Disaster Propagation in Heterogeneous Media via Markovian Agents

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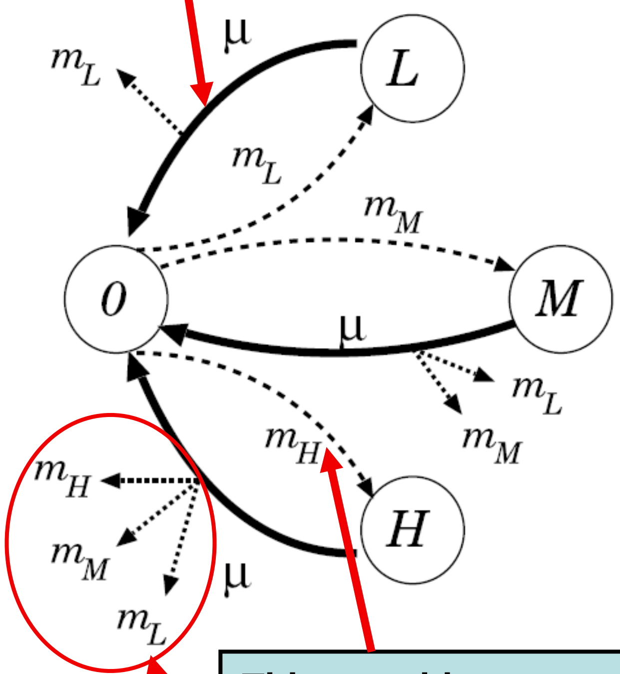
Introduction

- A Critical Infrastructure Protection (CIP) program requires the capability of forecasting how a potential threat originating in some geographical location propagates in an heterogeneous environment.
- We propose an approach to the disaster propagation analysis based on **interacting Markovian Agents**.
- To illustrate the approach, we model the propagation of a seismic phenomenon on an arbitrarily chosen geographical map.
- Fixed the epicenter, we can compute the speed and the intensity of the wave, and display them directly on the map.

Markovian Agents

Standard CTMC transition of rate μ



This transition occurs when a message of kind m_H is received

During this transition, a message of kind m_H, m_M or m_L may be generated

- *Markovian Agents* are an extension of ordinary Continuous Time Markov Chains (CTMC) to study systems characterized by a large number of similar interacting objects spread over a geographical space.
- Each object is represented as a *Markovian Agent*, and can communicate with other agents by sending and receiving *messages of various kinds*.
- During each transition of the corresponding CTMC, an agent can send a message of a given kind with a specific probability.
- The reception of a message of a given kind in a state, may cause an immediate jump to another state with a given probability.

- In this work we have used *Markovian Agents* to model the terrain excitation during the propagation of seismic phenomenon.
- The state space of the Markovian Agent represents the various levels of excitation a terrain may experience during the passage of the earthquake.
- Messages are used to model the wave that propagates the threat over the terrain.

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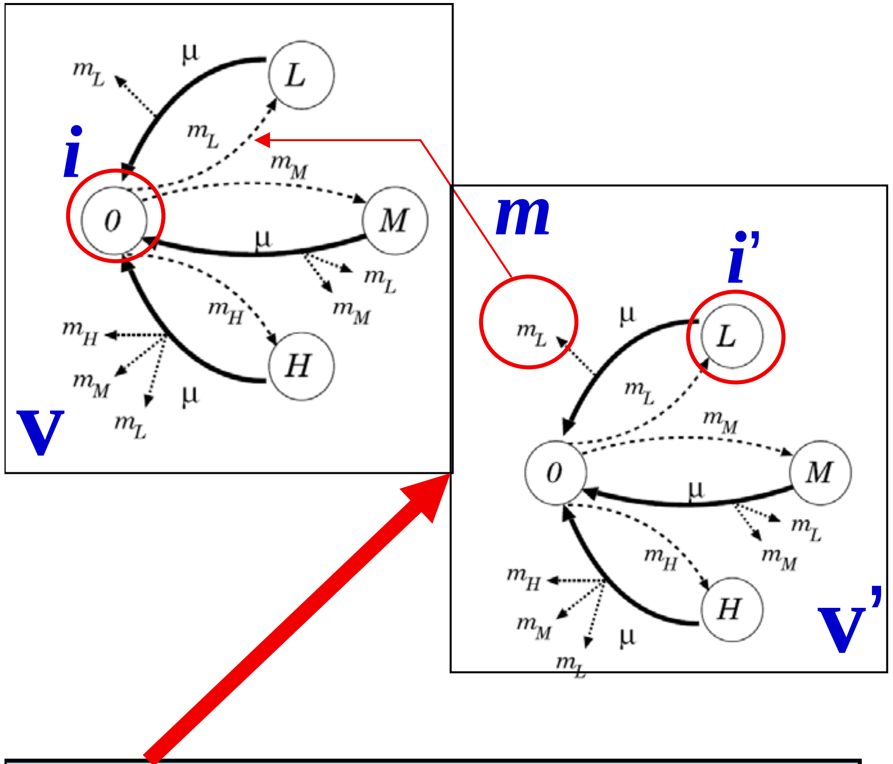
Spatial dependency

$$u(\mathbf{v}, i, \mathbf{v}', i', m)$$

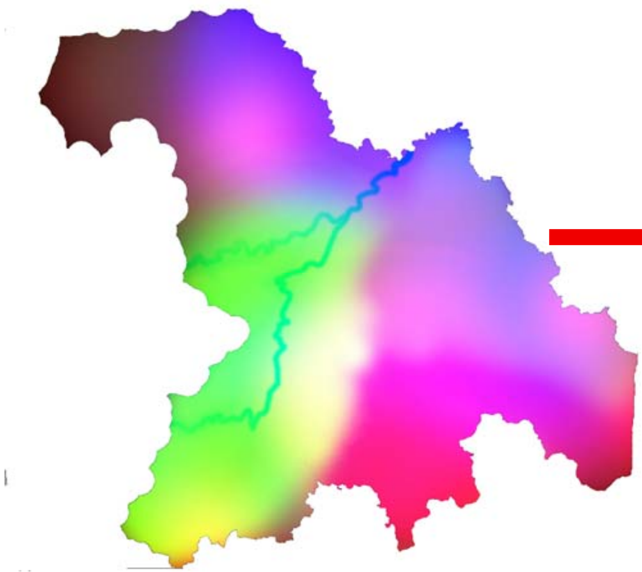


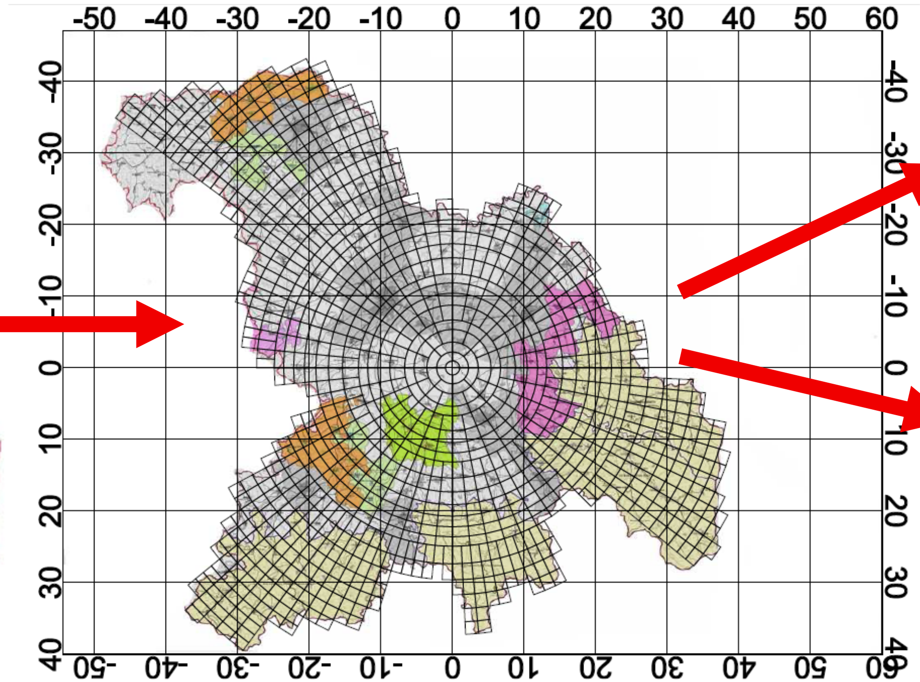
A visual representation of u (v, i, v', i', m_L)

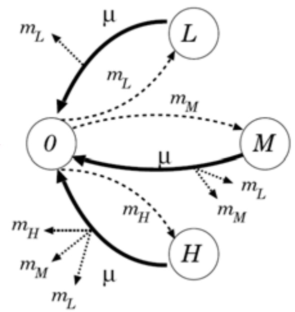
- Messages are routed according to a *propagation function* u (v, i, v', i', m_L) .
- u (v, i, v', i', m_L) defines the fraction of messages of kind m_L generated from an agent in state i' at position v', that are received by an agent in state i at position v.
- The *propagation function* is an important part of the model since it defines how messages propagate over the space.

- In this work the *propagation function* models how the seismic wave propagates over the terrain cells.
- It is defined to allow the transmission of a message only from one agent to its first neighbor (or neighbors) in the direction of propagation of the wave.

Discretization





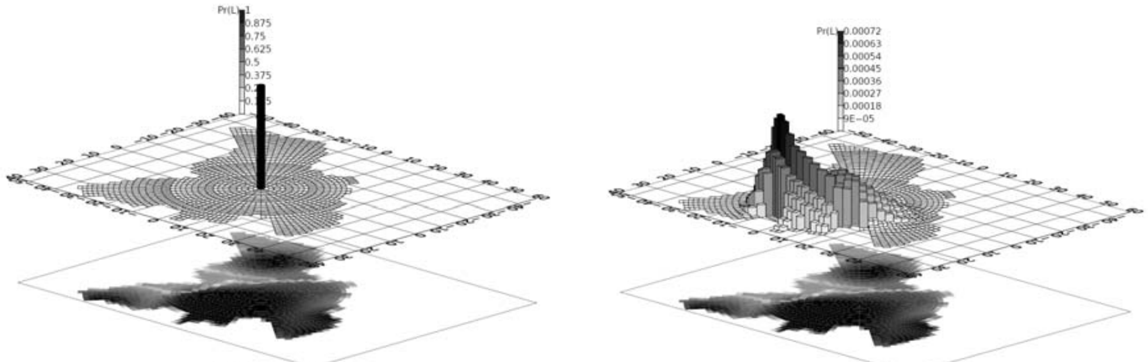


$$u(\mathbf{v}, i, \mathbf{v}', i', m)$$

- **Starting from a map of the area, that encodes various geological information of the terrain, we have produced a discretized version of the map, centered in the event epicenter.**
- **We have assumed that all the geological information are constant inside a cell**

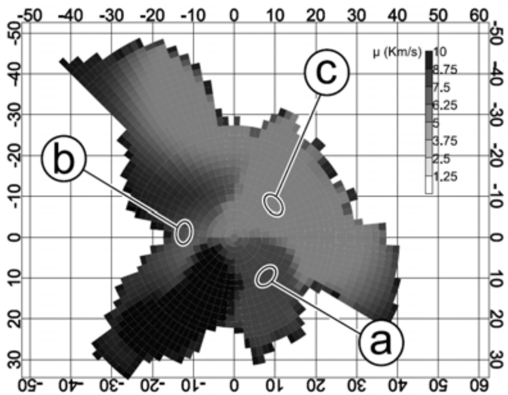
- **Each cell is modeled by a different Markovian Agent.**
- **Both the Agent parameters and the propagation function are defined according to the discretized geological data.**

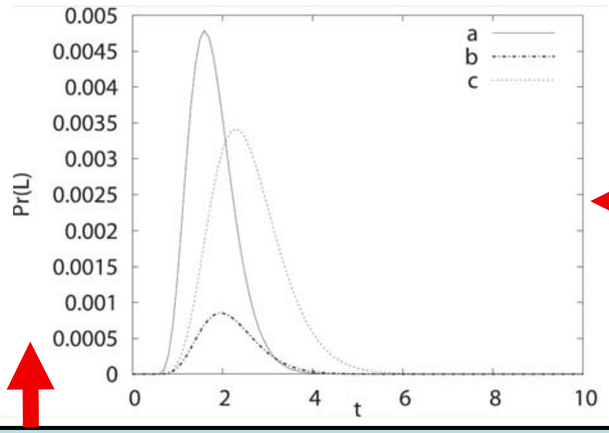
Excitation probability



(a) t = 0 *s* (b) t = 5 *s*

- By computing the transient solution of the interacting Markovian Agent model, we obtain the propagation of the earthquake as a function of time.
- The solution includes the state of each terrain cell.

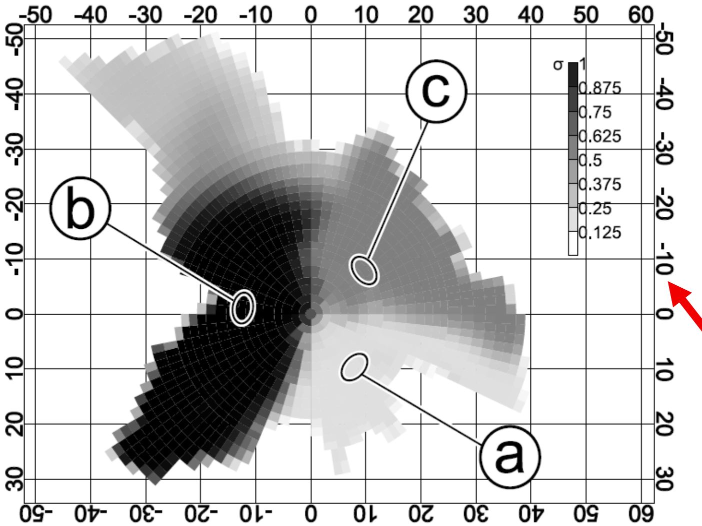




•To exemplify data analysis, we may focus on some points, and study the effect of the threat propagation in those points.

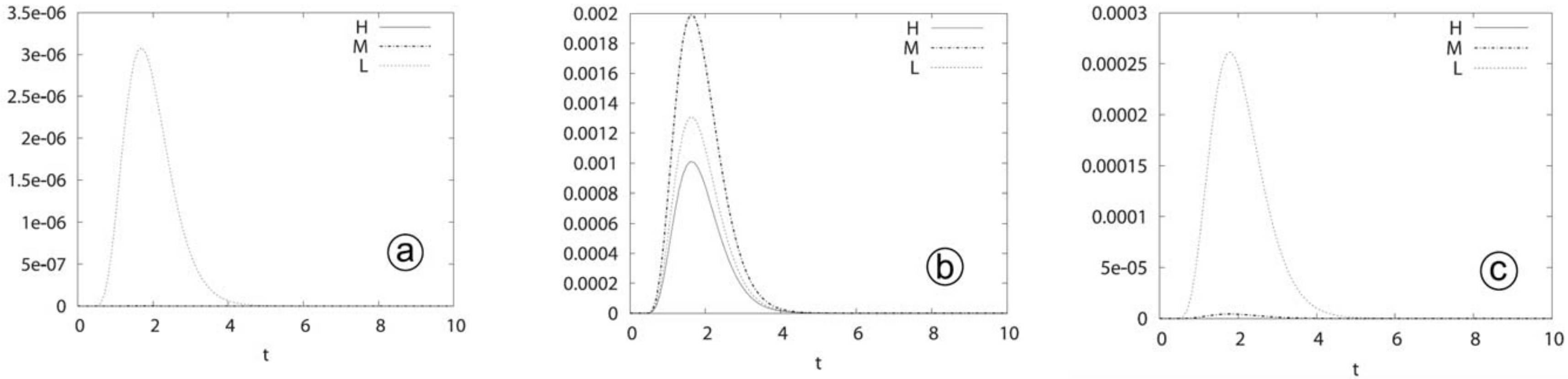
The results show how the threat intensity depends on the geological characteristics of the terrain from the epicenter to the given point along the the wave direction

Different threat levels



- We have performed several studies, to see how the different terrain characteristics, considered by the model, influence the threat propagation.
- The propagation model is instantiated with 3 parameters μ, σ, α.

•The following figures show the transient probability of being subject to a particular level of the threat as a function of the time.



Parameterization

The MA earthquake propagation model has been instantiated cell by cell by means of the following 3 parameters:

- μ defines the speed at which a message is released by a MA;
- σ defines the mixture of messages of 3 levels emitted by a MA;
- α defines the transmittance of the medium and enters into the propagation function ***u (v, i, v', i', m)***.

The overall computational cost of the analysis is affordable on a laptop PC.

References

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