Adjustment of Observational Data to Specific Functional Forms Using Particle Swarm Algorithm and Differential Evolution: Rotational Curves of Spiral Galaxy as Case Study

Miguel Cárdenas Montes, Mercedes Mollá, Miguel A. Vega-Rodríguez, Juan José Rodríguez-Vázquez, Antonio Gómez-Iglesias

CIEMAT (Spain) and University of Extremadura (Spain)
miguel.cardenas@ciemat.es

La Palma, June 2nd 2011

Table of Contents

Introduction

Introduction I

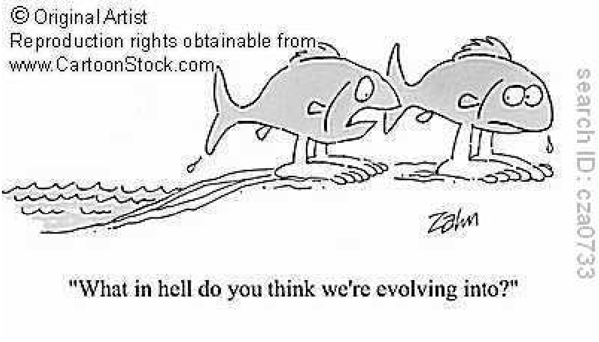
- The fitting of experimental or observational data to specific functional forms requires high computational capacities in order to tackle with the complexity of the calculations.
- This complexity forces the usage of efficient search procedures, such as evolutionary algorithms.
- Evolutionary algorithms have proved their capacity to find sub-optimal high-quality solutions to problems with large search space.

Introduction II

The final goal of this work is two-fold:

- Firstly, to provide a theoretical functional form representing the features of the rotational curves of spiral galaxies in order to be coupled to other computational models.
- Secondly, to demonstrate the applicability of the evolutionary algorithms to the matching between astronomical data sets and theoretical models —even if large and complex data set are used—.

Evolutionary Algorithms



Evolutionary Algorithms

Evolutionary Algorithms used in this work

- Particle Swarm Algorithm.
- Differential Evolution.

Why these EAs:

- Widely used.
- Easy to implement.
- Specially suitable for first approach to problems.
- Easy to hibridise with other evolutionary techniques.

Production Setup

Fitness Function

- Considering a standard fitting problem, where one is given a discrete set of N data points with associated measured errors σ, and is asked to construct the best possible fit to these data using a specific functional form for the fitting function, the most appropriated fitness function is the merit function χ^2, Eq. 1.

$$\chi^2 = \sum_{for\ all\ points} \left(\frac{y_{simulated} - y_{observed}}{\sigma_{observed}}\right)^2 \tag{1}$$

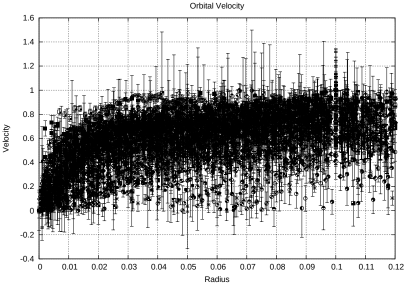
Galaxies employed in this study

- 56 galaxies (5051 points).

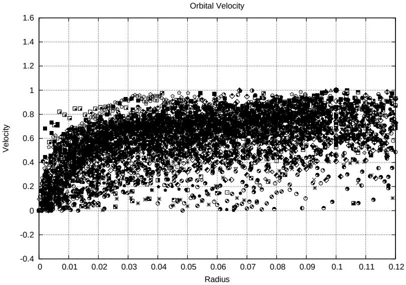
NGC 828	NGC 2460	NGC 2543	NGC 2552	NGC 2608	NGC 2633	NGC 2701
NGC 2748	NGC 2770	NGC 2964	NGC 2998	NGC 3041	NGC 3183	NGC 3320
NGC 3370	NGC 3395	NGC 3396	NGC 3471	NGC 3501	NGC 3507	NGC 3689
NGC 3769a	NGC 3769	NGC 3976	NGC 4047	NGC 4284	NGC 4389	NGC 4496a
NGC 4496b	NGC 4793	NGC 4800	NGC 5012	NGC 5172	NGC 5351	NGC 5394
NGC 5395	NGC 5480	NGC 5533	NGC 5641	NGC 5656	NGC 5678	NGC 5740
NGC 5774	NGC 5775	NGC 5899	NGC 5963	NGC 5970	NGC 6070	NGC 6106
NGC 6181	NGC 6207	NGC 6239	NGC 7177	NGC 7217	NGC 7448	NGC 7479

All rotation curves doubly normalized

With error bars



Without error bars



Analysis and Results

Results I

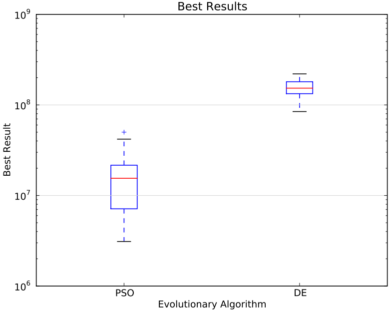


Figure: Best results obtained for PSO and DE algorithms, and configuration of 100 particles and 5,000 cycles. 25 tries.

The application of the Wilcoxon signed-rank test to the data shown indicates that the differences are significant —$\alpha = 0.05$—.

Results II

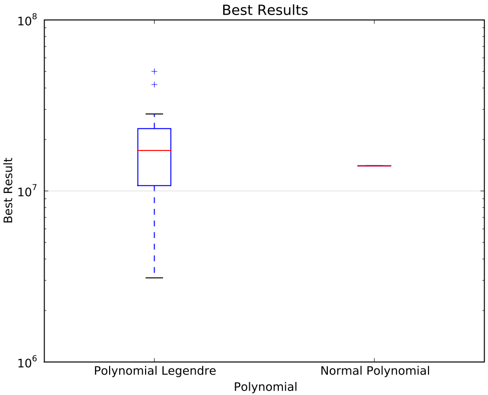


Figure: Best results obtained for PSO algorithm when using a series of Legendre Polynomial and Normal Polynomial, and configuration of 100 particles and 5,000 cycles. 25 tries.

Results III

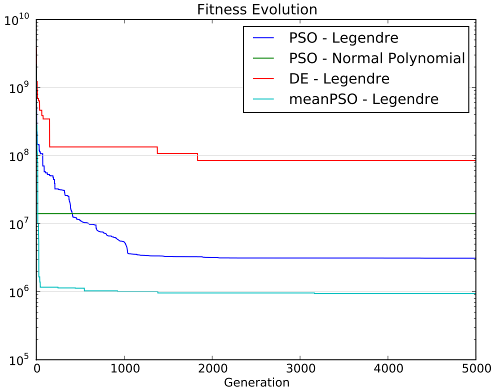
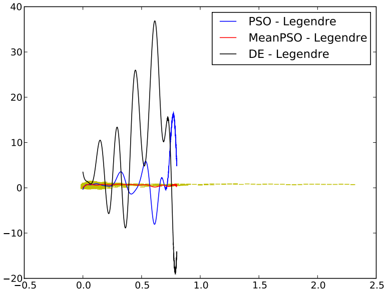


Figure: Fitness evolution of the best case for diverse configurations

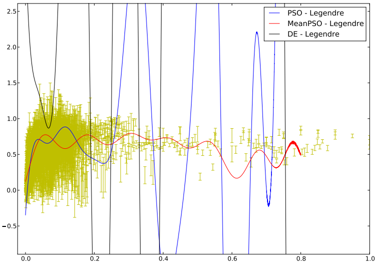
Results IV

Table: Absolute best result —fitter adjustment to experimental data— obtained. Configuration used PSO with configuration of 100 particles and 5,000 cycles, and a serial of Legendre Polynomial of 50 degrees

Fitter



Detailed View



Conclusions

Conclusions

- In general, the results obtained demonstrate the effectiveness of the usage of Evolutionary Algorithms in order to cope with the extraction of essential information from huge volume of astronomical and astrophysical experimental data.
- Particularly, the numerical experiments performed show that PSO algorithm obtains more accurate results that DE algorithms.

Future Work

- Further refinements in PSO: low discrepancy sequences vs RNG; and mechanism to avoid fitness stagnation.
- Checking of other EAs, as well as other functional forms to generate fitter adjustment.

Thanks

Thank you

Questions?

More questions?