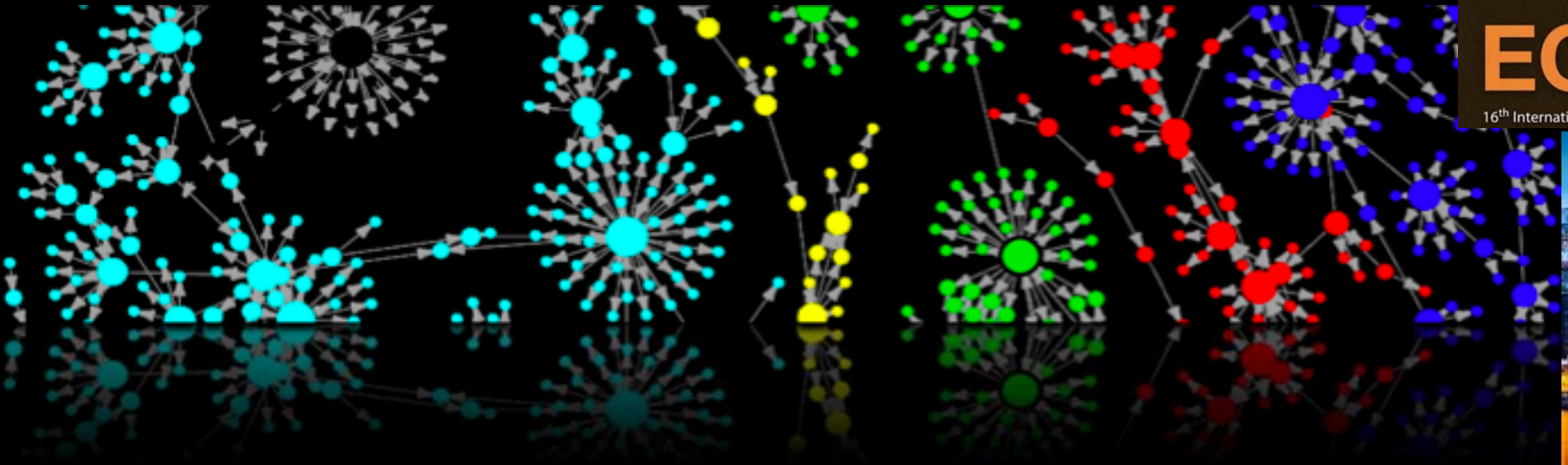

ECTA 2024 IJCCI

16th International Conference on Evolutionary Computation Theory and Applications

SEARCH TRAJECTORIES ILLUMINATED

Gabriela Ochoa

UNIVERSITY of STIRLING

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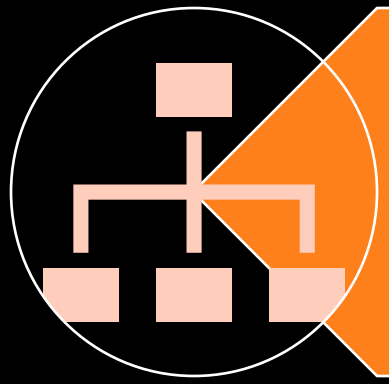
SEARCH IN COMPUTING SCIENCE

Stored Data

- Info in disk or memory
- Binary search, sequential search



Tree-like Structure

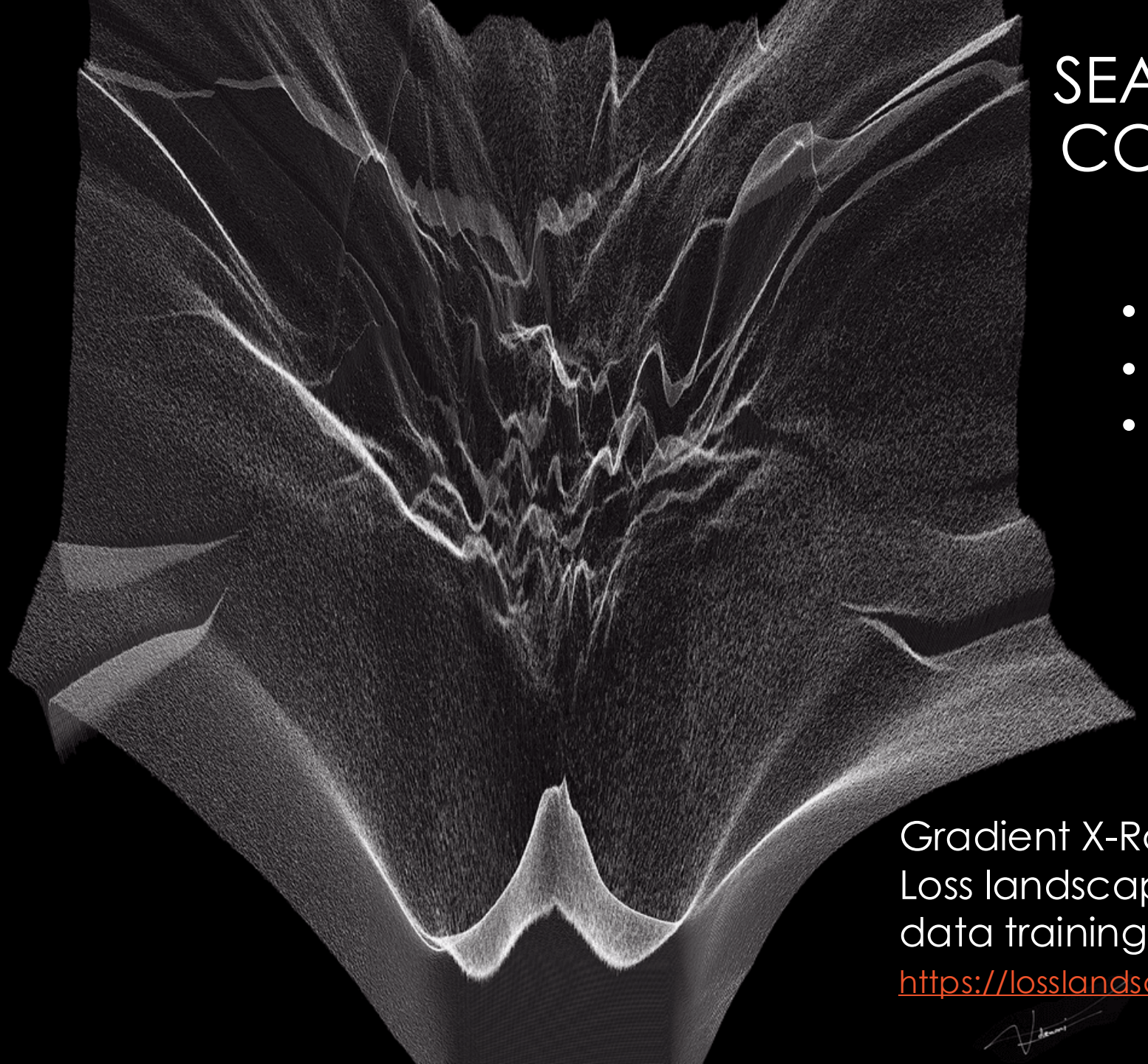
- Set of actions from start to goal states
- DFS, BFS, A*

Web Documents

- Info on the WWW
- Web crawling

Solutions

- Solution in a large space
- EAs, metaheuristics



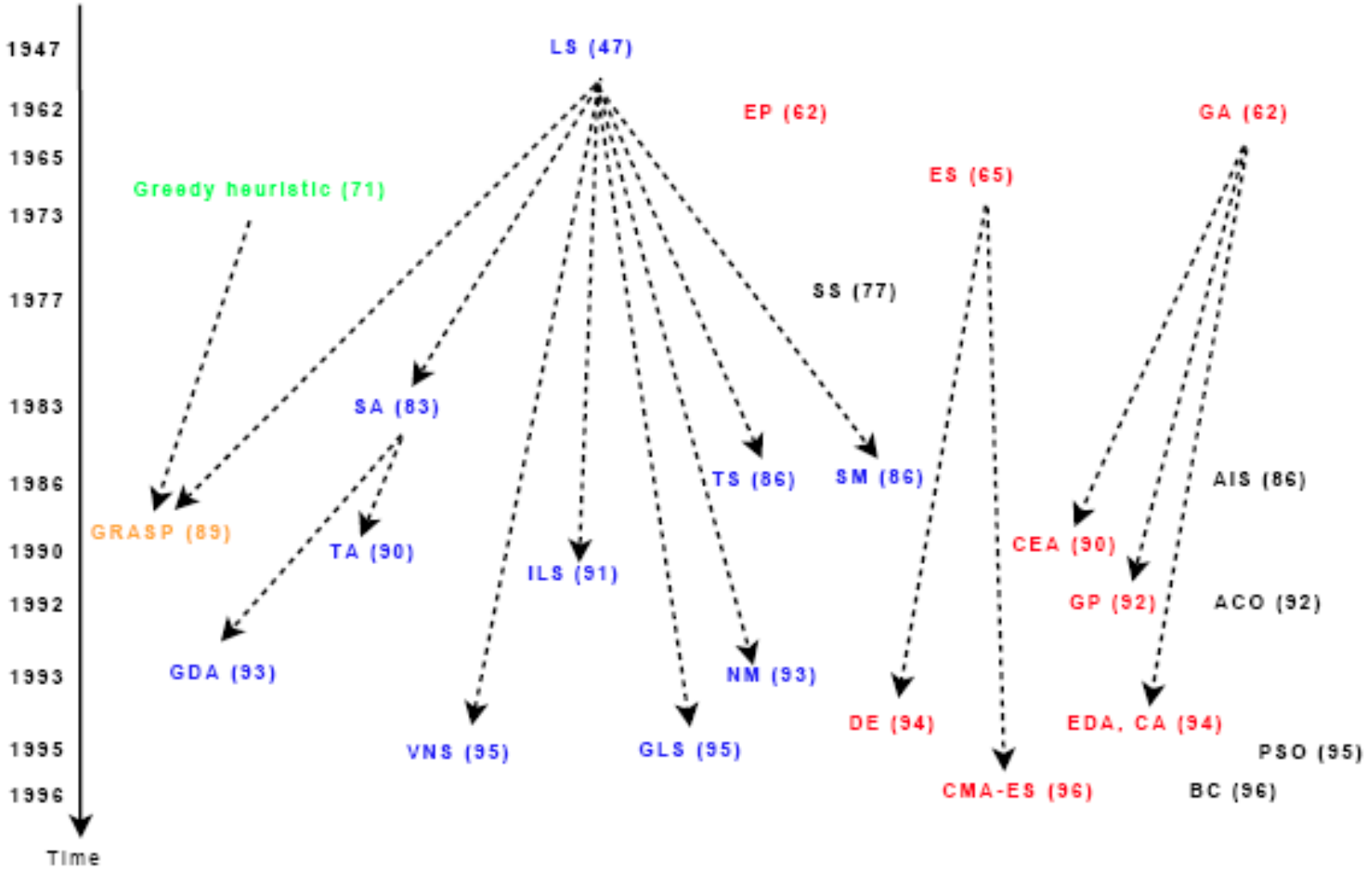
SEARCH FOR SOLUTIONS COMPLEX LANDSCAPES

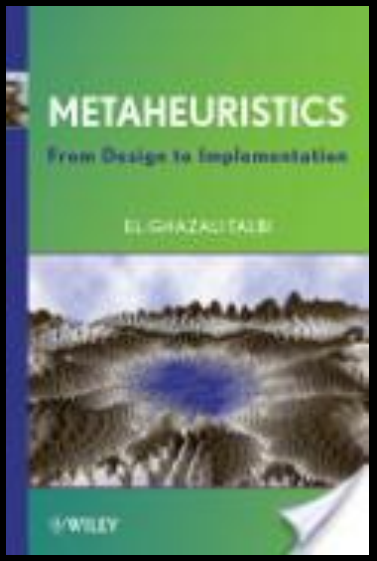
- Vectors (Real, Integer, Binary)
- Permutations
- Grammars, Trees, Graphs

Wide applicability!

Gradient X-Ray (Javier Ideami)
Loss landscape: from real data training a deep NN
https://losslandscape.com

GENEALOGY OF METAHEURISTICS





E. Talbi (2009)

NATURE-INSPIRED ALGORITHMS:
CITATIONS

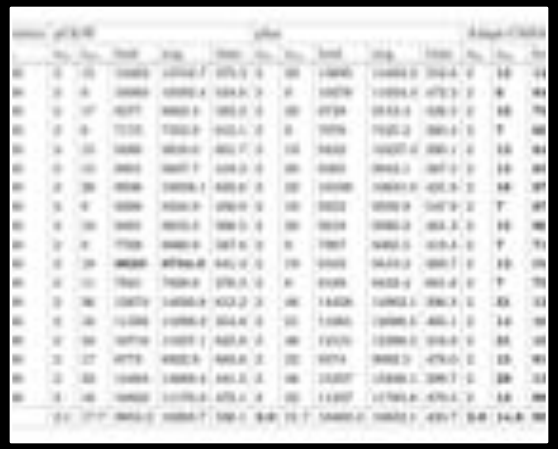
ABC Artificial Bee Colony
HS Harmony Search
CS Cuckoo Search
GSA Gravitational Search Algorithm
BFO Bacterial Foraging Optimization
FA Firefly Algorithm

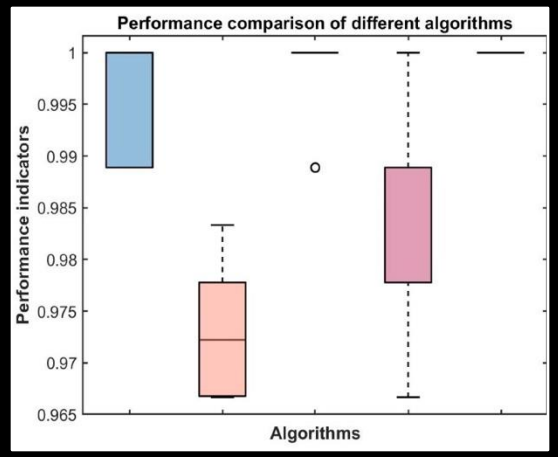
When the metaphor is stripped away, is the search process any different from the search process of existing established algorithms?

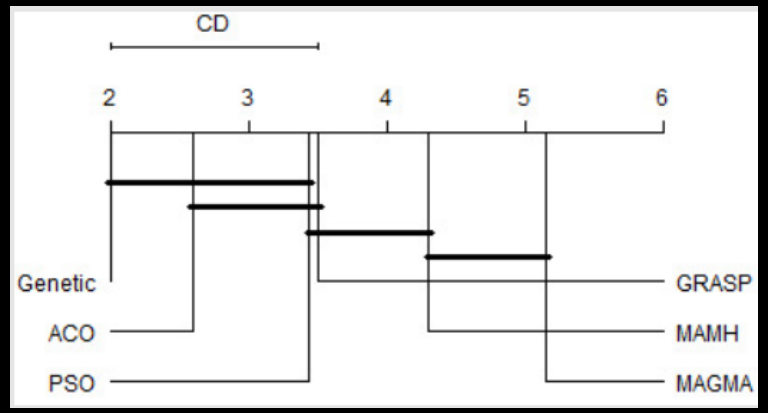
Lones, M. A. (2020) Mitigating Metaphors: A Comprehensible Guide to Recent Nature-Inspired Algorithms, *SN Computer Science* 1, 49

CONTRASTING ALGORITHMS
MOTIVATION FOR STNs

At the end of runs

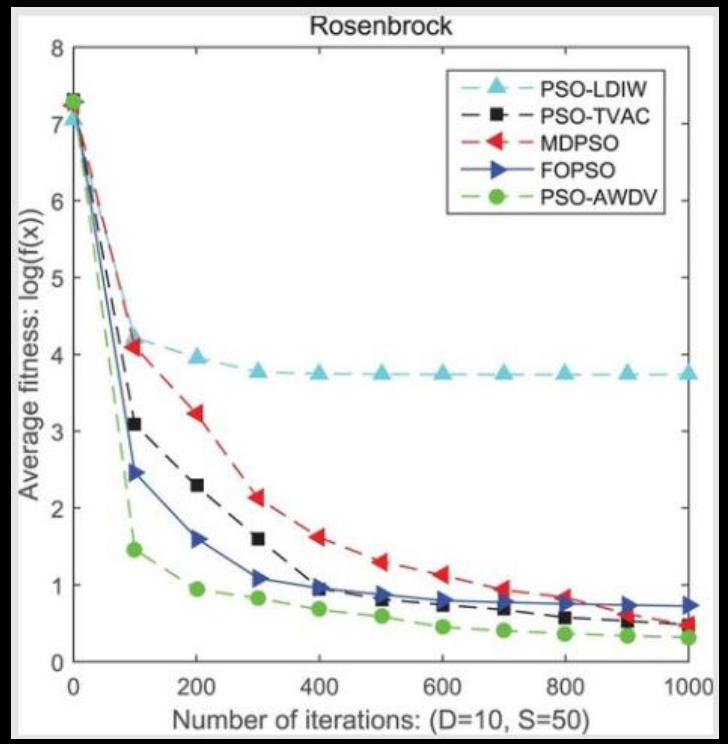






Critical difference plots

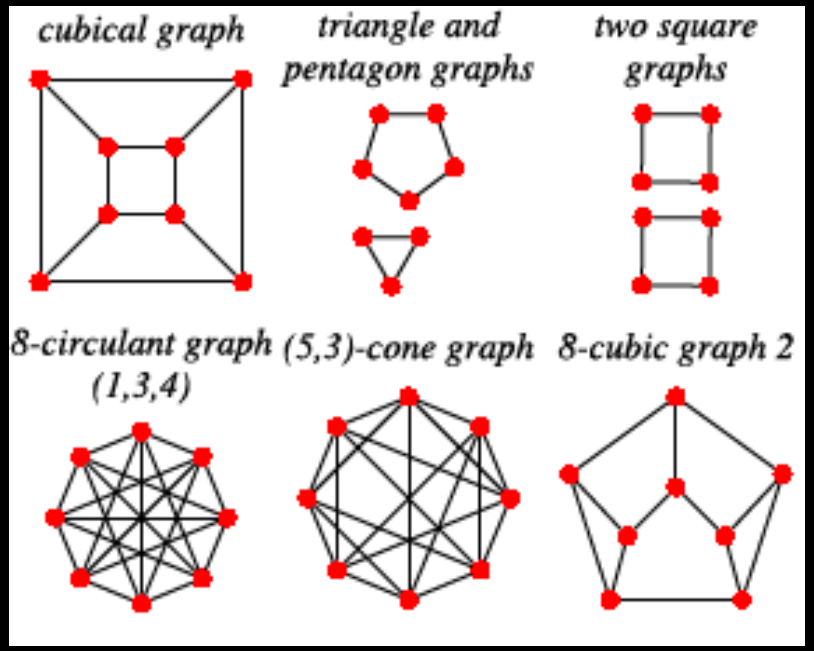
During the run



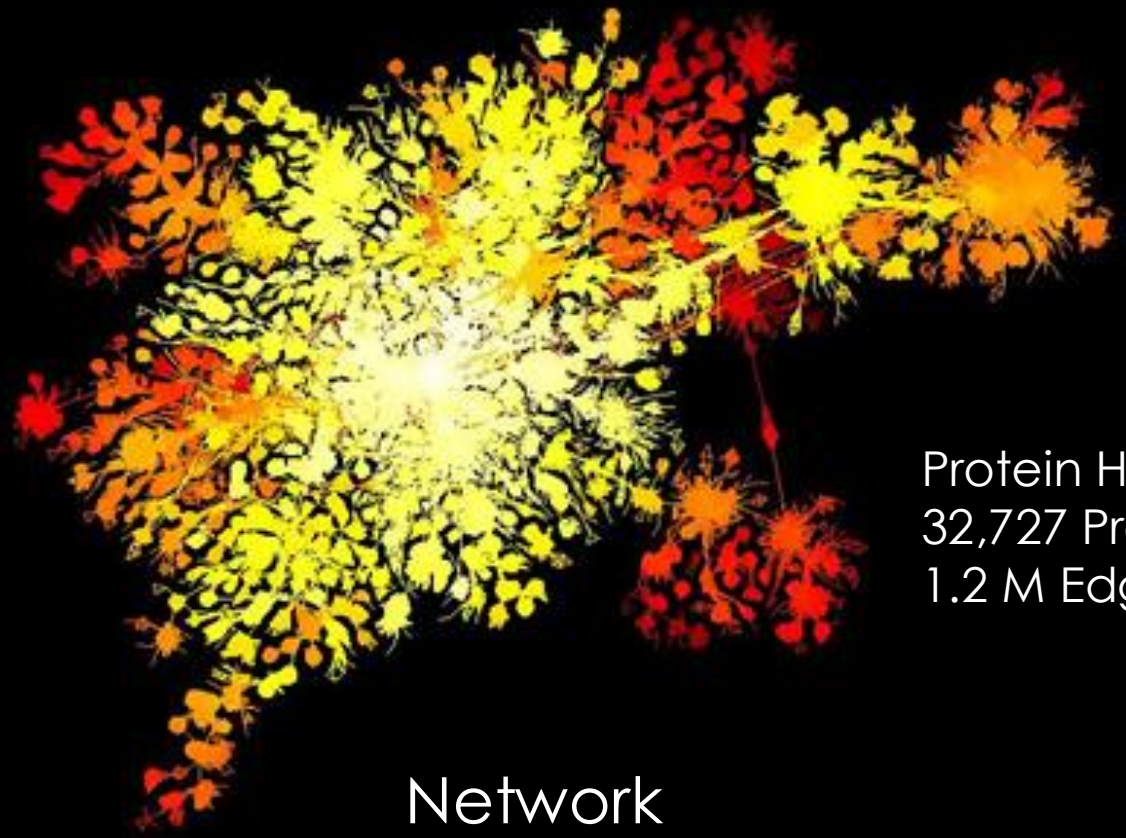
Convergence curves - show dynamics **only** on the objective space

WHAT IS A (COMPLEX) NETWORK?

https://mathworld.wolfram.com/WeaklyRegularGraph.html



Graph
Mathematical Object

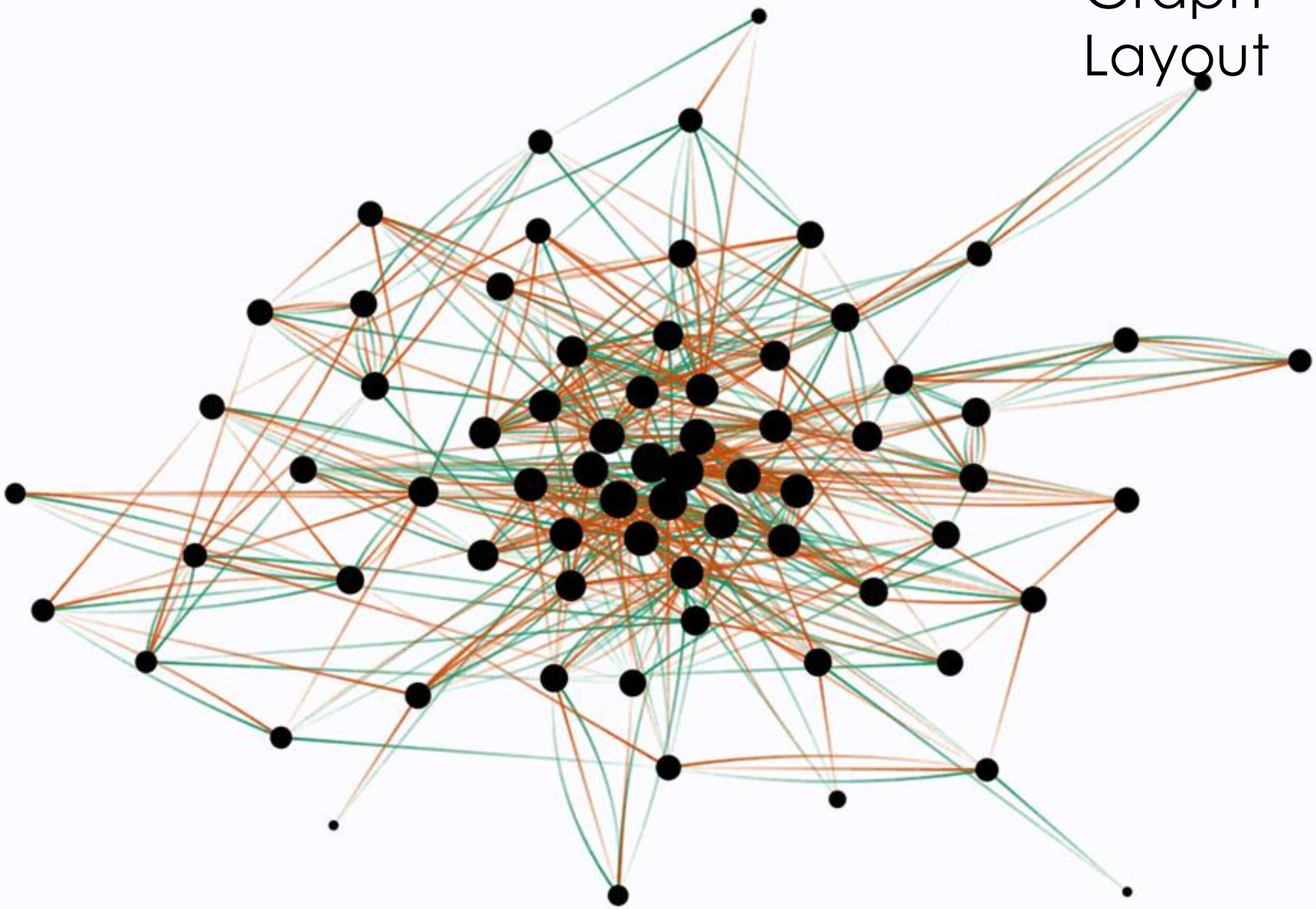


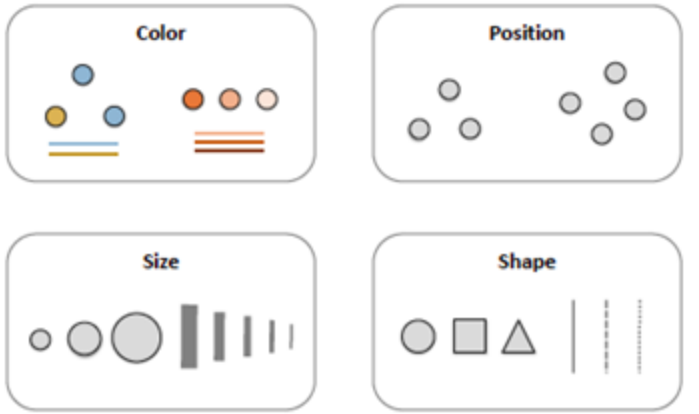
Protein Homology
32,727 Proteins
1.2 M Edges

Network
Data Driven Instantiation

Behind each complex system, there is an intricate network that encodes the interactions between the system's components. Albert-László Barabási, Network Science

Network Visualisation

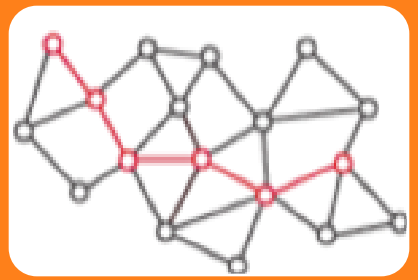




https://kateto.net/network-visualization

https://www.data-imaginist.com/2017/ggraph-introduction-layouts/

NETWORK METRICS

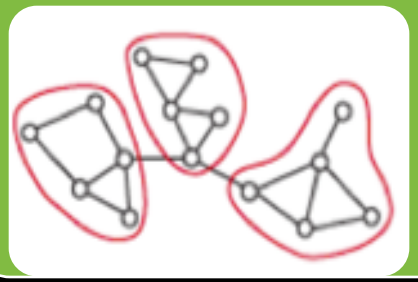


Distance

- Diameter
- Average shortest path

Topology

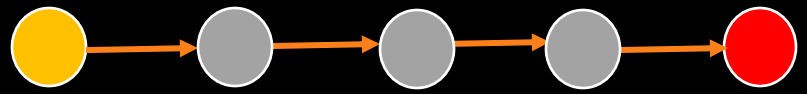
- Degree distribution
- Mean degree, Assortativity, disparity, centrality

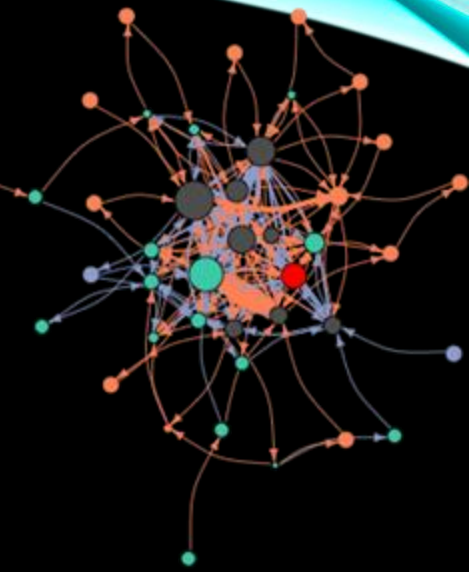


Cohesion

- Clustering coefficient
- Community structure

SEARCH TRAJECTORY NETWORKS
THE CONCEPT





Nodes (N)

Locations of representative solutions

Edges (E)

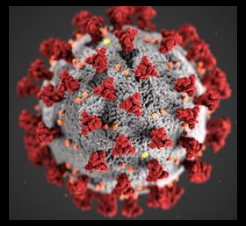
Directed, connect two consecutive locations

Representative Solution → Location (Partition) → Nodes

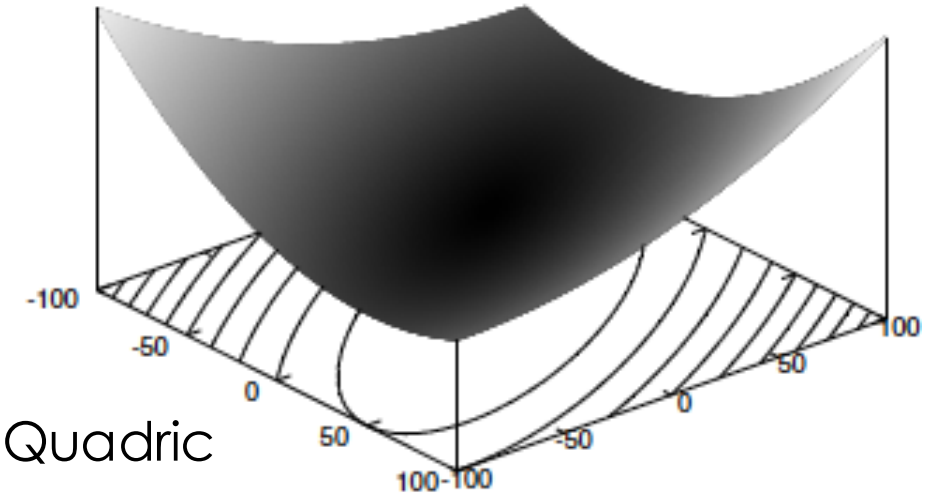
STN

Directed graph
STN = (N, E)

(Ochoa, Malan, Blum, EvoApps 2020, *Appl. Soft Comput*. 2021)

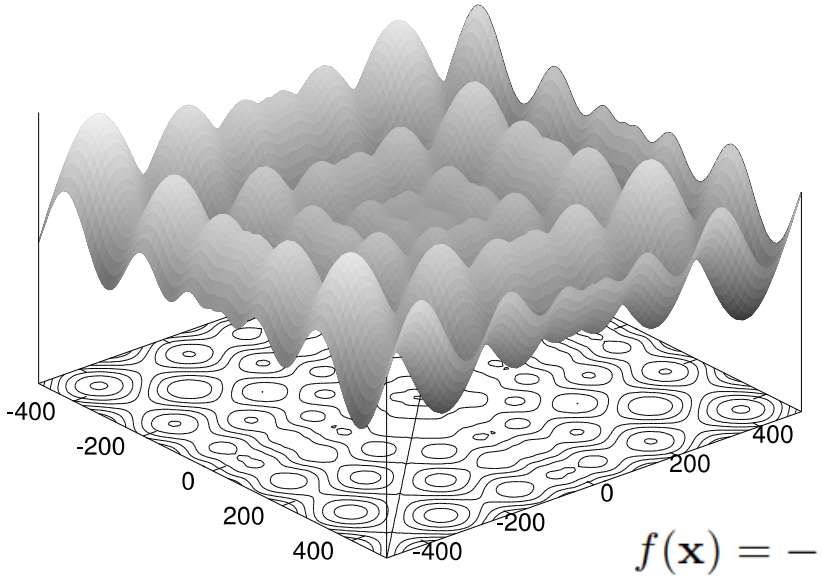


CONTINUOUS BENCHMARK FUNCTIONS



Quadric

$$f(\mathbf{x}) = \sum_{i=1}^{D} \left(\sum_{j=1}^{i} x_j \right)^2$$



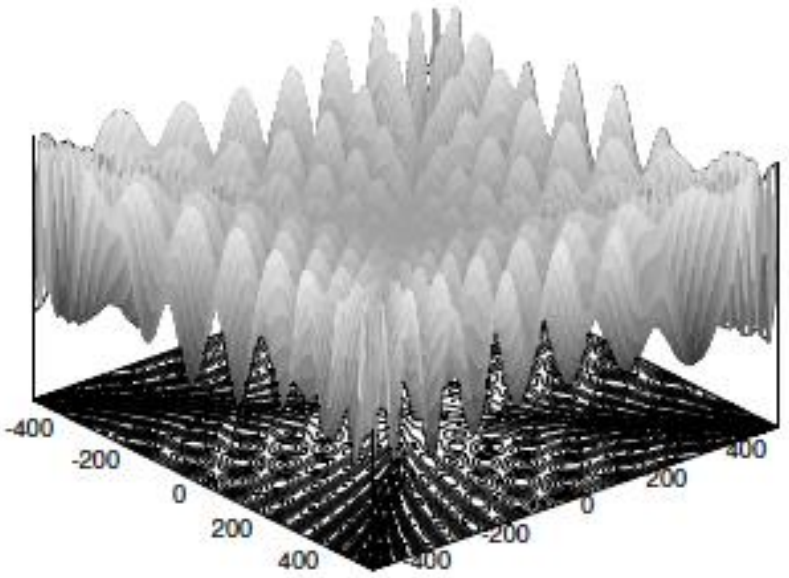
Schwefel

$$f(\mathbf{x}) = -\sum_{i=1}^{D} \left(x_i \sin(\sqrt{|x_i|}) \right)$$

Rana

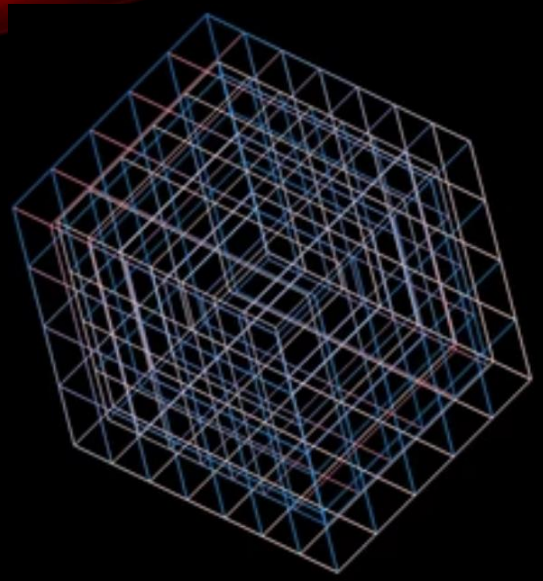
$$f(\mathbf{x}) = \sum_{i=1}^{D} x_i \sin(\alpha)\cos(\beta) \quad +$$

$$\left(x_{(i+1)\mathrm{mod}D} + 1\right)\cos(\alpha)\sin(\beta),$$



MAPPING SOLUTIONS TO LOCATIONS

Solution space is divided into hypercubes



Example with D = 3

[0.170574, 0.83234, 1.016740]

Solution

Rounding

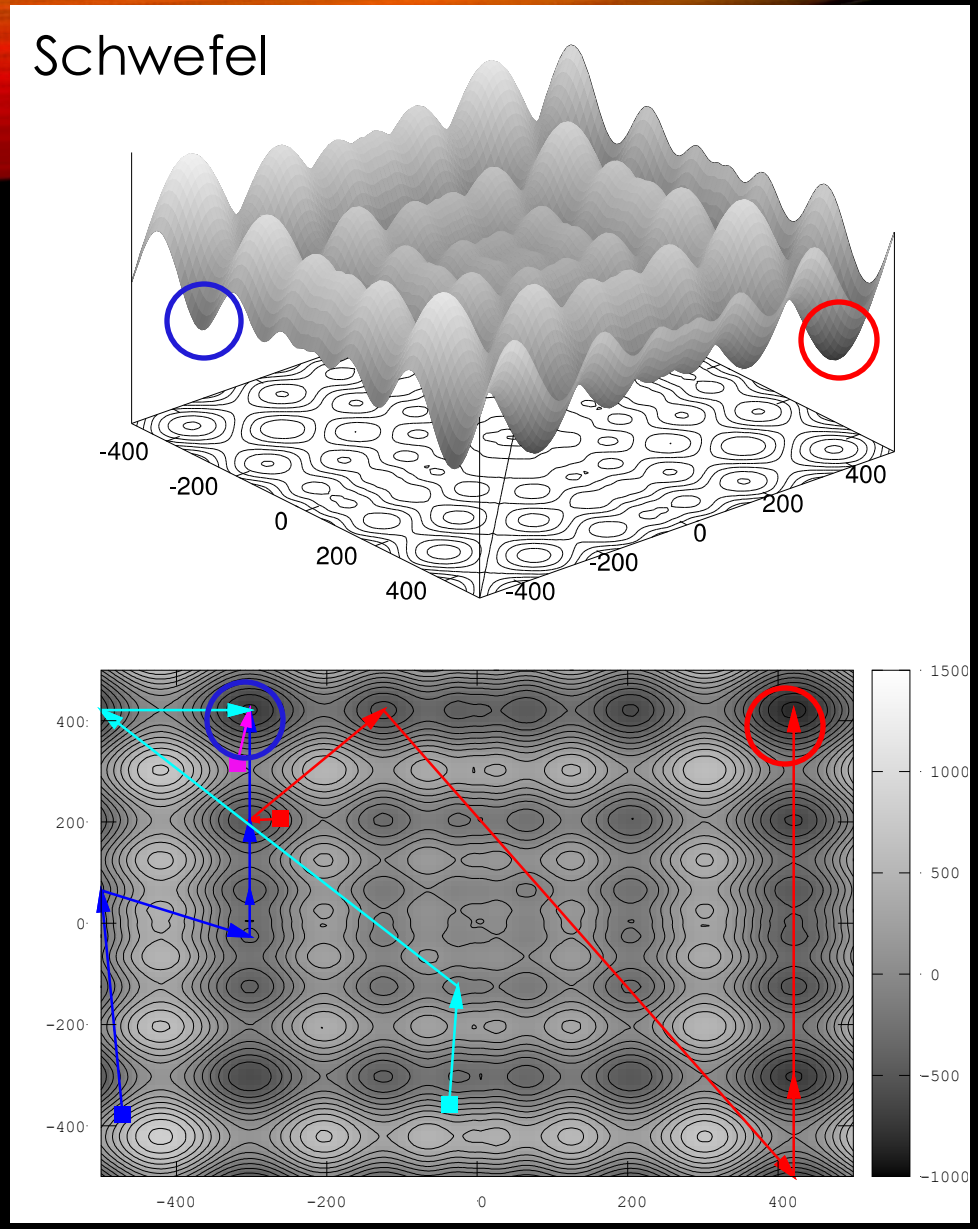
- Precision Factor PF = -1 (i.e 10^{-1} 0.1)
- [0.2, 0.8,1.0]

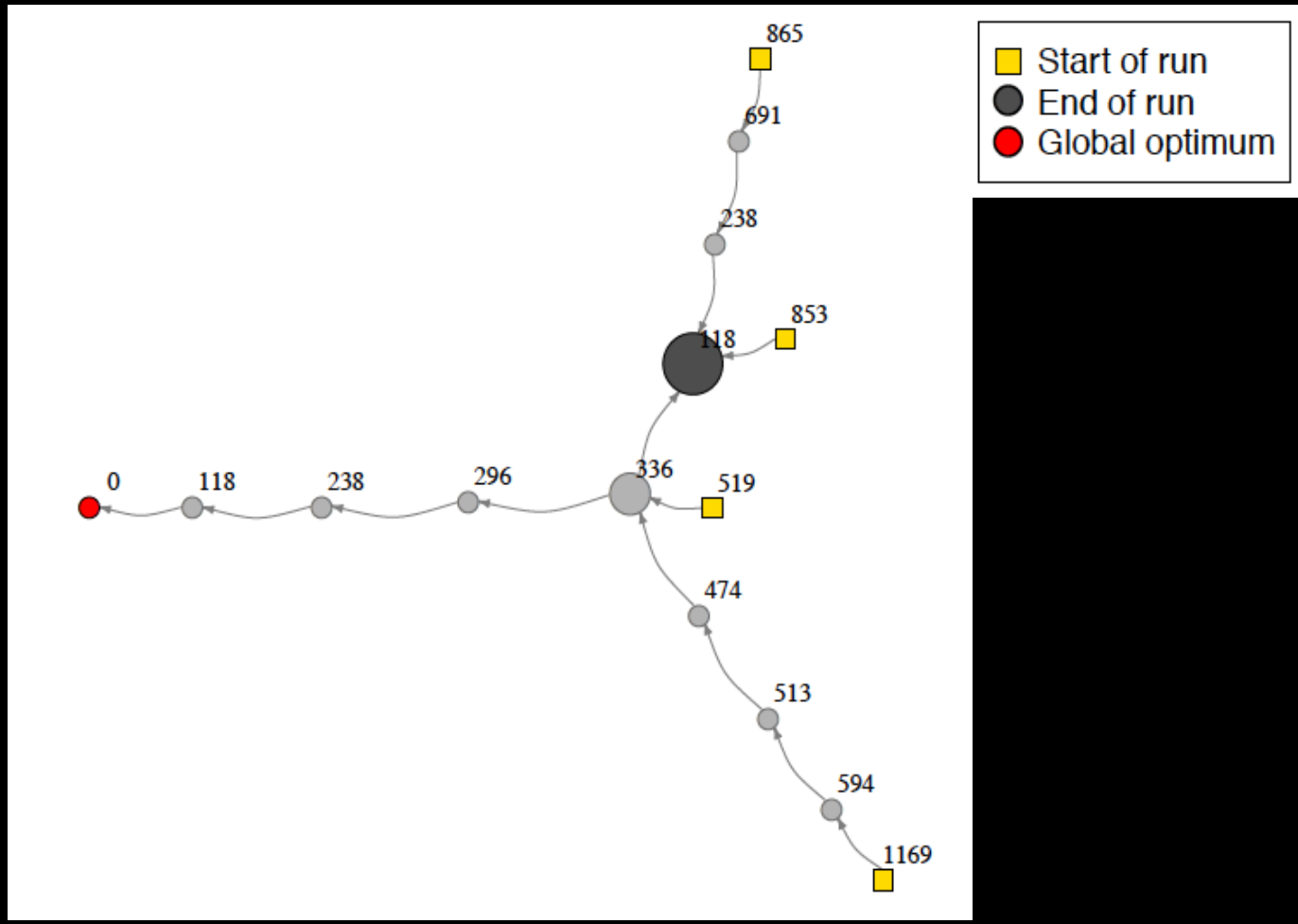
Example Input, Search Traces

Run	Fitness	Solution
1	12.079147	0.170574,0.832340,1.016740
1	9.693960	0.009483,0.788237,0.947641
1	6.600536	0.099082,1.102965,1.0443980
1	2.975199	0.005325,1.058486,0.0779451
2	22.757999	0.829453,1.129413,3.1201914
2	8.927973	1.018141,1.088751,0.1684573
2	5.947124	0.034037,1.042938,2.0281033
2	3.764063	0.973246,1.083225,0.0289796

…

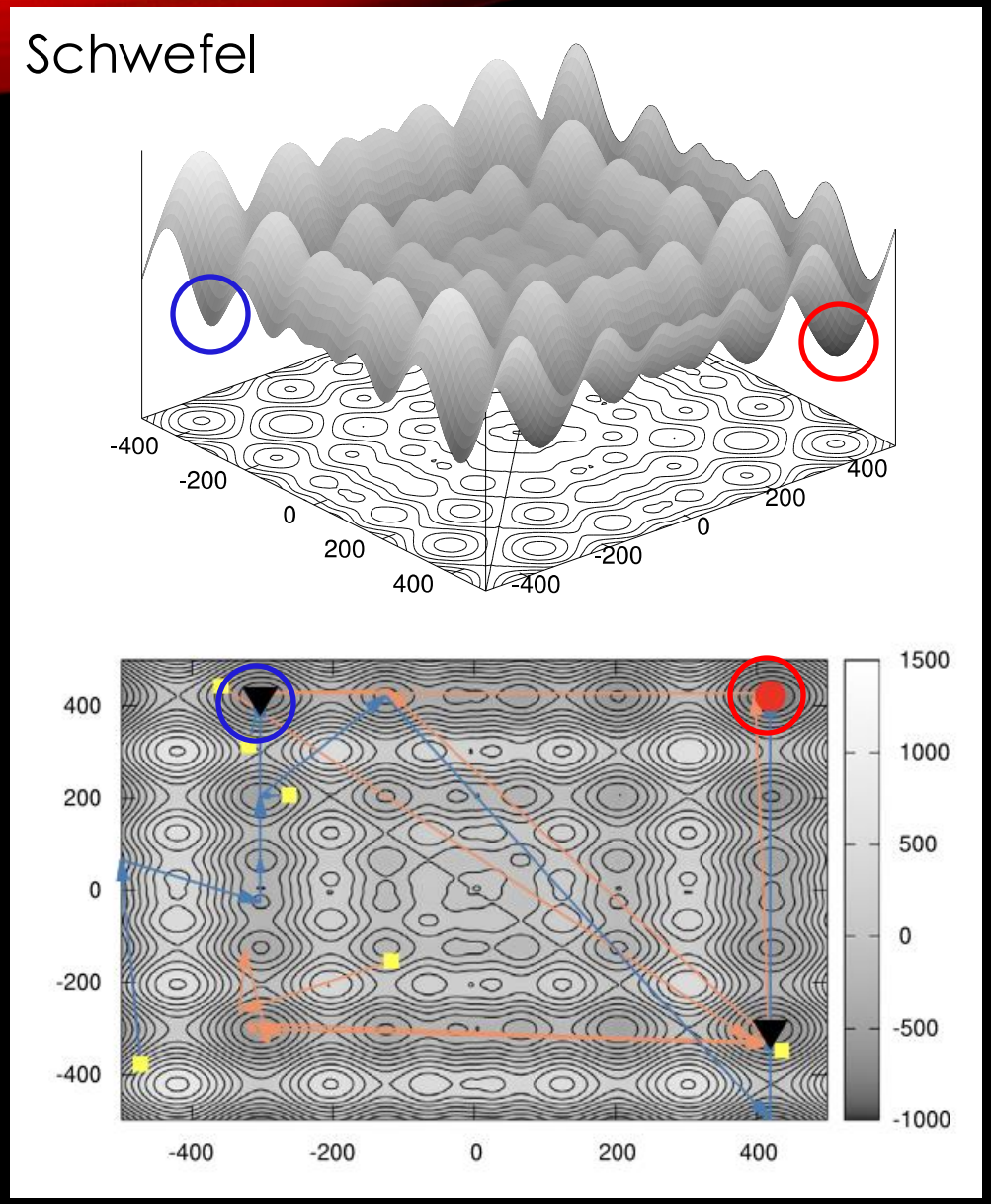
STN MODEL

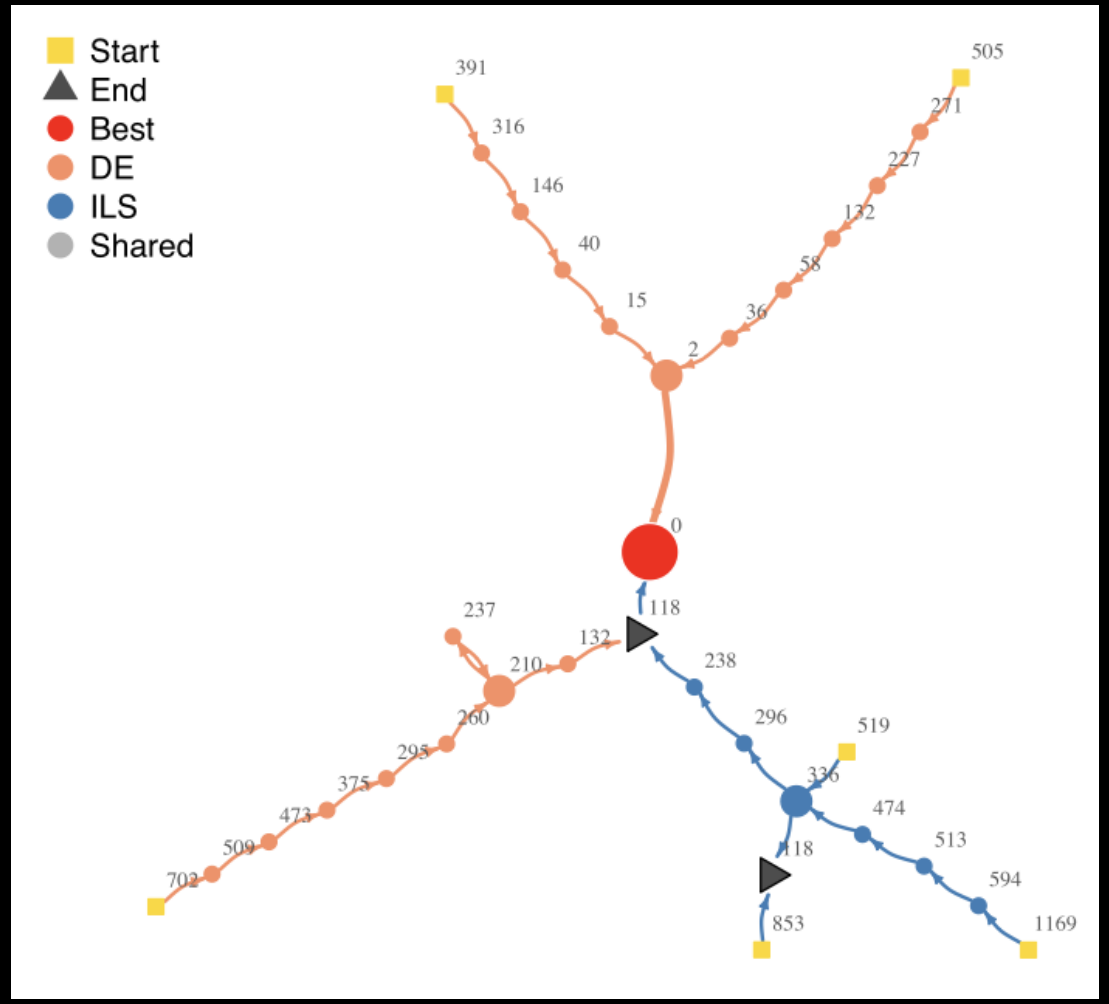




4 Runs
One Algorithm (ILS) It. Local Search

MERGED STN MODEL

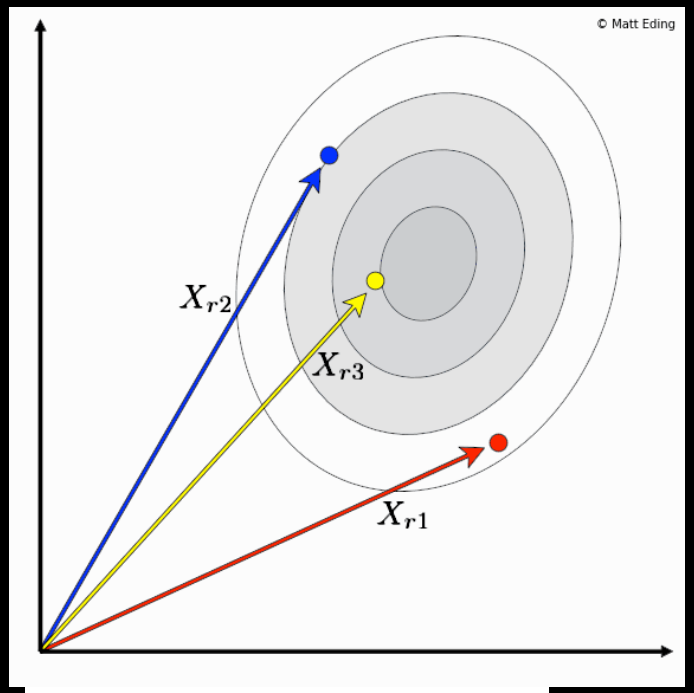




3 Runs
2 Algorithms: ILS and Differential Evolution (DE)

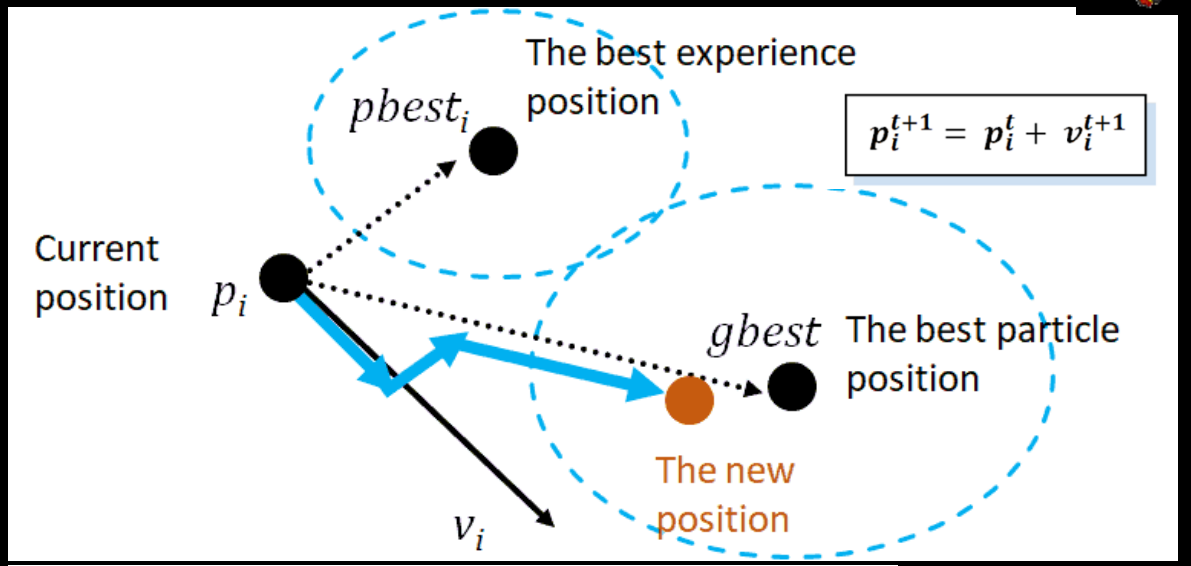
POPULATION-BASED ALGORITHMS

Differential Evolution (DE/rand/1)



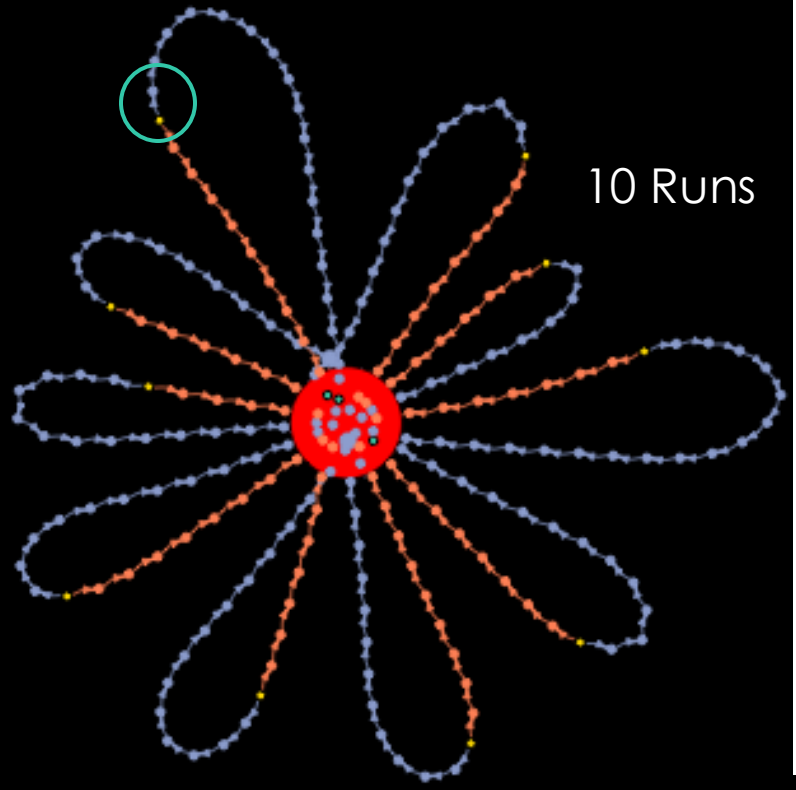
$$\vec{v}_i = \vec{x}_{r_1} + F_{xc}(\vec{x}_{r_2} - \vec{x}_{r_3})$$

Particle Swarm Optimisation (Global best PSO)



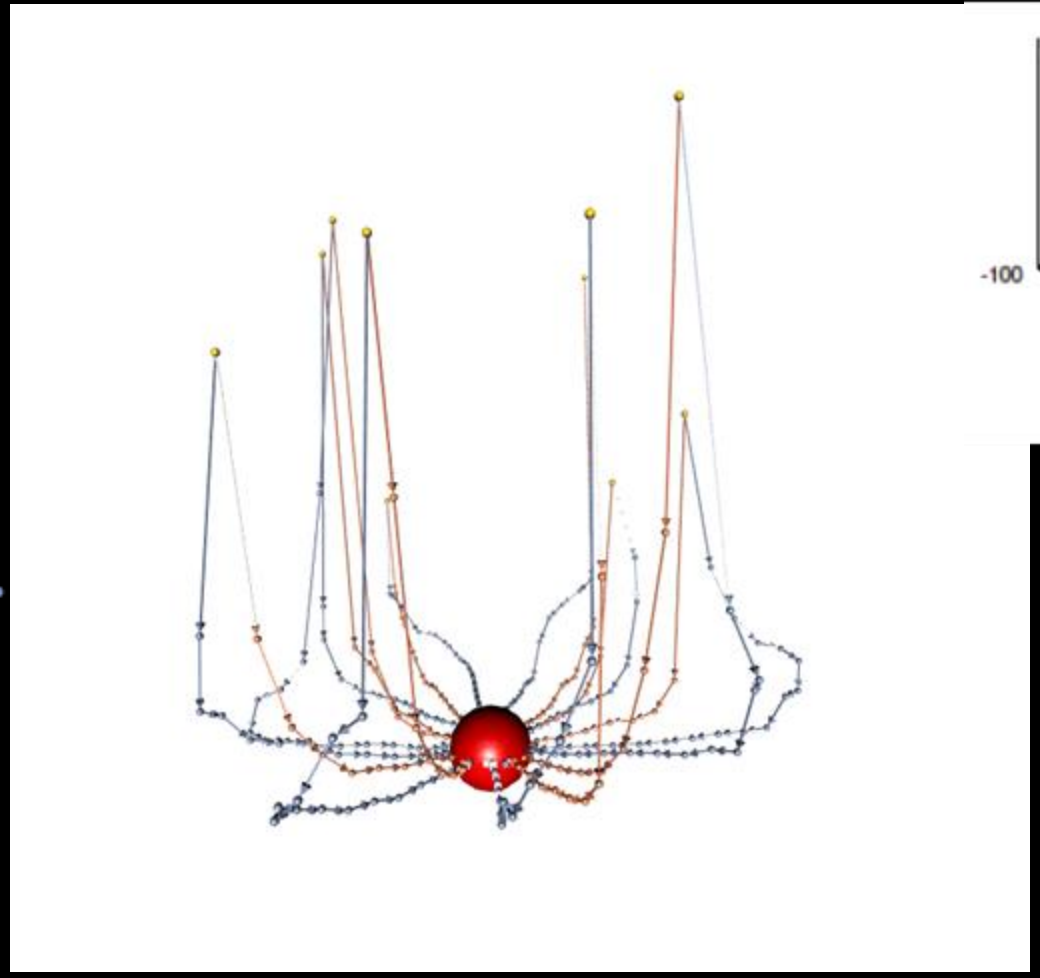
$$v_i^{t+1} = \underbrace{v_i^t}_{\text{Inertia}} + \underbrace{c_1 r_1 (pbest_i^t - p_i^t)}_{\text{Personal influence}} + \underbrace{c_2 r_2 (gbest^t - p_i^t)}_{\text{Social influence}}$$

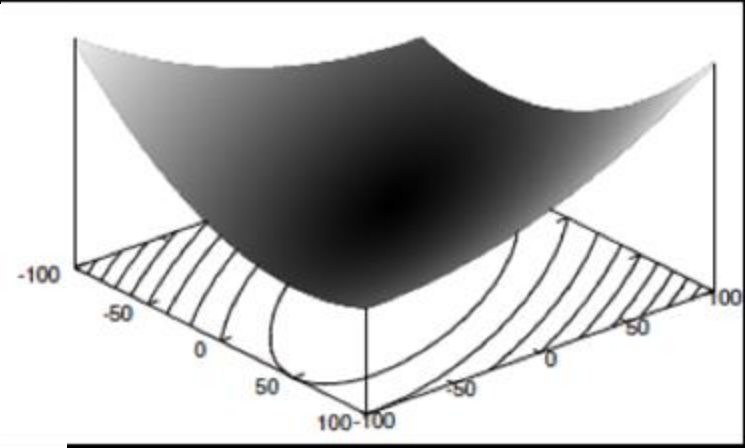
QUADRIC, D = 10



10 Runs

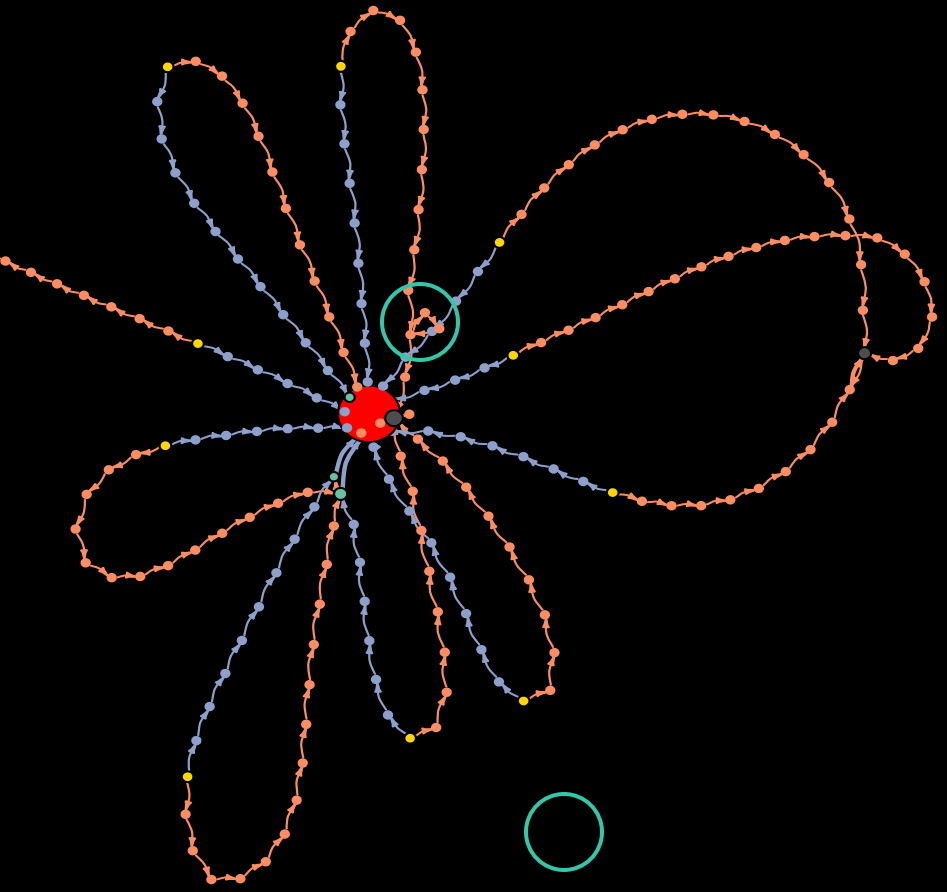
- Global
- PSO
- DE
- Both
- Start
- End



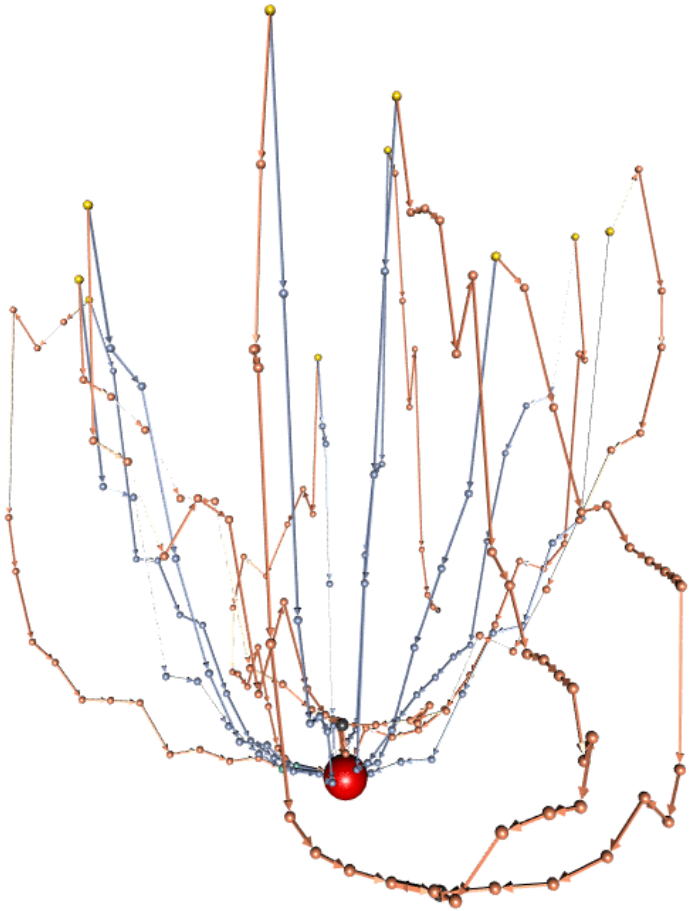


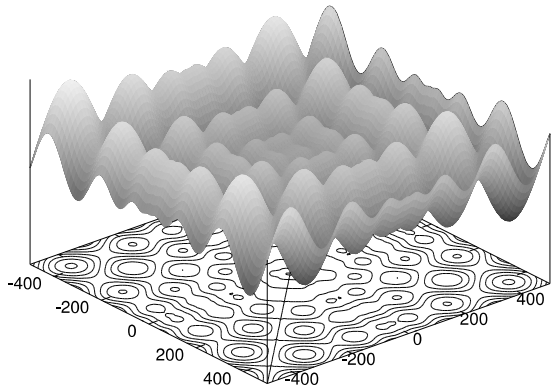
	PSO	DE
Nodes	93	154
Path length	9.2	15.1
Success	100%	100%

Schwefel, *D* = 5



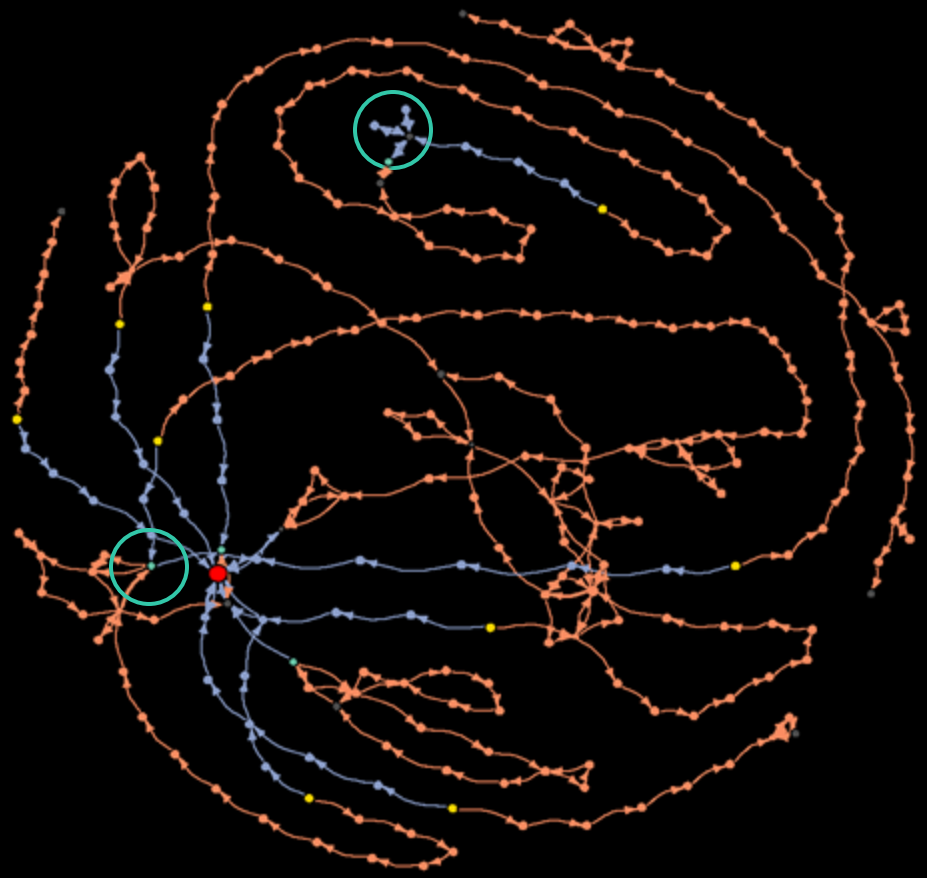
Global
PSO
DE
Both
Start
End



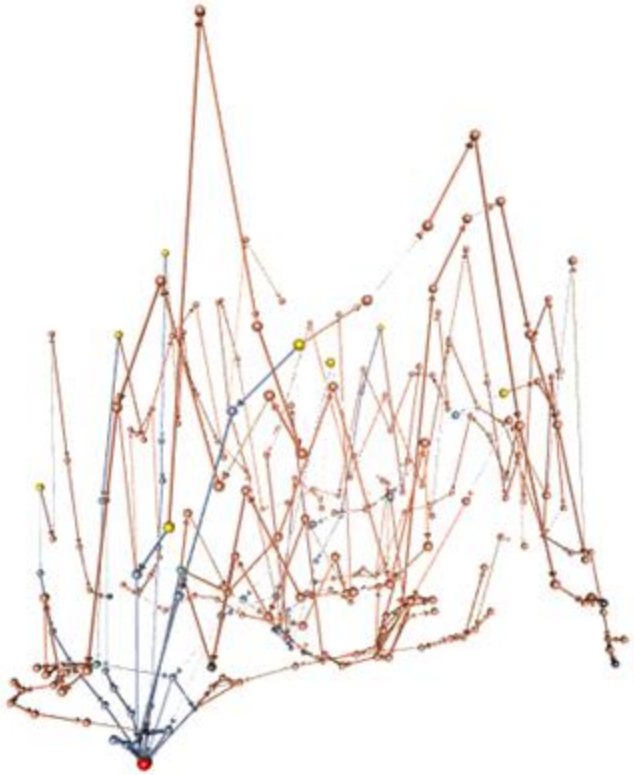


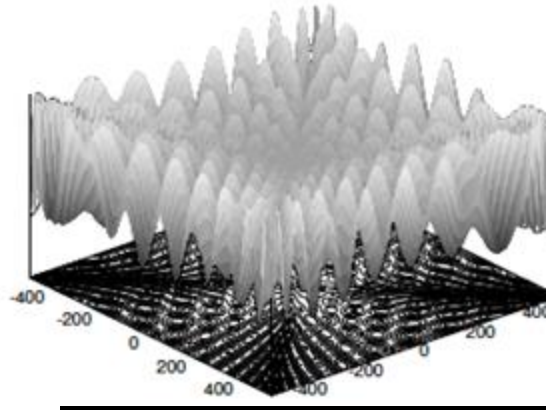
	PSO	DE
Nodes	138	81
Path length	12.6	8.0
Success	50%	100%

Rana, D = 3



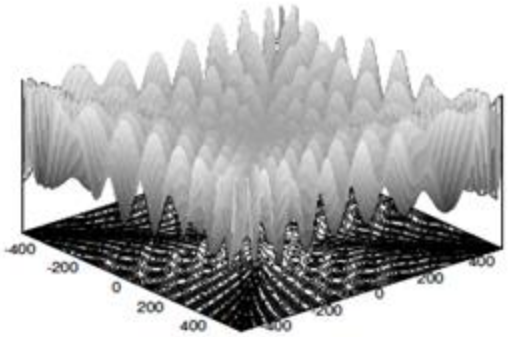
Global
PSO
DE
Both
Start
End

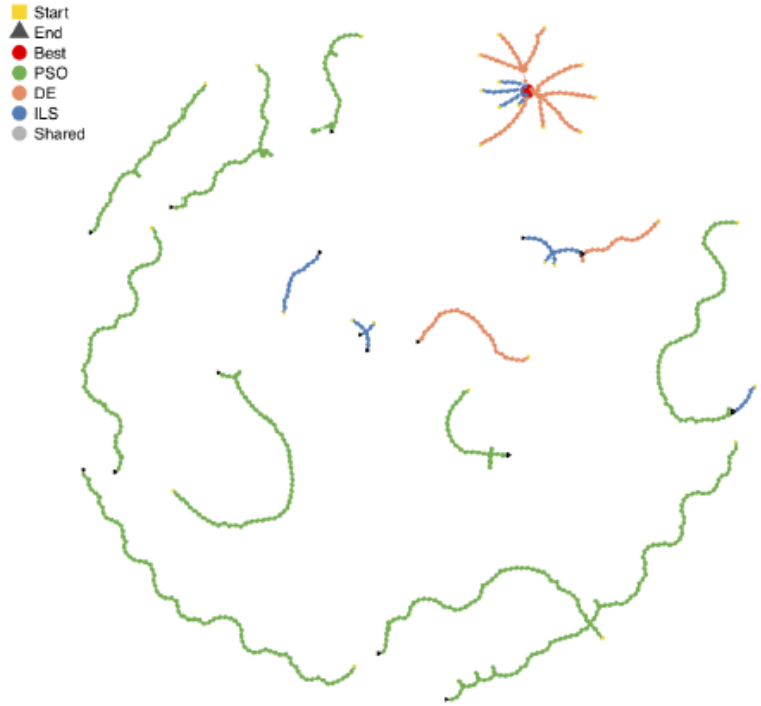




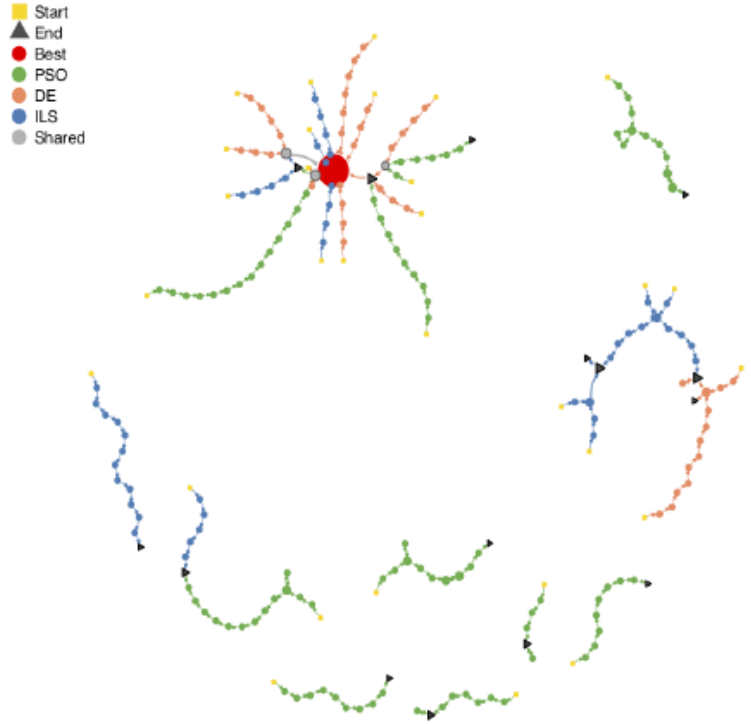
	PSO	DE
Nodes	211	49
Path length	13.5	4.7
Success	0%	90%

CHANGING PARTITIONING FACTOR

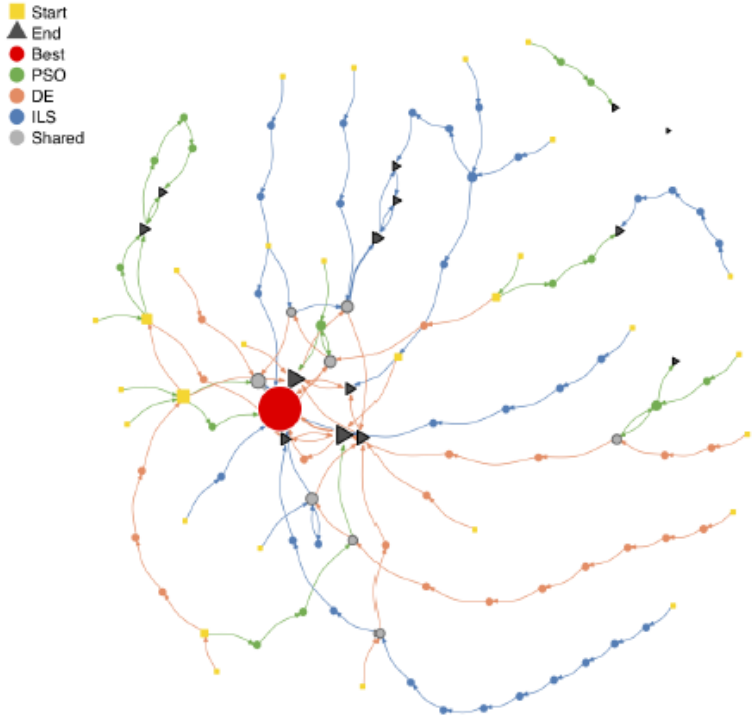




Fine partitioning $PF = -1$.



Medium partitioning, $PF = 1$.

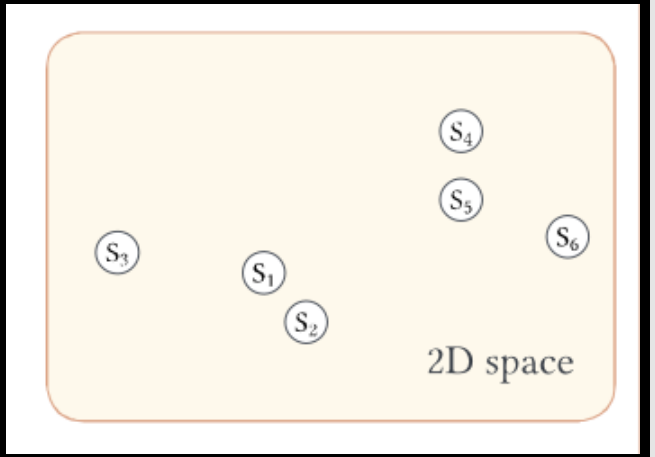


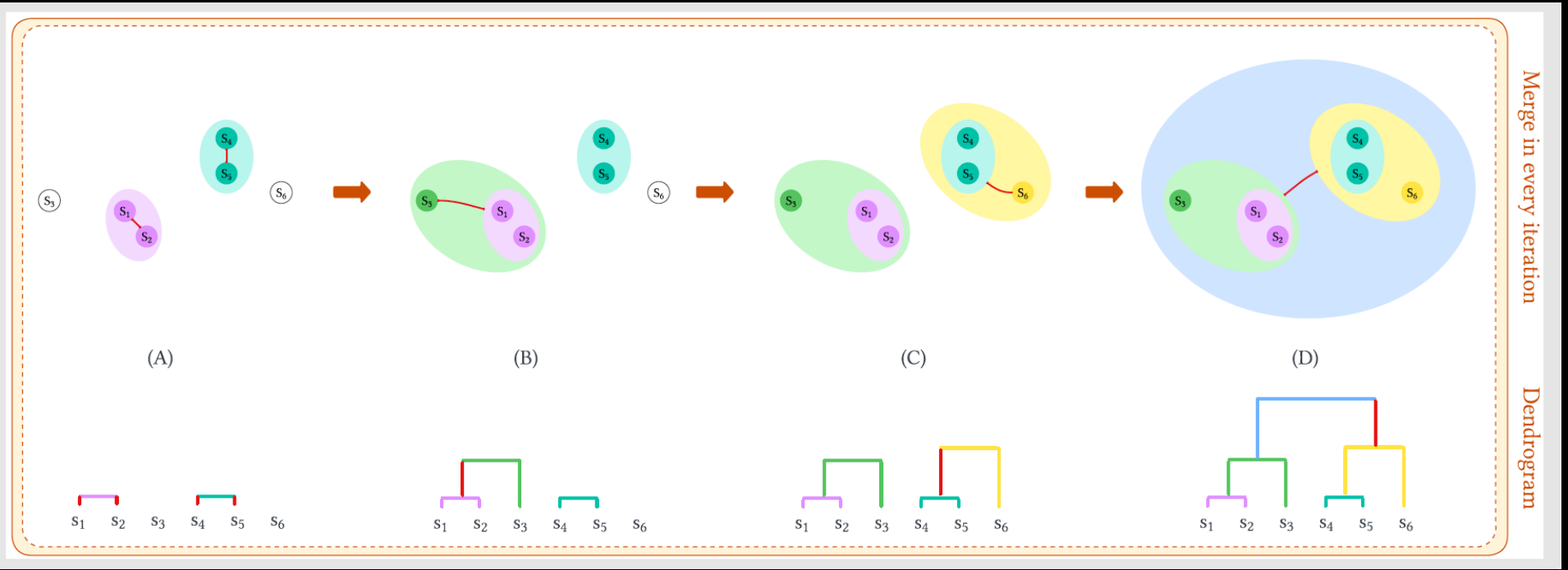
Coarse partitioning, $PF = 2$.

Rana function
Success rate: PSO (0%), DE (80%), ILS (40%)

ALTERNATIVE PARTITIONING METHOD

Hierarchical Agglomerative Clustering





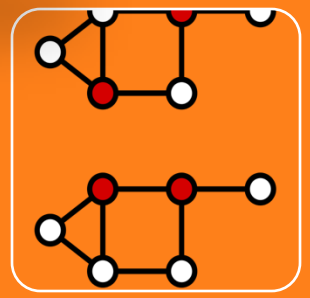
At each step, the two cluster with minimum distance are merged

Modified to exclude clusters that are too large

(Chacon, Blum, Ochoa, GECCO'24)

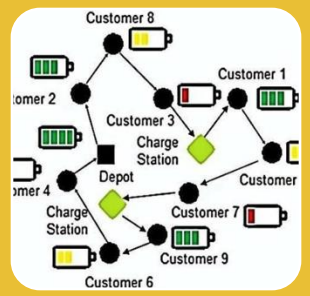
COMBINATORIAL OPTIMISATION: TWO CASE STUDIES

Christian Blum
IA Research Institute, Barcelona, Spain
https://www.iiia.csic.es/~christian.blum/



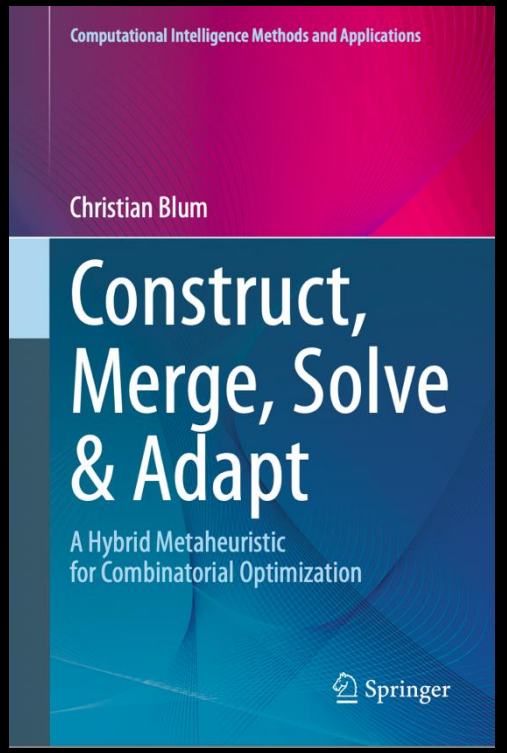
Dominating Set Problem

Minimum positive influence dominating set (MPIDS)



Electrical Vehicle Routing Problem

Two-Echelon Electric Vehicle Routing Problem with Simultaneous Pickup and Deliveries

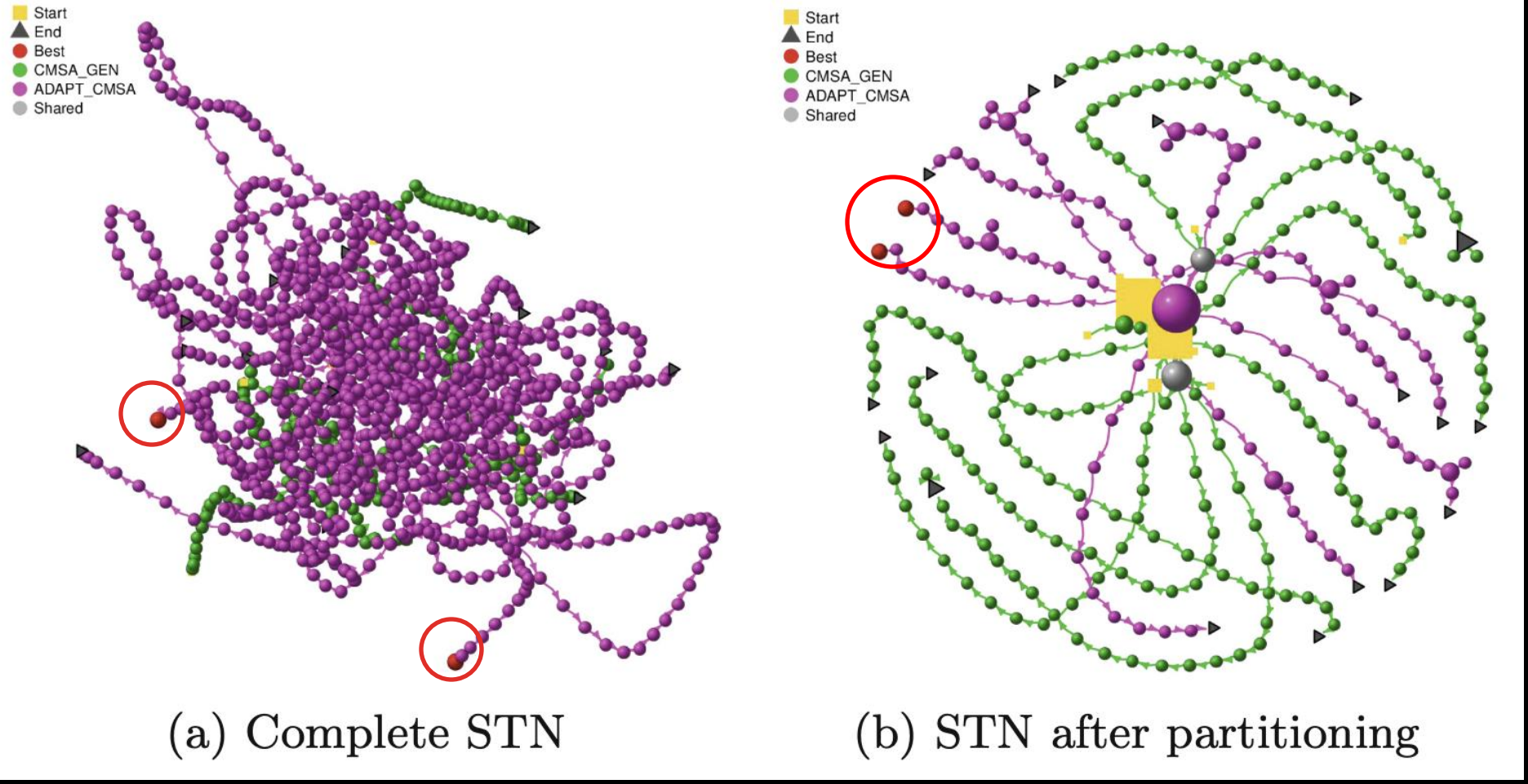


Akbay, M.A., Blum, C. (2024) Two Examples for the Usefulness of STNWeb for Analyzing Optimization Algorithm Behavior. Metaheuristics. MIC.

DOMINATING SET PROBLEM

Numerical Results

Algorith	best	avg.
Green	3955	3958.9
Pink	3930	3934.2



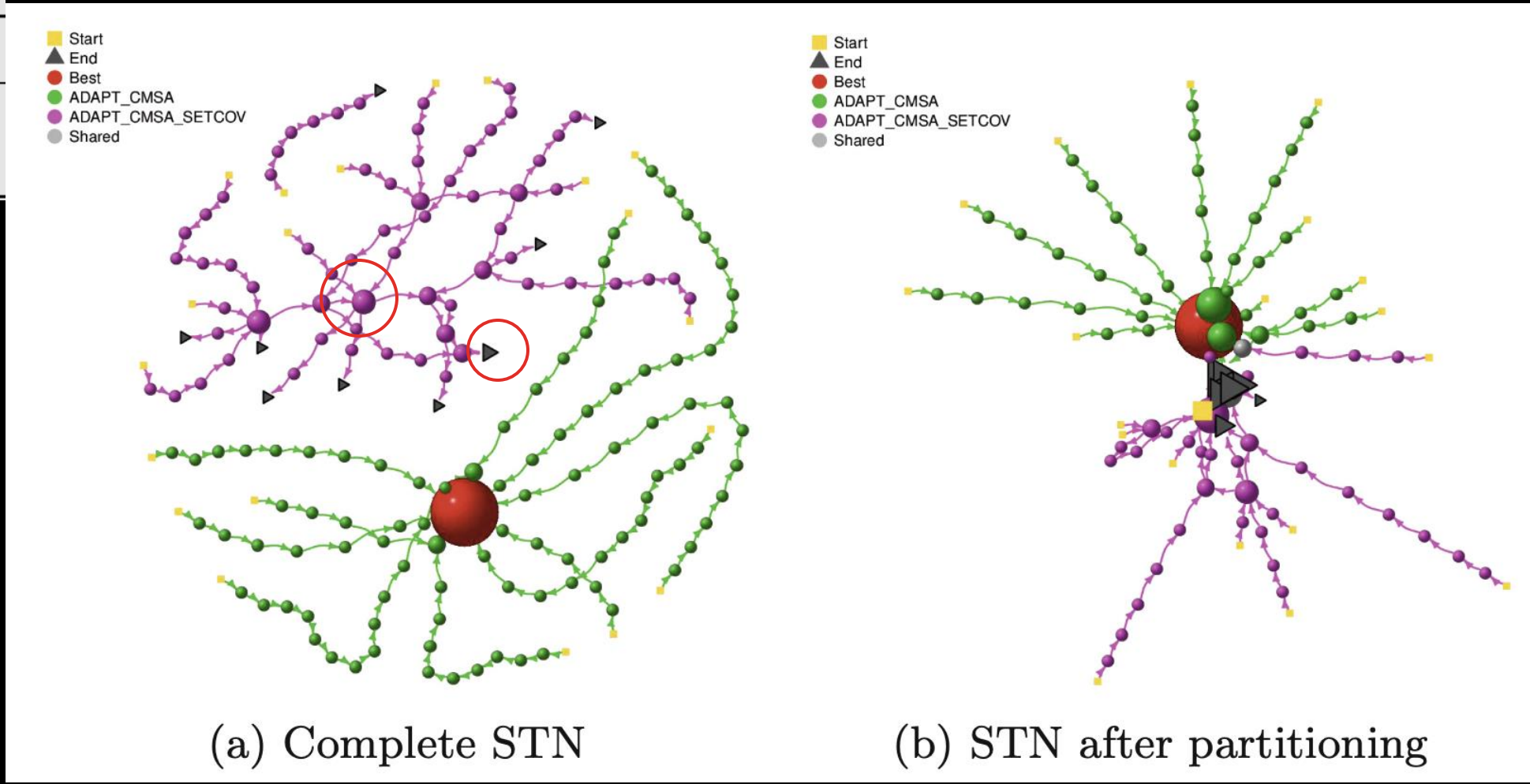
(a) Complete STN

(b) STN after partitioning

ELECTRICAL VEHICLE ROUTING

Numerical Results

Algo.	best	avg.
Green	4629.95	4629.95
Pink	4678.37	4703.43



(a) Complete STN

(b) STN after partitioning

NEUROEVOLUTION

- Evolve weights, fixed topology
- Evolve topology, learn weights with gradient-based methods
- Evolve both weights and topology
- Evolve components, hyperparameters, learning rules

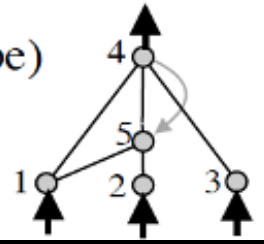
NEAT – Neuroevolution of Augmented Topologies

Genome (Genotype)

Node Genes	Node 1	Node 2	Node 3	Node 4	Node 5
	Sensor	Sensor	Sensor	Output	Hidden

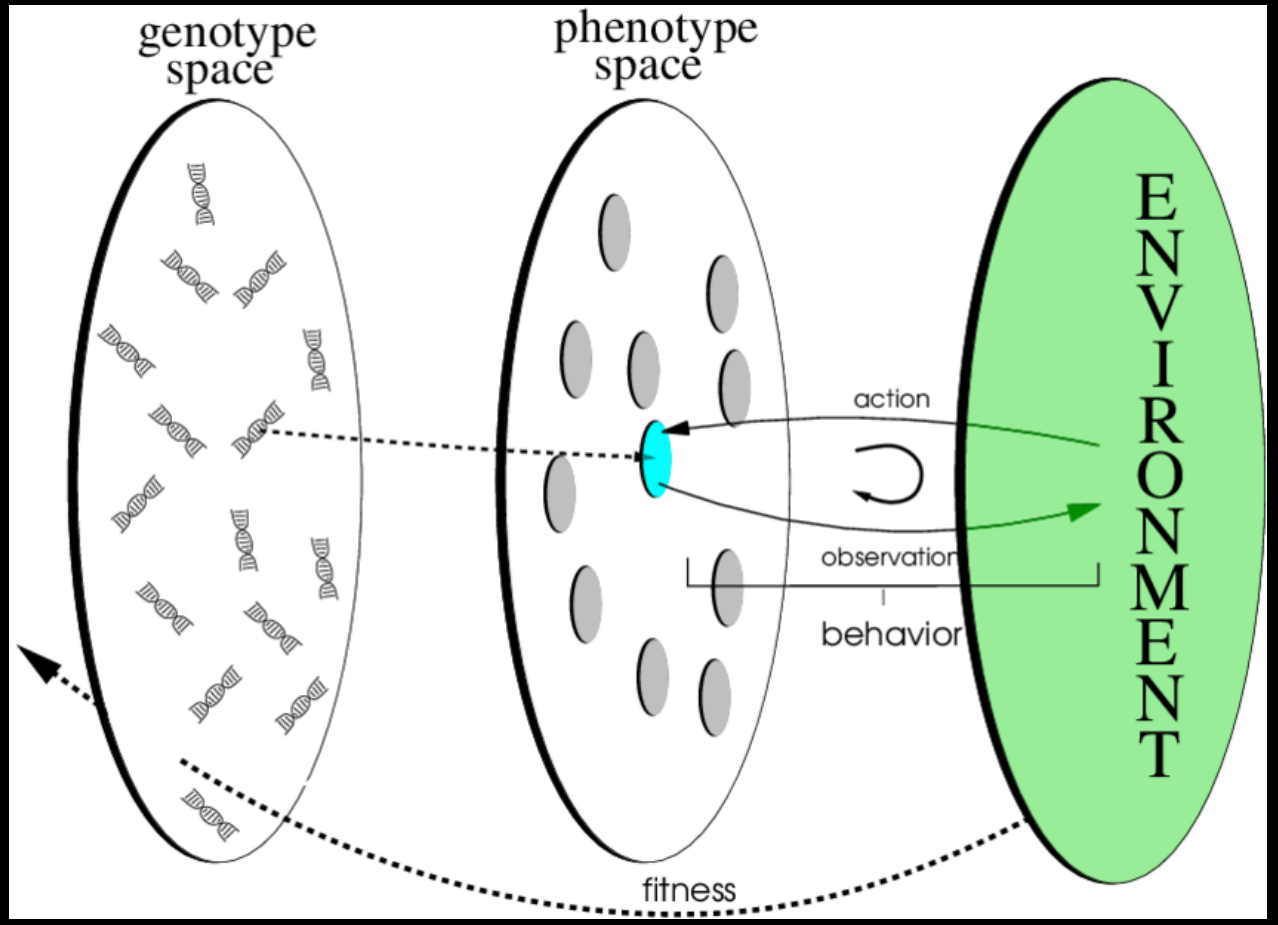
Connect. Genes	In 1 Out 4 Weight 0.7 Enabled Innov 1	In 2 Out 4 Weight -0.5 **DISABLED** Innov 2	In 3 Out 4 Weight 0.5 Enabled Innov 3	In 2 Out 5 Weight 0.2 Enabled Innov 4	In 5 Out 4 Weight 0.4 Enabled Innov 5	In 1 Out 5 Weight 0.6 Enabled Innov 6	In 4 Out 5 Weight 0.6 Enabled Innov 11

Network (Phenotype)

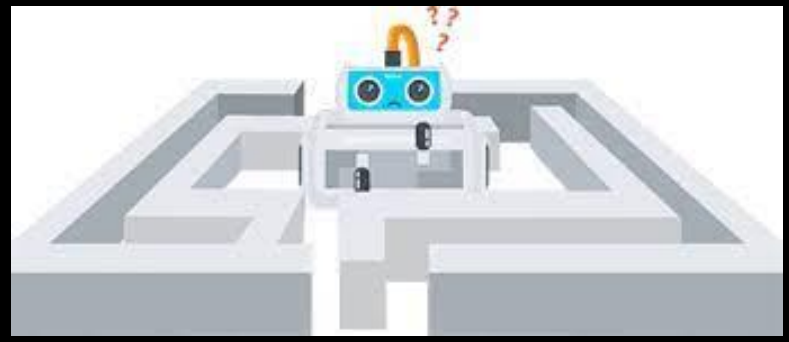


(Stanley & Miikkulainen, 2002)

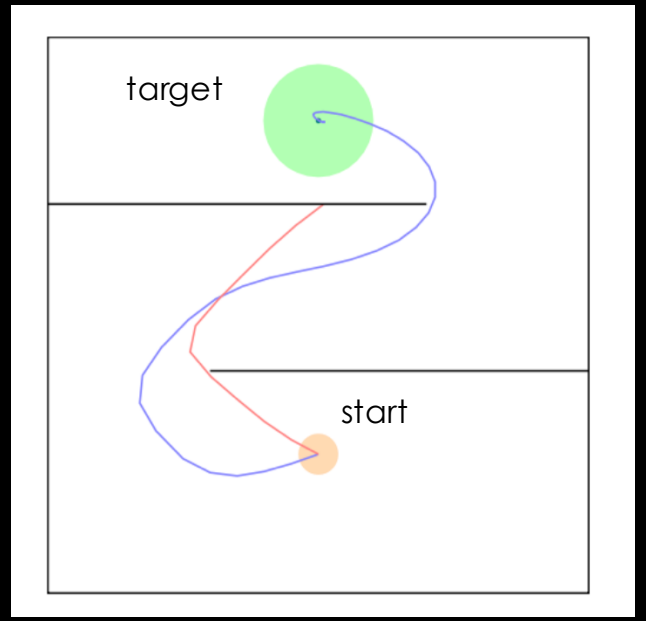
NEUROEVOLUTION & NAVIGATION TASKS



Genotype-Phenotype map.
(Gomez, Togelius, Schmidhuber; 2014)

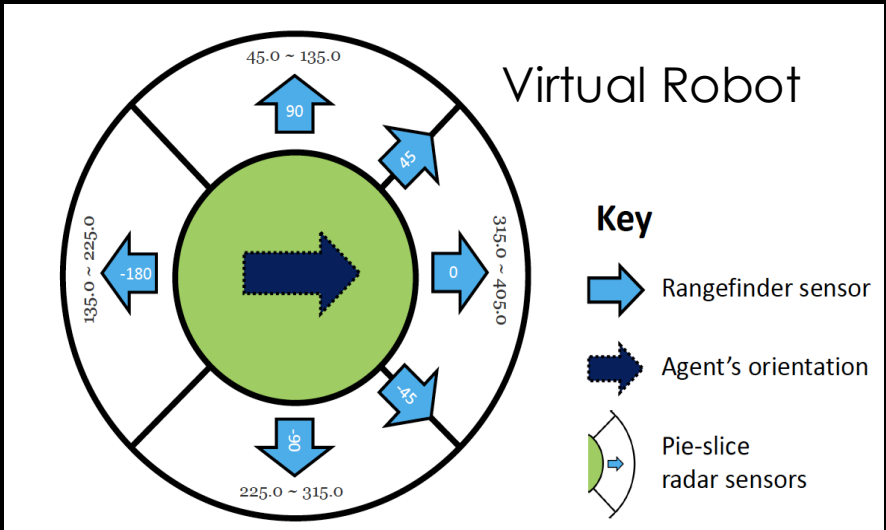


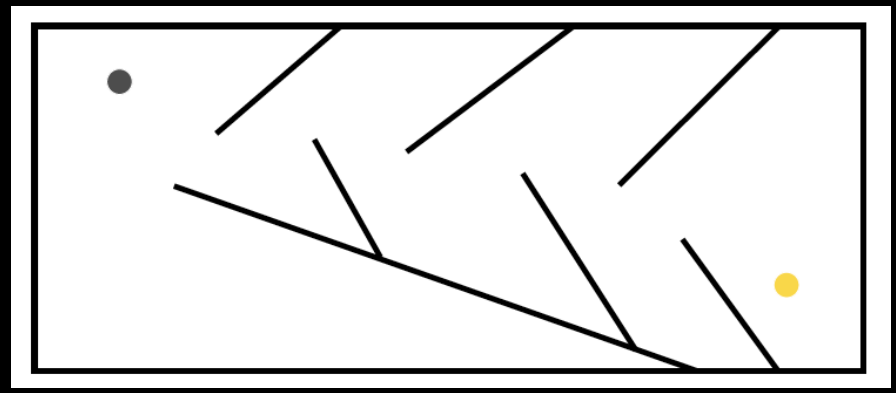
Sequential Decisions
Reinforcement Learning



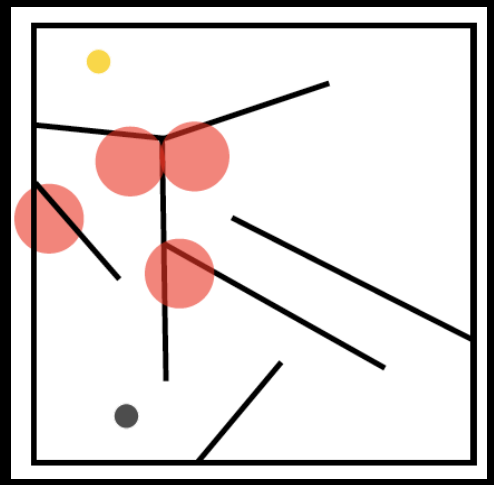
Evolving a virtual robot controller

STNs FOR NEAT BENCHMARKS





Medium Maze



Target

Start

Deceptive traps

Hard Maze
Deceptive problem

S Sarti, JAdair, G Ochoa (2022) Recombination and Novelty in Neuroevolution: A Visual Analysis. *SN COMPUT. SCI.* 3, 185

STNs FOR NEAT ALGORITHMS

(Lehman Stanley, ECJ 2011)

Fitness-based search

Novelty search

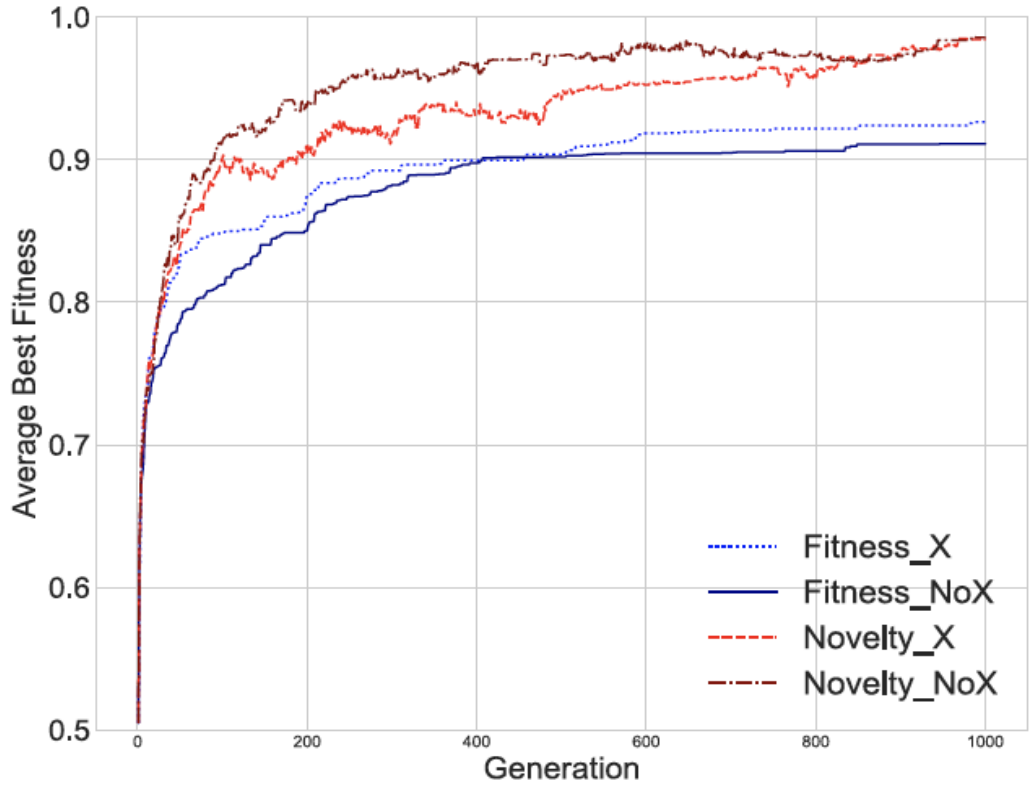
Crossover vs. no Crossover

Novelty Search

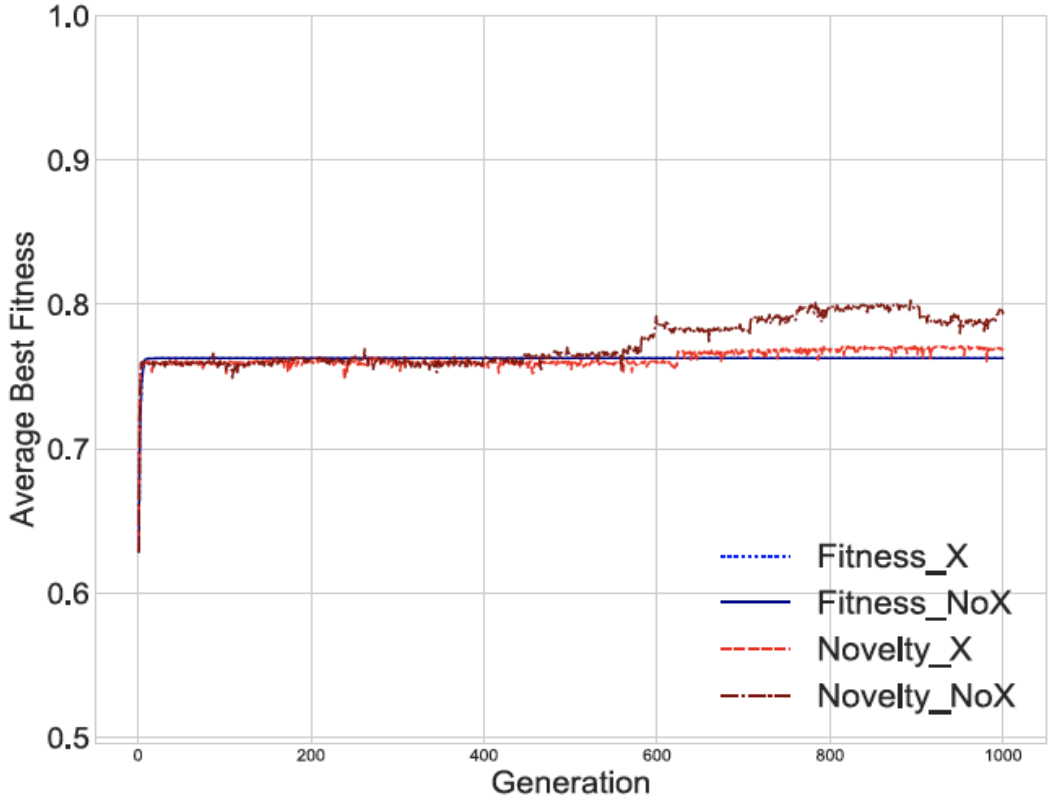
- Abandon objectives!
- Reward novel *behaviours*

NEAT PERFORMANCE CURVES

Average best fitness (30 runs) for the 4 NEAT variants



(a) Medium Maze Domain



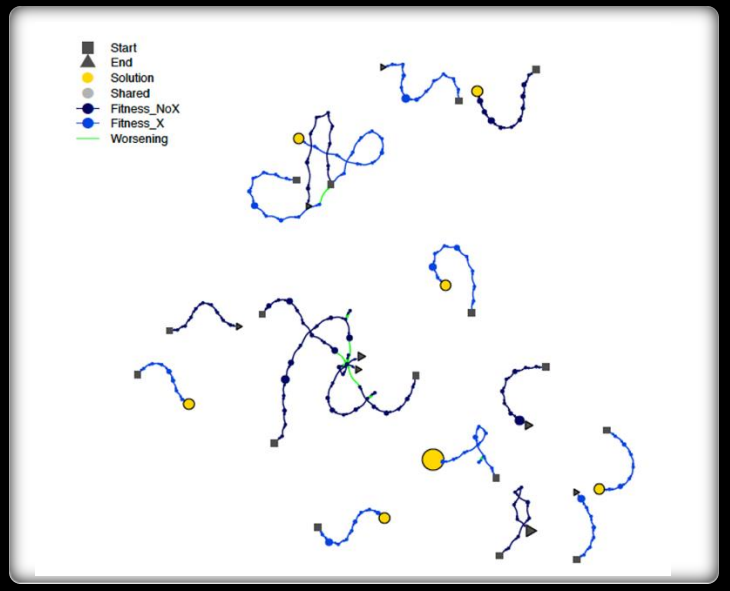
(b) Hard Maze Domain

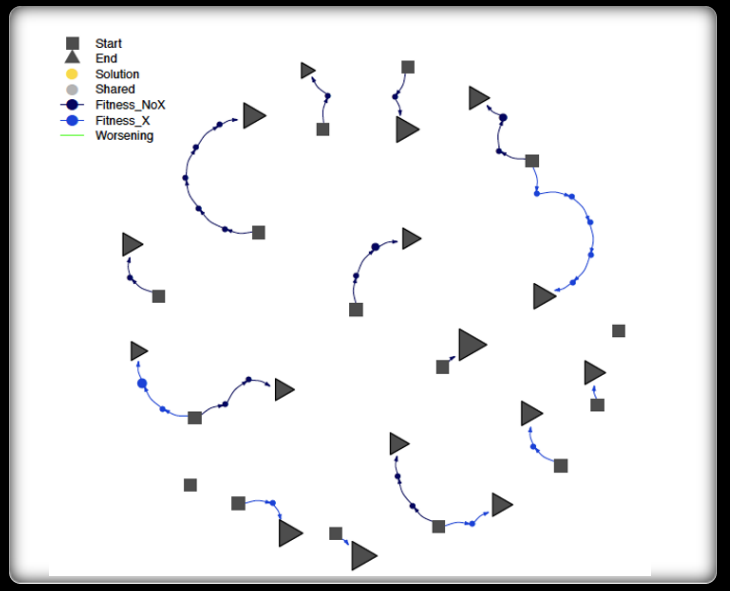
NEAT STN ANALYSIS

Medium Maze

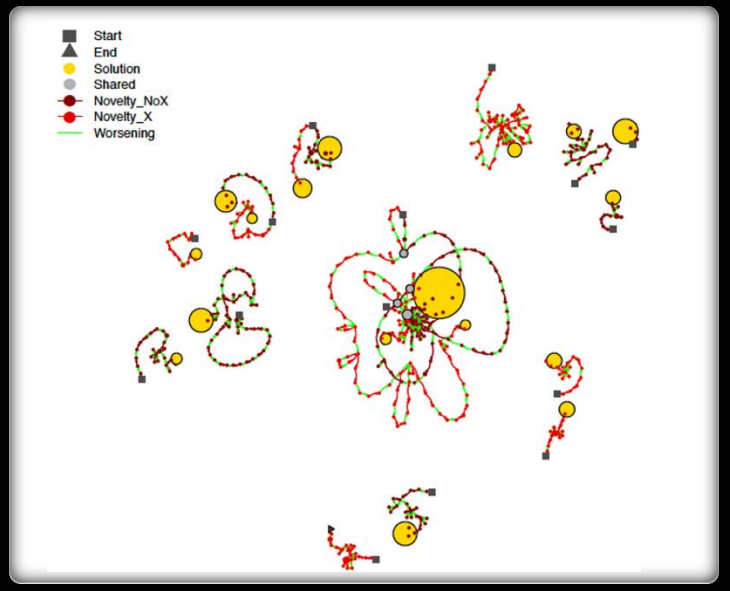
Hard Maze

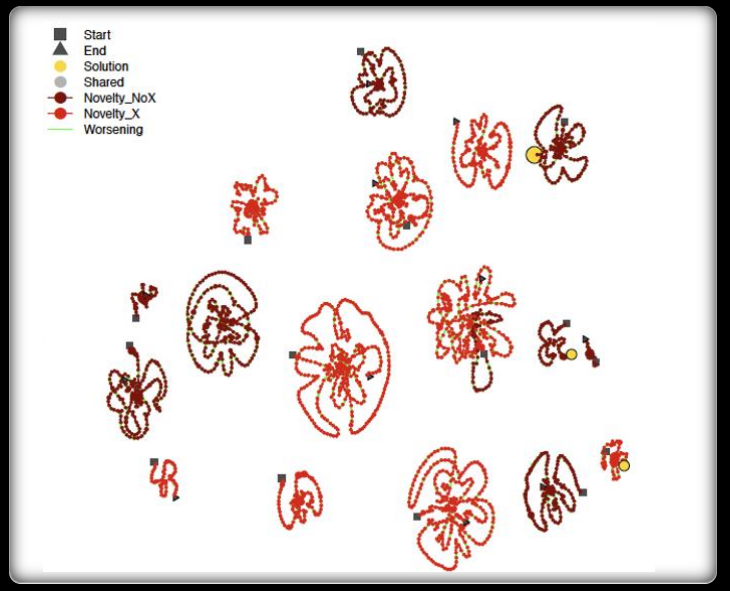
Fitness-Based Search



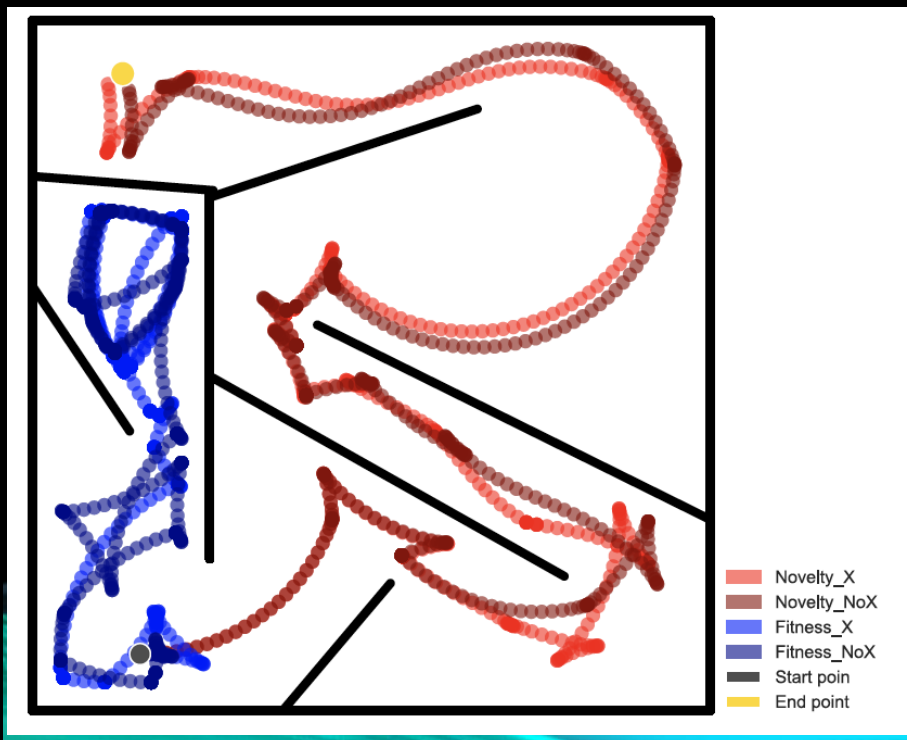


Novelty Search





Hard Maze

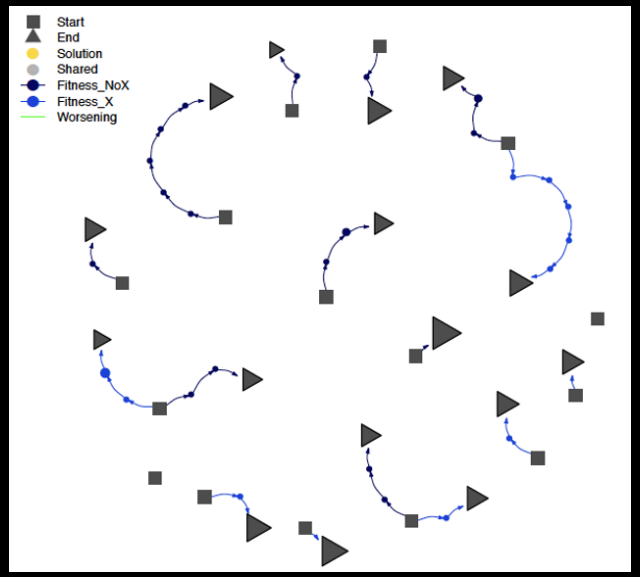


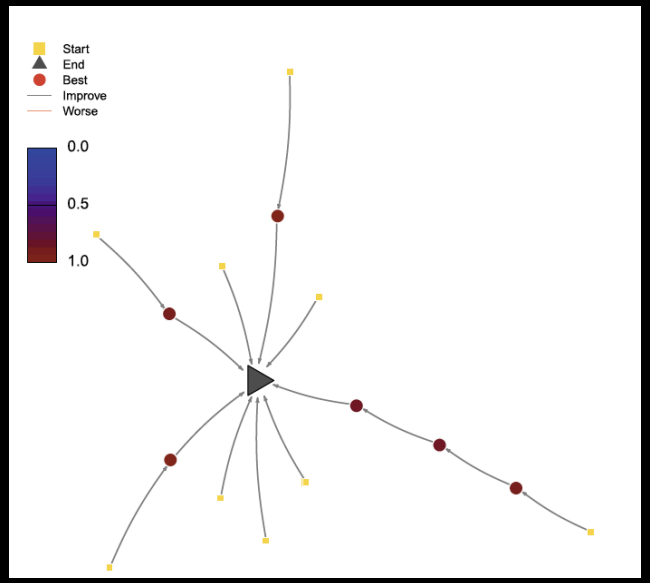
STNs IN BEHAVIOUR SPACE

Genotype Space

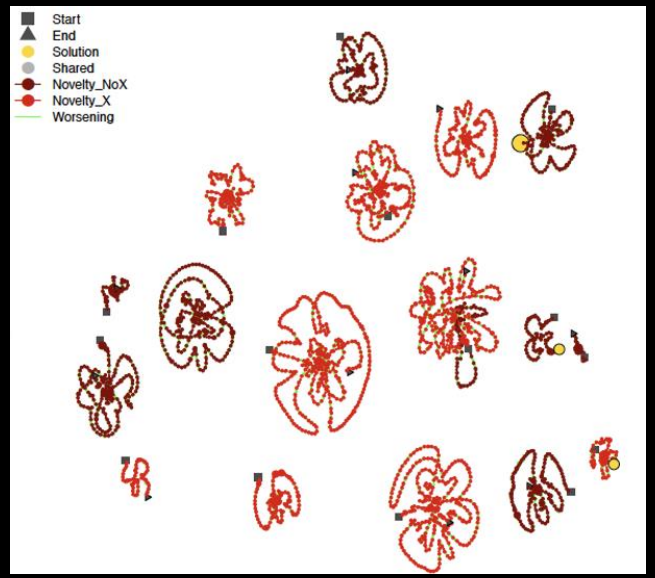
Behaviour Space

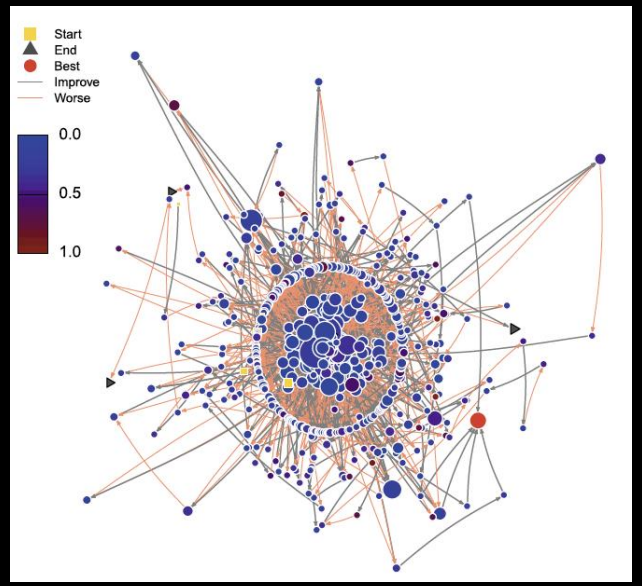
Fitness-Based Search



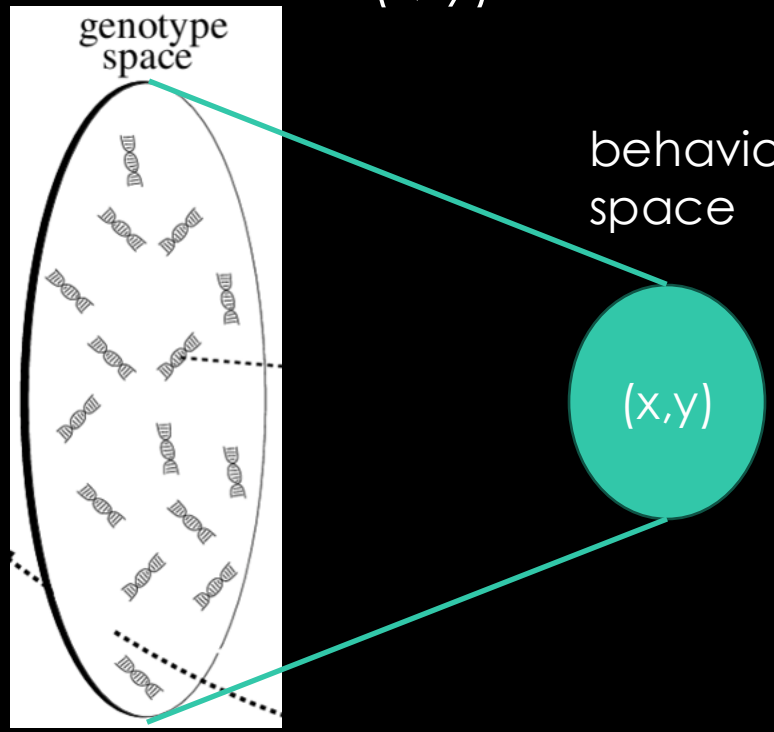


Novelty Search





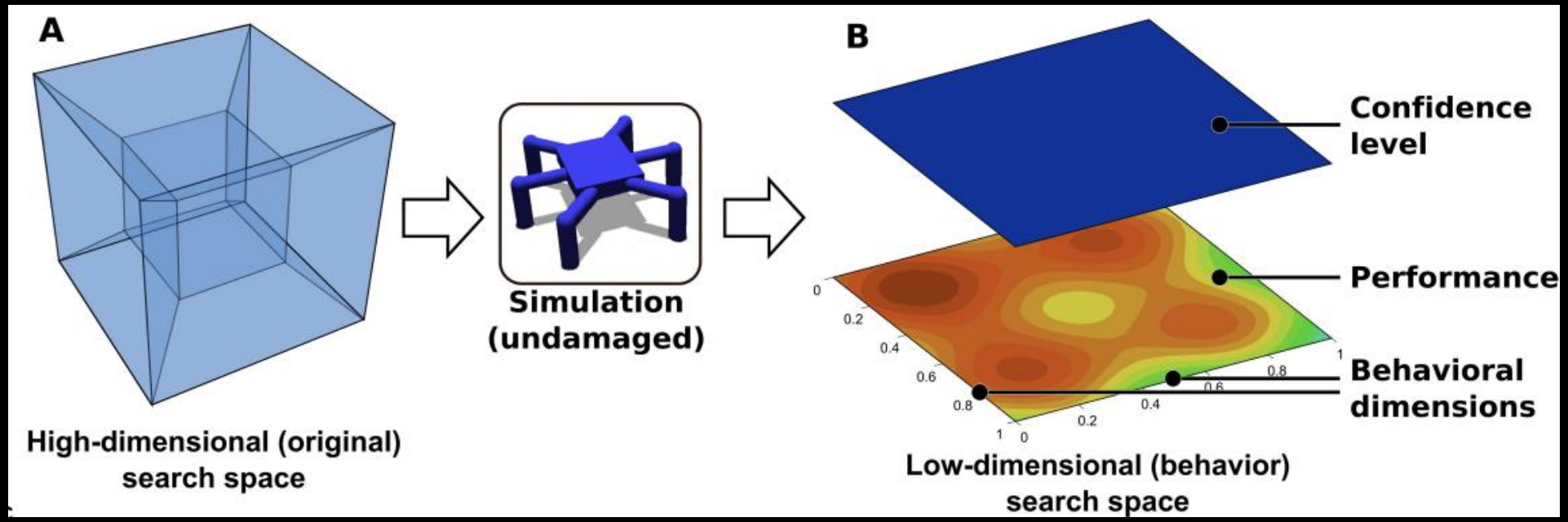
Behaviour Descriptor
(x, y) end of simulation



Neuroevolution trajectory networks of the behaviour space. Sarti, Ochoa, EvoApps 2022

MAP-ELITES & STEPPING STONES

MAP-Elites - Multi-dimensional Archive of Phenotypic Elites



J.-B Mouret, J. Clune (2015). Illuminating search spaces by mapping elites

A. Cully, J Clune, D Tarapore, J_B Mouret(2015) Robots that can adapt like animals. *Nature*,

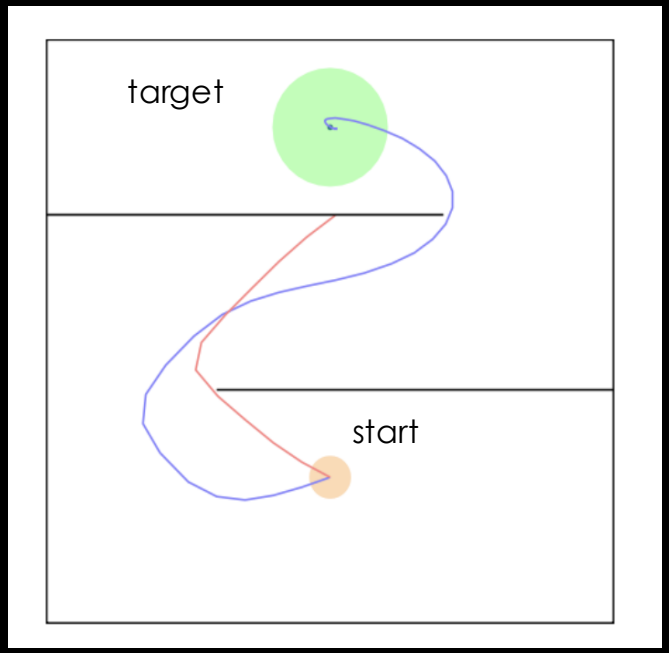
FINDING STEPPING STONES WITH STNs:
EXPERIMENTAL SETUP

Georgia Nadizar,
Univ. of Trieste, Italy

Ongoing Work

Point Agent

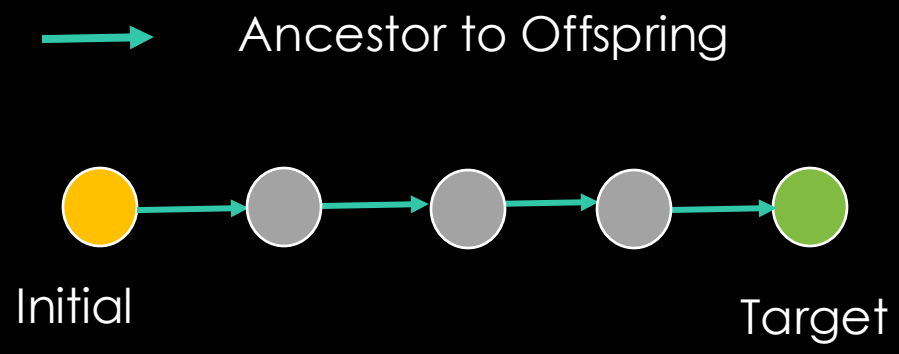
Controller
$f(x, y) \rightarrow (s_x, s_y)$



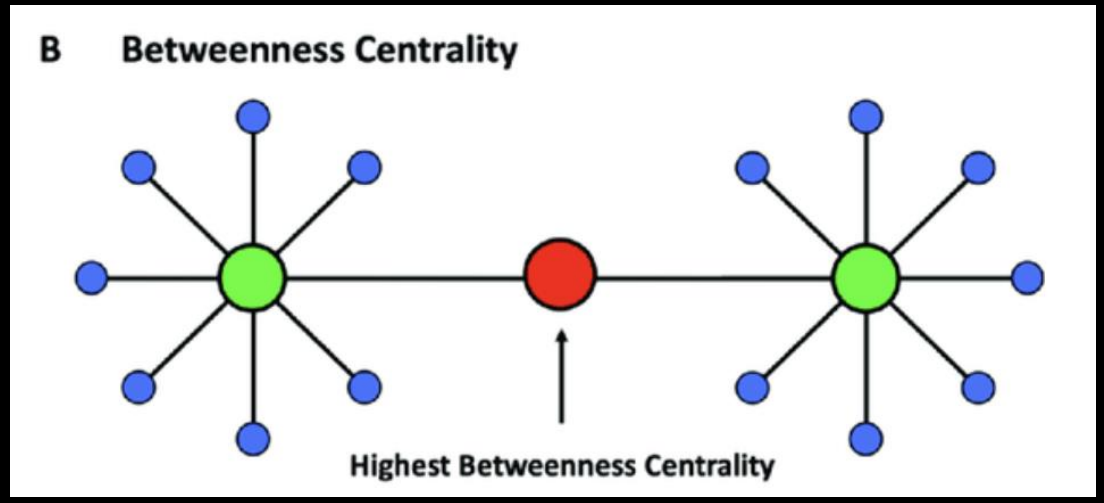
Representations	Algorithms
1.Polynomial 2.ANN 3.Tree-based GP	1.Map-Elites 2.GA

FINDING STEPPING STONES WITH STNs: DEFINITIONS & CONSTRUCTION

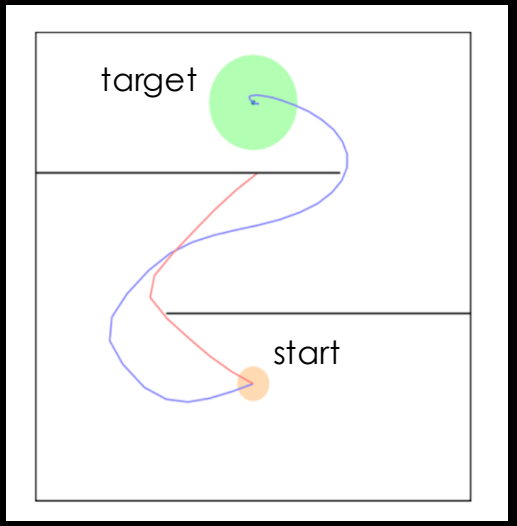
Representative Solution ancestors → Location behaviour descript. (x, y) → Nodes



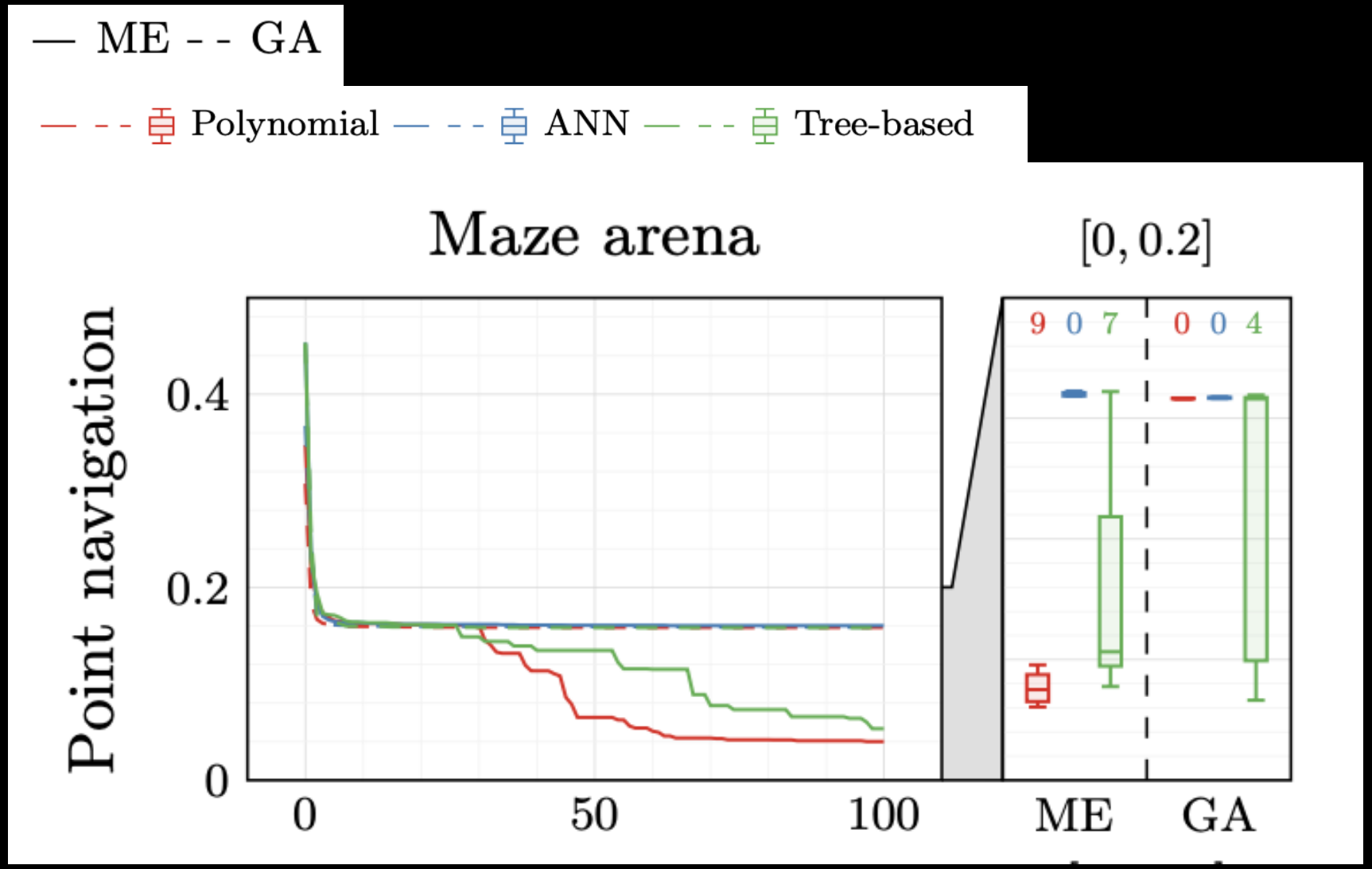
Stepping Stones



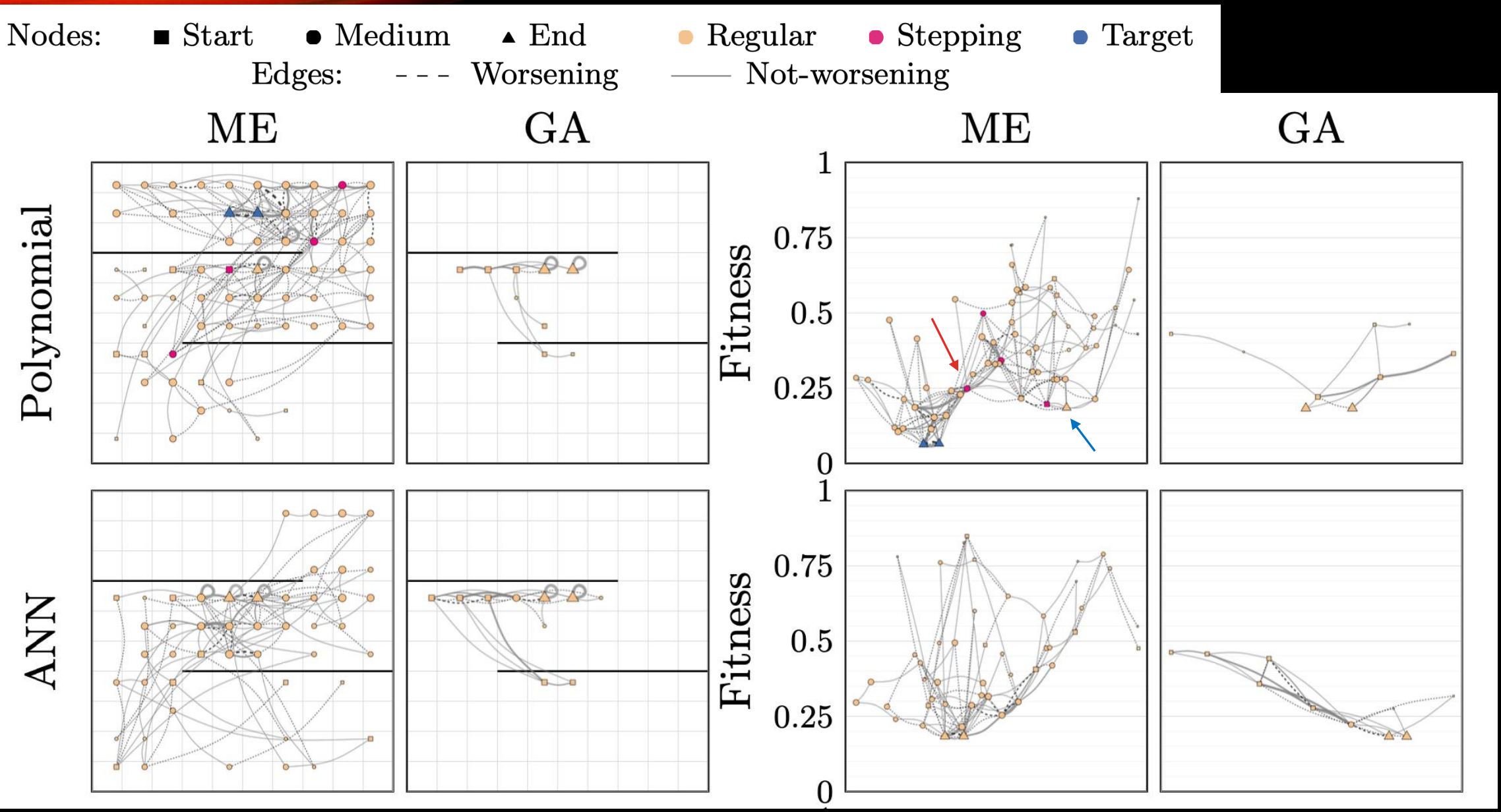
FINDING STEPPING STONES WITH STNs:
PERFORMANCE RESULTS



Maze Navigation



STN ANALYSIS



TAKE-HOME MESSAGE

Search Trajectory Networks - STNs

Visual, quantitative, accessible, versatile tool
to study the dynamics of algorithm behaviour

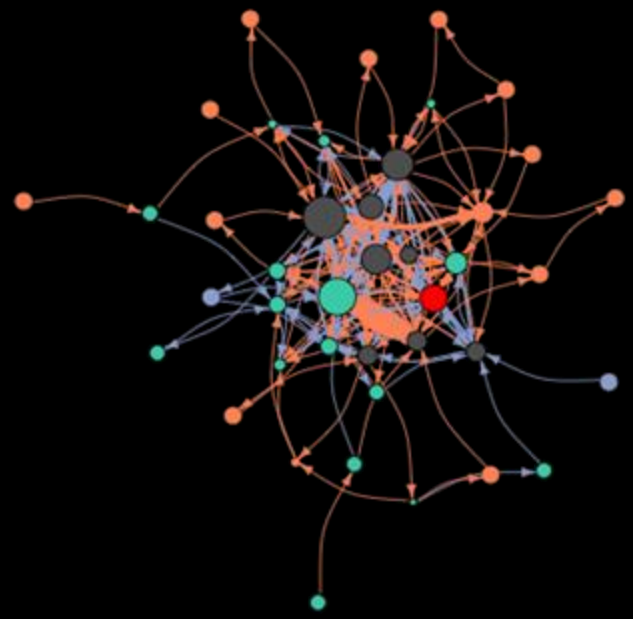
Nodes

Locations

Rep. solution/
Partition

Edges

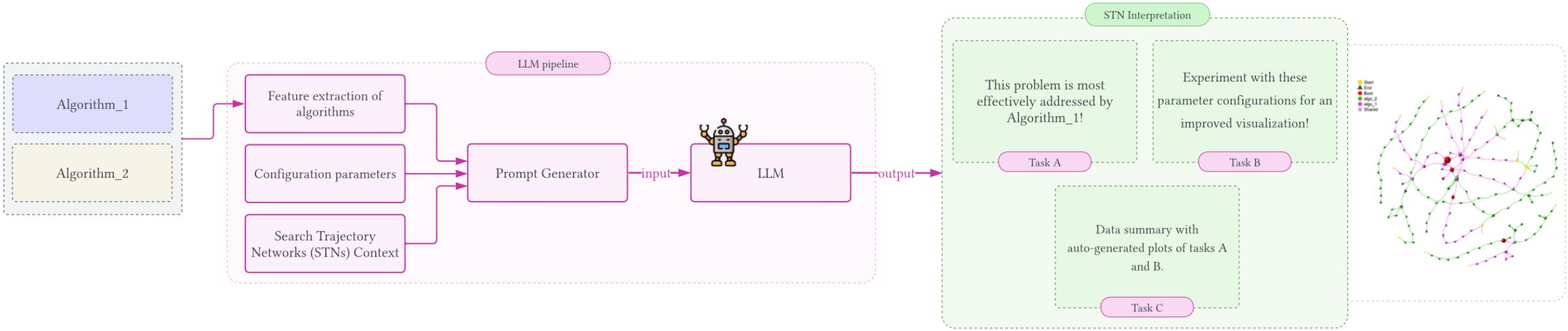
iterations/genealogy



STNs & LLMs

PhD student: Camilo Chacón Sartori, Christian Blum & Gabriela Ochoa
Artificial Intelligence Research, Institute (IIIA-CSIC), Barcelona

Large Language Models for the Automated Analysis of Optimization Algorithms (GECCO, 2024)



https://arxiv.org/abs/2402.08472

User interaction

ACO

```
1 ,1050 ,110110100101010101
1 ,950 ,010110100101010101
1 ,931 ,010110100101010101
2 ,1120 ,010110100101010101
2 ,1100 ,010110100101010101
2 ,860 ,010110100101010101
3 ,1100 ,010110100101010101
3 ,999 ,010110100101010101
3 ,800 ,010110100101010101
3 ,790
```

BRKGA

```
1 ,990 ,010111100101010101
1 ,950 ,010110100101010101
1 ,931 ,010110100101010101
2 ,1201 ,010110100101010101
2 ,1110 ,010110100101110101
2 ,860 ,010110100101010101
3 ,1100 ,010110100101010101
3 ,999 ,010110100101010101
3 ,800 ,010110100101010101
3 ,790 ,010110100101010101
```

Create files for each algorithm

1

Configuration

Minimization | Maximization

Discrete Problem | Continuous Problem

Strategy ⓘ Shannon Entropy

Partitioning ⓘ 0

(0% = no partitioning)

Advanced options

Input files (algorithms)

Name #1

Color

Choose file No file chosen

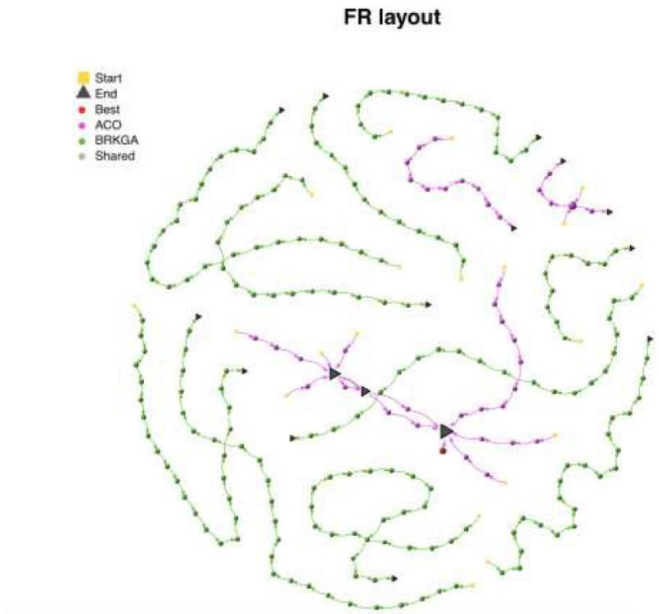
Allowed file extensions: .csv, .txt, .tar.*

Add New Algorithm ⊕

Generate

Complete the configuration and upload the files

2



View generated and download the PDF

3