Responsible Land Governance: Towards an Evidence Based Approach

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Spatial Data and Service Infrastructures to Support Inter-Disciplinary Modeling of Disaster Cascades and Resilience Assessment

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Introduction

The increasing complexity of systems that support human activities gives ground to new services for individuals and societies, that facilitate many aspects of life and accelerate development. However, external factors such as natural disasters, failures of systems, or malicious human activities, could initiate chains of cascading events that severely affect other elements of natural or artificial structures, including networks as well as social and economic systems.

This calls for a holistic, inter-disciplinary approach that needs to take into account the inter-dependencies of structures and networks to each other and to the physical environment; to do that, we need efficient Spatial Data Infrastructures (SDIs) to support the modelling of semantic and quantitative links among data and services and enable the integration of tools from different disciplines.

We focus on the requirements and architecture of a SDI to support different kinds of risks and hazards, and produce results that correspond to the complex inter-dependent nature of modern systems to each other, as well as to the physical and social space. The proposed SDI and service architecture enables researchers and decision makers to account for cascading effects on infrastructures and networks, in order to support the design and implementation of resilient social and artificial structures at any scale.

Methodological approach

Conceptually, in our approach the modeling of cascades is based on a "Cascading Effect Scenario (CES)" directed graph whose nodes represent environmental modeling or network analysis, and links represent cascades. Three types of nodes can be recognized:

- Structural and environmental modeling (SE)
- Network/system analysis (NS), and
- Loss/Resilience modeling (LR)

Links in a CES graph represent the four kinds of cascades:

- *Hazard-to-hazard*, as is the case of a flood caused by an earthquake; such links connect different SE nodes.
- *Hazard-to-network*, as is the case of disruption of electric power distribution caused by a flood; such links connect SE to NS nodes.
- *Network-to-network*, as is the case of degradation of transportation networks, due to failures in electric power networks; such links connect different NS nodes.
- *Any-to-loss/resilience* links, to represent triggering of any kind of loss or risk assessment model.

The proposed SDI and service architecture

An example of a CES graph shown in Figure 1: a seismic event results in severe damages at the road network of the area. It also triggers a tsunami that causes a flood, which in turn causes a partial failure of the electric power network which, in its own turn, affects the local telecommuni-cations network.

A n-tier architectural pattern that can be used to implement the proposed infrastructure, is shown in Figure 2. The main elements of the data tier are the re-lational and spatial DBMSs, where all data are stored. Geographical features are made available either by standards-based OGC web services, or by other methods. In this case, it is important the respective meta-data and data models to be shared across all the members of the inter-disciplinary team that will be us-ing the data.

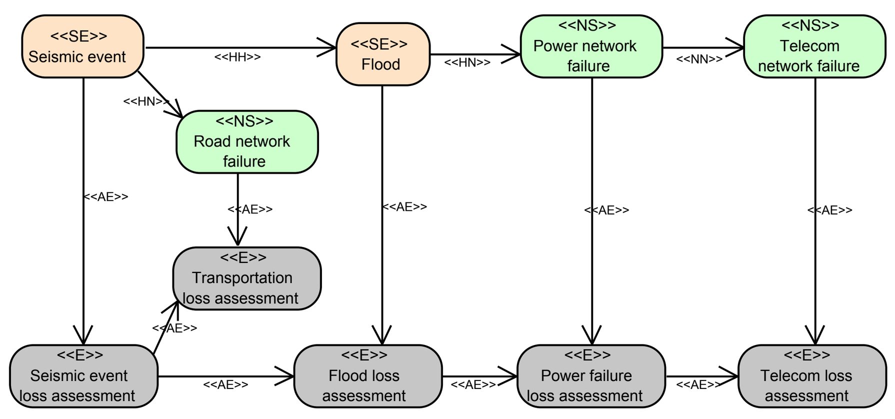


Figure 1

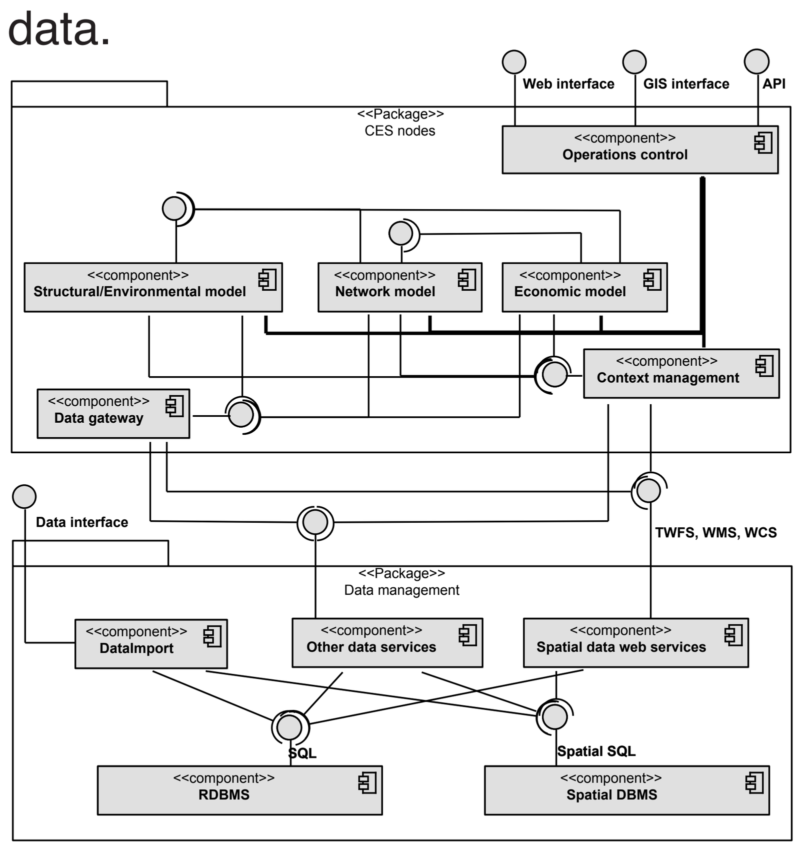


Figure 2

A generic deployment model that shows the as-signment of components to computational nodes is shown in Figure 3. The number and type of nodes in a specific instantiation of this model largely depends on the resources and performance requirements of a specific environment.

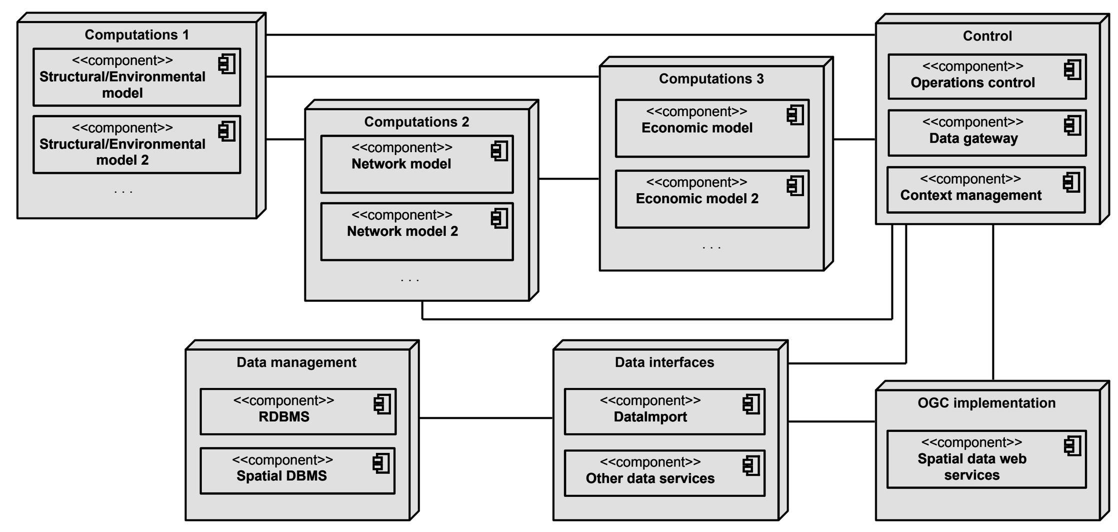
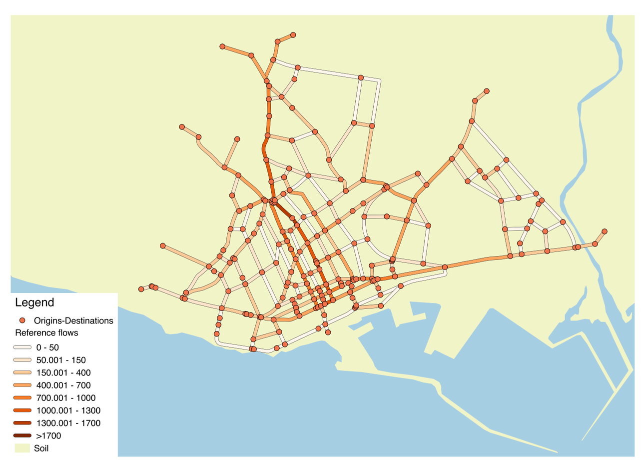
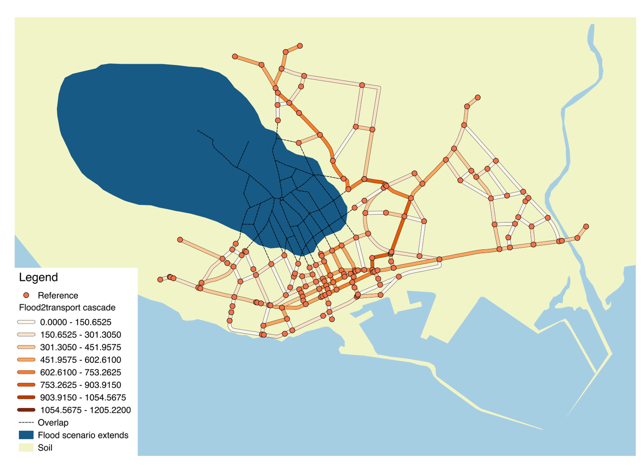


Figure 3

A case study





The cascade modeling approach introduced, has been applied to a case study that focuses on the modeling of the cascading effects of flood scenarios to the transportation network in Alexandroupolis, a city of 73,000 population in Greece. A combined integrated study of the effects of floods to the direct and indirect cost of road transportation in the post-flood situation, has been conducted. The flood classification has been eventually mapped into transportation indexes that can be used to assess operational losses causes by each flood scenario. The understanding and modeling of interactions between these two dynamic systems has been a challenge as it also involves human behavior; one reference and nine flood scenarios were studied, to cover:

Scenario		Cascade effects to road transportation network				
		OD	General		Congestion variance	
ID	Flood rating	(+/-) Total transportation load (%)	(+/-) flows progr. (%)	(+/-) time, cost (%)	links	Max(Flow-Capacity) per link (%)
S1	A	-47,25	-44,40	-37,13	-21	-83,84
S2	A	0,00	2,45	52,74	21	106,32
S3	B	-14,27	-12,38	-13,98	2	-7,43
S4	C	-6,80	-5,69	-5,20	3	3,46
S5	D	-32,51	-26,51	-18,84	0	-30,03
S6	B	-19,04	-13,36	2,21	9	25,10
S7	E	0,00	5,70	7,58	2	13,71
S8	E	0,00	0,07	0,18	0	0,00
S9	E	0,00	1,75	4,25	4	79,66

- three flood hypotheses in which relatively large parts of the city,
- three flood hypotheses with the same road network as before, but with different traffic demands,
- three cases where the affected areas are smaller but with the same transportation demand .

To simulate the transportation load, the Frank-Wolfe algorithm has been used, among several other options; a key advantage of this approach is that the SDI and service architecture allows any other transportation network analysis algorithm to be used. Future work will focus on applying different algorithms to more complicated networks, including railroad networks, along with the corresponding loss estimate models.

References

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