Spatial agents for geological surface modelling

E.A. DE KEMP [1*]

[1]3D Earth Imaging and Modelling, Geological Survey of Canada, Ottawa, Canada, Eric.dekemp@canada.ca
*presenting author

Abstract

Semi-autonomous software entities called Spatial Agents can be programed to perform spatial and property interrogation functions, estimations and construction operations for simple graphical objects, that may be usable in building 3D geological surfaces. These surfaces form the building blocks from which full topological models are built and may be useful in sparse data environments, where ancillary or a-priori information is available. Spatial Agents are used to represent common geological data constraints such as interface locations and gradient geometry, and simple but topologically consistent triangulated meshes. Spatial agents can potentially be used to develop surfaces that conform to reasonable geological patterns of interest, provided they are embedded with behaviors that are reflective of the knowledge of their geological environment. Initially this would involve detecting simple geological constraints; locations, trajectories and trends of geological interfaces. Local and global eigenvectors enable spatial continuity estimates which can reflect geological trends with rotational bias using a quaternion implementation. This simulation environment implemented in NetLogo is potentially useful for complex geology - sparse data environments where extension, projection and propagation functions are needed to create more realistic geological forms.

Keywords – Spatial Agents, 3D Geological Model, Simulation, Surfaces

Introduction

Spatial Agents and Spatial Multi-Agent Based Modelling Systems (SABS and SMABS), or the non-spatial Agent Based Modelling Systems (ABMS) form a family of approaches which have been used in a wide range of applications that take advantage of the efficiencies and freedoms that these systems posses (Torrens 2010). The agent(s) in these systems are software entities that have been programed to work according to specific or general pre-programed beliefs. When 2D/3D or 4D maps are involved in the modelling process we can refer to Spatial Agent Based Models (SABM). In general, an agent based system is used to see the effects of autonomous individuals, groups or objects on the overall system when solutions are onerous and/or computationally expensive. Agents operate as semi-autonomous entities that are not directly controlled by any centralized command structure and may have a great deal of independence from each other as well. These 2 characteristics, freedom from central command and a good degree of independence, combine to make a powerful modelling combination that has been successful in many domains to solve complex problems.

Agent applications are extensively used in the entertainment industry, computer games for sports and battle simulation (Guo and Sprague 2016), Urban planning (Motieyan.and Mesgari 2018); crowd modelling for public transport and community infrastructure design (Dickinson et al. 2019); Climate change and adaptation modelling (Amadou et al. 2018); Architecture and Engineering design (Guo and Li 2017) as well as hazard response and real time 3D mapping (Schlögl et al. 2019); transportation and surveillance using semi-automated or fully-autonomous vehicles such as drones and automobiles (de Swarte et al. 2019). Agent based modelling has been used in the Earth Sciences for modelling solar storm and flare activity (Schatten 2013), Groundwater modelling (Jaxa-Rozen et al. 2019) and Earthquake prediction (Azam et al. 2015) to name a few examples. This research is an initial attempt to highlight some of the properties and general behavior of spatial agents for the simplest of geological data, through several agent demonstration programs, in order to start the process of examining their potential for solving some geological modelling problems. Spatial agents are used to represent simple contact surfaces as agent constructed triangular meshes, fold closures and simulations of unmeshed structural swarms from sparse points. The code implementation was done in Netlogo-3D agent-based modelling software (Wilensky 1999), taking inspiration from some earlier model examples such as wave 3D (Wilensky 1996) and flocking codes (Reynolds 1987, Wilensky 1998). Download the Netlogo-3D software and try some simple examples to gain a better appreciation of the agent environment. Each code example (contact eric.dekemp@canada.ca) provided will have a Netlogo implementation version that can run the code.

1 Current Geological Surface Modelling

Geological models are currently constructed through an iterative process of automated interpolation combined with interpretation from data constraints (Caumon 2009, Groshong 2006). Computer methods and workflows are applied to data and output a collection of essential geological features, generally faults and horizons, which combine to form a framework structural and stratigraphic model. A common theme with our arsenal of tools for this work is that it is becoming more and more difficult to come up with a range of solutions that can both respect all the data inputs and the known complexity of features being modelled (Jessell et al. 2014).

Are Agents a way to more efficiently tackle this problem by providing a framework from which our existing tools can be embedded? This remains to be seen, but at a minimal we need to see if simple agent operations can be used to model geological data.

2 Spatial Agents

An area of current research for surface modelling in sparse regional domains is the use of spatial agents for enhancing knowledge embedded estimation, projections and extension functions (Torrens 2010, de kemp and Jessell 2013). A simple demonstration set is presented that produces simple fold solutions for sparse data, interpolation of planar and linear structure data as well as polarity control of observations and estimations (figure 1 & 2). Spatial agent triangulated meshing can be controlled to grow from single point sources such as observation sites, respect simple rules to maintain local and over all surface polarity as well as topologic rules to accept or reject topologic meshing criteria.

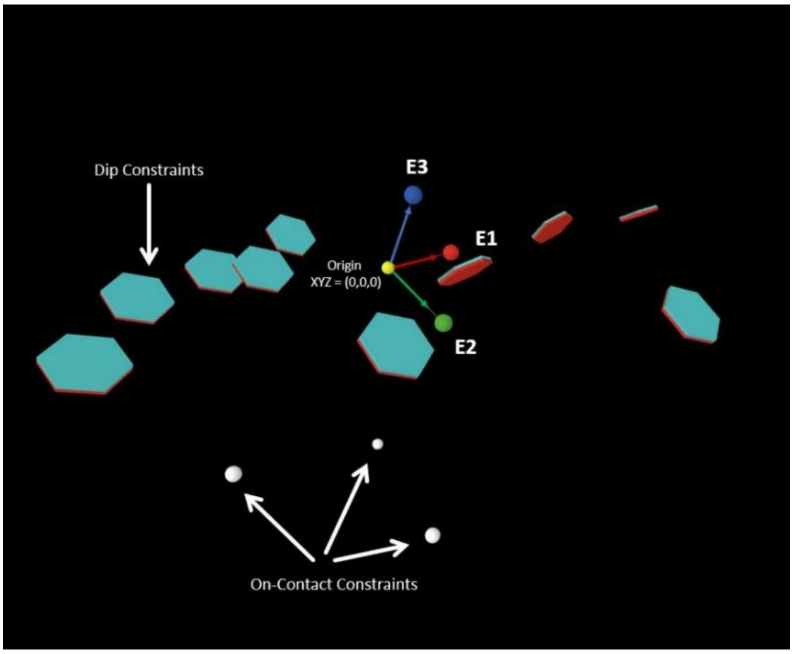

Figure 1 – On-contact (white spheres) and dip (blue=upright, red=down, thin hexagonal prisms) representing simple 3D geological data constraints. Arrows at origin indicate the calculated orthogonal unit Eigen vector directions for the structural data. The data is generated artificially by randomly positioned sites on the plane of the main controller (see figure 2). The orientation of each dip data point is set by random rotation perpendicular the E1 axis, to achieve a user specified variability

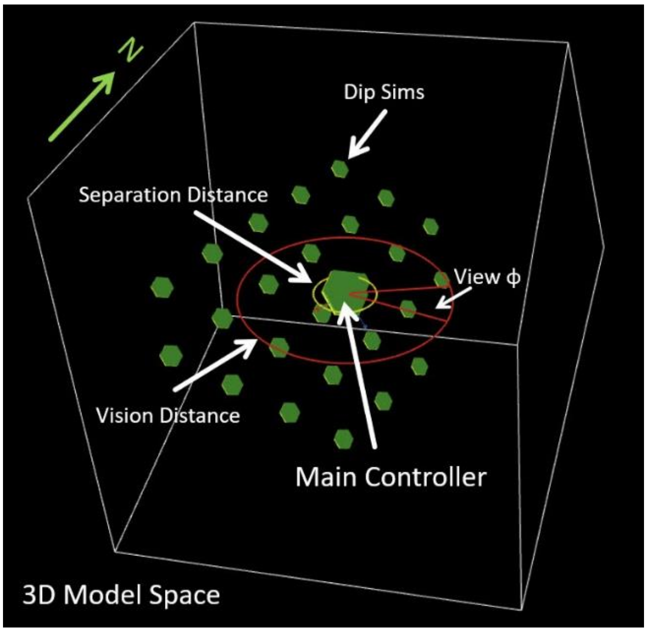

Figure 2 - Components of the Spatial Agent Based System (SABM). Model (X,Y,Z) dimensions = (100,100,100) with model centre at (X,Y,Z) = (0,0,0). Main Controller, large green-yellow hexagon symbol is stationary at model centre with orientation (strike,dip, polarity) defined by user. Surrounding Dip Sims, act as interrogation agents, represented as smaller hexagons that are dynamic and sense adjacent agents. Dip Sims can only see other Dip Sims within the Vision Distance and the View Angle (ϕ), they are kept from each other by a user defined Separation distance. All planar feature rotations performed through use of Quaternion geometry.

2.1 Agent Behavior and Characteristics

- Agents can explore all the model space and all the data regardless of how irregular the space is and how varied or complex the data is. The approach can make many or no solutions, simple or complex depending on the model design. Generally traditional methods use more regular partitioned spaces, fixed coordinate systems and one or two geologic parameters.

- Agents can be more suitable to natural multi-scalar complex systems in which agents can preserve contributions from all data. Important in combining geology-structure-geophysics.

- A variety of knowledge-based Rules, Missions (Beliefs) and Behaviors can be applied while interacting with and interrogating data thus supporting the interpretive process for the domain expert.

- Many spatial estimation algorithms can still be applied within an agent system (Kriging, DSI Discrete Smooth Interpolation, RBF Radial Basis Functions, Implicit, IDW Inverse distance Weighted, SVM Support Vector Machine, etc.) at local or regional scales depending on the requirements.

- Produces group – swarm behavior that emerges from simple agents interaction-communication. Potentially modelling complex geometric features or triggering other spatial behaviors (discontinuities), topologic changes or spawn new agent driven events. Important when mapping and visualizing complex relationships within vector fields such as fabric intersections, fold trains, vergence relationships and multiply folded and faulted stratigraphic boundaries.

- Simple rules-sets drive the agent interaction rather than solving for a single large global matrix. Agent approach may have good optimization potential, it can benefit from faster and denser CPU/GPU architecture and could potentially be easier to parallelize. Important when combining 3D vector and multi-scalar properties from structural fields (i.e. Burns 1988, Hillier et al. 2013), geophysics and geology.

Discussion

This study focuses on the rudimentary requirements for geological modelling using spatial agents. Primarily, their ability to interrogate, communicate and represent solutions to simple sparse geometric or structural constraint data configurations. Natural examples of agent behavior, such as swarm behavior, have emerged over millennia through the embedding of simple rules into organisms which have evolved for optimization of the group survival. This paradigm, although perhaps not obvious for geological applications, could take a similar path and may be an opportunity to leverage geological knowledge through embedding of specific behaviours for given geological processes that could be controlled through simple geological rule sets, for example by programing agents to maintain a range of thickness between stratigraphic layers as they are propagated regionally.

Conclusion

Spatial Agents can be used to develop simple meshed surfaces, fabrics traces, anisotropies and structurally sensitive swarm surfaces. Structural agent interrogators exploring a model space can update local or group behavior to conform to on-contact or within volume topological dip constraints.

Agent based tools as applied to geological applications are yet in their infancy but can be used to interpolate or extrapolate from data to produce fabric trajectories, gradients, vector fields and continuous or discontinuous polyhedral meshed surfaces.

Investigation into the use of and optimization of Spatial Agents needs to be undertaken to demonstrate any benefits for complex geological modelling in a variety of data configurations that could represent typical geological scenarios.

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