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Progressive metaheuristics for high-dimensional radiative transfer model inversion

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Abstract

Determining planetary surface composition via remote spectroscopy frequently requires the use of inverse modeling, as the surface presents a complex mixture of materials which cannot be directly identified from the spectra. Depending on the complexity of the radiative transfer model (RTM) used, however, the inverse problem can be nonlinear and very high-dimensional, and the computational cost of traditional optimization methods becomes prohibitive. We demonstrate the utility of a multi-step metaheuristic approach for the inversion of high-dimensional RTMs, using the example of Pluto.

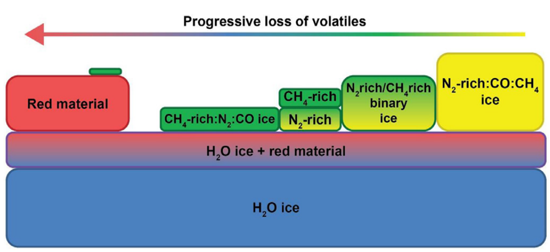

Figure 1: Schematic representation of the various materials present on Pluto and their possible mixing states [1]

1 Example case: Pluto

Since arriving at Pluto in 2015, New Horizons has sent back vast quantities of data, including high-resolution hyperspectral cubes from the LEISA instrument. Data reduction and PCA has allowed us to identify the major types of surface material and to qualitatively map their composition [1]. These types of material interact in multiple ways, including molecular, granular and vertical mixing (Fig. 1). A first quantitative map based on a pixel-by-pixel model inversion has also been created, but the model used is simplified, only taking into account sub-pixel areal mixing [2].

Work is ongoing to produce an accurate surface composition map of Pluto based on the RTM Spectrimag [3], which takes into account a multitude of free physical parameters including grain size, material porosity, and material abundance in the various types of mixtures. As the dimensionality of the model can exceed 40, the search space becomes too big for conventional optimization methods such as gradient descent, and higher-level methods such as metaheuristics may become more efficient.

2 Progressive metaheuristics

When the solution landscape for the inversion problem is "rugged", metaheuristics such as simulated annealing have a strong advantage, as they offer a good compromise between exploration and exploitation. In a high-dimensional landscape, however, randomly drawing initial parameters might not suffice to explore all promising solutions.

To avoid this shortcoming, our proposed method starts by stochastically evaluating the magnitude of effect and variability of each parameter to obtain a ranking. We then use standard metaheuristics to get candidate solutions for a subset of high-importance parameters and progressively increase the dimensionality by including parameters of lesser importance.

We expect this approach to be very fruitful for inverse problems with high-dimensional parametrization in general and the compositional cartography of Pluto in particular, and will discuss the methodology and preliminary results in detail during the congress.

References

[1] Schmitt, B., et al. Physical state and distribution of materials at the surface of Pluto from New Horizons LEISA imaging spectrometer. Icarus 287 (2017): 229-260.

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[3] Douté S. and B. Schmitt. A multi-layer bidirectional reflectance model for the analysis of planetary surface hyperspectral images at visible and near infrared wavelengths. J. Geophys. Res. E, 103 (1998): 31367-31390