Evolutionary Objects for Glacial Landforms recognition: GRASS Possibilities

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Summary

This study extends the possibilities of a general application model, which has been successfully applied to natural complex systems simulation, this model is obtained merging elements from evolutionary computing and object-oriented paradigms. The extended model, which in before papers was called Object-Oriented Genetic Model (OOGM), takes advantage of new features in evolutionary computing modeling. This model shows a novel representation method of the objects composing the studied system and their evolution rules. These objects become evolvable, in the meaning that they possess the ability to depict dynamics or evolutionary processes in the system. Besides, it is shown that this integration let us take advantage of the holistic and evolutionary paradigms, simulating static and dynamic complexity, respectively. Basically it is shown in this paper the initial phase of a extended application of this model for the recognition of landforms in glaciers, mainly moraines, with a support of Grass 6.0 possibilities. The model allows additionally a expansion to others very complex dynamic problems in glaciology which are also discussed.

1. Introduction

The Evolutionary Computing, which is strongly related to evolutionary algorithms (EAs), has become an increasingly popular methodology and it is growing everyday in interest because of lots of possibilities that are being opened to study and understand dynamic and non-lineal natural systems, some of them with a very big necessity to be simulated or modeled in a more realistic and simple way: earthquakes risk zones, soils dynamics, rivers path dynamics, natural resource reservoirs behavior, high biodiversity areas variations, etc. Generally, linearization or reduction processes appear when this kind of systems are modeled; however, the modern computing tools offer a promising and very interesting alternative to get a better understanding of these systems and give solutions to very difficult and complex problems in dynamic environments. It is well known that many of these complex systems exhibit similar characteristics in their behavior, and a general model may be used as a structure basis to model and to study some of related-or-not-related natural systems.

Though in recent decades have appeared a lot of novel techniques that have been tried to achieve this goal: cellular automatas, artificial neural networks, fuzzy logic, expert systems, bioinspired systems, artificial life, collective intelligence, autonomous agents, fractal analysis methods, etc; however, many fields of scientific studies lack of simple and realistic methods and languages to describe the structure and dynamics of those natural complex systems: co-adaptation or coevolution of populations in dynamic environments, multiple convergence, symbiotic cooperation, are some of the abilities to be modeled. For that reason, new modeling languages and computational methods are necessary today, which will help us better to specify and manipulate objects, attributes, relationships and processes in these domains. Some new techniques of the evolutionary computing and neuroevolution have found convergence points and they have similar particular objectives to help us with this goal.

Within this study, two successful independently developed paradigms were merged to produce a new model of general application in order to handle problems related to recognition and appraisal of landforms in glaciology. The object-oriented conceptual modeling (OO) is well known for its closeness to natural processes representation and holistic orientation; also, the evolutionary computing is well known for giving good answers to problems with a marked non-lineal behavior and for his closeness to biological orientation modeling [***Michalewicz 1999; Angeline 1996***], as that previously was mentioned. It takes as basis an earlier study and model that have been called object-oriented genetic model (OOGM) [***Torres 2000***] and a preliminary application of this new proposed model is developed along with the use of some geomorphometric parameters, which were calculated and analyzed with the Grass 6.0 aid, in order to automate geomorphological recognition of periglacial landforms in glaciers at different scales, it considers the disposition and interrelation of the different elements that control the geodynamic of the topographical transformation and evolution of the glacier. Initially it is tried to classify, to recognize and to segment meaningful landforms units mainly moraines from a 3 meter DTM for La Sierra Nevada del Cocuy in Colombia. The idea is that this model and initial application methodology can be useful as a basis for later studies about tropical glaciers: evolution of the glacial retreat, glacial behavoir of the glaciers during the last climatic fluctuations, dynamics of valleys and periglacial deposition systems, glacial effects and tendencies of the Climate Change, etc.

2. Preliminary Work

Since 90's years, a lot of studies have been addressed to mark the relationship and integration between OO (object-oriented) systems and evolutionary computing as a powerful tool for systems modeling and optimization. Some of this studies have tried to model the natural complexity [***Pöyhönen 1996; Rocha 2000***], others have tried to optimize the OO systems evolution and "object emergence" [***Casais 1991; Tamzalit 1999***], in addition it ist tried to enable object-oriented programs to be evolved [***Bruce 1996; Lucas 2004***] and some others optimize the OO system modeling processes [***Benoit 2000; Senin 1999***]. Besides, the advantages of combining OO modeling with artificial intelligence methods, generally, have been also addressed in [***Tello 1989; Oussalah 2003***]. In spite of all these studies, the effort has concentrated mainly in the development of effective techniques for evolving solutions focused to problems in computer science tools and it has been few explored to extend these models to the solution of increasingly complex dynamic problems in natural sciences, only few studies involving the integration between these two paradigms have been engaged with a general model for complexity in natural environments.

In an earlier study it has been built a model called object-oriented genetic model (OOGM) [***Torres 2000***] , which is very easy to use and to implement due to the natural origin und confluence of both models, the OO representation of the system elements under analysis and the integration with an evolutionary algorithm representing their own evolution and dynamism. This model has been partially applied to several problems in natural complex systems, specially, in gas reservoir simulation [***Torres 2001a***], path optimization in GIS [***Sánchez 2001***], non-linear equation systems optimization [***Torres 2000***] and machine learning simulation in games [***Tirado 2001***].

In relation to glaciology is really certain what has been previously said, very few studies in geomorphology and glacial dynamics take advantage of the mentioned tools. Bonk [***Bonk 2002***] calculated morphometric parameters to automate geomorphological mapping at different scales, he considers the hierarchical organization of the topography and developed also a object oriented model, which represented that hierarchy and the elements that control the geodynamics of topographic evolution. According to him the current software cannot automatically extract meaningful terrain units or objects from a DEM, in his own words: "There have been attempts to extract homogeneous units such as valley bottoms, ridges, pits and saddles, and higher-order geomorphologic features such as landform types. Various methods, however, are not appropriate for extracting complex terrain features such as slope facets, river terraces, or the active extent of a modern-day glacial valley".

Schmidt [***Schmidt 2003; 2004***] used and discussed some problems in automated mapping routines for land elements from digital terrain models (DTM) based in the estimation of the curvature characteristics of landscapes and complex classification systems, he tries to give solution to those problems with a new model which uses fuzzy classification, the quadratic matrix and window used so far discusses he also as problematic, according to him, the selection of the window always appears like one of the main limitations of the most methodologies in landscape analysis, because there the problem of the dependency of the scale is camouflaged, besides he analyzes the uncertainty of his methodology, the problems with the semantics of the geomorphometric models, the available quadratic functions und neighborhood approaches.

Vélez [***Vélez 2006***] identified landforms caused by erosion at a canyon with steep slope areas; he has considered some of the above mentioned geomorphometric methodologies and has utilized the available interpolation and geomorphological algorithms in GRASS.

3. The Object-Genetic Model description and derivation of a model for intelligent spatial objects.

An object-oriented evolutionary model developed to model complex systems, namely natural systems, should represent the structure and dynamics of a system; in the last years, complexity theory has been developed enough and it let us nowadays have a better understanding of the nature complex systems .

3.1 Types of Complexity

Natural systems are in continuous evolution, adaptation and interacting in relation to its surrounding environment, which in turn, is evolving itself. This combination of interdependent mutual evolution yields a high level of complexity in the formulation of one solution. Furthermore, the representation of the elements of a natural system is multidimensional and includes features, such as, the component geometry, directionality, neighborhood or closeness, similarity, energy fluxes, etc. Nowadays it is proposed, like in [***Salery 1998***], and formerly in [***Senge 1994***], that there are two types of complexity in simulation models:

- *Detail complexity*: it is related to the detail definition, structure and management of the static individual components of the model.

- *Dynamic complexity*: it deals with the dynamic consequences of the interactions among the individual components of the system. This is the kind of complexity with highest importance in order to understand a natural system since the consequences or results of the interrelationships are generally unpredictable. It can be said that uncertainty is mainly due to the dynamic processes in a complex system, and these processes are consequence of the natural behavior. Generally, this complexity is observed as spatio-temporal variability, turbulent and random behavior, a lot of unknowns in the system rules or equations, strongly non-lineal partial differential equations (PDE) modeling the system variability and common numeric instability when the system is studied by computer simulation.

We try to put together the detail complexity of a system with its dynamic complexity through its modeling and simulation, it could be said that the latter is the change in the space-time of the former, nevertheless, the actual control of most of the models lies in the understanding of the latter, instead of the former type of complexity. [***Salery 1998***].

3.2 The OOGM Model

An object-oriented evolutionary model developed to model complex systems, namely natural systems, might represent the structure and dynamics of the system. The system components can be represented along with its properties and functions by using the OO paradigm. This paradigm not only has shown its worth in the last decades due to its modeling capabilities, but when it is extended and integrated with other paradigms, like the evolutionary computing, it has proved to be a simple natural way of representing complex systems whose components evolve into a satisfying solution to the system as a whole [***Pöyhönen 1996***]. A way for this integration was proposed in [***Torres 2000***] as the Object-Oriented Genetic Model, useful to model dynamic systems accounting for both, its dynamic and detail complexity by representing the transformation of evolution of the objects together with their traits and functions into new stages, how it is shown in the figure 1.

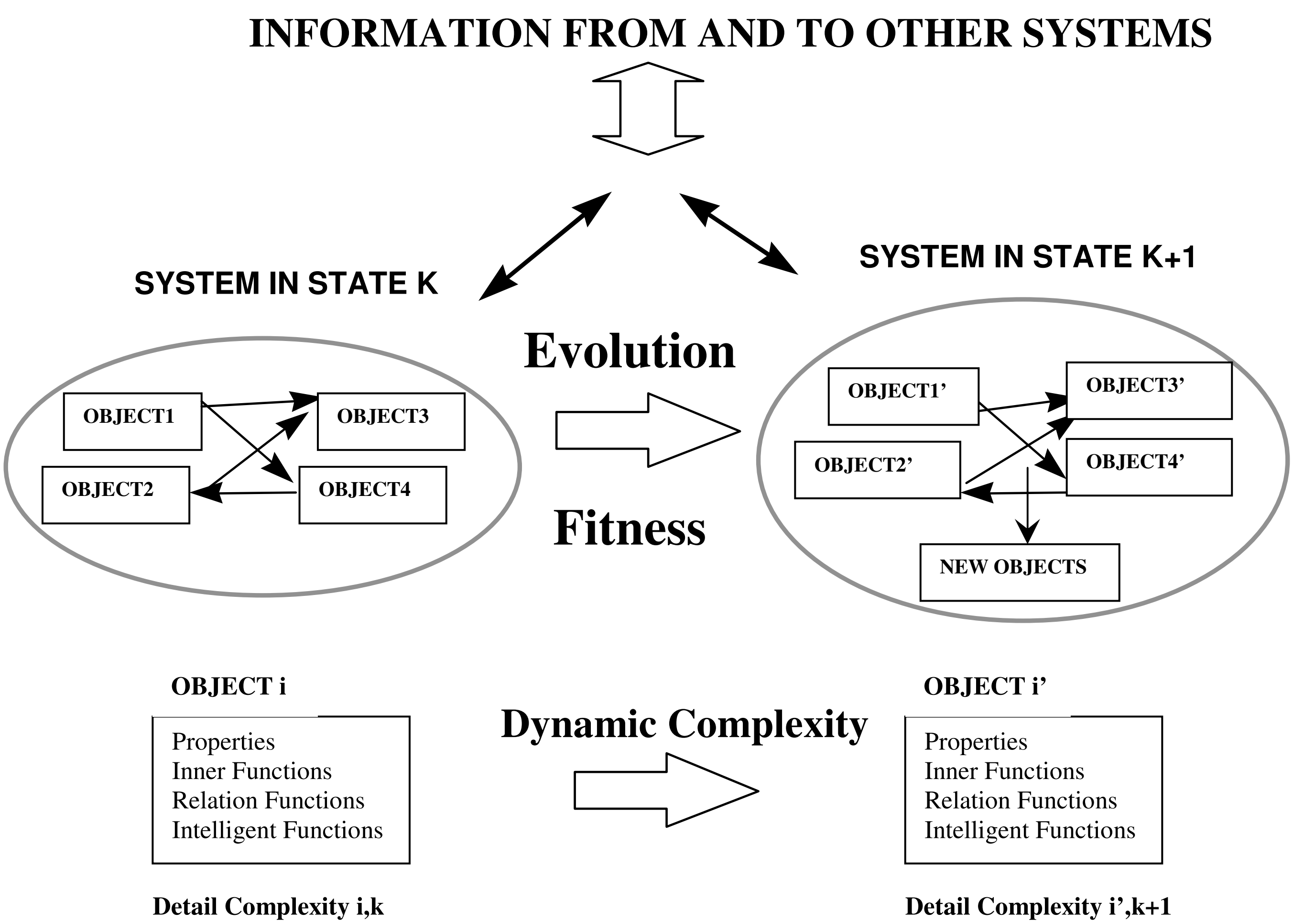

Figure 1. Object-Oriented Genetic Model (OOGM) used to simulate a natural complex system.

As Dorsey and Hudicka [***Dorsey 1999***] said, “a natural philosophy of modeling” is expected to constitute a basis for a new generation of scientific languages. They also show the way in which the universe of modeling of the real world moves swiftly toward the paradigms integration using these new languages like UML. The OOGM conducts still into this direction, even though it is not initially thought to solve all the mentioned difficulties, it opens up a wide route that may be used as support for this purpose. For example, in figure 2 it is shown a schema for intelligent objects that may have the ability to perform as an evolved object, and, in a different way as it is proposed by Woolridge [***Woolridge 2002***] who says that objects are more static and inflexible entities than intelligent agents, this study follows rather the way of García [***García 2001***] who builds intelligent agents from objects, our proposal schema might integrate the intelligent objects which are proposed and the intelligent agents concepts or well might be directed to skip that discussion between their differences, the main idea of OOGM model is kept in spite of this linguistic and conceptual debate.

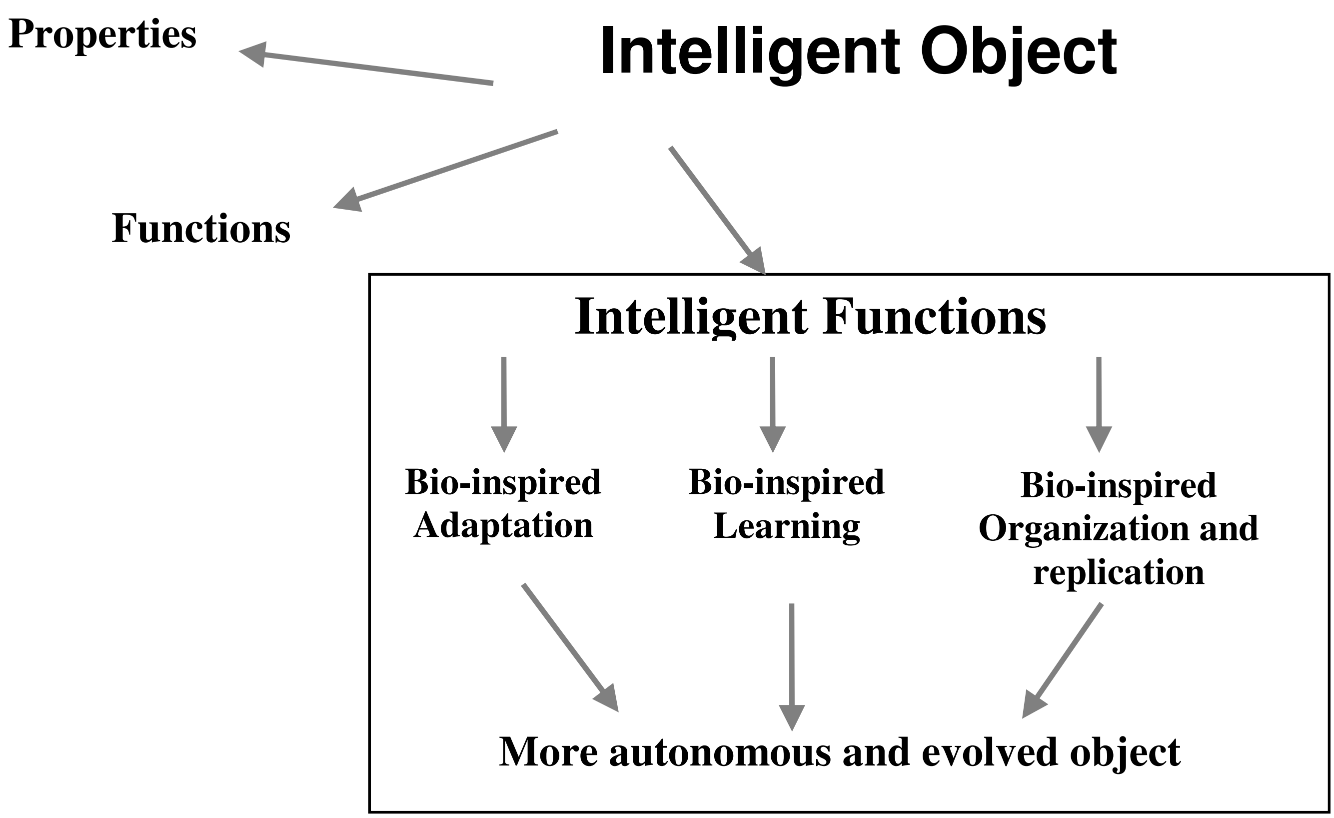

Figure 2. Intelligent object using a biological basis.

3.3 Derivation of the model for intelligent spatial objects from the OOGM model

From the previous model a new one could be derived to try to solve problems related to the analysis of images handled in photogrammetry and GIS (geographic information systems) [***Cabrera 2003***], as it is shown in figure 3. Here we have used the agent concept as an appropriate way to call to these objects, but because of the previously mentioned difficulties, we stay separated of some preliminary given definitions in the artificial intelligence for this concept [***Tirado 2001***]. The figure 4 shows a initial application schema to landforms recognition in glaciers.

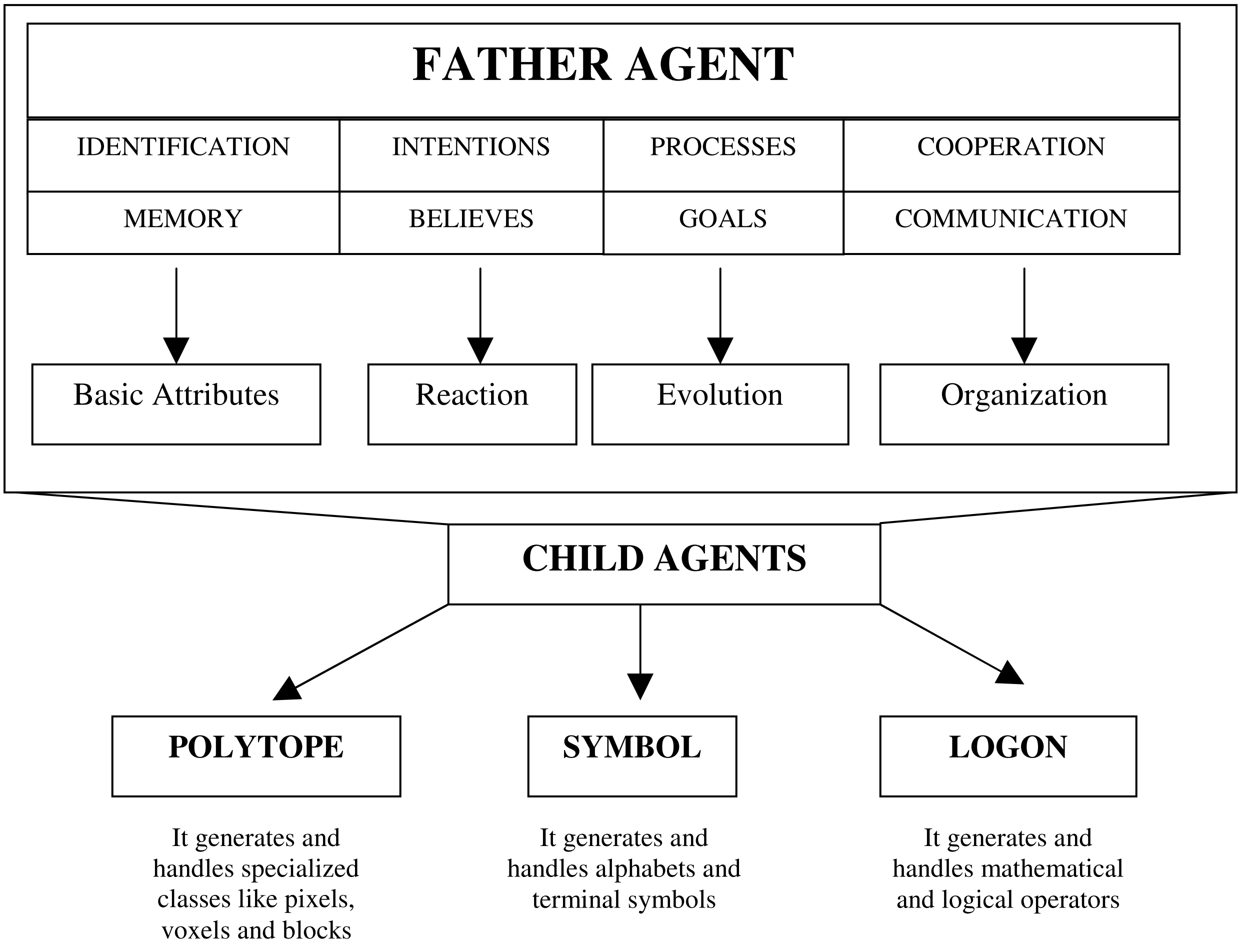

Figure 3. Propose Ontology for spatial intelligent objects.

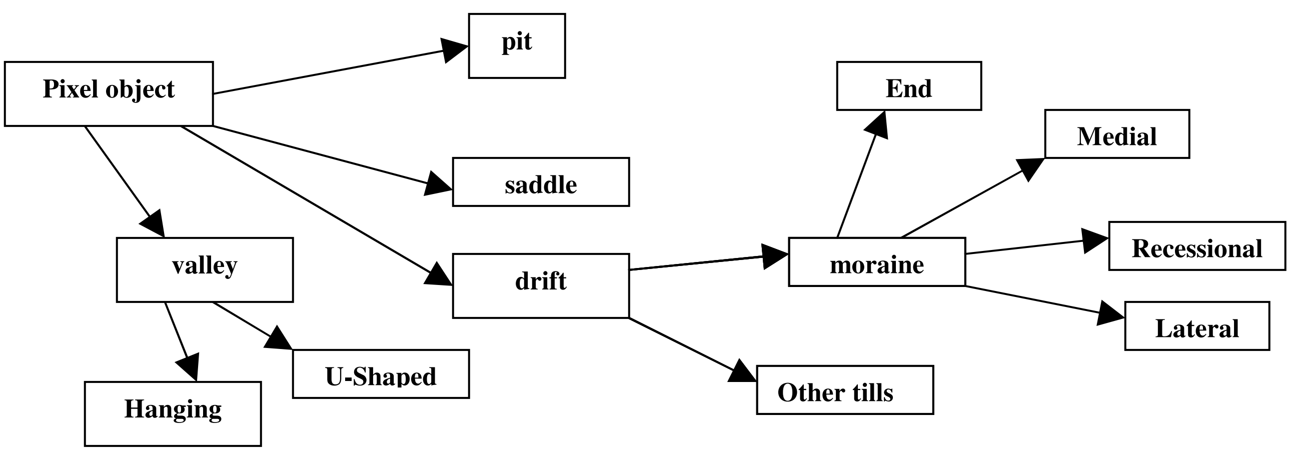

Figure 4. Example for a application of the spatial intelligent objects.

4. Early applications

The model has already been partially tested through complex problems in modeling and simulation of very different natural complex systems, although successful results were achieved after an initial phase of application and test, by different reasons there was not enough time to improve the built application, the model should have been adapted for each specific application, also the problem which in this study is performed it was made a new adaptation and an extension of this model for the new analyzed system. A short summary of these early applications appears at once, and next, the new problem which is nowadays modeled.

4.1 Object - Evolutionary model for gas reservoir simulation

It is well known that the flux in a gas reservoir satisfies non-linear conditions of turbulence. The model was applied to a real case of a colombian gas reservoir in order to provide a practical projection. Gas flux through a porous medium exhibits a turbulence level that can be regarded sometimes as very complex, but chaotic, which tends to be a no linear model when it is going to be simulated. The process of simulation of this phenomenon depends on multiple factors and assumptions necessary to construct a model that converges in the shortest time without loss of validity or precision. Thus, the problem is normally to simulate the future behavior of the reservoir, providing important information about the economic life of an oil field to be managed. Reservoir's elements and the equations which represent its behavior were modeled in object classes with dynamic interaction [***Torres 2001a***].

4.2 Network and path optimization in GIS

Many natural complex systems include optimization problems, particularly network optimization problems that are present in GIS. Because of their excellent flexibility, robustness and adaptability characteristics, genetic algorithms have been successfully applied in the non-linear and complex optimization problems; also, they are very appropriated to face combinatorial problems associated to real systems optimization and transportation networks. An application model using genetic algorithms and object oriented programming, embedded in an interface for geographic information system, was built and implemented [***Sánchez 2001a***]. It is a frequent nowadays practice to get high reliability data coming from satellital spatial records or digital maps; these data are handled, shared and integrated between geographic and cartographic information systems. These kinds of data can help important decision making processes, thus, the main advantage of the network analysis proposed method is flexibility to impose new non-lineal conditions –or constraints– to the target solution and the adaptability to dynamic requirements accustomed to get in the real transportation problems. All elements of the system were represented as objects belonging to one of three classes: nodes (locations, cities, towns, special places, etc), routes (streets, highways, roads, rivers, etc, linking two locations) and paths (sequence of routes). One of the OOGM representation advantages in this application is that, the costs might be non-linear functions depending of geographical aspects, risk probabilities, road failures, etc. Additionally, other arcs connection constraints might be non-linear functions. The genetic algorithm helped to evolve the possible solutions for a proposed path problem.

4.3 Coevolutive machine learning framework in dynamic games.

Game theory have been used since the 1950's to emulate special learning abilities on human societies, herds or colonies; nowadays, game theory is quickly been joined to other related techniques like collective intelligence, coevolutive and neuroevolutive systems [***Stanley 2002; Chern 2001***], trying to build models for giving solution to the most dynamic complex problems. Social aspects theory as self-organization, autopoiesis [***Maturana 1980***] among others, are been used to help this models.

The OOGM were also used to make a preliminary framework for intelligent objects, that lets in a very natural way the learning simulation in computer games [***Tirado 2001***]; this new proposal allows an "intelligent" human-machine interaction, letting they learn each other according with their abilities, knowledge and skills. The interacting entities are depicted as world real intelligent objects, and their properties and relation functions evolve through genetic programming (GP) [***Koza 1996; 1992***], today have been developed new representantion forms in this way [***Rocha 2000; Maley 1999***].

5. Application of the new model for glacial landforms recognition.

The present glaciers change and melting are nowadays analyzed to estimate the Climate Change, besides the development of a glacier can evidence the past history of a ecosystem which plays an important role in the present state of the glacier research activities. In order to illustrate the advantages and apply the proposed model and develop a initial phase of a tropical glacier research, it is applied to recognition of tropical glacial landforms in Colombia. As it is showed in the figure 4, the idea is that by means of this proposed model to be able to recognize basic moraines and others basic glacial landforms, which the model will understand like new objects formed by associations of pixel objects, additionally it could recognize specialized objects from others already determinated like lateral moraines or hanging valleys; the model also offers even the possibility of finding associations of the previous ones like: moraine systems, glacial stadiums or staggered valleys. Recognition of these landforms, which take part of the static complexity of the glacial system, and regarding the same objects with temporally variables, it will be possible at the same time to simulate and analyze also elements of the dynamic complexity or evolution of the glaciological system.

5.1 Digital terrain model (DTM) used.

Initially been selected the Sierra Nevada of the Cocuy has to apply this model, as it is showed in the figure 5a and 5b, this glacier is located in the East Cordillera in Colombia between 6ºN Lat. and 72ºW Long. There are in Colombia a quickly melting process of all glaciers and it is the goal in further studies other important glaciers to model. A 3 meter DTM was achieved from aerial photographs provided for the colombian cartographic service IGAC, satellite LANDSAT TM+ images with 14,25 meter pixel and an AST14DEM image with 30 meter pixel. It was made a photo connection process with EMATIE and aerotriangulation process with BINGO, finally it was effected the DTM with help of LEICA, a part of this model already imported into GRASS ist displayed in the figure 6.

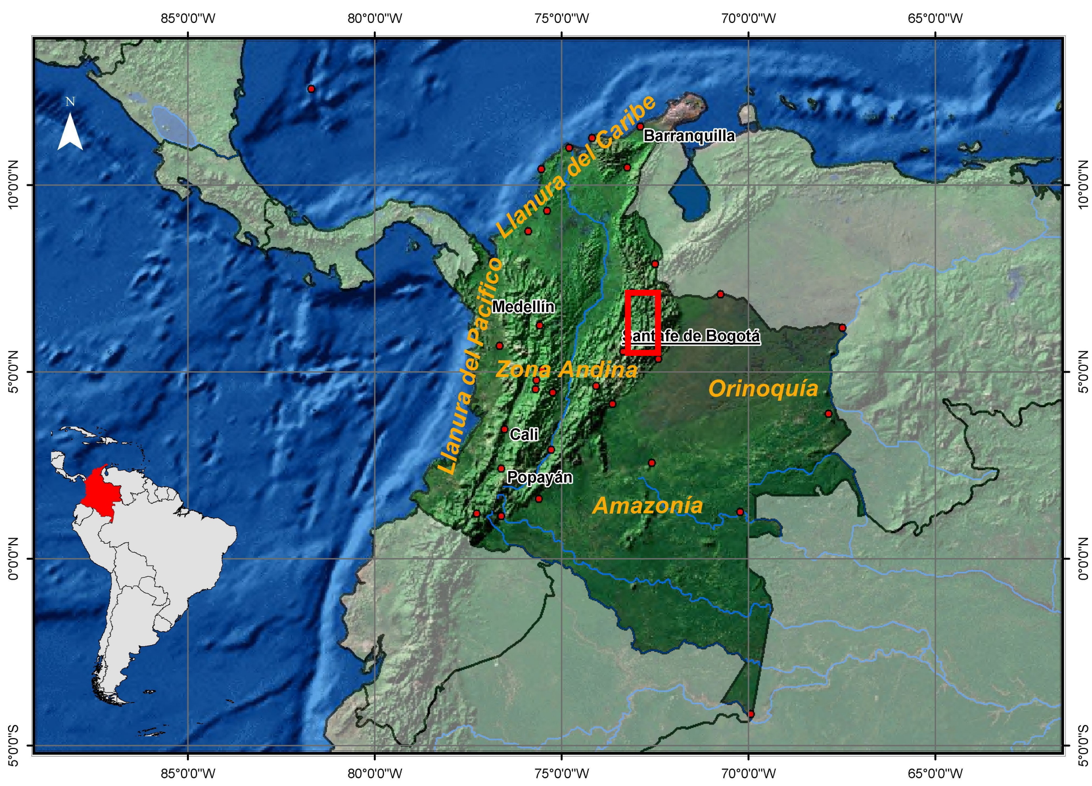

Figure 5a. Investigated area in the East Cordillera in Colombia.

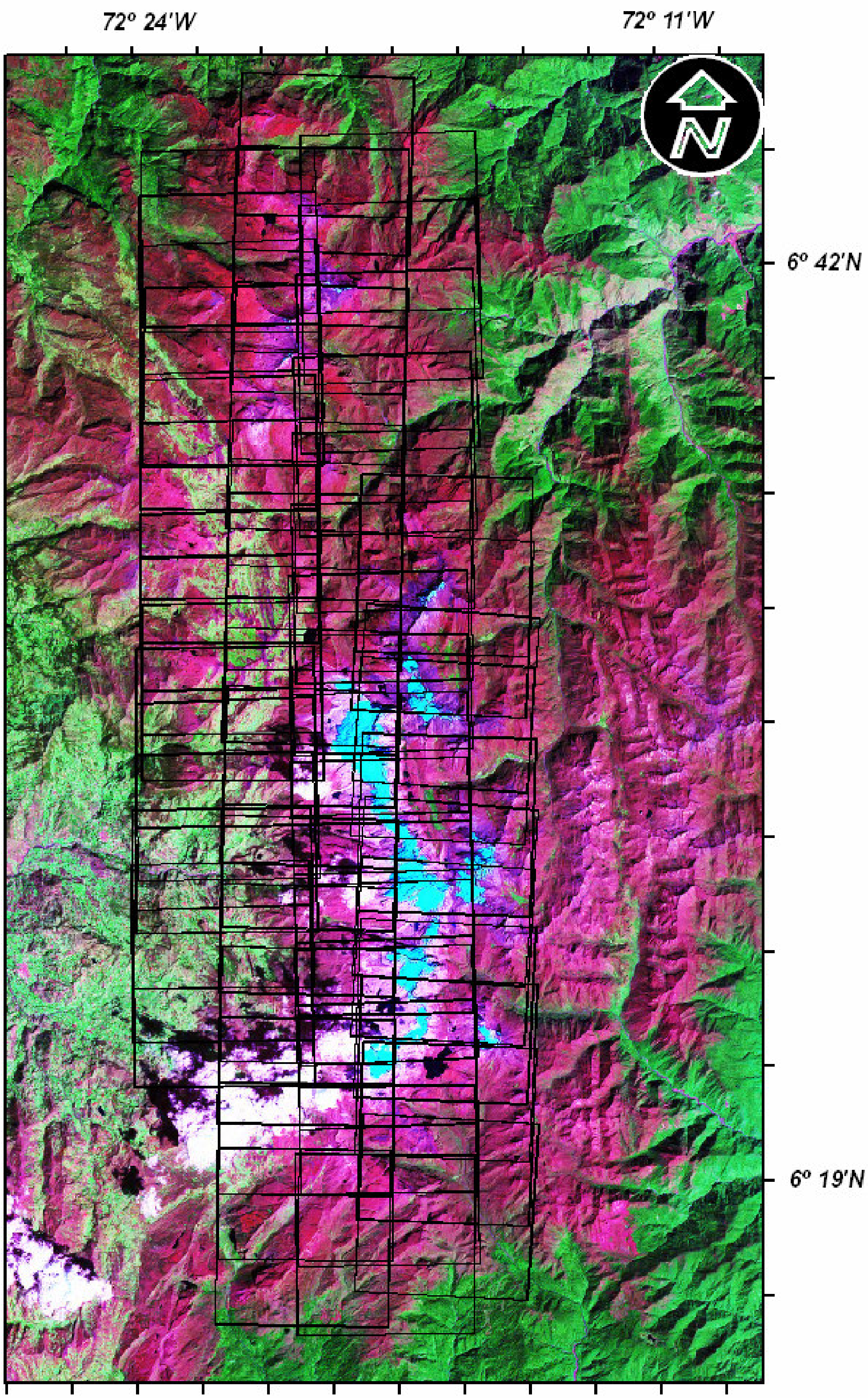

Figure 5b. Investigated area. Photographs and DTM limits depicted on a LANDSAT TM+ image.

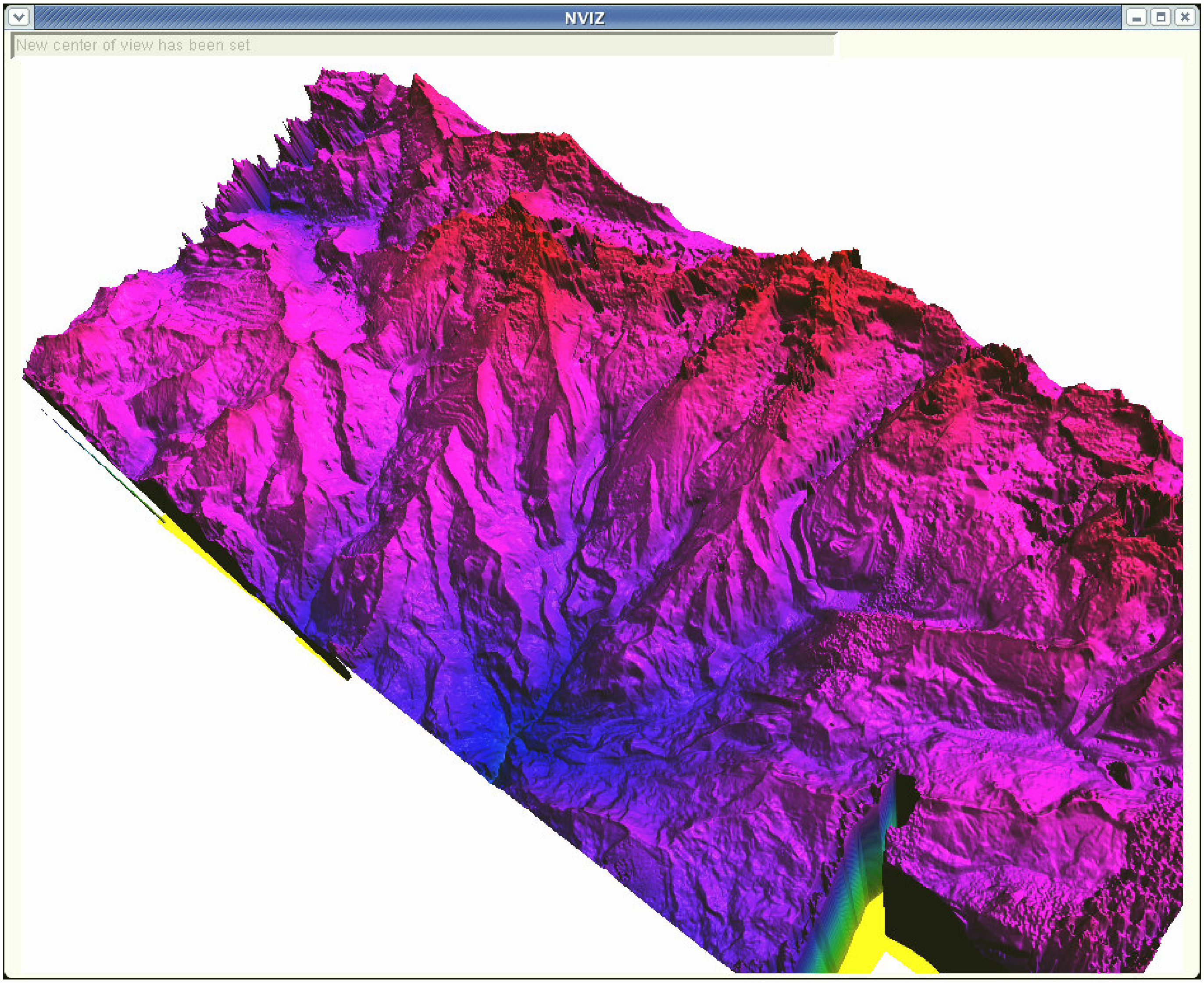

Figure 6. Part of the generated DTM showed in NVIZ.

5.2 Initial glacial landforms recognition through GRASS

Despite the grower number of geomorphometric studies, topographic analysis and theorical modeling; classification processes and good understanding with respect to the temporal and spatial variability of landforms in glaciers are still rather limited [***Schmidt 2003; Wood 1996***]. Tangential curvature has been especially preferred when classifying form elements using two or more curvature components, profile and contour curvatures have also showed a high influence [***Vélez 2006***; ***Schmidt 2004***]. Bonk [***Bonk 2002***] used also morphometric parameters to automate geomorphological mapping at different scales, he has found the similar problems which later Schmidt would also find.

Very interesting for this study are the contributions which Schmidt has performed. Schmidt [***Schmidt 2004***] used a fuzzy methodology for modeling land elements in a two-step process: classification based on local geometry, and derivation of landforms in their landscape context, he has used additionally other curvatures for his classification rules with which could also estimate the prediction uncertainty. In a earlier study discusses also Schmidt [***Schmidt 2003***] the quadratic matrix which is used by curvature and other geomorphological parameters like problematic, besides the selection of the window always appears like one of the main limitations of this methodology, because there is the problem of the dependency of the scale camouflaged. According with his fuzzy model Schmidt claims like important problems to give solution the followings: spatially variable scale, locally adaptive thresholds, improved modeling of landscape position, better rules describing neighborhood relationships and geomorphometric context, and the form and connectivity constraints of land elements.

By using of the techniques suggested by Vélez [***Vélez 2006***] were done the first recognition processes in GRASS, as it is showed and appraised in the figure 7, there were obtained first classifications of valleys and moraines, nevertheless because of the rugosity and strong textures of the landscapes, the valleys tend to mix with others planar landforms and the moraines with the aretes and long high edges. It is very difficult only with the geomorphological parameters to achieve at a precise recognition from landforms in glaciers, and even more difficult, specializations or hierarchical clumps of these.

In agreed with Vélez it was used the following algorithm in order to generate all the possible landscapes, however it is only a way of all possible ones by working with GRASS:

r.mapcalc landforms=R*tcurv*3+R*pcurv.

Where R corresponds to the reclassified maps, tcurv the tangential curvature and pcurv the profile curvature, and the R values are chosen so that represent convex curvatures or concave curvatures, as much in the sense of the maximal gradient like in the sense of the contour perpendicular to the previous one. With this operation a initial map of landforms is obtained that contains nine elements of the landscape modeled [***Vélez 2006***].

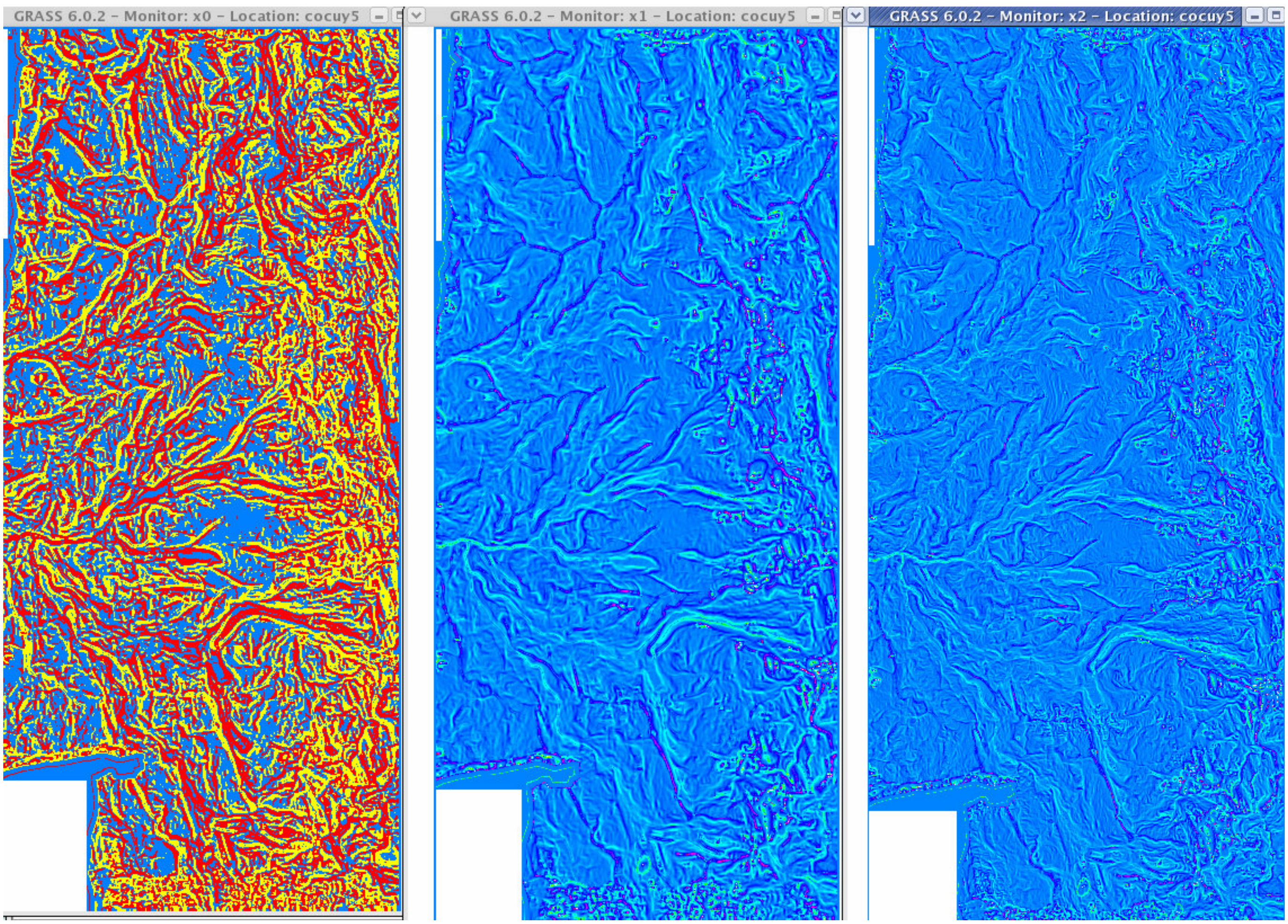

Figure 7. First geomorphometric based classification in GRASS: landforms, profile and tangential curvatures resp.

6. Future work

This study will follow with the planted model and the methodology showed in the figure 8, which tries to extend the previous mentioned techniques and give solution to some of those discussed problems, by enabling a mixture of other variables and techniques, using the new modules in GRASS and by creating new ones. The aim of the presented study is, therefore, to try to develop and test automatic methods for landforms recognition and detection at one or more specific regions of a glacier. It would be possible that the evolutionary algorithms in this area could show many useful advantages. Indeed by using the previous methodology looks for including more variables to be accounted for new algorithms and, due to these landforms mainly the moraines represent the process of glacial evolution, to try to model the development of that process in some of the regions better conserved and not too much deteriorated by the erosion and other glacial processes which have erased the indicating tracks of this history, however it could be that with some partial evidences also these altered landforms can be reconstructed.

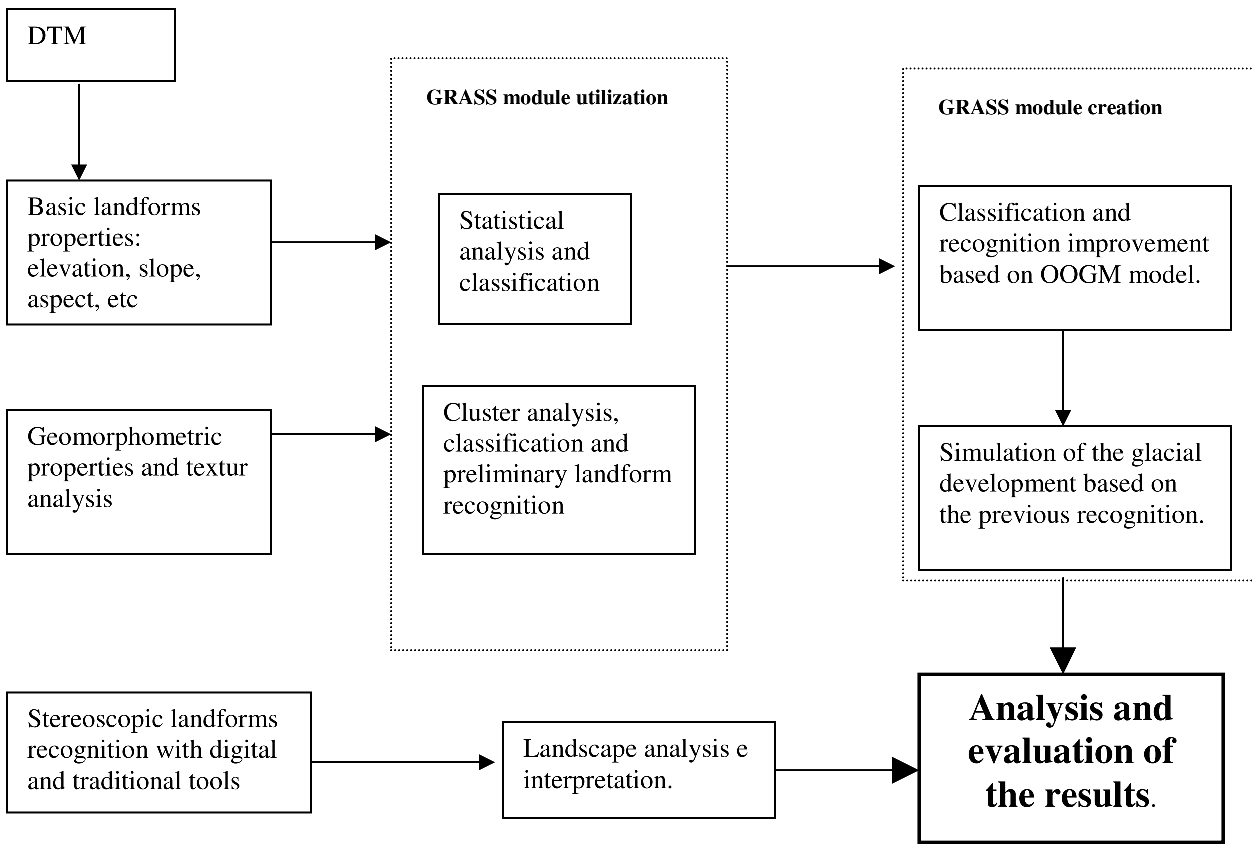

Figure 8. Methodology to be used.

7. Results analysis and relevance

How Jordan suggests [***Jordan 2001***], in the tropical Andes the retreat of glaciers have been documented since the Little Ice Age (LIA) only at a few sites, this is also true for the studies about their glacial development since the Last Ice Age. Today is possible to overcome a detailed study with the modern tools and investigate the probable extinction of these glaciers in the near future due to the drastic shrinkages which could seriously affect the hydrological regime and water resources of the high elevation basins, in addition to the surviving ecosystems and the style of culture and life of many agriculturists in the tropical Andes **[*Vélez 2006*]**.

The Sierra Nevada of the Cocuy is also one of the surviving and more important glaciers of Colombia, it has a very high and unique biodiversity in the ***páramos*** ecosystems, and it is a very important fluvial source because there some are originated numerous rivers that feed the Orinoco river, their maximum height reachs 5500 meters and also undergones the fast glacial defrosting present in all the tropical glaciers [***González 1965***]. Because of all those reasons it is very important to resume with this study and apply open and sophisticated computer techniques like those that GRASS offers in order to develop own models and programs which would help with to simulate and study these ecosystems.

Besides González [***González 1965***] and later Flórez [***Flórez 1996***] have studied the glacial geology and development, and the pollen stratigraphy of this glacier in some drift areas, their investigations can be a support to verify the results of this work

8. Conclusions

This study to try verify that there are a lot of advantages of combining OO modeling with evolutionary computing methods, besides the new evolutionary paradigms like: coevolution in multiagents systems [***Chern 2001***], neuroevolution [***Stanley 2002***; ***Maley 1999***], etc, are promising tools in the study of natural complex systems, still expecting to be evaluated; some of them addressed the similar problems as here was discussed.

The application of this model can help to recognize glacial landforms and to understand glacial processes and to quantify strong non-linear problems in glaciers, generally solved forcibly by linearization. By using GRASS routines and in general OPEN GIS is possible to develop new programs and apply the more modern technology in modeling and simulation.

Problems in geomorphological analysis in glaciers like selection of the window, scale dependency, besides uncertainty of the model or applied methodology, semantic of the geomorphometric models and neighborhood rules, heavy dynamic processes, etc, are waiting for more intelligent solution tools and models, the new opportunities which are offered for the evolutionary computing, could become very important to get better results.

The tropical glaciers in the Anden are disappearing rapidly generating big problems with the nature resources availability for many communities, among others, water and hydropower, further studies and work will be needed in order to quantify, estimate and adequately sustain these resources [***Vélez 2006; Jordan 2001***], besides so many ecosystems with very high and unique biodiversity, mainly in the so called ***Páramos***, are endangered to disappearing in next years because this phenomenon, that makes sense to offer new tools and evolved technology to study the past and present change of these high-mountain systems.

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