Advances in Computational Sciences and Technology
ISSN 0973-6107 Volume 10, Number 3 (2017) pp. 343-352
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Discretization of Function Based Astronomical Objects Using Procedural Modelling

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Abstract

Many classification methods are designed for processing the huge quantities of data generated by modern astronomical instruments. Digital photography provides the tools for describing how a particular image structure is configured, and, therefore, how it relates to the characteristics of a particular astronomical object. An algorithm to discretize function based astronomical objects is developed and named as procedural astro object discretization. The generated functional representation of this astronomical object provides compact, precise, and arbitrarily parameterized models, which can undergo blending, deformations, and other geometric operations. The problem of distinguishing the stars from galaxies and some techniques that have been applied to it are briefly reviewed. A simplical complex converts the function of a heterogeneous object into a cellular model. The obtained complex is optimized using edge swapping, edge splitting, edge collapsing and vertex relocation operations. This approach can easily distinguish stars and galaxies on digitized photographic plates. It is also widely applicable to other discretization problems, especially when the data being classified are not completely homogeneous.

Keywords: Digital Photography, Function Representation, Simplical Complex, Astronomical Object.

I. INTRODUCTION

A large amount of data are available to the astronomers through the combination of ever larger detector formats, powerful computers capable of processing vast amounts of data, and on-line access to large databases. There must be a powerful technique used to search a single or combined database to locate our object of interest. Also some optimization techniques are required to convert the function derived from the raw data collected at observatories into a model.

This paper focuses mainly on the problem of discretization of astronomical objects for example distinguishing the stars from the galaxies. The main difference between stars and galaxies is that stars have sharp images and look completely unresolved, while galaxies look fuzzy. The telescope images of stars have finite resolution and the stellar images are non-zero in size. Figure 1 represents a small section from a digitized photographic plate with galaxies marked. Distinguishing stars from galaxies becomes complicated when both are faint and the galaxies are small in size. If the stars are very bright it is again difficult to distinguish them since they can saturate the detector and no longer look compact. Usually all the galaxies are centrally concentrated. A small fraction of galaxies have activity near their centers. This makes them to appear as a stellar core surrounded by faint fuzz. In such cases the objects are especially difficult to classify correctly.

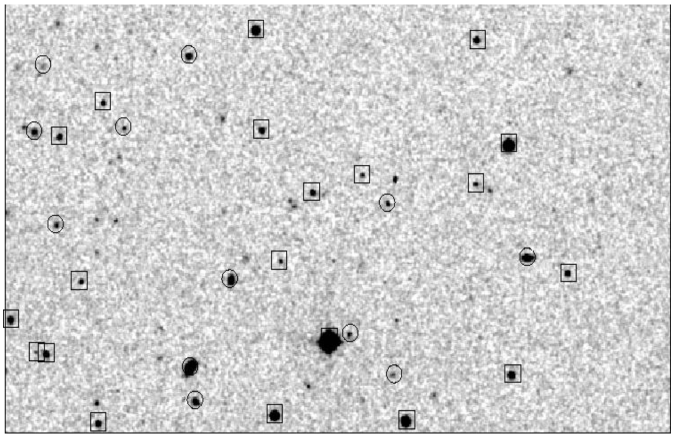


Figure 1: 530 x 300 pixel section of digitized Palomar Sky Survey II plate. The contrast has been enhanced to make both faint objects and the noise visible in the sky. From Postman's deep CCD objects brighter than V=20.5 are marked as stars (squares) and galaxies (circles). Our aim is to develop a classification algorithm that can distinguish the stars from the galaxies.

The classification of the astronomical objects depends on their morphological parameters such as shape, central concentration, boundary and colors. The procedural astro object discretization algorithm initially deals with the discretization problem within the hybrid cellular functional model **[1]** of heterogeneous objects. By using a simplical complex the function representation of the initial 3D astronomical object is converted into a cellular representation. The algorithm comprises the following phases:

1. Surface polygonization.
2. Repeated simplification.
3. Refinement of the surface mesh.
4. Reconstruction of sharp features.

The initial object parameters are used at all steps both for controlling geometry and topology of the resulting object. The same parameters are optimized for calculating new attributes for the resulting cellular representation.

II. PROBLEM STATEMENT

A. ***Initial heterogenous astronomical object***

The problem of classification of functionally based heterogeneous astronomical objects within a hybrid cellular functional representation framework in which objects are treated as multidimensional point sets with multiple attributes(hyper volume) **[2]** is considered for modelling.

Let O be an initial heterogeneous astronomical object – a hyper volume expressed by a tuple:

$$O\ (G, P_1 ... P_k) \longrightarrow \text{Eq.1}$$

Where G is a 3D point set, P_i is a parameter and k is a number of parameters. We assume that the object's geometry G is described by the function representation (FRep) [3]:

$$G_F = \{X \mid\ = (x_1, x_2, x_3)\ \ \Omega\ E^3, F(X)\ 0\} \longrightarrow \quad \text{Eq.2}$$

Where G_F is the function representation of object geometry, X represents point sets x_1, x_2, x_3 , Ω is a modelling space, E is a constant and $F\colon \Omega \to R$ is (at least a C^0 continuous) real valued defining function. The boundary of the object O is an implicit surface described as

$$B_F = \{X \mid\ = (x_1, x_2, x_3)\ \ \Omega\ E^3, F(X) = 0\} \longrightarrow \quad \text{Eq.3}$$

Where B_F is the functional representation of the object boundary.

B. ***Resulting heterogenous astronomical object***

Given the initial object O, we are going to build a resulting heterogeneous object HO a hyper volume

$$HO\ (HG, HP_1 ... HP_k) \longrightarrow \quad \text{Eq.4}$$

Here, the geometry component HG is an approximate discrete representation of the initial geometry G, and HP are the attributes that describe the object's properties. Also G can be expressed as a model based on the cellular representation (CRep)

$CG=\{ X \mid X \text{ € } \Omega \ \underline{C} \ E^3, X \text{ € } |K^3|\} \longrightarrow$ Eq.5

Where CG is the cellular representation of the model and K is a constant.

C. Problem formulation

Initially the functionally based heterogeneous astronomical object O is converted into the object HO with discrete (mesh-based) geometry:

$O = (G_F, P_1 \ldots P_k) \rightarrow HO\,(CG, P_1 \ldots P_m) \longrightarrow$ Eq.6

Where G_F is a FRep based model, and *CG* is a CRep based model. The boundary of the astronomical object O is an implicit surface B_F.

III. PRIOR WORK

A. Heterogenous objects modelling

Modelling of astronomical objects with multiple materials and non-uniform internal material distribution is usually done through boundary representation, function based representation, voxel and cellular models.

Heterogeneous astronomical objects are modeled as multidimensional point sets with multiple attributes. Based on function representation (FRep) the proposed constructive hyper volume model supports uniform constructive modelling of point set geometry and attributes using vectors of real-valued functions of several variables. Multiple materials are described by vectors of real valued functions**. [4] To** model changing material properties the distance parameter is used.

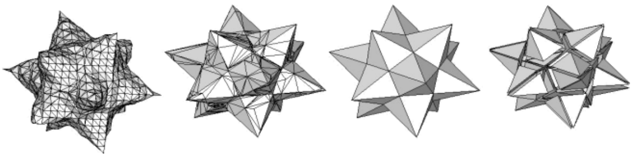
The function and cellular representations of astronomical object are combined into a single hybrid model.

B. Polygonization

The polygons are generated as the result of the intersection of the implicit surface with cells of a regular grid. But the main disadvantage of this approach is smoothing or cutting sharp feature of the surface. Considering the surface curvature the sharp edges are extracted. The optimization is done using special vertex relocation strategy and triangles subdivision. But this optimization does not control the shapes and relative sizes of neighboring triangles that results in degenerate triangles. So a special mesh refinement preserving sharp features is needed.

C. Preservation of sharp features

The approximate and precise functional surface model is used to determine the functional characteristics. The advancing front technique gives the accurate boundary representation of a star or galaxy. By incrementing one element at a time this technique initiates from the domain boundary classification and proceeds processing the next one. To increase the effectiveness of this procedure 3D mesh optimization procedures are used. [5, 6, 7, 8 and 9]



A b c d

Figure 2: An example of classification of a functionally based object with sharp features: a) polygonization of the initial object surface; b) a surface mesh after sharp features reconstruction; c) the optimal surface mesh; d) the final tetrahedral tessellation

IV. PROCEDURAL ASTRO OBJECT DISCRETIZATION ALGORITHM

Step I:

The discretization problem is divided into two relatively independent sub procedures:

Surface mesh generation and refinement of astro object:

$CB_C = CB_C\,(B_F, A_1, \ldots, A_K) \longrightarrow$ Eq.7

Where CB_C is conformable surface mesh generation.

Volume meshes generation of astro object:

$CG_C = CG_C\,(CB_C, G_F, A_1, \ldots, A_K) \longrightarrow$ Eq.8

Where CG_C is conformable volume mesh generation.

Step II:

A simplical complex L is developed for the CRep based surface model:

$L_0^2 = L_0^2(B_F) \longrightarrow$ Eq.9

Step III:

Mesh optimization procedures are used for sharp feature reconstruction.

CB_0 is optimized to CB_1 by the complex

$L_1^2 = L_1^2(L_0^2\ , B_F) \longrightarrow$ Eq.10

Initially resampling of curvature-weighted vertices is done by projecting the triangle centroids onto the implicit surface. Then the vertex is moved to a new position so as the sum of the squared distances from the vertex to the plane is minimized. The mesh triangles are subdivided one to four times so that the mesh normal has large deviations from implicit surface normal.

Step IV:

The CRep based model B is built by optimizing complex L. The operations such as edge swapping, edge splitting, and edge collapsing and vertex relocation are applied repeatedly. Edge splitting enriches the mesh, edge collapsing simplifies the mesh and edge swapping and vertex relocation refines the mesh. Finally a CRep based model CB_c^2 is obtained described by the complex below and by optimization of complex L_1^2.

$L_2^2 = L_2^2(L_1^2, B_F) \longrightarrow$ Eq.11

Step V:

The singular lines and points of attribute functions are projected on surface B. A new complex with singular lines and points described by 1D and 0D sub complexes is obtained as

$L_3^2 = L_3^2(L_2^2, B_F, A_1, \ldots, A_K) \longrightarrow$ Eq.12

Step IV is repeated and finally we get the required complex as

$L_4^2 = L_4^2(L_3^2, B_F, A_1, \ldots, A_K) \longrightarrow$ Eq.13

Step VI:

$CG_{c0} = CG_{c0}(CB_{c4}, G_F, A_1, \ldots, A_K) \longrightarrow$ Eq.14

$CB_c = CB_{c4} \longrightarrow$ Eq.15

$L_c^2 = L_4^2 \longrightarrow$ Eq.16

A tetrahedral mesh Eq.14 is generated based on CRep based model of the surface mesh Eq.15 described by the complex Eq.16.

Step VII:

To rebuild the volume mesh described by the complex K_0^3

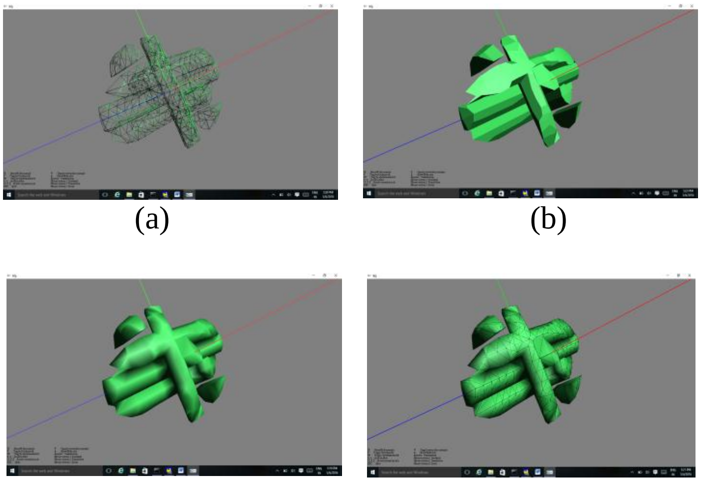
Face swapping, tetrahedral subdivision and vertex relocation operations are done. Then again the sharp features, singular points and boundary lines are preserved. Finally a new complex Eq.17 is obtained.

$K_1^3 = K_1^3(L_C^2, A_1, \ldots, A_K) \longrightarrow$ Eq.17

Step VIII:

$CO = (CG_{C1}, CA1, \ldots, CA_M) \longrightarrow$ Eq.18

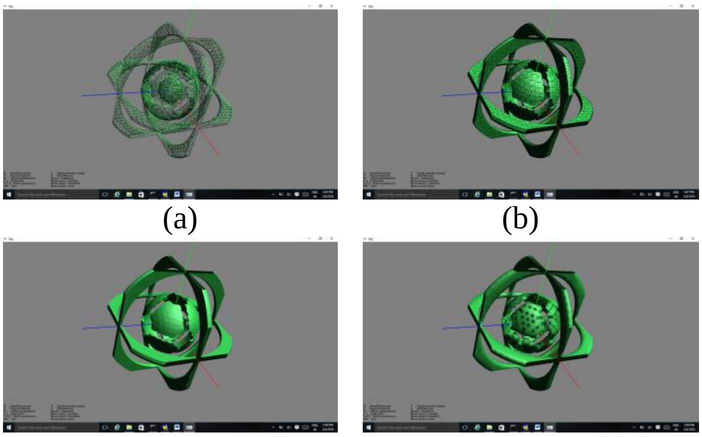
The final step in classification of stars and galaxies is conversion of initial attributes to get new ones. The attribute conversion procedures depend on the specific application. Finally, the searched discrete model Eq.18 of the initial heterogeneous object Eq.1 with CRep based geometry, and CRep and CFRep based attributes is obtained. The resultant discrete model O contains a very sharp boundary feature that easily differentiates a star from a galaxy. Figure 3 and 4.



(a) (b)

(c) (d)

Figure 3: Actual output of a heterogeneous function based galaxy (a) polygonization (b) sharp features reconstruction (c) optimal surface mesh (d) final tetrahedral tessellation



(a) (b)

(c) (d)

Figure 4: Actual output of a heterogeneous function based star (a) polygonization (b) sharp features reconstruction (c) optimal surface mesh (d) final tetrahedral tessellation

V. EXPERIMENTAL RESULTS

Using sampling techniques the parameters of three data sets were used for testing. The First Data Set (FDS) holds the parameters for 383 galaxies and 383 stars. The Second Data Set (SDS) holds the parameters for 1128 galaxies and 1128 stars. The Third Data

Set (TDS) holds the parameters for 546 galaxies and 546 stars. The result of the procedural astro object discretization algorithm is compared with the results of Data Mining techniques. Table 1.The experimental data was collected from Vikram Sarabhai Space Center, Trivandrum. It was observed that the Artificial Neural Network (ANN) provided higher accuracies than Support Vector Machines (SVM), Random Forest (RF) and Decision Tree (DT) data-mining techniques but was outperformed by the procedural astro object discretization (PAOD) algorithm. **[10]** **Figure** 5.

Table 1. Accuracy of the techniques when tested against three datasets.

Discretization Techniques	**FDS (%)**	**SDS (%)**	**TDS (%)**	**Average Deviation (%)**
DT	80.03	80.54	80.68	0.26
RF	82.90	82.98	82.97	0.03
ANN	72.58	72.52	75.82	1.45
SVM	36.81	36.44	37.82	0.53
PAOD	79.63	79.59	79.65	0.02

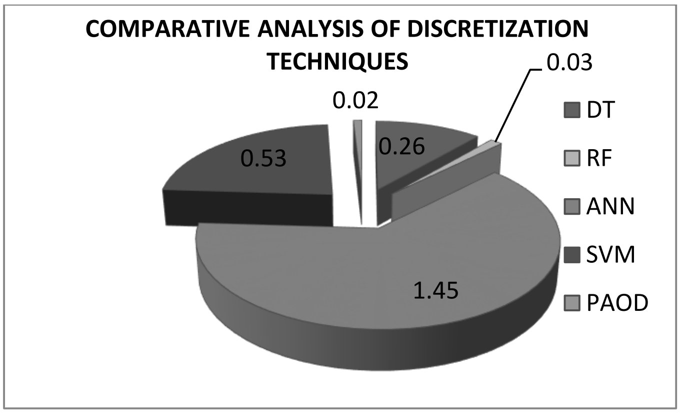


Figure 5: A graph depicting comparative analysis of Average deviation of various discretization techniques.

VI. CONCLUSION

In this paper a new procedural astro object discretization algorithm is reviewed focusing on the problem of distinguishing the stars from galaxies. There are several methods available for discretization. A discretization procedure resulting in surface and volume meshes for heterogeneous objects with geometry and attributes defined using real value functions is worked out. This procedure serves as a template for the cellular functional modelling framework where the function is converted into a cellular model.

The main purpose of this work is to generate meshes that satisfy the constraints of the heterogeneous astro object. The following points summarize the main contributions of the paper:

1) The algorithm is developed for function based astro three dimensional heterogeneous objects with implicit surfaces and scalar parameters.
2) Various known techniques are followed and they are further developed to work with the function based heterogeneous astro objects.
3) The surface mesh optimization worked out in the algorithm preserves the sharp features of implicit surfaces.
4) By considering the defined geometric function of the heterogeneous astro object the advancing front method of 3D tetrahedrization is extended.

Tetrahedrization of heterogeneous astro objects with complex topology and sharp features is illustrated. An example of distinguishing the stars from galaxies is worked out and the result is compared with some of the data mining techniques recently adopted for discretization. The procedural astro object discretization algorithm gives a good result when compared with all other data mining techniques. The procedural function based modelling is worked out by using a three dimensional modelling language known as Hyperfun.

In the developed cellular functional model, heterogeneous astro objects are transformed into hyper volumes which are a multidimensional point set that can hold multiple parameters. All the objects that have more than three dimensions can also use the multi-dimensional point sets but in this paper only the three dimensional heterogeneous astro objects are considered. In future this algorithm can be extended for time dependent heterogeneous objects with more than three dimensions.

ACKNOWLEDGMENT

The authors would like to thank Vikram Sarabhai Space Center, Trivandrum for providing the data for testing our algorithm. We also thank Dr. Richard L. White Space Telescope Science Institute for the Object Classification in Astronomical Images.

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