Network science as a foundation for metrics, models and theories of large-scale pervasive systems

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Background and experience

Vassilis holds a PhD in Computer Science. His research focuses on the intersection of people, spaces, and technology at the city scale. He has been involved in a number of cross-disciplinary research projects addressing issues such as urban flows and networks, metrics for pervasive systems, pervasive systems and urban design, social and complex network analysis, urban transport, emulation and simulation of epidemics. He organised the first workshop on Social Networks and Ubiquitous Computing at the NetSci 2008 conference, bringing together for the first time experts on network science and ubiquitous computing.

Vision

My vision is to develop metrics, models and theories for large-scale pervasive systems. This white paper argues that network science can provide a foundation for these.

Argument

Network science is a discipline, a collection of tools, and a set of theories that allow for abstraction and flexibility in the analysis of sets of "things" and their relationships. The network analysis approach has been used to describe systems in a diverse set of domains, ranging from natural and biological phenomena to man-made constructs. The flexibility of network analysis allows us to model aspects of large-scale pervasive systems ranging from small-scale details to large-scale emergent phenomena. This is possible because network science lets us model with varying granularity three crucial aspects of large-scale pervasive systems: people, places, and technology.

- **People**: One of the most widely-used application of network science is the analysis of people and their relationships. Network science and social science have developed a substantial body of knowledge and tools to construct and analyse such networks. Crucially, our understanding of social networks ranges from micro-level dynamics of simple dyads and triads to macro-level social networks and their associated scale-free phenomena. In addition, network analysis provides us with the conceptual and analytical tools to bridge the gap between online and real-world social networks. Recent work has shown that such diverse networks can be analysed jointly [1]. This is a crucial step in understanding and modelling humans and their actions in a world where pervasive systems allow people to be better connected both online and offline.

- **Places**: A substantial body of work, *space syntax,* has pioneered the use of network analysis to represent and describe urban space. Space syntax has been used to analyse spatial environments as small as galleries and museums, and as large as the city of London. The key insight and finding of this work is that human behaviour in urban space can be understood by considering the way that space and roads are connected to each other, i.e. its structure. Crucially, however, the representation of a city as a network has recently provided pervasive systems researchers a foothold in understanding how to design for a city, and more importantly how to compare systems between cities [2].

- **Technology**: Network science has provided substantial insights into the design of computer networks and algorithms for supporting such connectivity [e.g. 3]. A number of issues relating to large-scale connectivity can be understood in terms of networks: cascading, resilience, contagion, opportunistic networking, forwarding algorithms.

But how can a network approach to analysing people, places and technology help us build and evaluate large-scale pervasive systems? Surely people are more than just their relationships, there is more to space than how it is connected, and technology is much more than just networks. This is indeed the case, but by adopting such an abstraction in describing large-scale pervasive systems we can begin to establish a unifying set of *metrics*, *models* and *theories* for such systems.

Network science has identified hundreds of *metrics* that have been useful in analysis across domains. The flexibility of this approach allows for a virtually infinite number of new metrics to be developed and tested for their usefulness. Unlike conventional metrics, network analysis ensures that metrics are formally defined, straight-forward to apply, and transferable across environments and systems. Furthermore, the existence of such metrics have enabled the development *models* to describe observed behaviour across various domains. While such models are not necessarily predictive, they are able to describe the observed behaviour of a system or an underlying process, largely because of the power of metrics, their reliability and their transferability. Finally, the mathematical nature of networks, their metrics and associated models offer a promise that such an approach can ultimately yield testable theories with predictive powers in relation to large-scale pervasive systems.

Research agenda for the future

This white paper argues that research on large-scale pervasive systems can hugely benefit from having a unified set of metrics, models and ultimately theories that can describe people, spaces and technologies. Metrics can embody standards and allow theories to be tested. They also let us create models which embody our understanding of a system or a process. Ultimately, these can be used to develop theories which, in turn, can yield new metrics and models. As argued here, all these can be supported by the flexibility and analytical strength of network science. Of course, adopting such an approach leads to abstractions that sacrifice much of the richness of people, places and technology in favour of unification, tractability and concreteness.

A crucial first step in the research agenda for achieving the vision set forth in this white paper is the development of metrics. A second objective is the development of a realistic testbed, ideally of city-scale, where researchers can further their work and understand better the challenges of large-scale pervasive systems. Finally, the community needs to be engaged, and through the use of appropriate metrics and testbeds advance our knowledge and understanding of large-scale pervasive systems.

References

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