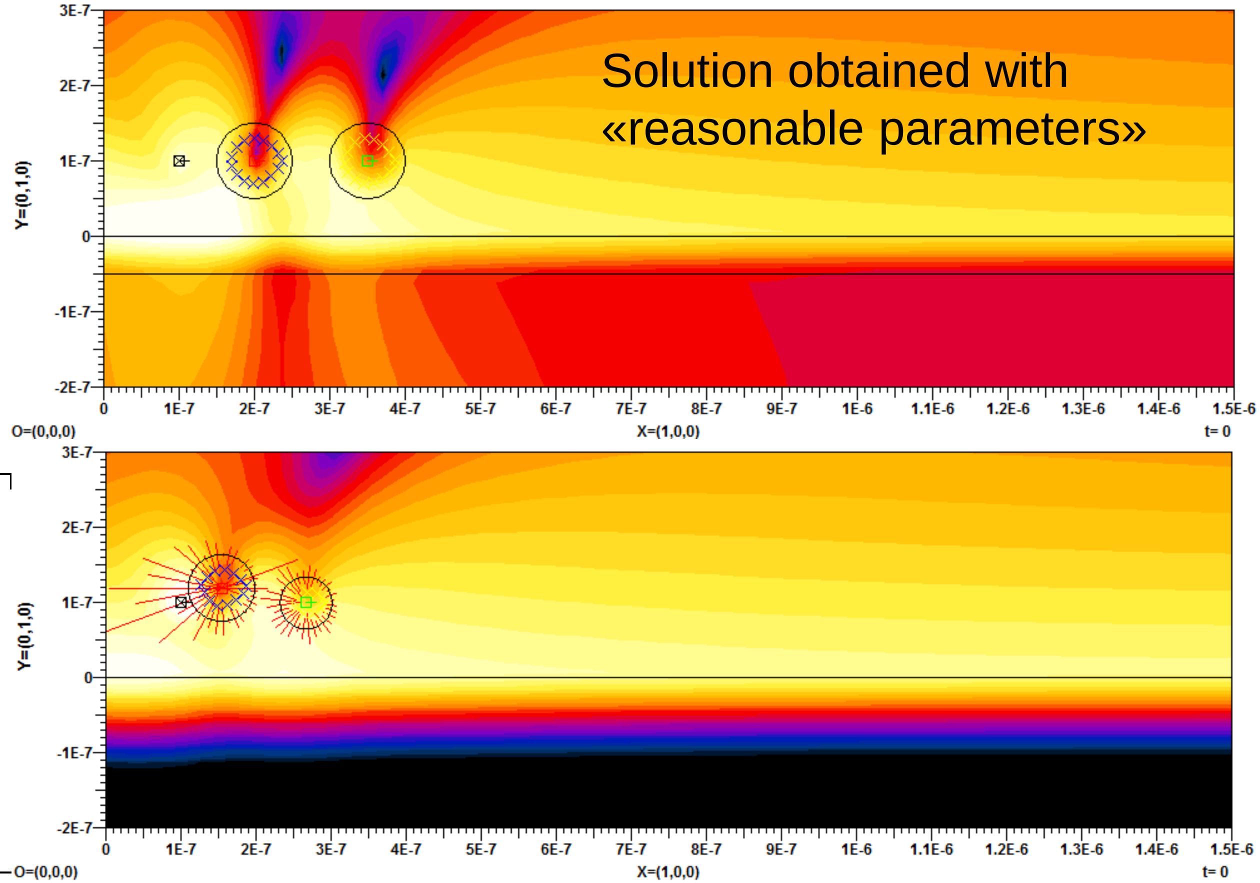
OpenMaX-MMP model by Aytac Alparslan

- Arrange 2 circular 2D particles near a point source above a metal slab in such a way that strong plasminic wave is obtained along the slab
- Vary 7 parameters: radii, distances, slab width
- Number of MMP expansions depends on particle sizes, gaps...
- Fitness evaluation times vary strongly (>factor 10)

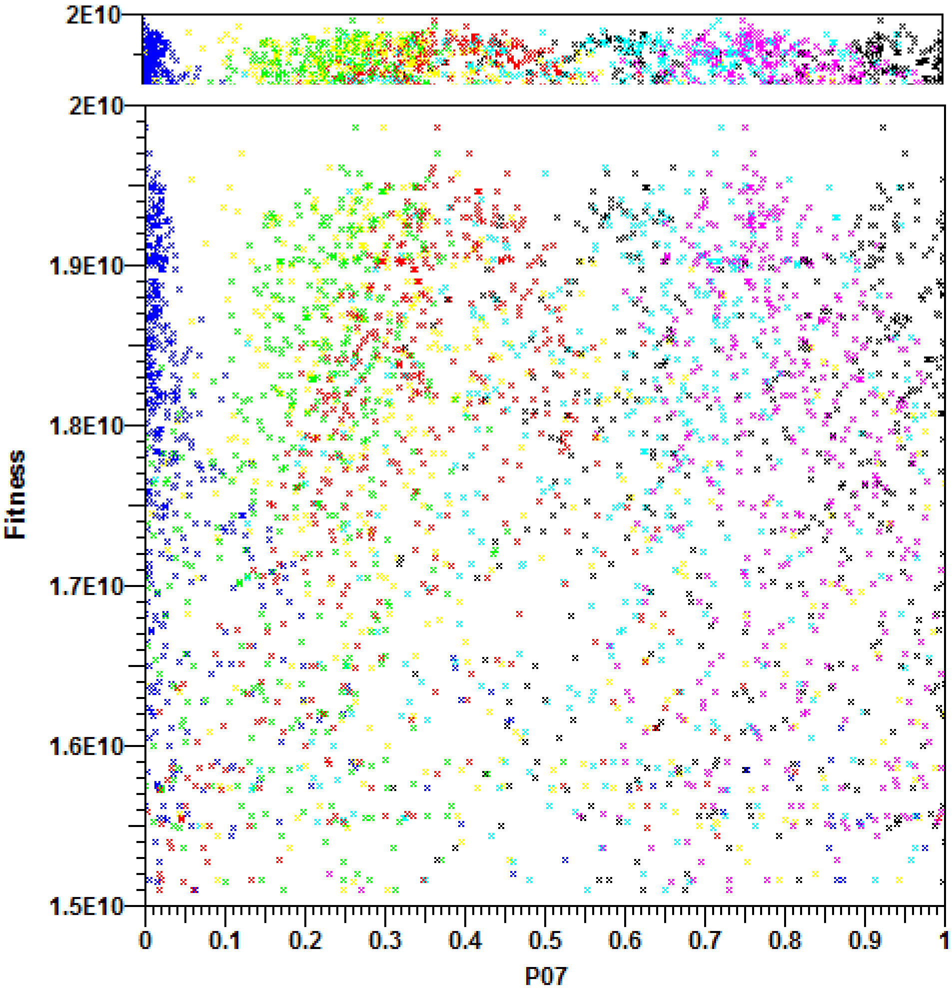
Example: Excitation of surface wave by 2 particles II

- Parallel ES performs very well
- Good solution found already after <200 fitness evaluations





Example: Excitation of surface wave by 2 particles III



Analysis of optimization results

- Has global optimum been found?
- Is best solution good enough?
- Should a longer optimization run be started with what optimization parameters?
- Was the selected parameter range reasonable?

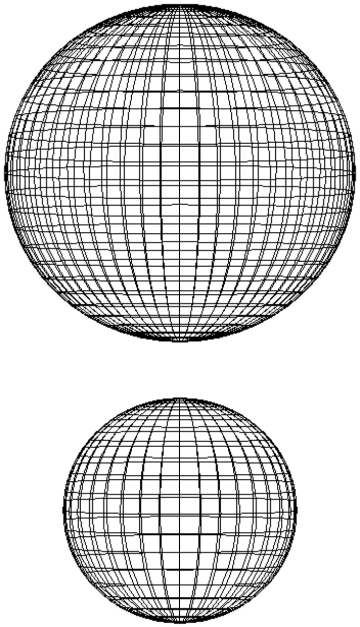
Plot Fitness versus normalized parameters (p0...p6: black, red, green, blue, yellow, pink, light blue)

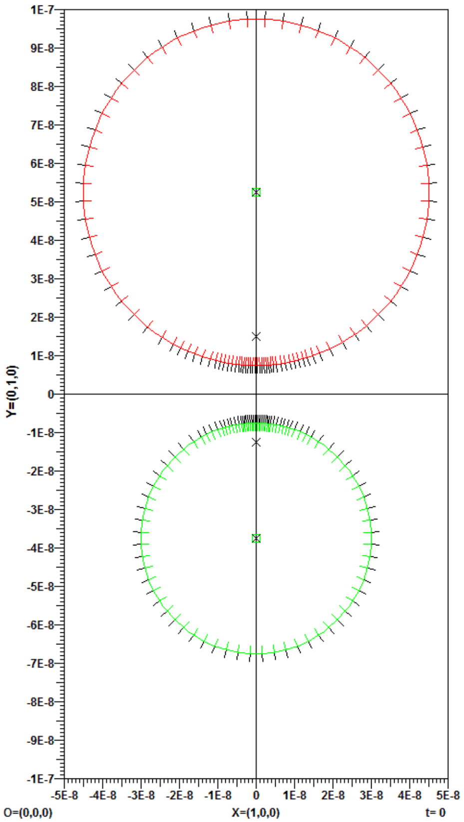
Optimal blue: 0 might be <1

Optimal black: near 1, might be >1

→ Adjust at least ranges of p0, p3

Plasmonic optical antenna I





Pair of spheres, Ag, Au

- Optimize radii and gap
- Only 3 parameters
- Full 3D model
- Fitness evluation expensive
- Expansions must be adapted to radii and gap size for saving computation time
- Computation time depends on parameters

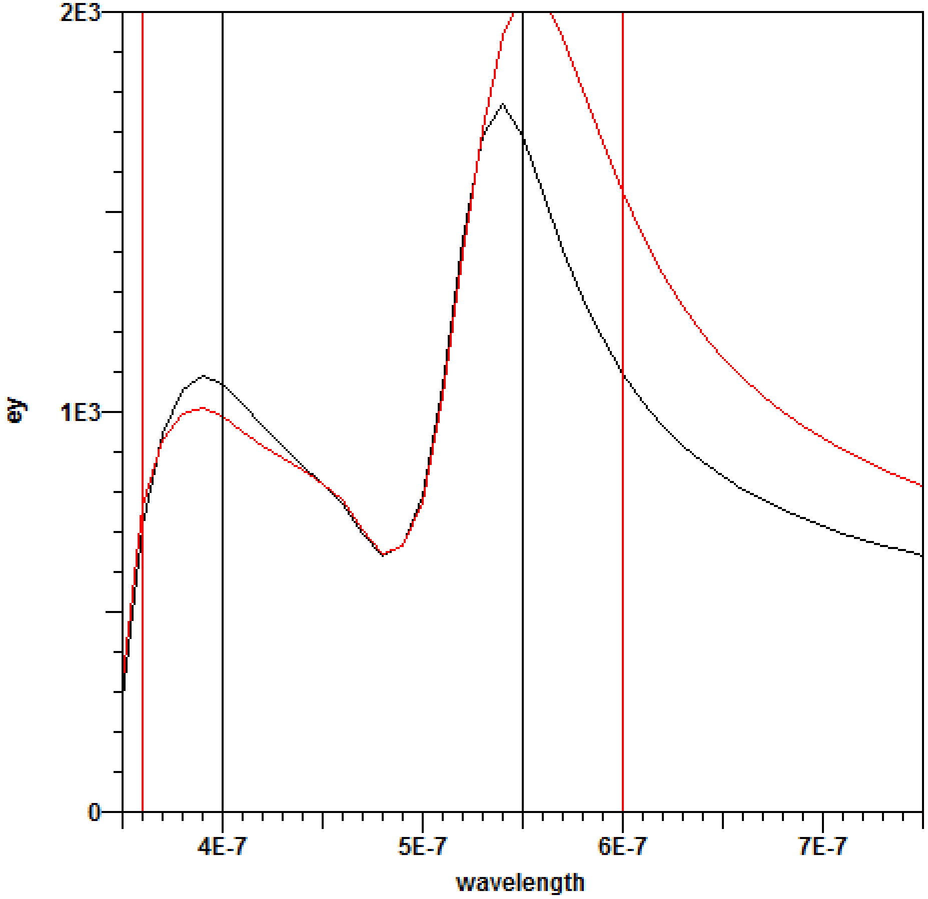
Plasmonic optical antenna II

```
!set var v0 30e-9 ! radius r1
!set var v1 30e-9 ! radius r2
!set var v2 5e-9 ! gap g
! all other variables computed using formula
set var v3 for add(v0,div(v2,2)) ! center y1
set var v4 for neg(add(v1,div(v2,2))) ! center y2
set var v5 for div(mul(sub(v3,v4,),v0),add(v0,v1)) ! d1
set var v6 for div(mul(sub(v3,v4,),v1),add(v0,v1)) ! d2
set var v7 for sub(v3,div(sqr(v0),v5)) ! y1'
set var v8 for add(v4,div(sqr(v1),v6)) ! y2'
! set boundaries (circles)
set bou 1 cor 1 0 v3 v0
set bou 2 cor 1 0 v4 v1
!dra bou 0
! set 3d expansions
set exp 1 3dl 0 v3 0
set exp 2 3dl 0 v4 0
set exp 3 3dl 0 v8 0
set exp 4 3dl 0 v7 0
set exp 5 3dl 0 v3 0
set exp 6 3dl 0 v4 0
set exp 7 3dl 0 v7 0
set exp 8 3dl 0 v8 0
! set auxiliary 2d multipoles for matching point setting
set exp 9 loc 0 v3
set exp 10 loc 0 v4
set exp 11 loc 0 v7
set exp 12 loc 0 v8
```

Adapting 3D MMP model

- Optimizer provides 3 parameters v0, v1, v2
- Skript language
- Evaluate auxiliary variables v3...v8 using formula interpreter
- Compute locations of 3D multipole expansions
- Set auxiliary 2D multipoles for adapting the matching points

Plasmonic optical antenna III

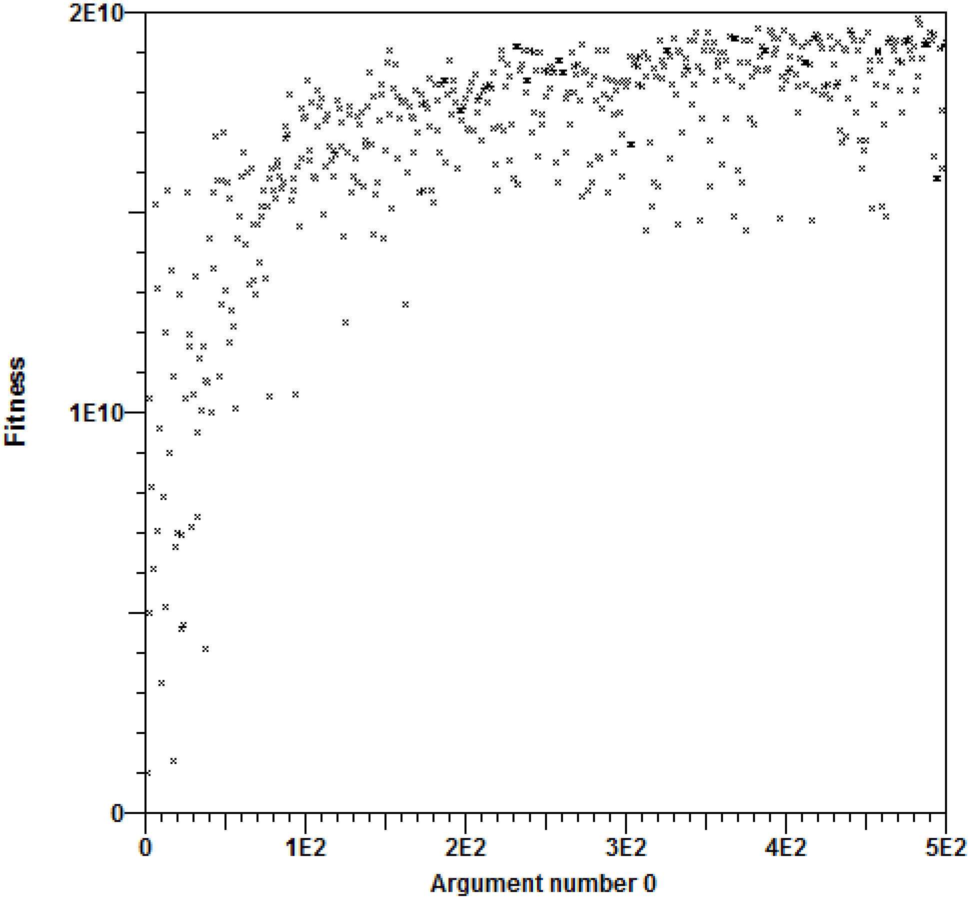


Different goals possible

e.g. maximum response at two wavelengths l1,l2

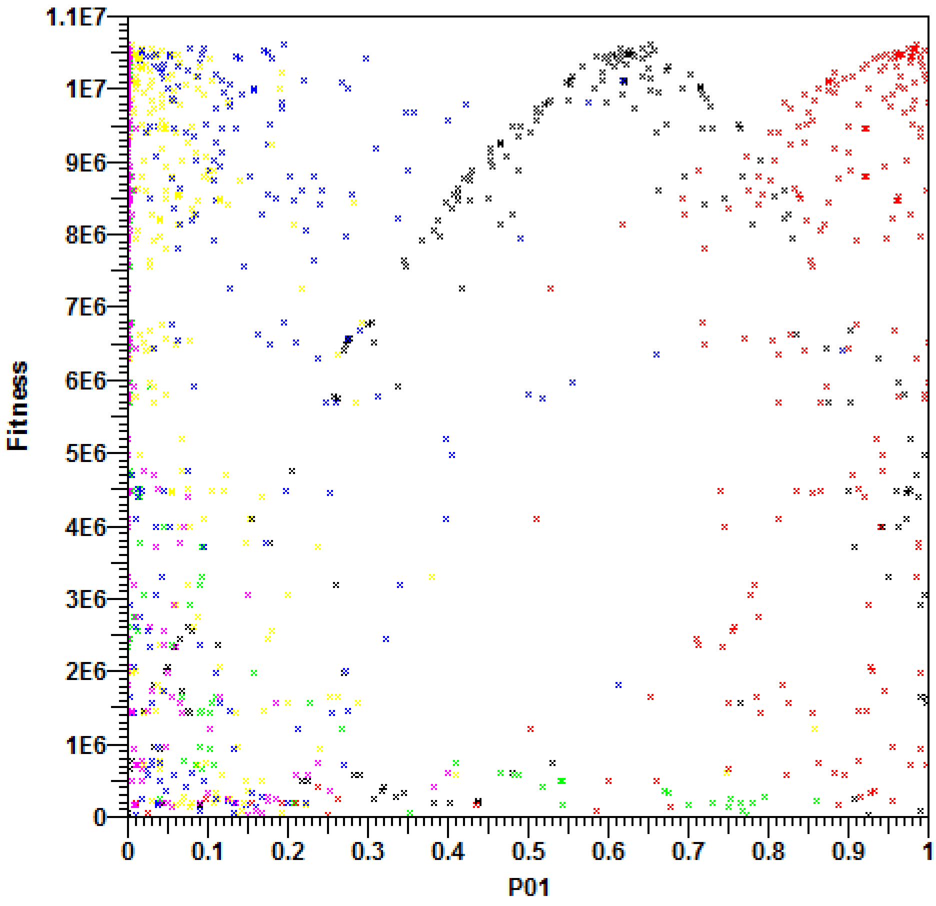
- Solution depends on l1,l2
- High quality solutions only for certain selections of l1, l2
- Better solutions: shape optimization, other materials,
  → more parameters

Plasmonic optical antenna IV



- Good fitness obtained very quickly
- Good results after < 200 fitness evaluations
- Parallel ES performs very well

Plasmonic optical antenna V



Check parameter range

- Black: R1 OK, might be reduced
- Red: R2 should be extended to larger values
- Green: Gap should be as narrow as posible!

Check sigma values

- All sigma reduced with increasing fitness
- Blue: sigma(R2) keeps highest values
- Pink: sigma(Gap) tends to very small values