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Tracing the dynamics in cosmological n-body simulations with a computer vision software

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Abstract. N-body simulations are very important for several areas of physics, since they are used to simulate the dynamics of particles that interact through mechanical forces, such as imposed by the gravitational field. Many of these computer simulations are widely used in astrophysics to investigate cosmological phenomena, such as the formation of large-scale structures as filaments and dark matter halos in the cosmic web. In this context, machine learning techniques can become extremely useful to compare different cosmologies since they have great performance for pattern classification. Several frameworks have open source code and are available for implementation on several platforms, such as MediaPipe and OpenCV. These machine learning solutions commonly applied to computer vision problems still have a little explored potential in the analysis of data from physical simulations, mainly in pattern recognition during the formation of structures with, for example, homogeneous and non-homogeneous models in cosmological scales. Therefore, it is intended to apply these tools in the analysis of large-scale cosmological simulations, such as the Millennium Simulation, doing Multiple Object Tracking of particles so that, with machine learning tools, it can be verified whether it is possible to carry out the analysis of the cosmological parameters by calculating the distance of some triangle centroids formed by the particles along the snapshots of the simulations. In this work test, based on particle triangulation, a set of geometric metrics are tested in order to quantify the snapshots tracking. Partial results indicate that the evolution of some scores based on the triangles areas variation are able to trace the evolution of gravitational instability throughout the simulation for different initial conditions, indicating that the technique can be useful for characterizing different cosmological simulations. The use of the presented method for training models in computer vision is also discussed.

Resumo. Simulações de N-corpos são muito importantes para diversas áreas da física, pois são utilizadas para simular a dinâmica de partículas que interagem por meio de forças mecânicas, como as impostas pelo campo gravitacional. Muitas dessas simulações computacionais são amplamente utilizadas em astrofísica para investigar fenômenos cosmológicos, como a formação de estruturas de grande escala como filamentos e halos de matéria escura na teia cósmica. Neste contexto, técnicas de aprendizado de máquina podem se tornar extremamente úteis para comparar diferentes cosmologias, uma vez que apresentam ótimo desempenho para classificação de padrões. Diversos frameworks possuem código-fonte aberto e estão disponíveis para implementação em diversas plataformas, como MediaPipe e OpenCV. Estas soluções de aprendizado de máquina comumente aplicadas a problemas de visão computacional ainda possuem um potencial pouco explorado na análise de dados de simulações físicas, principalmente no reconhecimento de padrões durante a formação de estruturas com, por exemplo, modelos homogêneos e não homogêneos em escalas cosmológicas. Portanto, pretende-se aplicar estas ferramentas na análise de simulações cosmológicas em grande escala, como a Simulação do Milênio, fazendo Rastreamento de Múltiplos Objetos de partículas para que, com ferramentas de aprendizado de máquina, seja possível verificar se é possível realizar a análise dos parâmetros cosmológicos calculando a distância de alguns centroides triangulares formados pelas partículas ao longo dos instantâneos das simulações. Neste trabalho de teste, baseado na triangulação de partículas, é testado um conjunto de métricas geométricas para quantificar o rastreamento dos snapshots. Resultados parciais indicam que a evolução de alguns escores baseados na variação das áreas dos triângulos são capazes de traçar a evolução da instabilidade gravitacional ao longo da simulação para diferentes condições iniciais, indicando que a técnica pode ser útil para caracterizar diferentes simulações cosmológicas. O uso do método apresentado para treinamento de modelos em visão computacional também é discutido.

Keywords. Cosmology: miscellaneous – Gravitation – Instabilities – Methods: data analysis – Methods: miscellaneous – Methods: numerical

1. Introduction

N-body simulations are very important for several areas of physics, since they are used to simulate the dynamics of particles that interact through mechanical forces, such as imposed by the gravitational field. Many of these computer simulations are widely used in astrophysics to investigate cosmological phenomena, such as the formation of large-scale structures as filaments and dark matter halos in the cosmic web (Rosa et al (2009), Stalder & Rosa (2012)) (example in figure 1). In this context, machine learning (ML) techniques can become extremely useful to compare different cosmologies since they have great performance for pattern classification.

2. Objectives

The main objective of this work is to test the applicability of ML in identifying cosmological structures from N-body computer simulations, in addition to monitoring its evolution with computer vision tools for the purpose of validating cosmological models.

3. Methodology

Several frameworks have open source code and are available for implementation on several platforms, such as MediaPipe and OpenCV (Google (2023), OpenCV (2023), CVZone (2023)).

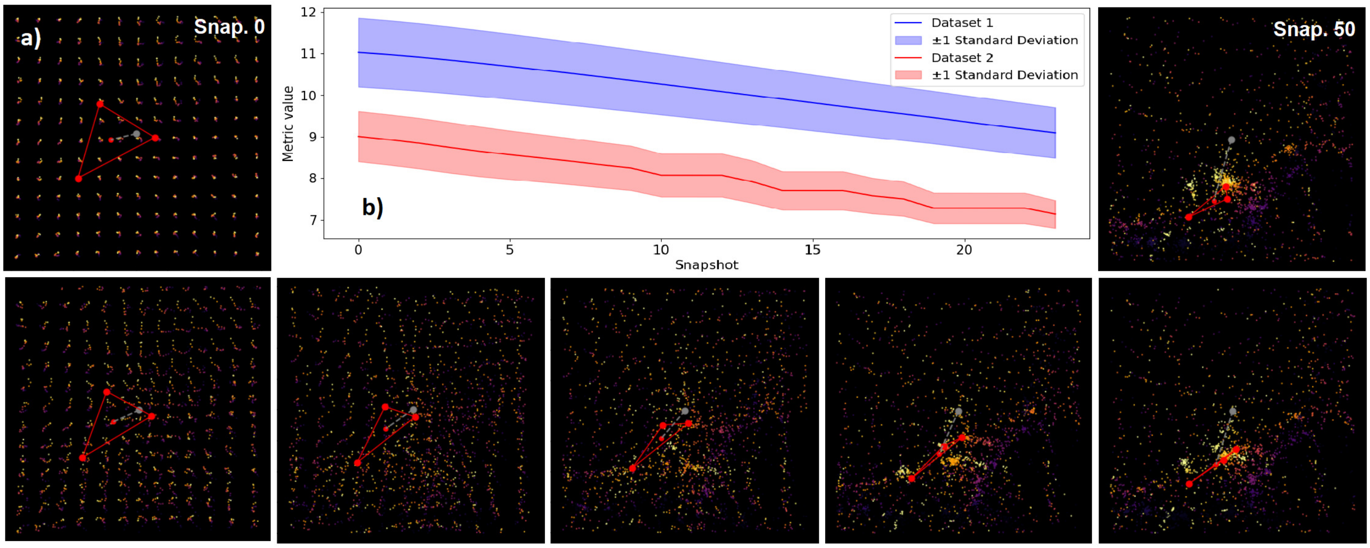

Figure 2. (a) Example of a temporal evolution of the system made with COLATUS together with the Δ_n metric measurement scheme. (b) Example of two time series obtained with the metric Δ_n. The dataset 1 corresponds to the metric calculated from the temporal evolution of a system with "homogeneous" initial particle distribution. The second corresponds to the evolution of a system with some structures already formed.

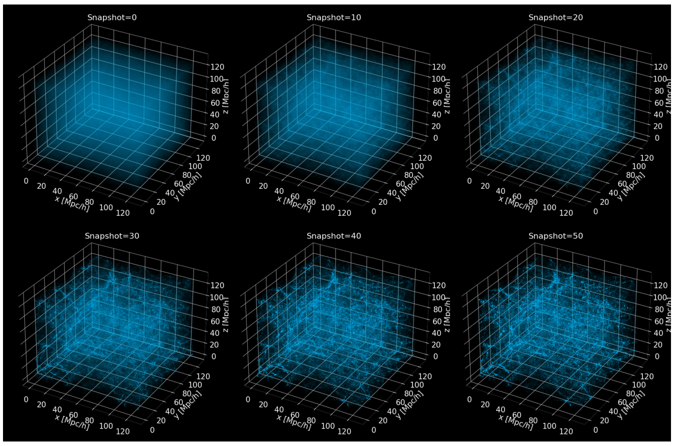

Figure 1. Cosmological N-Body simulation conducted using the COsmic LAgrangian TUrbulence Simulator (COLATUS) (Stalder and Rosa, 2012). Demonstrating the evolution of large-scale structures, including clusters, filaments, and voids, across multiple snapshots.

These machine learning solutions commonly applied to computer vision problems still have a little explored potential in the analysis of data from physical simulations, mainly in pattern recognition during the formation of structures with homogeneous and non-homogeneous models in cosmological scales.

It is intended to apply these tools in the analysis of large-scale cosmological simulations, such as the Millennium Simulation (Lemson & Consortium (2006)), doing Multiple Object Tracking of particles so that, with machine learning tools (such as deep learning), it can be verified whether it is possible to carry out the analysis of the cosmological parameters by calculating the distance of the centroids formed by the particles along the snapshots of the simulations. In this work we introduce a new metric that contains the minimum geometric information which consists of the triangulation among three particles. An example can be seen in figure 2. Once the particles are chosen, the algorithm allows to follow the evolution of the simulation from the following measure:

$$\Delta_n = \frac{A_1(n) + A_2(n)}{A_1(n)} + d(n), \quad (1)$$

where A_1 is the total area considered (aspect ratio equals one), A_2 is the area of the triangle defined by the three tracked particles and d is the distance between the center of A_1 and the centroid of A_2, for snapshot n. We call Δ_n the Label of the technique.

4. Preliminary Results and Conclusions

Based on the preliminary results (as seen in figure 3), from a given learning function, it is possible to train deep learning models to detect and characterize simulated patterns from different initial conditions or different models, and also detect typical patterns found by simulation in real data. In this sense, The methodology must be adapted to a computer vision library compatible with already established solutions such as OpenCV and Mediapipe.

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References

CVZONE, 2023, CVZone. Available in: https://github.com/cvzone/cvzone . Acessed on: 28, sep., 2023.
Lemson, G. & Consortium, V., 2006, arXiv:astro-ph 0608019, pp. 1.
Google, 2023, Mediapipe, GitHub. Available in: https://github.com/google/mediapipe . Acessed on: 28 sep. 2023.
OPENCV, 2023, OpenCV library. Available in: https://opencv.org/ . Acessed on: 28, sep, 2023.
Rosa, R. R.; Ramos F. M.; Caretta, C. A. & Velho, H. C., 2009, Computational Physics Communications, 180, pp. 621.
Stalder, D. H. & Rosa, R. R., 2012, AIP Conference Proceedings, 1483, pp. 447.