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Determination of Initial Conditions of M81 Triplet Using Evolution Strategies

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Abstract. In this work we present Evolution Strategies (ES) as an efficient method to approximate the initial conditions of the main interacting group of three galaxies in M81.

The M81 group is one of the nearest groups of galaxies. Its biggest galaxy, M81, sits at the core of the group together with its two companions M82 and NGC3077. The interaction between these three galaxies is very well defined on an image taken in HI. In this first attempt we use non-self-gravitating simulations to approximate the initial conditions; even with that restriction our method reproduces the density distribution of the three galaxies with great precision.

Results presented here show that ES is an ideally suited method to work in optimization problems in Astrophysics, where the solution is hard to find by common methods. In particular we argue that ES is a good method to find initial conditions of groups of interacting galaxies, where a large number of parameters need to be determined.

1. Introduction

It now established that galaxies are not "island universes", but rather interact with each other in pairs or in small or big groups. Interactions can form spirals, bars, warps, rings and bridges. Thus, observing the morphological and kinematics results of an interaction can give us crucial information about the interaction scenario.

Yet very few detailed studies of individual interacting systems exist. The reason is that the number of free parameters in such simulations is very large and one needs an excessively large number of simulations to cover the corresponding parameter space.

The problem of finding the right parameters for modelling the interaction of a given system of galaxies can be posed as an optimization problem. Indeed any simulation will give a projected surface density map and line-of-sight velocities. These can be compared to the corresponding observed quantities, and then the best model is the one that minimizes the difference.

We will here use a method called Evolution Strategies (ES), which, while having much in common with Genetic Algorithms (GA) (Charbonneau 1995), is better suited for working with continuous spaces, i.e. real parameters. Since most of the parameters of interacting systems are continuous, this constitutes a clear incentive for trying out ES. We have chosen the M81 triplet as the interacting system to be studied.

The M81 group is one of the nearest groups of galaxies. Its biggest galaxy, M81, sits in the core of the group together with its two nearby companion M82 (in the upper part of the image) and NGC3077 (in the lower part of the image).

2. Evolution Strategies

Evolution Strategies (ES) (Rechenberg 1975) is a technique for finding the minimum of a function with a large number of variables using ideas based on biological evolutionary process. We start by choosing K individuals, each characterized by an object parameter vector $\mathbf{O}$ and a corresponding strategy parameter vector $\mathbf{S}$:

$$\mathbf{O} = o_i = \langle q_{1,i}, q_{2,i}, \cdots, q_{L,i} \rangle i = 1, \cdots, K \tag{1}$$

$$\mathbf{S} = s_i = \langle \sigma_{1,i}, \sigma_{2,i}, \cdots, \sigma_{L,i} \rangle i = 1, \cdots, K \tag{2}$$

The elements q are the parameters we need to find, and $\mathbf{S}$ contains standard deviations of the L variables $q_{l,i}, l = 1, \cdots, L$

In the initialization of the process, the first generation, the elements of the $\mathbf{O}$ and $\mathbf{S}$ vectors, can be chosen either totally at random, or with some help from previous knowledge about the system.

Each of the K individuals, i.e. each set of initial conditions, is used as input for the simulation program. The result of each simulation has to be evaluated with the help of a fitness function.

The next sept is to produce a new population with the help of genetic operators: cross-over and mutation. For cross-over two individuals are chosen at random and in a such way that each individual is used once and only once. Mutation is applied to the individuals resulting from the cross-over operation. Each element of the new individual is calculated from the old individual using the simple equation:

$$q_{\rm mut} = q_j + N(0, \sigma_j) \tag{3}$$

where $N(0, \sigma_j)$ is a random number obtained from a normal distribution with a zero mean an a standard deviation σ_j, which is given from the strategy parameter vector. The process is repeated until the population converges.

3. Aplication to Interacting Systems of Galaxies

We use 30 individuals per iteration ($K = 30$). In constituting the children population we apply first cross-over and then mutation to the parent population, then we merge both populations, select the K best individuals from this merged population, and use the result as input for the next iteration.

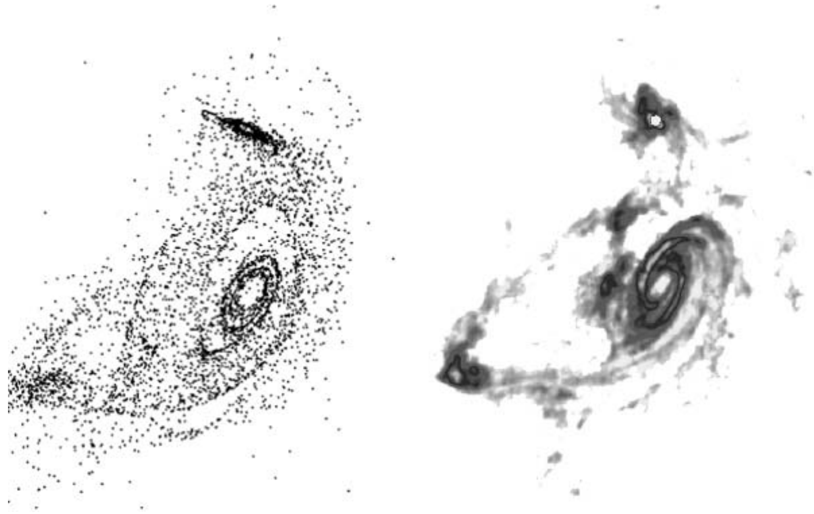

Figure 1. Simulated and HI images for M81 group

In order to obtain the fitness fuction we used mainly the HI density information, summarized in a 48×48 grid. We also grided the simulation results on a similar grid and then obtained the fitness as the Kullback-Leibler distance (Kullback & Leibler 1951).

For the simulation we use the test particle approach. In this approximation the mass of each galaxy is assumed to be concentrated in a single point in its center, while the disc, which responds most to the interaction, is represented by test particles, initially on co-planar circular orbits around the center of the galaxy. This approach is very fast and thus allows us to run the very large number of simulations necessary for tackling this problem. Furthermore, in our case the galaxies are not inter-penetrating and thus they are perturbed only in their outer parts, making the test particle approach fairly adequate.

4. Results

We obtained the density matrix of the original image simply by scanning the HI density map given in (Yun 1997). By using only this information we obtained a good fit to the density matrix after 100 generations, i.e. a total of 100×30 simulations. The images in Figure 1 show the best simulation reached and the original HI image. Table 1 shows the corresponding parameters for the best simulation.

Although the density was fairly well reproduced in this way, the velocities were innacurate. So, in future work we are planning to introduce some velocity information to improve the velocity distribution.

z_2	z_3	V_{x1}	V_{y1}	V_{x2}	V_{y2}	V_{x3}	V_{y3}	i_1	PA_1	i_2	PA_2	i_3	PA_3	m_1	m_2	m_3	t
62.05	11.14	3.17	1.59	-61.91	41.78	-168.75	-0.90	44.90	113.37	38.62	32.58	53.83	232.87	19.47	1.04	1.06	812

Table 1. Parameters to produce the simulation in Figure 1

Index 1 is for M81, 2 for M82 and 3 for NGC3077

5. Conclusions

In this work we presented an efficient method, based on ES, to approximate the initial conditions of the M81 triplet.

Even with the several simplifying assumptions done in simulations, searching with ES has demonstrated to be an excellent method for optimization problems where an exploration of continuous parameters spaces is needed; ES could find a good simulation that match very well the HI density distribution in this problem. We are planning to extend the application of ES to the study of other interacting systems.

5.1. Future Work

In order to improve the method, the possibility of implementing a parallelization of the ES could be considered with the purpose of reducing the computing time required. Also, methods based on self-gravitating N-body simulations can be used to improve the match between simulations and the HI density distribution.

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