

Further development of Particle Swarm Optimization method applied to accelerators

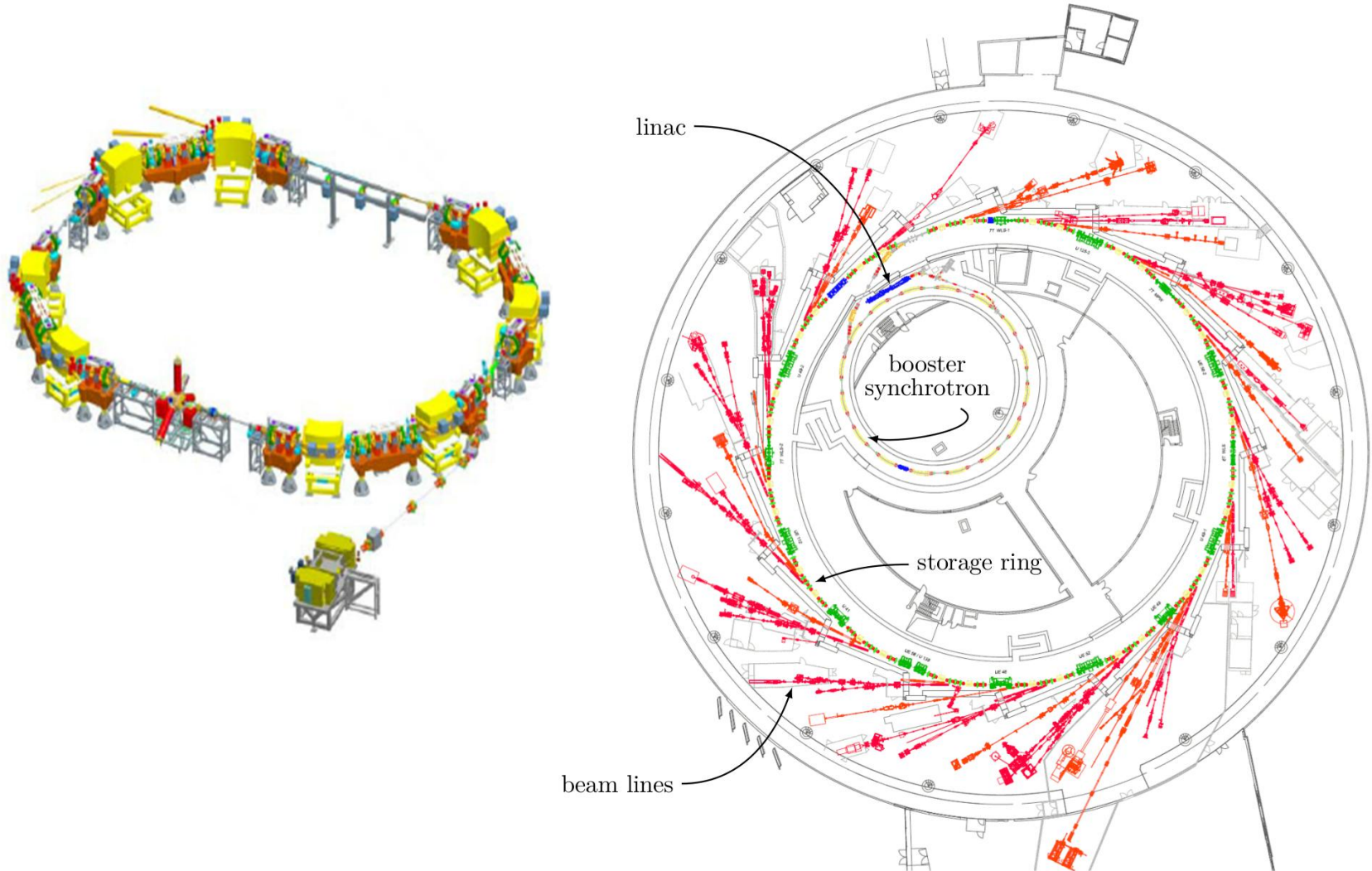
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Supervisor: Dr. Ji Li

FG-IA

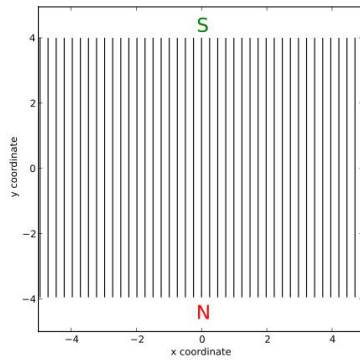
Helmholtz Zentrum Berlin, Germany

- Background and motivation
- Introduction of Particle Swarm Optimization (PSO)
- Improvements applied to PSO
- Experimental and simulation results
- Multi-objective PSO

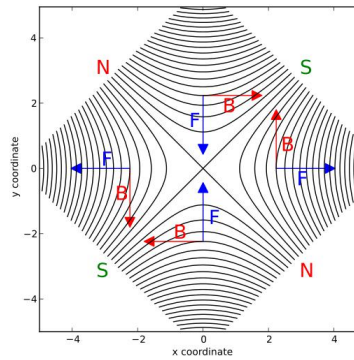


Field lines of an idealized
dipole, **quadrupole** and **sextupole** magnet
in the plane transverse to the beam direction

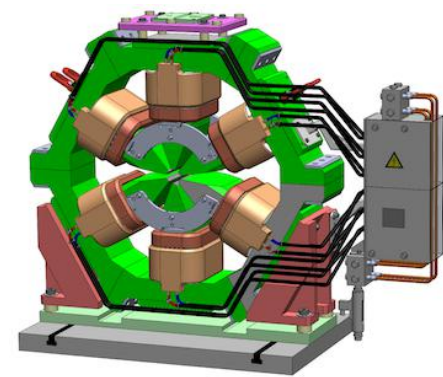
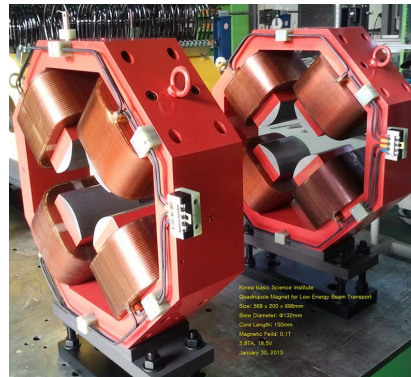
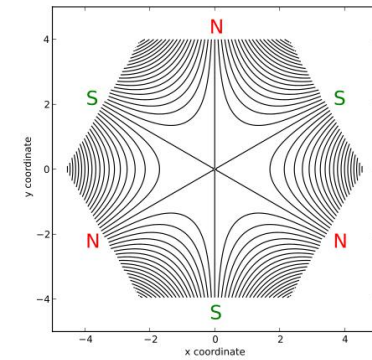
dipole



quadrupole



sextupole



1) Injection efficiency = $\frac{\text{Beam current injected to storage ring}}{\text{Beam current from injector}}$

2)
$$I = I_0 \cdot e^{-\frac{t}{\tau}}$$

lifetime

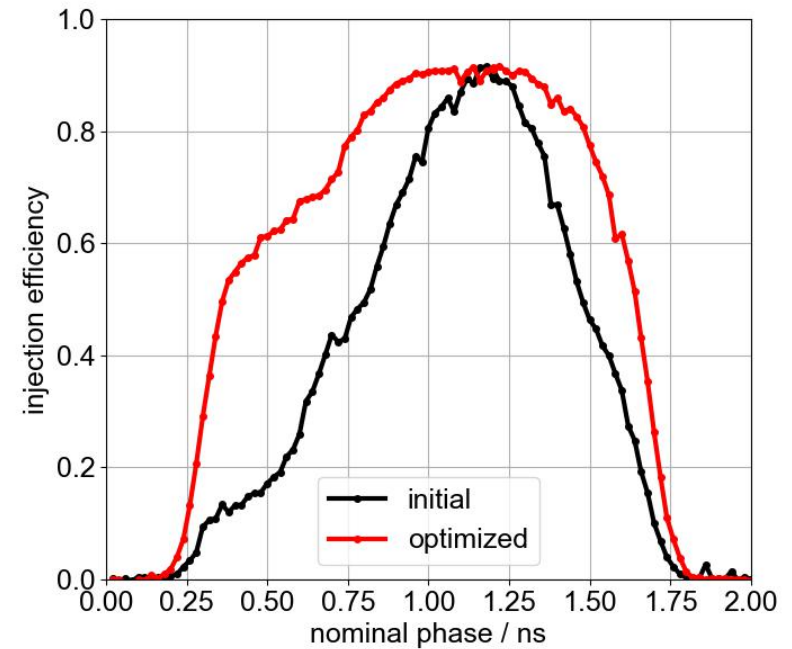
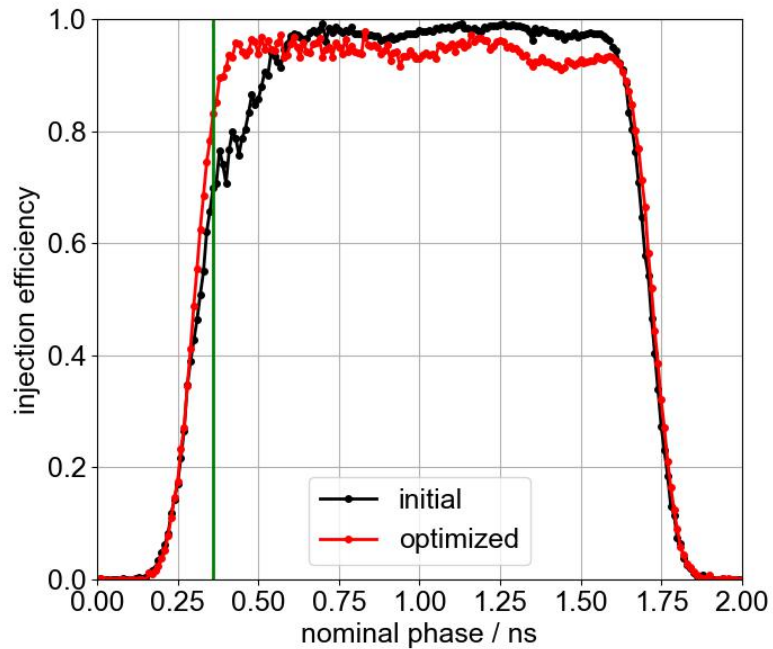
ring-Sextadl

Girag 2018/06/30

Ring Sextupoles

Cmde: !

Name	S	Setpoint	Readback	Mem	C
S1PR	●	88.6272	88.578	88.6272	
S2PDR	●	72.6533	72.640	72.6533	
S2PTR	●	72.6533	72.639	72.6533	
S3PDR	●	39.9495	39.911	39.9495	
S3PTR	●	39.9495	39.934	39.9495	
S4PDR	●	31.1680	31.121	31.1680	
S4PTR	●	31.1680	31.119	31.1680	
S3PD1R	●	39.9495	40.13	39.9495	
S4PD1R	●	31.1680	31.45	31.1680	
S3P1T6R	●	39.9495	40.20	39.9495	
S3P2T6R	●	39.9495	39.97	39.9495	
S4P1T6R	●	31.1680	31.30	31.1680	
S4P2T6R	●	31.1680	31.24	31.1680	



- optimization of 10 sextupoles
- insertion devices deteriorate injection efficiency

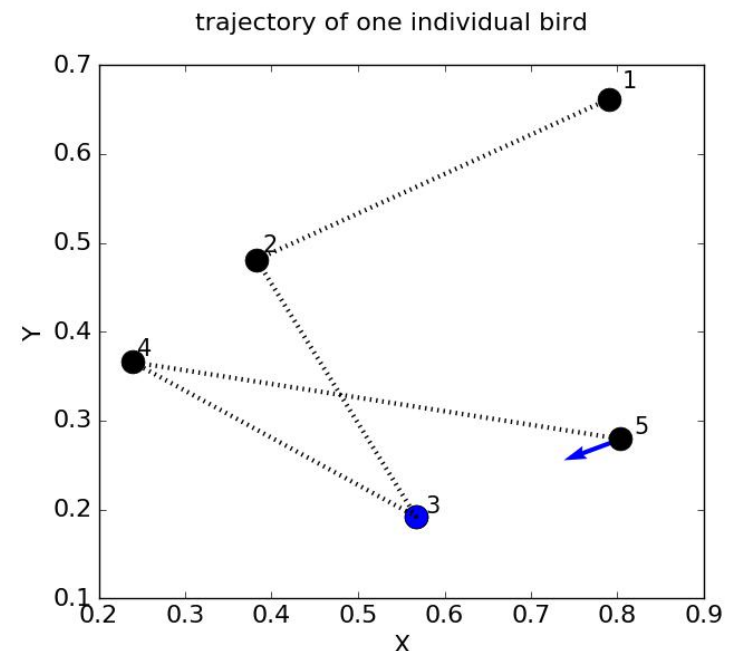
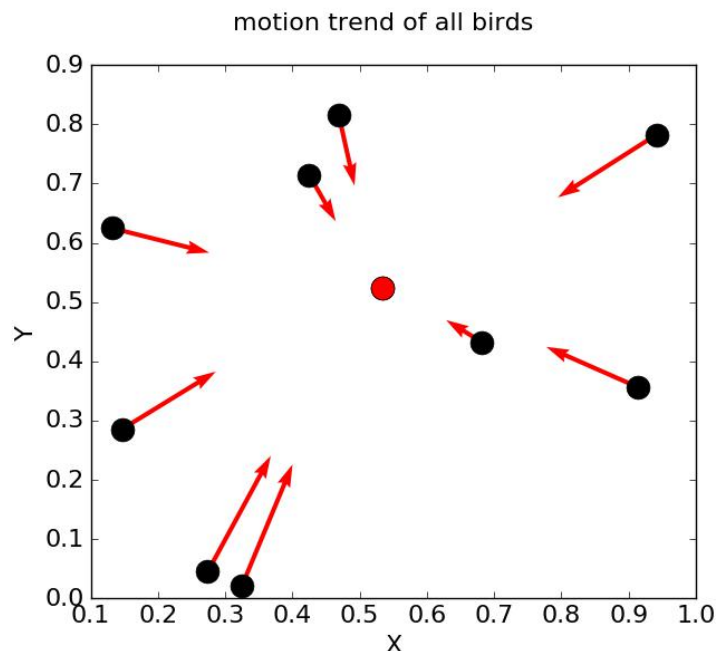


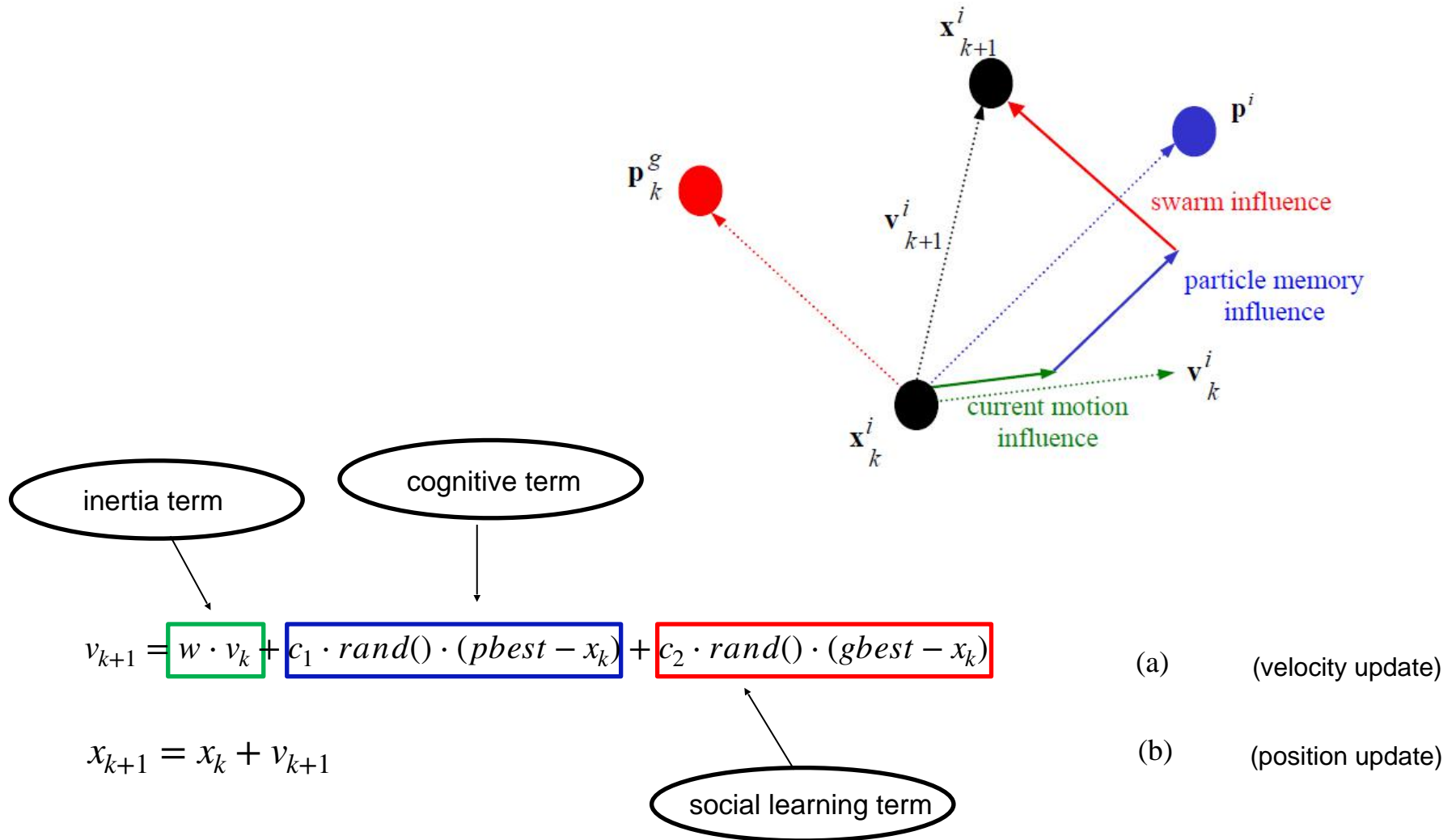
Birds in a flock searching for food

Developed by Dr. Eberhart and Dr. Kennedy in 1995

SCENARIO:

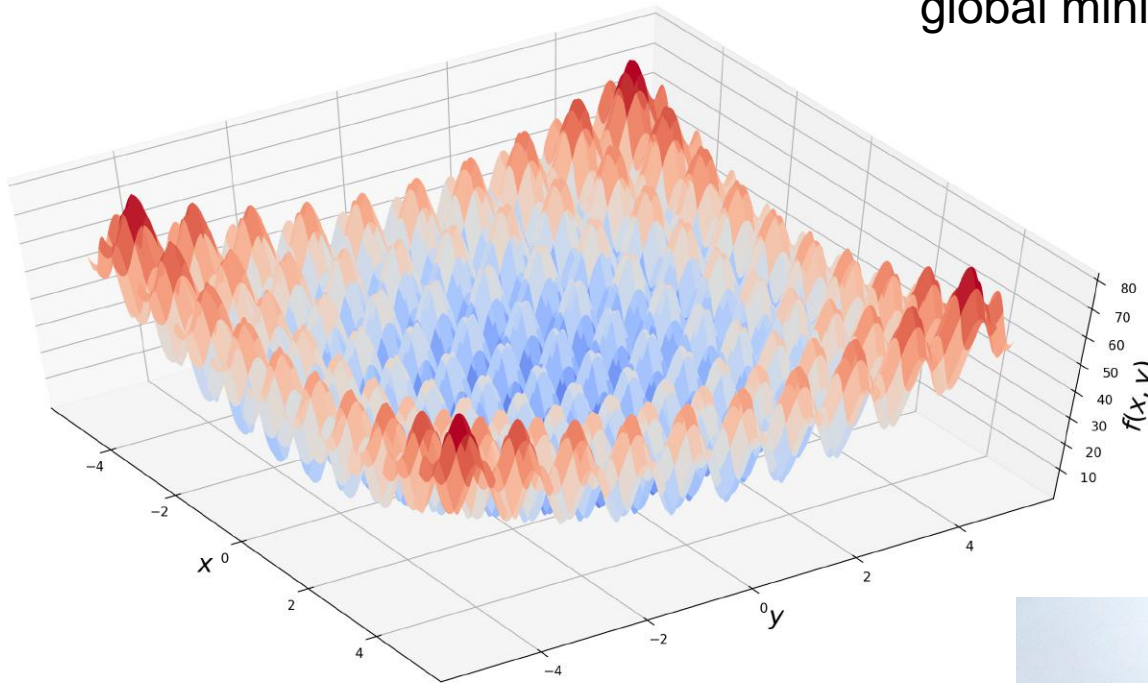
- A group of flying **black** birds searching the only one piece of food in a certain space
- No bird knows where the food is
- The bird closest to the food turns **red** and can be recognized (**gbest**)
- The birds have memory, every bird marks the best position in its flightpath with **blue** color (**pbest**)
- All birds follow **the red bird** and are influenced by their **blue positions** until the food is found

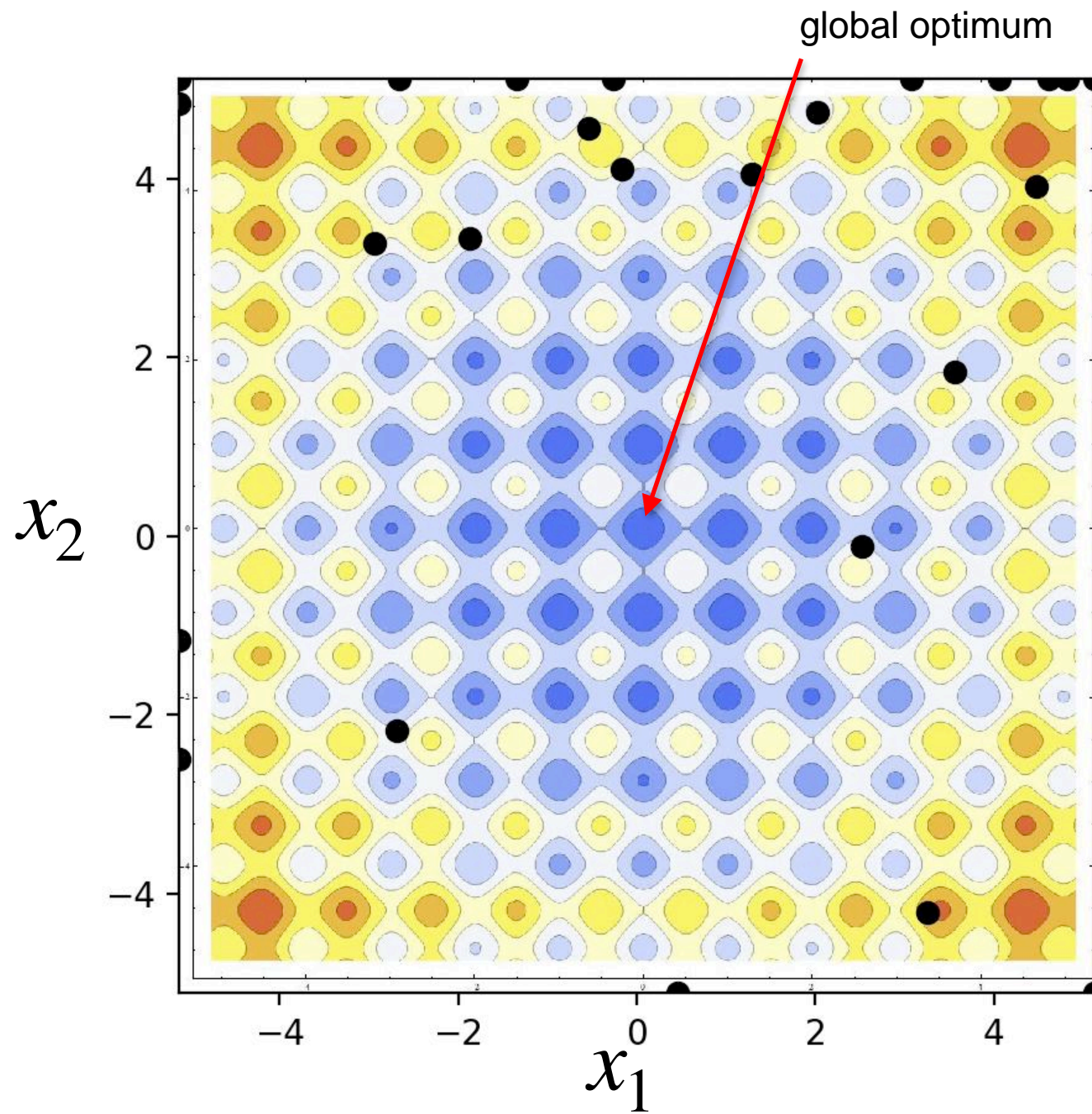




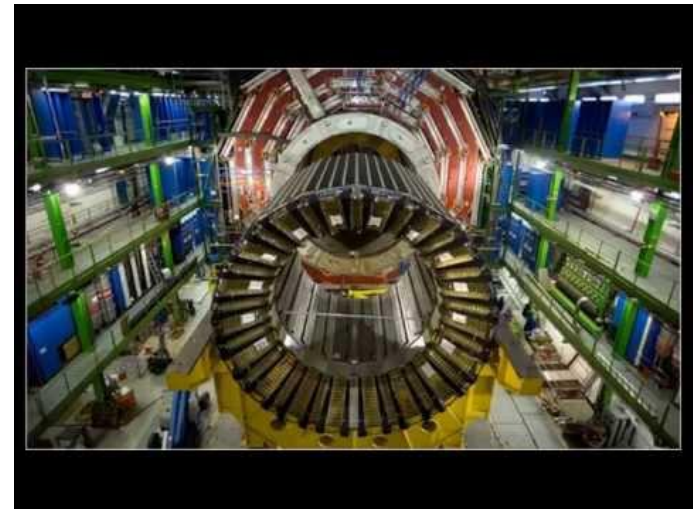
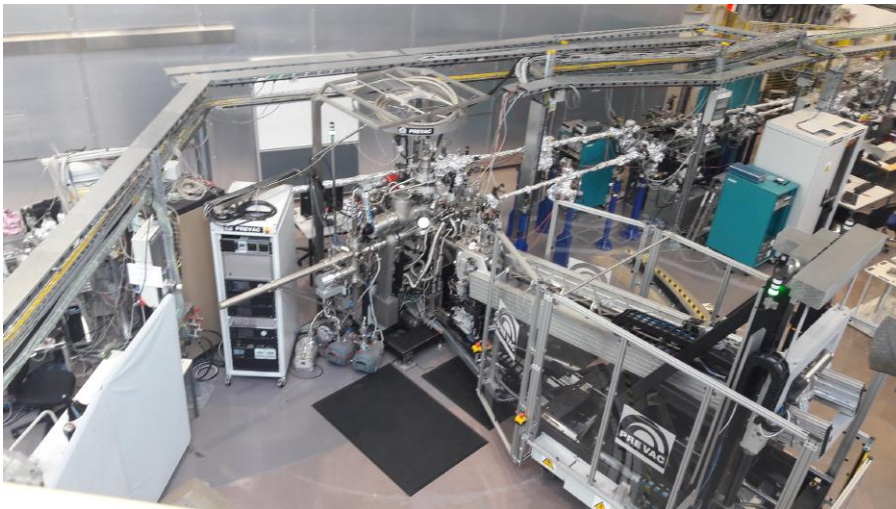
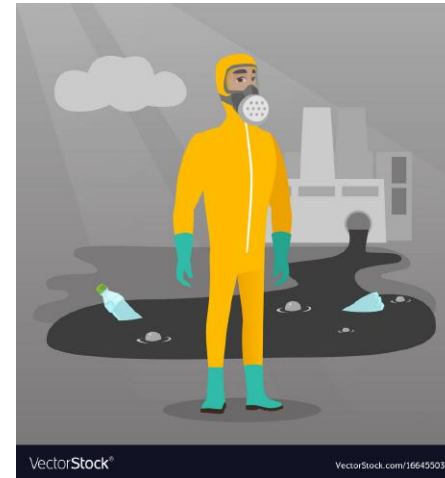
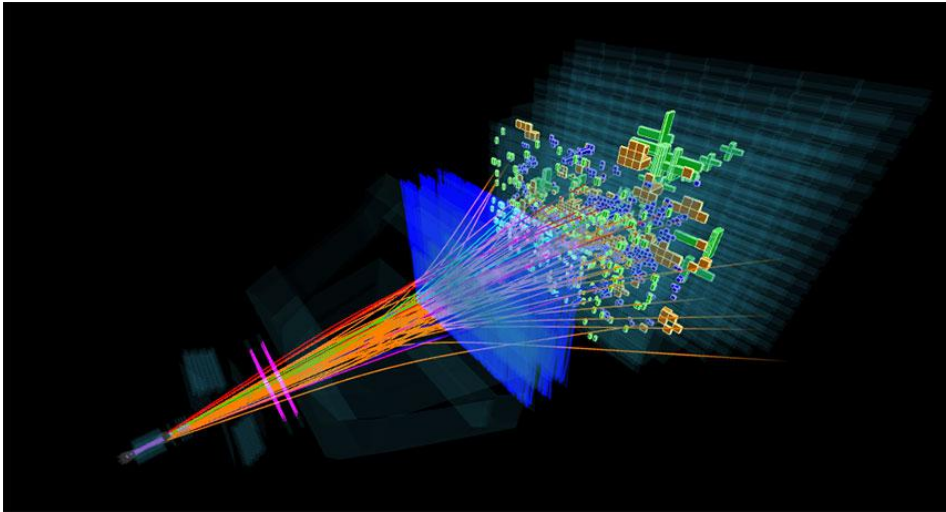
global minimum: $x_1, \dots, x_n = 0, \dots, 0$

$$f(0, \dots, 0) = 0$$





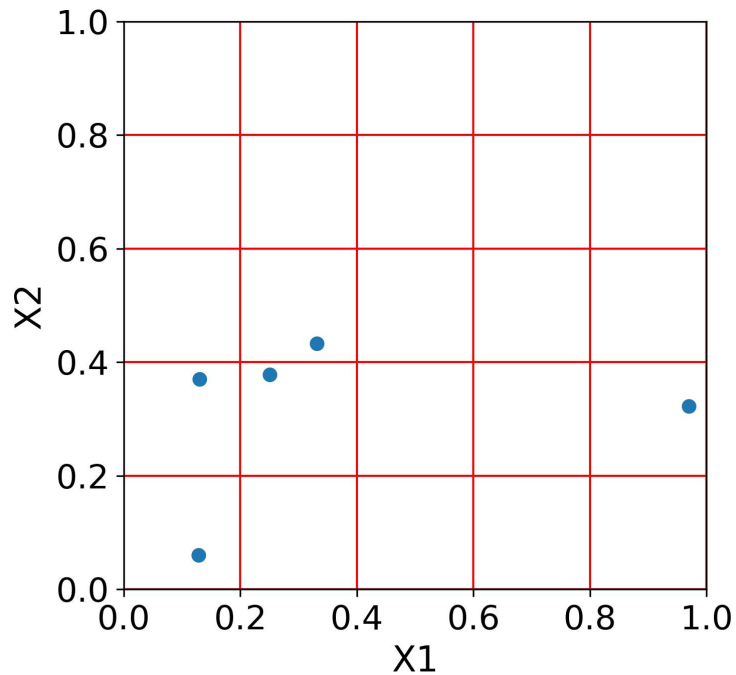




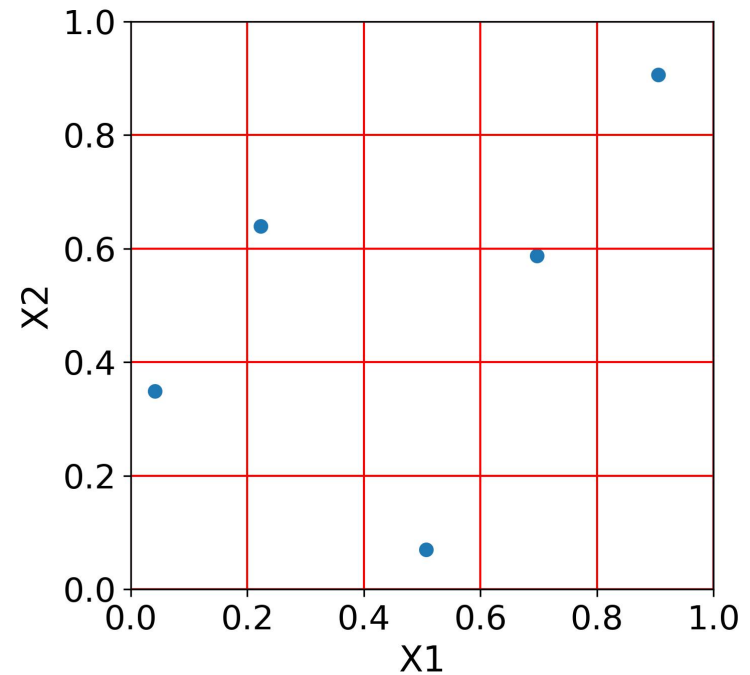

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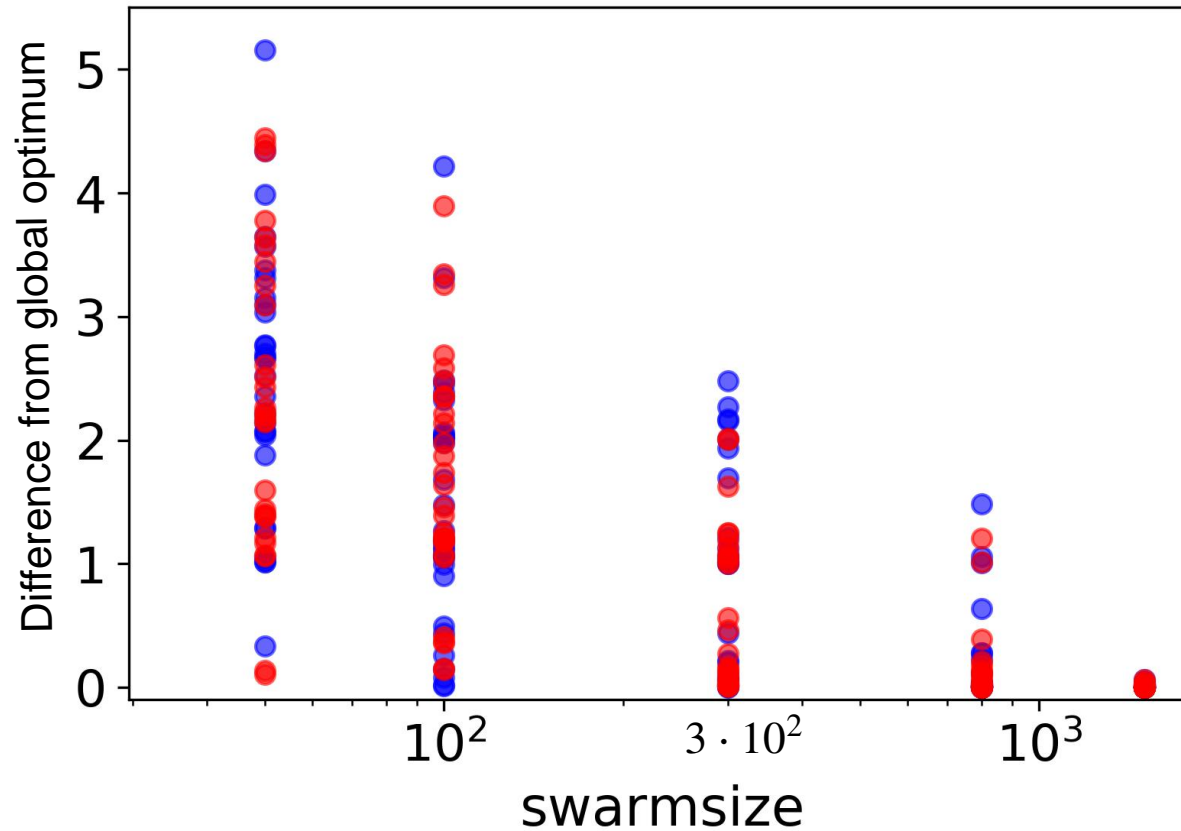
pso.py
23 class PSO:
24
25 > def __init__(self, func_name, lb, ub, Nobj = 1, nRep = 100, bait = np.array(
67 > def lhs(self):=
78
79 def _obj_wrapper(self, func, args, kwargs, x):
80     return func(x, *args, **kwargs)
81
82 def _is_feasible_wrapper(self, func, x):
83     return np.all(self.func(x)>=0)
84
85 def _cons_none_wrapper(self, x):
86     return np.array([0])
87
88 def _cons_ieqcons_wrapper(self, x):
89     return np.array([y(x, *self.args, **self.kwargs) for y in self.ieqcons])
90
91 def _cons_f_ieqcons_wrapper(self, x):
92     return np.array(self.f_ieqcons(x, *self.args, **self.kwargs))
93
94 > def Mutate(self, x, pm, mu, lb, ub):=
106
107 > def Mutate_many_dimensions(self, x, pm, mu, lb, ub):=
130
131 > def Dominates(self, X, Y):=
136
137 > def nondomSolutions(self, X, F):=
155
156 def inverse_permutation_crowding(self, p):
157     #This function computes an "inverse permutation"
158     return np.array([p.index(l) for l in range(len(p))])
159
160 def crowding_sorting(self, archiveX, archiveF):
161     nondomN = len(archiveF)
162     crowdDist = np.zeros((nondomN, ))
163     for i in range(self.Nobj):
164         indexes = np.argsort(archiveF[:,i])
165         archivetestF = archiveF[indexes, i]
166         crowdDist[indexes] #(*)
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Random Sampling



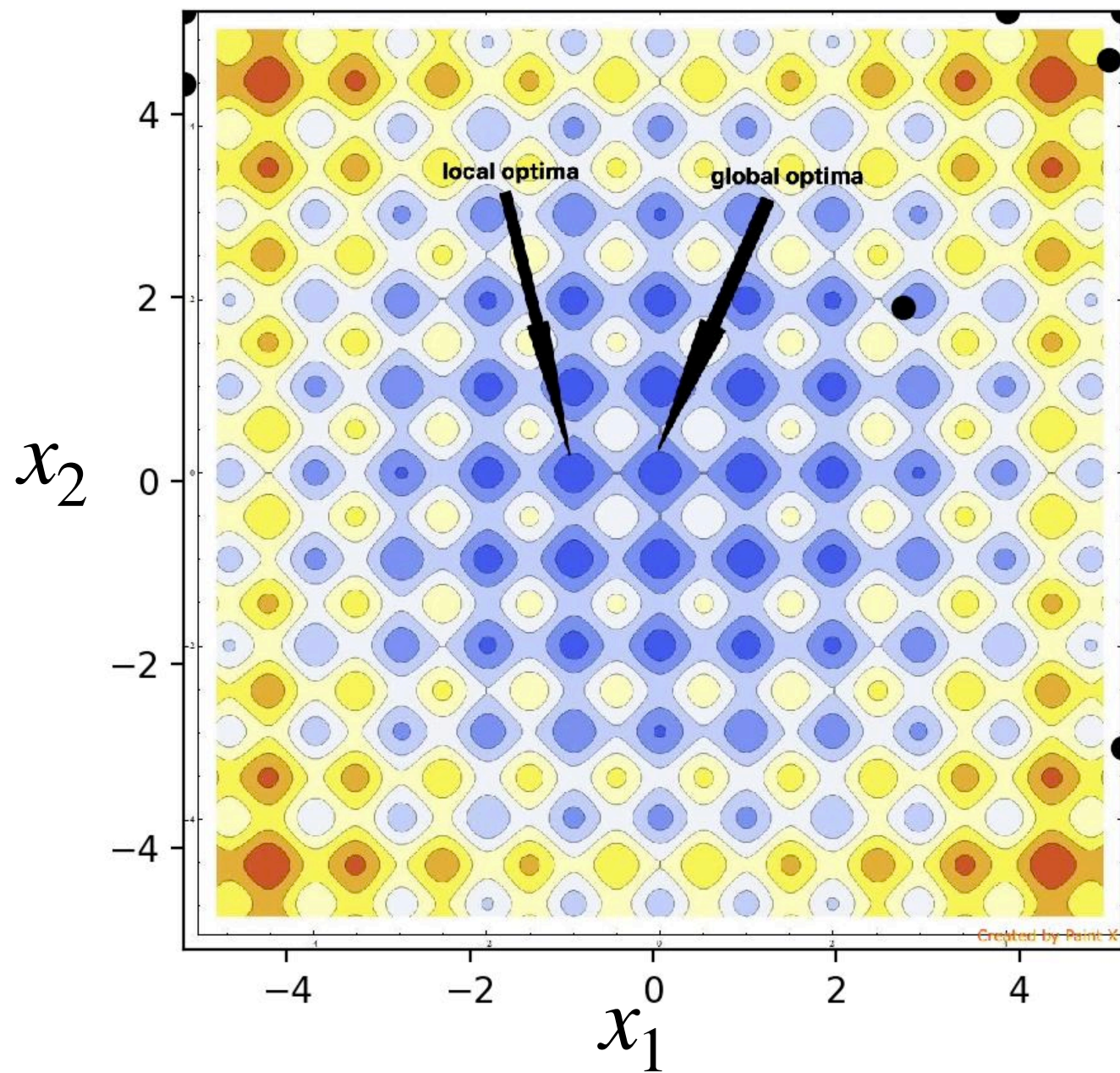
Latin Hypercube Sampling

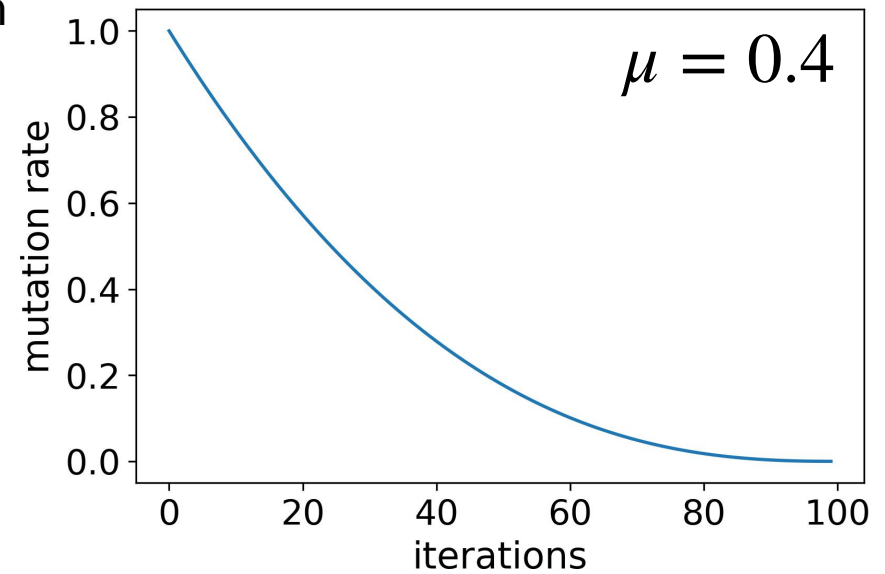
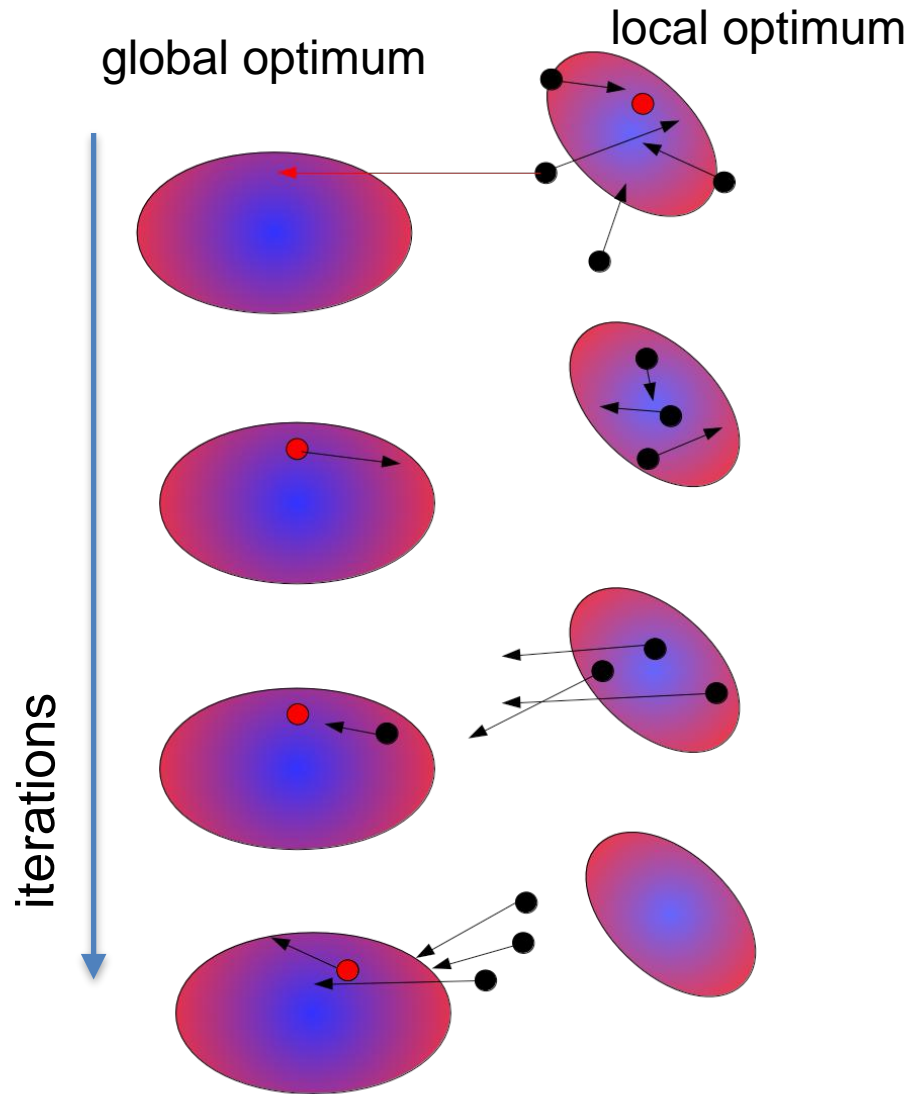




- – random
- – latin hypercube

- function: Rastrigin
- dimensions: 4
- iterations: 70





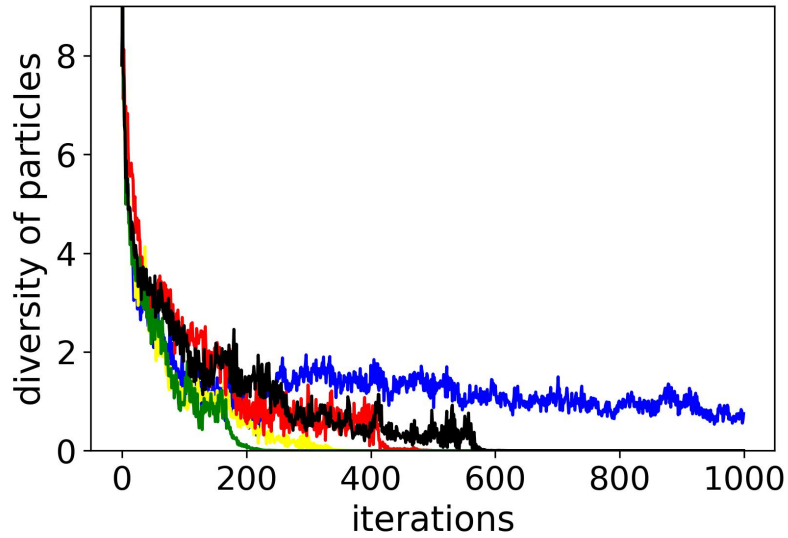
$$\text{Mut. rate} = \left(1 - \frac{n}{N}\right)^{\frac{1}{\mu}}$$

μ – mutation factor

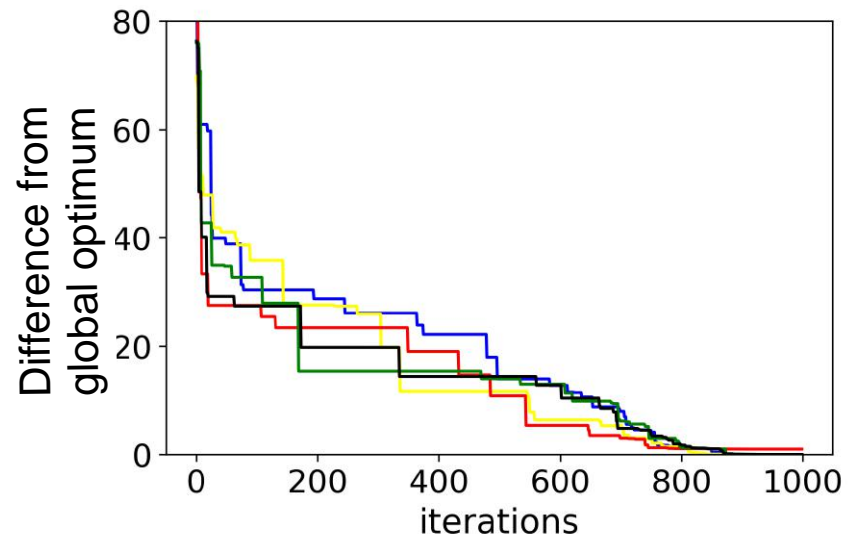
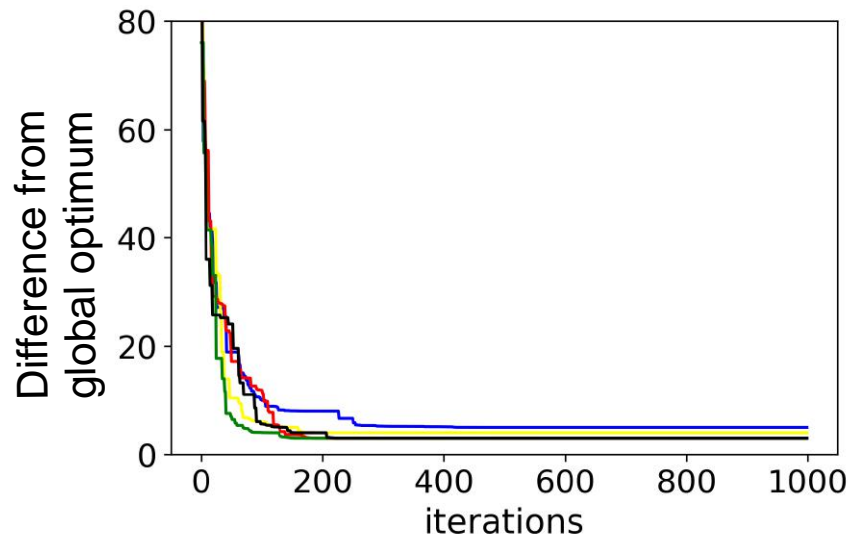
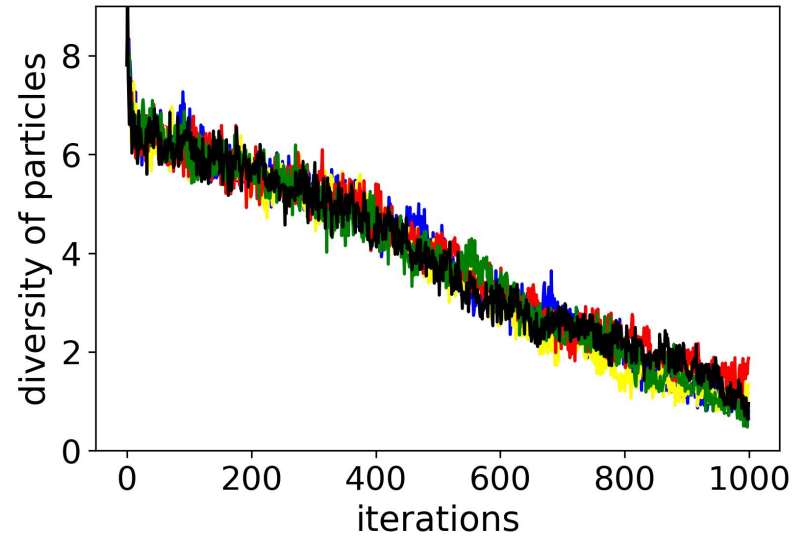
n – iteration number

N – maximum number of iterations

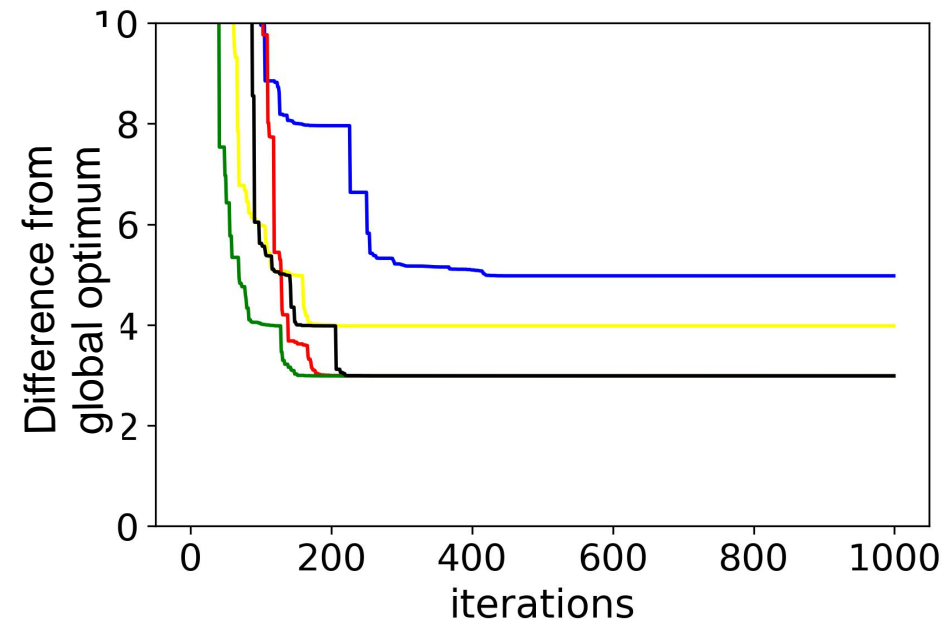
without mutation



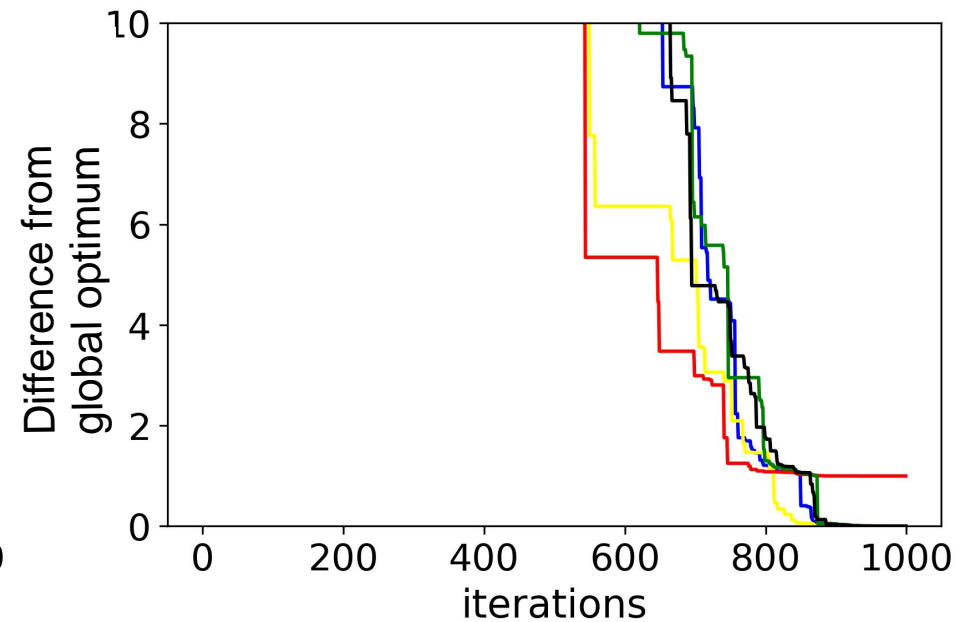
with mutation



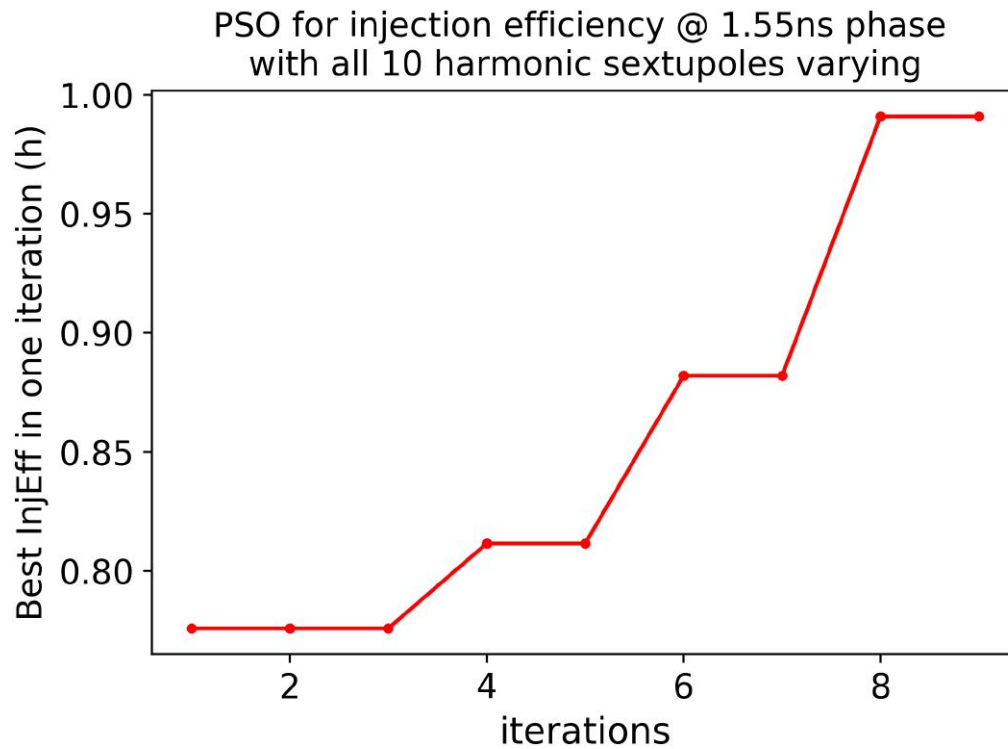
without mutation



with mutation



- Dimensions: 7
- Function: Rastrigin
- Swarm size: 30

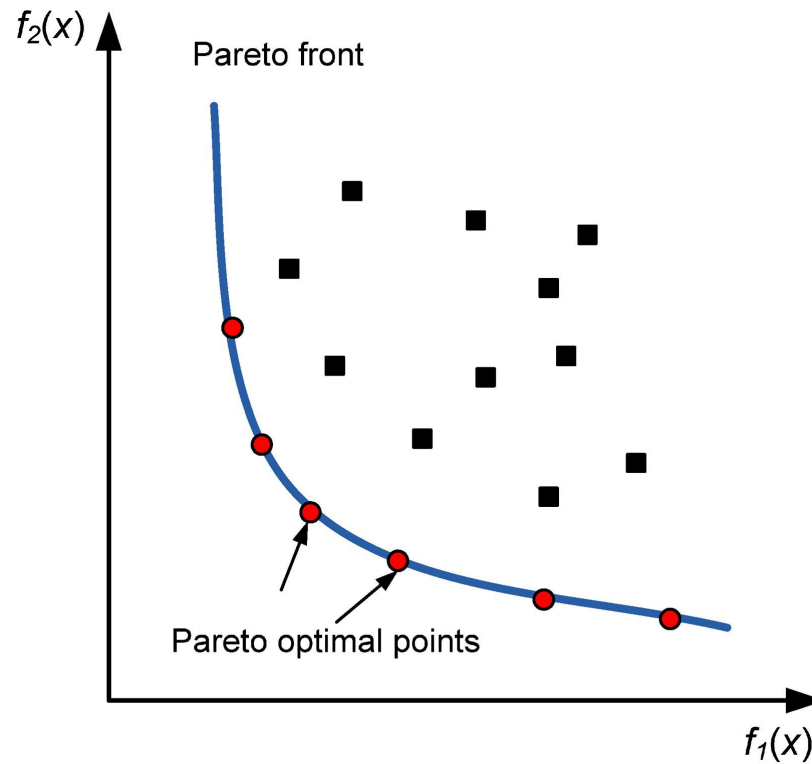


ring-Sextadl
Girag
2015/06/30

Ring Sextupoles

Cmde: !

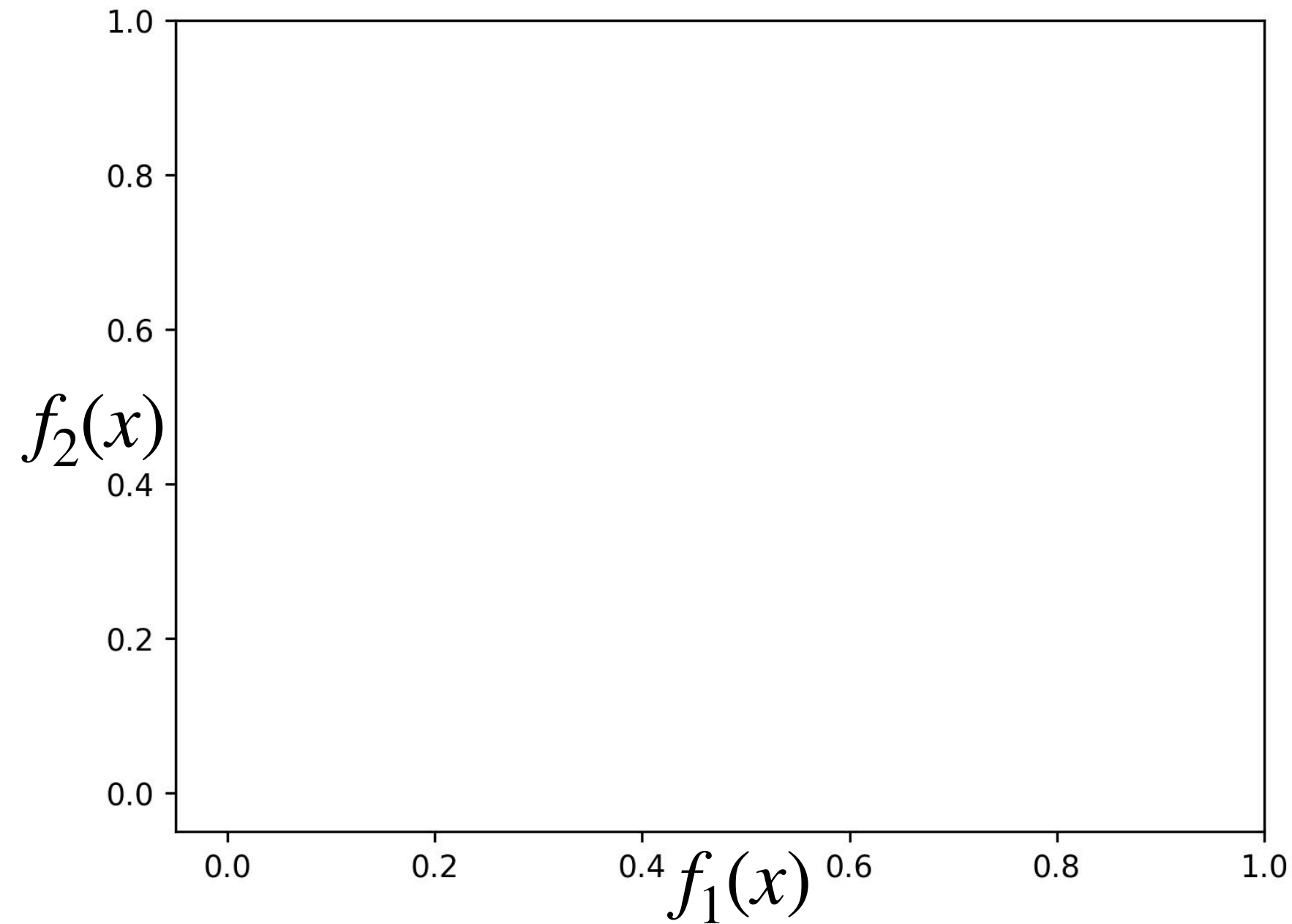
Name	S	Setpoint	Readback	Mem	C
S1PR	●	88.6272	88.578	88.6272	
S2PDR	●	72.6533	72.640	72.6533	
S2PTR	●	72.6533	72.639	72.6533	
S3PDR	●	39.9495	39.911	39.9495	
S3PTR	●	39.9495	39.934	39.9495	
S4PDR	●	31.1680	31.121	31.1680	
S4PTR	●	31.1680	31.119	31.1680	
S3PD1R	●	39.9495	40.13	39.9495	
S4PD1R	●	31.1680	31.45	31.1680	
S3P1T6R	●	39.9495	40.20	39.9495	
S3P2T6R	●	39.9495	39.97	39.9495	
S4P1T6R	●	31.1680	31.30	31.1680	
S4P2T6R	●	31.1680	31.24	31.1680	



*def. **Pareto front** is the best set of solutions*

<https://github.com/txt/fss17/blob/master/review2.md>

ZDT1 function



- Implementation of LHS and mutation in PSO
- Experimental work at BESSY II
- Debugging Multi-objective PSO

$$\vec{f}_1 = (f_{11}, \dots, f_{n1})$$

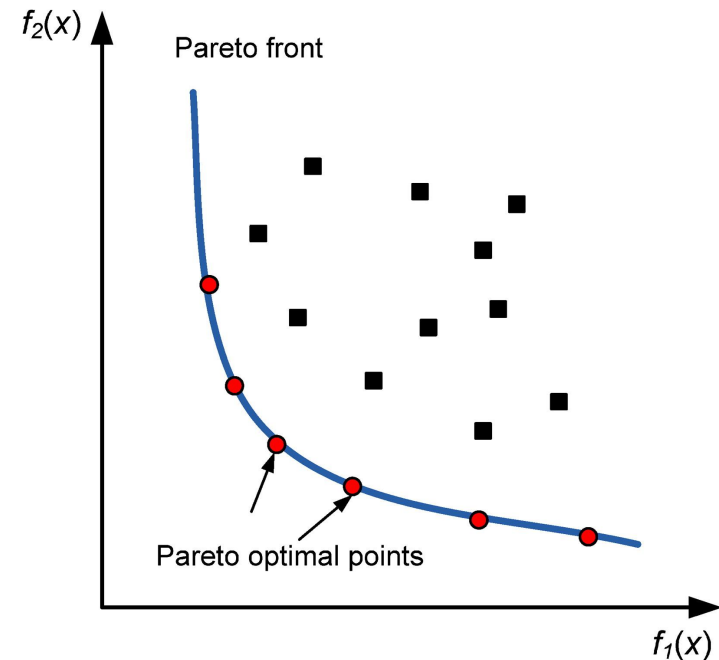
$$\vec{f}_2 = (f_{12}, \dots, f_{n2})$$

\vec{f}_1 **dominates** \vec{f}_2 if:

$$\forall i \in 1, \dots, n : f_{1i} \leq f_{2i} \quad \text{and} \quad \vec{f}_1 \neq \vec{f}_2$$

def. Set is called **non-dominated set** of solutions if no point in the set dominates other points

def. **Pareto front** is the best non-dominated set



Zitzler–Deb–Thiele's function 1