STAG: Smart Tools and Applications in Graphics (2022)
D. Allegra, C. E. Catalano, G. Cherchi, and R. Scateni (Editors)

Poster

MUSE: Modeling Uncertainty as a Support for Environment

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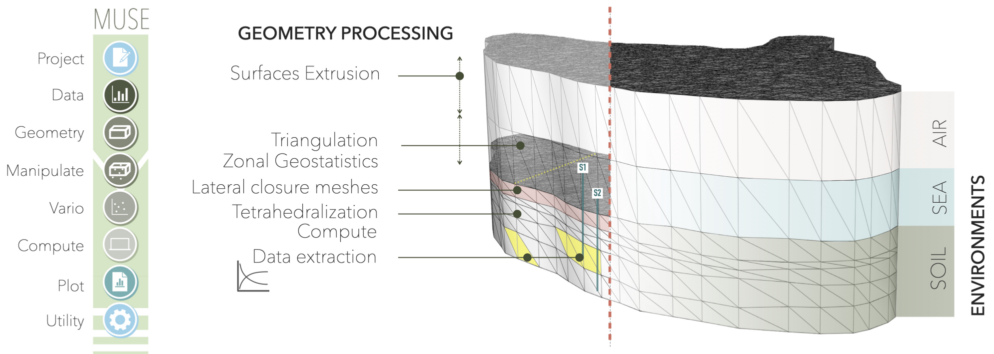

Figure 1: *Summary of MUSE preliminary results: the green bar shows the developed MUSE Core applications (at left); scheme of useful geometry processing functionalities, combined with geostatistical techniques (at center); environmental spatial domains in which the tool is involved (at right).*

Abstract

To fully understand a Natural System, the representation of an environmental variable's distribution in 3D space is a mandatory and complex task. The challenge derives from a scarcity of samples number in the survey domain (e.g., logs in a reservoir, soil samples, fixed acquisition sampling stations) or an implicit difficulty in the in-situ measurement of parameters. Field or lab measurements are generally considered error-free, although not so. That aspect, combined with conceptual and numerical approximations used to model phenomena, makes the results intrinsically less performing, fading the interpretation.
In this context, we design a computational infrastructure to evaluate spatial uncertainty in a multi-scenario application in Environment survey and protection, such as in environmental geochemistry, coastal oceanography, or infrastructure engineering.
Our Research aims to expand the operative knowledge by developing an open-source stochastic tool, named MUSE, the acronym for Modeling Uncertainty as a Support for Environment. At this stage, the methodology mainly includes the definition of a flexible environmental data format, a geometry processing module to discretize the space, and geostatistics tools to evaluate the spatial continuity of sampled parameters, predicting random variable distribution. The implementation of the uncertainty module and the development of a graphic interface for ad-hoc visualization will be integrated as the next step. The poster summarizes research purposes, and MUSE computational code structure developed so far.

CCS Concepts

• ***Computing methodologies*** → ***Mesh geometry models; Uncertainty quantification;*** • ***Software and its engineering*** → *Software prototyping;* • ***Applied computing*** → *Environmental sciences;*

1. Introduction

Modeling natural phenomena is addressed in different application scenarios. As a matter of examples and with no loss of generality, consider the survey of physical and chemical properties of seawa-

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DOI: 10.2312/stag.20221265

ter, the real-time acquisition of atmospheric parameters, and the prediction of the compositional features of a rock mass. They are characterized by clear differences related to the data acquisition system, types of information, and application domain. However, it is possible to recognize features and issues in common among them. Data are characterized by a well-defined configuration in space, related to a specified reference system. Also, they can be described by sampled regionalized variables and by manageable stochastic computational models by approximations. This also applies to many other scenarios and applications where environmental data are captured by sensors embedded into a bounded volume.

The main objective of MUSE (*Modeling Uncertainty as a Support for Environment*) is to provide a software solution for the management of geospatial information for modeling natural systems. The issue related to the heterogeneity of environmental data is addressed by a specialized data format. Standard methods in computational geometry are applied for the localization and spatial data management, adapting the state-of-the-art algorithms to the needs of the application. A powerful feature concerns the full data analysis in general spatial reference systems, to ensure the processing of distributed data in a standard reference system. Particularly, the computational tool is planned to be flexible enough to deal with Cartesian, Euclidean and non-Euclidean space through the management of geodesics and simplex spaces using barycentric coordinates. MUSE exploits the interplay between geometry modeling and geostatistical analysis to both evaluate the spatial continuity of sampled parameters and predicting random variable distribution. Additionally, MUSE represents an innovative contribution, offering functionalities for a more conscious interpretation of environmental phenomena, by integrating the uncertainty intrinsic to data. Then, we intend to deal not only the uncertainty on the results, but also on data, widening the analysis to ranges or measurements with their confidence interval (i.e. *soft data*) as input.

2. MUSE Design and Implementation

The computational code structure can be split into three modules. *MUSE Core* focus on loading and processing environmental data. That module will be extended at later stages by the integration of the uncertainty models (*MUSE Uncertainty*), and by the development of advanced graphical interfaces to visualize, process, and query the results (*MUSE Visual*). The tool is built according to a modularized procedure and software design, to make it as robust as possible, and easily upgradeable according to new needs. The code is developed in C++ and works on different Operating Systems.

Preliminary results about *MUSE Core* main functionalities are summarized in the scheme in Figure 1.

Input Data Format To address the problem of data heterogeneity, input have been organized according to their common features. Data are formatted including in headers specific information about their nature, and then prepared through a system of flags to be processed by optimal algorithms. For example, continuous variables, defined on a set of real positive numbers, are distinguished by R+ flag from categorical variables (K). A plain .csv file with fixed header is chosen as input data format. Each .csv file column corresponds to a single variable, which will then be read and suitably processed coherently to flags. After passing checks, the variables are stored into *MUSE Data Format*, defined as a pair of data file, and json file for additional information.

Geometry Processing tools The geometry module comprehends all tools necessary for 2D and/or 3D discretization of the space, where the samples are located. It includes the pipeline developed and described in the work [MCP*22], to generate volumetric objects from the triangulated surfaces definition. In *MUSE Core-Geometry*, that workflow is extended and generalized to support different input, such as raster and vector geospatial data formats (e.g., *ESRI Shapefile*, *GeoPackage*), exploiting the functionalities of *GDAL* external library [GDA22]. Additional tools are also included to extract data, located in different sub-domains, to properly compute the variography, and simulations at next step.

Geostatistics Starting from the definition of *regionalized variable*, the next stage is to process and predict spatial distribution of sampled random variables on the reference geometry. After the evaluation of the existence of a model of spatial dependence (variogram), least-squares regression algorithms (Kriging interpolator) supports stochastic models simulation-based to estimate values at unsampled locations [Goo*97]. The geometric model, obtained as previously shown, coupled with the spatially distributed random variable, becomes the support for these analyses, by exploiting the full set of features. The first approach to the assessment of local uncertainty will be performed by the application of simulations algorithms on a synthetic multi-variable field. At this stage, *MUSE Core-Vario* is able to calculate 3D omnidirectional, and 2D directional variograms, in both automatic and manual mode. Geostatistical processing tool, *MUSE Core-Compute*, works on continuous variables exploiting *Sequential Gaussian Simulation* (SGS) algorithm [WO07]. All functionalities are developed for continuous variables, and will be extended for discrete variables.

3. Conclusions

In the field of Geosciences, MUSE solves the lack of a unique and complete tool, that can handle different environmental data, on a generalized geographical reference system adapted to different situations, making available an explanatory representation of uncertainty. Additionally, we expect to address the results to the widest audience, such as theorists, Environmental Agencies, Research Institutions and policy or decision makers.

At this stage, the main pipeline of computational code is under development. At the current status, the system works only on error-free measurements (i.e., *hard data*). After testing *MUSE Core* with real case studies, the activities will be focused on *MUSE Uncertainty*, and *MUSE Visual*.

Acknowledgments

This work is developed under the Ph.D. Research Project in Earth and Environmental Science and Technology, supported by PON "Ricerca e Innovazione" 2014-2020, Asse IV "Istruzione e ricerca per il recupero", Azione IV.5 "Dottorati su tematiche Green" DM 1061/2021.

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