# *ESPLICITAZIONE DELLA VELOCITÀ PER LA MODELLIZZAZIONE E SIMULAZIONE DI FLUSSI DI SUPERFICIE MACROSCOPICI CON AUTOMI CELLULARI ED APPLICAZIONI ALLE COLATE DI LAVA DI TIPO ETNEO*

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## ABSTRACT

Cellular automata are widely utilised for modelling and simulating complex dynamical systems, whose evolution depends on the local interactions of their constituent parts. SCIARA is a Cellular Automata model for simulating lava flows; its release $\gamma 2$ introduces innovations to the empirical method for modelling macroscopic phenomena that was utilised in the previous releases. The lava flows are described as "blocks", individuated by their barycentre co-ordinates and velocities. This approach is different from the previous releases of SCIARA and from cellular automata derived models for fluid-dynamical phenomena such as lattice-gas and lattice-Boltzmann models. Block specifications permit to obtain a more physical description of the phenomenon and a more accurate control of its development. SCIARA $\gamma 2$ was applied to the 2002 Etnean lava flows with satisfying results, obtaining better simulations in comparison with the previous releases.
Lava flows represent one of greatest dangers for people security and involve invasion of land and property. Lava flow simulation could abate this hazard by forecasting lava paths and evaluating the effects of human interventions such as the construction of embankments or channels. Nonetheless, lava flows are complex phenomena and need, in general, sophisticated modelling tools. In fact, the major difficulty in modelling lava flows arises since derived equations (i.e. conservation, state and constitutive equations) must also satisfy additional variables to describe the physical properties of lava and its environment. For instance, because of cooling and crystallization, lava may change from a viscous fluid to a brittle solid during emplacement. Consequently, it is extremely difficult to characterize the resistance of lava to motion (Kilburn & Luongo, 1993). This work deals with a different approach, modelling flow field growth with Cellular Automata techniques.
Cellular Automata (*CA*) are one of the first Parallel Computing models (von Neumann, 1966); they capture the peculiar characteristics of systems, whose global evolution may be described on the basis of local interactions of their constituent parts (i.e. locality property).
A homogeneous *CA* (Worsch, 1999) can be considered as a d-dimensional space, the cellular space, partitioned into regular cells of uniform size, each one embedding an identical finite automaton, the elementary automaton (*ea*). Input for each *ea* is given by the states of the *ea* in the neighbouring cells, where neighbourhood conditions are determined by a pattern, which is invariant in time and constant over the cells. At time *t=0* (step 0), *ea* are in arbitrary states and the *CA* evolves changing the state of all *ea* simultaneously at discrete times, according to the transition function of the *ea*.
Complex phenomena modelled by classical *CA* involve an *ea* with few states (usually no more than two dozens) and a simple transition function, easily specified by a lookup table (Toffoli & Margolus, 1987).

Fluid-dynamics is an important field of *CA* application: lattice gas automata models (Frisch et al., 1990) and lattice Boltzmann models (Succi, 2001) were introduced for describing the motion and collision of "fluid particles" on a discrete space/time. It was shown that such models could simulate fluid dynamical properties; the continuum limit of these models leads to the Navier-Stokes equations.
This *CA* approach doesn't permit to make velocity explicit in the local context of the cell: i.e., an amount moves from the central cell to an adjacent cell in a CA step (which is a constant time), implying a constant "velocity". Nevertheless, velocities can be deduced by analyzing the global behaviour of the system in time and space. In such models, the flow velocity is an emergent property. It can be deduced implicitly by averaging quantities on space (i.e. considering clusters of cells) or by averaging quantities on time (e.g. considering the average velocity of the advancing flow front in a sequence of Cellular Automaton steps).
Many complex macroscopic fluid dynamical phenomena, which own the same locality property of *CA*, the surface-flows, like lava flows, seem difficult to be modelled in these *CA* frames, because they take place on a large space scale and need practically a macroscopic level of description that involves the management of a large amount of data, e.g., the morphological data.
SCIARA γ2 adopts and extends some mechanisms (Di Gregorio & Serra, 1999), which permit to define the macroscopic phenomenon of lava flow in terms of CA formalism. In particular, the flows are characterised by a mass centre position (inside the cell), that changes according the velocity and produces an outflow, when position moves to a neighbouring cell.

**References**


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