BRNO UNIVERSITY OF TECHNOLOGY FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION

DREL DEPARTMENT OF RADIO ELECTRONICS

Evolutionary Optimization in Electromagnetics

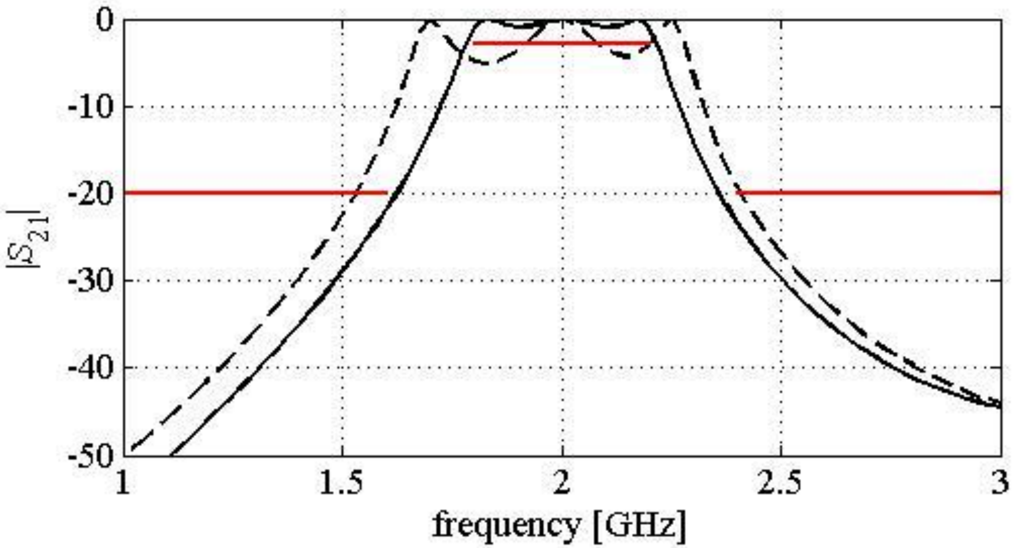
COST IC 1407 Workshop,
Bratislava, 5.4.2017

Outline

- Optimization fundamentals
- Local vs. global methods
- Evolutionary algorithms
- Genetic Algorithms
- Particle Swarm Optimization
- Multi-objective optimization
- Examples in FOPS

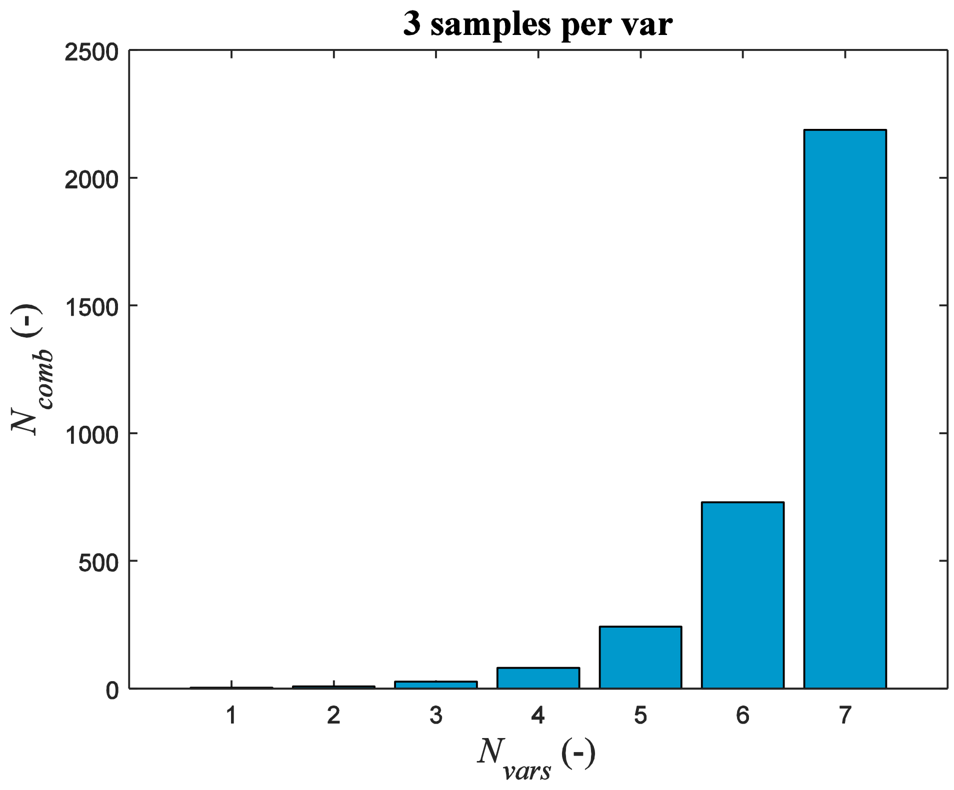
Motivation

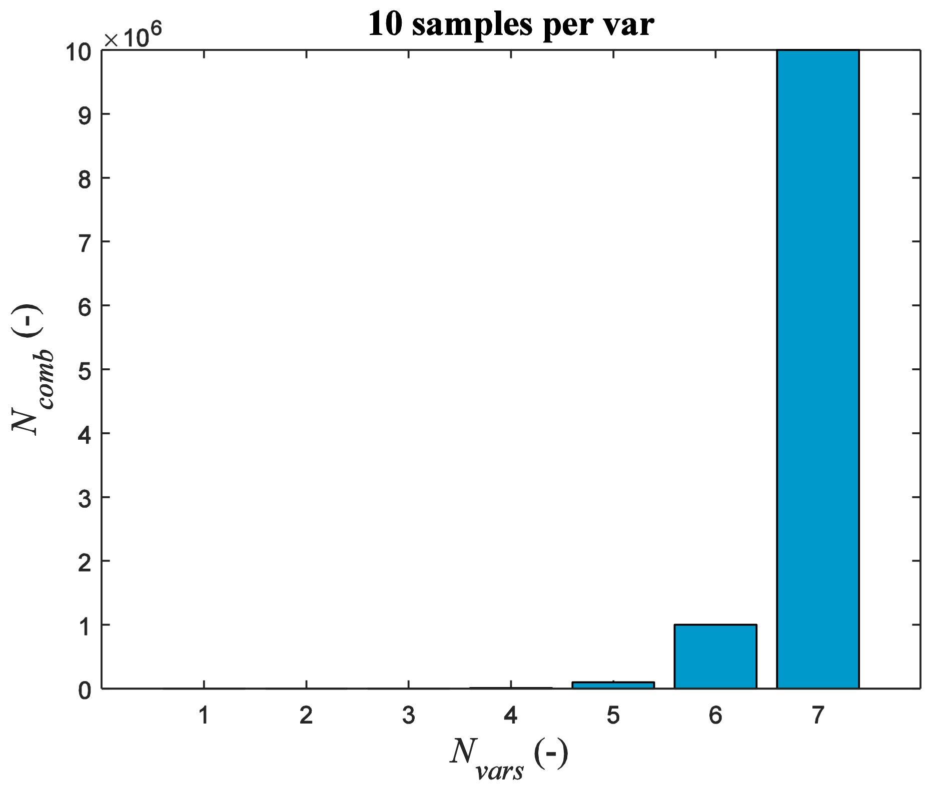
Always try to do the best…



Motivation

Is parametric analysis the way?





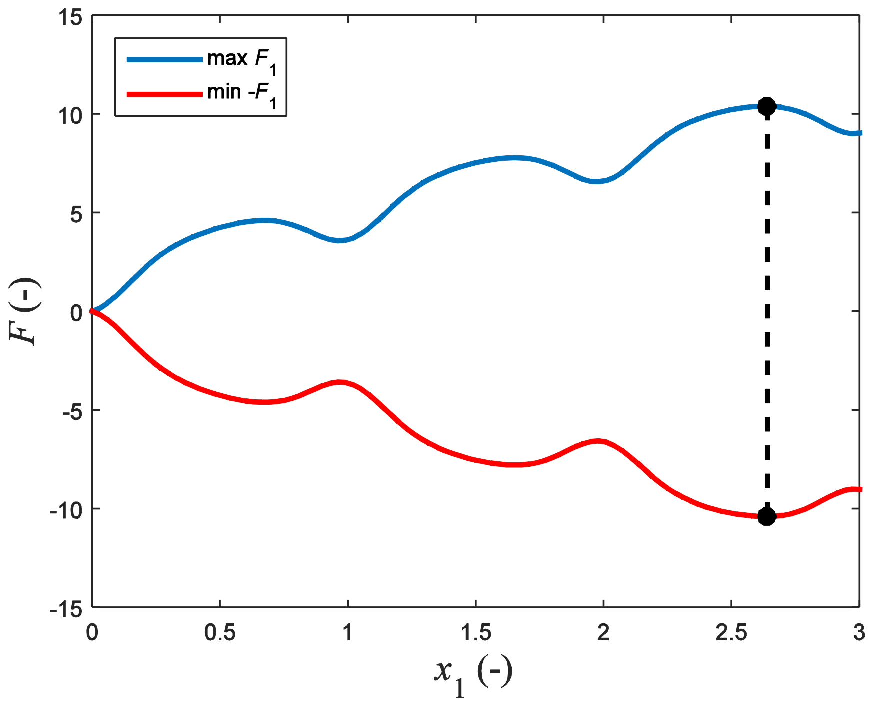
Optimization

- Choice of the best variant from available options
- In mathematics:

$$\begin{aligned}
&Minimize \quad F_m(\mathbf{x}), && m = 1,2,\ldots,M, \\
&subject\,to \quad g_j(\mathbf{x}) \geq 0, && j = 1,2,\ldots,J, \\
&x_{n,\min} \leq x_n \leq x_{n,\max}, && n = 1,2,\ldots,N.
\end{aligned}$$

Min vs. Max

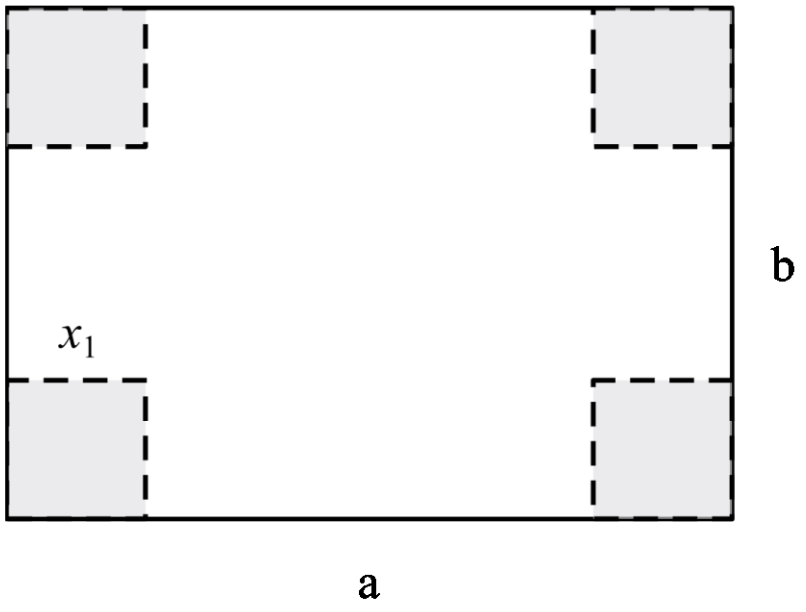
$$Min\,F_m(\mathbf{x}) \approx Max - F_m(\mathbf{x})$$



Objective formulation

Problem:

Having sheet of paper with dimensions *a* and *b*, what is the size of squares to be cut from the corners of the sheet to build a box with the highest volume?



Decision space:

$$\mathbf{x} = [x_1]$$

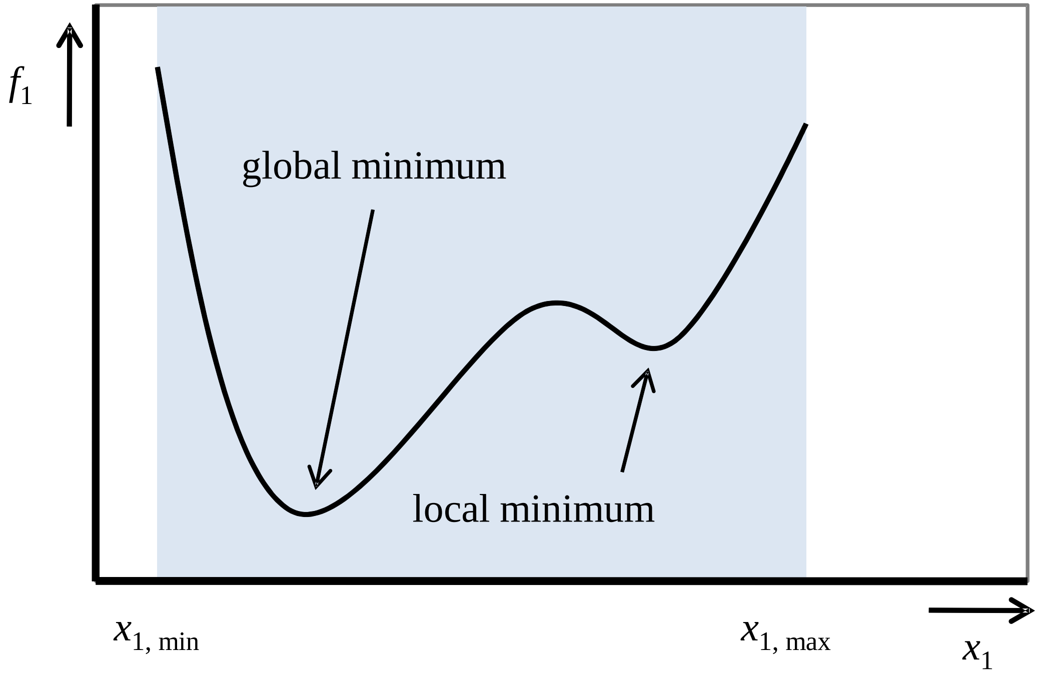
Objective space

$$f_1 = 4x_1^3 - (2a + 2b)x_1^2 + abx_1$$

Optimization taxonomy

SOO (Single-Objective)	MOO (Multi-Objective)
Single variable	Multiple variables
Global	Local
Continuous dec. space	Discrete dec. space
Unconstrained	Constrained
Static	Dynamic

Global vs. local minimum



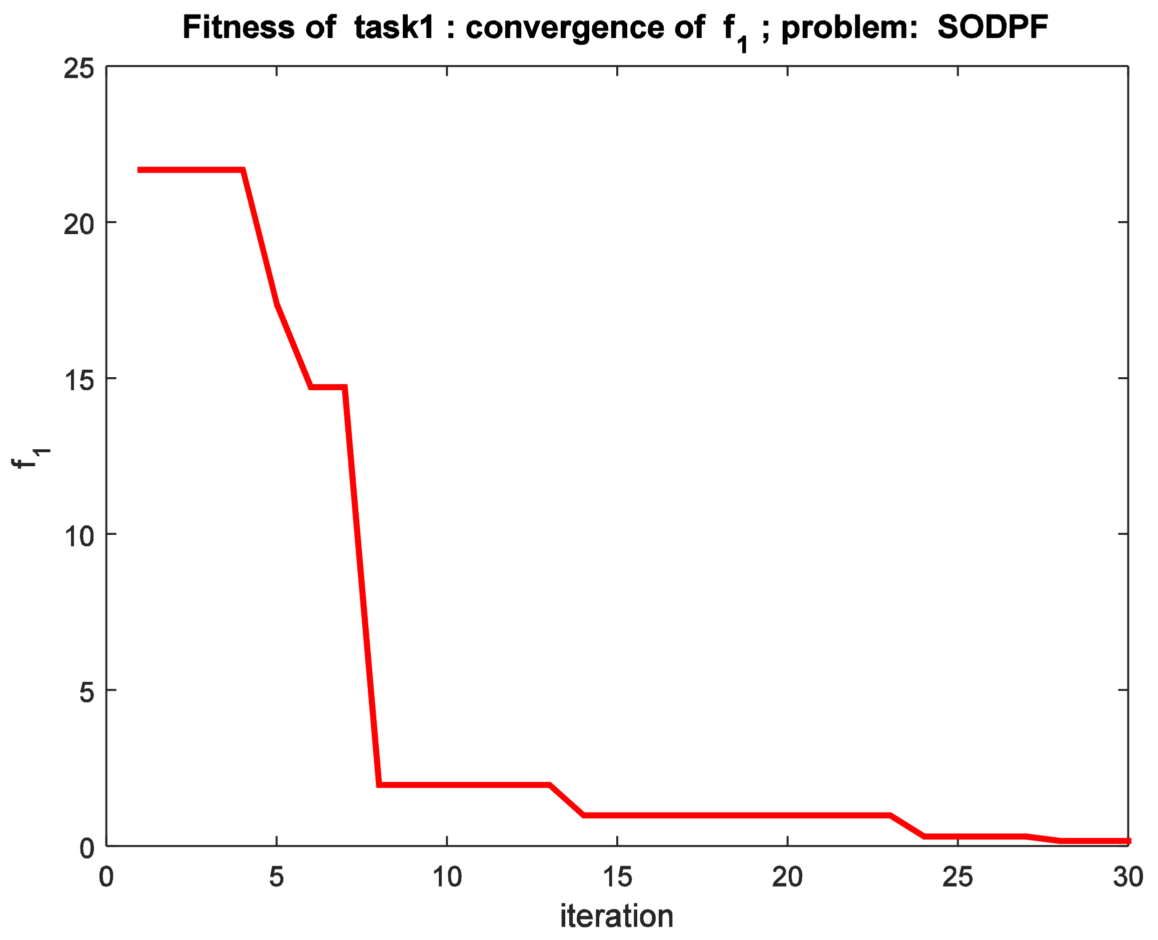
Global vs. Local

- local methods are faster and more efficient, but global are more robust, no dependence on initial guess
- derivatives can not be evaluated,
- objective functions cannot be formulated in closed form (e.g. use of solver output),
- initial guess is too far,
- user is lazy!

Evolutionary methods

- random start – choice of the initial guess is not so important
- agent (individual, …) updates its position within the decision space
- agents are able to escape from local minimum (maximum)
- stochastic – different runs different results (at least development)

Convergence plot



Genetic algorithms

- Holland 1962
- Inspired by Darwin – only good properties of genome are maintained for next generations

- **GAs work with discrete decision space!!!**

GA - taxonomy

- Gene – variable coded in binary form
- Gene length – number of bits used for decoding
- Chromosome – genes from all variables
- Generation – multiple chromosomes
- Decimation – reduction of the worst Chromosomes in Generation
- Mating pool – set of Chromosomes selected for reproduction
- Crossover – combination of two Chromosomes
- Mutation – bit change in one Chromosome

GA - reproduction

- **Crossover:**

  00|1010 → 00|0011
  10|0011 → 10|1010

- **Mutation:**

  001010 → 001110

GA - reproduction

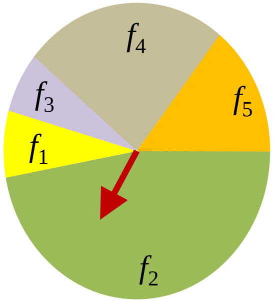
- **Decimation:**

g_1	g_2	g_3	f
110	0101	00010	0,15
101	1101	00101	0,36
011	1011	00110	1,53
100	1010	10001	6,27
011	0011	11010	11,83
101	1011	10010	13,21
100	0101	00101	20,89
011	0101	10101	56,12

- **Elitism:**
  - Solution with the best value of objective function is automatically considered also for the next generation.

GA - reproduction

- **Roulette selection:**



#	f (-)	$1/f$ (-)	%
1	6.82	0.15	7.80
2	1.11	0.90	47.94
3	8.48	0.12	6.28
4	2.57	0.39	20.71
5	3.08	0.32	17.28
total	22.06	1.88	100.00

- **Tournament selection:**

f	Chrom.	Round	Mating pool
1.25	C1	C1 vs. C2	C1
7.37	C2	C4 vs. C2	C4
2.42	C3	C1 vs. C3	C1
6.12	C4	C4 vs. C3	C3

Particle Swarm Optimization

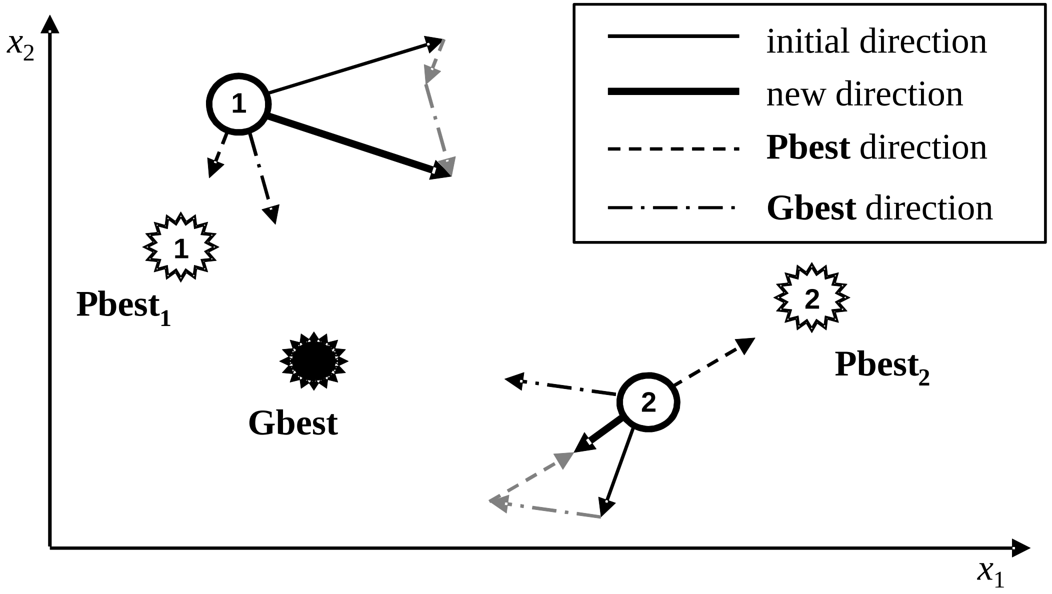
- 1995 - Eberhart and Kennedy
- cooperation of swarm over the meadow
- cognitive learning: personal experience of agent
- social learning: experience of the whole swarm

Swarm update

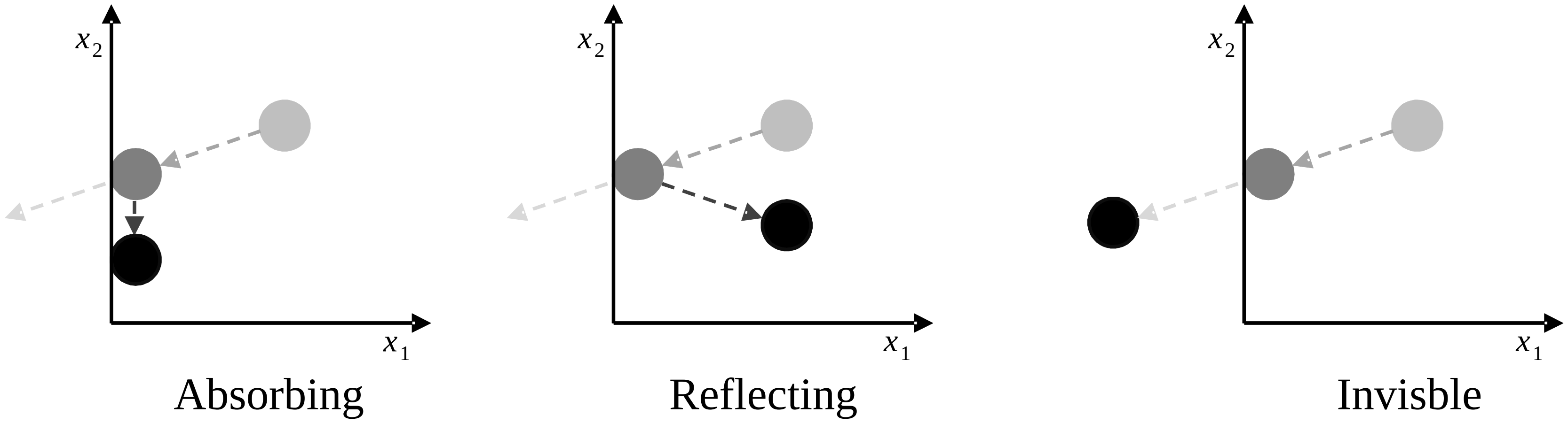
$$\mathbf{x}_q(i) = \mathbf{x}_q(i-1) + \mathbf{v}_q(i-1)$$

$$\mathbf{v}_q(i) = w \cdot \mathbf{v}_q(i-1) + c_1 \cdot \mathbf{rnd}_q\left[\mathbf{Pbest}_q(i-1) - \mathbf{x}_q(i-1)\right]$$
$$+ c_2 \cdot \mathbf{rnd}_q\left[\mathbf{Gbest}(i-1) - \mathbf{x}_q(i-1)\right]$$

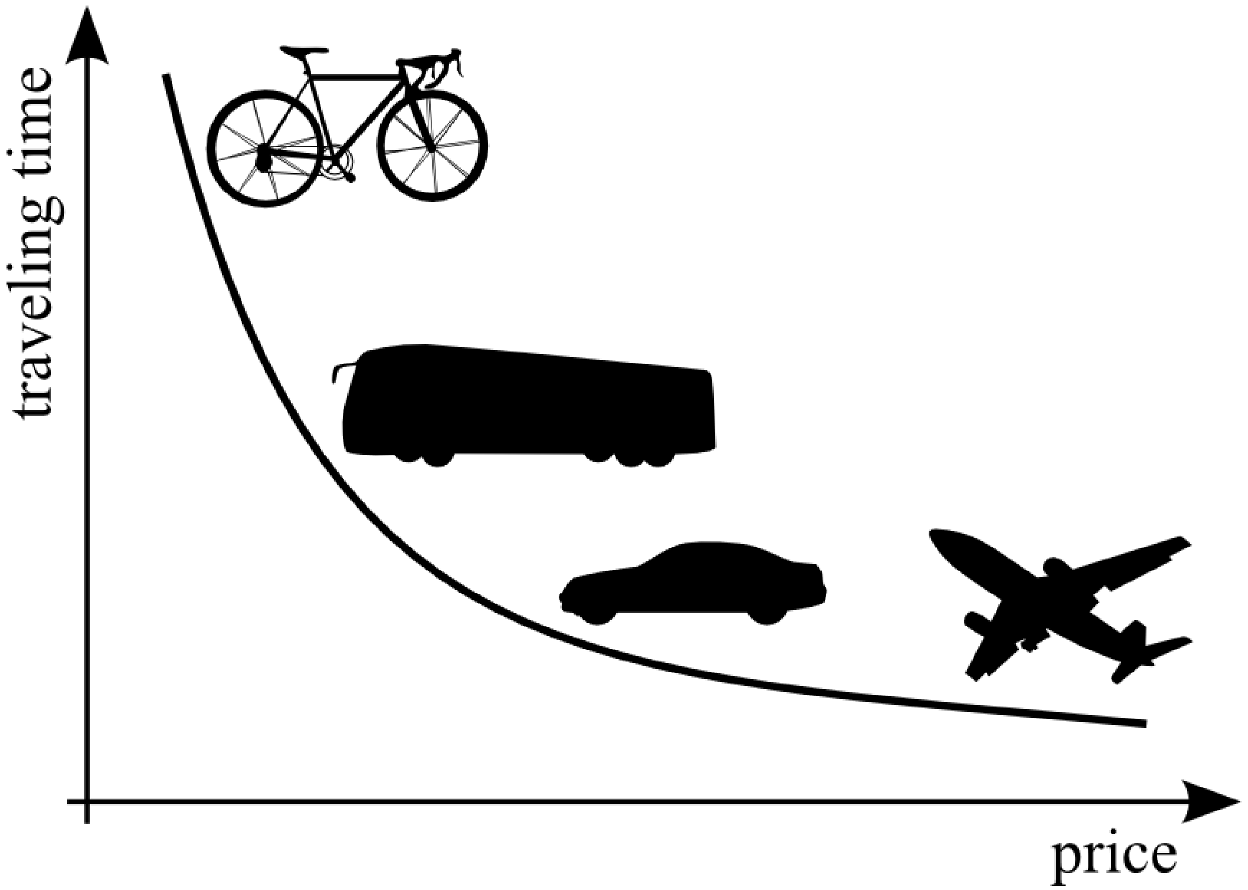
Swarm update



Wall types

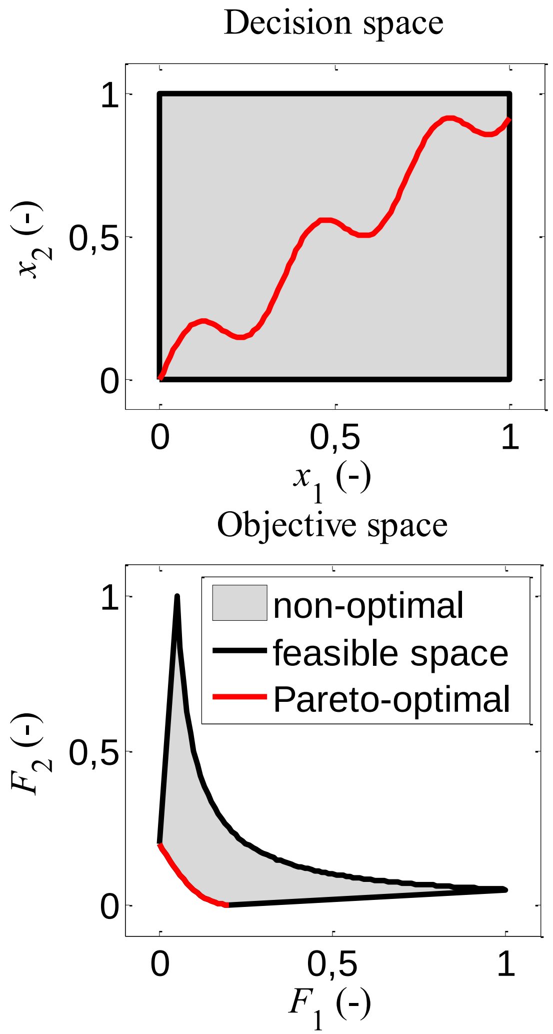


Multi-objective optimization



Pareto front

- Trade-off solution
- Decision space vs. Objective space
- Two goals – accuracy vs. Distribution
- Choice of final solution
- Pareto front shapes



Multi-objective strategies

Aggregating methods

Transform to SOOP

Single solution

How to choose w?

$$F = \sum_{m=1}^{M} w_m F_m, \sum_{m=1}^{M} w_m = 1.$$

MO Optimization

More complex routine

Set of Pareto optimal

Extra information

Decision making

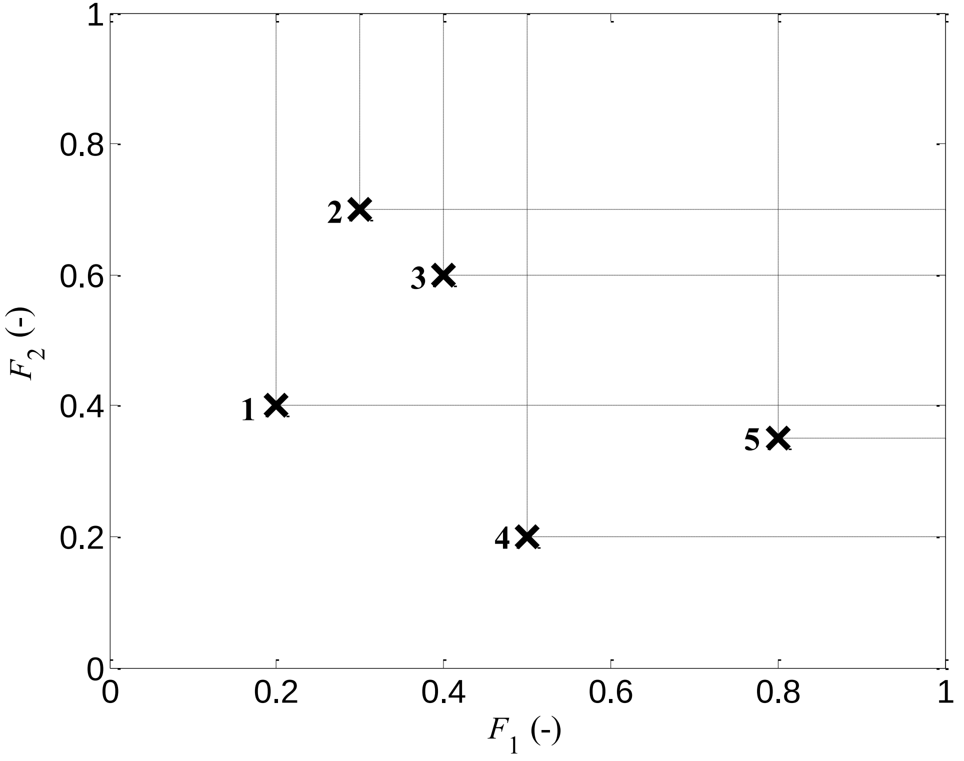
Dominance concept

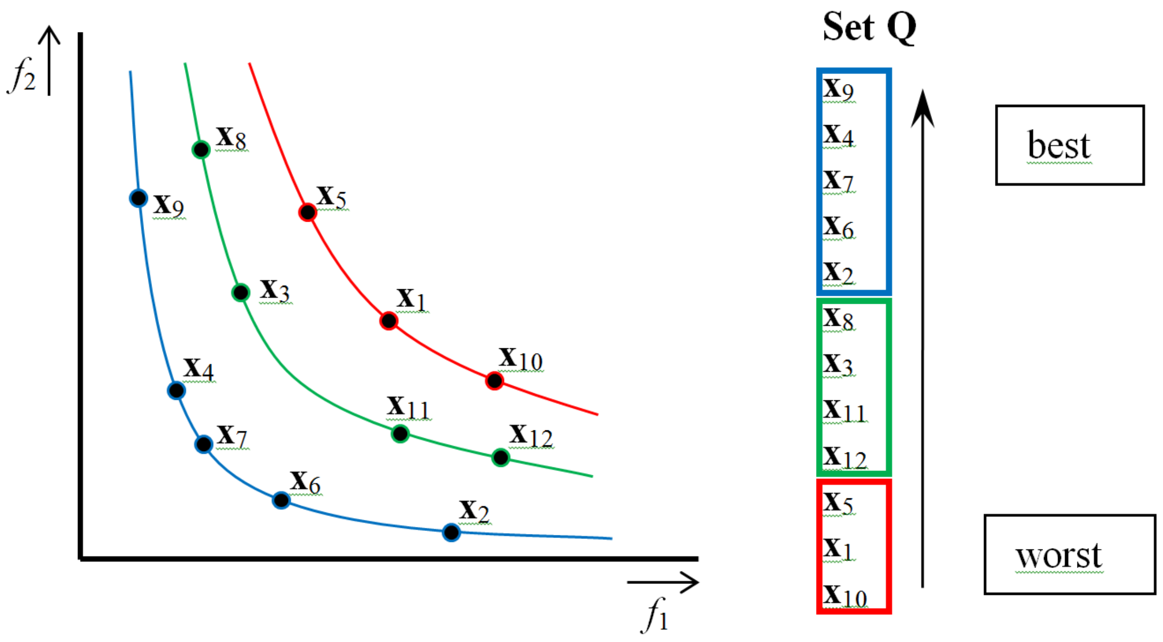
Solution $\mathbf{x}_1$ *is said to dominate the other solution* $\mathbf{x}_2$*, if both conditions 1 and 2 are true:*

1. Solution $\mathbf{x}_1$ *is no worse than* $\mathbf{x}_2$ *in all objectives.*

2. Solution $\mathbf{x}_1$ *is strictly better than* $\mathbf{x}_2$ *in at least one objective.*

Dominance concept

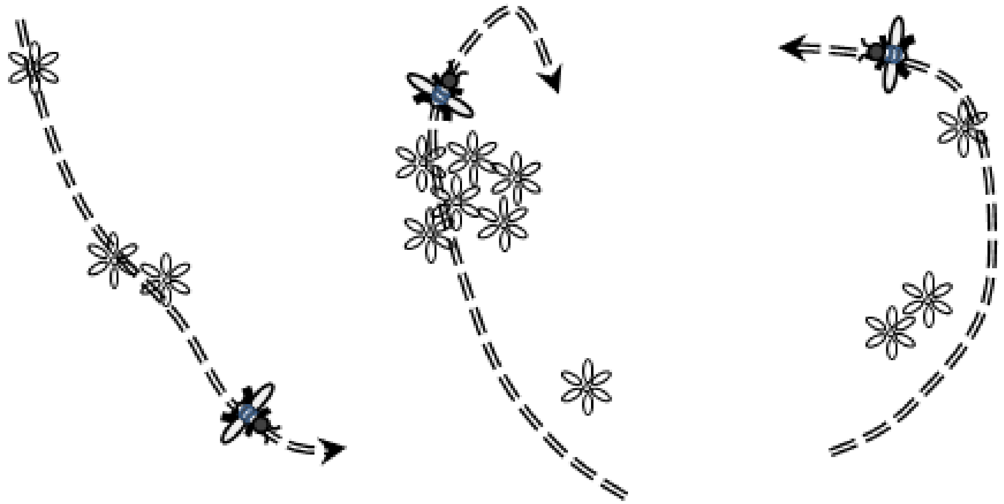




MOPSO

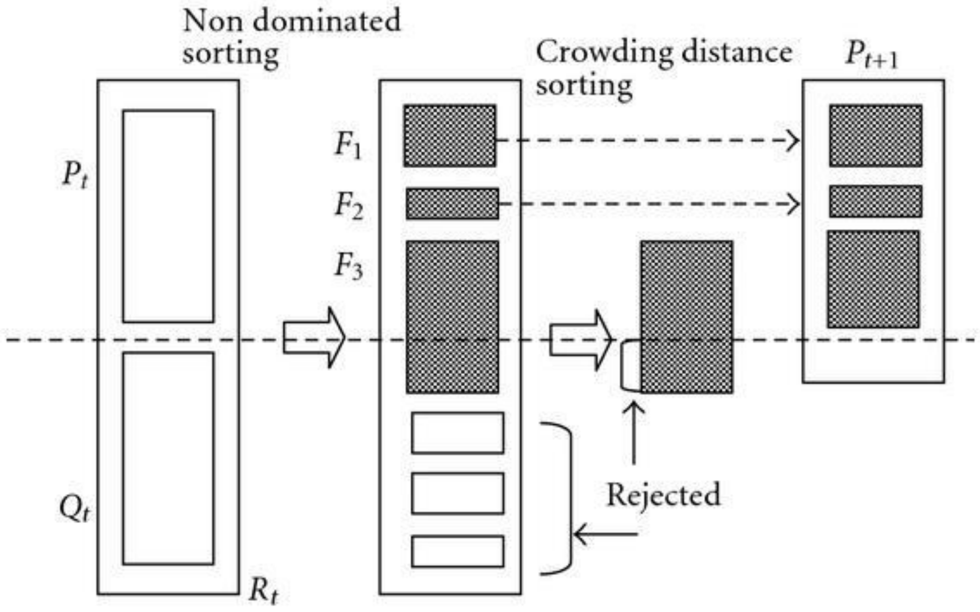
Nanbo, J., Rahmat-Samii, Y. " Advances in Particle Swarm Optimization for Antenna Designs: Real-Number, Binary, Single-Objective and Multiobjective Implementations," IEEE Transactions on Ant. Propag., vol. 55, no. 3, pp. 556-567, 2007.

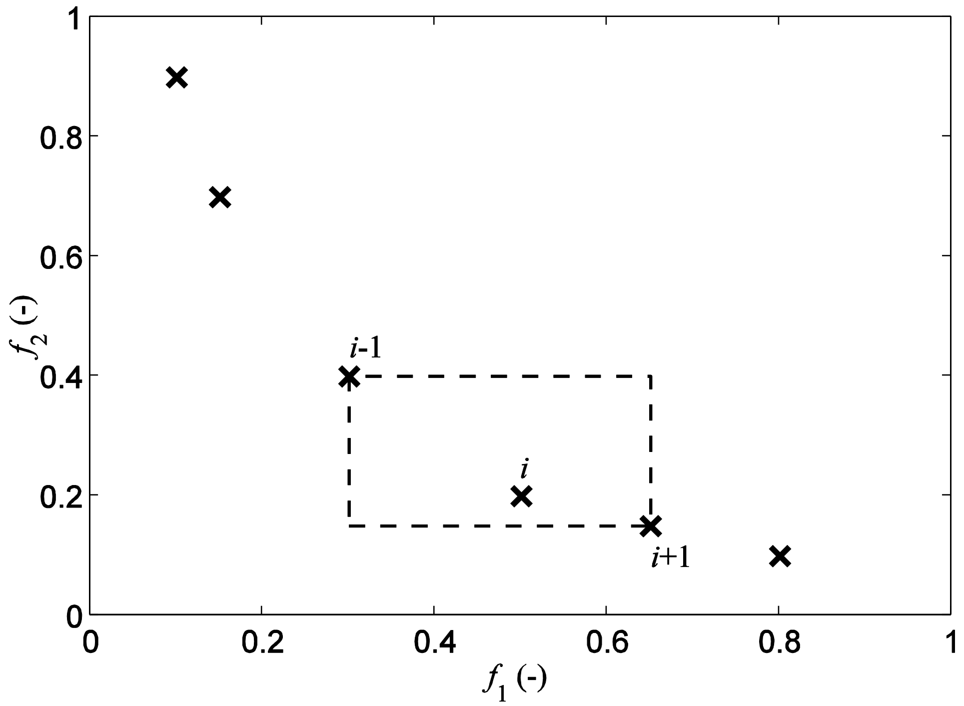
- **gbest** – closest solution from external archive
- **pbest** – first non-dominated solution found by particle



NSGA-II

Deb, K., Pratap, A., Agarwal, S., Meyarivan, T. " A fast and elitist multiobjective genetic algorithm: NSGA-II," IEEE Transactions on Evol. Comput., vol. 6, no. 2, pp. 182-197, 2002.





FOPS

- Fast Optimization ProcedureS
- http://antennatoolbox.com/fops-about.php
- single- and multi-objective codes
- chains from individual methods
- local methods: steepest descent, Newton method
- global methods: Nelder Mead, GA, PSO, DE, SOMA …

Feeding Point

Problem:

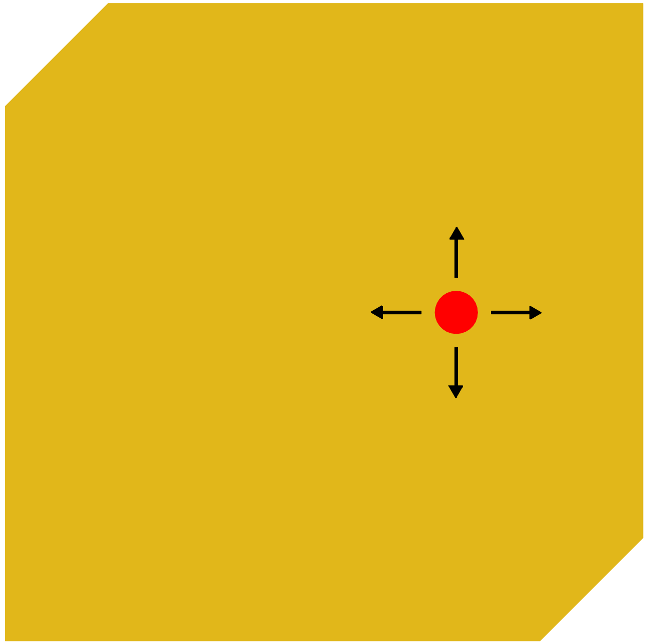
Find proper point on antenna for coaxial port.

Decision space:

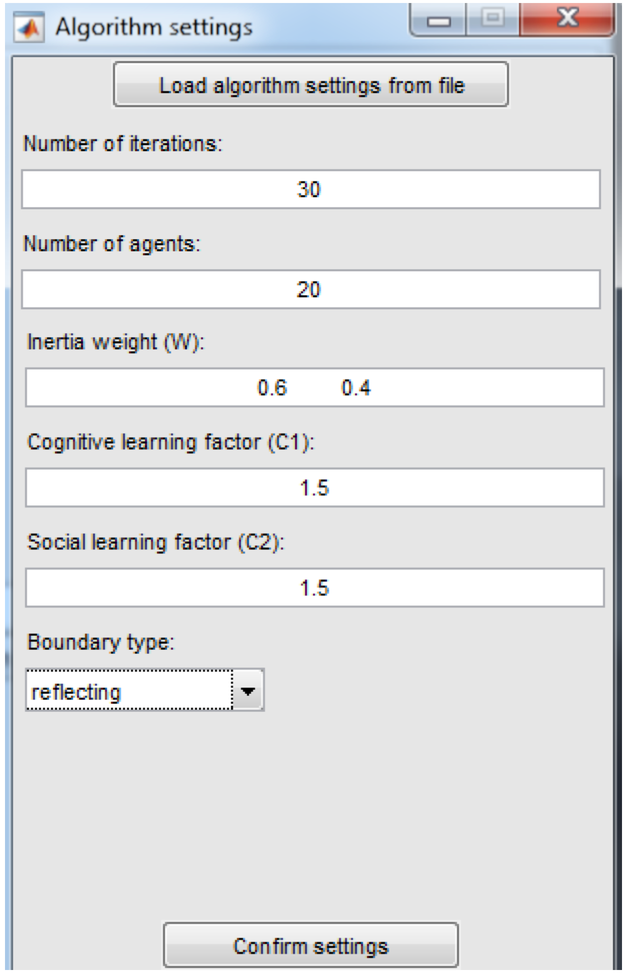
$$\mathbf{x} = [x_1, x_2]$$

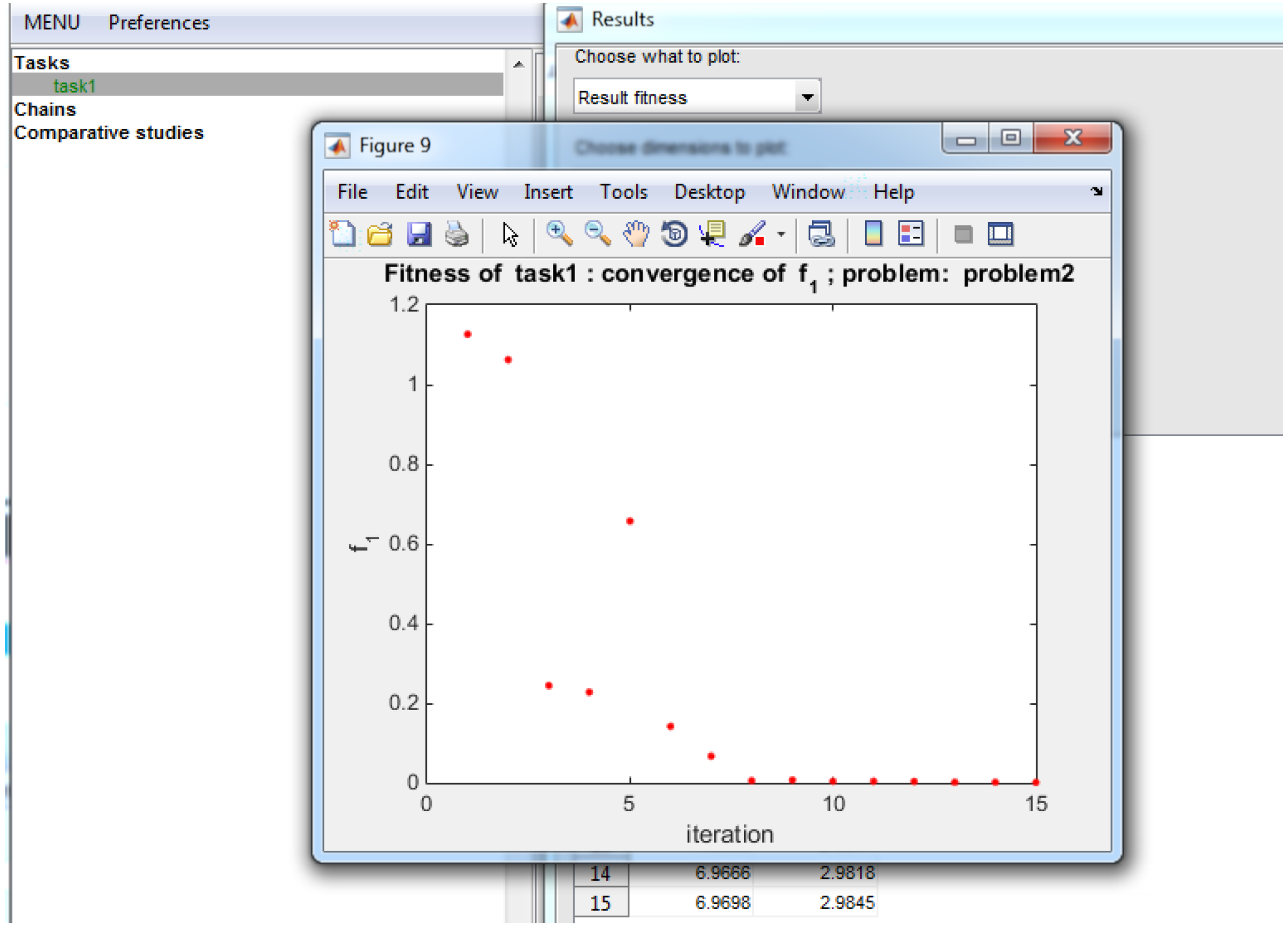
Objective space

$$f = \left(\mathrm{Re}\{Z_{inp}(\mathbf{x})\} - 50\right)^2 + \left(\mathrm{Im}\{Z_{inp}(\mathbf{x})\} - 0\right)^2$$



Feeding Point





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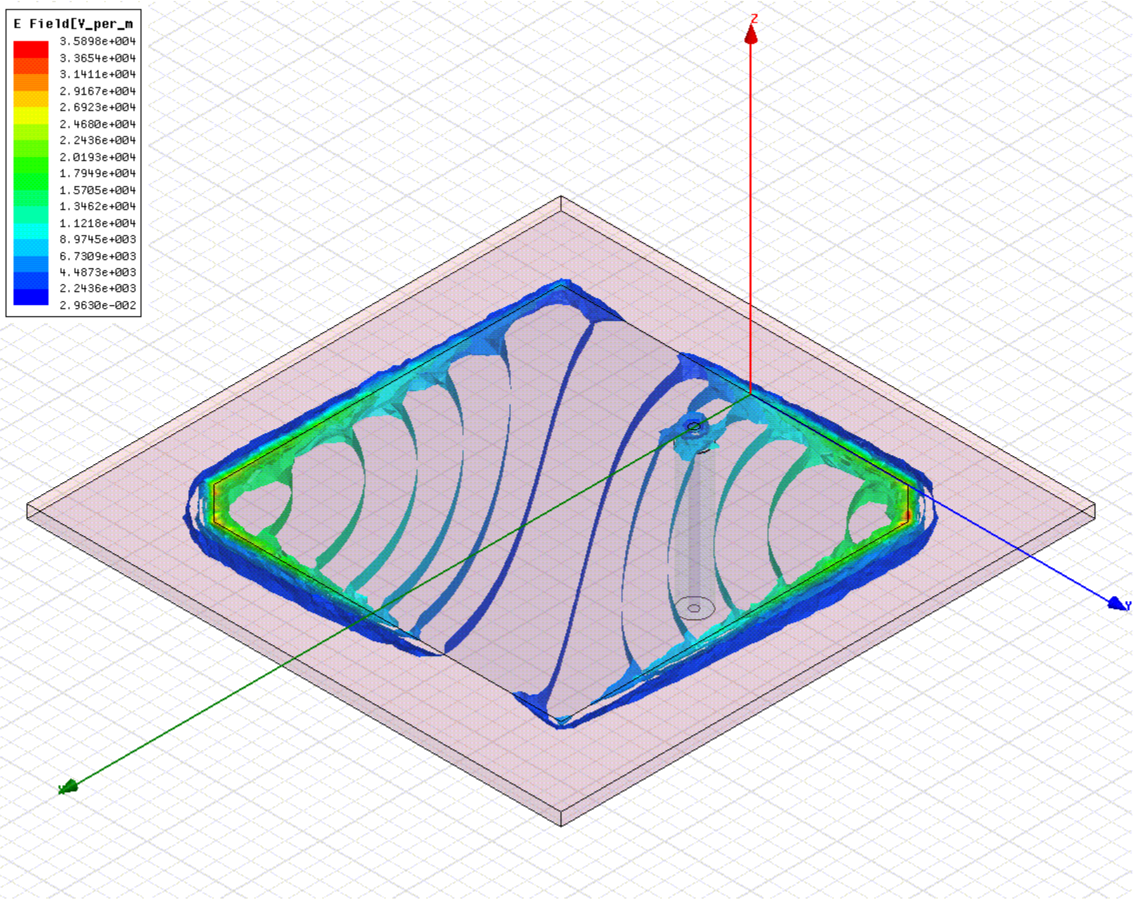


Filter design

Problem:

Find proper material and width of layers to design band pass filter.

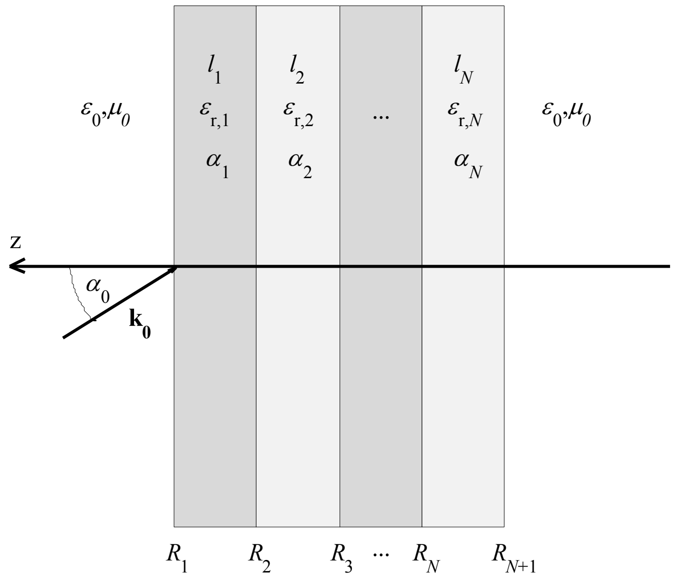
Decision space:

$$\mathbf{x} = \left[l_1, \varepsilon_1, l_2, \varepsilon_2, \ldots, l_7, \varepsilon_7 \right]$$

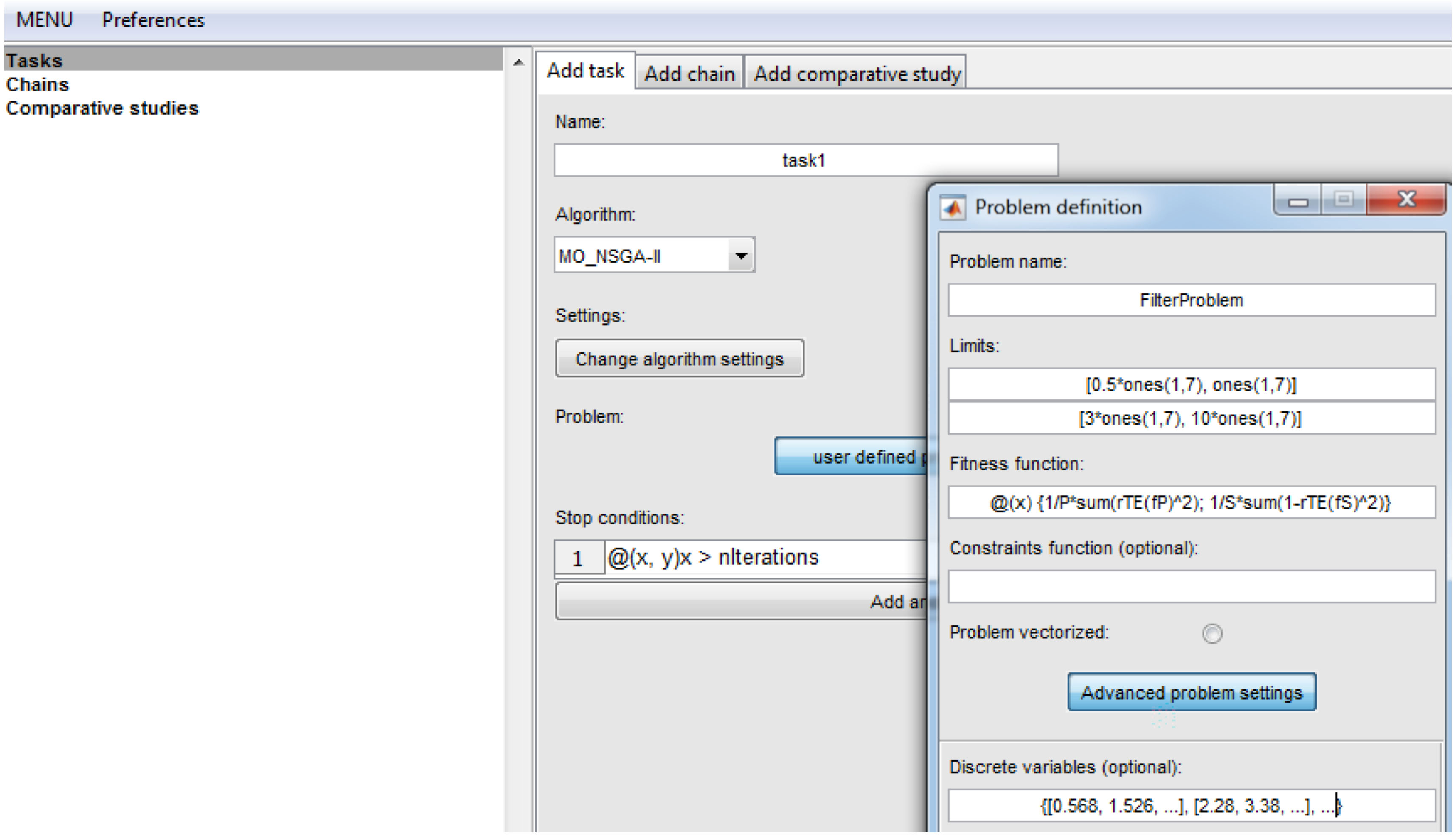
Objective space

$$F_1 = \frac{1}{P} \sum_{p=1}^{P} \left[\left| R_{1,\mathrm{TE}} \left(f_p \right) \right|^2 + \left| R_{1,\mathrm{TM}} \left(f_p \right) \right|^2 \right]$$

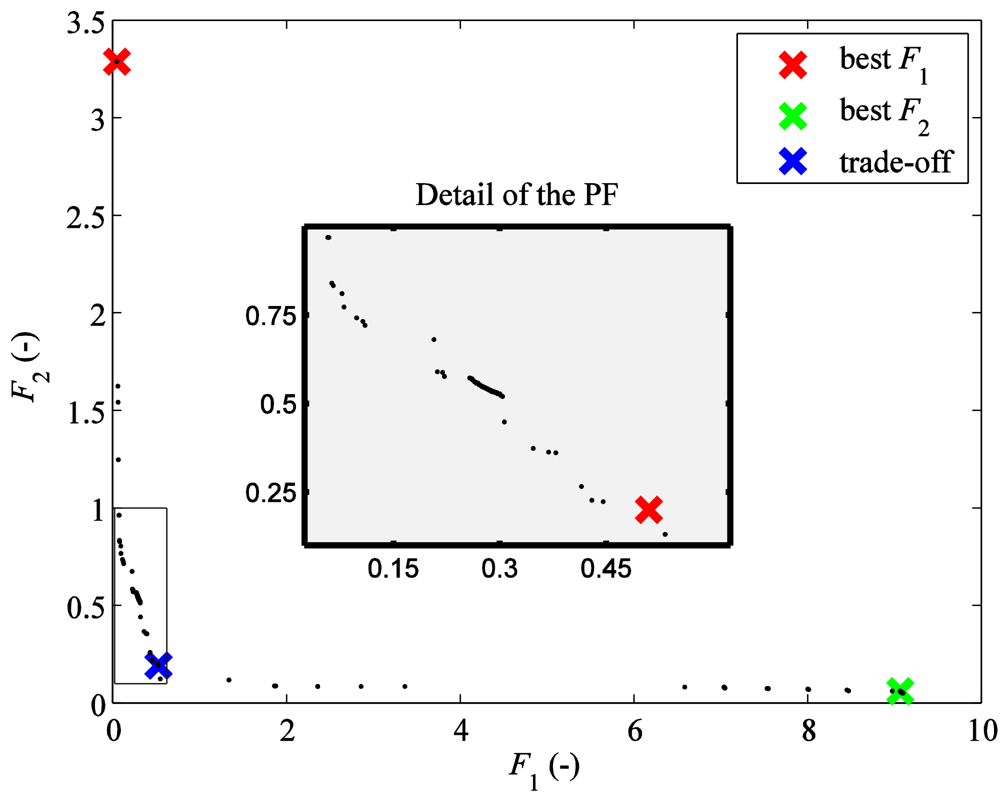
$$F_2 = \frac{1}{S} \sum_{s=1}^{S} \left[2 - \left| R_{1,\mathrm{TE}} \left(f_s \right) \right|^2 - \left| R_{1,\mathrm{TM}} \left(f_s \right) \right|^2 \right]$$

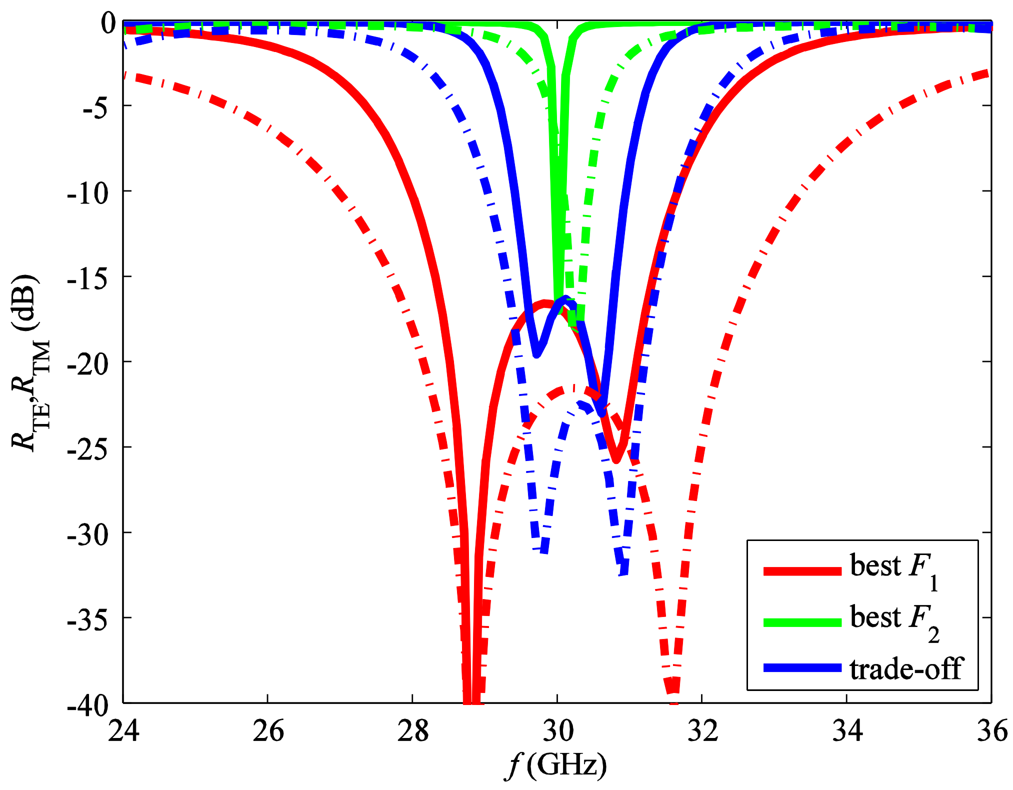


Filter design

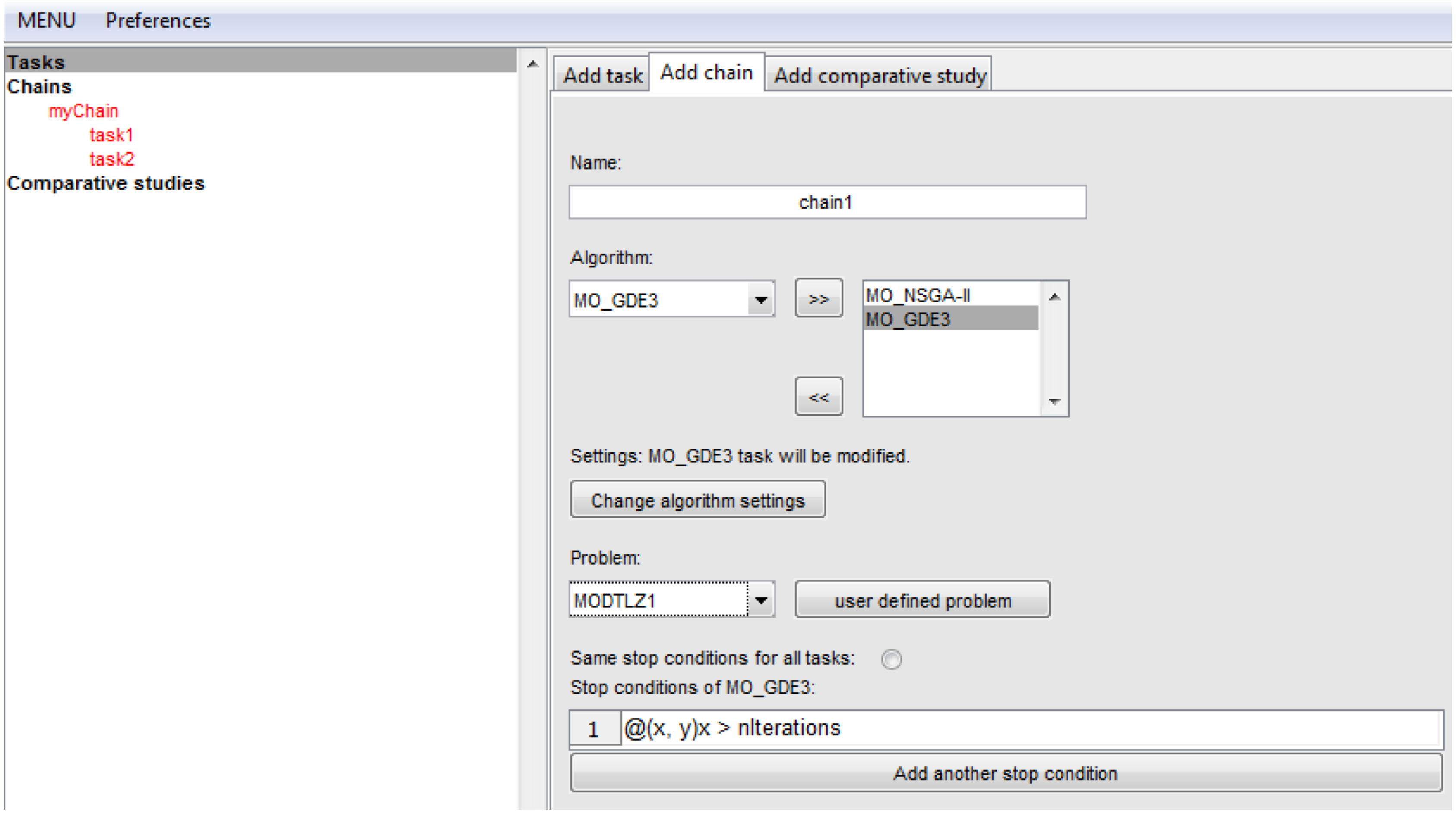


Filter design



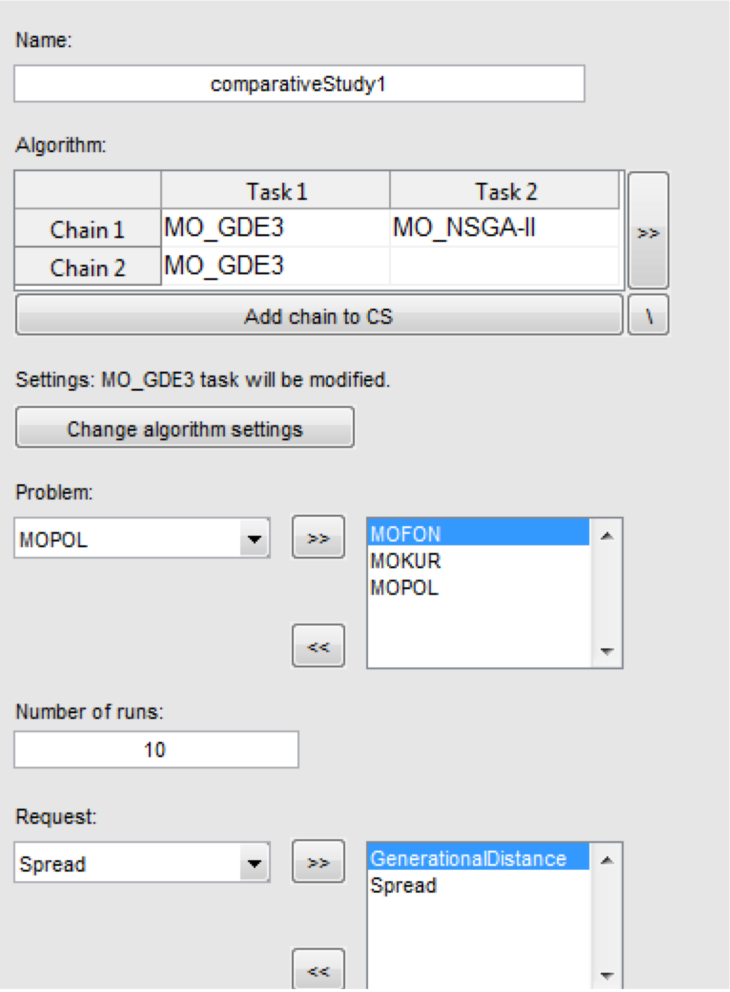


Chain



MENU
Preferences
Tasks
Chains
myChain
task1
task2
Comparative studies
Add task
Add chain
Add comparative study
Name:
chain1
Algorithm:
MO_GDE3
>>
<<
MO_NSGA-II
MO_GDE3
Settings: MO_GDE3 task will be modified.
Change algorithm settings
Problem:
MODTLZ1
user defined problem
Same stop conditions for all tasks:
Stop conditions of MO_GDE3:
1
@(x, y)x > nIterations
Add another stop condition

Comparative Study



Comparative Study

Tasks
Chains
- myChain
  - task1
  - task2

Comparative studies
- comparativeStudy1
  - chain1
    - task1
    - task2
  - chain2
    - task1
  - chain3
    - task1
    - task2
  - chain4
    - task1
  - chain5
    - task1
    - task2
  - chain6
    - task1

Add task | Add chain | Add comparative study

Name:

comparativeStudy2

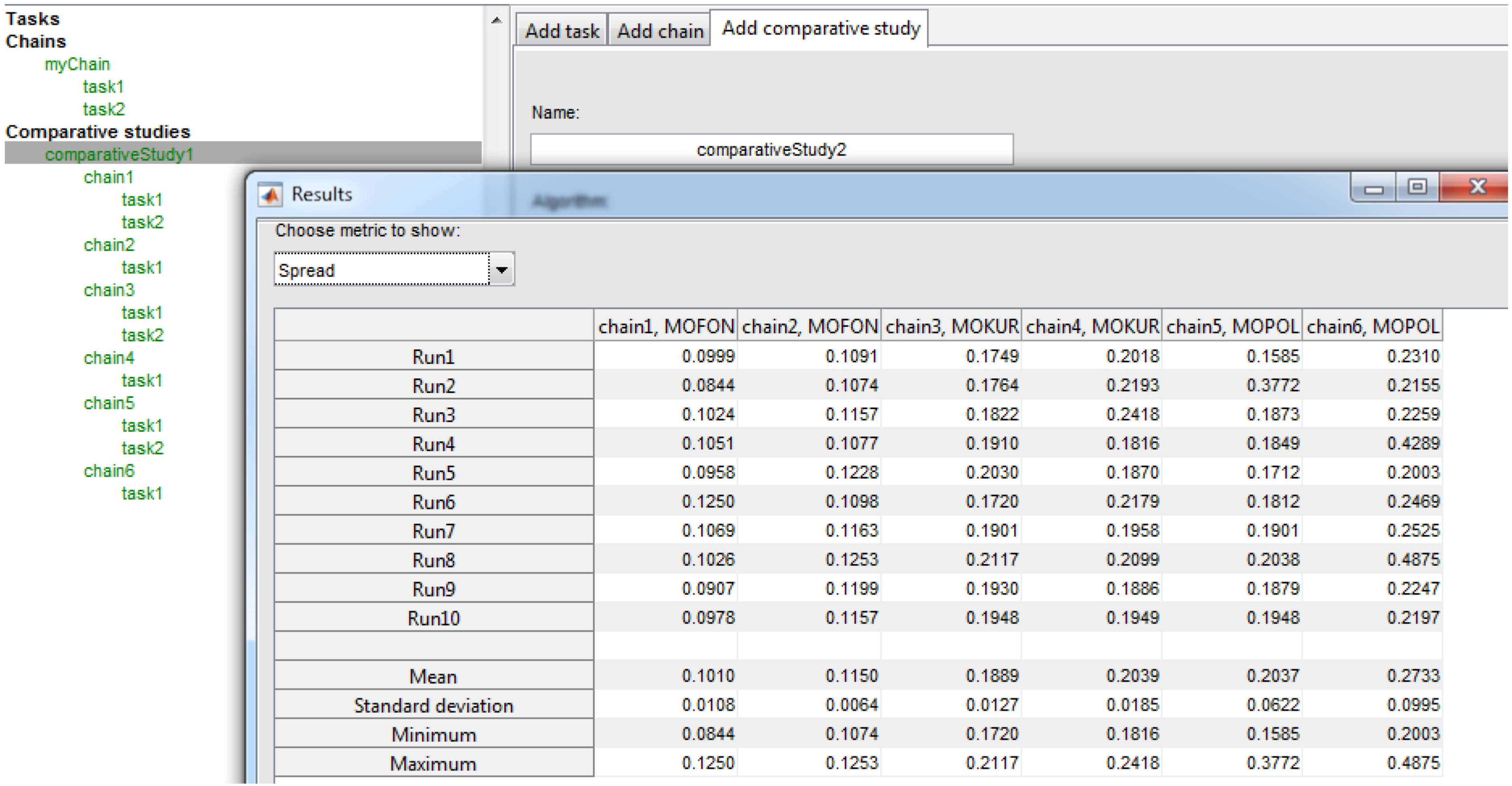
Results

Choose metric to show:

Spread

	chain1, MOFON	chain2, MOFON	chain3, MOKUR	chain4, MOKUR	chain5, MOPOL	chain6, MOPOL
Run1	0.0999	0.1091	0.1749	0.2018	0.1585	0.2310
Run2	0.0844	0.1074	0.1764	0.2193	0.3772	0.2155
Run3	0.1024	0.1157	0.1822	0.2418	0.1873	0.2259
Run4	0.1051	0.1077	0.1910	0.1816	0.1849	0.4289
Run5	0.0958	0.1228	0.2030	0.1870	0.1712	0.2003
Run6	0.1250	0.1098	0.1720	0.2179	0.1812	0.2469
Run7	0.1069	0.1163	0.1901	0.1958	0.1901	0.2525
Run8	0.1026	0.1253	0.2117	0.2099	0.2038	0.4875
Run9	0.0907	0.1199	0.1930	0.1886	0.1879	0.2247
Run10	0.0978	0.1157	0.1948	0.1949	0.1948	0.2197
Mean	0.1010	0.1150	0.1889	0.2039	0.2037	0.2733
Standard deviation	0.0108	0.0064	0.0127	0.0185	0.0622	0.0995
Minimum	0.0844	0.1074	0.1720	0.1816	0.1585	0.2003
Maximum	0.1250	0.1253	0.2117	0.2418	0.3772	0.4875

Comparative Study



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Thank you for your attention!

http://antennatoolbox.com/

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