Further development of Particle Swarm Optimization method applied to accelerators

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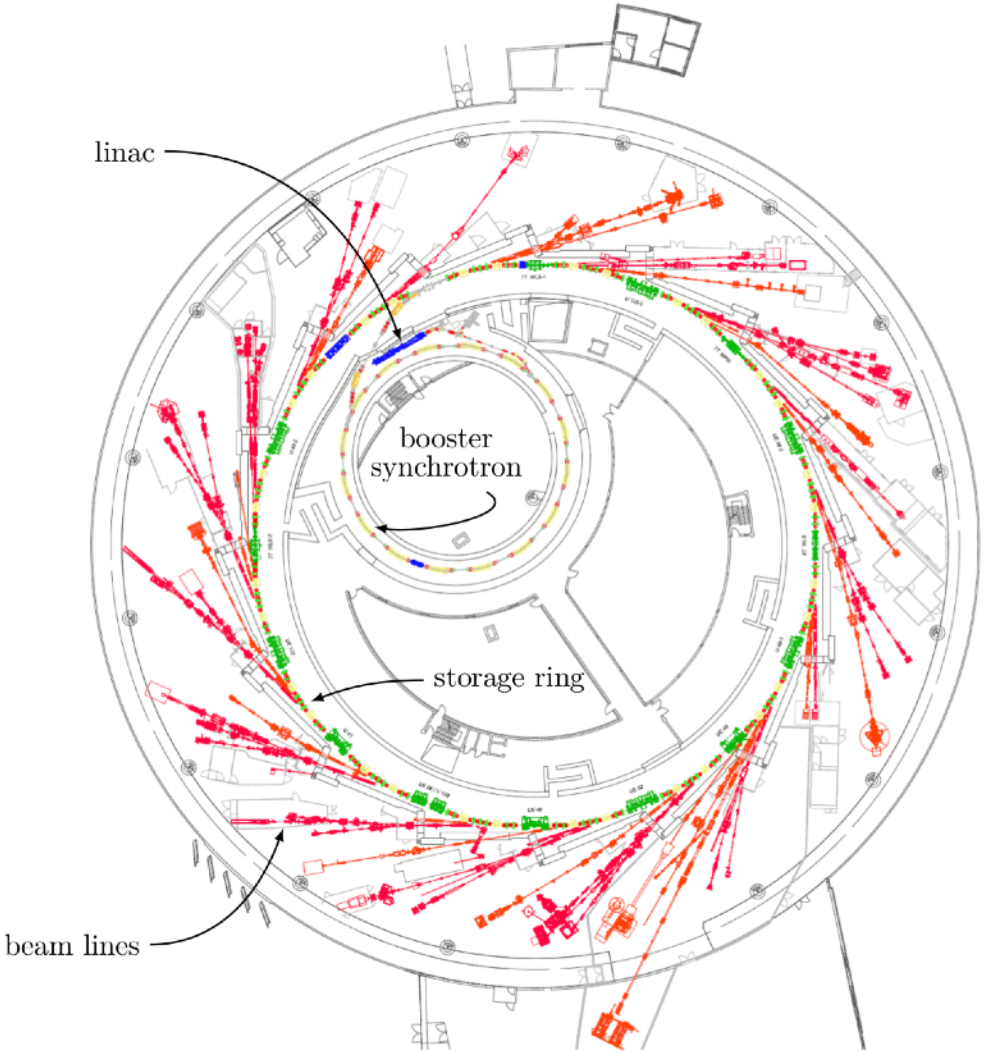
OUTLINE

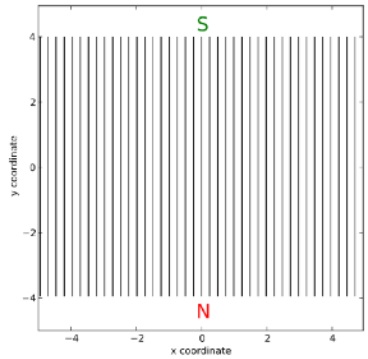
- Background and motivation
- Introduction of Particle Swarm Optimization (PSO)
- Improvements applied to PSO
- Experimental and simulation results
- Multi-objective PSO

MLS AND BESSY II

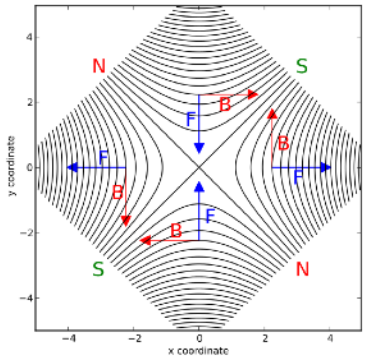


Field lines of an idealized
dipole, **quadrupole** and **sextupole** magnet
in the plane transverse to the beam direction

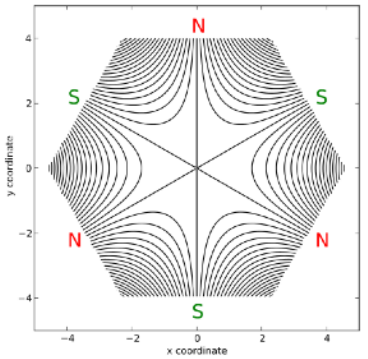
dipole

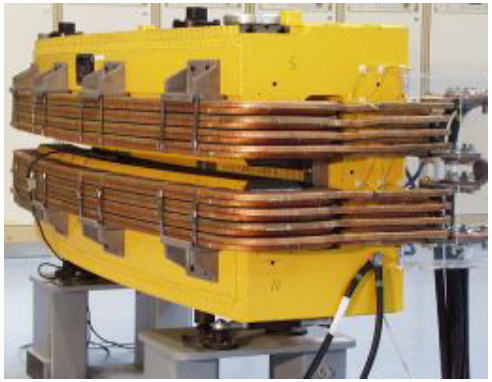


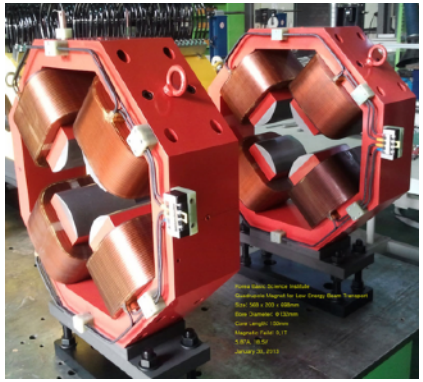
quadrupole

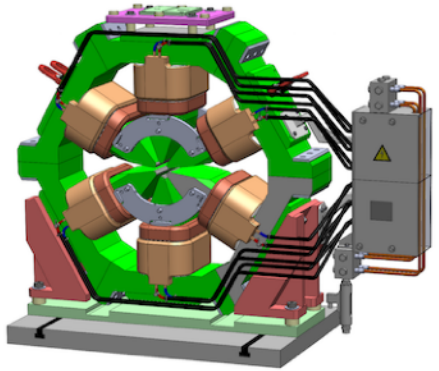


sextupole









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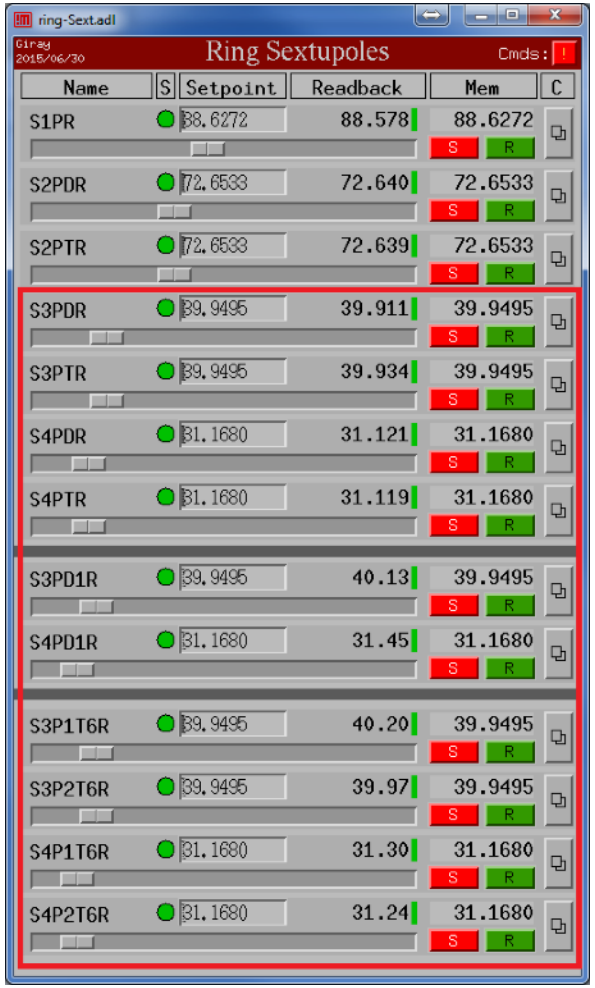
OBJECTIVES TO OPTIMIZE

1)

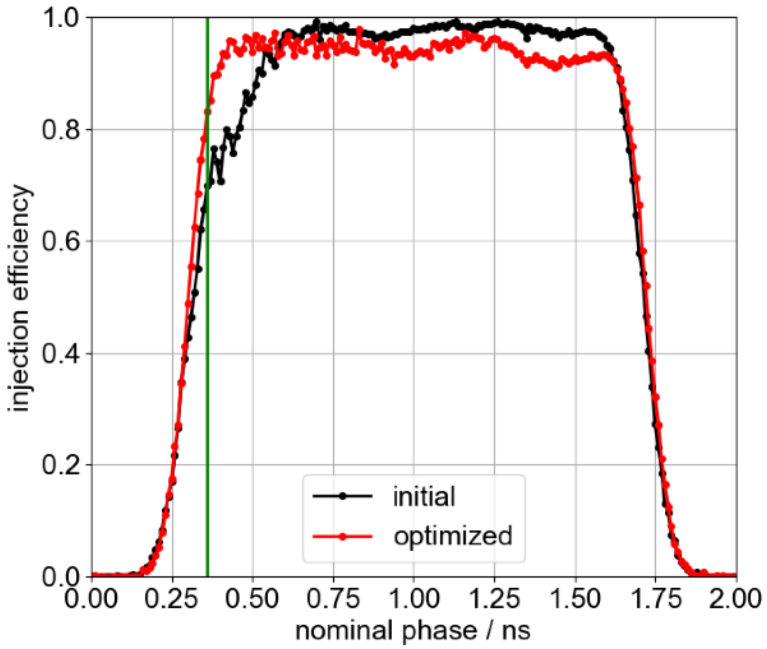
Injection efficiency = $\dfrac{\text{Beam current injected to storage ring}}{\text{Beam current from injector}}$

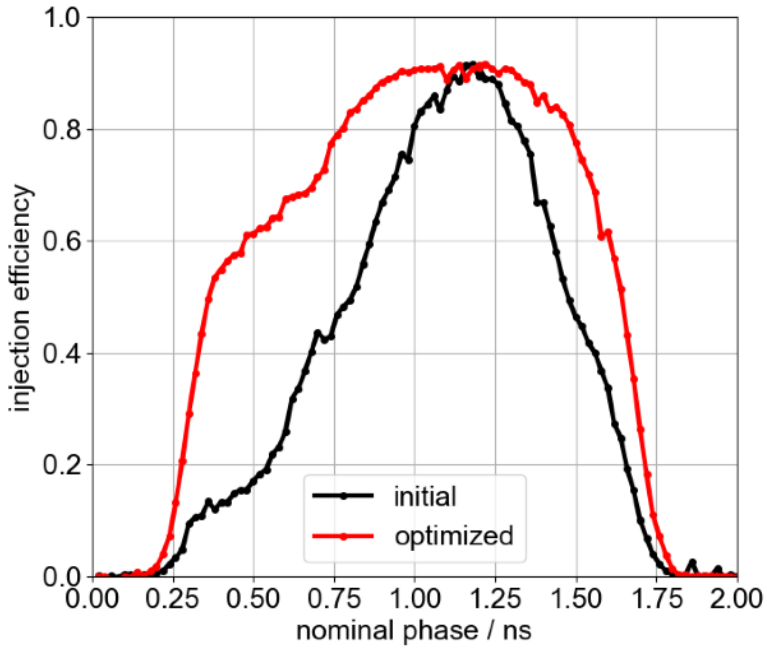
2) $$I = I_0 \cdot e^{-\frac{t}{\tau}}$$

lifetime



PHASE SCAN





- optimization of 10 sextupoles
- insertion devices deteriorate injection efficiency

Birds in a flock searching for food

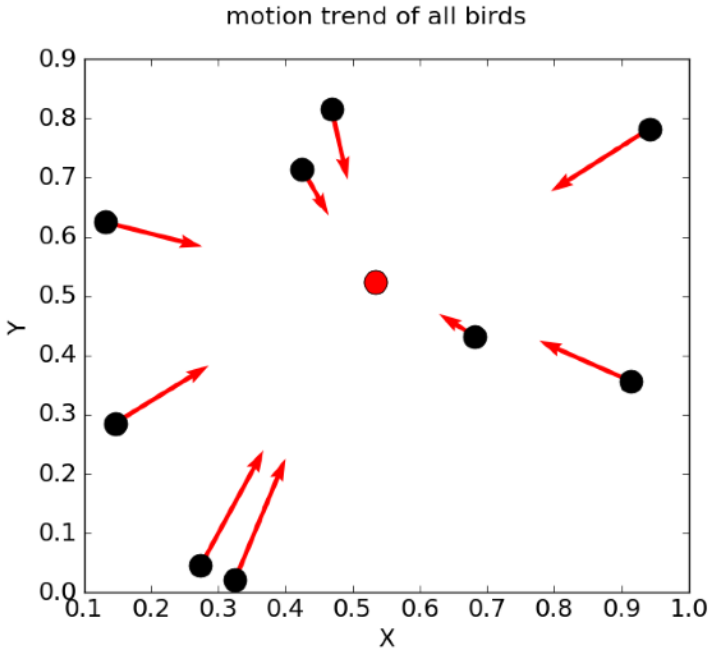
google.com

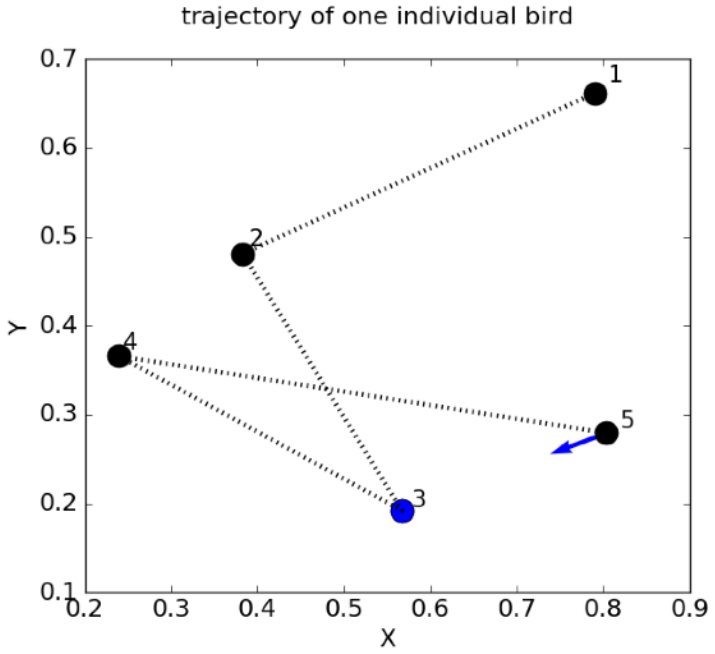
PARTICLE SWARM METHOD

Developed by Dr. Eberhart and Dr. Kennedy in 1995

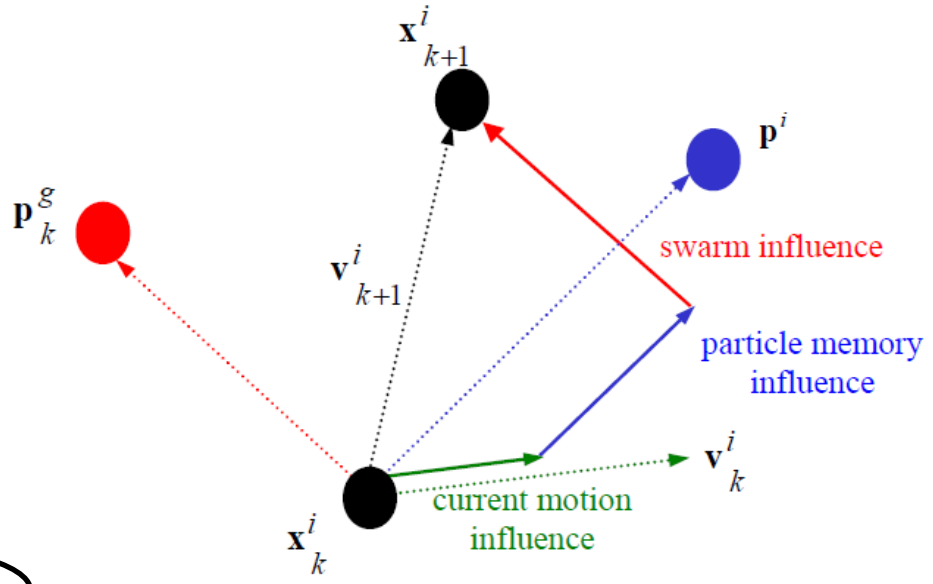
SCENARIO:

- 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





MAIN FORMULA OF PSO



inertia term

cognitive term

$$v_{k+1} = w \cdot v_k + c_1 \cdot rand() \cdot (pbest - x_k) + c_2 \cdot rand() \cdot (gbest - x_k) \quad \text{(a)}$$

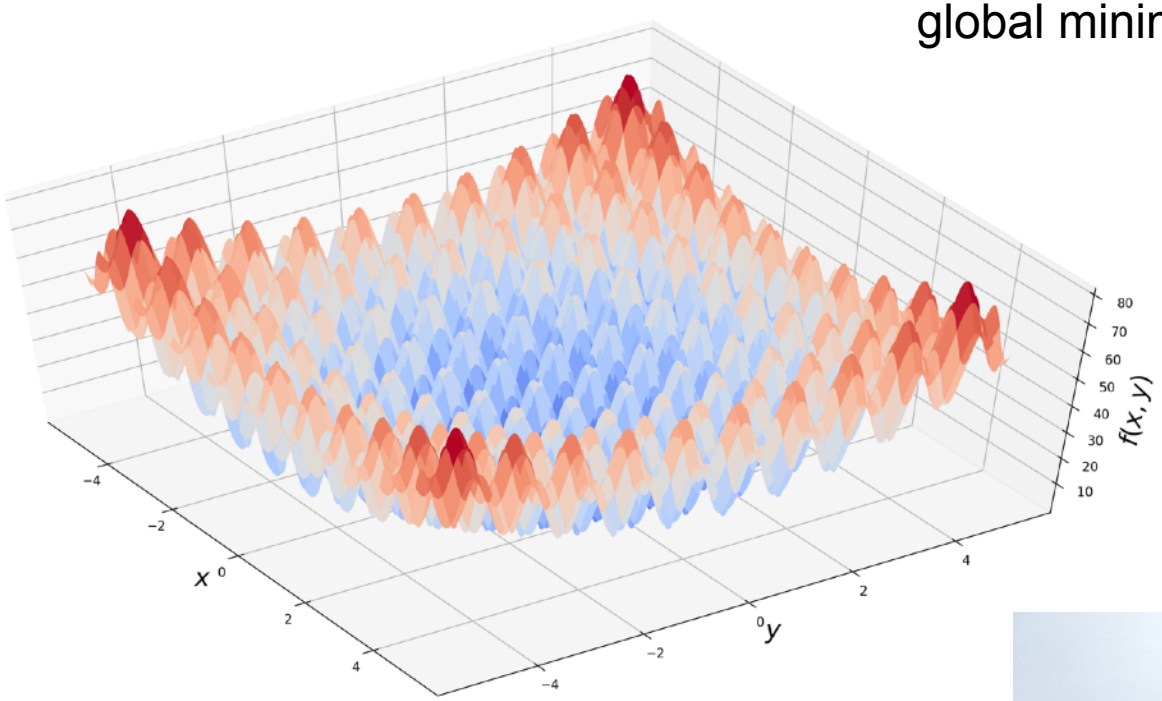
(velocity update)

$$x_{k+1} = x_k + v_{k+1} \quad \text{(b)}$$

(position update)

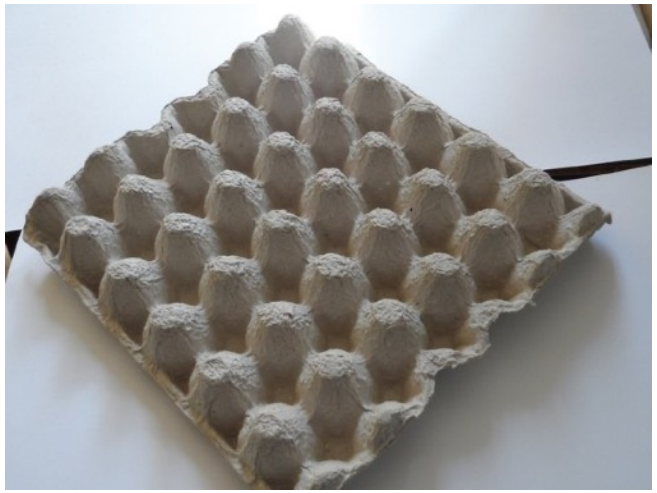
social learning term

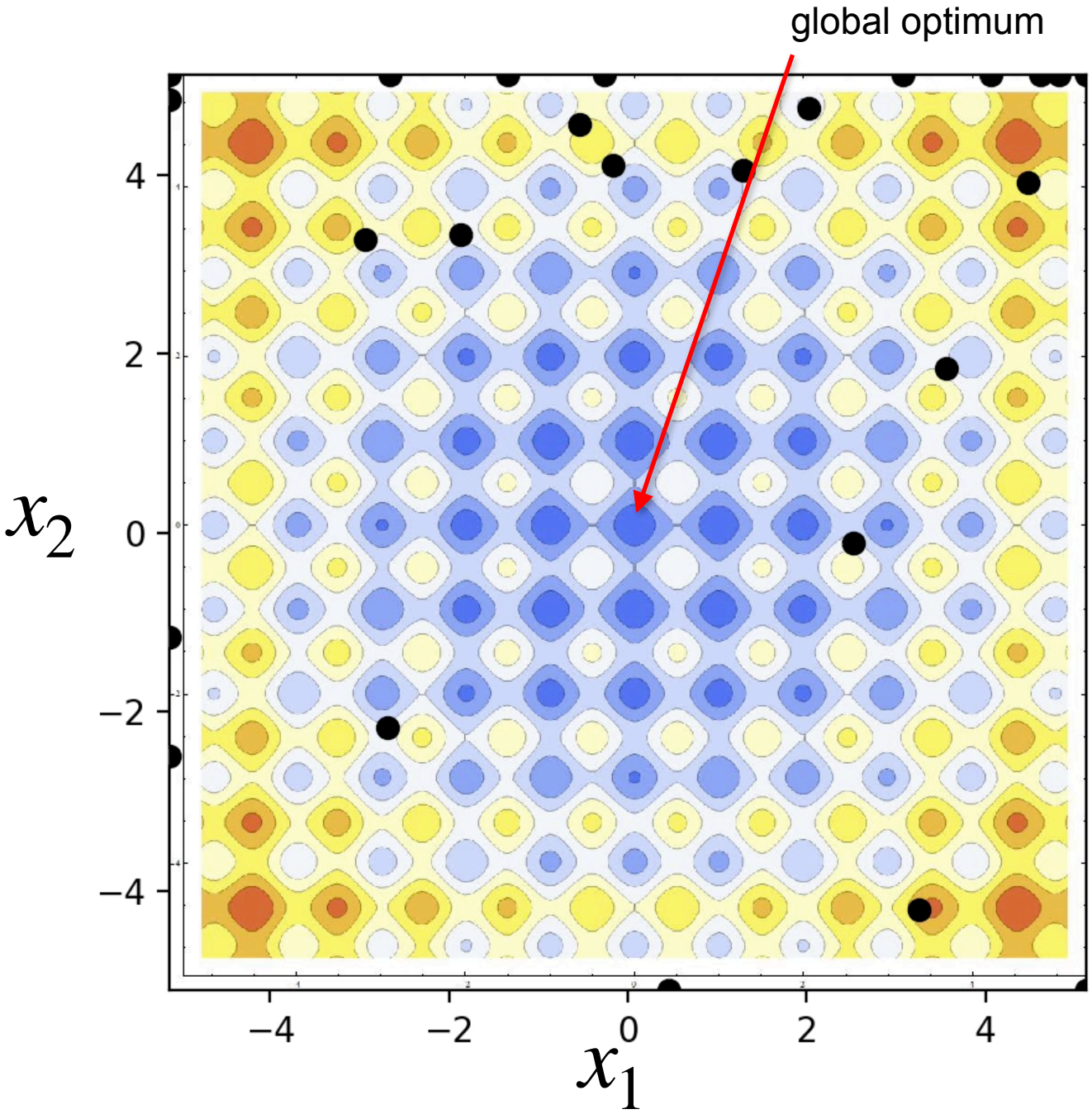
TEST FUNCTION: RASTRIGIN



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

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




global optimum
x_2
4
2
0
−2
−4
−4
−2
0
2
4
x_1

EXPECTATIONS

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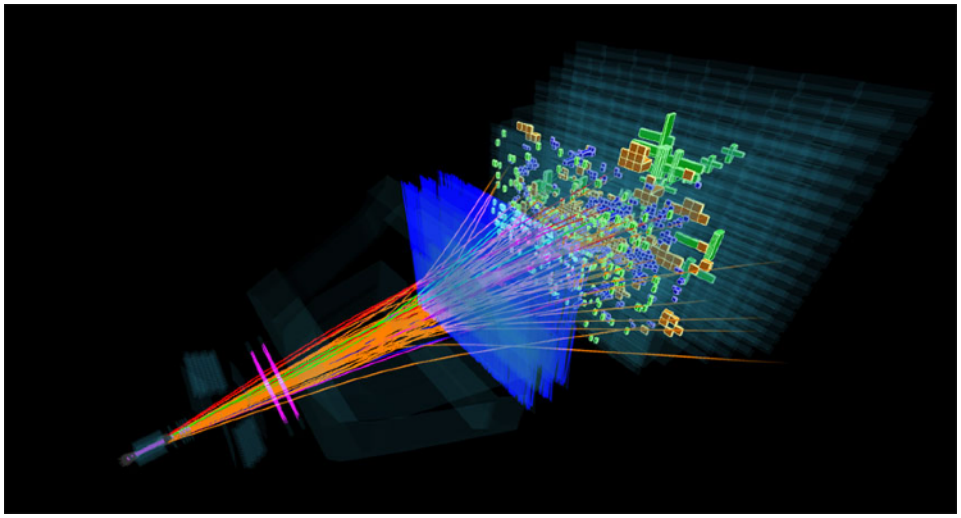
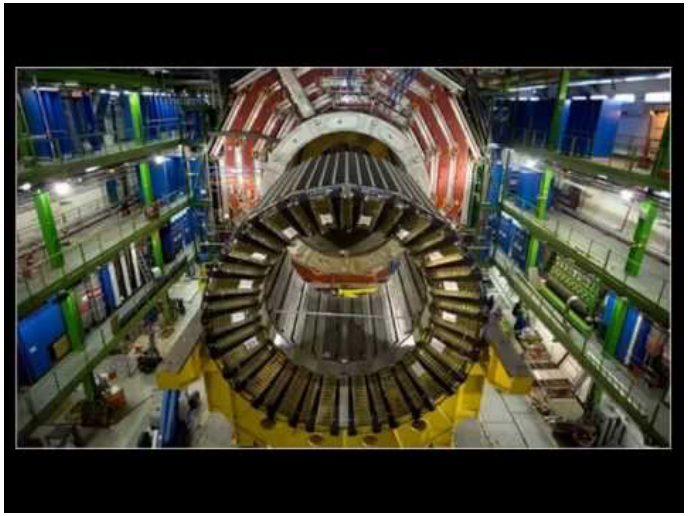
EXPECTATIONS





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REALITY

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pso.py

```
class PSO:

    def __init__(self, func_name, lb, ub, Nobj = 1, nRep = 100, bait = np.array(
    def lhs(self):

    def _obj_wrapper(self, func, args, kwargs, x):
        return func(x, *args, **kwargs)

    def _is_feasible_wrapper(self, func, x):
        return np.all(self.func(x)>=0)

    def _cons_none_wrapper(self, x):
        return np.array([0])

    def _cons_ieqcons_wrapper(self, x):
        return np.array([y(x, *self.args, **self.kwargs) for y in self.ieqcons])

    def _cons_f_ieqcons_wrapper(self, x):
        return np.array(self.f_ieqcons(x, *self.args, **self.kwargs))

    def Mutate(self, x, pm, mu, lb, ub):

    def Mutate_many_dimensions(self, x, pm, mu, lb, ub):

    def Dominates(self, X, Y):

    def nondomSolutions(self, X, F):

    def inverse_permutation_crowding(self, p):
        #This function computes an "inverse permutation"
        return np.array([p.index(l) for l in range(len(p))])

    def crowding_sorting(self, archiveX, archiveF):
        nondomN = len(archiveF)
        crowdDist = np.zeros((nondomN, ))
        for i in range(self.Nobj):
            indexes = np.argsort(archiveF[:,i])
            archivetestF = archiveF[indexes, i]
            crowdDist = crowdDist[indexes] #(*)
```

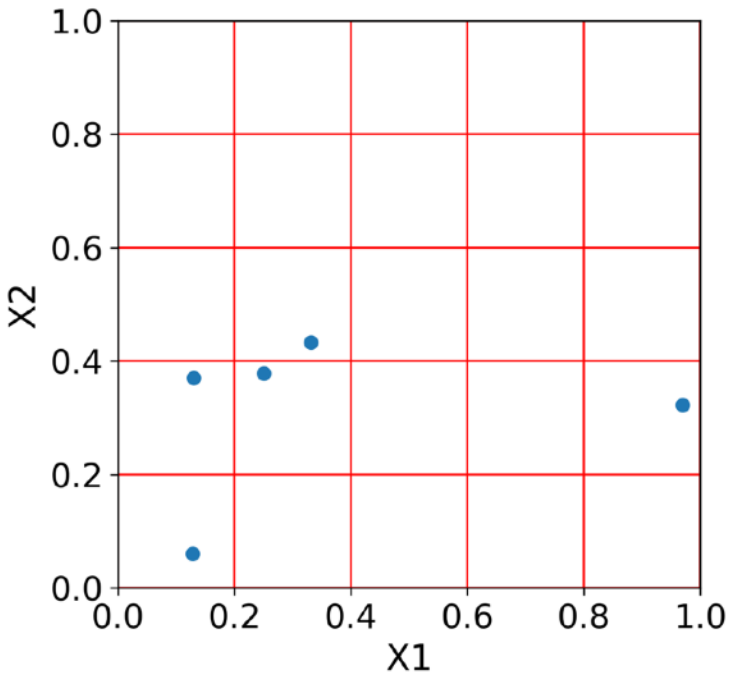
pso.py 427:14

pso_animate.py functions.py

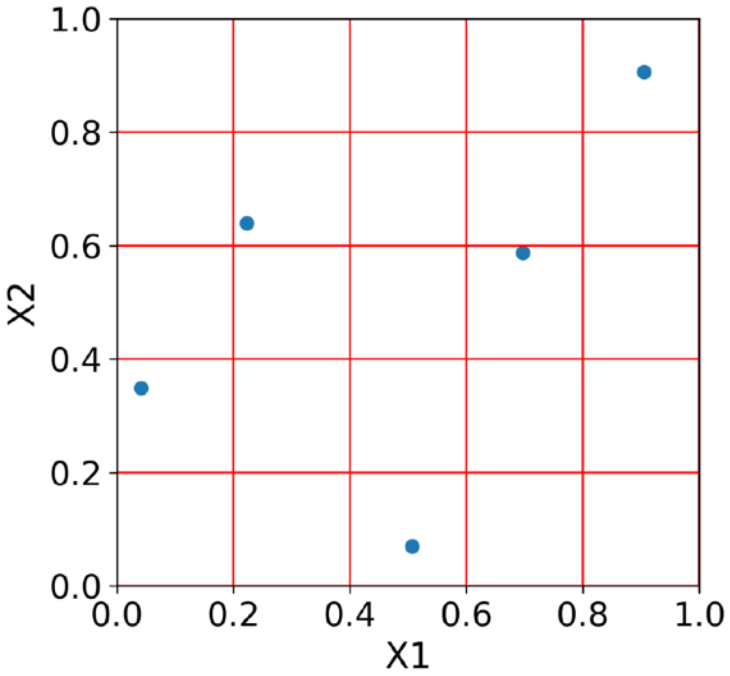
```
    for c in x:
        firstSum += c**2.0
        secondSum += np.cos(2.0*math.pi*c)
    return -20.0*np.exp(-0.2*np.sqrt(firstSum/n)) - np.exp(secondSum/n) + 20 + m
def Sphere(x):
    Sum = 0.0
    n = float(len(x))
    for c in x:
        Sum += c**2
    return Sum
def Rastrigin(x, A = 10):
    n = float(len(x))
    Sum = 0.0
    for c in x:
        Sum += c**2 - A * np.cos(2 * math.pi * c)
    return A*n + Sum
def Holder(x):
    return 19.2085 - np.abs(np.sin(x[0]) * np.cos(x[1]) * np.exp(abs(1 - np.sqrt

def Rosenbrock(x):
    Sum = 0.0
    for i in range(len(x)-1):
        Sum += 100.0*(x[i+1]-x[i]**2)**2 + (1-x[i])**2
    return Sum

def ZDT1(X):
    #:::: ZDT1 ::::#
    n = X.s
    G  = 1.
    F1 = X[
    F2 = G*
    F = np.
    return

def Viennet
    F1 = 0.
    F2 = ((
    F3 = 1/
    F = np.
```

HOW TO GENERATE STARTING POSITIONS

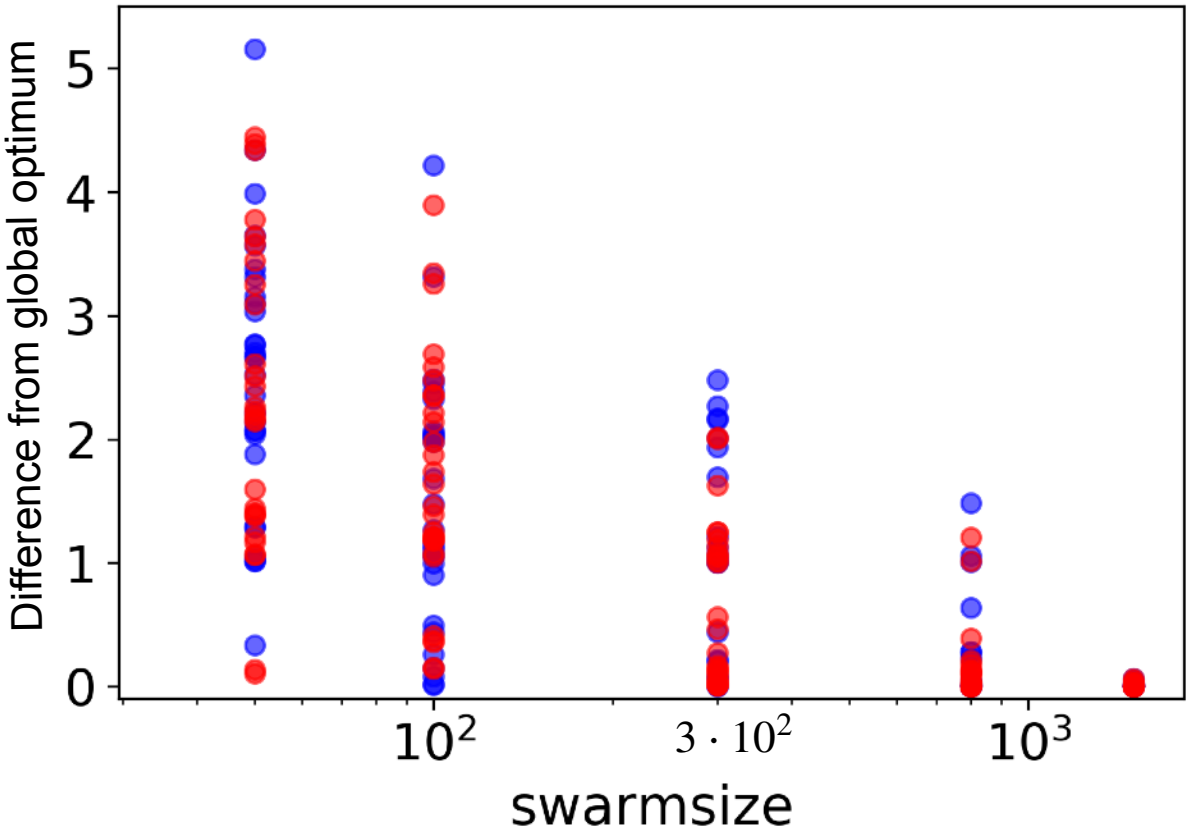
Random Sampling



Latin Hypercube Sampling

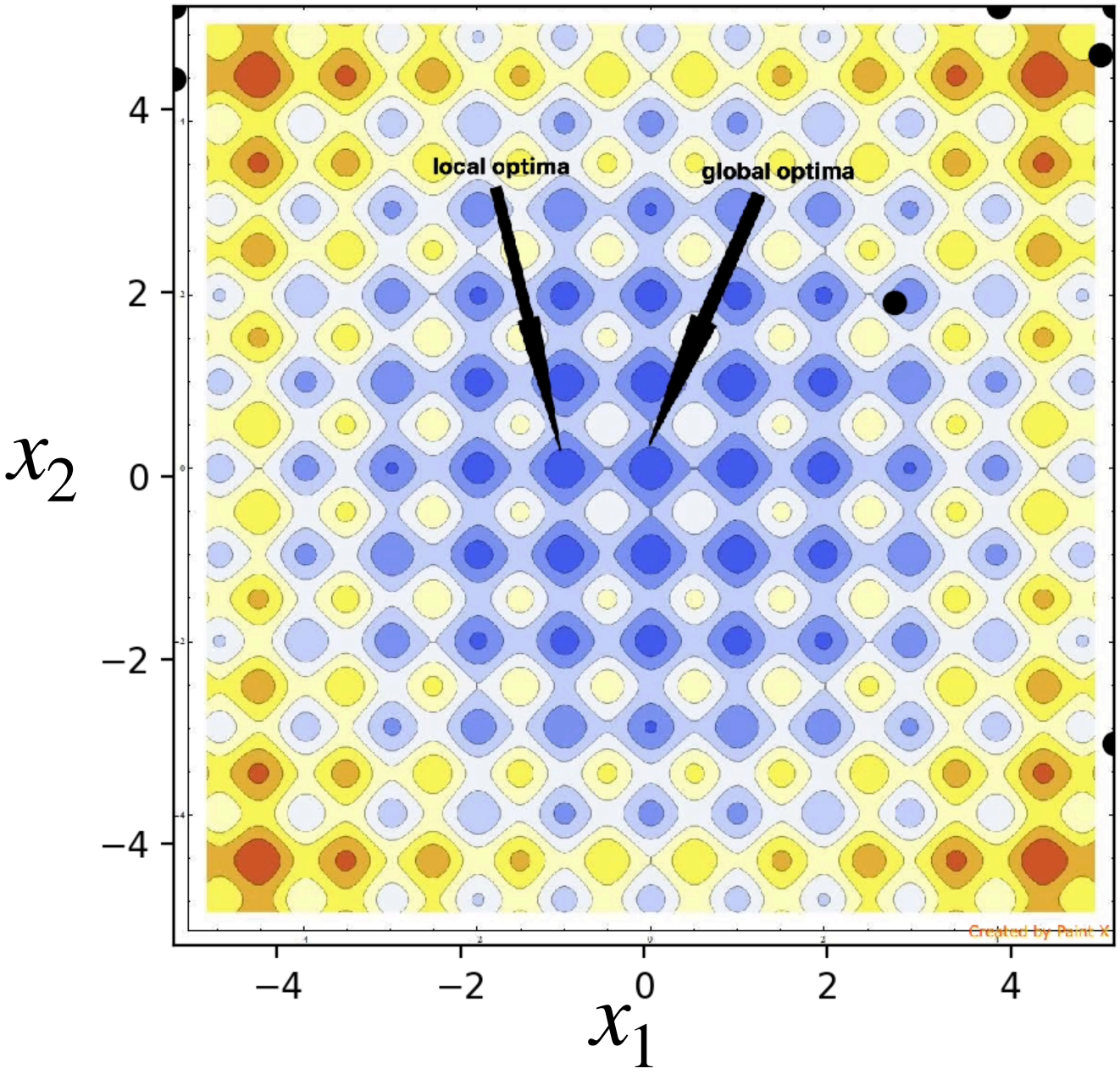


HOW TO GENERATE STARTING POSITIONS

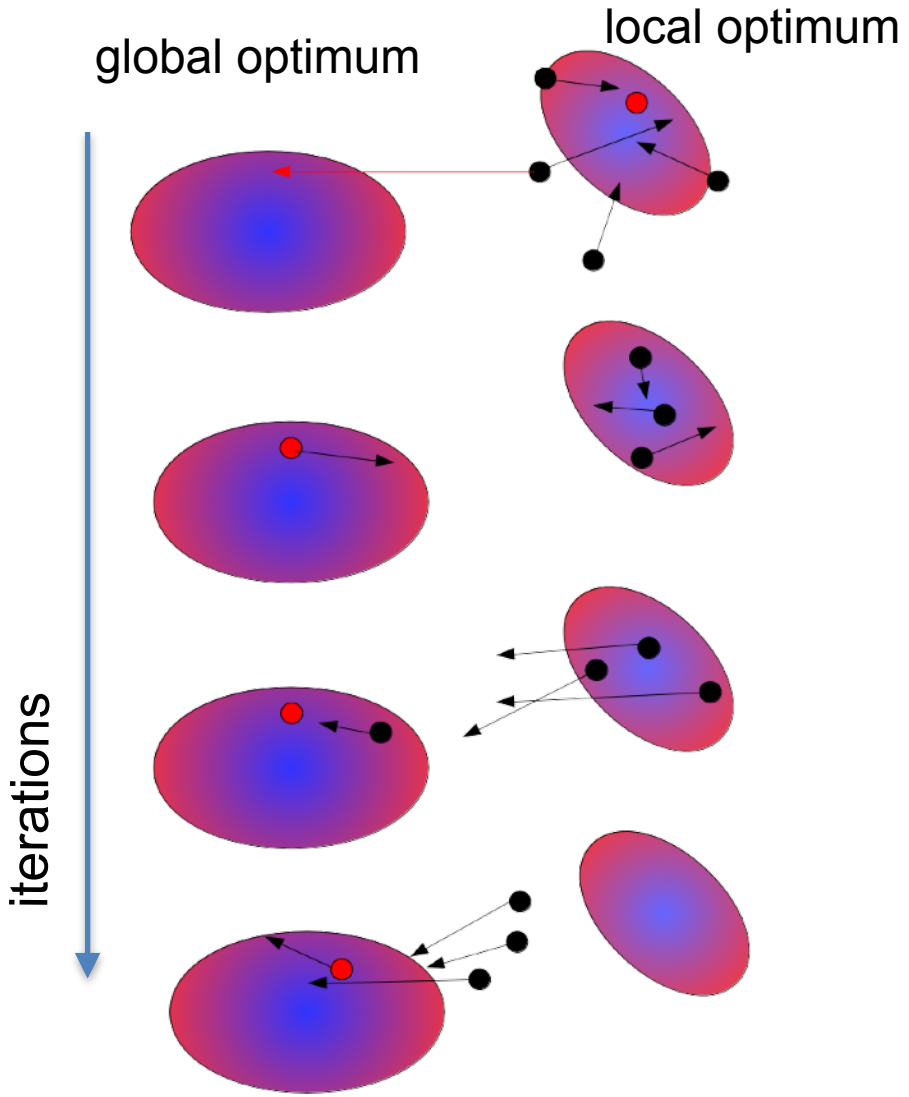


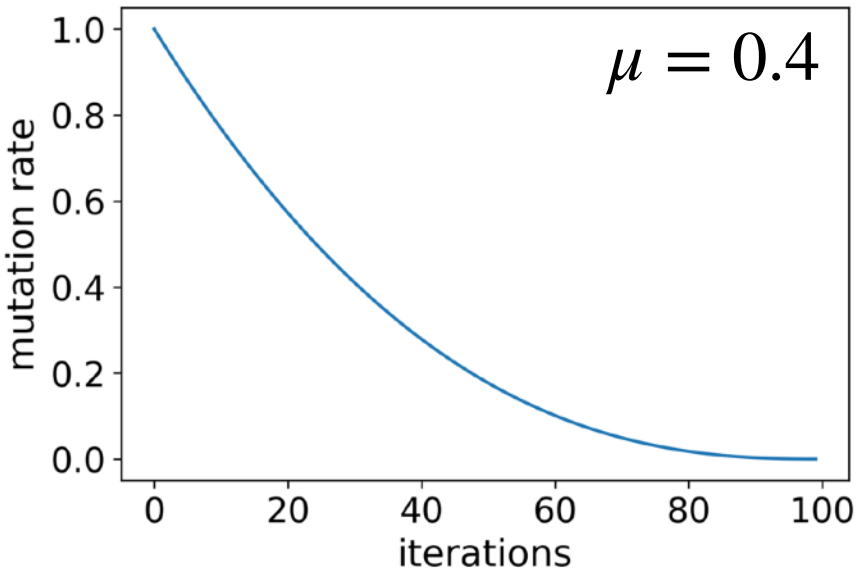
- – random
- – latin hypercube

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


local optima
global optima
x_2
x_1
4
2
0
−2
−4
−4
−2
0
2
4
Created by Paint X

MUTATION TECHNIQUE





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

μ – mutation factor

n – iteration number

N – maximum number of iterations

MUTATION TECHNIQUE

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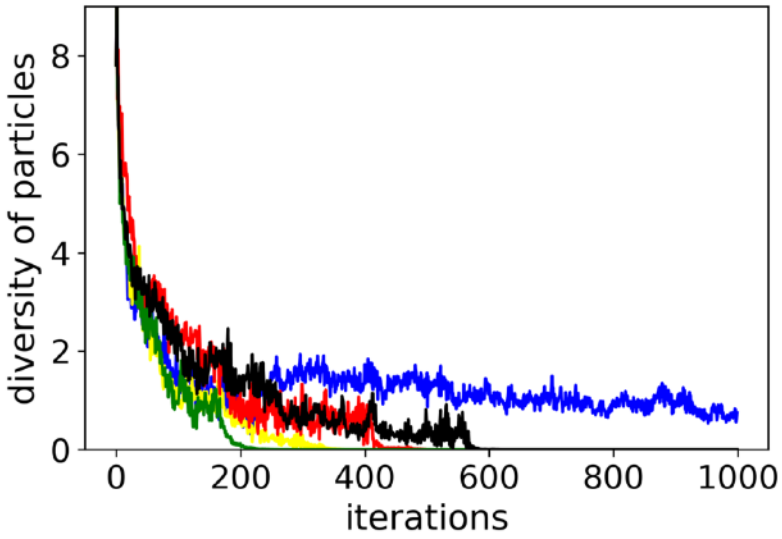
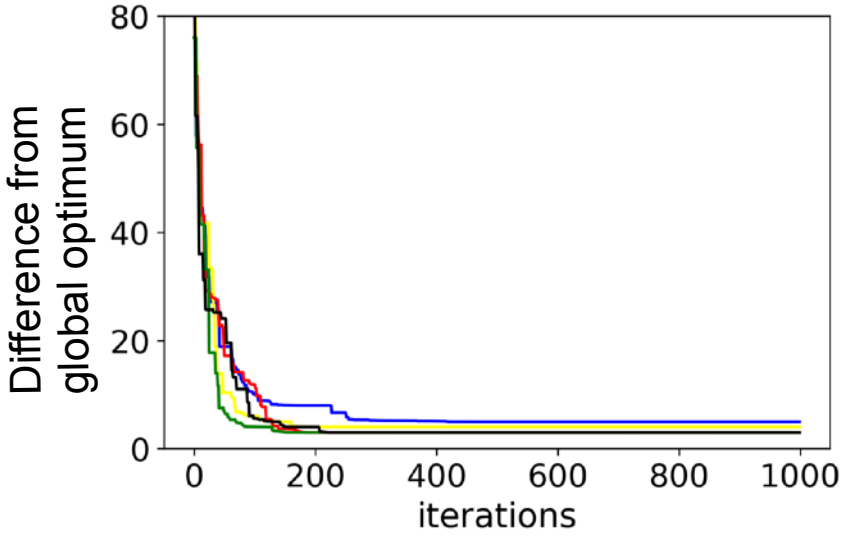
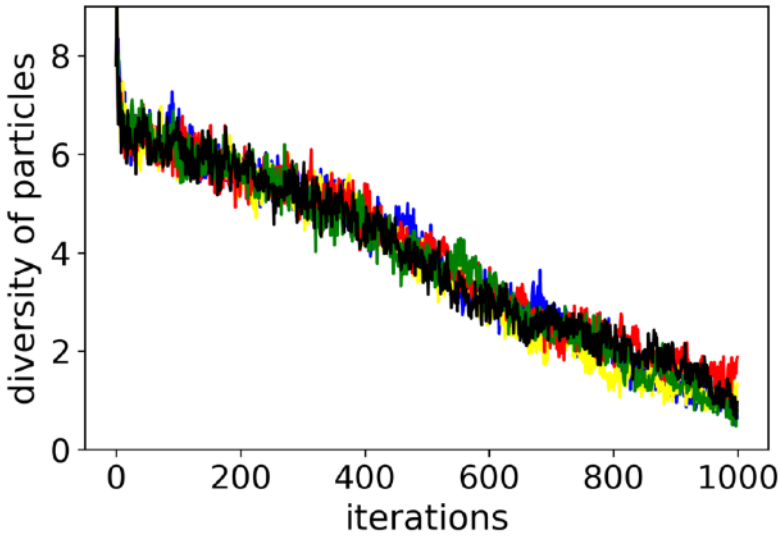
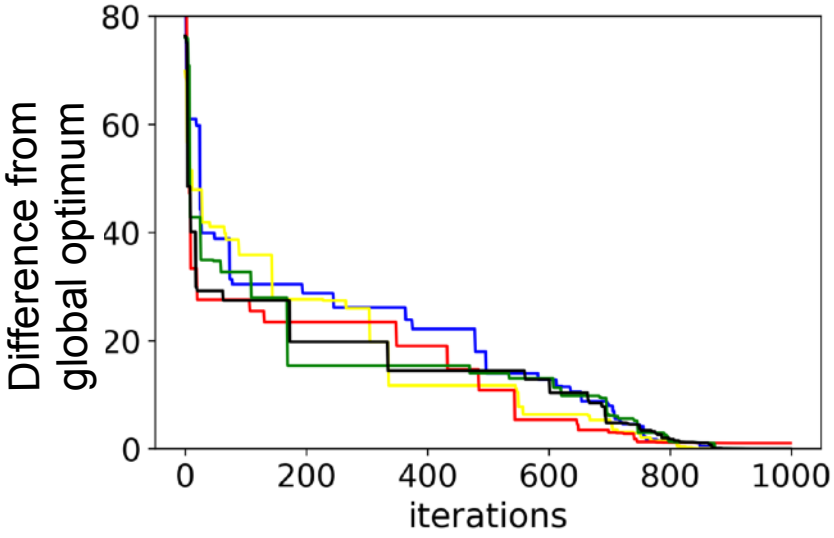
without mutation





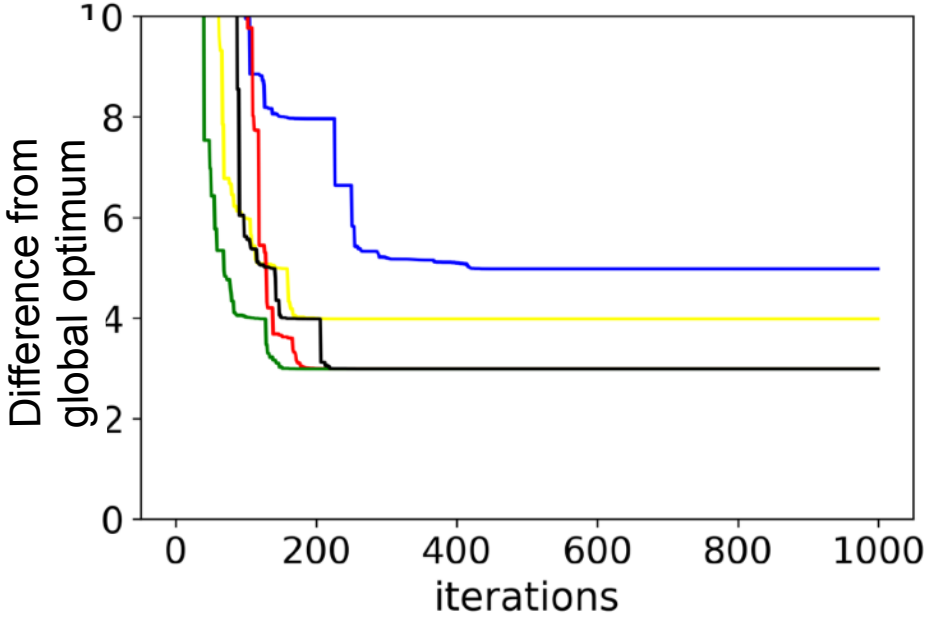
with mutation



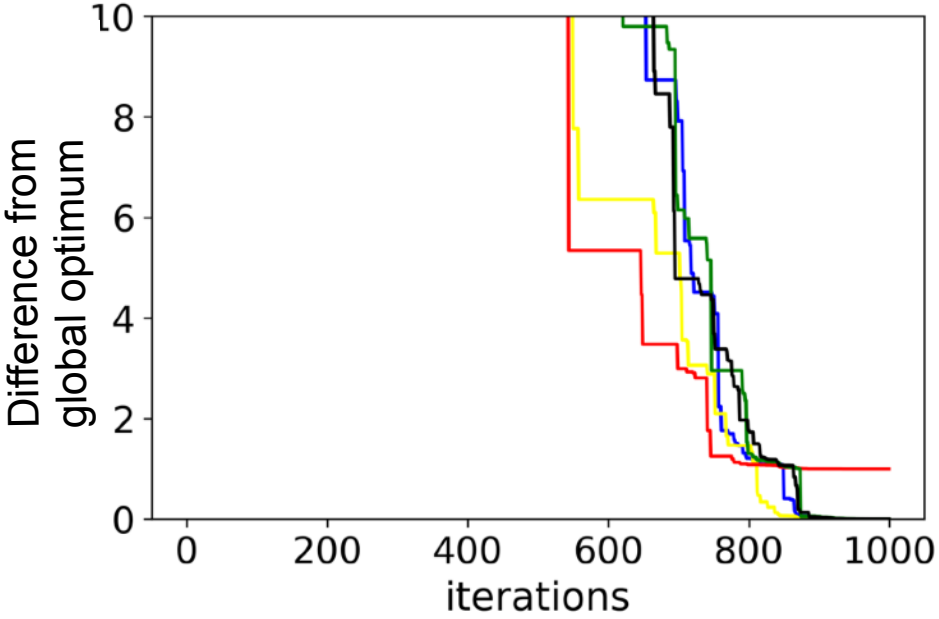


MUTATION TECHNIQUE

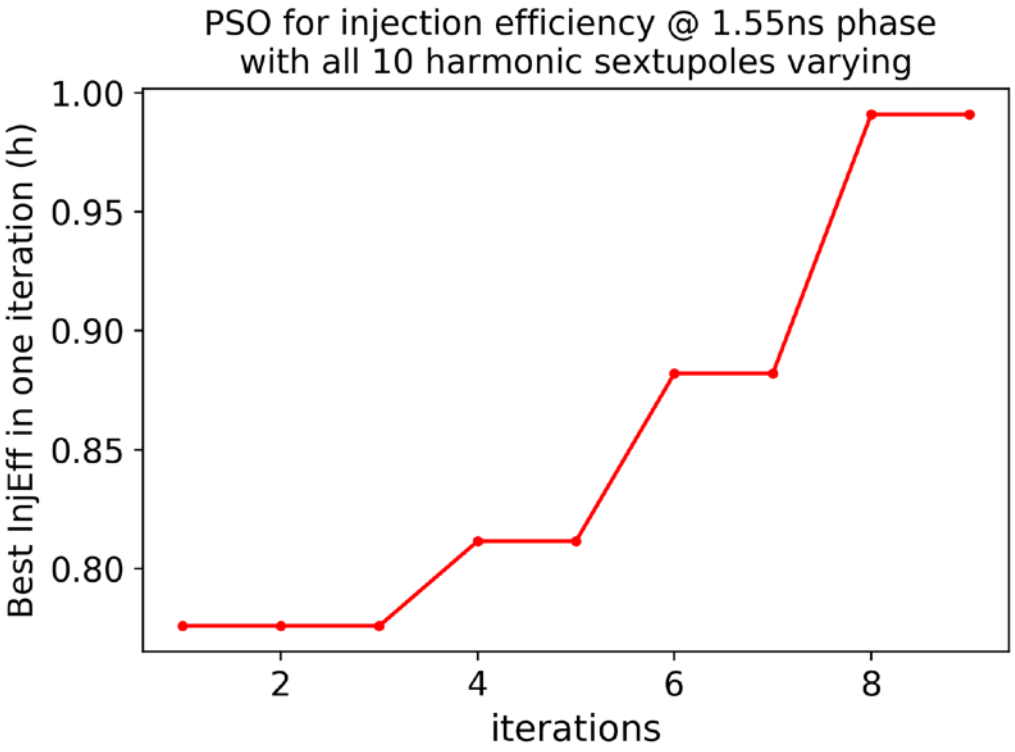
without mutation

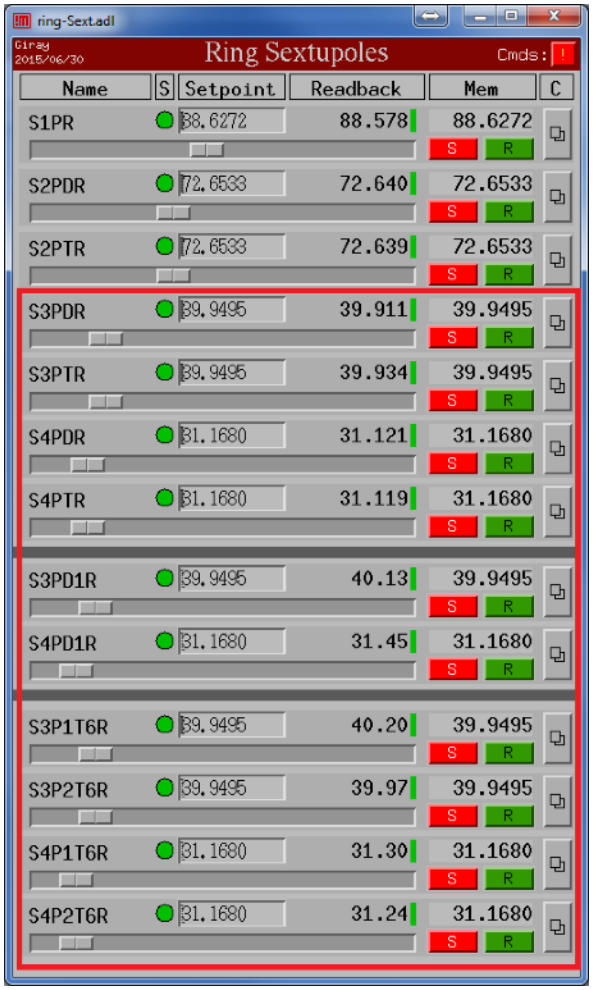


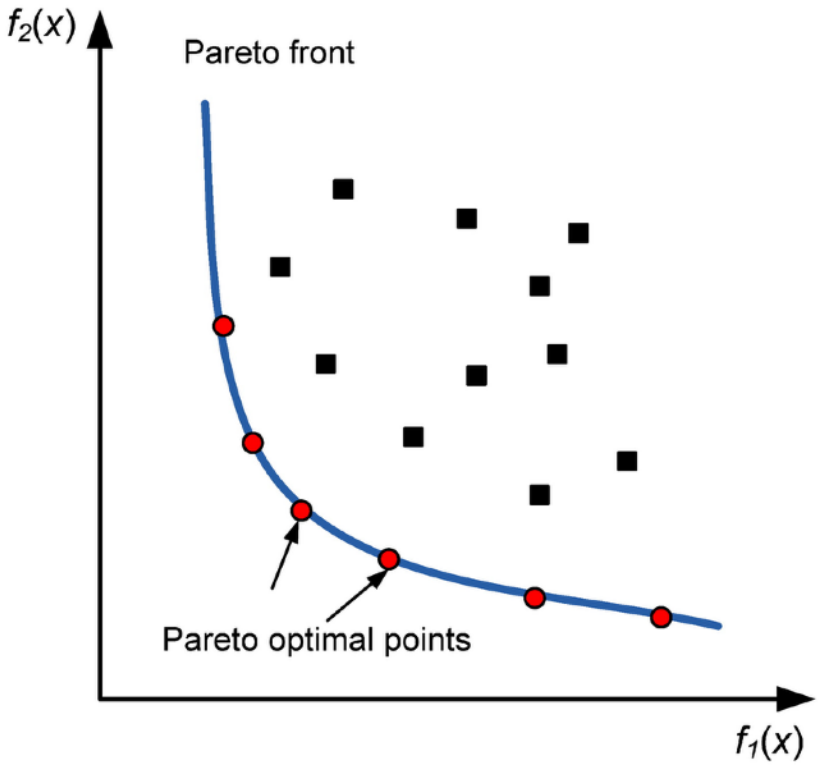
with mutation



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


PSO for injection efficiency @ 1.55ns phase
with all 10 harmonic sextupoles varying
Best InjEff in one iteration (h)
1.00
0.95
0.90
0.85
0.80
2
4
6
8
iterations

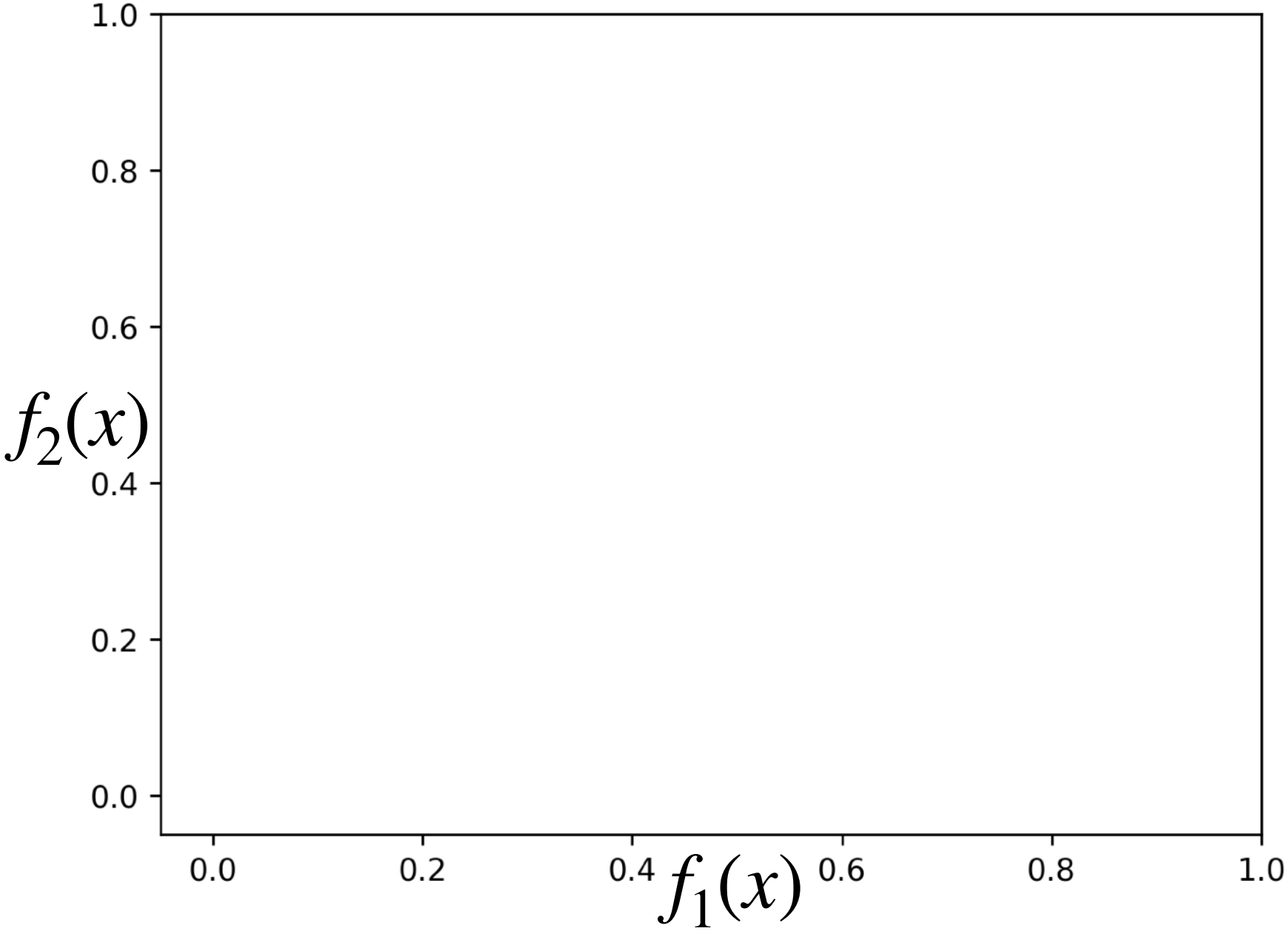

ring-Sext.adl
Ring Sextupoles
Cmds:
Name
S
Setpoint
Readback
Mem
C
S1PR 88.6272 88.578 88.6272
S2PDR 72.6533 72.640 72.6533
S2PTR 72.6533 72.639 72.6533
S3PDR 39.9495 39.911 39.9495
S3PTR 39.9495 39.934 39.9495
S4PDR 31.1680 31.121 31.1680
S4PTR 31.1680 31.119 31.1680
S3PD1R 39.9495 40.13 39.9495
S4PD1R 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



OUTLINE

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

$$\overrightarrow{f_1} = (f_{11}, \ldots, f_{n1})$$

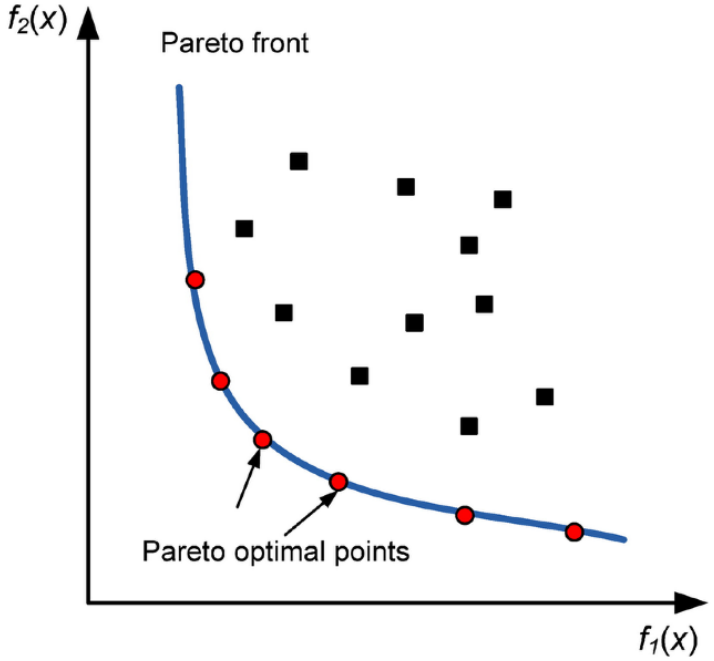
$$\overrightarrow{f_2} = (f_{12}, \ldots, f_{n2})$$

$\overrightarrow{f_1}$ ***dominates*** $\overrightarrow{f_2}$ *if:*

$$\forall i \in 1,\ldots,n : f_{1i} \leq f_{2i} \quad \textit{and} \quad \overrightarrow{f_1} \neq \overrightarrow{f_2}$$

*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