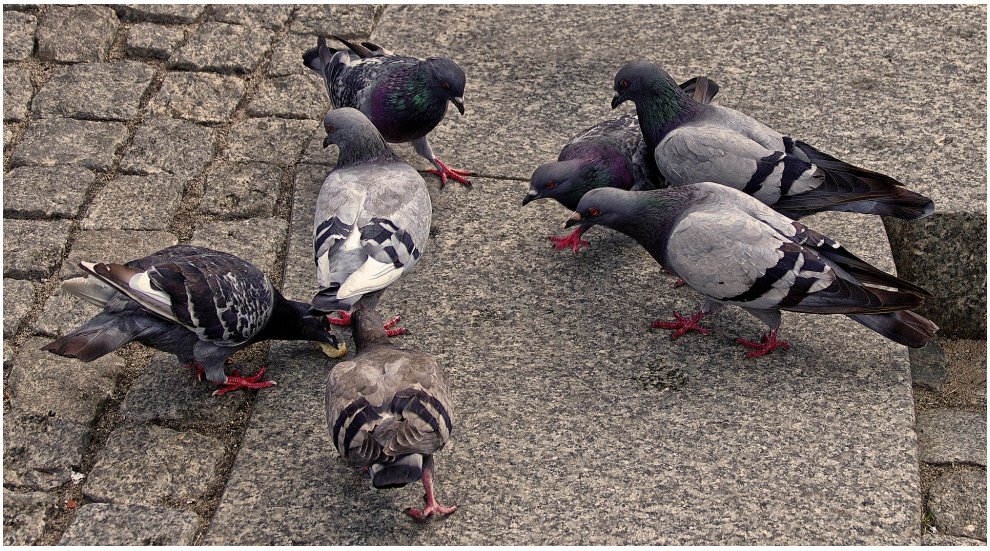

PUPIReal

A tool for numeric function optimisation
inspired in the behaviour of urban pigeons

User Guide

Version 1.16

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Bogotá, Colombia

Overview

PUPIReal is a software tool designed to find approximate solutions to optimisation problems whose decision variables take numeric values in the real domain. The method used by PUPIReal to find a solution, is inspired in the foraging behaviour or urban pigeons, adapted to the framework of agent–based models. The idea behind is to simulate a flock or swarm of artificial pigeons that explore an input space, so as to discover regions with promising sources of food, that is, regions representing suitable approximate solutions for the optimisation problem.

The approach of solving an optimisation problem with a swarm of artificial agents undergoing an adaptation process is known as Swarm Intelligence algorithm. Instead of using mathematical analysis of aggregated variables describing the phenomena, this approach resorts to modelling the interaction of a group of individuals in a simulated environment and trace the evolution of such variables as the simulation progresses. In this way, PUPIReal assumes that global information about the problem emerges as an intrinsic property of the evolution of the algorithm, which can not be explained away by isolated contributions of single agents. In addition, visual inspection of the emerging patterns of pigeons flocking and wandering, in response to changes in the simulation parameters, can give useful insights regarding the hidden particularities of the problem.

PUPIReal v1.16 has been released under GNU General Public License (GPLv3); it is available online at:

http://modelingcommons.org/browse/one_model/6390

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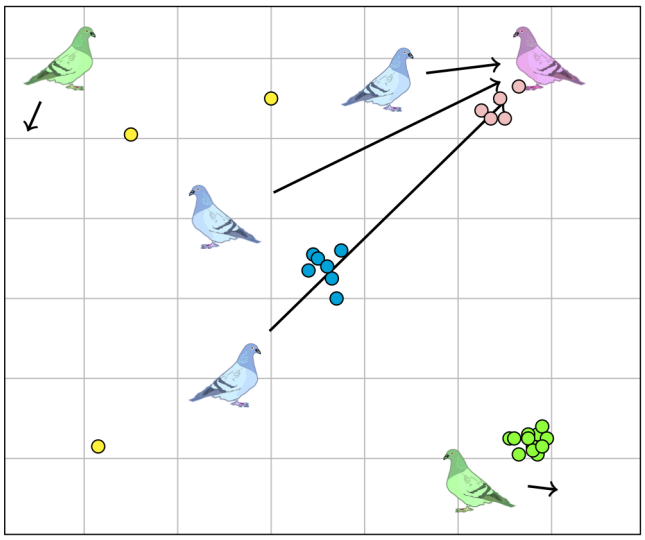
Chapter 1

The optimisation tool

1.1 What is PUPIReal?

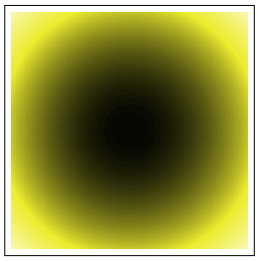
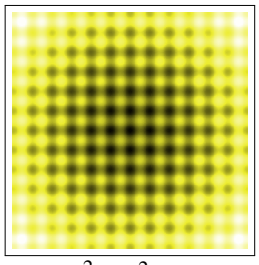
PUPIReal is a software tool developed as an agent-based model of a recently introduced swarm-based search algorithm for numeric real-valued unconstraint optimisation, inspired in the foraging behaviour of urban pigeons (see [1] for details). The tool is intended to find valuable areas or spots in a simulated optimisation landscape, by mimicking how pigeons manage to discover sources of food as they navigate their natural territories, i.e urban parks. The landscape obeys to the variation of a cost function evaluated in the different coordinates of the search space (here, a 2D space).

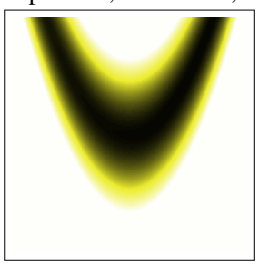
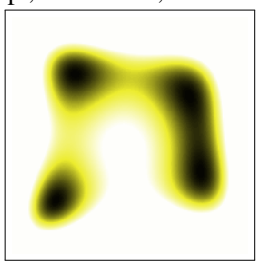
The software considers three distinct pigeon roles or agent types: a leader, who is the pigeon located at the richest source of food at any moment during the simulation (coloured fuchsia), the followers, who are pigeons pursuing the leader in the hope of getting a share of his food (coloured blue), and the walkers, who are pigeons wondering around aimlessly but with an eye looking for food too (coloured green).

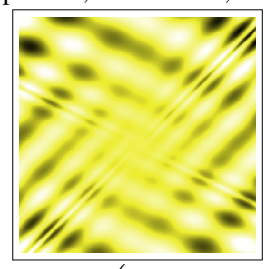
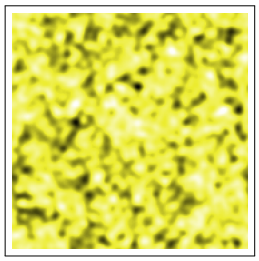


1.2 How it works

The numeric optimisation problem is determined by the LANDSCAPE that is obtained as a discrete projection of the real-valued cost function onto the 2D grid of cells comprising the simulation view area. The set of benchmark LANDSCAPEs available in the tool are described next. We provide the name, characteristics, 2D surface plot, function definition, range, optimal solution and optimal cost for each problem:

SPHERE	RASTRIGIN
Separable, Unimodal	Separable, Multimodal, Local minima
	
$f(\mathbf{x}) = x_1^2 + x_2^2$	$f(\mathbf{x}) = 20 + \sum_{i=1}^{2}(x_i^2 \quad 10cos(2\pi x_i))$
$6 < x_1; x_2 < 6$	$6 < x_1; x_2 < 6$
$\mathbf{x}^? = (0;0)$; $f(\mathbf{x}^?) = 0$	$\mathbf{x}^? = (0;0)$, $f(\mathbf{x}^?) = 0$

ROSENBROCK	HIMMELBLAU
Non-Separable, Unimodal, Valley	Non-Sep., Multimod., Non-local min.
	
$f(\mathbf{x}) = 100(x_2 \quad x_1^2)^2 + (1 \quad x_1)^2$	$f(\mathbf{x}) = (x_1^2 + x_2 \quad 11)^2 + (x_1 + x_2^2 \quad 7)^2$
$6 < x_1; x_2 < 6$	$6 < x_1; x_2 < 6$
$\mathbf{x}^? = (1;1)$	$\mathbf{x}^? = \begin{cases} (3;2); (2{:}81; 3{:}28) \\ (3{:}78; 3{:}28); (3{:}58; 1{:}85) \end{cases}$
$f(\mathbf{x}^?) = 0$	$f(\mathbf{x}^?) = 0$

EGGHOLDER	RANDOM (example)
Non-Separable, Multimodal, Local min.	Separable, Multimodal, Local min.
	
$f(\mathbf{x}) = \quad x_1 \sin\left(\sqrt{jx_1 \quad (x_2+47)j}\right)$ $(x_2+47)\sin\left(\sqrt{j0{:}5x_1 + (x_2+47)j}\right)$	$f(\mathbf{x}) \quad \mathcal{N}((0;0);500)$
$512 < x_1; x_2 < 512$	$6 < x_1; x_2 < 6$
$\mathbf{x}^? = (512; 404{:}23)$, $f(\mathbf{x}^?) = \quad 959{:}64$	$\mathbf{x}^?$: not fixed (on-the-fly)

Hence, pigeons will "search for food" in the projection of said landscape into the 2D view area, where the spots with lower values are shown black in the landscape, whereas the higher values are shown white, and middle values are shown in shades of yellow. Since the purpose of the model is optimisation, the goal is to discover a spot which optimises the value of the cost function evaluated at the coordinates of each cell. Notice that in the current version the algorithm minimises, that is, it searches for a spot with the lowest cost function value.

The main elements taken into account during the design of the tool are given next:

Purpose. The tool is intended to mimic the behaviour of urban pigeons while foraging for sources of food, within a simulated optimisation landscape.

Agents. We define three distinct pigeon roles, i.e. agent types: a *leader*, who is the pigeon located at the richest source of food in a given time step in the simulation, the *followers*, who are pigeons pursuing the leader in the hope of getting a share of his food, and the *walkers*, who are pigeons wondering around aimlessly but with an eye looking for food too. The number of pigeons in the population, named POP-SIZE, is kept fixed. The number of walkers is determined as a percentage WALKERS-RATE of the population.

Environment. The landscape where pigeons search for food will be represented as a 2D grid of cells. Since the purpose of the model is optimisation, the goal is to discover the cell with maximum (or minimum) concentration of food, which in turn is obtained by evaluating a cost function at the coordinates of each cell.

Properties. Each pigeon is characterised by a location in the landscape $(x; y)$ and the perceived density of food which is given by a function cost value associated to the LANDSCAPE at such location. The latter in turn defines its *fitness*.

Behaviours. All pigeons in the population can sense who is the leader (that is, we enable a global information-sharing mechanism). Followers will move towards the leader, so their location is updated in the direction of the leader's location. The walkers, in contrast, move randomly in any direction. The size of the steps of followers' and walkers' movements are defined with parameters $0 < \text{ALPHA} < 1$ and $0 < \text{SIGMA} < 1$, respectively. Notice that pigeons may change their roles during their lifetime, depending on their actual fitness.

Input and Output. The input for the model are the cost function to optimise (LANDSCAPE) and the parameters POP-SIZE, WALKERS-RATE, ALPHA and SIGMA. The output is the location of the cell found as the richest source of food, that is, the solution given by the pigeon with best fitness throughout the simulation.

Timeline. The initial location of the population of pigeons is assigned randomly within the boundaries of the landscape. Afterwards, at each time step each pigeon moves according to its role, its fitness is updated, and if needed, the leader is re-assigned.

Language. The software is implemented using the special–purpose ABM developing platform NetLogo 6.1.0 (see [2]).

In summary, each pigeon is characterised by a location $(x; y)$ in the LANDSCAPE and the perceived density of food (or cost) in such location which determines its fitness to solve the problem. Besides, all pigeons in the population can sense who is the leader (that is, we enable a global information-sharing mechanism). Followers will move towards the leader, so their location is updated in the direction of the leader's location. The walkers, in contrast, move randomly in any direction. Pigeons may change their roles during their lifetime as the simulation progresses, depending on their current fitness.

At each step of the simulation performs four simple actions: find the leader, move the followers, move the walkers and update the best solution found so far. These actions correspond to the following routines: FIND-LEADER (chooses as leader pigeon the one having the best fitness and updates the best fitness ever if necessary), FOLLOW-MOVE (moves each follower towards the leader with the step-size ALPHA, plus a random shift in its orientation due to wind or collisions), and WALK-MOVE (moves each walker around randomly with a step-size SIGMA). These two movement rules correspond to the exploration/exploitation mechanisms of the search algorithm (see [1] for more details).

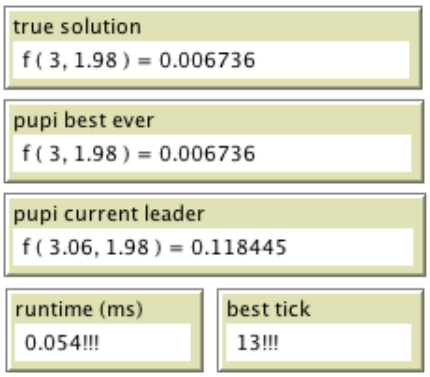
The simulation is terminated either after a maximum number of steps, MAX-STEPS, or when the truth optimal solution is found prematurely.

1.3 How to use it

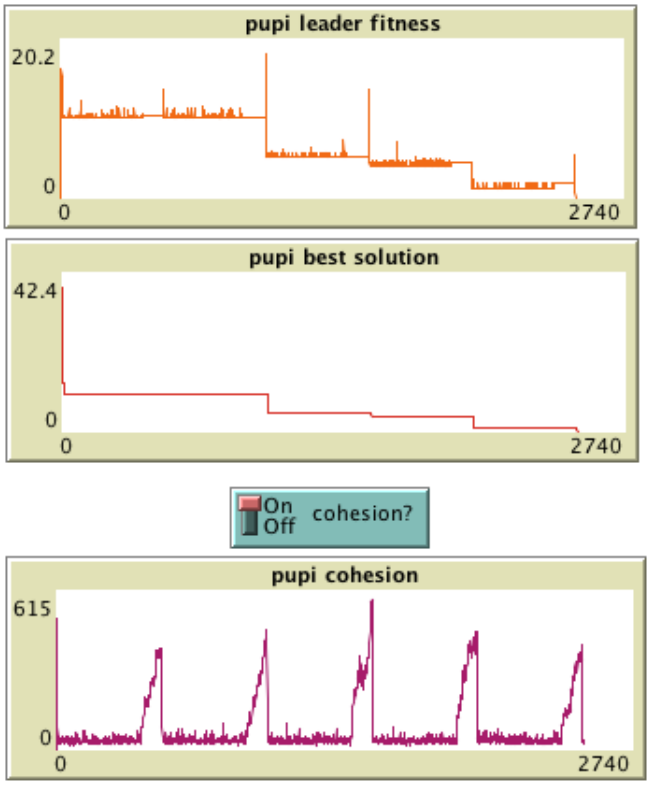
Firstly, from the control panel shown above, choose an optimisation problem to be solved from the LANDSCAPE pull-down list. For any of these problems, then define the appropriate limits of the search space coordinates, namely the XY-BOUNDS. Additionally, define the algorithm parameters POP-SIZE, WALKERS-RATE, ALPHA and SIGMA. You can also set the termination criterion MAX-TICKS. Then press SETUP, then GO.

The initial location of the population of pigeons will be assigned randomly within the boundaries of the landscape. Afterwards, at each time step pigeons move according to its role, the population fitness is updated, and if needed, the leader is re-assigned. The emergent behaviour of the pigeon flock will show up, while they attempt to discover the promising regions within the landscape; the simulation will show the three breeds of pigeons, leader, followers and walkers with different colours (red, blue and red, respectively), see the next image.

The output monitors show the location and cost of the true solution for the problem, the best location and best cost ever found by the algorithm during the simulation, and the location and cost associated to the current leader. If the algorithm is able to find the true solution, then the BEST-TICK and RUNTIME monitors will display a "!!!" sign inserted behind their actual values (see below).



Lastly, the model also outputs the plot of the leader fitness vs time, the plot of fitness of the best solution found vs time and the plot of flock cohesion vs time if the COHESION? switch is enabled. The latter implies an additional cost to the running time, as the model needs to compute distances between all the pigeons in the follower's flock. The plot panel of the tool is shown next.



1.4 Other distinctive features

You can see that the flock of follower pigeons moves out from one local minima to another. This is explained because every certain number of ticks, the entire population become walkers that start looking around for other regions as sources of food. This phenomenon is attested by the fitness variation of the leader pigeon during the simulation timeline, as it can be seen in the corresponding plot. Nonetheless, the best found ever solution always has a decreasing fitness as it can be verified in its respective plot.

Similarly, the transition of the flock from one local minimum location to another is depicted in the periodic patterns that appear in the cohesion plot.

1.5 Try it yourself

The model includes the mathematical expression and projection of a set of widely-known benchmark functions for unconstrained continuous optimisation: SPHERE, RASTRIGIN, ROSENBROCK, HIMMELBLAU, EGGHOLDER (see the definitions in Section 1.2) . In addition to these benchmarks, we defined a RANDOM landscape that is generated on- the-fly with values sampled from a scaled normal distribution; hence, in this problem the real optimum is not known in advance, in contrast to the other functions. Lastly, a seventh benchmark was included, a modified SPHERE with the optimum shifted to the second quadrant. Each problem exhibits different properties (multi-modality, convexity, separability, etc.) and search ranges (we suggest using a XY-BOUNDS of 512 for EGGHOLDER and XY-BOUNDS of 6 for the other problems).

Notice that all the problems produce a constant landscape (except RANDOM), so you can try and see the effect of varying the different parameters. For starters, a typical configuration can be:

POP-SIZE = 20,

WALKERS-RATE = 0.25,

ALPHA = 0.1,

SIGMA = 1,

MAX-TICKS = 10000,

XY-BOUNDS = 6 (or 512 if LANDSCAPE is EGGHOLDER).

If you want to highlight the location of the true solution or the current leader turn on the SPOTLIGHT. The RANDOM problem produces a different landscape and true solution each time you press SETUP. It is interesting to see how the pigeon-inspired algorithm is able to solve it nonetheless most of the times.

1.6 Extending the tool

An interesting question arising is if the convergence speed of the algorithm can be improved without compromising its simplicity for practical purposes, for example using time-decay updates of the step sizes of pigeon movements. In addition, the experiments with the RANDOM benchmark hints at the possibility of the model to solve non-stationary problems, that is, problems were landscape may vary over time, an interesting setting for real-world problems.

Other topics for further research are validating whether the ABM approach to swarm intelligence can be extended or is feasible to address optimisation in higher dimensions, different function domains (continuous, binary, combinatorial) or to incarnate other metaphors originating from the field of collective intelligence.

1.7 References

[1] Garzon, M., and Rojas-Galeano, S. (2019). An Agent-Based Model of Urban Pigeon Swarm Optimisation. In: 2019 IEEE Latin American Conference on Computational Intelligence. https://ieeexplore.ieee.org/document/9036758. doi: 10.1109/LA-CCI47412.2019.9036758.

[2] Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Chapter 2

Installation and execution

2.1 Online version

The easiest way of experimenting with PUPIRealis by using its online version. The software is available at the ModellingCommons website. So, you just need to follow these steps:

1. Open your favourite Internet browser and point it to the following URL: http://modelingcommons.org/browse/one_model/6390

2. The following web page should appear:

3. From the toolbar, choose the “Run in Netlogo Web” tab:

4. A grey area in the middle of the screen is shown. Do “Click to Run Model”:

5. The model main screen will show up:

6. That's all! Choose the running parameters in the control panel, click SETUP and then GO! You will see how the ock of pigeons adapt to the landscape of the problem in the simulation view area, while the performance indicators will be shown in the monitors and the plots.

2.2 Desktop version

The desktop version is recommended if you want to try heavy experimentation, such as parameter tuning, average behaviour of multiple runs or simulations with large populations. For this purpose, PUPIRealruns over the NetLogo desktop simulation platform [2]. In this case, you need to go through the following steps:

1. Download and install the NetLogo desktop software. For this purpose, go to http://ccl.northwestern.edu/netlogo/ , click in “DownloadNetLogo” and follow the instructions:

2. Download the PUPIRealmodel le from the model webpage, using the “Export” button:

A le called Urban Pigeon-inspired Model for Unconstraint Optimisation.nlogo would be downloaded to your local disk.

3. Run NetLogo on your computer. Choose the menu option File! Open

Locate the PUPIReal.nlogo le that you downloaded previously and open it.