A Real Space Cellular Automaton Laboratory (ReSCAL) to analyze complex geophysical systems

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Abstract

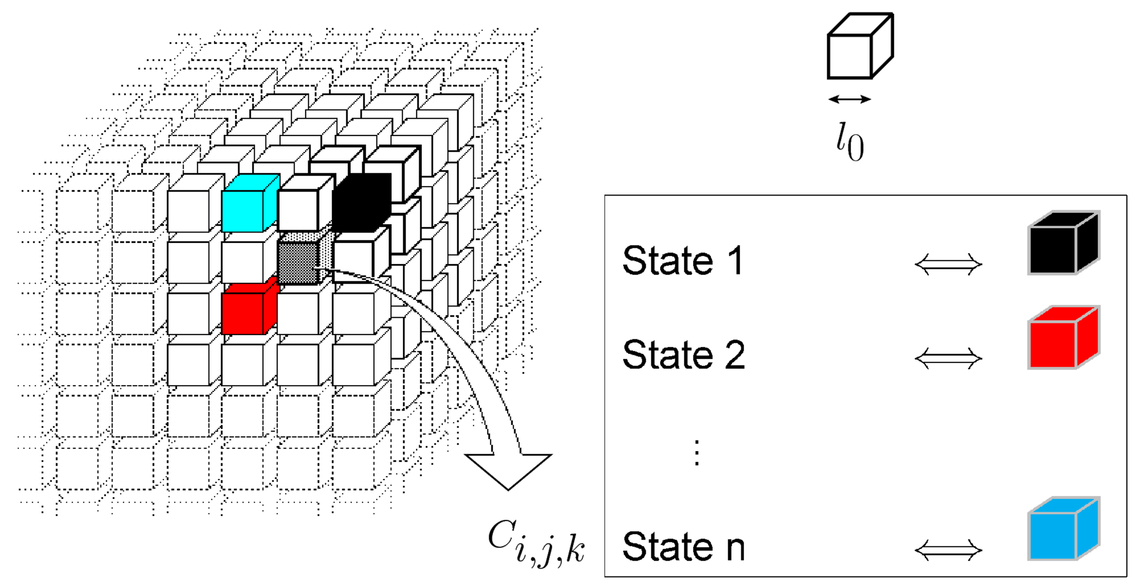
The Real Space Cellular Automaton Laboratory (ReSCAL) is a generator of 3D multiphysics, markovian and stochastic cellular automata with continuous time. The objective of this new software released under a GNU licence is to investigate the dynamics of complex geophysical systems and develop interdisciplinary research collaboration.

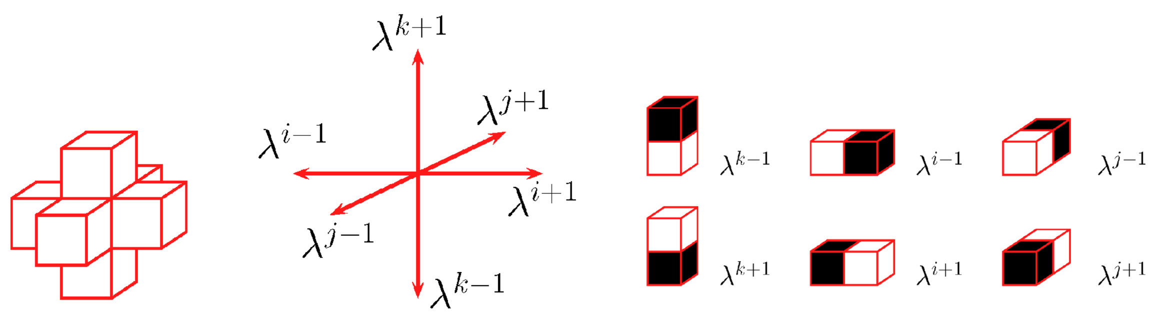
ReSCAL key features

- Stochastic process for transition of neighboring cells (doublets).
- Setting physical environments and boundary conditions.
- Computation of the physical length and time scales.
- Detection of solid surfaces and steepest slopes.
- Avalanche dynamics (segregation and stratification).
- Localized control and forcing of the transition rates.
- Optional coupling with a multispeed lattice gas automata.
- Real-time rendering and light shading.

Stochastic cellular automaton

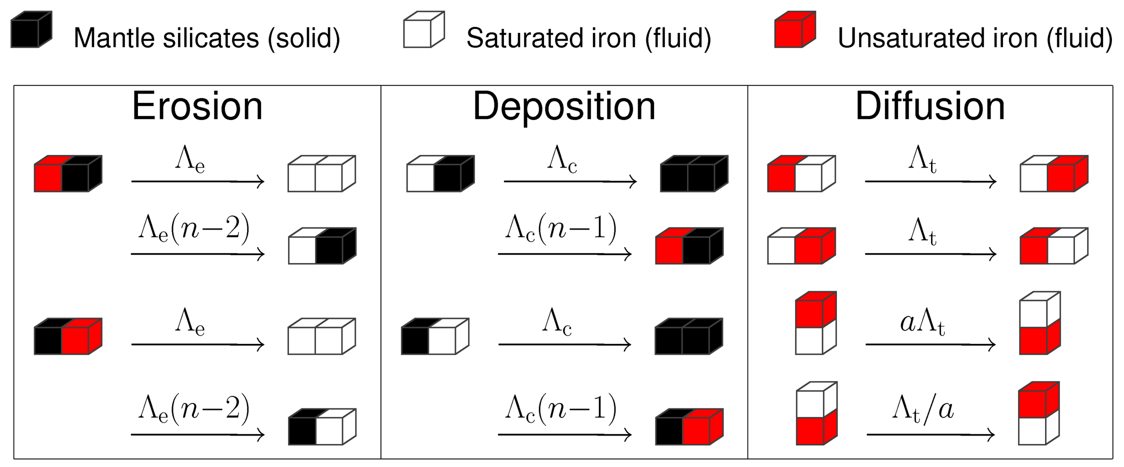
Our cellular automaton consists of a discrete dynamic system within a 2D or 3D grid of cells with a finite number of states. The evolution processes are defined in terms of stationary or non-stationary transition rates between the various possible states of the doublets (e. g. Poisson process).

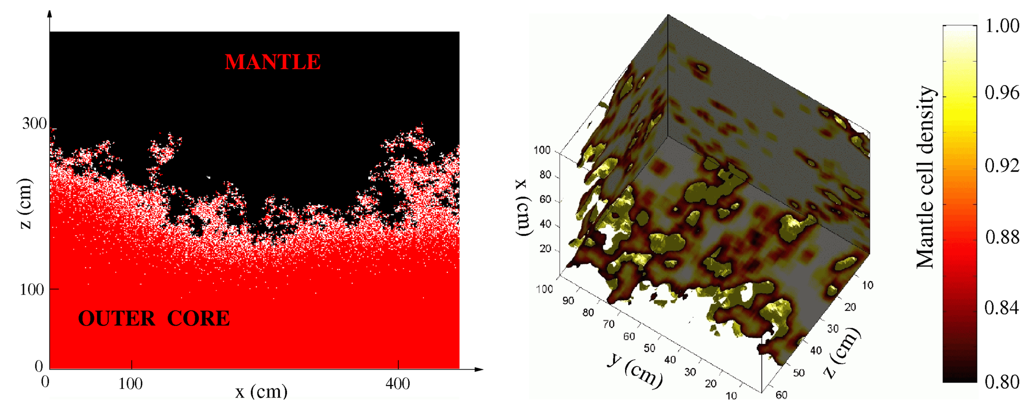




l_0: elementary length scale in meters.
t_0: time unit in seconds. Transition rates λ are in units of $1/t_0$.

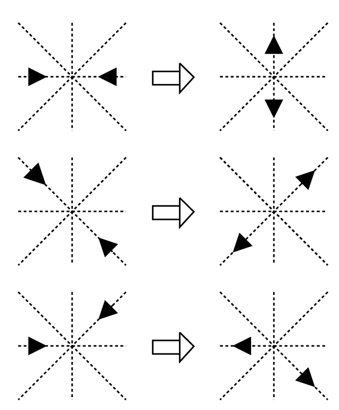
Model #1: Roughness of the core-mantle boundary



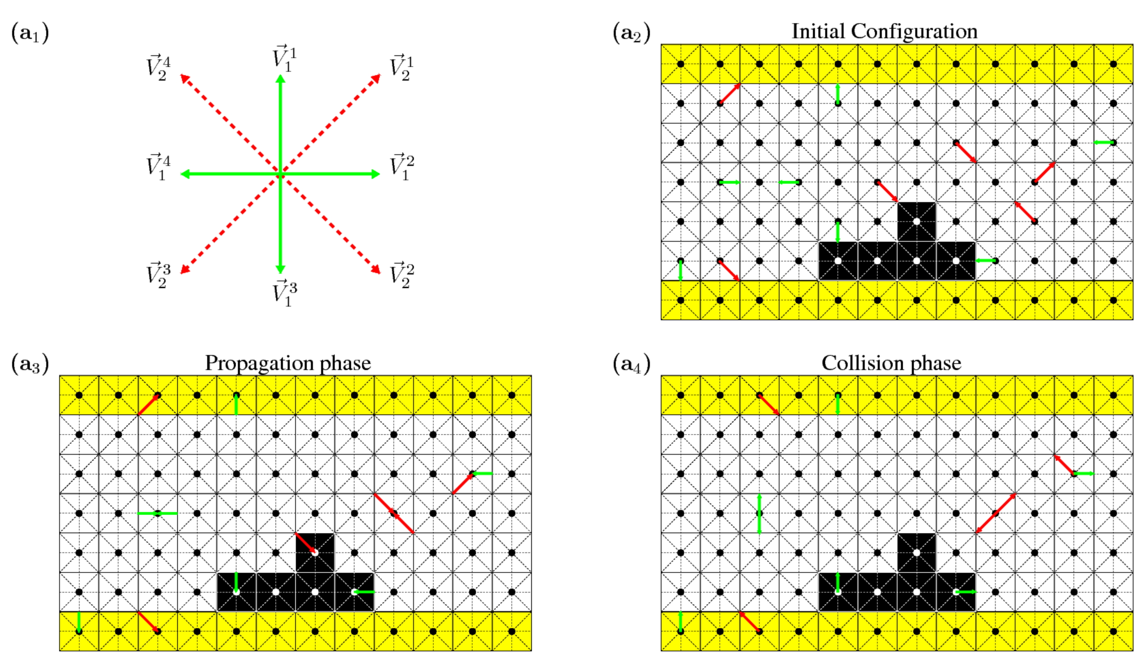


Lattice gas coupling

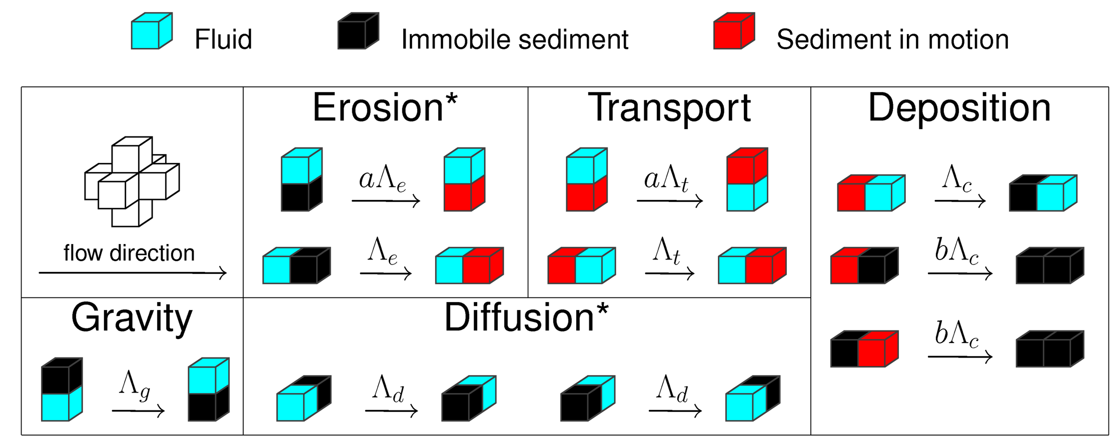
Optionally, a 2D fluid flow can be computed from the discrete motions of particles along 8 directions, according to a set of collision rules. Numerical methods provide the mean velocities for the local modulation of transition rates. Thus we obtain a permanent feedback between the topography and the flow.



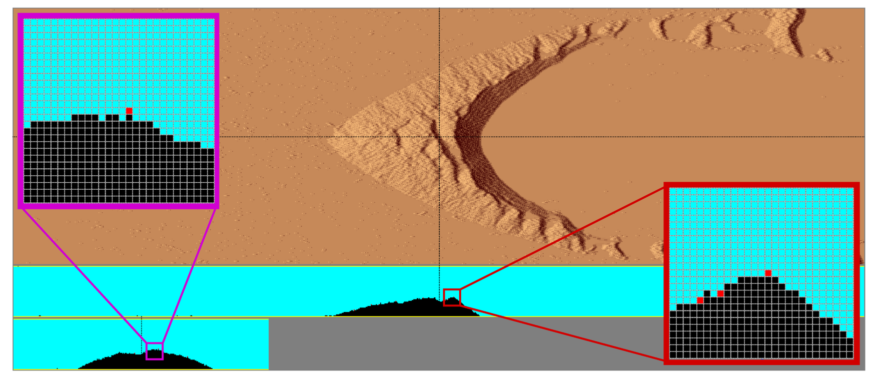
Collision rules



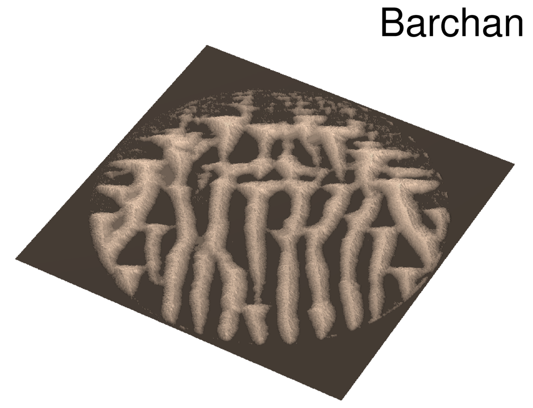
Model #2: Dune morphodynamics



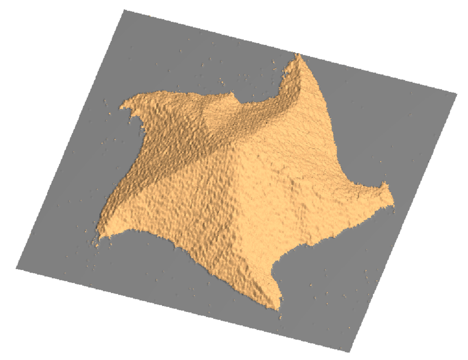
(*) transitions controlled by the shear stress of the flow



Barchan dune



Longitudinal dunes (2 winds)



Star dune (5 winds)

Algorithm

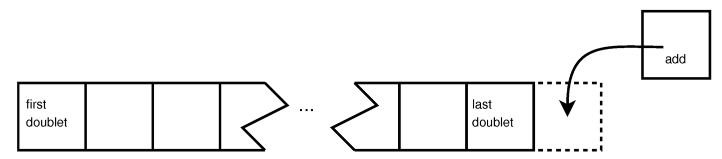
```
creation of the cellular space;
initialization of the lattice gas;
surface topography;
time scale;
while end_of_simulation = FALSE do
    if elapsed_time > lgca_delay then
        lattice gas collisions;
        lattice gas propagations;
        interpolation of the velocity field;
    end
    probability distribution;
    stochastic transition of doublet cells;
    time evolution;
end
```

Structured data

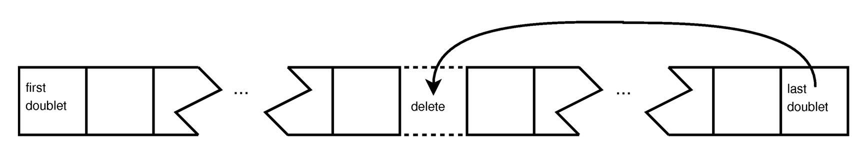
- Cross referenced arrays of cells and doublets, providing direct access to the cellular space location.
- Polymorphism of the cells.

Optimization

We implemented dynamic arrays of active doublets with automatic defragmentation. Thus we obtain contiguous memory pools for each kind of active doublets.



Add doublet



Delete doublet

Execution speeds

- up to 10^8 transitions/min. without lattice gas.
- up to $3 \cdot 10^7$ transitions/min. and 1000 cycles/min of lattice gas.

Conclusion

Our modular approach can be applied (and developed) to analyze various complex geophysical systems with reasonable numerical efficiency.

Supplementary informations

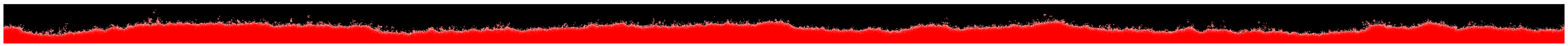
Sources available online via
http://www.ipgp.fr/~rozier/ReSCAL/rescal-en.html

References

[1] C. Narteau, J.-L. Le Mouël, J.-P. Poirier, E. Sepulveda & M. Shnirman, On a small scale roughness of the core-mantle boundary, *Earth and Planetary Science Letters*, **191**, 49–60 (2001).

[2] C. Narteau, D. Zhang, O. Rozier & P. Claudin, Setting the length and time scales of a cellular automaton dune model from the analysis of superimposed bed forms, *J. Geophys. Res.*, **114**, F03006 (2009).

Dune figures by Deguo Zhang.



Numerical simulation of the core-mantle boundary with 20000x500 cells

EGU, General Assembly 2012, Session GM2.4, Vienna, Austria