Production Process Optimization

Functional REQUIREMENTS

- Form Feature process planning
- Process Planning & Scheduling integration

- CAD/M Design
- Production Time

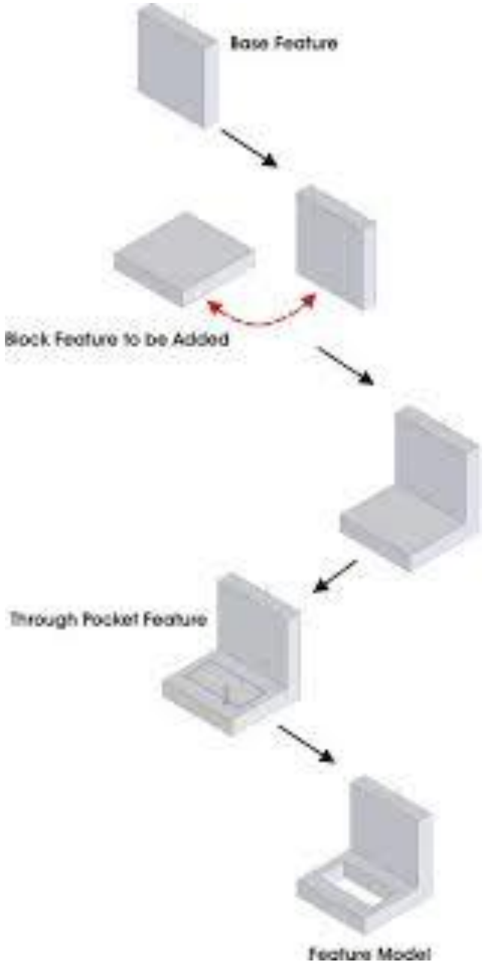
Objective function

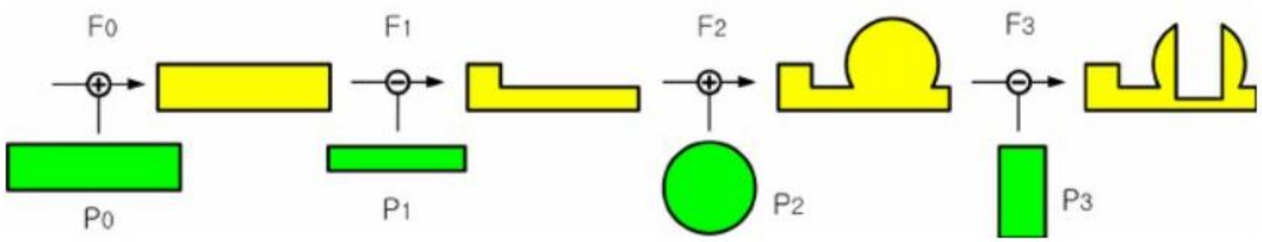
Production Process Optimization

HOW THE PRODUCT IS CUSTOMIZED ?

- Material customization – material / FEM
- Form customization – design by CAD / process planning
- Functional customization – assembly / tolerance / metrology

Feature Based Process Planning

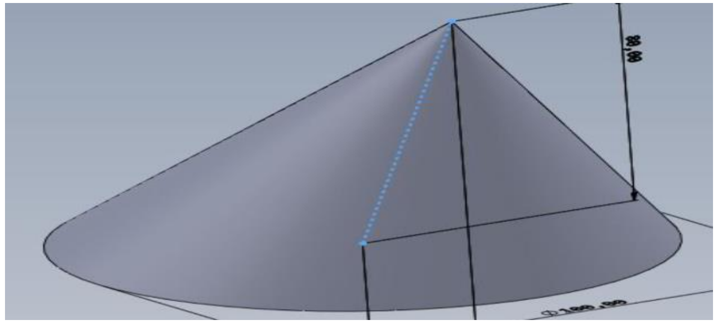


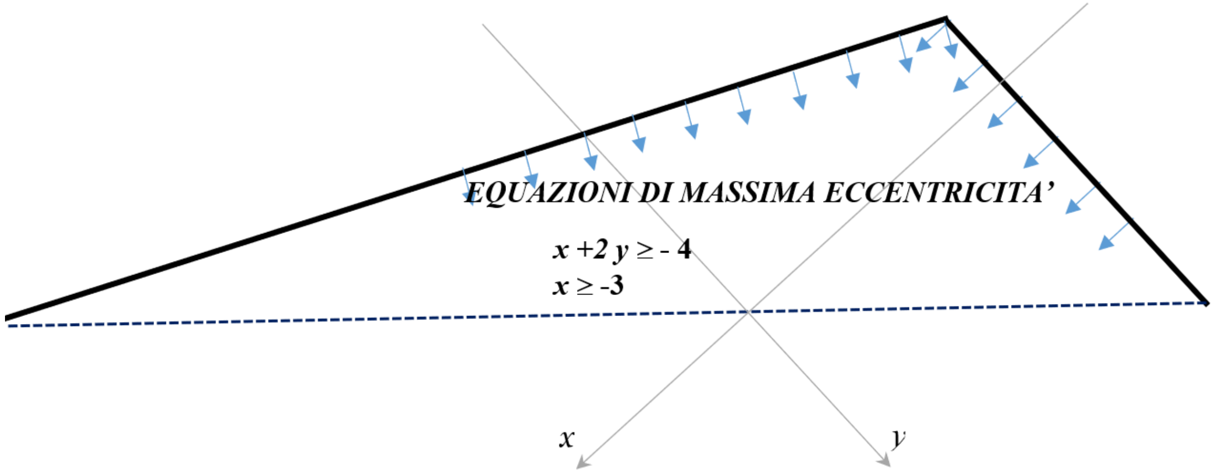


PROCESS OPTIMIZATION IN PRODUCTION
Each elementary surface (volume) has a specific subtractive/additive/hybrid production process, which must be optimized in terms of time.
Costs, such as energy and the use of machines, equipment, and tools, are a function of production time.

"How is the construction of a single brick optimized?"

Computer-Aided Manufacturing (CAD-CAM)
ADDITIVE 3D PRINTING / SUBTRACTIVE MACHINING. CHIP REMOVAL.





Operational research

Functional Optimization

"Find the minimum of $f(x_1, ..., x_n)$ starting from point P_1.
f is called the objective function.

Operational research

Functional Optimization

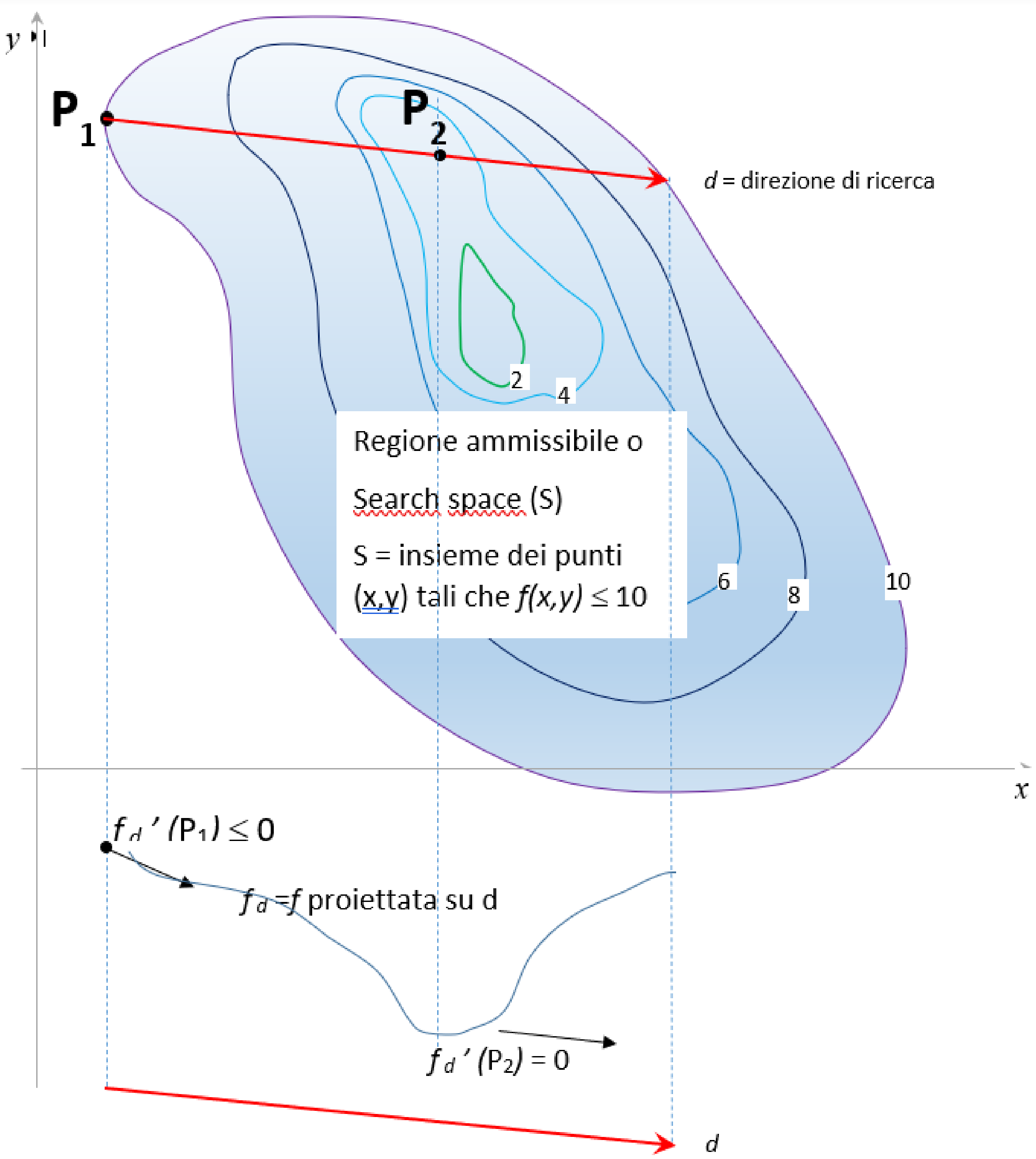
NOTE: The analytical form of the objective function is **NOT KNOWN**, but it is **MEASURABLE** at individual points.

$$\min f(x)$$

Operational research

Optimization problem

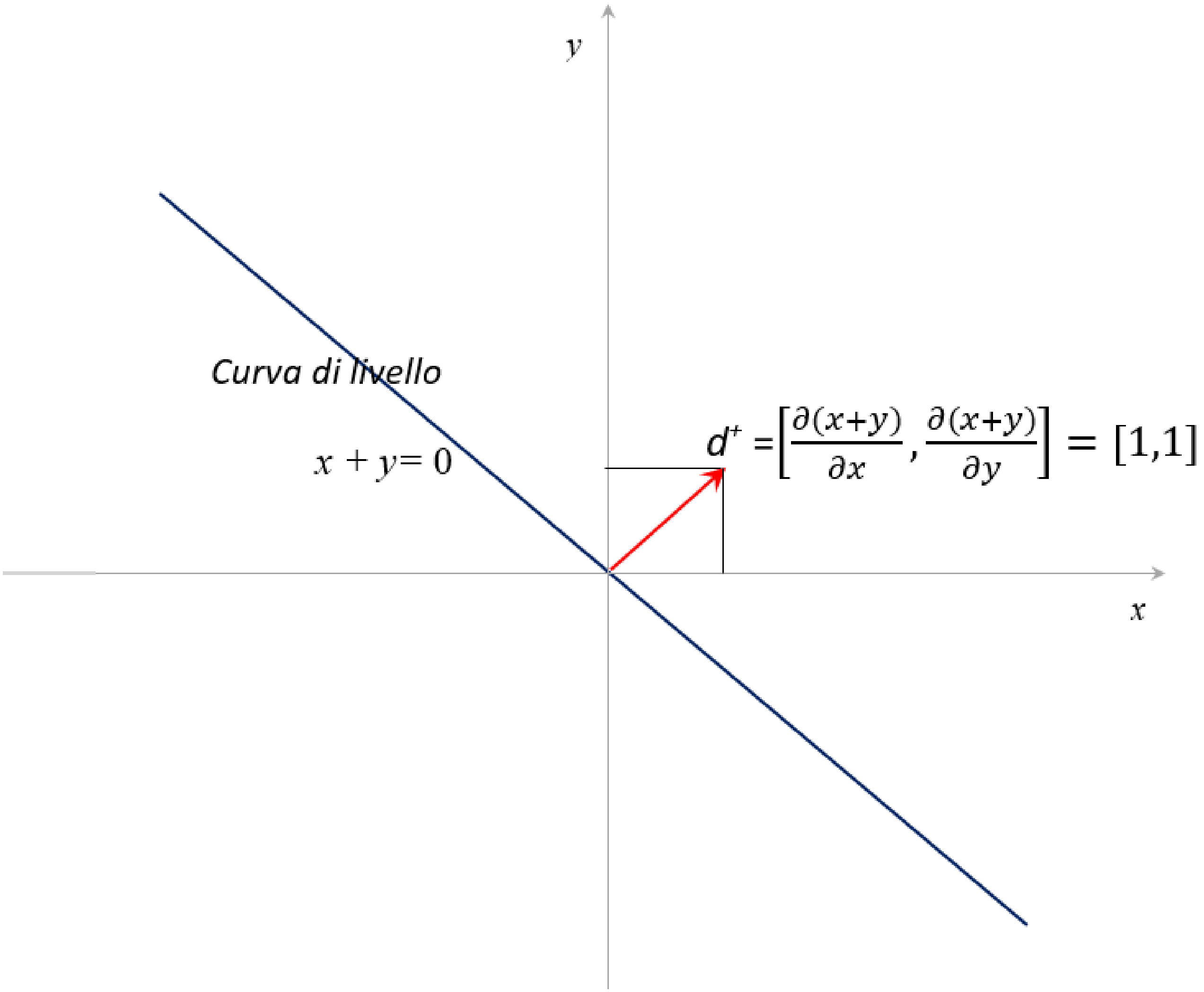
find the minimum objective function defined by the **parameters**/variables of the considered **problem model x** (simply, **model**)



Operational research

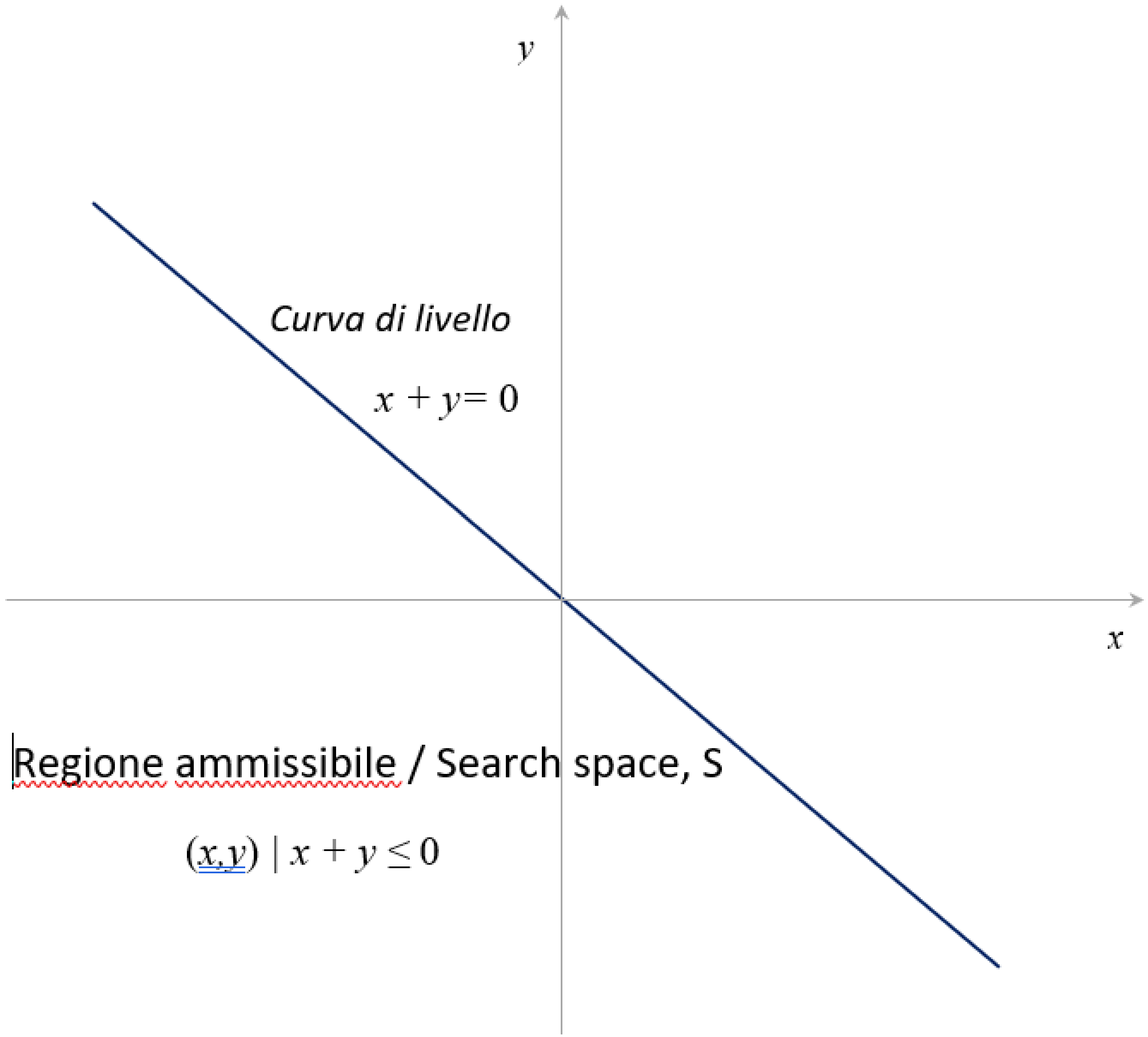
admissible search direction
"Move along d within the search space f until reaching the minimum point where the first derivative is zero."

Operational research



Linear search for maximum gradient

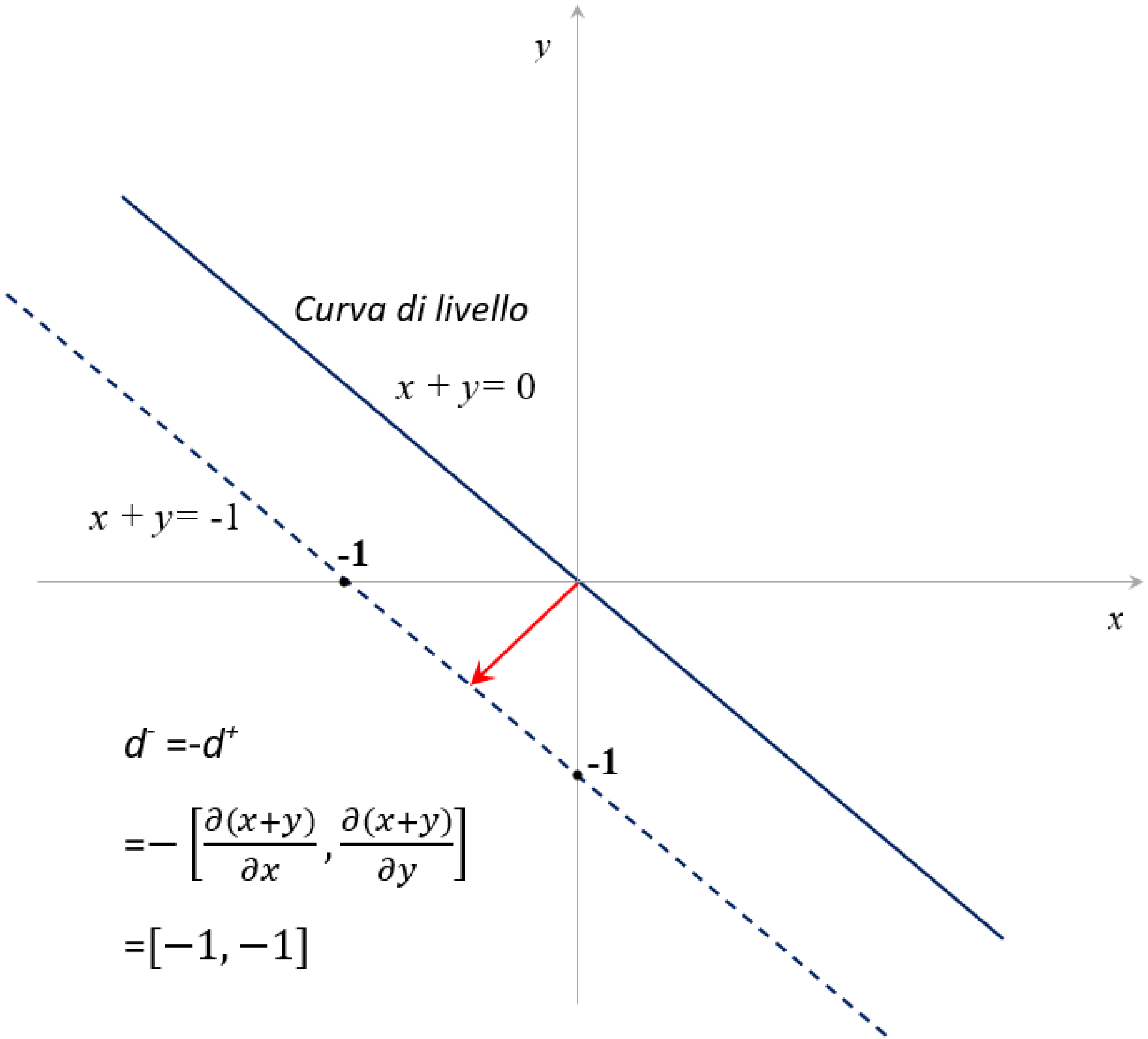
d^{+} is a straight line, and its direction is that of the maximum gradient.
The maximum gradient is orthogonal to the level curve.



Operational research

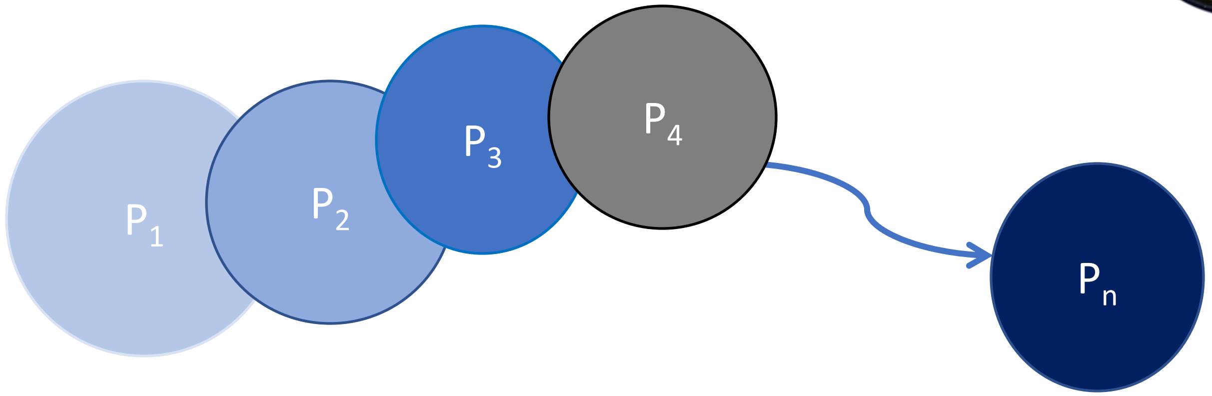
Linear search with gradient descent

"If the problem is to minimize an objective function, the feasible region F lies below the level curve.

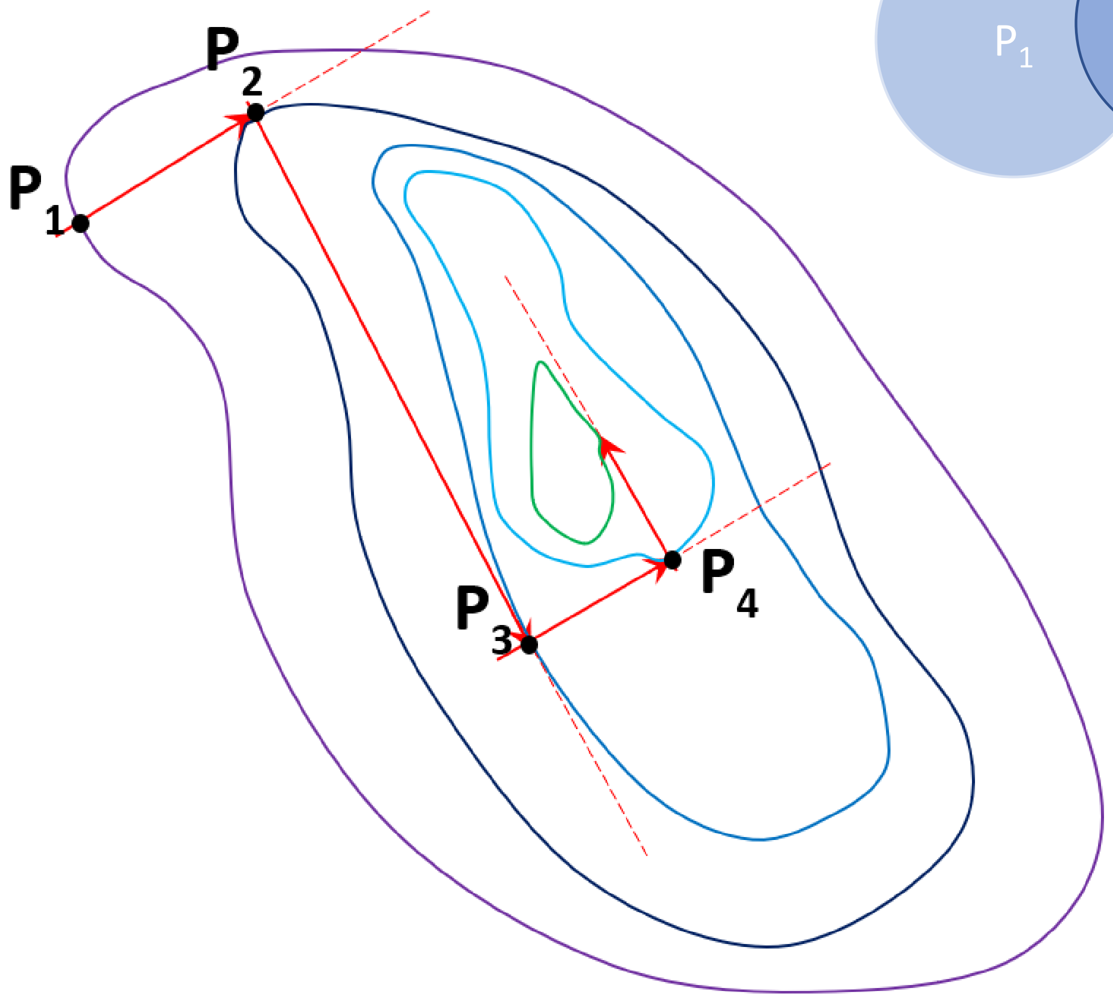


Operational research

Linear search with gradient descent
"In the minimization of an objective function, d^-, is considered, the direction of maximum gradient descent.
The maximum gradient descent is orthogonal to the level curve and opposite to d^+



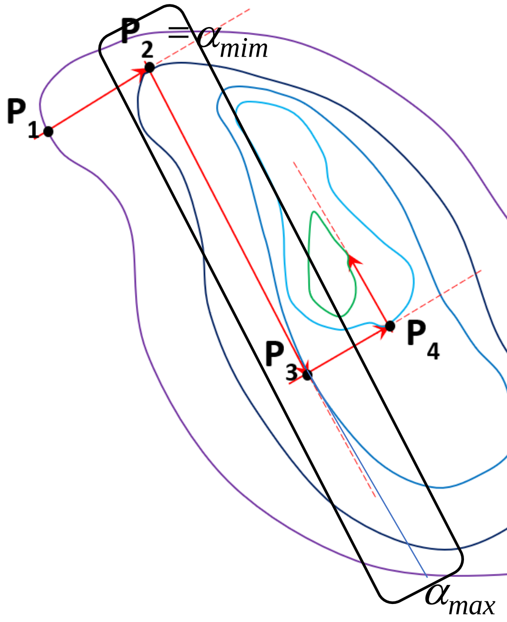
Operational research



Local Search

Local Search Algorithm

"Proceed step by step, at each step find the admissible direction d^- until converging to the minimum of f



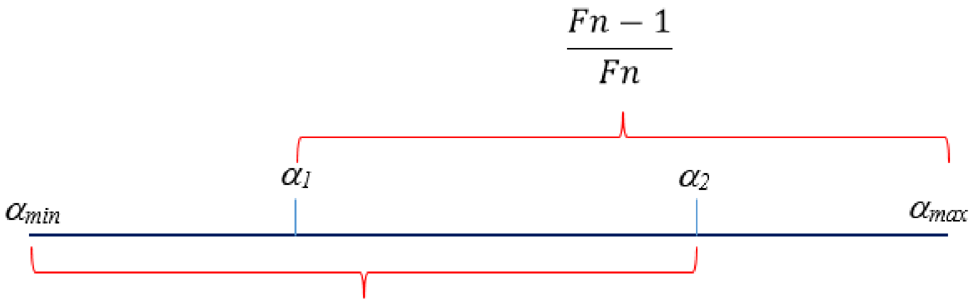
Operational research

Single direction Search

Fibonacci's method

$\frac{1}{Fn} \rightarrow 0$ exponentially

α_1 e α_2 simmetrici rispetto agli estremi



$$\frac{Fn-1}{Fn} = \alpha_2 - \alpha_{min} = \alpha_{max} - \alpha_1$$

Ricerca minimo

$f(\alpha_1) < f(\alpha_2) \Rightarrow$ il minimo in $[\alpha_{min}-\alpha_{max}] \in [\alpha_{min}, \alpha_2]$

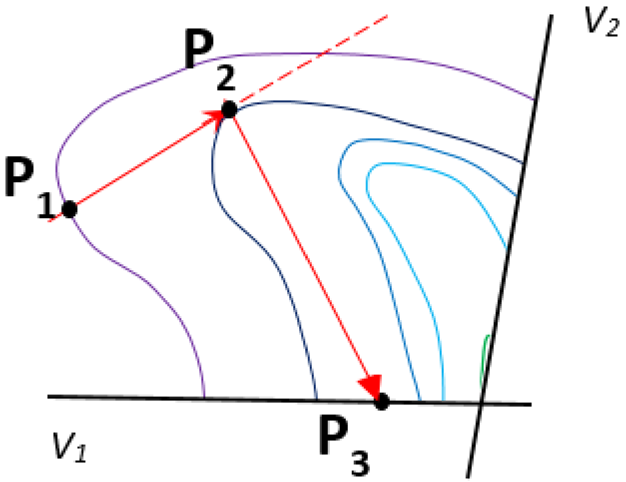
$f(\alpha_1) = f(\alpha_2) \Rightarrow$ il minimo in $[\alpha_{min}-\alpha_{max}] \in [\alpha_1, \alpha_2]$

$f(\alpha_2) < f(\alpha_1) \Rightarrow$ il minimo in $[\alpha_{min}-\alpha_{max}] \in [\alpha_1, \alpha_{max}]$

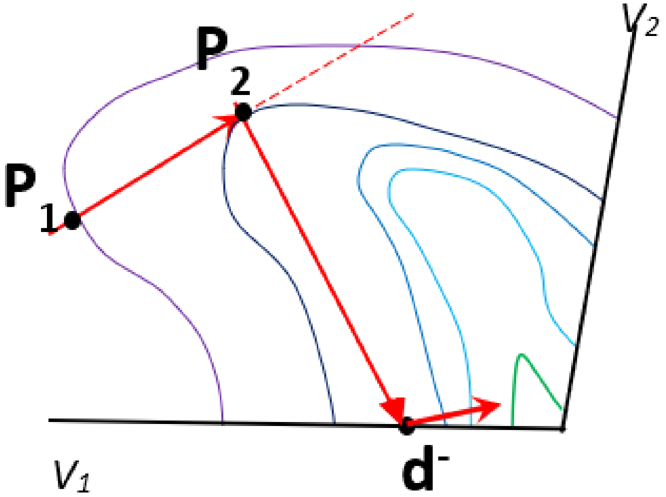
Convergenza

Step 1 ... *Step n-1*

$$\alpha_{max} - \alpha_{min} = \frac{Fn}{Fn} \qquad \alpha_{max} - \alpha_1 = \frac{Fn-1}{Fn} \ldots\ldots \qquad \alpha - \alpha_{n-1} = \frac{Fn-(n-1)}{Fn} = \frac{F1}{Fn} = \frac{1}{Fn} \rightarrow 0$$



Punto intersezione tra direzione ricerca e vincolo



Nuova direzione di ricerca,

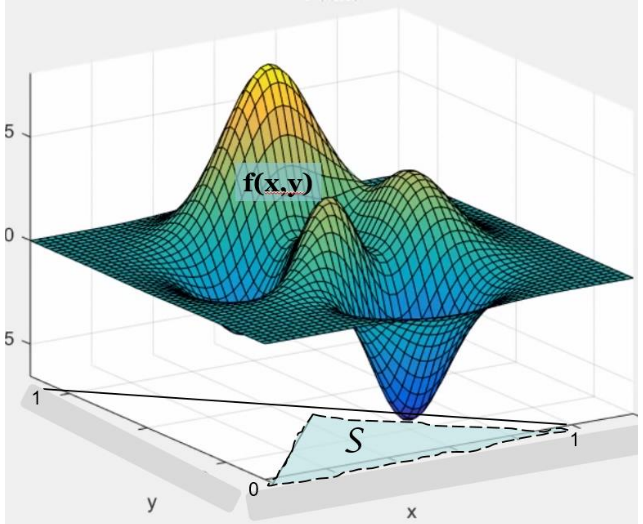
$$d^{-} = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right] \leq 0$$

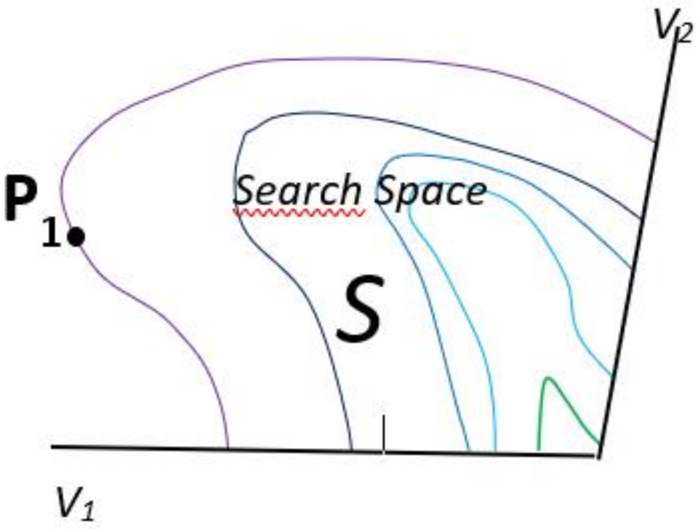
Operational research

Search direction with constraints

"The projection of the constraint onto the search direction must be positive."

$$\min f(x)$$
$$x \in S$$



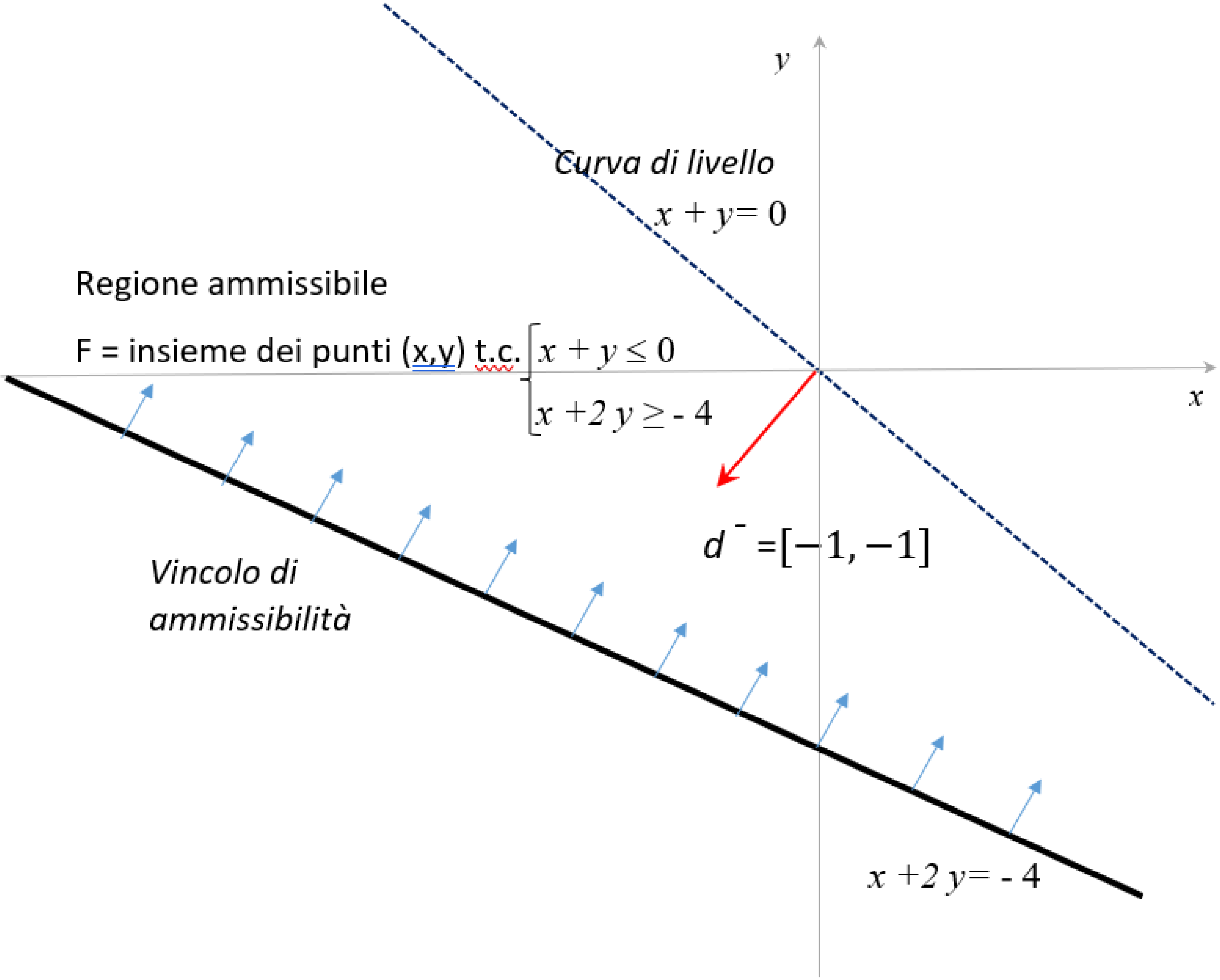


Operational research

Optimization problem

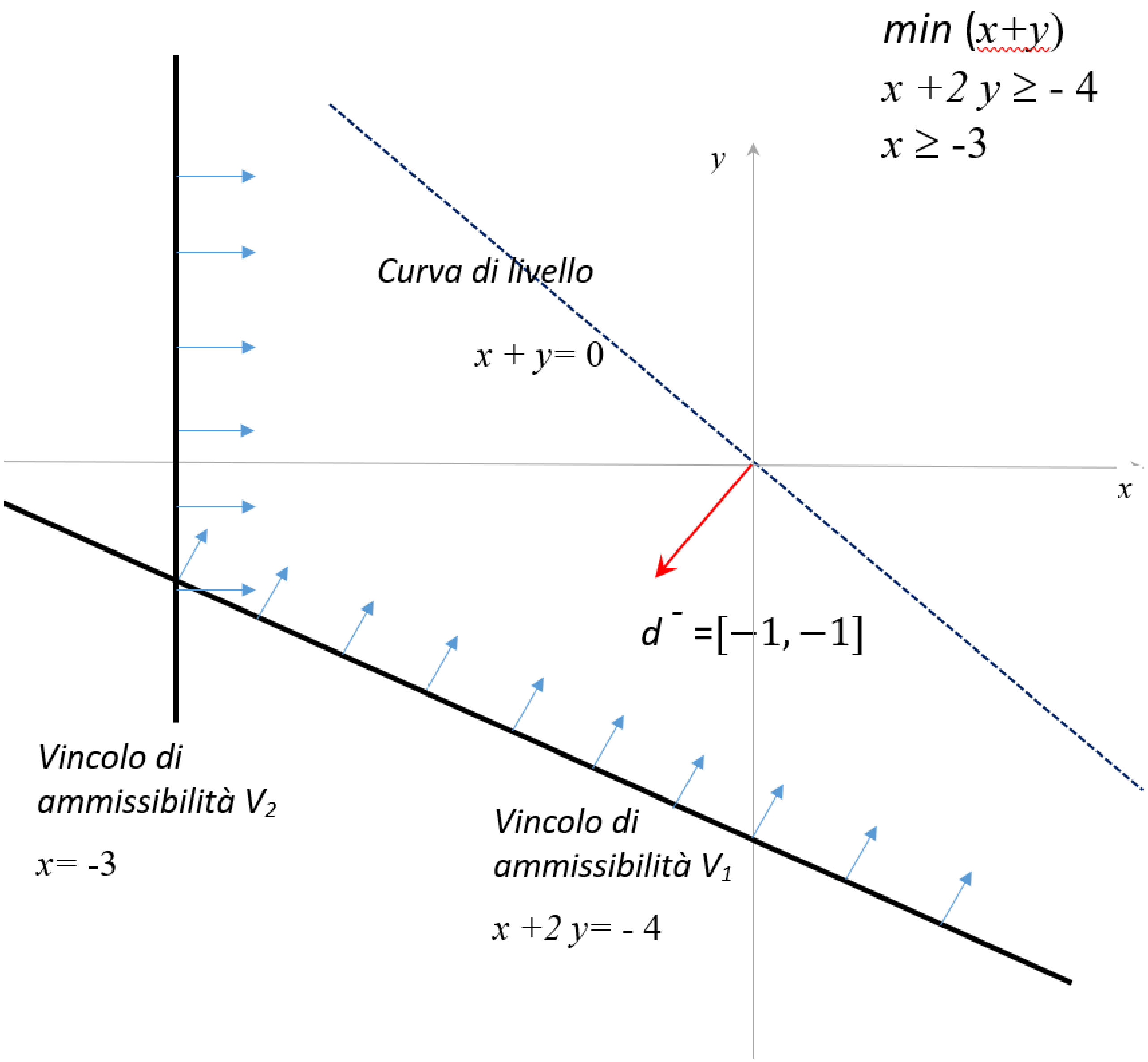
find the minimum objective function defined by the **parameters**/variables of the considered **problem model x** (simply, **model**)

where the parameter values are **constrained to stay** within the **search space S**



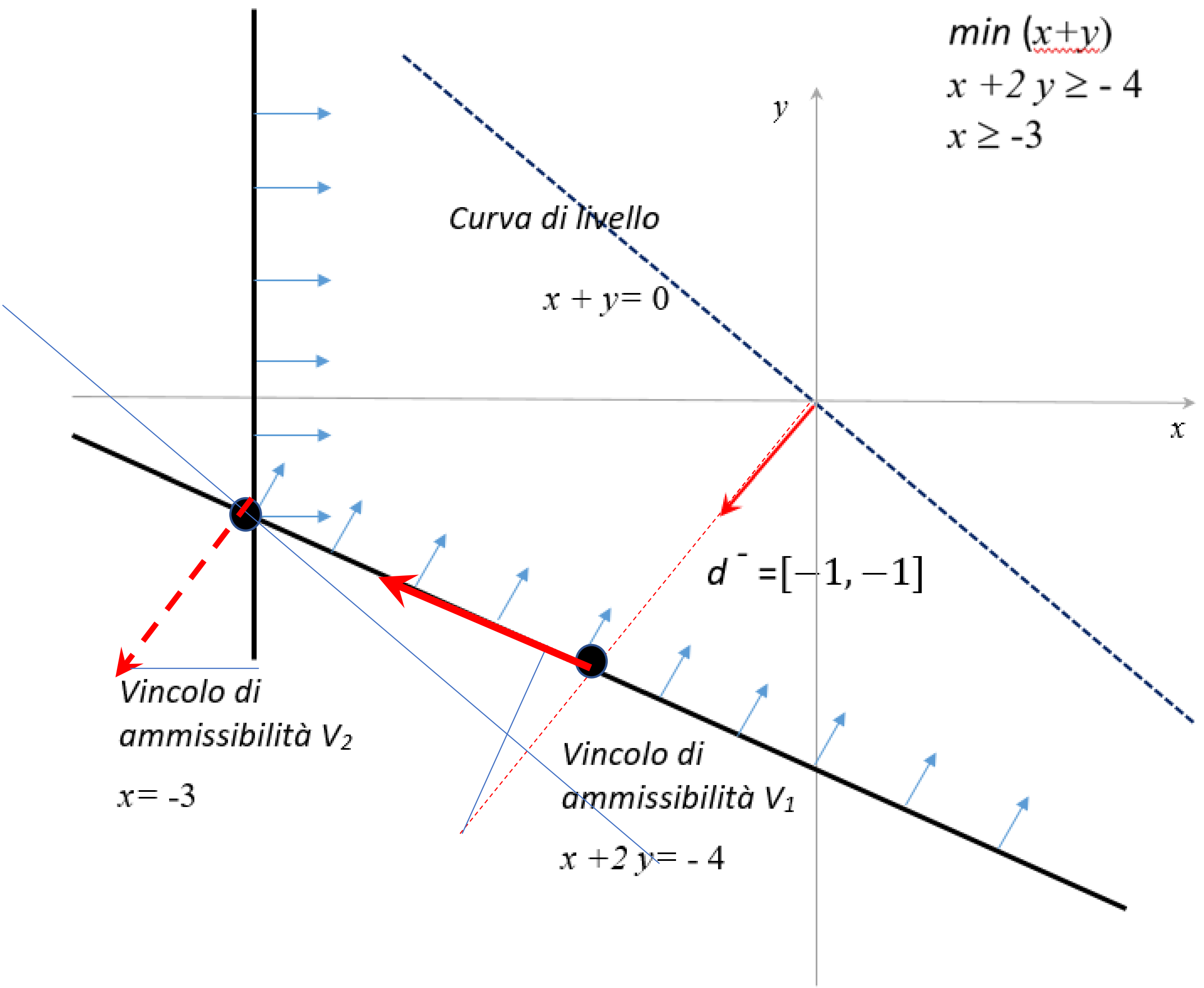
Operational research

Direction of search with contraints



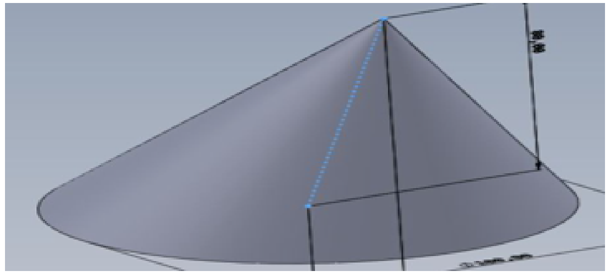
Operational research

Solving the optimization problem



Operational research

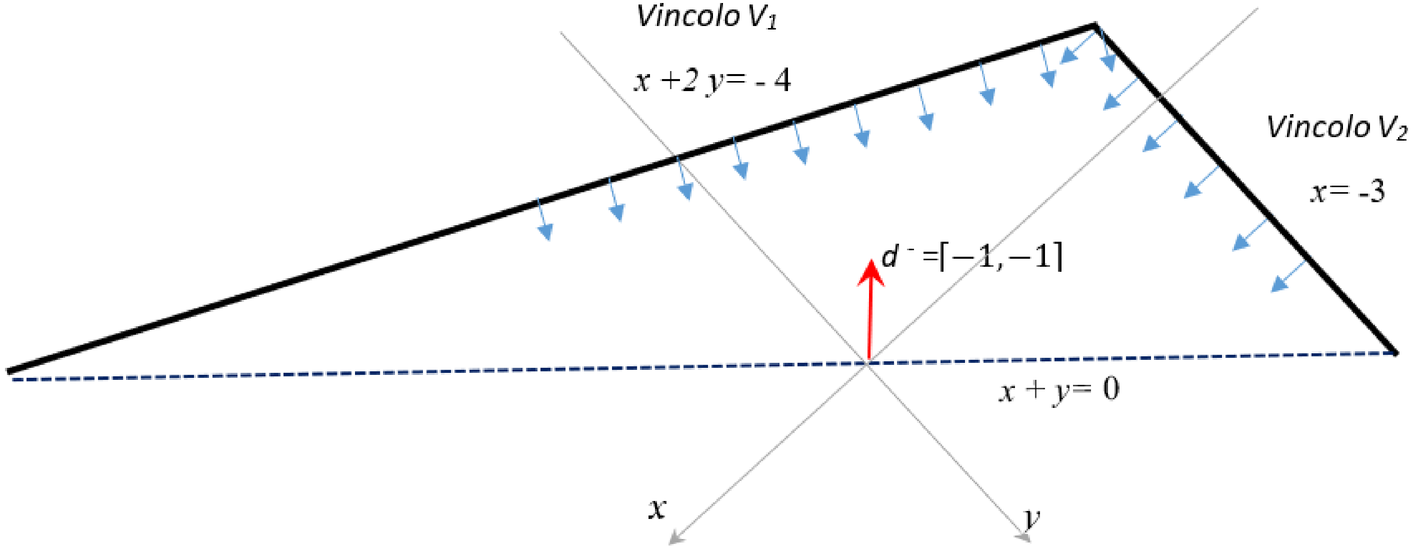
Solving the optimization problem and define the acceptance zone



MODELLO SOLIDO

min ($x+y$)

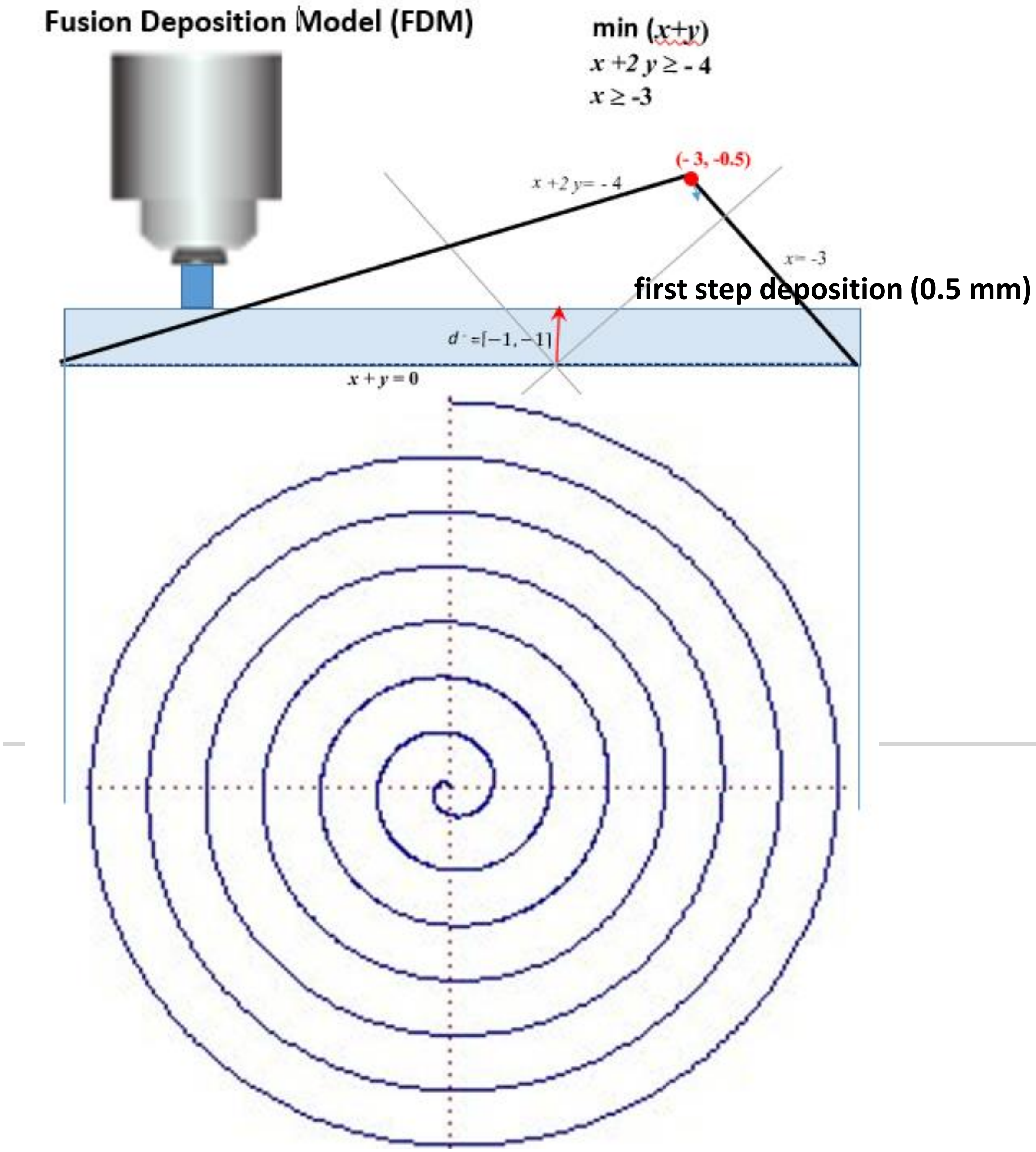
EQUAZIONI MAX ECCENTRICITA'	$x + 2y \geq -4$ $x \geq -3$



Operational research

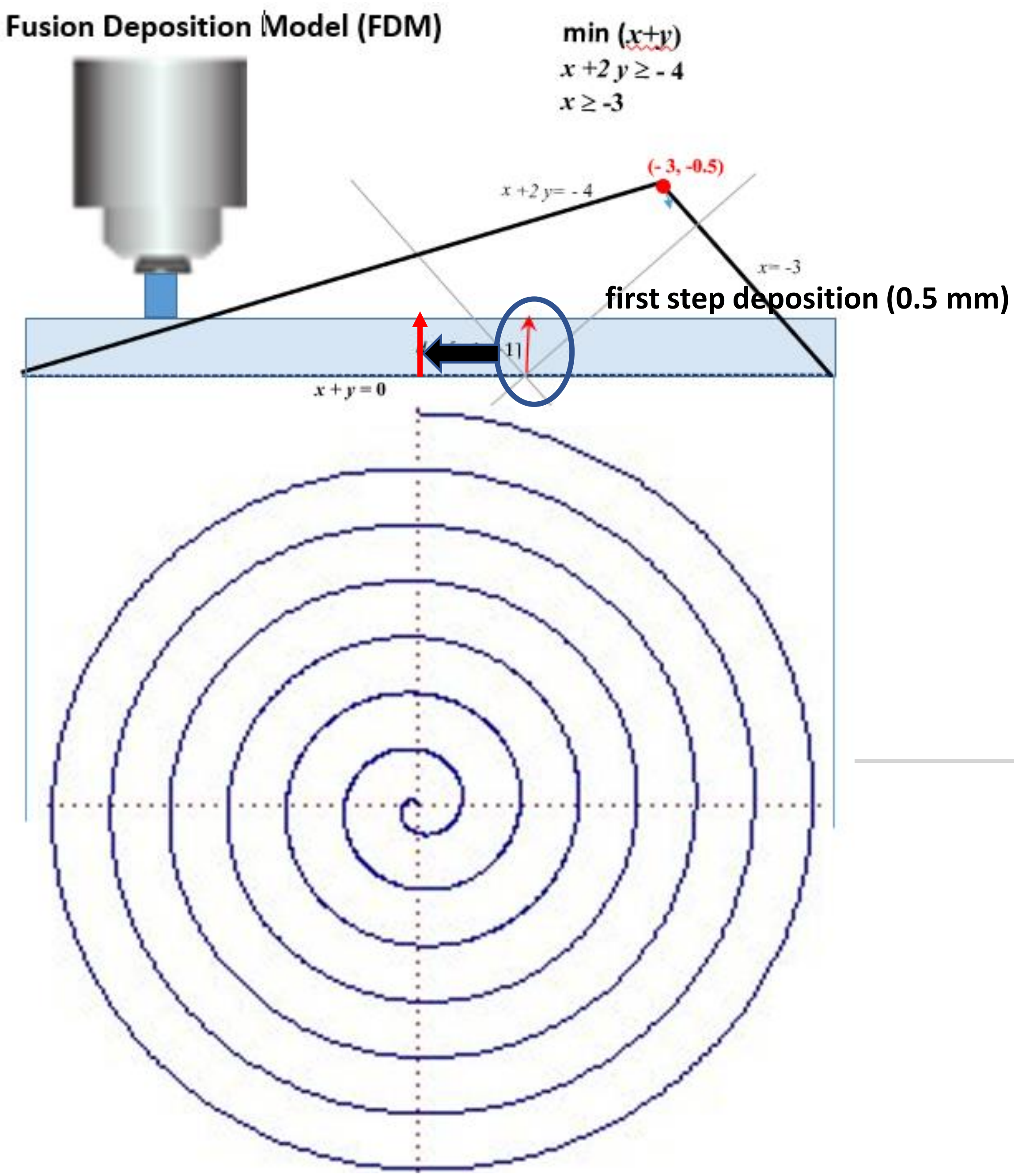
Constrained optimization 3D

CAM Additive (and subtractive)



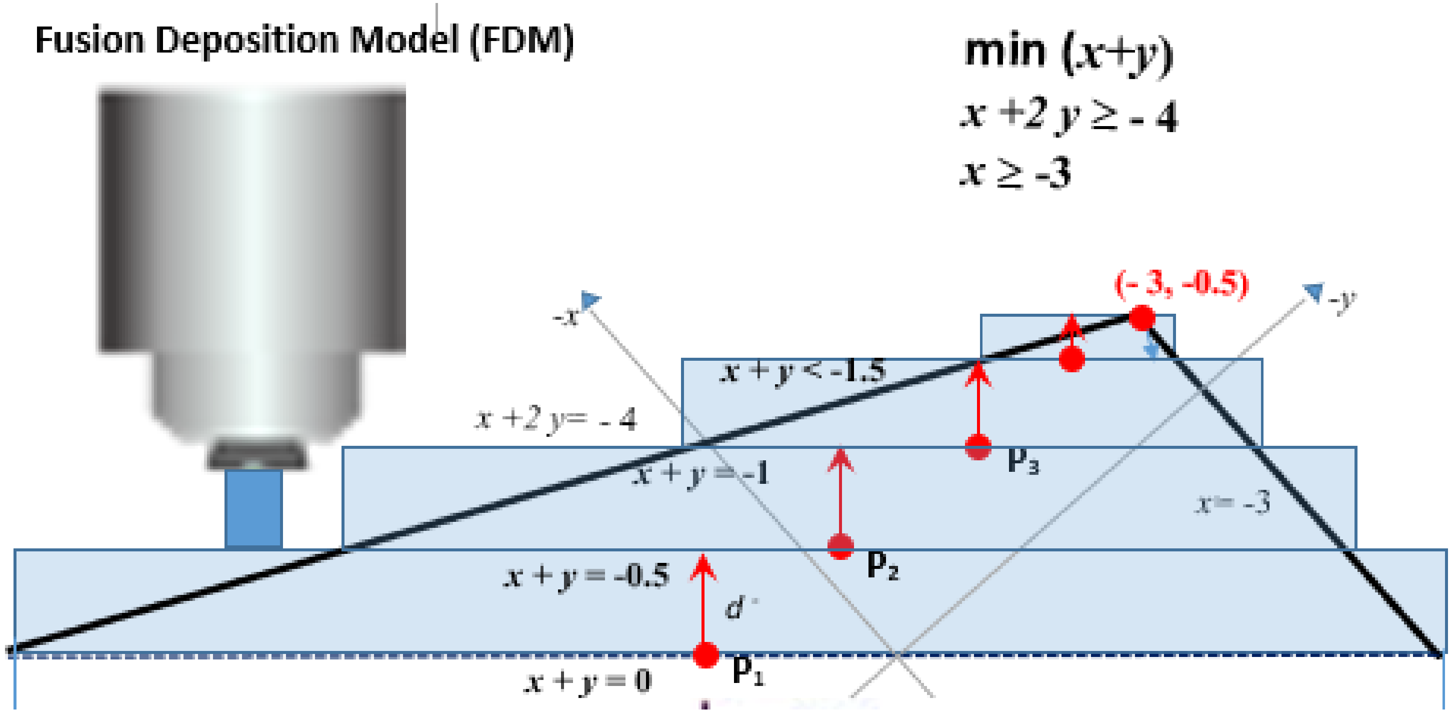
Operational research

Constrained Optimization 3D Fusion Deposition Modeling
"Proceed step by step along the direction of the gradient descent. Suppose the step size is 0.5 mm



Operational research

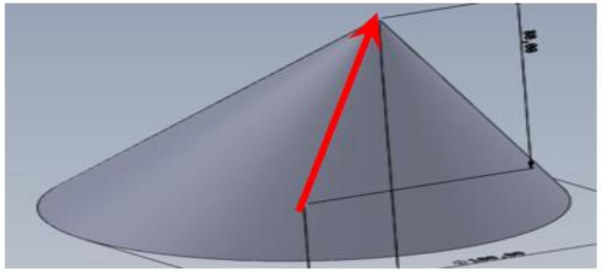
CAD vs CAM
"In the transition from the solid model to the physical model, the problem of alignment with the physical process (FDM) arises.
By setting the FDM strategy to Archimedean Spiral, the initial point P1 must be translated to the center of the base area of the cone."

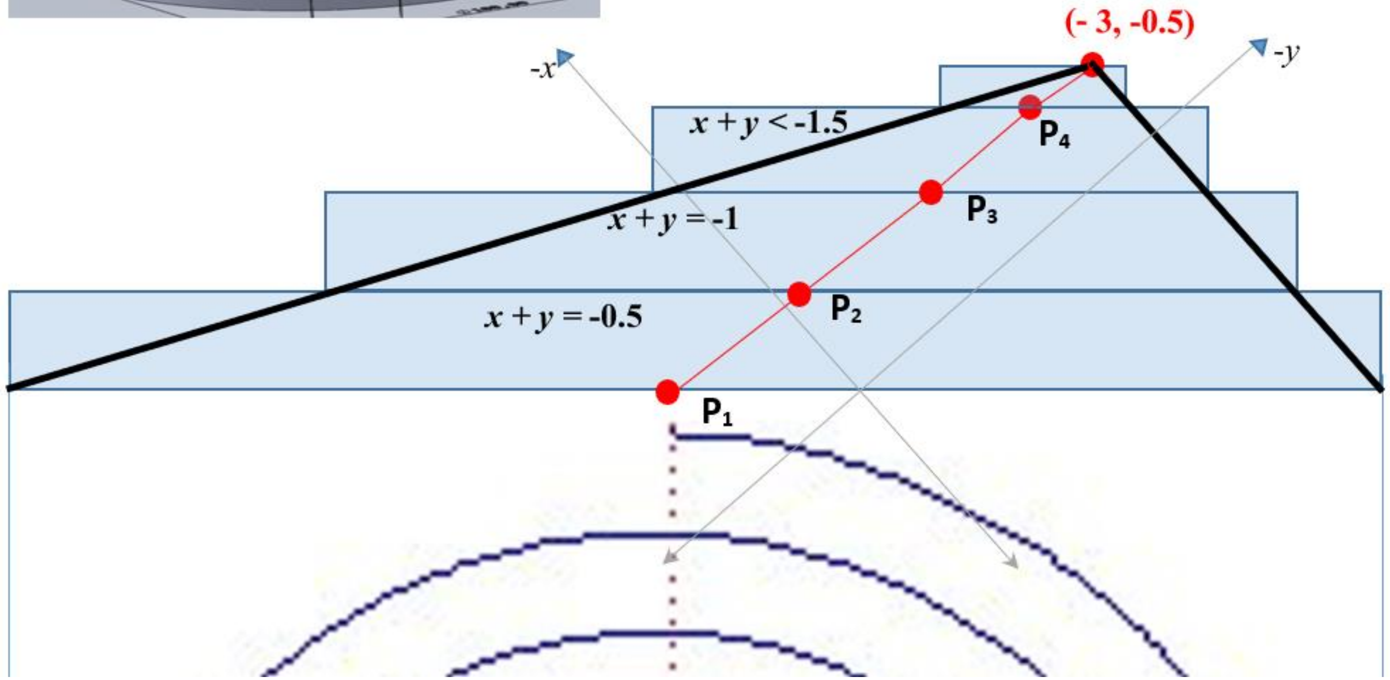


Operational research

Constrained Optimization 3D
CAD vs FDM-CAM

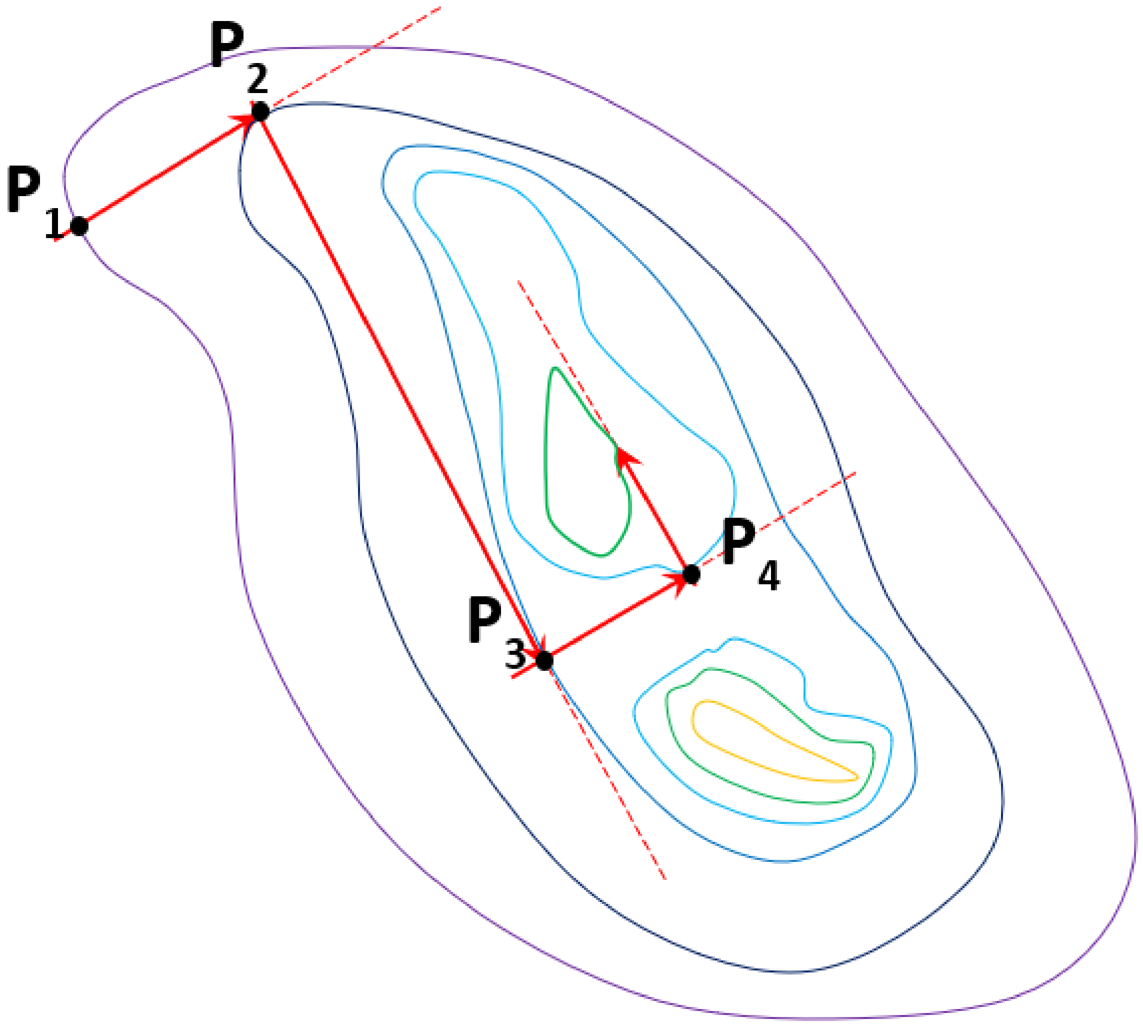
"Proceed step by step along the direction of the gradient descent. Each step is equal to the height of the pass."





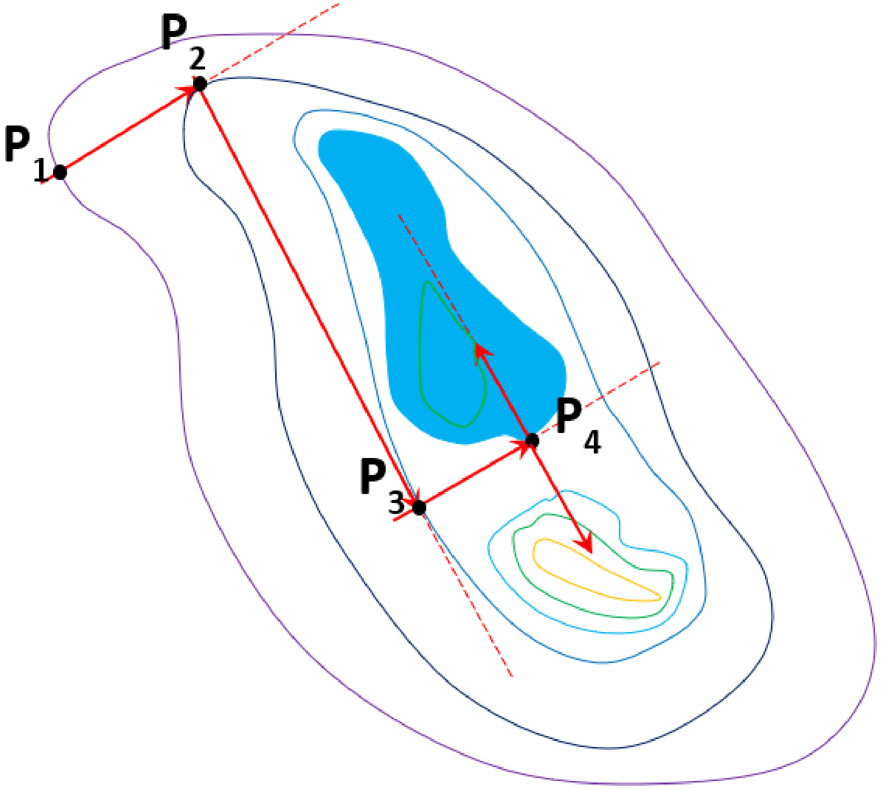
Operational research

Constrained Optimization 3D
CAD vs FDM-CAM
"The optimal search direction involves the application points of the FDM strategy (e.g., Archimedean spiral) and can be approximated by the **MAIN INERTIA AXIS** of the solid."



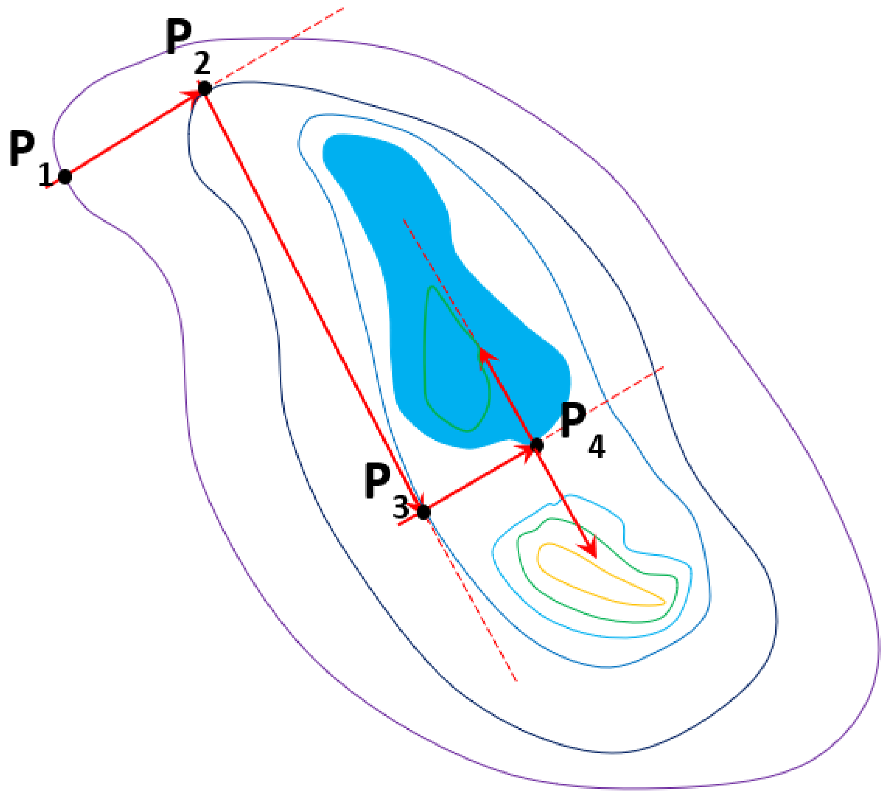
Operational research

Stagnation
"Local Search is a local search for the minimum that fails when *f* is not convex (or not unimodal, meaning it has more than one local minimum)."



Operational research

Remedies for Stagnation
"There is no absolute remedy, and for this reason, in general, it will not be possible to reach the global optimum.
Current remedies
Go back a few steps and cover the dip at the same height as the reached level curve. That area will no longer be accessible, it becomes taboo (Tabu Search).
Jump out of the dip and restart the search from another part of the search space."



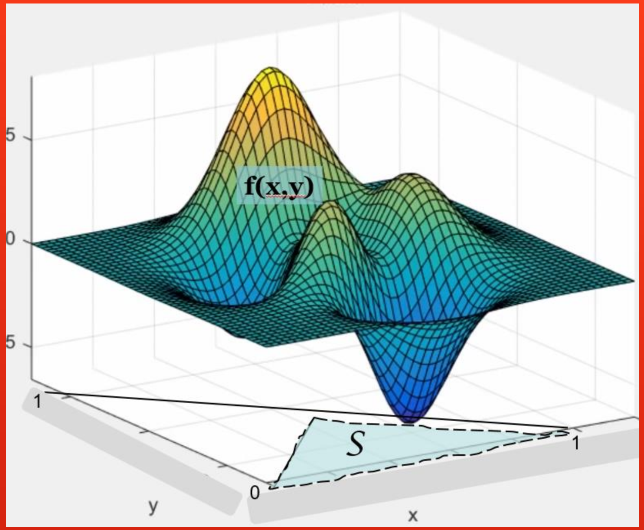
Operational research

Remedies for Stagnation

"Radical change of approach.
Use of Swarm Intelligence, a recently developed Artificial Intelligence system.
In this course, we will use a conceptual-implementation approach, learning concepts by implementing examples."

OPTIMIZATION PROBLEM

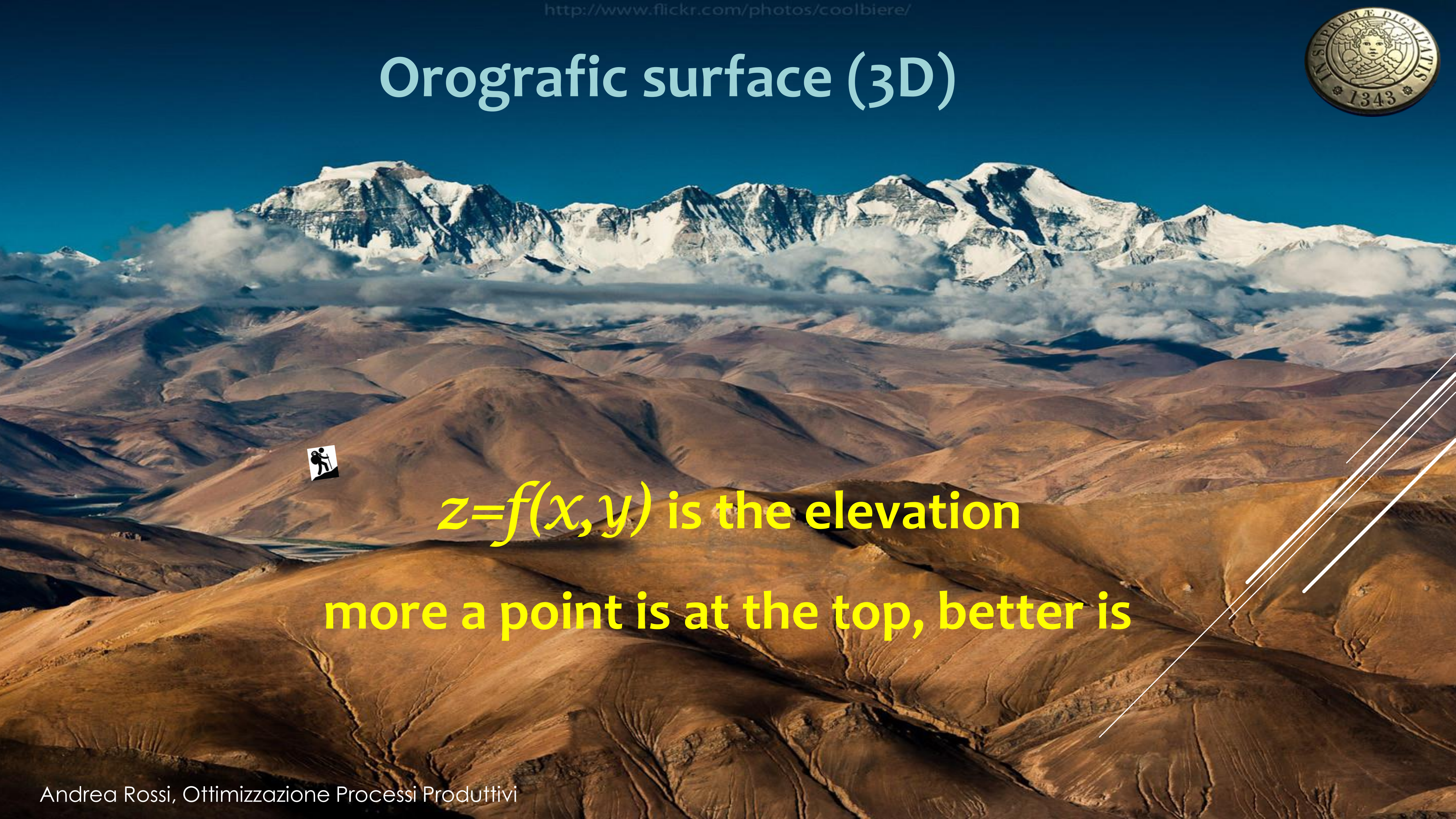
$$\min f(x)$$
$$x \in S$$



We use a general tool of Artificial Intelligence for Optimize a Multimodal-Constrained Function termed as

METAHEURISTICS

Orografic surface (3D)



$z=f(x,y)$ is the elevation

more a point is at the top, better is

KEYWORDS

Objective function, measure

Problem's model

The orographic optimization problem (OOP)

$$\max \; \text{elevation}(x, y)$$

i. $(x,y) \in S$

search space

maximization

Find (x,y)*∈S that height(x,y)* is a maximum

Max Elevation(Explorer)

Explorer $\in$ Oreographic region with Severe weather condition

KEYWORDS

Population item/problme’s model

The orographic optimization problem (OOP)

$$\max \ elevation\ (x, y)$$

i. $(x,y) \in S$

ii. $visibility\ (x, y) < distance$

where $distance \ll \sqrt{|S|}$

Visibility function for every item in the population

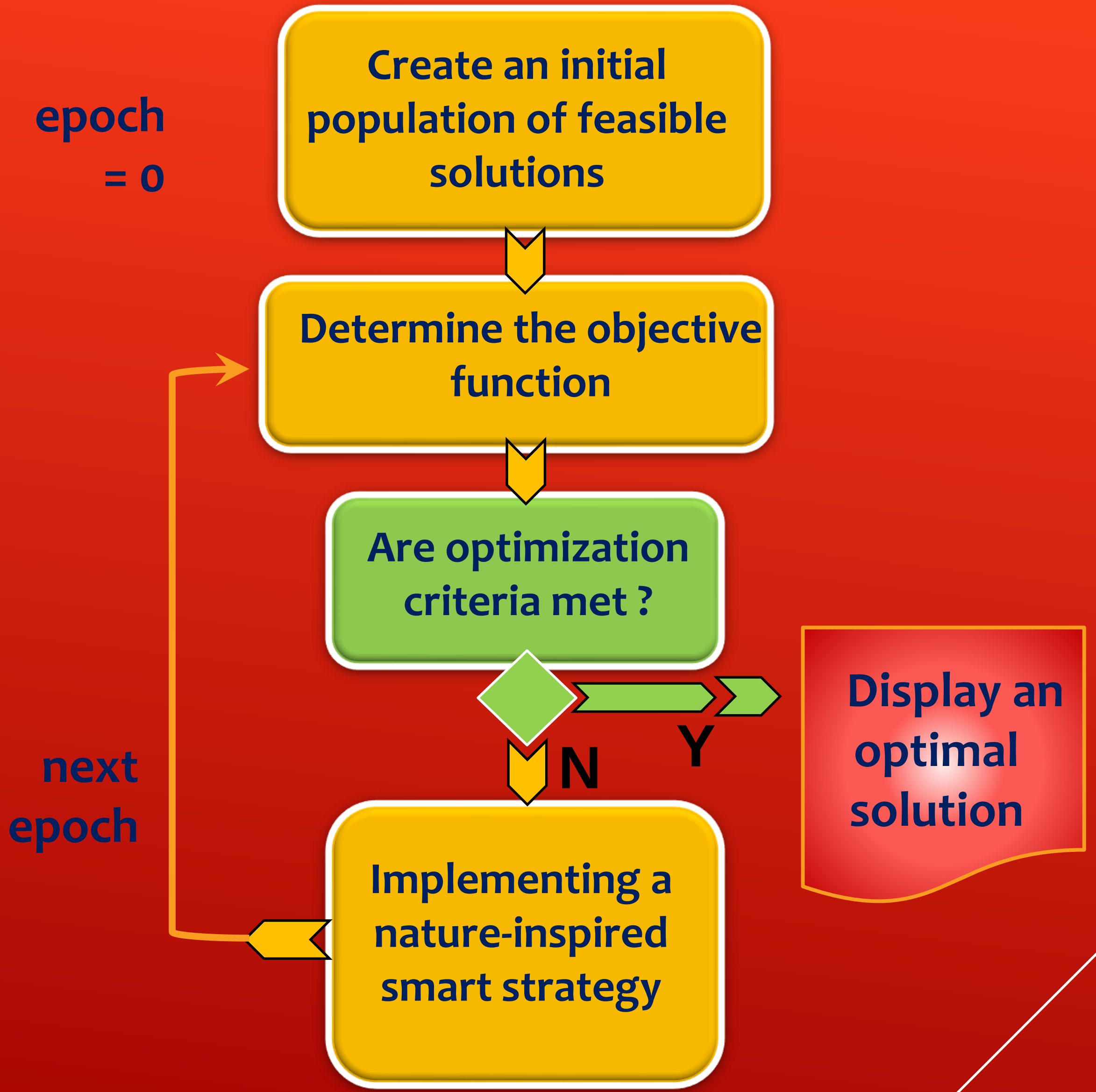
constraints

SWARM INTELLIGENCE:
on the same model of the problem coexist several individuals

Max Elevation(Explorers)

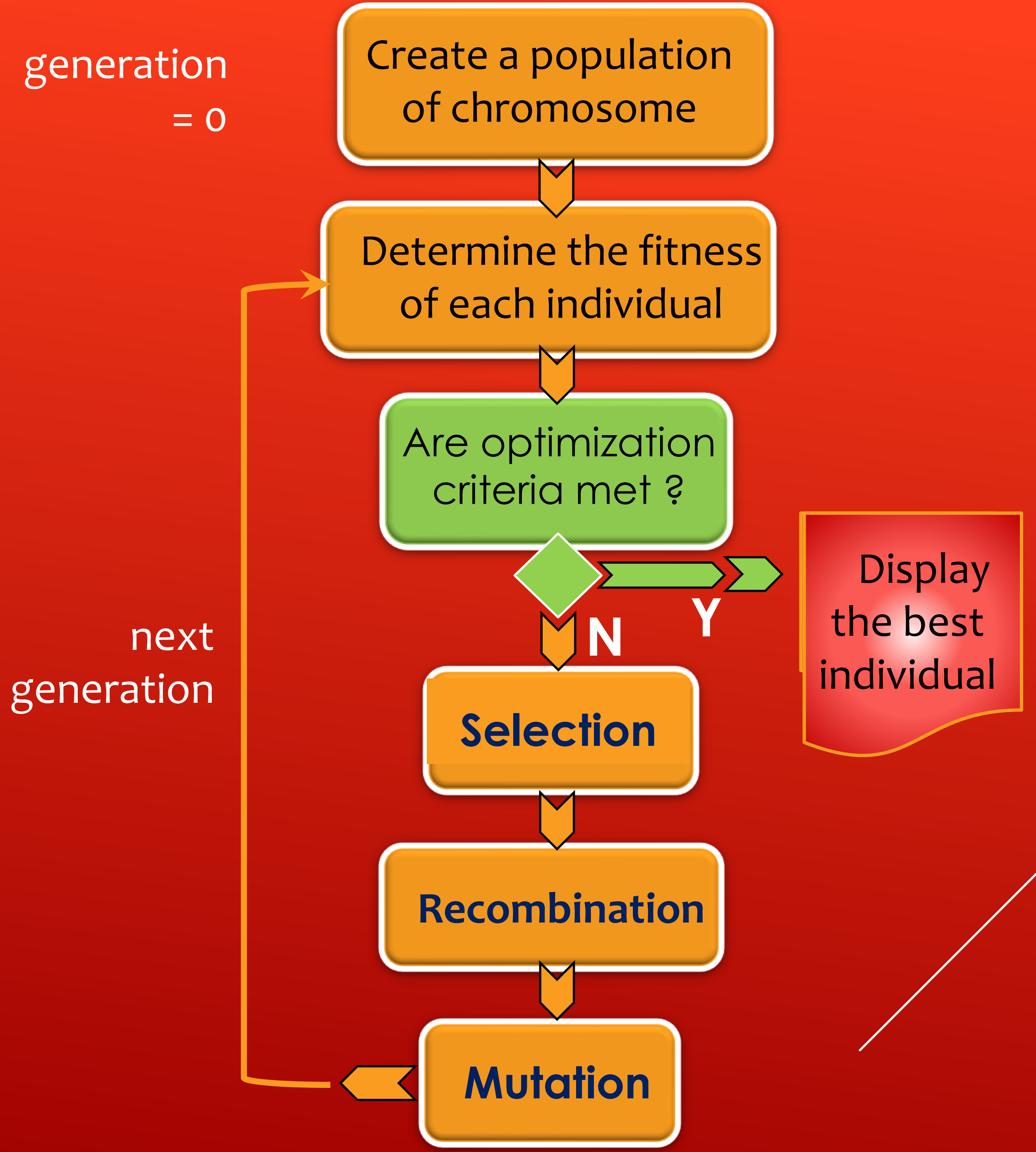


Explorers ∈ Oreographic region with Severe weather condition

Metauristic algorithm

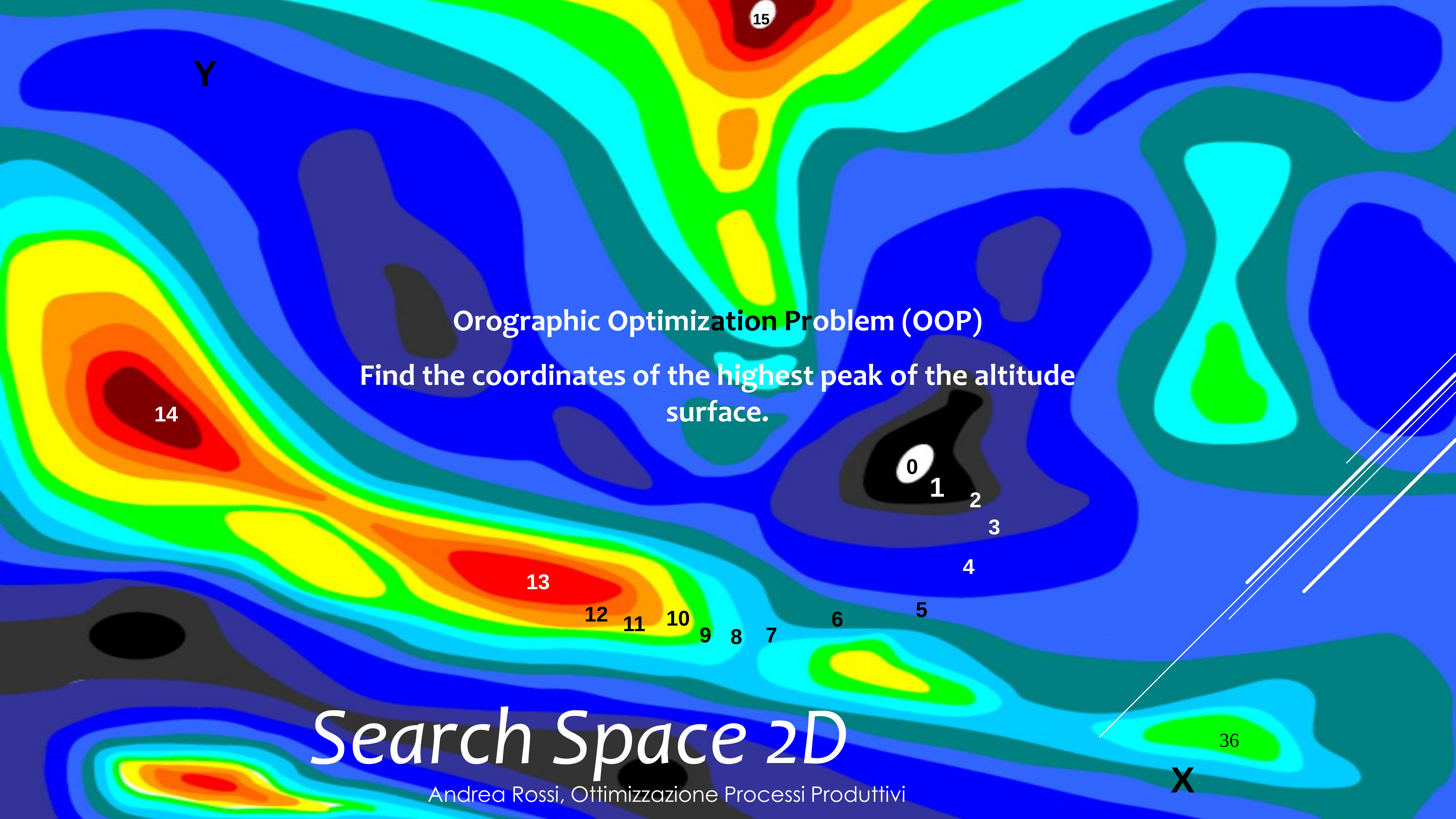
Genetic Algorithm
the basic structure



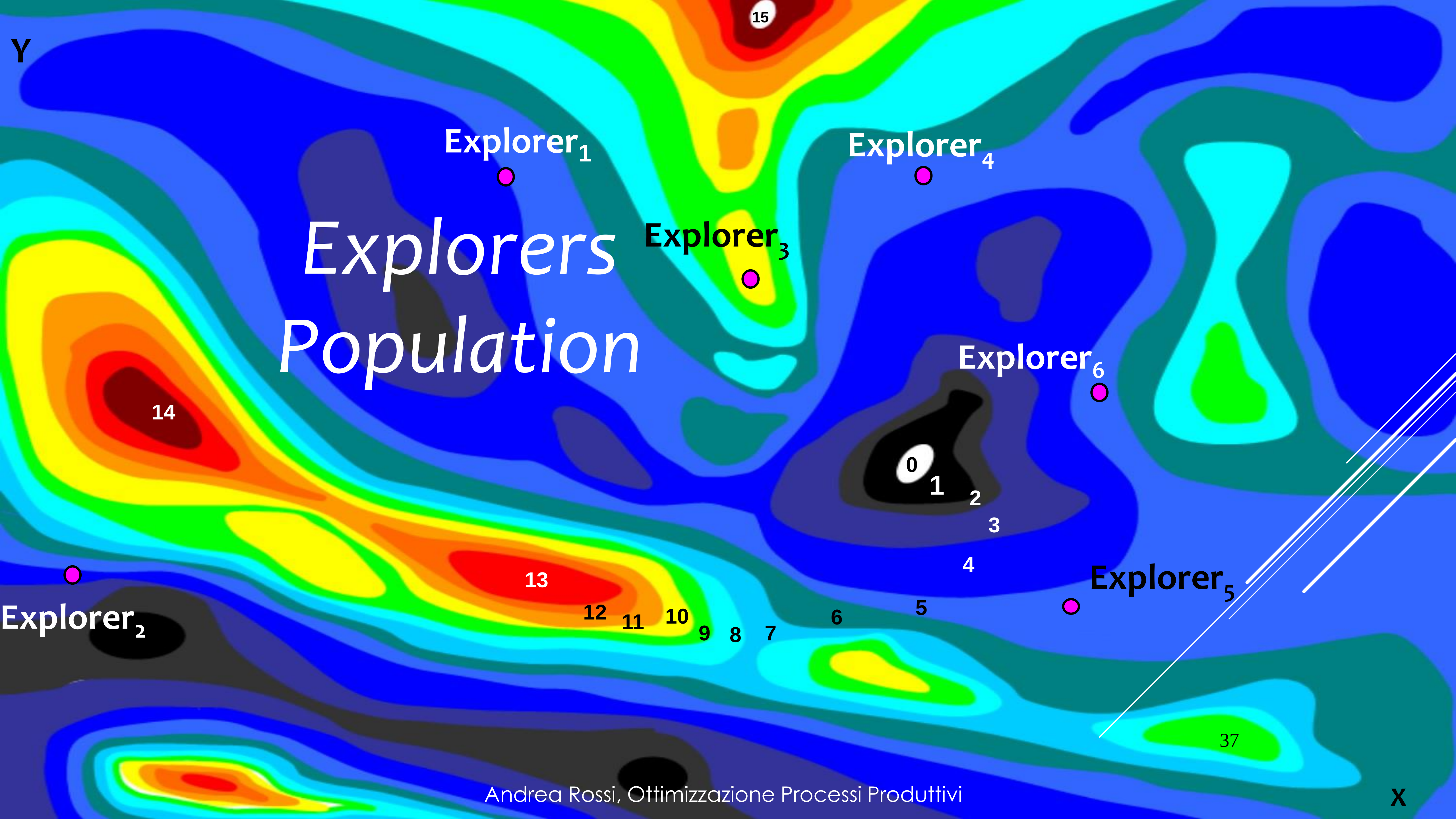
Search Space 2D

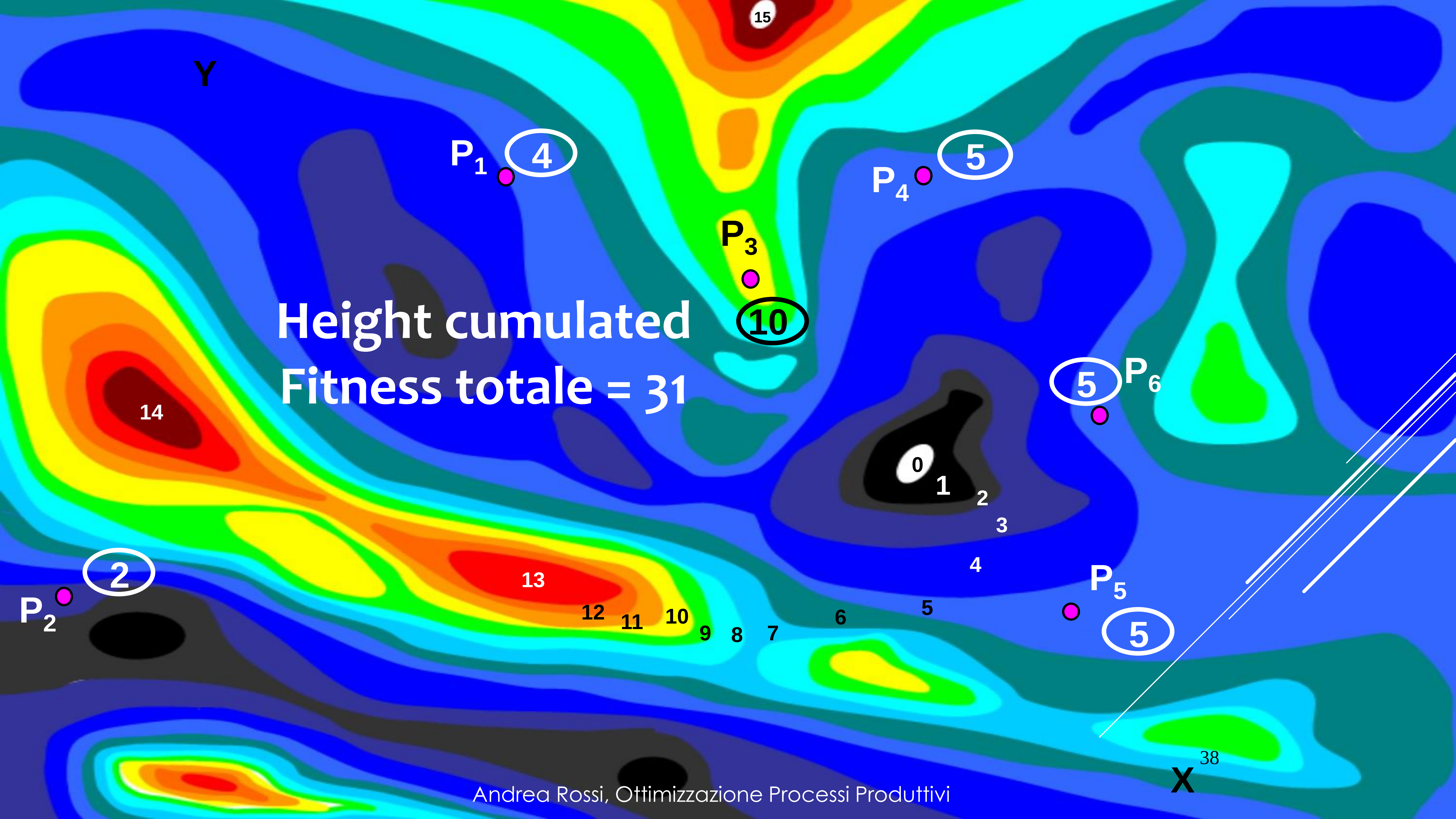
Orographic Optimization Problem (OOP)

Find the coordinates of the highest peak of the altitude surface.

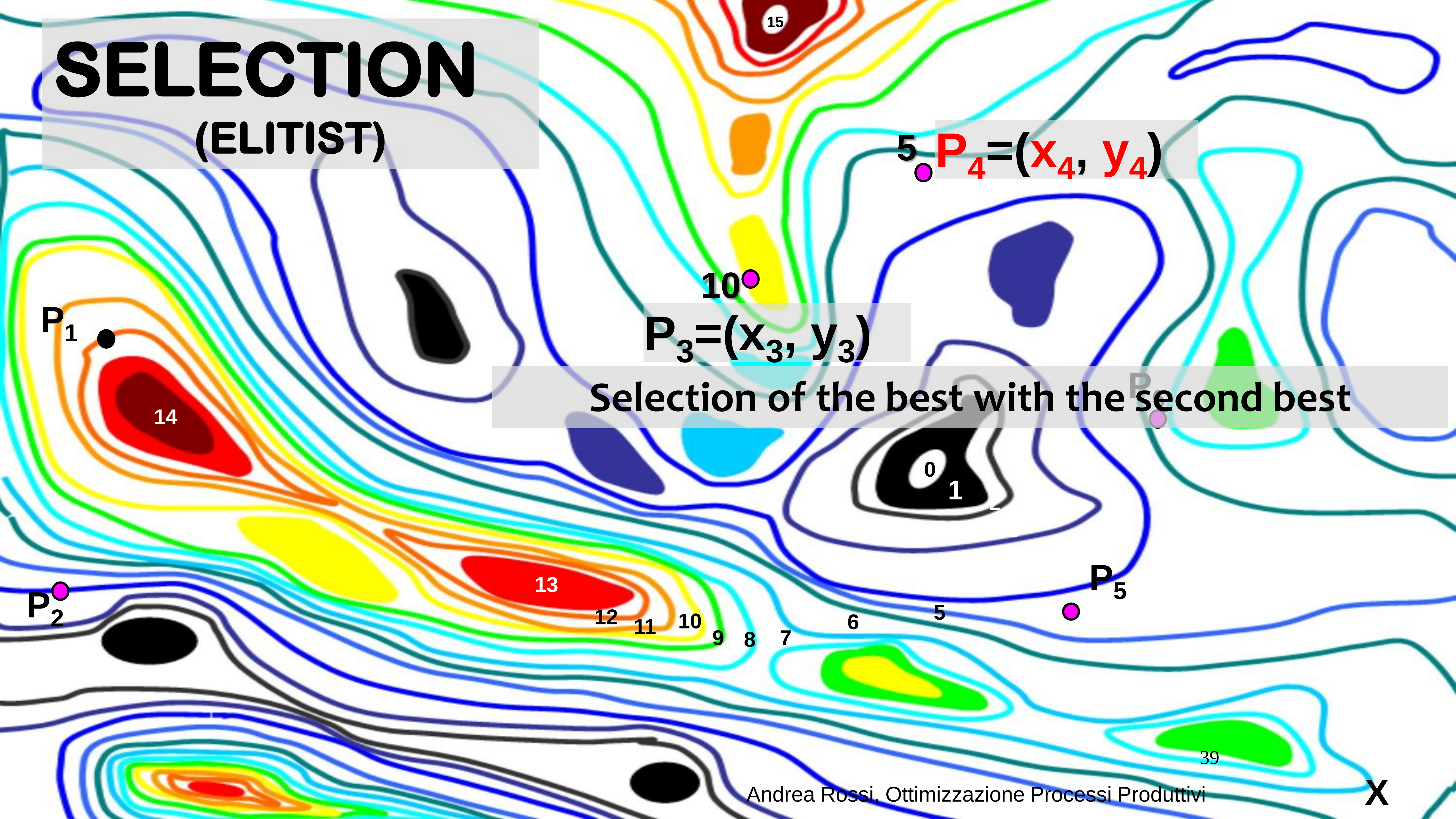


Explorers Population



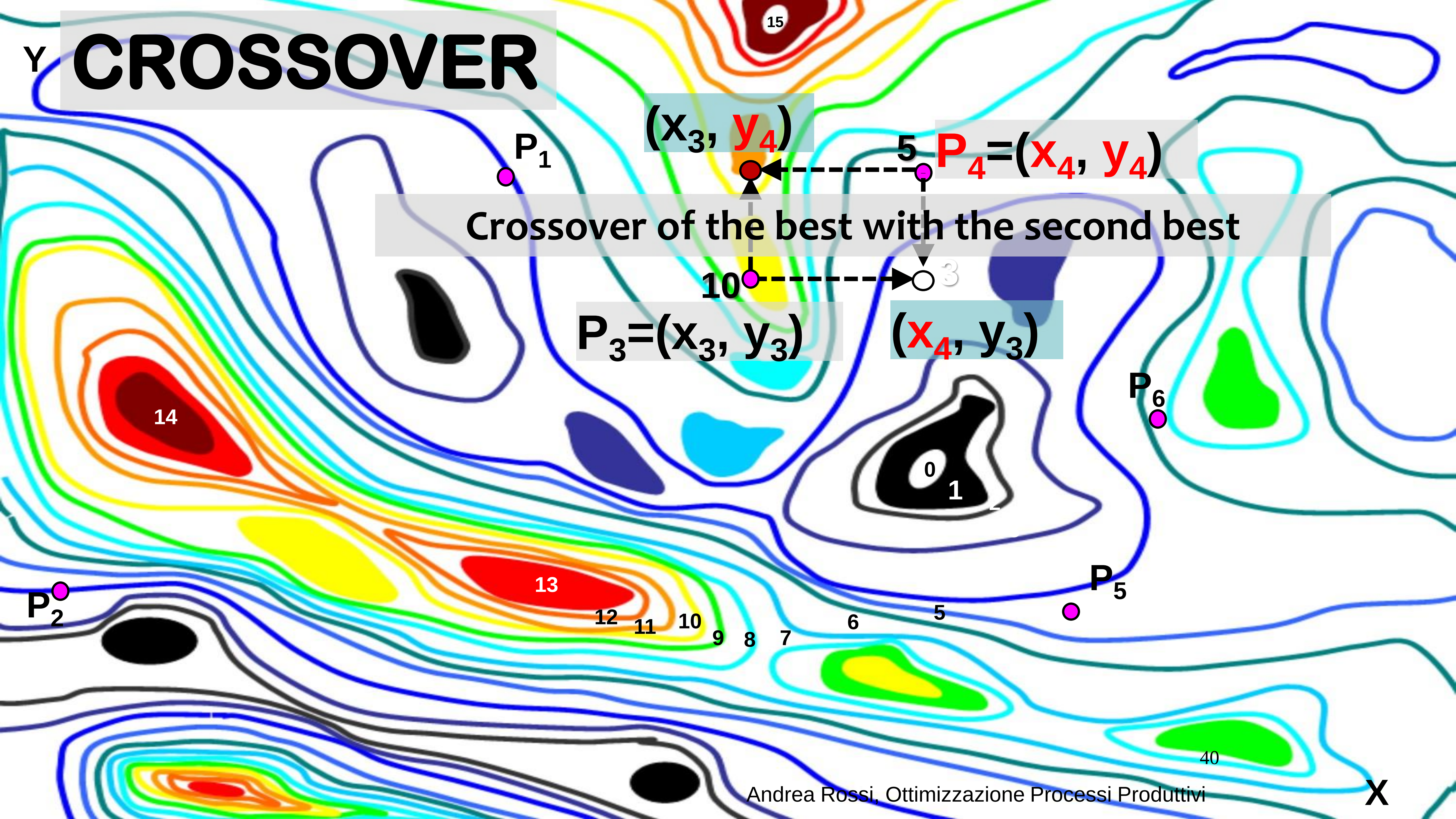

15
Y
P_1 4
P_4 5
P_3
10
Height cumulated
Fitness totale = 31
14
5 P_6
0
1
2
3
4
5
6
7
8
9
10
11
12
13
2
P_2
P_5
5
X

SELECTION
(ELITIST)

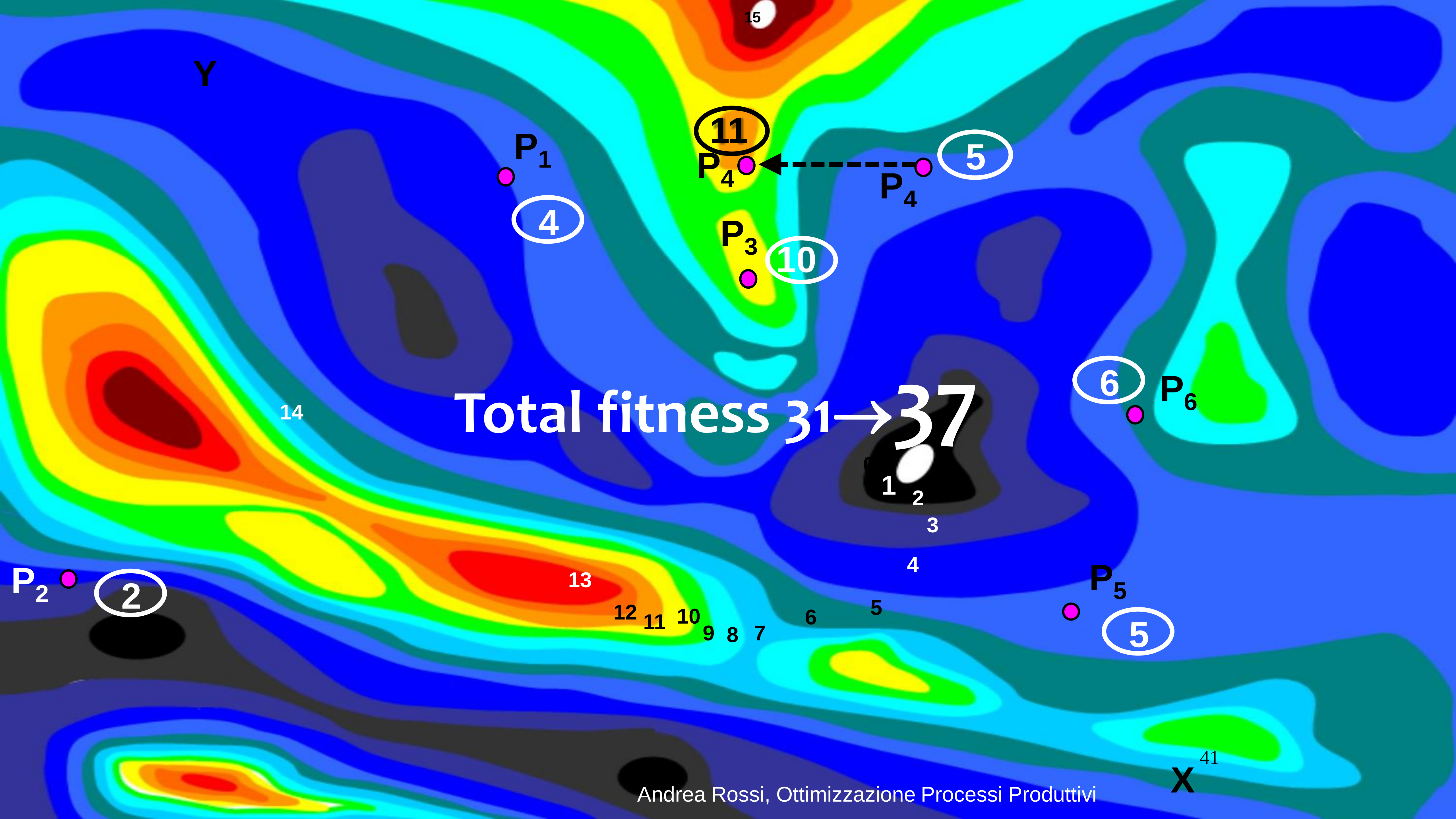


Selection of the best with the second best

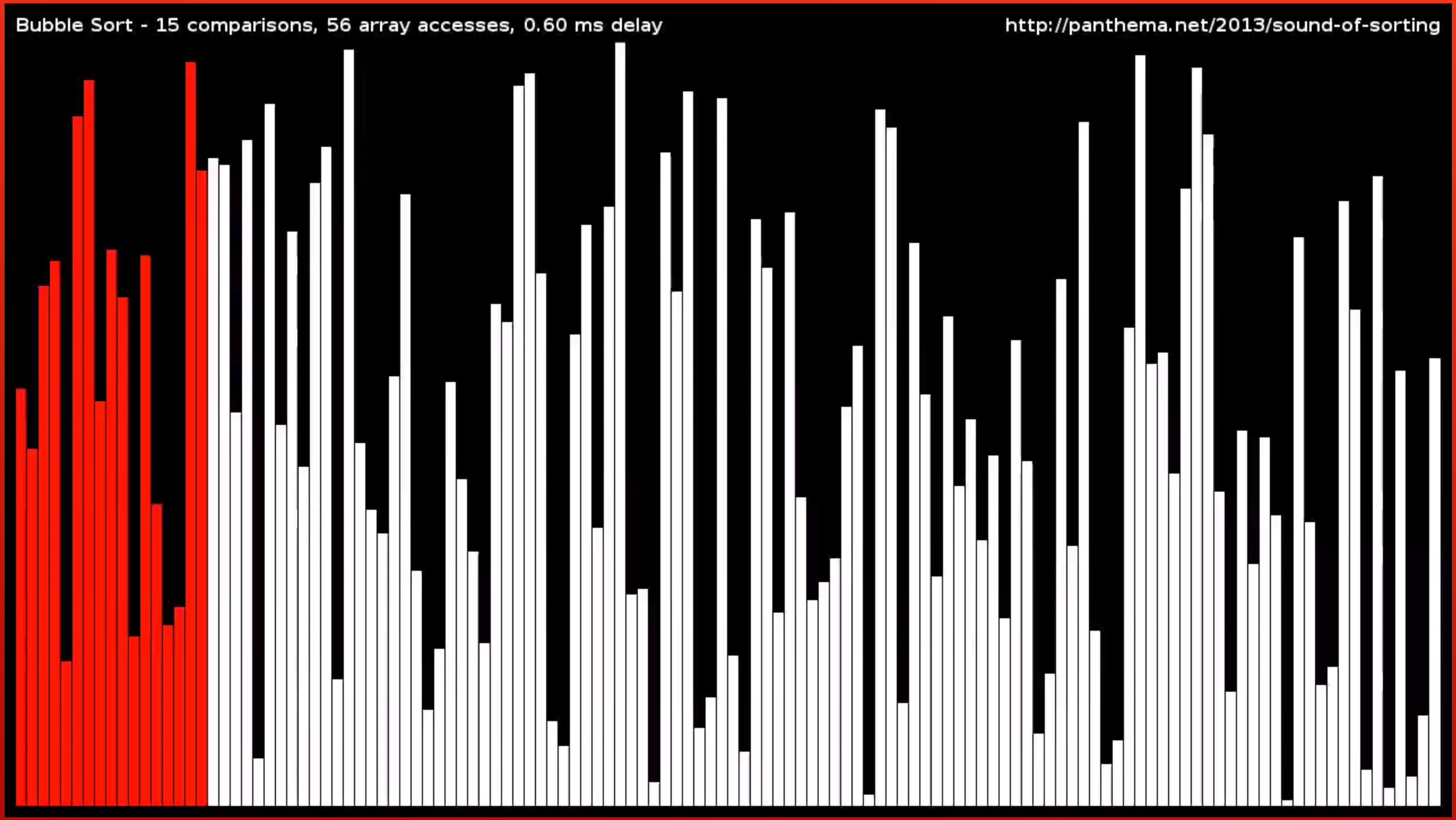
CROSSOVER



Crossover of the best with the second best

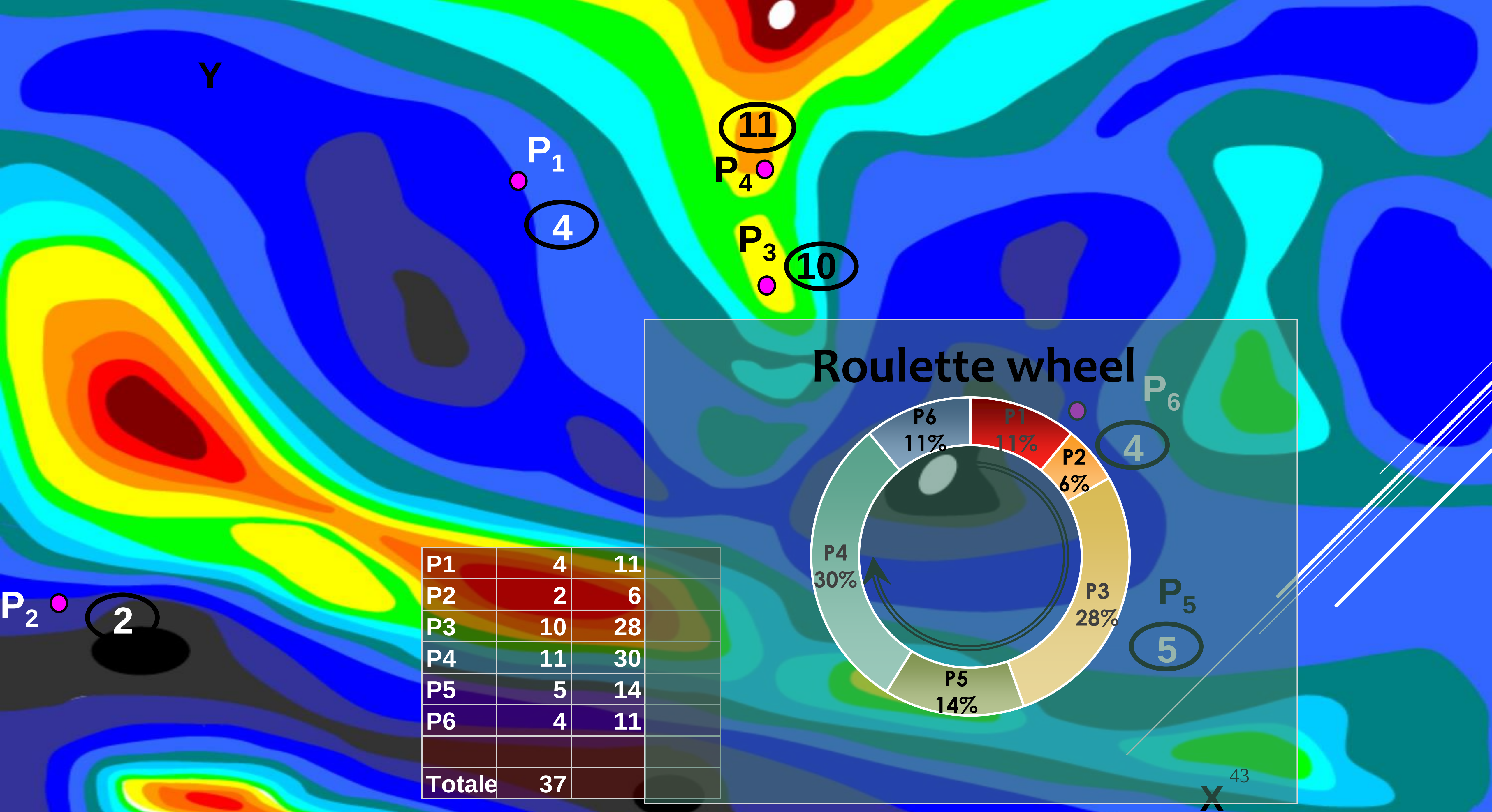

Y
X
P1
4
P2
2
P3
10
P4
11
P4
5
P5
5
P6
6
Total fitness 31→37
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Algorithms to order the explorers according to their heights.

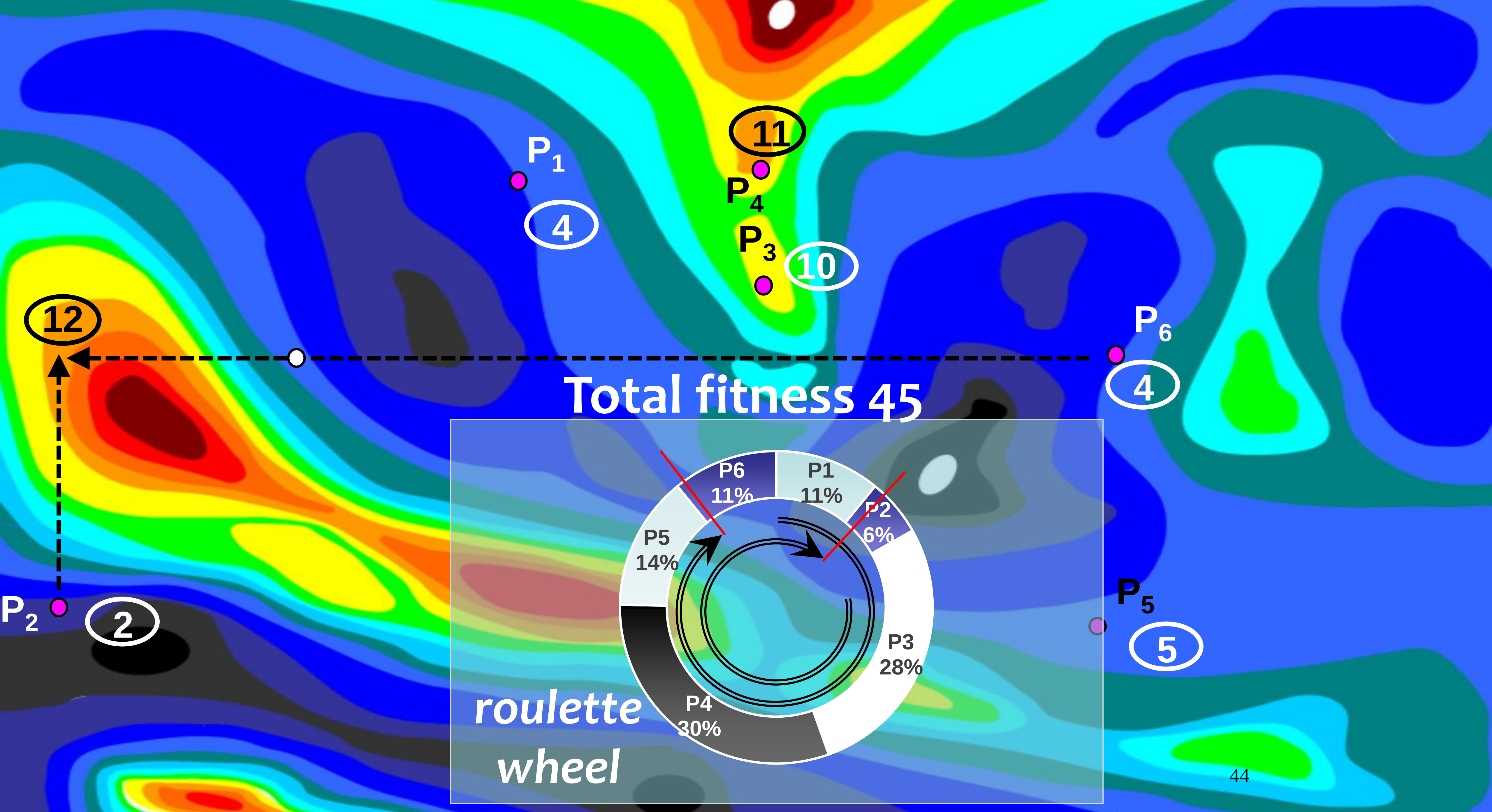


Points' heights

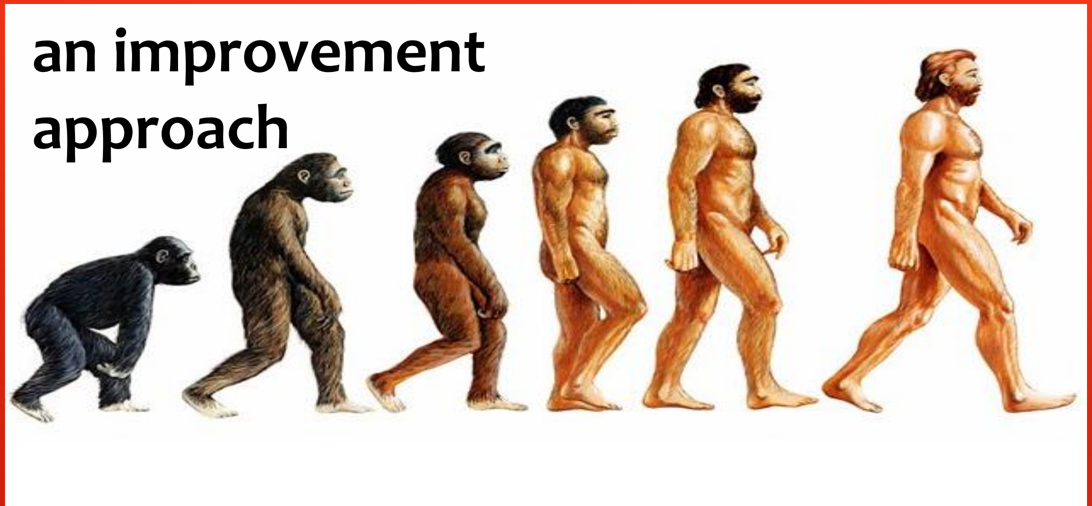
Roulette wheel

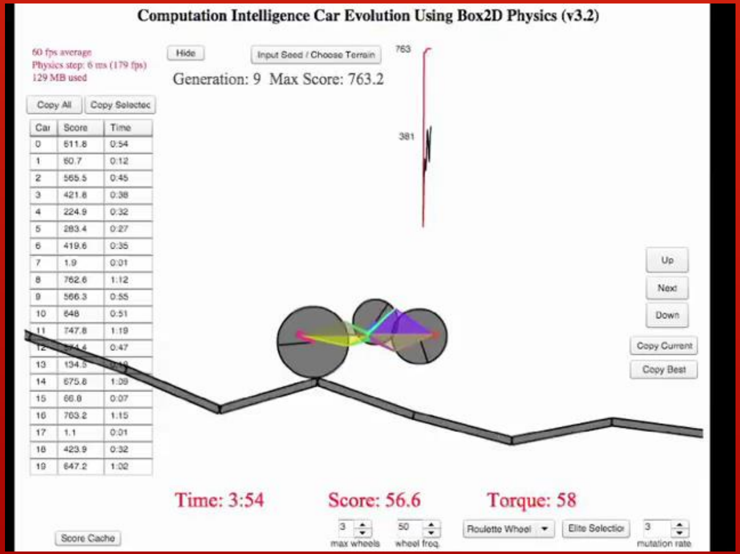


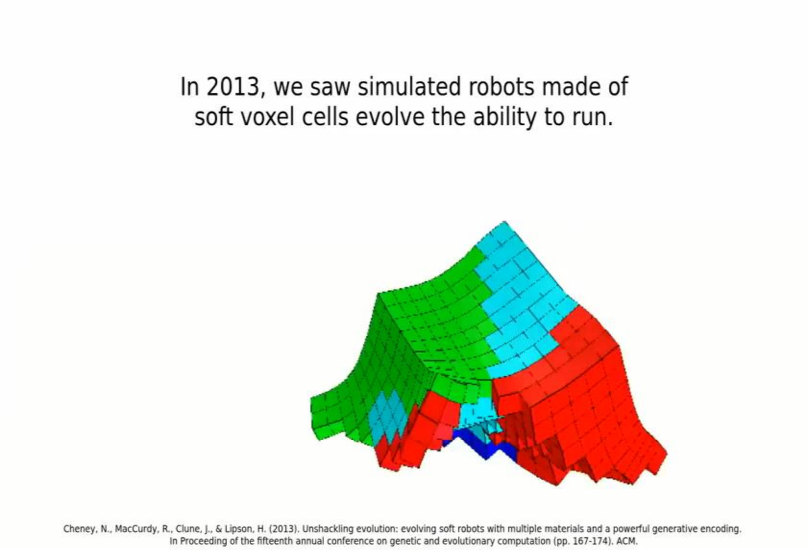
P1	4	11	
P2	2	6	
P3	10	28	
P4	11	30	
P5	5	14	
P6	4	11	
Totale	37		

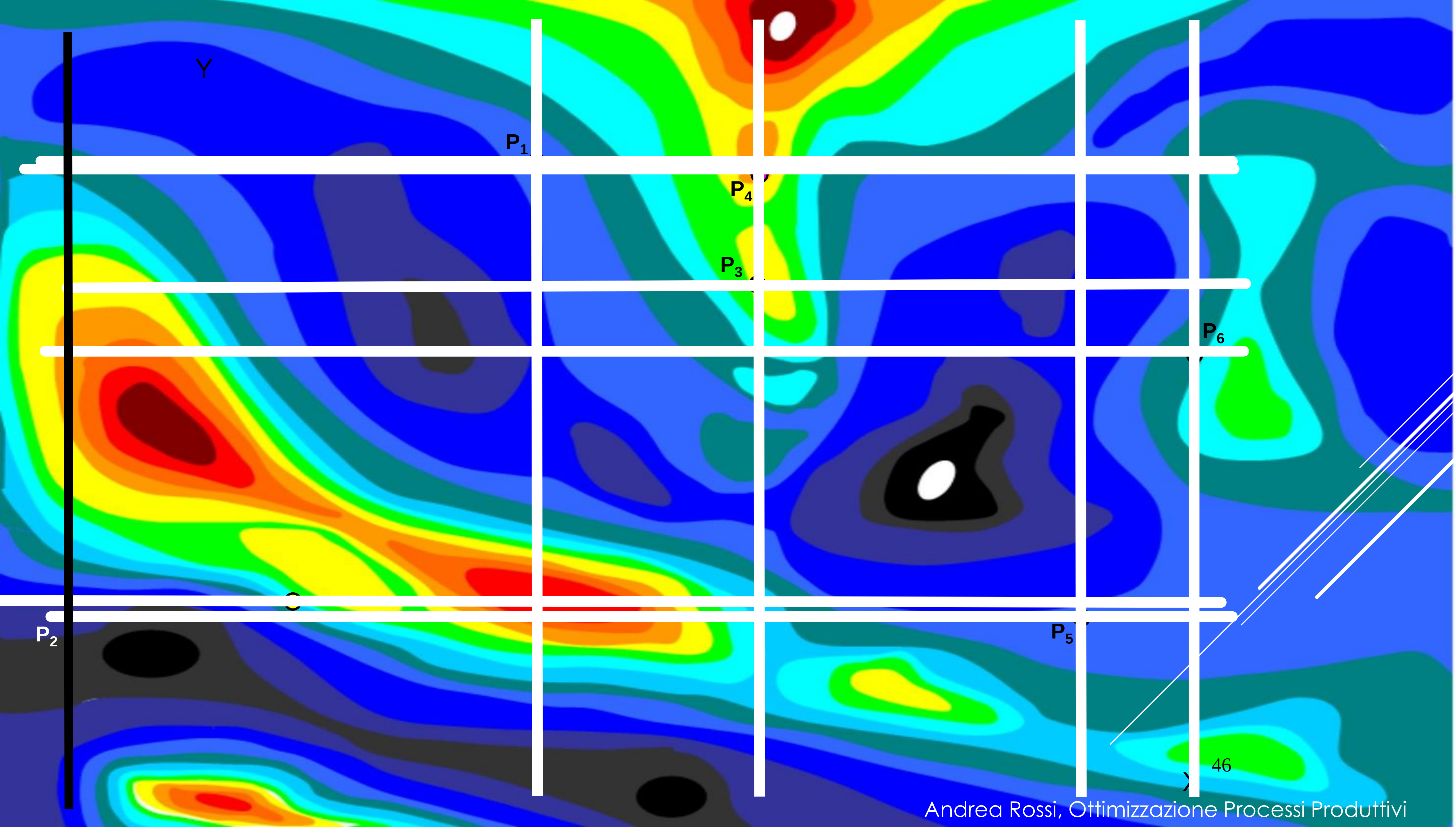

P1
4
11
P4
P3
10
12
P6
4
Total fitness 45
P6 11%
P1 11%
P2 6%
P5 14%
P3 28%
P4 30%
roulette wheel
P2
2
P5
5

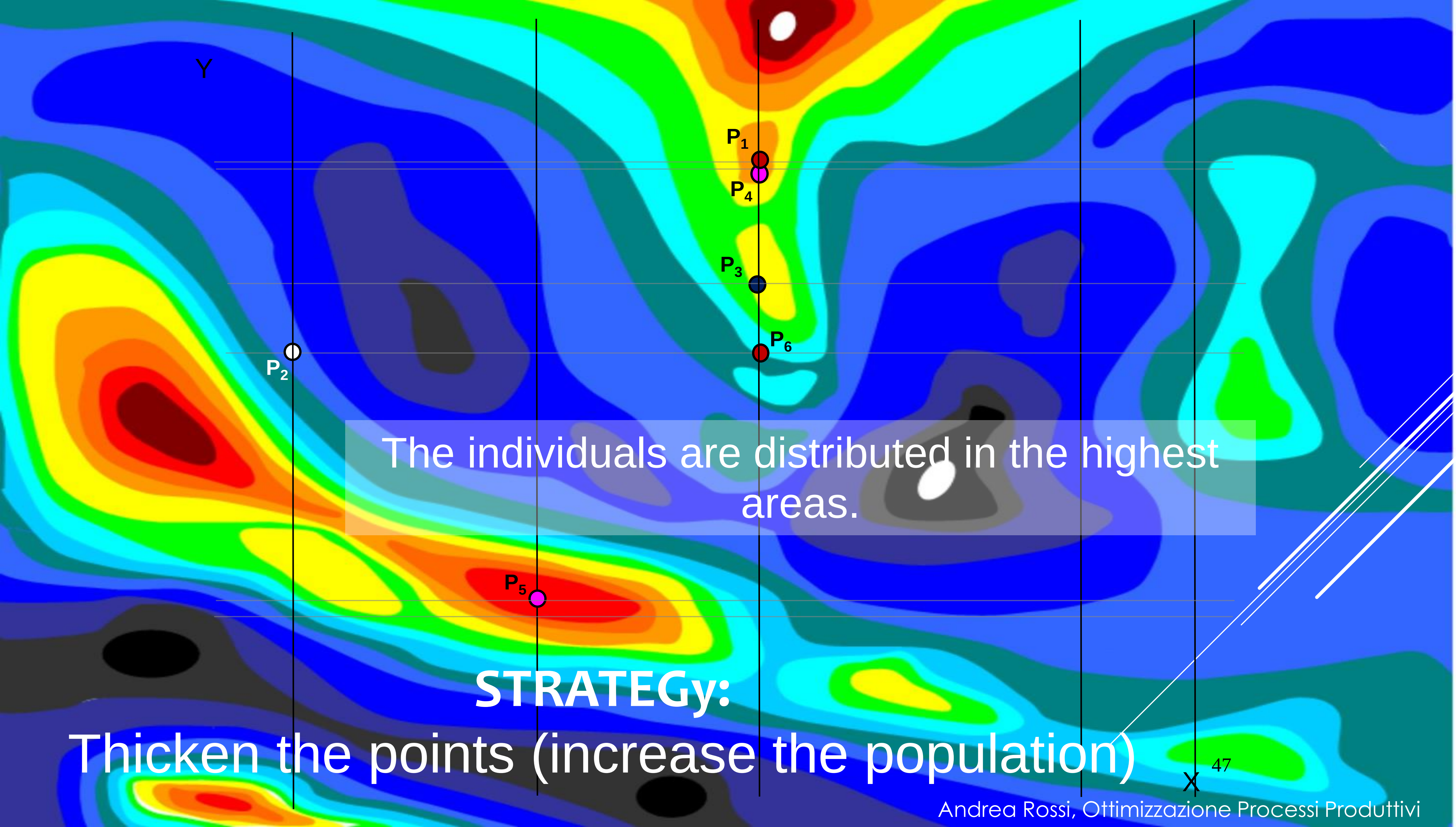
GENETIC ALGORITHM







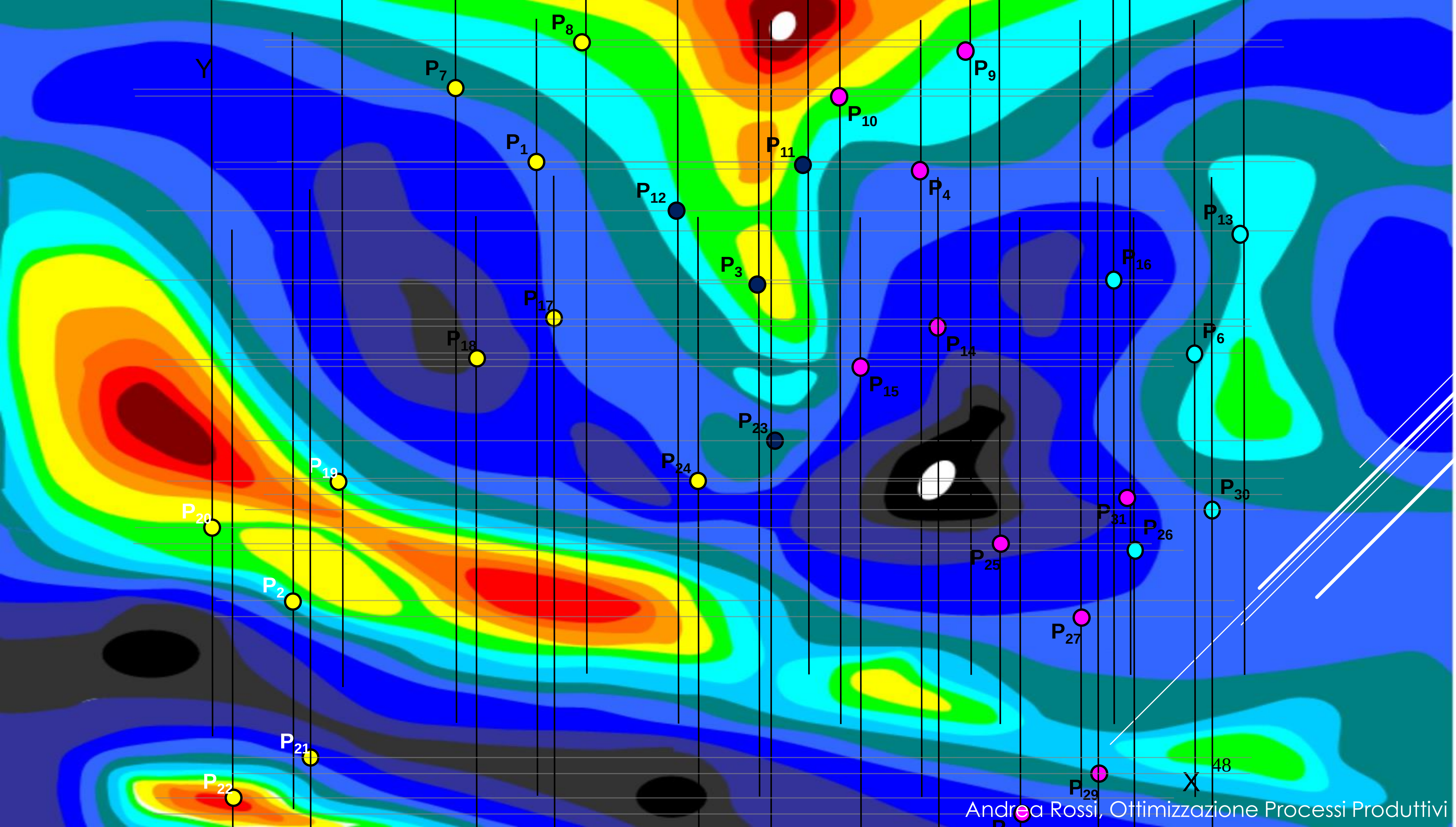

Y
P1
P4
P3
P6
P2
P5



The individuals are distributed in the highest areas.

STRATEGy:

Thicken the points (increase the population)



Y
P8
P7
P9
P10
P1
P11
P12
P4
P13
P3
P16
P17
P18
P14
P6
P15
P23
P24
P19
P30
P20
P31
P26
P25
P2
P27
P21
P22
P29
X

48

METAURISTICS

- Improvement
  - Genetic Algorithms (GA)
  - grandient search techniques
  - ………
- Constructive
  - Ant Colony Optimization (ACO)
  - dispatching rule (heuristics)

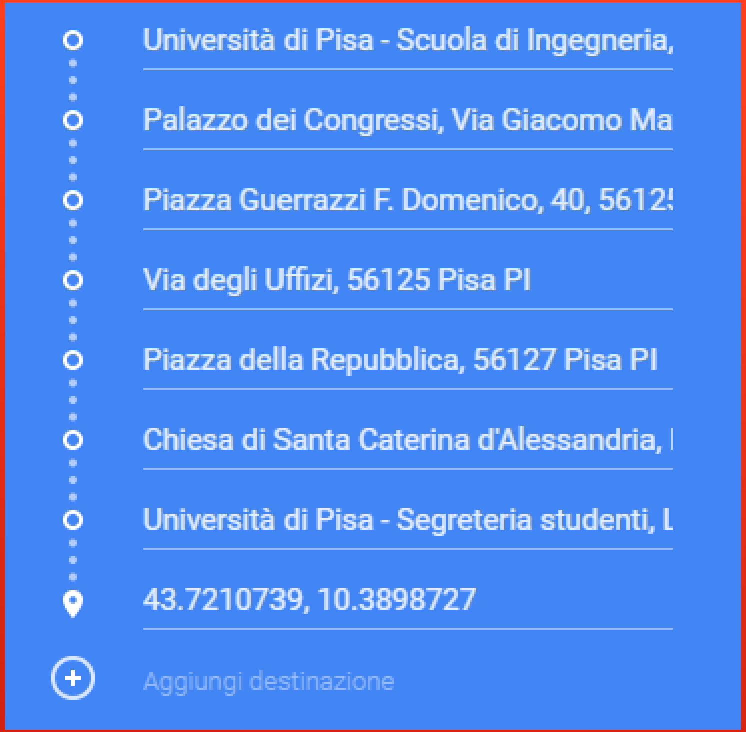
ANT COLONY OPTIMIZATION

a constructive approach

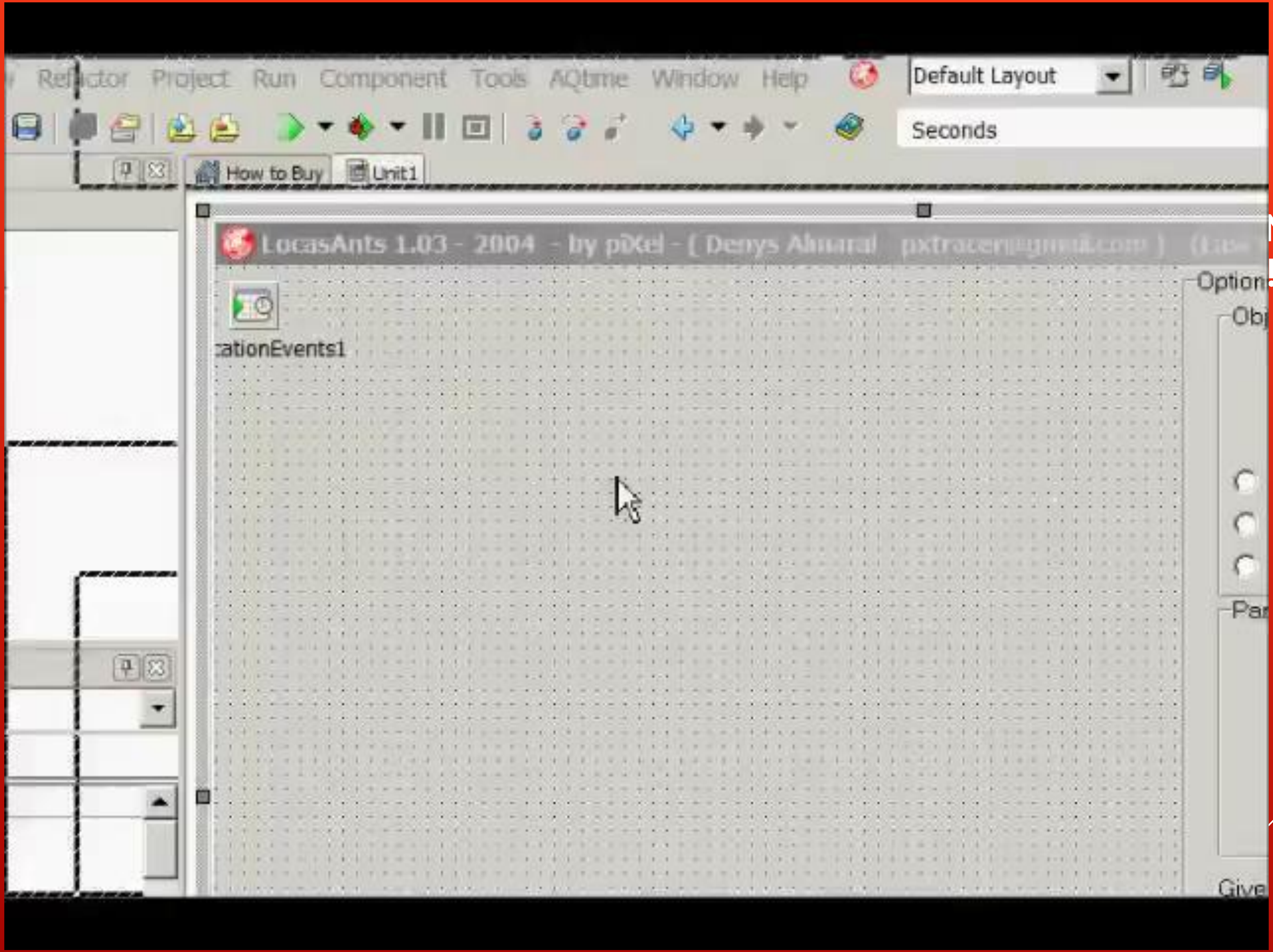
BIKE SHARING PISA

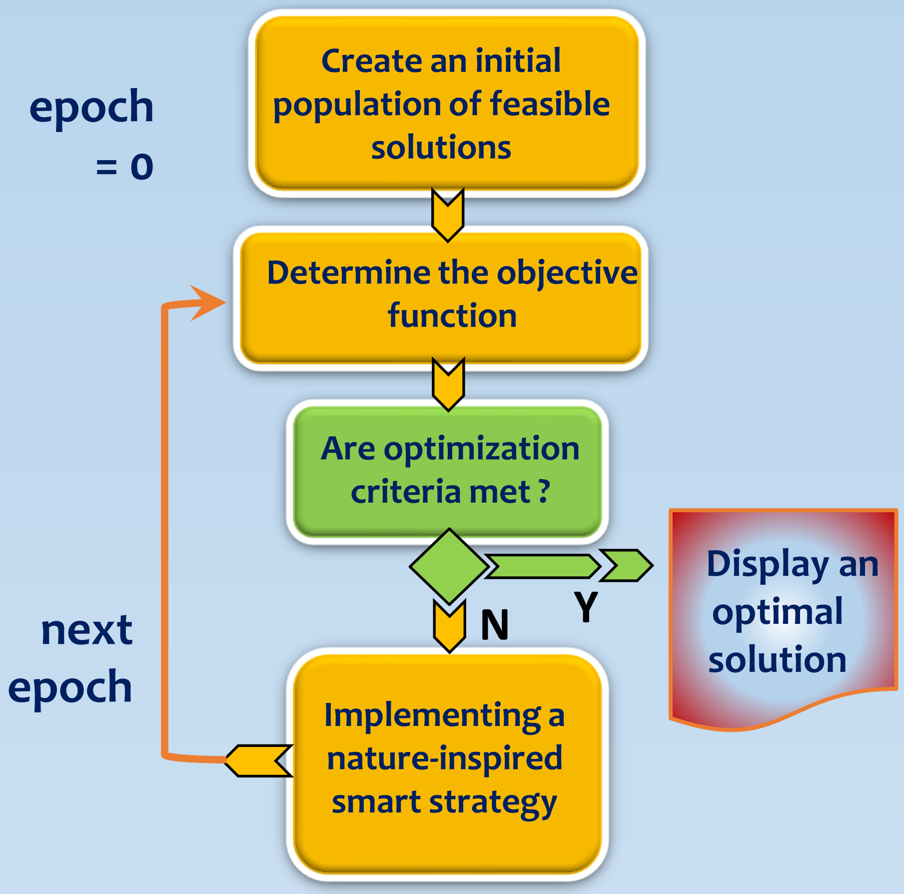
- Università di Pisa - Scuola di Ingegneria,
- Piazza Guerrazzi F. Domenico, 40, 5612!
- Palazzo dei Congressi, Via Giacomo Ma
- Via degli Uffizi, 56125 Pisa PI
- Piazza della Repubblica, 56127 Pisa PI
- Chiesa di Santa Caterina d'Alessandria, l
- Università di Pisa - Segreteria studenti, l
- 43.7210739, 10.3898727
- Aggiungi destinazione


Stadio Arena Garibaldi - Romeo Anconetani
Via Lucchese
San Giul
Via Contessa Matilde
Via A. Paparelli
SS12
Piazza del Duomo
Torre di Pisa
Pisa
Via Vittorio Veneto
Piazza Martiri della Libertà
Piazza dei Cavalieri
Via S. Giovan
Via Bonanno Pisano
1 h 32 min
7,4 km
Lungarno Gambacorti
Via degli Uffizi
Lungarno Mediceo
Lungarno Galileo Galilei
Giardino Scotto
Arno
Tuttomondo di Keith Haring
Piazza Guerrazzi F. Domenico, 40
Palazzo dei Con

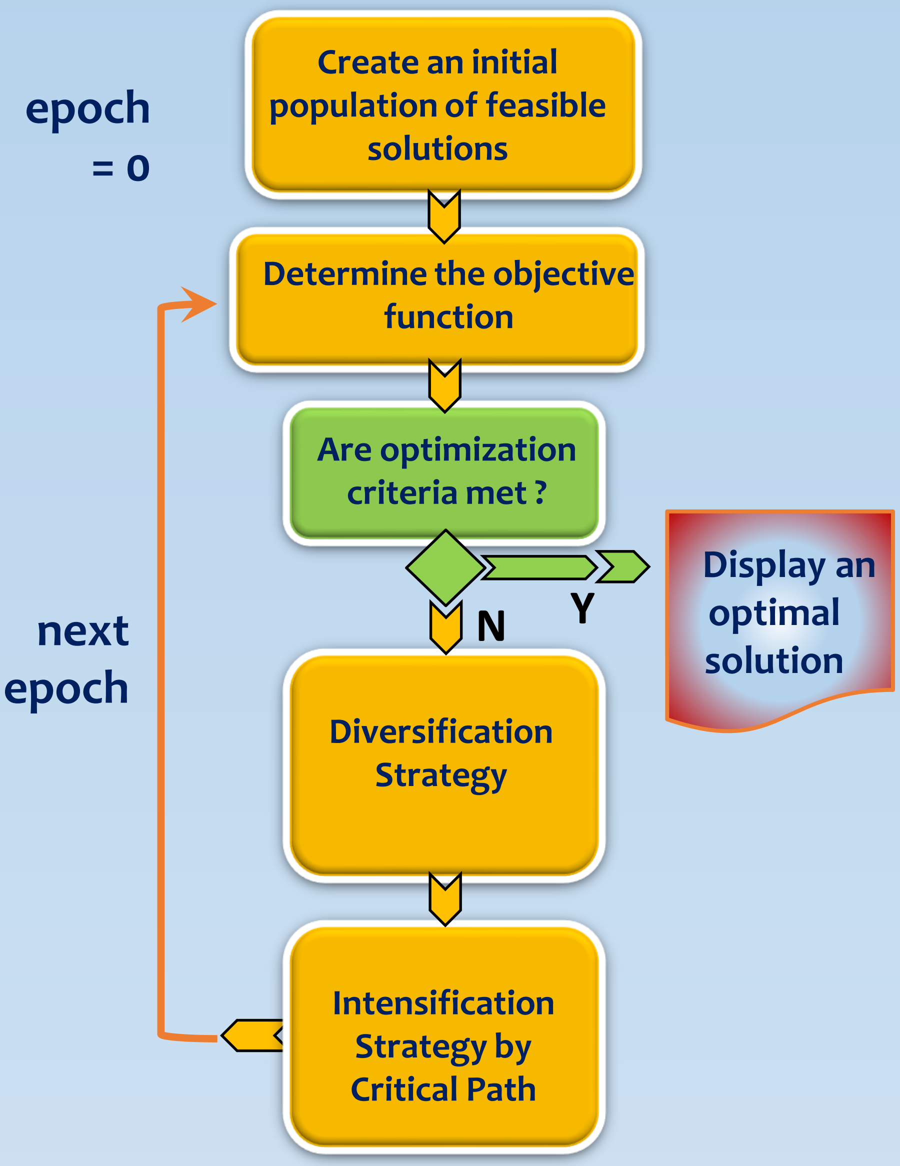

Università di Pisa - Scuola di Ingegneria,
Palazzo dei Congressi, Via Giacomo Ma
Piazza Guerrazzi F. Domenico, 40, 5612
Via degli Uffizi, 56125 Pisa PI
Piazza della Repubblica, 56127 Pisa PI
Chiesa di Santa Caterina d'Alessandria,
Università di Pisa - Segreteria studenti,
43.7210739, 10.3898727
Aggiungi destinazione

ANT COLONY OPTIMIZATION





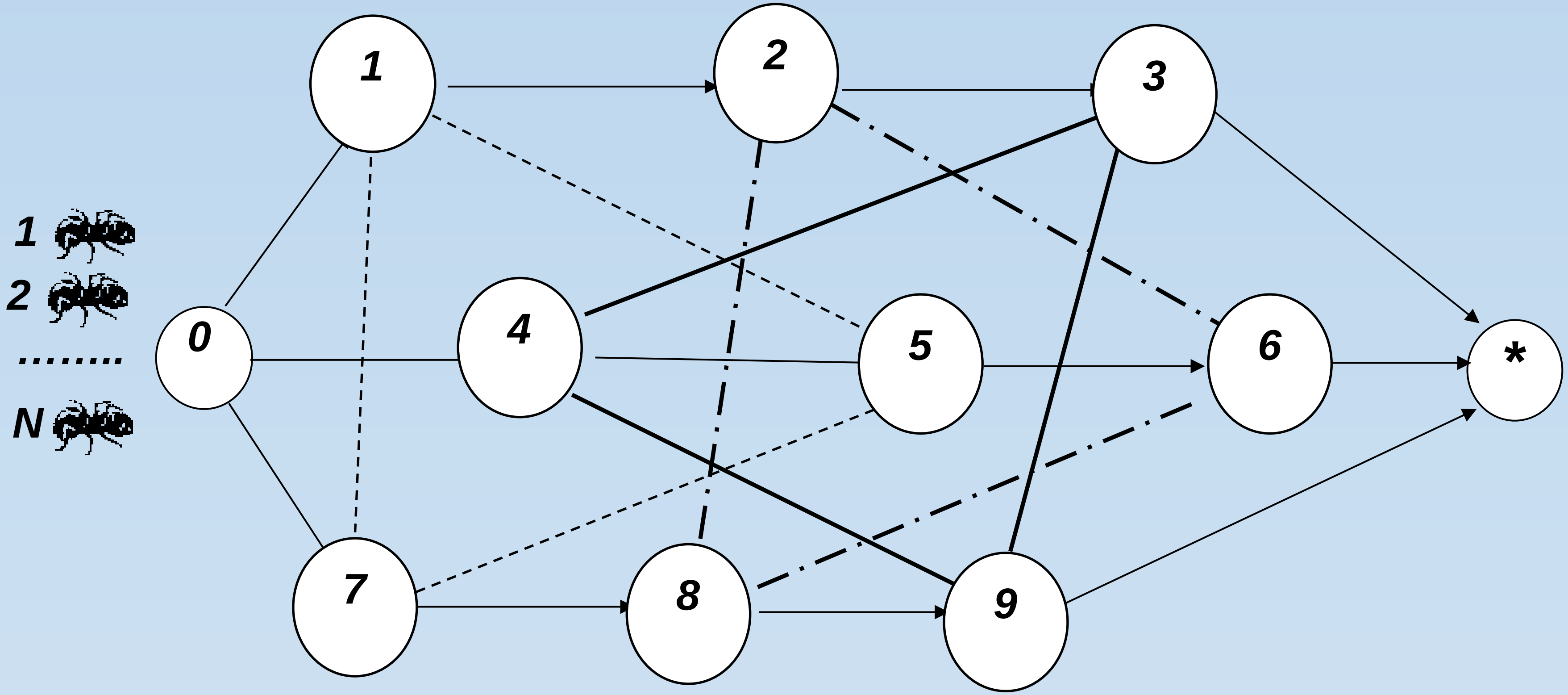
Metauristic algorithm



Ant Colony Optimization

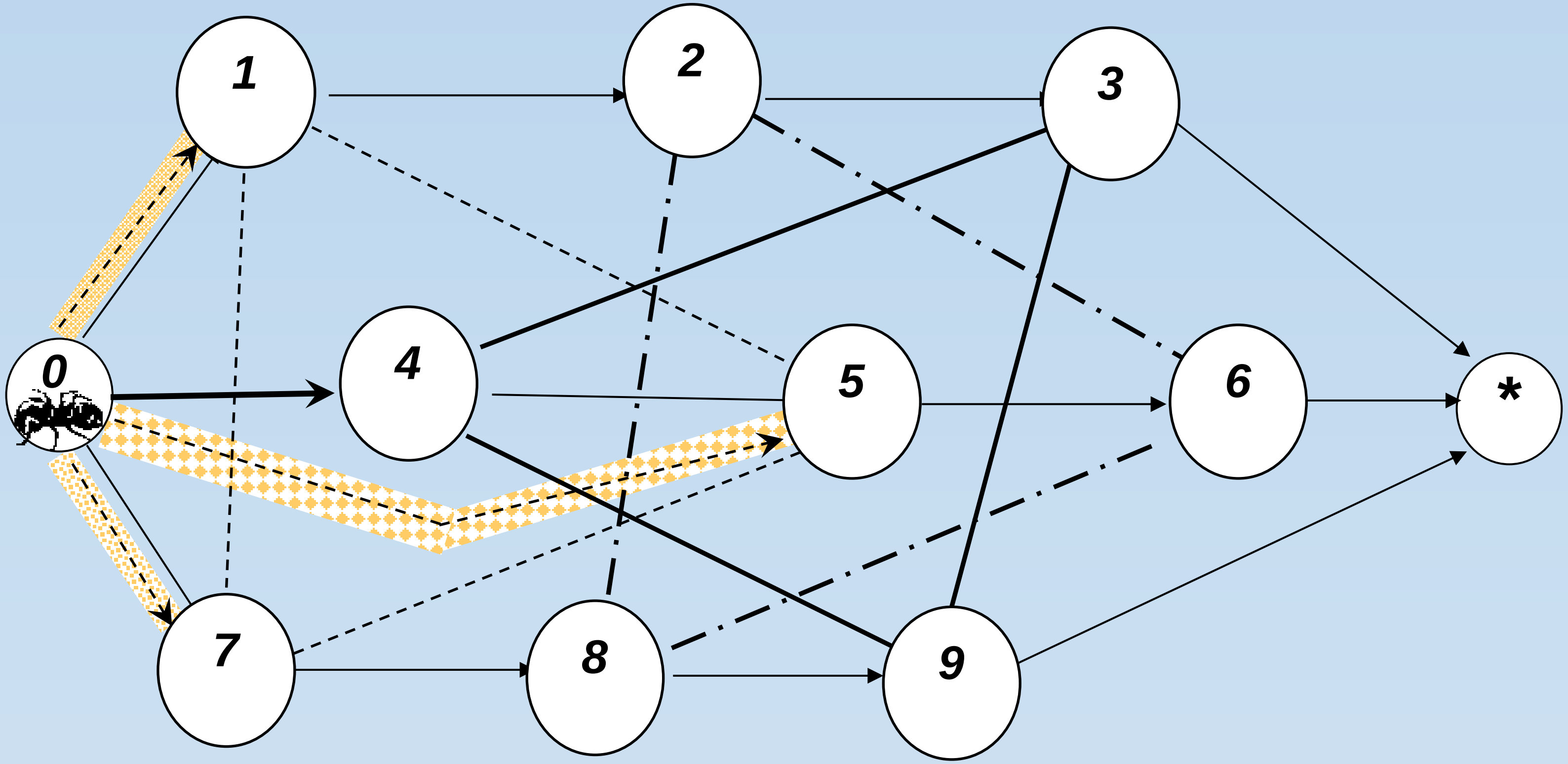
Ant Colony Optimization (AC0)

The system is cyclical: in each cycle, N ants build the feasible source-destination path.



Feromone

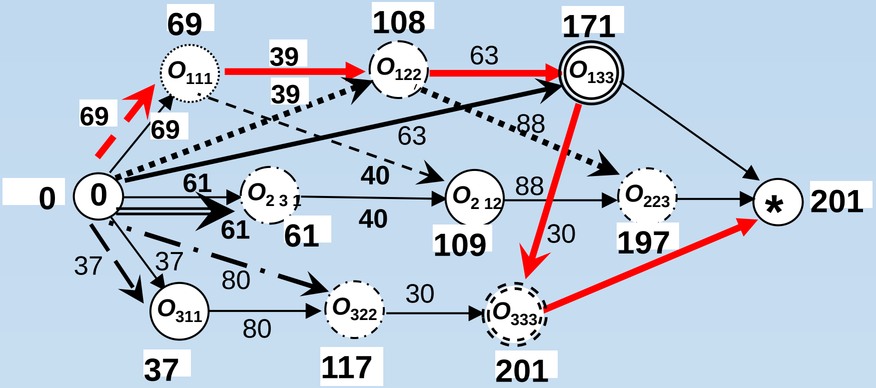
The pheromone values on the edges guide the ant in constructing the path.



Path generation guided by pheromones.

The mechanism by which an ant creates the nest-food path (ant path generation) is the selection of edges at each step, which occurs probabilistically based on the roulette wheel.

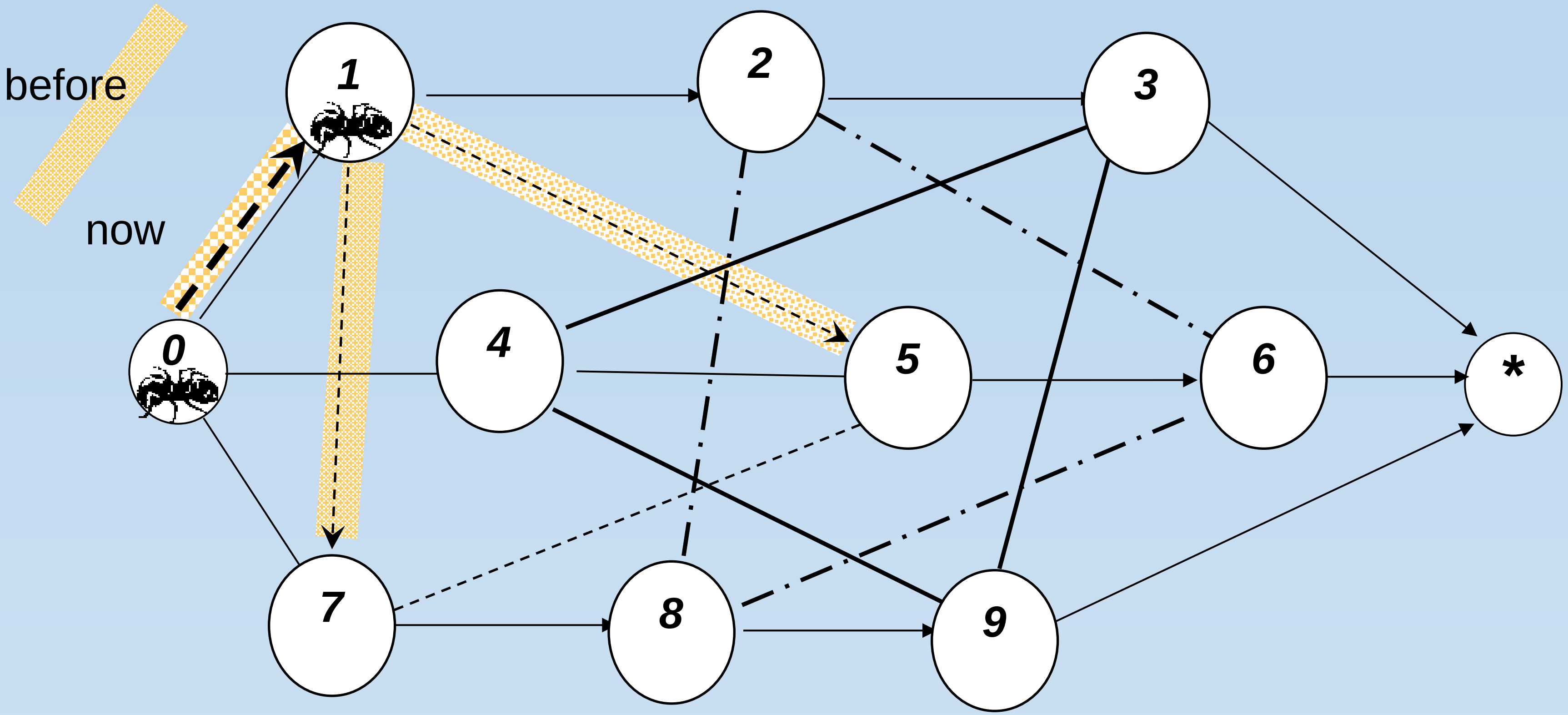
Directed graph representing the solution.



In practice, the nest-food path is represented by the critical path obtained by traversing the graph backward from the destination to the source, and for each node, the longest edge is selected, because the problem is to minimize the objective function. In other words, the ant with the shortest path is the best.

Diversification

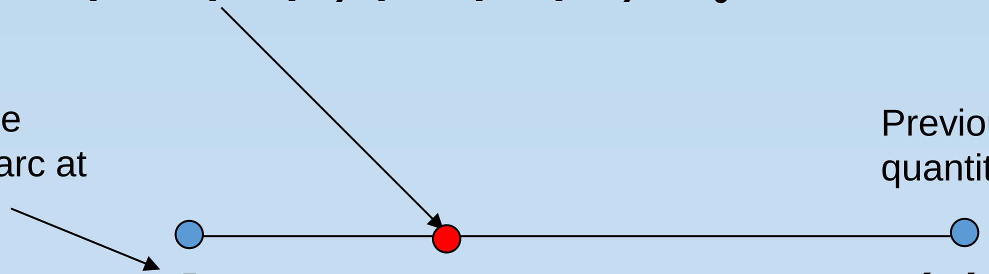
Once an edge is traversed, the pheromone decreases to allow subsequent ants to choose alternative paths



"How is the pheromone decrease on an edge implemented?"

1. In-line update rule: When an edge is selected (oriented), the ant immediately (on-line) deposits an amount of pheromone τ; however, this amount is negative (meaning it is actually evaporation).)

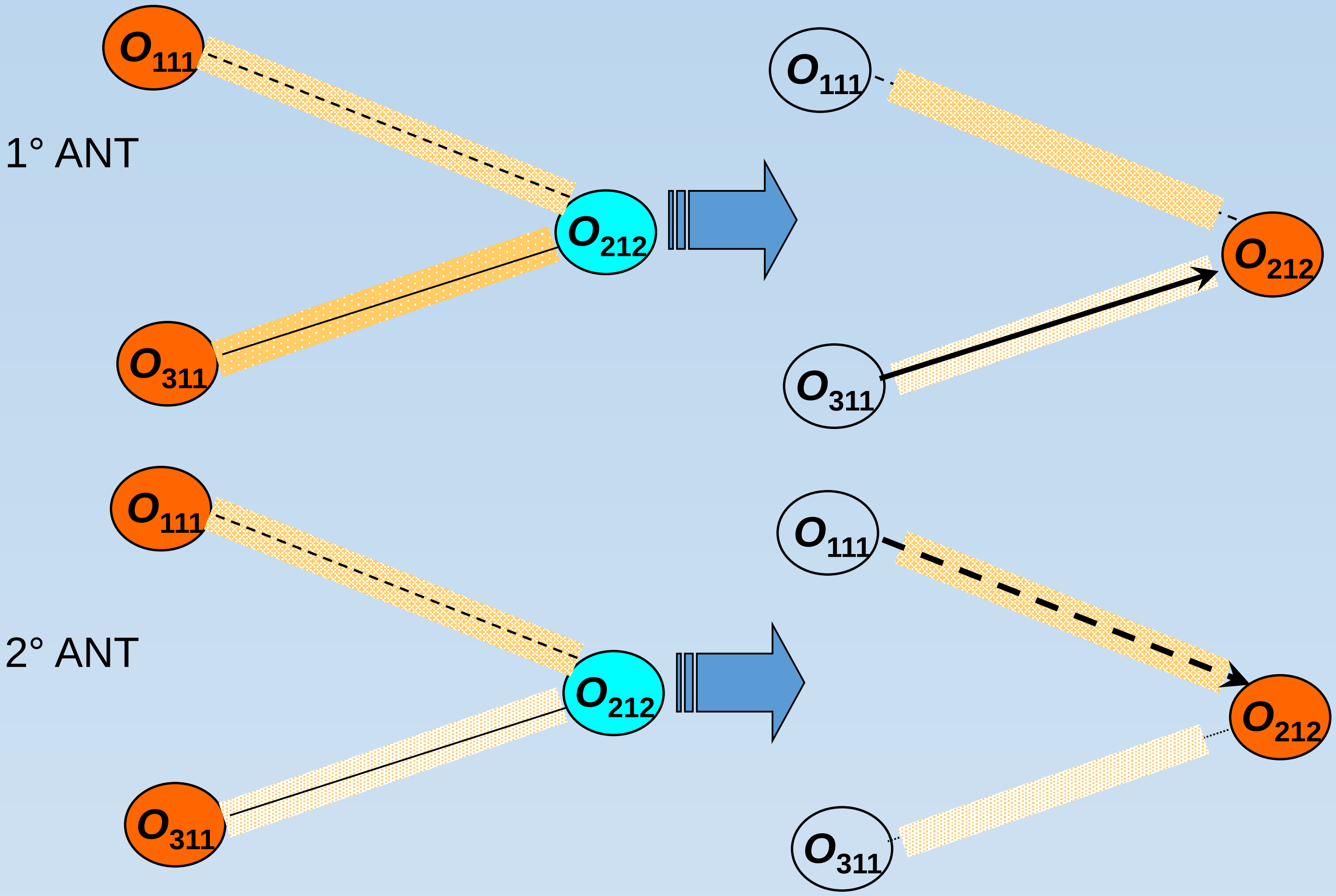
$$\tau\ (NEW) = (1-\rho) \cdot \tau\ (old) + \rho \cdot \tau_0$$



Is a convex combination τ_0 e τ (*old*) because ρ ***is between 0 and 1***

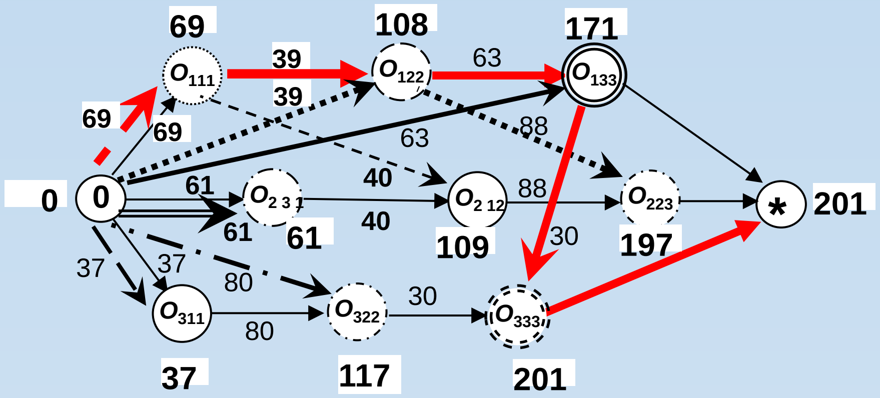
Thus, by the definition of convex combination, it is between the two points and, in particular, is smaller than the pheromone that was there before, τ ***(old)***

diversification mechanism

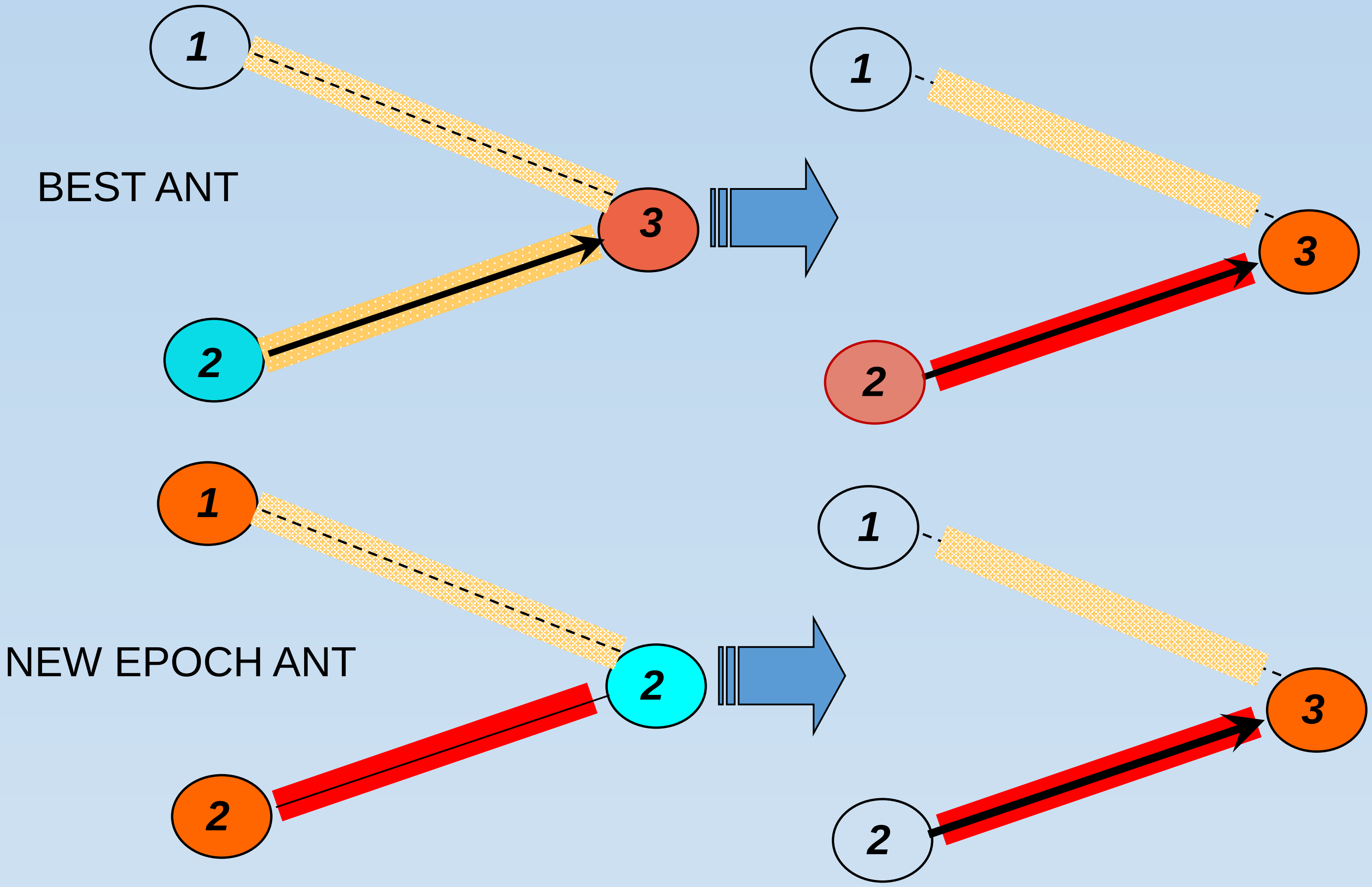


2. ***Off-line update rule:*** *Once all the ants in the colony have created their paths, a reward is given to the ant that found the shortest critical path, which consists of depositing a positive amount of pheromone backward (off-line)* **τ**

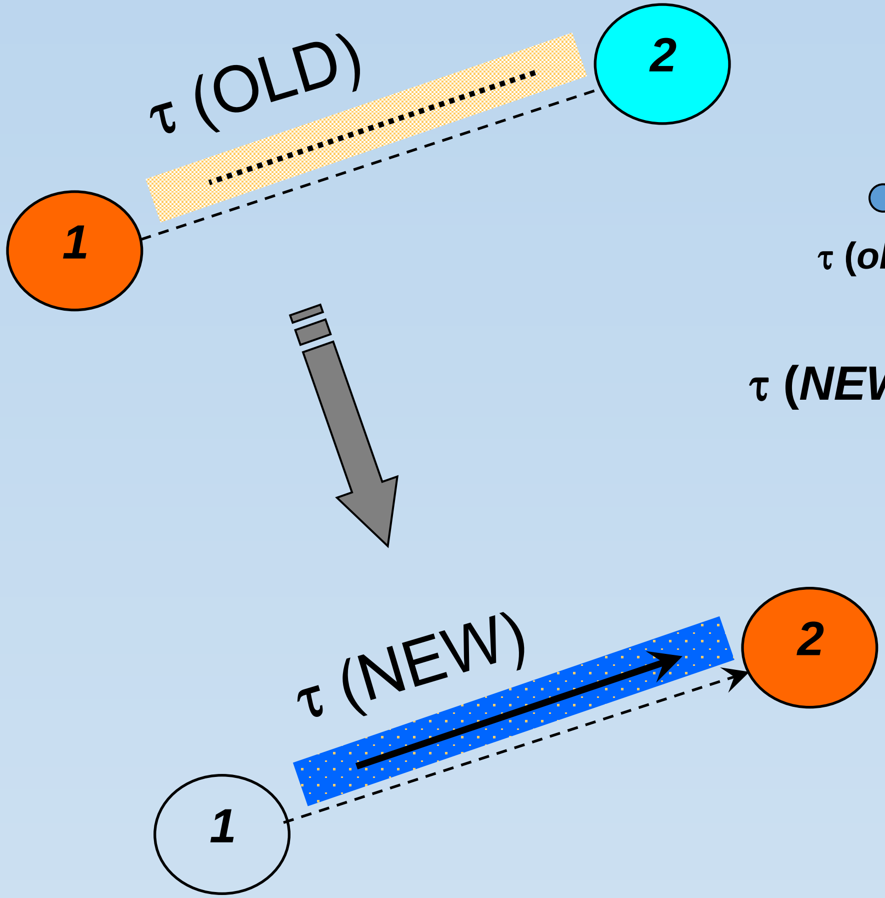
On the critical path pheromone is incremented



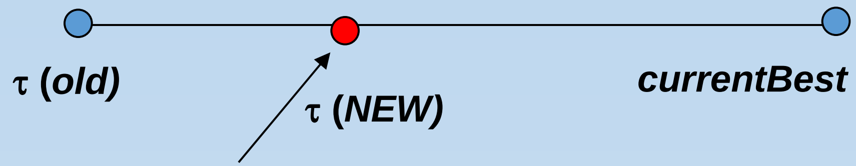
intensification mechanism



INTENSIFICAZIONE



Is a convex combinationof the points ***currentBest and*** **τ(old) [*1,2*]**
because ρ ***is between 0 and 1***



$$\tau\,(NEW) = (1-\rho)\cdot\tau\,(old) + \rho\cdot currentBest$$

$$0 \leq \rho \leq 1$$

Thus, by the definition of convex combination, it is between the two points and, in particular, is greater than the

pheromone that was there before, **τ (old)**

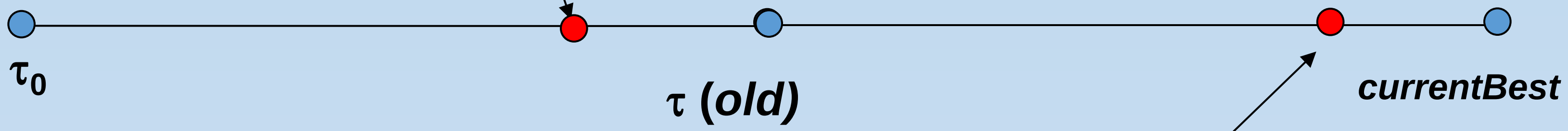
Pheromone control mechanism

(parameter ρ)

τ (*new*) = (1-ρ) · τ (*old*) + ρ · τ_0

On-line update rule

diversification



Off-line update rule

intensification

τ (new) = (1-ρ)· τ (*old*) + ρ · *currentBest*

Peculiarities of ACO system

An Ant Colony Optimization extends the pioneering Ant Systems (AS, which are thus a special case of Ant Colony) with the following components:

- **Candidate List (CW)**: The next edge to be oriented (move) is not chosen from all possible candidates but only from a restricted subset (e.g., only those of ready machines and not those currently in use).
- **Diversification Rule (DR)**: **PHEROMONE EVAPORATION ON THE CHOSEN EDGE** (ON-LINE pheromone update rule).
- **Intensification Rule (IR)**: An off-line update is performed by the only ant holding the shortest critical path after the entire colony has passed (OFF-LINE pheromone update rule).
- **Local Search (LS)**: Each path generated by an ant is modified by swapping edges according to a strategy that works only in the neighborhood of the critical path, until the best in the neighborhood (i.e., the shortest critical path) is found.

REVIEW OF THE MAIN HARD PROBLEMS
PRODUCTION ENGENEERING OPTIMIZATION

Production planning in a variety of flexible flow line

Design For Scheduling (Fully-developed process planning)

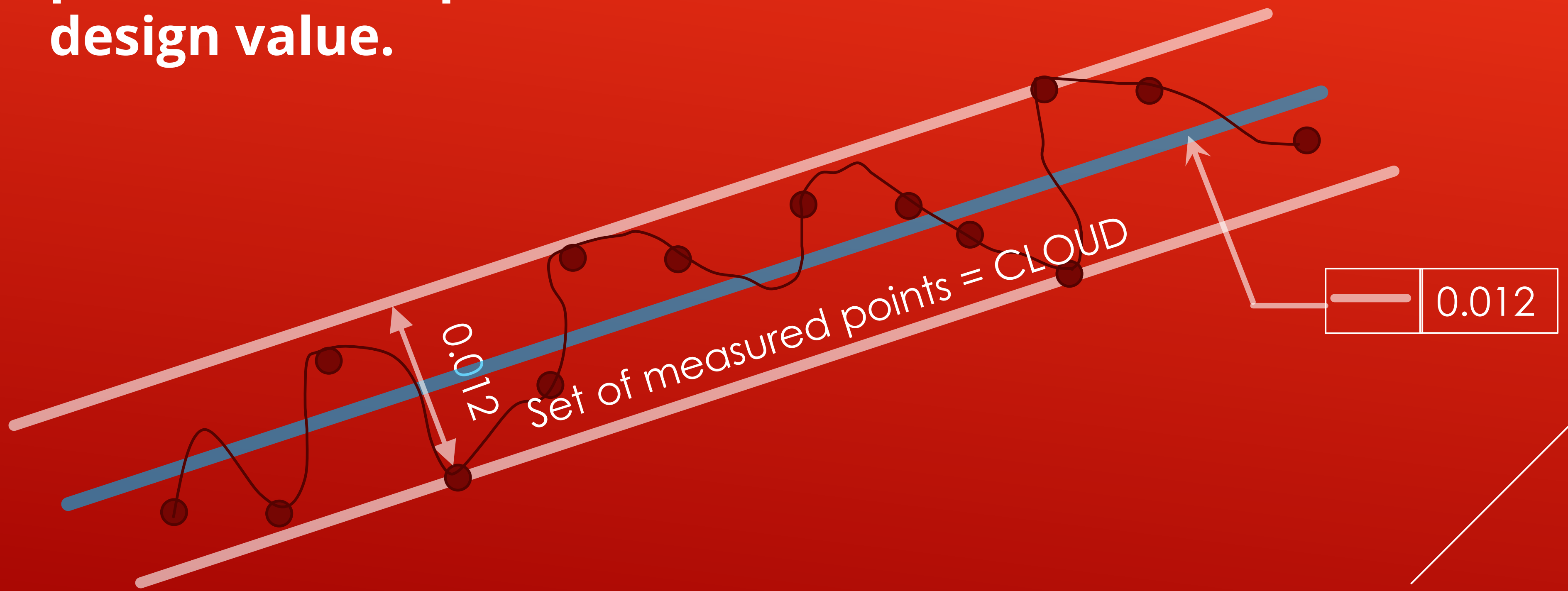
Dynamic Scheduling

The Peg-In-Hole Problem

Surface inspection in accordance with ISO

The ISO measure is the minimum distance between two parallel geometries that contain all the points of the geometry considered in the design.

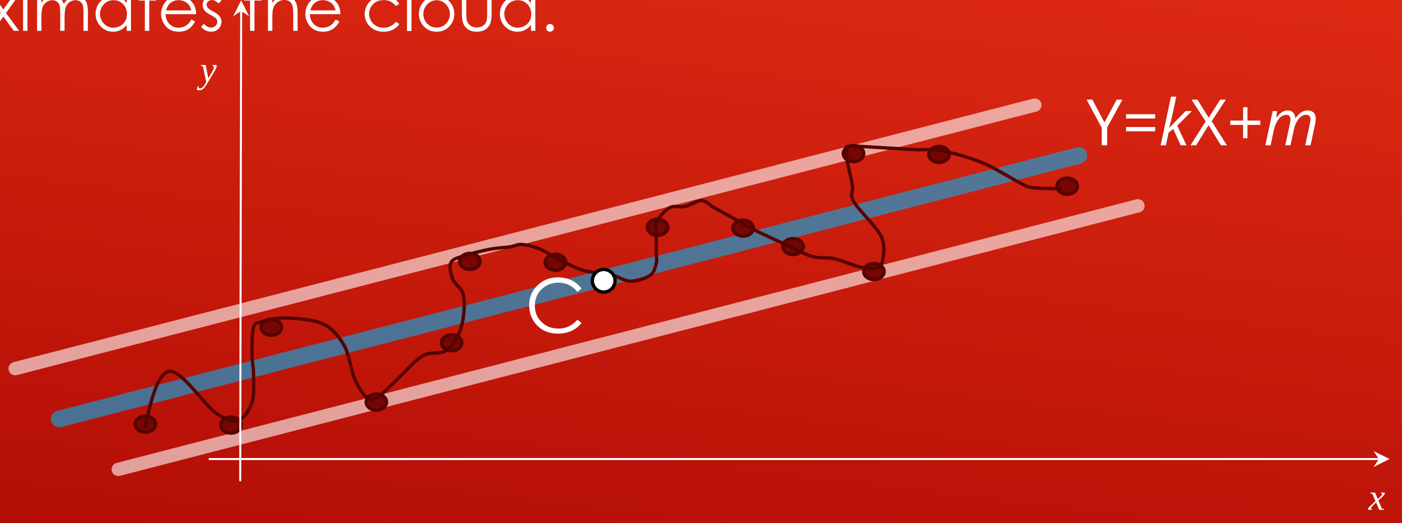
The tolerance on the shape obtained from the manufacturing process is accepted if the measured value falls within the design value.



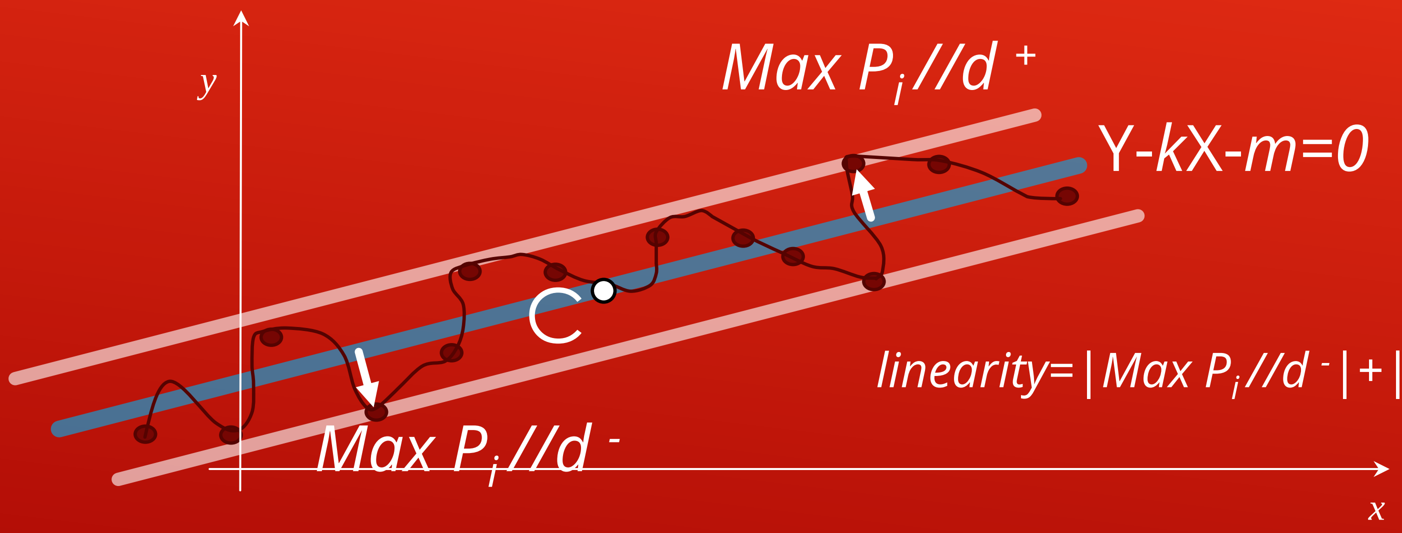
Each datapoint cloud can be approximated by a geometry passing through its centroid C (or center of mass).

In the case of linearity, the geometry is a line $Y=kX+m$

The distance between the line and the two opposite points of the cloud gives us an error indicating how well the line approximates the cloud.

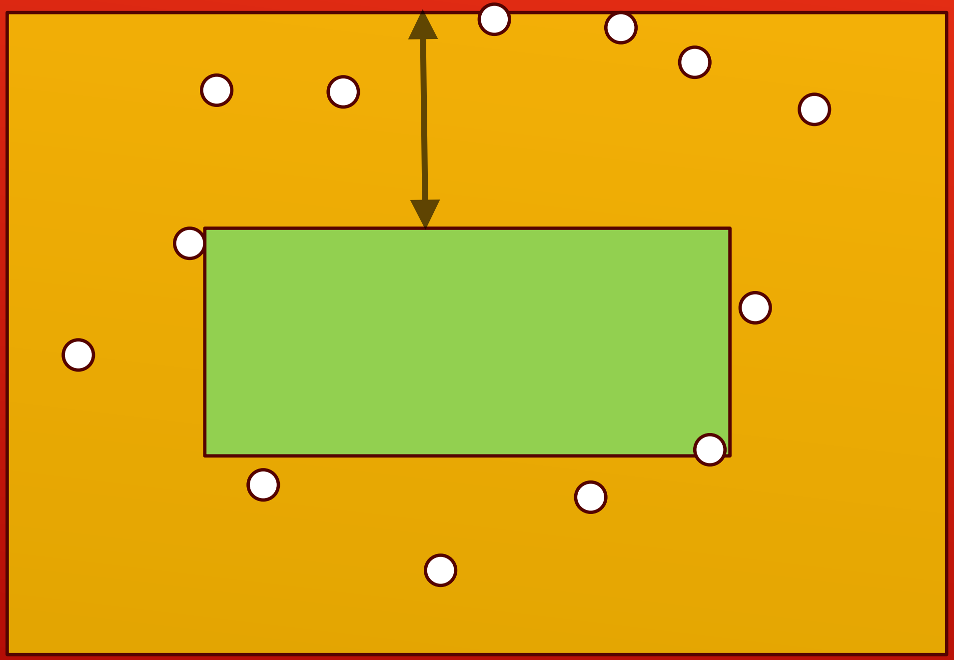


Among all the infinite lines passing through C, there is one that minimizes the error and therefore BETTER APPROXIMATES THE CLOUD.
This error is the LINEARITY, and it can be compared with the tolerance indication expressed in the design.

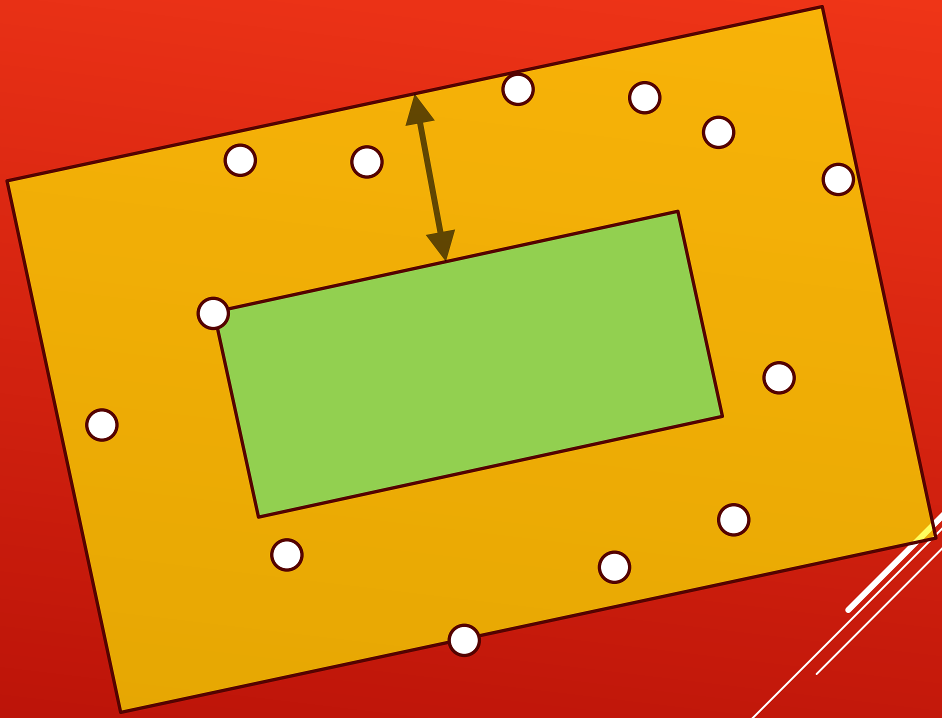


First problem (measure of closed features)

The set of deviations produced on the part could modify the shape parameters of the geometry. It is as if the part on the measuring table is not aligned with the reference system of the measuring machine.



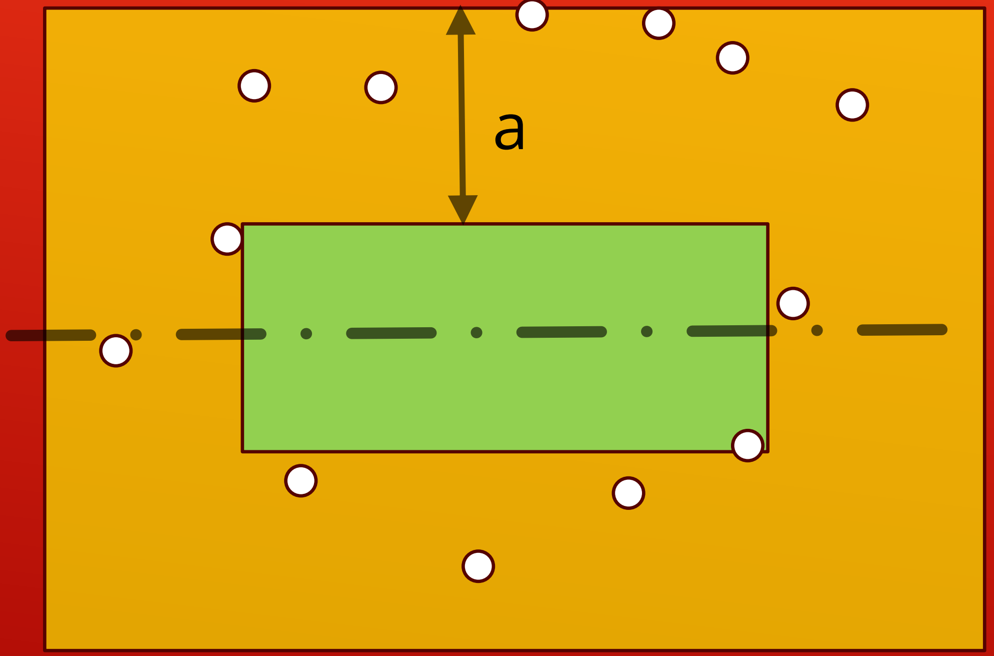
Measures in the machine reference frame



Alignment with measurements correction

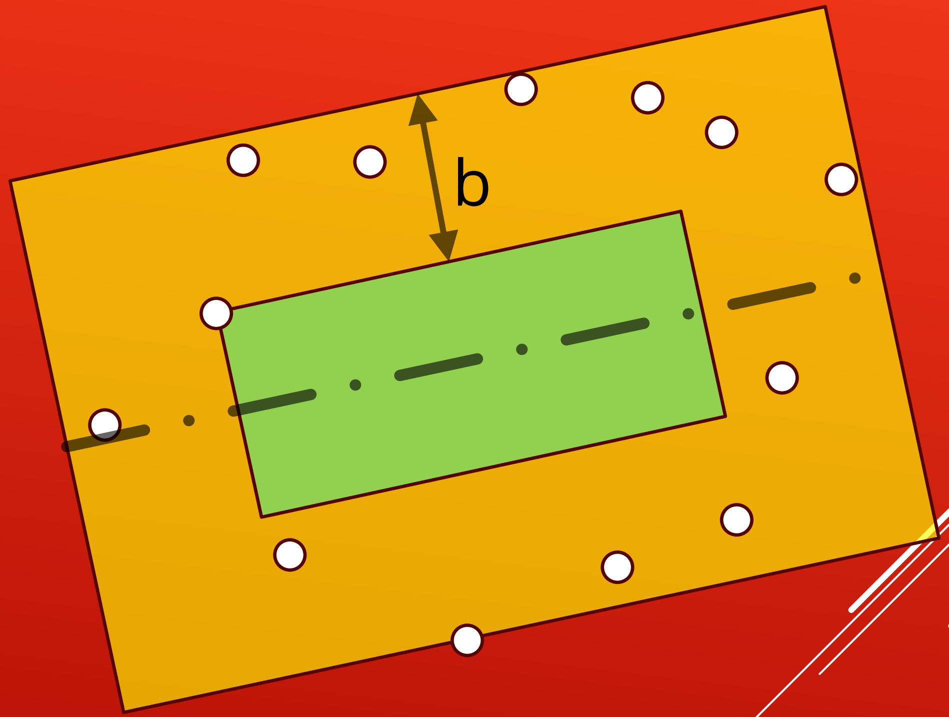
ISO Problem = Optimization Problem

Find the axis of the cloud that minimizes the distance between the two parallel geometries that contain the cloud.



Generic axis of the cloud

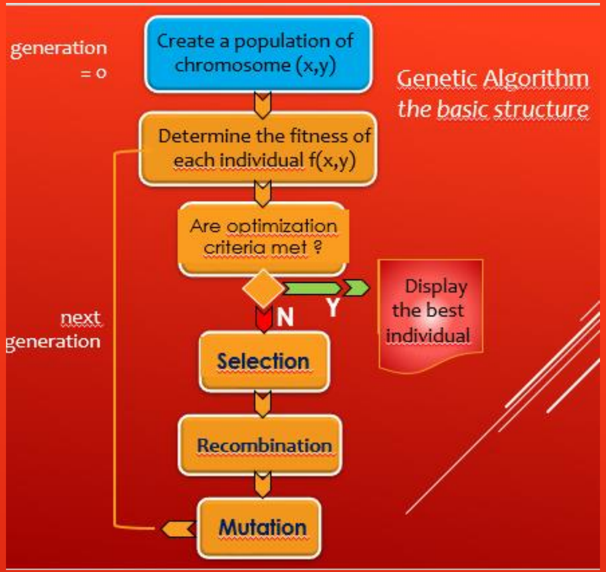
Y = k X + m   f(Y) = a



Principal axes of inerti of the cloud

Y = k ' X + m '   f(Y) = b < a

PROBLEM MODEL (CHROMOSOME)



- Orographic Optimization: $(x,y) \subset \Re^2$ (i.e. 2D)
- ISO Rectangularity: $(k,m) \subset \Re^2$ (2D)

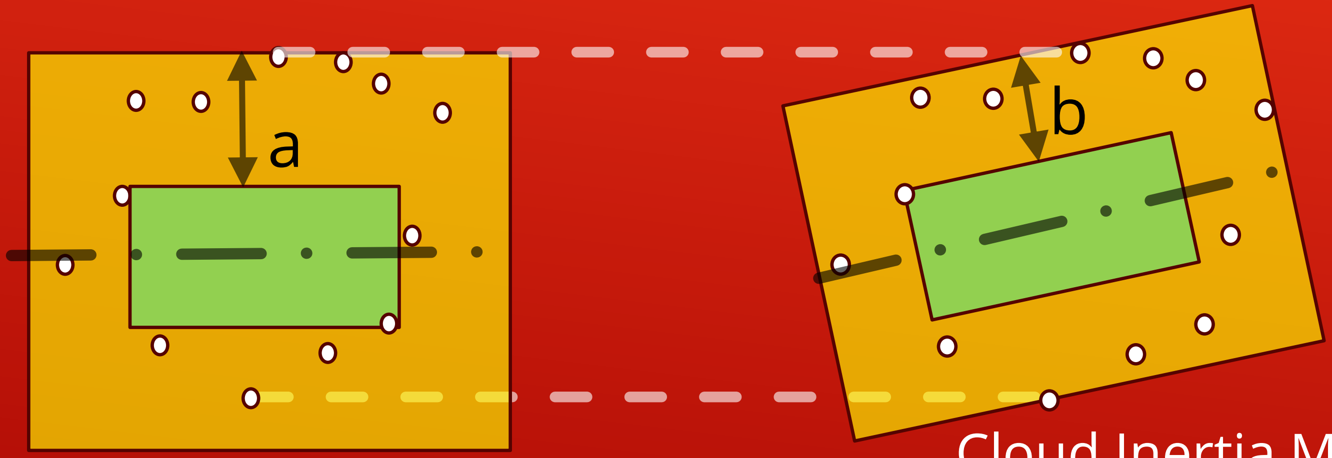
The ISO-tolerance Problem = Optimization Problem

OE **(k,m) = outer height vs Inertia main axis**

IE **(k,m) = inner height vs Inertia main axis**

$$\min \; OE(k,m) - IE(k,m)$$

$$(k,m) \in [-\infty, +\infty] \times [-\infty, +\infty] = \Re^2$$



Generic Axis

I **(k,m)** = k X + m

$f(k,m)$ = *OE* (k,m) - *IE* (k,m) = a

Cloud Inertia Main Axis

I **(k',m')** = k' X + m'

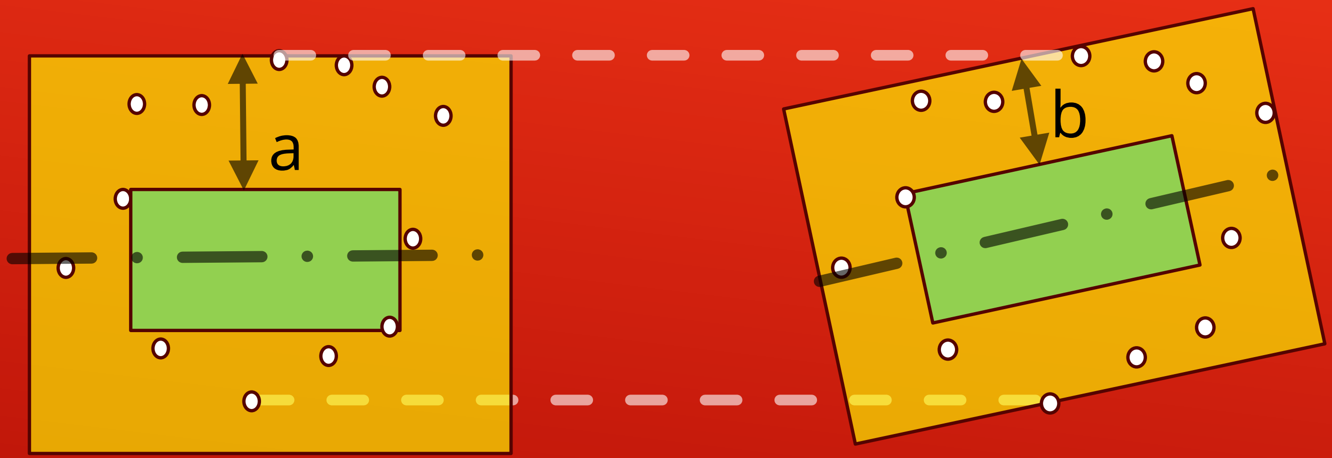
$f(k',m')$ = *OE* (k',m') – *IE* (k',m') = b < a

The ISO-tolerance Problem

$l\,(k',m')$ = Inertia main axis

$OE\,(k',m')$ = max $_{i=1,\ldots,n}$ $|(x,y)_i - l\,(k',m')\,|$, point-to-axis distance

$IE\,(k',m')$ = min $_{i=1,\ldots,n}$ $|(x,y)_i - l\,(k',m')\,|$



Cloud Inertia Main Axis

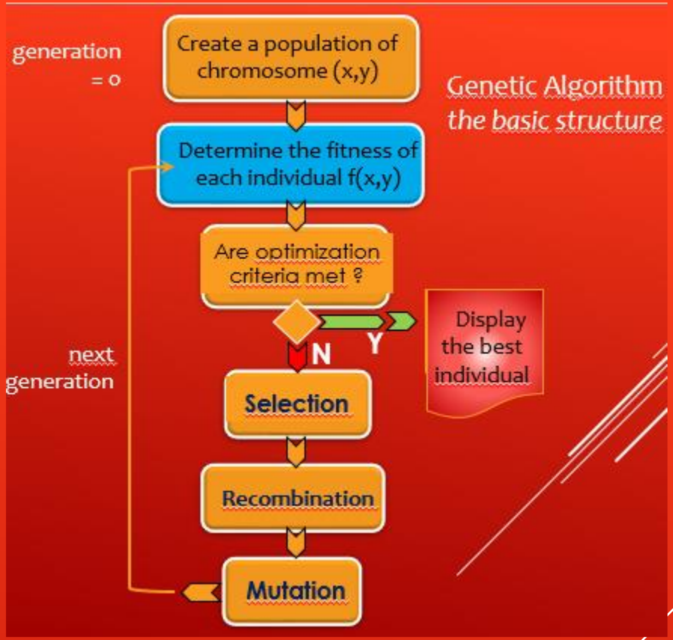
$\boldsymbol{l\,(k,m)} = k\,X + m$

$\boldsymbol{f\,(k,m)} =$ max $_{i=1,\ldots,n}$ $|(x,y)_i - l\,(k,m)\,|$ **-** min $_{i=1,\ldots,n}$ $|(x,y)_i - l\,(k,m)\,|$ **= a**

$\boldsymbol{l(k'm')} = k'\,X + m'$

$\boldsymbol{f\,(k',m')} =$ max $_{i=1,\ldots,n}$ $|(x,y)_i - l(k',m')\,|$ **-** min $_{i=1,\ldots,n}$ $|(x,y)_i - l(k',m')\,|$ **=** $b < a$

OBJECTIVE FUNCTION(FITNESS, ADAPTATION)



- Orographic Optimization: $f(x,y) = z$
- ISO Rectangularity:
  $f(k,m) = \max_{i=1,\dots,n} |(x,y)_i - l\,(k,m)| - \min_{i=1,\dots,n} |(x,y)_i - l\,(k,m)|)$