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An open source spatial database schema and interface for the storage, representation and analysis of interdependent infrastructure networks

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The evolution of infrastructure networks often leads to a 'network-of-networks' being created, whereby components from one system become dependent upon a service or commodity from another infrastructure system (Rosato, 2008). Such physical interdependencies between infrastructure systems are important to understand because these relationships can result in infrastructure networks being more vulnerable and exposed to greater risk of failure. One important relationship between infrastructure networks is that of their spatial interdependency, as failure in one network as the result of a spatially localised event (such as flooding) may propagate or cascade to other infrastructure networks within the same neighbourhood. To model and understand how spatial dependencies and interdependencies introduce complexity and risk to a series of networks, a holistic approach to network modelling, representation and analysis is required. Traditional approaches have often considered physical infrastructure networks in isolation and have neglected to consider the spatial interdependencies that are present. Furthermore, spatial network representation and analysis has often been performed within a GIS environment, which can lack the analytical framework and capability to handle the complex analysis required to understand spatial interdependencies and what effects they can have on networks.

To address these issues we present in this work an open source spatial database schema and interface that couples the complex network analysis functionality available within the NetworkX Python package to the robust data storage capability of a PostGIS spatial database. The PostGIS database schema allows the explicit spatial representation of an infrastructure system as a network model, while the interdependencies between two or more such network models are represented by a series of related spatial interdependency tables.

Analytical analysis of spatial infrastructure networks and their interdependencies is conducted using the functionality of NetworkX. A Python-based wrapper has been developed that allows a user to request a network or series of interdependent networks and pass this/these to NetworkX for analysis, manipulation and interpretation. To demonstrate the high-level of functionality provided by this software framework we present a relatively simple spatial interdependency failure analysis using the National Grid-owned electricity substation network and the London Tube network within the Greater London Authority. These two infrastructure networks have been encoded within the schema along with a first-order approximation of their spatial interdependency. This has then been used within a simple failure model using NetworkX to simulate the sensitivity of the London Underground to failure within the electricity national grid using metrics of degree and betweenness.

References

Rosato, V. S. (2008). A Complex System's View of Critical Infrastructures,. In D. Helbing, *Managing Complexity: Insights, Concepts, Applications* (pp. 241-260). Springer.