Network City

**Networks, networks, networks**

It often appears that in our daily urban lives, we encounter networks everywhere. They saturate the language we encounter in newspapers, online media, and even everyday conversations. What is more, they profoundly shape the very essence of our daily choreographies. From morning until night, we are constantly entangled in a multitude of networks. Our breakfast is delivered to us through food webs and logistics systems, while we enjoy content on the World Wide Web; we then commute to work using the street network, and once at work, we connect with various social and professional networks, and so on. It is safe to say that we simply cannot live without networks: They are an integral part of our lives, facilitating our interactions and generating a vivid urbanity. However, when we delve into the intrinsic nature of networks more profoundly, they reveal themselves as far more fascinating than just a metaphor for things interlinked. So, let’s start from the very basics: what do we mean when talk about networks?

A network is, by definition, a system of *nodes* – which can be people, animals, computers, or any other entities – and *links*, which represent the relations or connections between them. Using these simple rules, we can create a network model of anything that are related to each other. Depending on the system, the complicatedness of the resulting model can vary widely, from something very simple (like my family with four members and hence six links), to extremely complex (such as the Internet, with billions of nodes and connections) (figure 1). However, it is vital to remember that before creating such a model we must make a strategic decision of what qualifies as a system in this particular case. For instance, in the first example, we need to determine what we mean by a ‘family’: is it just the immediate relatives, the extended family with grannies and uncles, or perhaps some other, even broader circle. This choice depends on the culture and context, and there is no one-size-fits-all solution definition for “family”. We should always pose the question to ourselves of what we are seeking to ask or perceive.

Since this blog entangles with the WNICS seminar series, it is fair to ask next: why do we talk about networks in the context of city science? First compelling reason would be that networks, defined as I previously did as the *systems of interacting entities*, are fundamental requirement for all life on earth, including human culture. Generally, we differentiate between two types of networks: biological and cultural networks - in other words, *networks of life* and *networks of transportation and communication* (which already ties into the concept of cities).

**Networks of life and networks of communication and transportation**

In the realm of biological systems, network is a basic structure of all organisms, and systems they form. Network structure drive fundamental metabolic processes, but also support cognitive functions in the intricate neural networks of animal brains. Microbes, vital for the biosphere, establish complicated networks with each other. Moreover, we all may recall the food webs we learned about in elementary school biology where a fox prays on a rabbit and so forth – they seemingly simple systems are, in reality, significantly more complex and entangled with microbial and various other networks in myriads of ways, resembling the above example of the World Wide Web. Overall, life itself hinges on the existence of networks.

Then there are cultural networks in societies and cities, referring to networks through which we transport goods, people, and information. These cultural networks are inherently intertwined with the networks of life. There is no urban life detached from them. Us humans are integral parts of this interconnected web; they form a nested system of systems. The networks of communication and transportation encompass the physical networks like electricity, communication, and street networks, which are intentionally planned to take the form of a network, as there is no other way for them to operate effectively.

Within these physical networks, we have networks of flows – such as traffic or the internet, or various social networks both in the real world and online. Indeed, recently, these flows are becoming more and more digital and have increasingly occupied virtual space; they are partly physical, partly virtual, and extending spatially throughout the globe. We live in a planetary network of virtual-corporeal cities where everything is connected to everything else - and where exclusion from this network leads to almost certain decline, just like the consequences of isolation from natural networks.

In cities, it is essential to guide these systems to ensure prosperous urban life and viability of urbanity. Nevertheless, when it comes to networks, achieving this goal is often easier said than done. Networks possess unique characteristics which I’ll explain next, and that’s why we need to rely on the science of networks. This field provides specific mathematical and computational methods to study both network structures and the flows within them.

**Science of networks in a nutshell**

To illuminate the unintuitive characteristics of networks, we have to briefly delve into their history. One of the initial steps toward a better understanding of the nature of networks occurred in the 18th century. Immanuel Kant set a question of whether the seven bridges of Konigsberg, that connected the two banks of the river, and an island city was formed on, could be crossed once and only once by a person drifting around the city. While the mundane answer was no, this inspired mathematician Leonard Euler to build a first conceptualization of a network as ‘nodes’ and ‘edges’ , marking the birth of Graph theory and topology.

More rapid advances started to take place after WW2: in 1959, Paul Erdős and Alfréd Rényi proved that, surprisingly, aggressively adding links to the network does not mean significantly increasing connectivity. Actually, for maximal connectivity in a network, surprisingly little links are needed. In the 1960s, social psychologist Stanley Milgram decided to test a hypothesis that everyone is connected by each other just a few steps, called Small-world-problem. He set up a well-known experiment where people had to deliver a letter to a random person, but they could only give the letter to some they know, who’d pass it on. It was revealed that people are separated by any other person by astonishing six steps. What is more, today it is estimated that the number of these links would be reduced to less than four, thank to the social media and internet.

The quality of the links is as important as number of them. Mark Granovetter had already proven in 1973 that people succeed in job search best using so-called weak ties – people they do not know very well or interact with less frequently. This was formalized in a famous computational study of Duncan J. Watts & Steven Strogatz in 1998: their idea was to improve on a regular Random Graph by adding stochastically “weak ties” - short cuts to other social environments. To everybody’s surprise, the computer simulation showed that only a few random extra links, while only minimally reduced the clustering, significantly decreased the separation between the nodes. In practice, this would be equal to talking to people outside your usual circles: you don’t know the people someone else knows, or who their friends might know. Hence the weak ties might increase your social spheres very easily exponentially, to your great benefit.

Thanks to computational progress at the time, other milestones were reached simultaneously by Albert-László Barabási & Réka Albert in 1998 while studying the structure of the internet. They discovered that it exhibits a so-called scale-free, power-law network. In layman's terms, this means it consists of very few extremely large nodes with millions of links that typically grow larger over time, alongside myriad small nodes with only a couple of links. Importantly, there is an interesting dynamic dependency between the number of nodes and their connections, a pattern found in many other complex systems, ranging from epidemics and crime to employment, wages, and innovations in city systems. This implies that these systems self-organize — no external force 'designs' the internet to be this way.

One remarkable aspect for planning is that the two theories of weak ties and scale-free networks reveal features of cities as Complex Adaptive Systems (CAS). CAS are typically not just complicated but embrace more profoundly unique dynamics, departing from linear systems. Firstly, they usually exhibit self-organizing, bottom-up features like power-law dynamics, making their overall behavior sometimes unpredictable and difficult to control, similar to systems in nature. Secondly, these systems constitute complex networks, referring to distributed, small-scale, tightly knit networks connected to each other with weak ties. These are typical in CAS in nature since they are more resilient in times of crises compared to centralized networks. Such knowledge could be applied in ecosystem planning — both regarding natural and artificial systems. For example, infrastructure planning applying knowledge of complex networks could help avoid the impact of external shocks to spread in the entire network.

**Cities as networks**

Moving towards a more practical (urban) stance, it is quite interesting that network theories developed in concert with urban progress, answering questions emerging from the new timely phenomena in societies. Simplified, three phases can be recognized. In the first phase, from ancient times to early industrial times of people moving mostly with horse and carriage or on foot, little difference was seen between transportation and communication speed or networks. The message was as fast as the courier, moving along the same routes. Theoretical problematics, like those of Euler and the emergence of graph theory, date back to these times. In the second phase of industrial society, along with the innovations like telegram and telephone, revolutionary change was seen that separated communication from transportation. Questions like those regarding random networks appeared relevant. Finally, in the third phase of post-industrial, in the late modern or 'knowledge-based society,' computers, the internet, and finally smartphones changed the game; digitalization shifted urban communication systems from spatial-corporeal to coupled virtual spatialization, where knowledge of scale-free networks, small-worlds, and weak ties became necessary for the smooth operation of society.

In city science, networks have been an entangled ingredient for many theoretical and methodological advances assisting urban planning. Already in 1967, Christopher Alexander published his book titled 'A City is Not a Tree,' arguing against adopting the modernistic, too simplistic planning stance and promoting 'naturally' emerging cities with many more connections, overlappings, and simultaneous activities. These can even today be seen as necessary ingredients enabling livable and vital cities. The surge of the spatialization of network theories in cities started to emerge in the early 2000s as urban planners and scholars faced the inescapable problematics of late modern, complex and multi-nodal urban regions.

In early 2000s, French sociologist François Ascher introduced a term, Metapolis, combining 'metabolic' and the Greek word for city, 'polis.' He suggested that such cities are like processes – flows of people, information, and goods create good business places, and resulting configurations such as activity and service clusters start to steer the flow in a circular manner. For planning such dynamic urbanity, we must understand this process to be able to guide it. In his 2008 work on 'Network Urbanism,' Gabriel Dupuy categorized urban networks into three levels. The Urban Field Level analyzes the spatial organization's impact on urban dynamics, encompassing the physical structure and arrangement of urban elements. The Urban Network Level delves into transportation and mobility networks, studying connections and flows. At the Urban System Level, Dupuy examines the broader regional and global context, considering economic, social, and political factors influencing urban development and interactions between cities and their surrounding regions.

In their methodological approach Netsztadt, Franz Oswald and Peter Baccini (2003) argue that cities consist of morphology (i.e., material manifestation) and physiology (i.e., flows) that are interlaced. Cities change by the formation of these two in an evolutionary manner. Through careful and systematic analyses of the city as networks, synthesis, and suitable strategies can help guide them sustainably regarding socioeconomics, ecology, culture, and more.

Today, these lessons learned serve as the cornerstone for a fundamental understanding of sustainable city planning, leveraging digital techniques and data for contemporary means and methods. Knowledgeable urban planners and educators now commonly acknowledge that cities represent intricate systems of systems, interwoven networks of various elements. These networks signify the interlinked exchange of materials and information within urban ecosystems. Intrinsically, to address climate change in cities, we must view urban systems—from ecology to transport and social ones—through a network lens, recognizing that partial optimization in professional silos has never worked. Embracing network theories and supporting methodologies becomes crucial, offering valuable guidance for comprehending and steering urban dynamics.

Literature:

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