
Networking our
Common
future

MOTIVATION AND GOALS

A network is any method of sharing information between systems. Systems consisting of many individual units that are tied by one or more specific types of interdependency are found everywhere in the world. Networks are often very complex and difficult to analyse. Being of rather large scale to be seen from a single viewpoint, they can often be abstracted as graphs that appear to be the natural mathematical tool for facilitating the analysis.

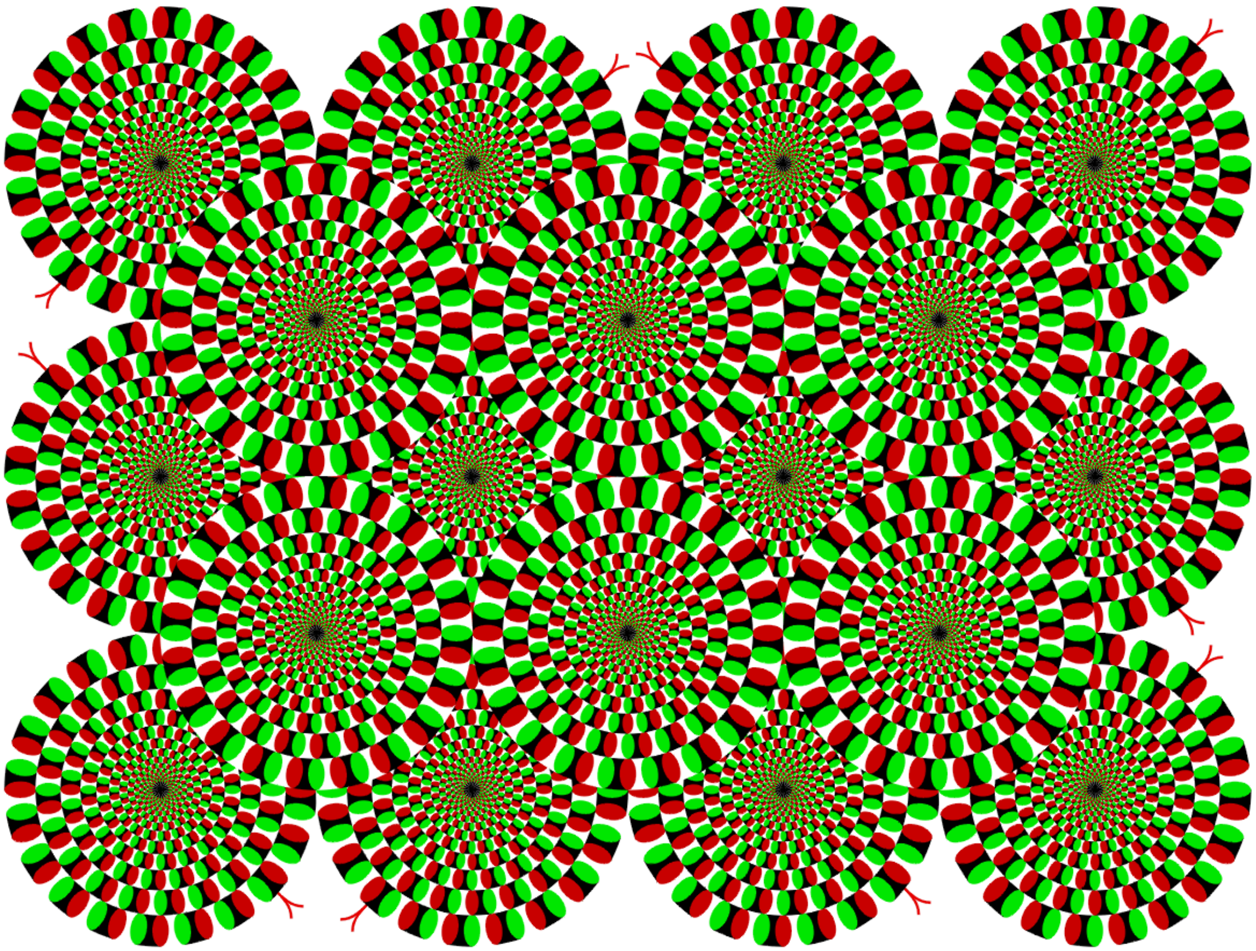
In view of the utmost practical significance in numerous applications, it is in our **common interest** to involve the set of network exploration techniques in commerce. Commercialization provides motivation, direction and increase access to opportunities of the methods and other skills having the objective of supplying real-world networks of whatever origin.

The goal of the project is to bring together a broad selection of professionals and facilities by promoting of each members endeavors and services both within the network and out in the broader market and increasing opportunities for all participants.

Networking may also become nationally involved, endorsing reforms, legislation or other drives that accommodate the municipal and governmental organization's goals. In particular, it may be considered as a part of national research programs aiming to design and implement a successful strategy to meet a wide range of needs and challenges while building **our common future.**

A CHALLANGE OF A NETWORK

Network analysis is challenging because of its subject does not have the structure of Euclidean space we used to live in. Thus, we never see a physical image of the entire network, but individual objects which we may recognize as nodes. Human interpretation of network scenes is always based in the emergence of simplified models that speed up the interpretation process but give rise to multiple illusions.



Rotating Snakes (Kitaoka, 2003)

Repeated asymmetric patterns cause many peoples' visual systems to infer the presence of motion where there is none. The rate of luminance adaptation is disproportionately faster at high contrast bars coded as deviations from a reference luminance. This evokes a pattern of neural activity that normally occurs only when an object really is moving (Backus, 2005).

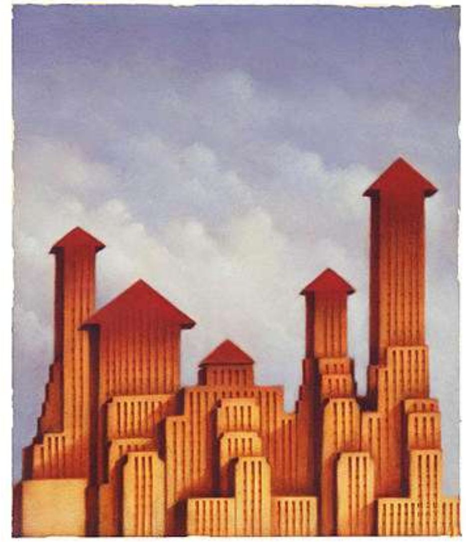
THE CHALLENGES WE FACE

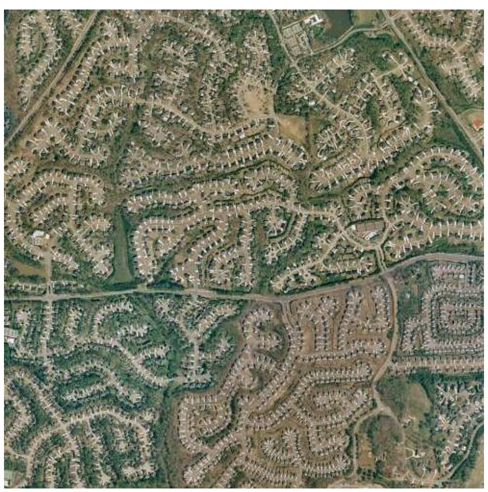
URBAN GROWTH

The U.N. Population Fund has issued a warning (Population, 2007) as the majority of the world's population shifts from rural to urban areas. The first time in history, more than half of the world's population, or 3.3 billion people, will be living in urban areas by the end of 2008.

The speed and scale of urban growth require urgent global actions to help cities prepare for growth and to avoid them of being the future epicentres of poverty and human suffering. Clogged roads, dirty air, and deteriorating neighbourhoods are already fuelling a backlash against urbanization; nevertheless this process cannot be stopped.

In most of countries, the population living in urban areas grows much faster than the total population, but the rate of urbanization varies from country to country, and from region to region.





City development planners will face great challenges in preventing cities from unlimited expansion. In accordance to the US Bureau of Census data on Urbanized Areas, over a 20-year period, the 100 largest Urbanized Areas in US sprawled out over an additional 41,000 km^2 (Switzerland area) of rural space that was covered over by the asphalt, buildings and sub-divisions of suburbia. Residents of sprawling neighborhoods tend to emit more pollution per person and suffer more traffic fatalities. Sprawling urban areas are helping to make road transportation the increasing source of the carbon emissions warming the earth's atmosphere. The urban design decisions made today on the base of the U.S. car-centered model, in cities in the developing world where car use is still low, will have an enormous impact on global warming in the decades ahead.

GLOBAL WARMING

The human population is living far beyond its means. There is now visible evidence of the impacts of climate change, and consensus that human activities have been decisive in this change: global average temperatures have risen by about 0.74°C since 1906.

Ice cores show that the levels of carbon dioxide and methane are now far outside their ranges of natural variability over the last 500,000 years.

Carbon dioxide from industrial and automobile emissions has been suspected to be the primary force in global warming.

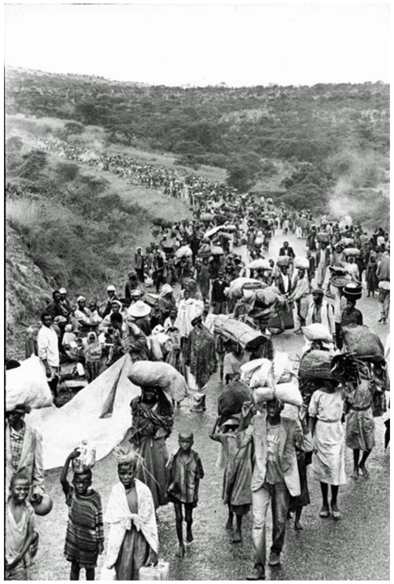
Urbanization deepens global warming: the effects of urbanization and global warming on subsurface environment were estimated by (Taniguchi, 2003) to be 2.5, 2.0 and 1.5 degree centigrade during the last century in Tokyo, Osaka and Nagoya, respectively.

Present trends do not favour greenhouse gas stabilisation.

MASS MIGRATIONS

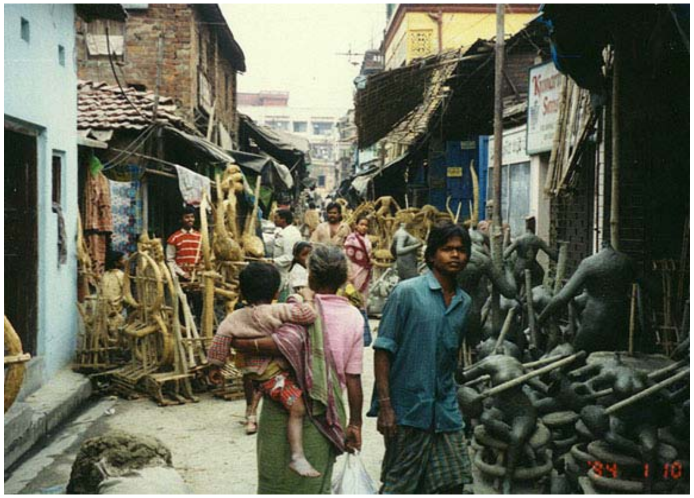
Sea-level rise caused by thermal expansion of water and the melting of glaciers and ice sheets will continue for the foreseeable future, with potentially huge consequences: over 60 per cent of the population worldwide lives within 100 kilometres of the coast (GEO-4, 2007).
The well-being of billions of people in the developing world is at risk, because of a failure to remedy the relatively simple problems which have been successfully tackled elsewhere such as waterborne diseases.
Unsustainable pressure on resources causes the increasing loss of fertile lands through degradation and the dwindling amount of fresh water triggering conflicts and resulting in mass migrations.

Migrations cause a dislocation and disconnection between the populace and their ability to undertake traditional land use.
Major metropolitan areas and the intensively growing urban agglomerations attract large numbers of immigrants with limited skills.
Many of them will end up a burden on the state, and perhaps become involved in criminal activity.
The phenomenon of clustering of minorities, especially that of newly arrived immigrants is well documented since the work of (Wirth, 1928).
Clustering and the subsequent physical segregation of minority groups dispersed over the spatially isolated pockets of streets and other inner-city areas being socially barricaded by railways and industries cause their economic marginalization.



GLOBAL POVERTY AND CITY DECLINE

The poor are urbanizing faster than the population as a whole.
Global poverty is in flight becoming a primarily urban phenomenon in the developing world.
Among those living on no more than $1 a day, the proportion found in urban areas rose from 19 percent to 24 percent between 1993 and 2002 (Ravallion,2007).
About 70% of 2 billion new urban settlers in the next 30 years will live in slums, adding to 1 billion already there.
The fastest urbanization of poverty occurred in Latin America, where the majority of the poor now live in urban areas.



A combination of interrelated factors, including urban planning decisions, poverty, the development of freeways and railway lines, suburbanisation, redlining, immigration restrictions would trigger urban decay, a process by which a city falls into a state of disrepair.
The concentration of poverty and crime radiating from the developments often cause the entire suburb to fall into a state of urban decay as more affluent citizens seek housing in the city, or further out in semi-rural areas.

NATIONAL AND PERSONAL SECURITY

Most riots in the last century have occurred in urban places suffering from the co-morbid problems of urban decay such as wide-spread poverty, high unemployment, and rapid changes in the racial composition of neighborhoods. Social revolutions had occurred under (and in some cases in part in response to) conditions of urban decay.

Nowadays these socioeconomic factors together with congestion and high urban growth rates are mentioned by U.S. Department of State among the main causes of terrorism.

There is a difficult dilemma between protecting the citizens and protecting the citizen's civil rights (the rights to privacy, freedom from unreasonable search and seizure, freedom to peaceably assemble). How does the government balance the requirements of national security with the inherent personal rights of the citizenry?

Government IT managers in USA believe that national security is more important than personal privacy, according to the last surveys.

Therefore, what happens in the cities of Africa and Asia and other regions will definitely shape our common future.

It is well known that the urban layout effects on the spatial distribution of crime (UK Home Office, 1998). The different types of crime are associated with the different levels of land use and social characteristics (Dunn, 1980).

In particular, crime seems to be highest where the urban fabric is creating most local segregation.

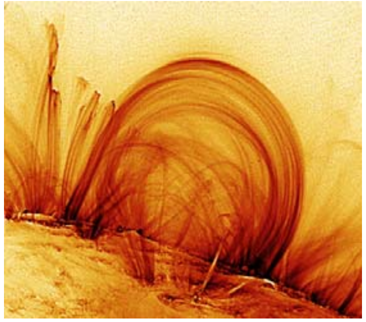
CHALLENGES OVERCOME

URBAN PLANNING, TRANSPORT LOGISTIC, AND ENERGY GRIDS

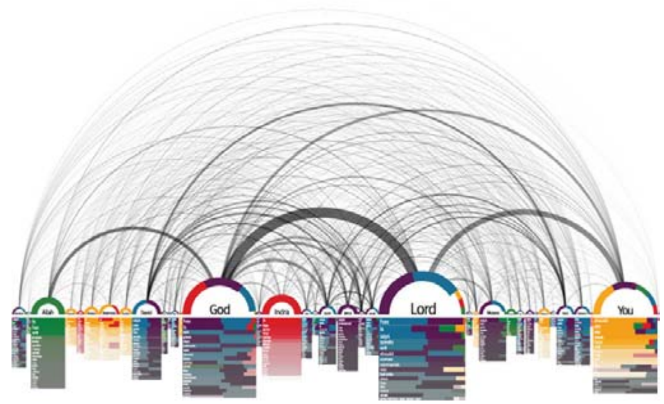
Urban planning is recognised to play a crucial position in the development of sustainable cities.
It is now common to suggest that compact, efficient land use; less automobile use yet with better access; efficient resource use, less pollution and waste; the restoration of natural systems; good housing and living environments; a healthy social ecology; sustainable economics; community participation and involvement can dramatically improve the long-term social and ecological health of cities and towns preventing them from long-term infrastructural decay.

The efficient management of the flows of goods, information and other resources, including energy and people is of the primary importance for the fruition of supply chains and resultant efficiencies. Public transport is an important example.
Logistics involve the integration of information, transportation, inventory, and warehousing.
Communication is vital for advanced logistic and transportation systems. Advanced communication modes generate more total interactions, including interpersonal interactions between people.
Transport is a major use of energy.

Engineers design transmission networks to transport the energy as efficiently as feasible, while at the same time taking into account economic factors, network safety and redundancy. Redundant paths and lines are provided so that power can be routed from any power plant to any load center, through a variety of routes, based on the economics of the transmission path and the cost of power. The gaming of a deregulated energy system may lead to a disaster. Reliable communications for control of the grids and associated generation and distribution facilities are required.



COMMUNICATION, LANGUAGE, AND BEHAVIOR



Communication is a process by which we assign and convey meaning in an attempt to create shared understanding that is essential for conferring knowledge and experiences, the vital issue of human sustainability.

Networks are a natural representation for many linguistic structures and almost all levels of language have been examined using graph-based methods.

Different kinds of words, like names and verbs, are represented, in the real brain, in distinct groups of neurons. And even words of the same kind seem to be processed, at least partially, in different parts of the brain depending on their meaning. The connectivity between different sub-groups of neurons devoted to processing different kinds of words it is not uniform (Martin, 1996).

Several kinds of empirical evidence point to the existence of an asymmetry between linguistic production and linguistic comprehension: in general, understanding words seems to be easier than producing them (Bates, 2002).

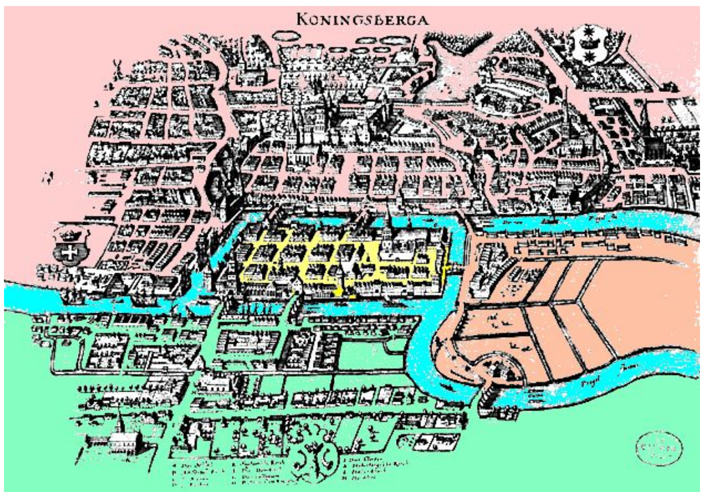
Communication provokes a response in social behavior that is followed by social actions, which are directed at other people and are designed to induce a response clearly seen in the development of norms and customs and everyday interaction between people.

The production, distribution, and consumption of goods and services are essentially shaped by social relations taking the increasingly flexible forms. Social relations and the roles of the individuals that make them up vary drastically from day to day forming a fairly complex perpetually variable network that we perceive as our everyday reality.

PARADIGMS OF NETWORK REPRESENTATIONS

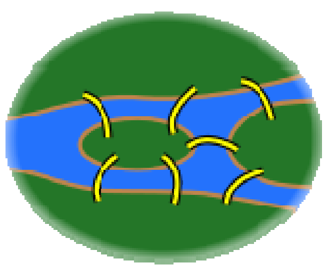
Any graph representation of a network naturally arises as the outcome of categorization process, when we abstract the system by eliminating all but one of its features and by grouping its units sharing a common attribute by classes or categories.

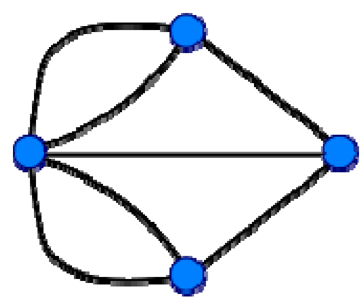
Before we can apply graph theoretic tools, we have to read the network geometry and translate it into a pattern that supports the type of analysis to be performed. Surprisingly, this step is not as easy as it looks at the first glance. A system of objects interacting in physical space in laps of time may be represented by the different graphs in accordance to three different paradigms:

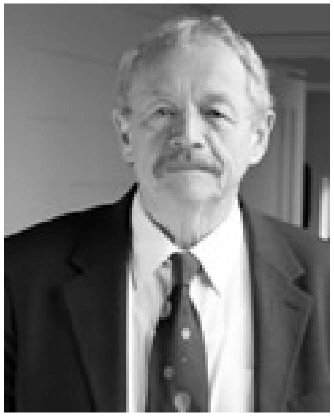


There is an ***object-based*** tradition of research originated from the famous paper of L. Euler on the seven bridges of Königsberg (Alexanderson, 2006), in which the landmasses, the city districts, the physical aggregates of buildings delivering place for people and their activity, are marked by nodes of a planar graph, while streets and other linear transport routes are considered as edges. The object-based representation arises naturally when we are interested in the dynamics of flows of commodity or people between the different network units.

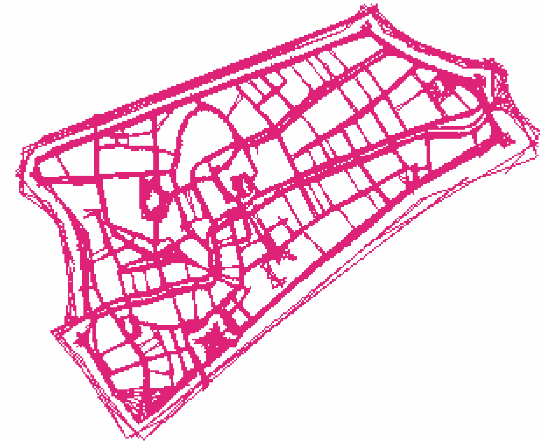
The graph resulted from the object-based representation of a network is always planar – the usual city plan is an example.

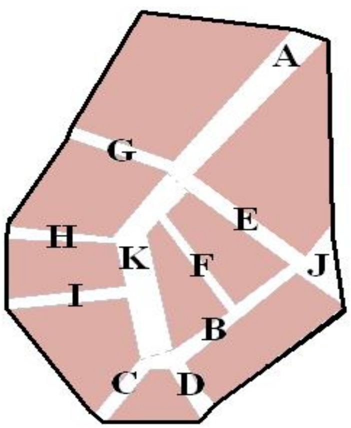


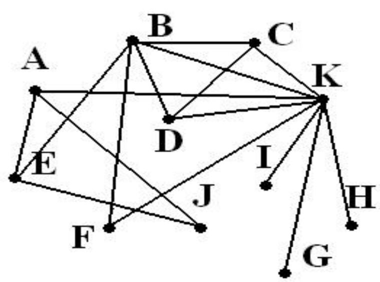




The ***space-based*** paradigm of network representaiton comes from the idea that people perceive and organize spatial information as they navigate through the city. In space syntax theory proposed by B. Hillier and his colleagues, the urban environment – the space we move through – is broken down into components, vista spaces, which are considered as nodes linked into a spatial grpah via their intersections and then analyzed as a graph of movement choices. Well-designed paths relying on the clarity of direction are significant not only for pursuing the practical tasks such as way-finding, but also are central to the emotional and physical well-being of the inhabitant population, personally as well as socially (Hillier, 1996).

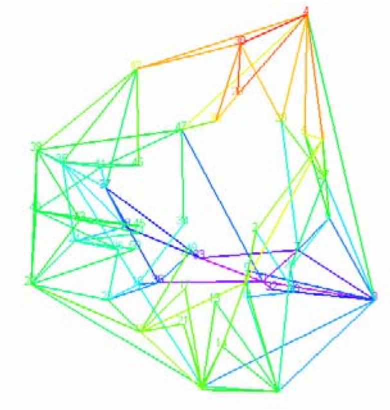




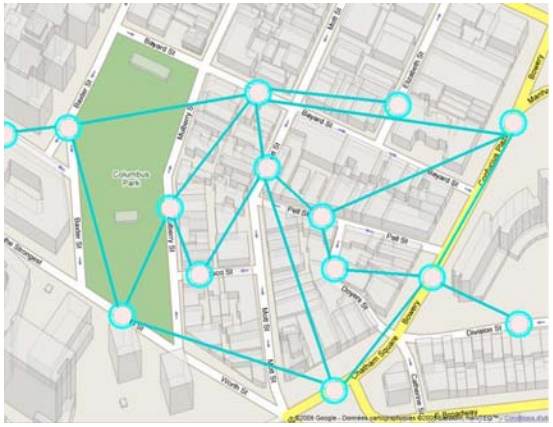


	A	B	C	D	E	F	G	H	I	J	K
A	0	0	0	0	1	0	0	0	0	1	1
B	0	0	1	1	1	1	0	0	0	0	1
C	0	1	0	1	0	0	0	0	0	0	1
D	0	1	1	0	0	0	0	0	0	0	1
E	1	1	0	0	0	0	0	0	0	1	0
F	0	1	0	0	0	0	0	0	0	0	1
G	0	0	0	0	0	0	0	0	0	0	1
H	0	0	0	0	0	0	0	0	0	0	1
I	0	0	0	0	0	0	0	0	0	0	1
J	1	0	0	0	1	0	0	0	0	0	0
K	1	1	1	1	1	1	1	1	1	0	0

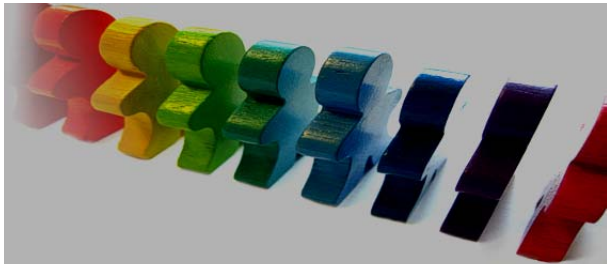
Eventually, the ***time-based*** representation of network arises naturally when we are interested in how much time a pedestrian or a vehicle would spend while travelling through a particular place in the city. The common attribute of all spaces of motion in the city is that we can spend some time while moving through them. Every space of motion is considered as a *service station* of a queuing network characterized by some time of service, so that the relations between these service stations - the segments of streets, squares, and round-abouts - are traced through their junctions.



It is remarkable that graphs of space- and time-based representations are not planar and have nothing in common with that constructed in accordance to the object-based paradigm.



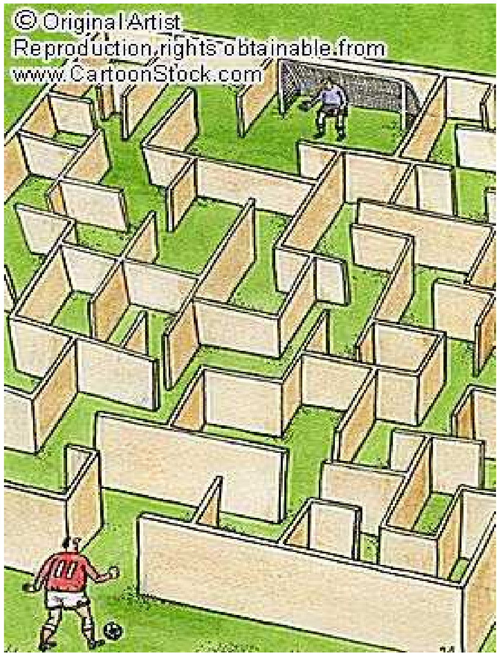
The A/B/C notation (1953): *A is interarrival time distribution, B is service time distribution, C is number of servers.*



Systems consisting of many individual units sharing information, people, and goods have to be modified frequently to meet the uncertain natural challenges. However, due to the lack of understanding of the result between the modifications and the possible response of the entire network, it has been always difficult to make the proper decisions on how to sustain the system and to cope with the new demand.

Euclidean space has a decisive role in visual and propriomotor percepts, and in hearing thus determining our spatial perception.
In addition, many of our feelings, of anger, fear and so on, have important links with parts of the body and hence indirectly with Euclidean space.

In general, networks do not possess the sturcture of Euclidean space. Thus, a mental representation of any network emerges as a result of a long learning process jointly with the planning of movements in that. However, usually we do not have enough time and cannot relay on our imagination in order to reliably predict the outcome of actions we take.



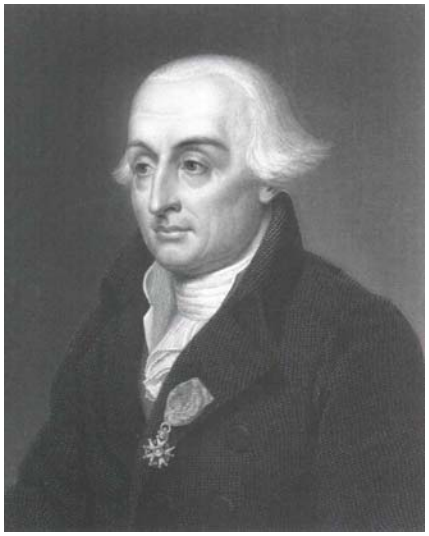
Networks possess the structure of Euclidean space, but in the probabilistic sense.

The set of linear automorphisms of an undirected graph $\boldsymbol{G}$ specified by the adjacency matrix $\boldsymbol{A}$,

$$T_{ij}^{(\beta)} = (1-\beta)\,\delta_{ij} + \beta\frac{A_{ij}}{k_i}, \quad k_i \equiv \sum_j A_{ij},$$

determines the probability transition operator of a *lazy random walk* over the graph $\boldsymbol{G}$, where $\beta \in [0,1]$ is the arbitrary "laziness" parameter.

The operator $\boldsymbol{T}_{ij}^{(\beta)}$ establishes a relation between nodes of the graph and eigenmodes of the diffusion process defined on that. The graph can be described by these eigenmodes as well as it was characterized by its adjacency matrix.



The idea to investigate the eigenmodes of a simple dynamical process (diffusion) defined on a graph in order to study its properties belongs to *Joseph Louis Lagrange* (Lagrange, 1867). He calculated the spectrum of the Laplace operator defined on a chain (a linear graph) in order to study the discretisation of the acoustic equations.

Nowadays it is well known that random walks can be used in order to investigate and characterize how effectively the nodes and edges of large networks can be covered by different strategies (see Tadic, 2002 and many others). The attractiveness of random walks defined on undirected non-bipartite graphs in many applications is due to the fact that the probability to visit a node after $t \gg 1$ steps tends to a well-defined stationary distribution π_i, which is uniform if the graph is regular.

PROBABILISTIC EUCLIDEAN SPACE

Euclidean space is an affine space, in which we can subtract points to get vectors, or add a vector to a point to get another point, but there is no any distinguished point that serves as an origin.
There is **no canonical choice of where the origin should go** in the space, because it can be translated anywhere.

In the probabilistic Euclidean space **any node $i \in G$ may be choosen as the origin with probability $\pi_i > 0$.**
The nodes of an undirected graph G are not equivalent for random walkers provided the graph is not regular; some nodes are oftenly visited by a walker, while others are not.

Eigenmodes of the diffusion process are expressed as linear combinations of basis vectors of the metric Euclidean space with the natural topology induced by the metric. Each node of the graph is therefore represented by a vector, and we can measure the distances and angles between nodes as we did in Euclidean geometry.
It is remarkable that the notions of probabilistic geometry are akin to the famous *path integrals* of Richard Feynman accounting for all paths possible in the graph.

For instance, let us try to reach a node of the graph starting from the randomly chosen origin and count the expected number of steps we make.

The **first-passage time (FPT)** to a node is the *expected* number of steps required to reach it from the randomly chosen origin.

$$\text{FPT} = \| \boldsymbol{i} \|_T^2$$

FPT plays the role of a (squared) norm of the vector representing the node in the probabilistic Euclidean space.

The **commute time**, the expected number of steps required for a random walker starting at $\boldsymbol{i}$ to visit $\boldsymbol{j}$ and then to return back to $\boldsymbol{i}$, is the (squared) Euclidean distance between any two nodes in the graph,

$$d(i, j) = \| i - j \|_T^2$$

The commute time is the sum of two terms,

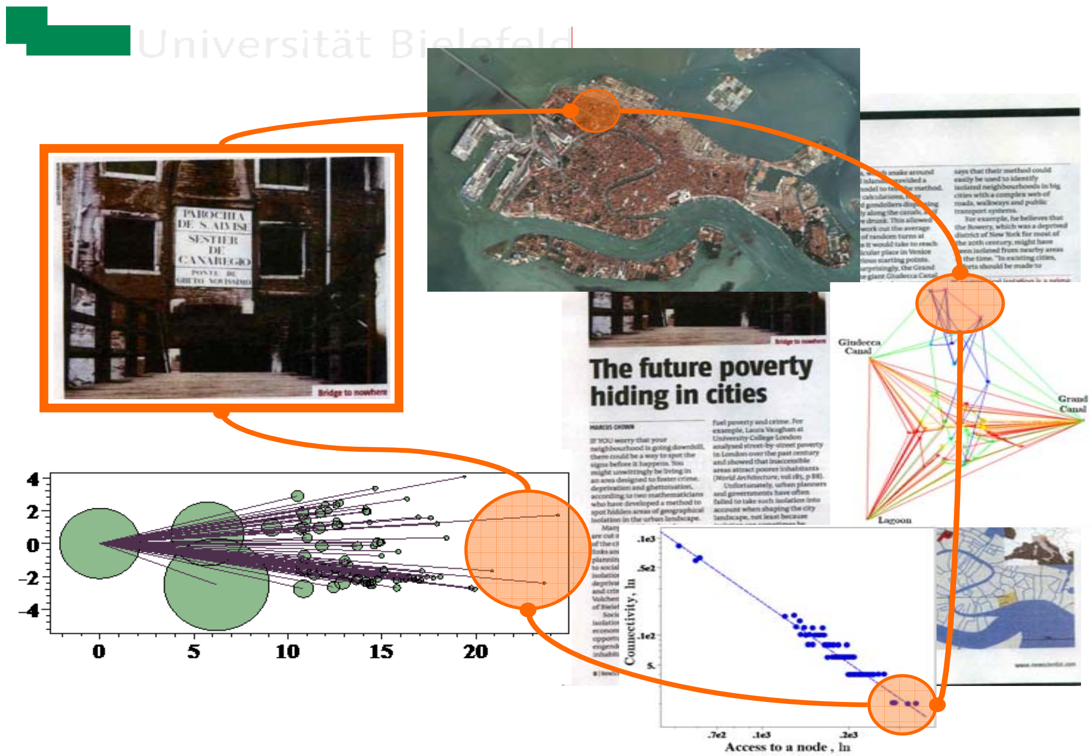
$$d(i,j) = \| i - j \|_T^2$$
$$= \| i \|_T^2 - 2(i,j)_T + \| i \|_T^2$$
$$= h(i,j) + h(j,i).$$

$h(i,j)$ and $h(j,i)$ called **the first-hitting times**, the expected number of steps a random walker starting from the node i reaches j for the first time. In general, $h(i,j) \neq h(j,i)$ even for a regular graph. The first-hitting times help to identify the structural traps and hidden nodes in the network.

Finally, the expected number of steps required for a random walker to reach a randomly chosen node in the graph (a target) is called the **random target time**, τ_G. The random target time is independent of the target node being a global characteristic of the graph.
We conclude that random walks embed connected undirected graphs into Euclidean space that can be used in order to compare nodes and to retrace the optimal coarse-graining graph representations.

THE FUTURE POVERTY HIDING IN CITIES

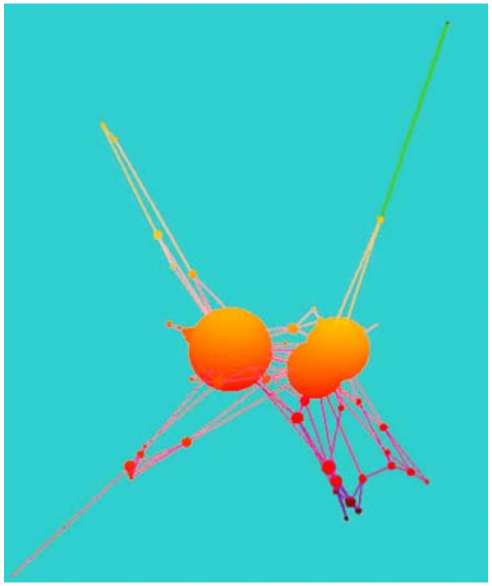
If you worry that your neighbourhood is going downhill, you might unwittingly be living in an area designed to foster crime, deprivation and ghettoisation (Chown, 2007) - many neighbourhoods are cut off from other parts of the city by poor transport links and haphazard urban planning, which can often lead to social ills. Urban planners and governments have often failed to take such isolation into account when shaping the city landscape, not least because isolation can sometimes be difficult to quantify in the complex fabric of a major city.



The study of linear automorphisms (random walks) of the spatial graphs of urban areas could be a way to spot the signs of isolation. In particular, the Ghetto of Venice and the Bowery, which was a deprived district of New York for most of the 20th century, are seen to be isolated from nearby areas.

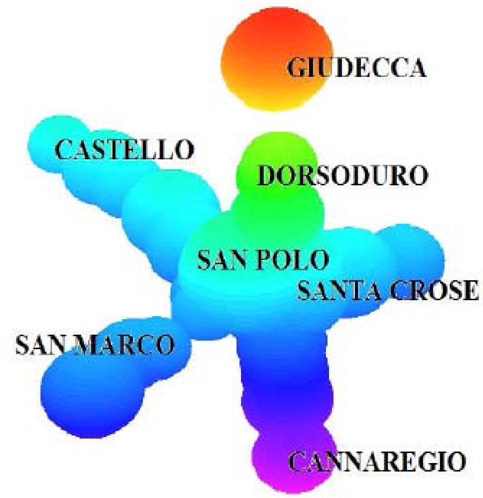
EXPLORING COMMUNITY STRUCTURE OF NETWORKS AND THEIR 3D-VISUALISATIONS

Random walks convert a graph into the metric Euclidean space, and we can use this natural metric in order to explore the network community structure and to construct its visual representations.



The 3D-image of the spatial network of Venetian canals. The radiuses of balls representing city canals scale with their connectivity.

The segmentation of the canal network in Venice in accordance to its historical divisions.

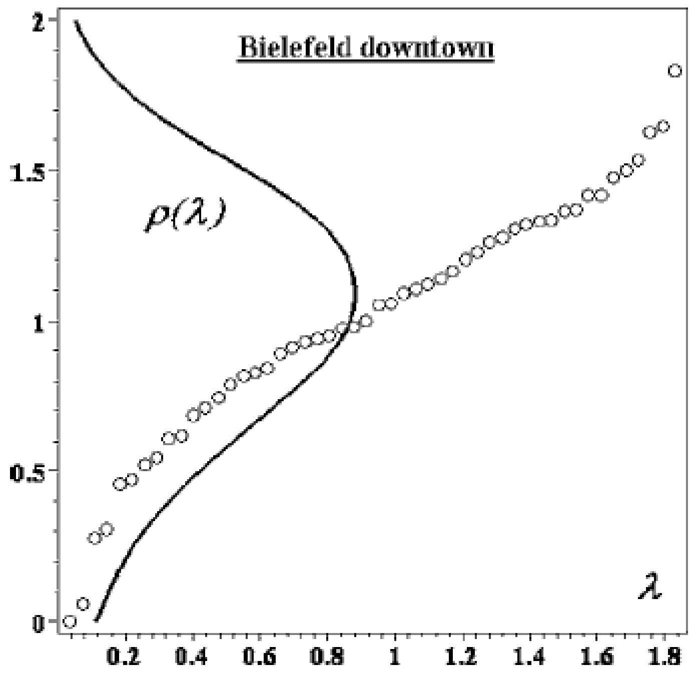


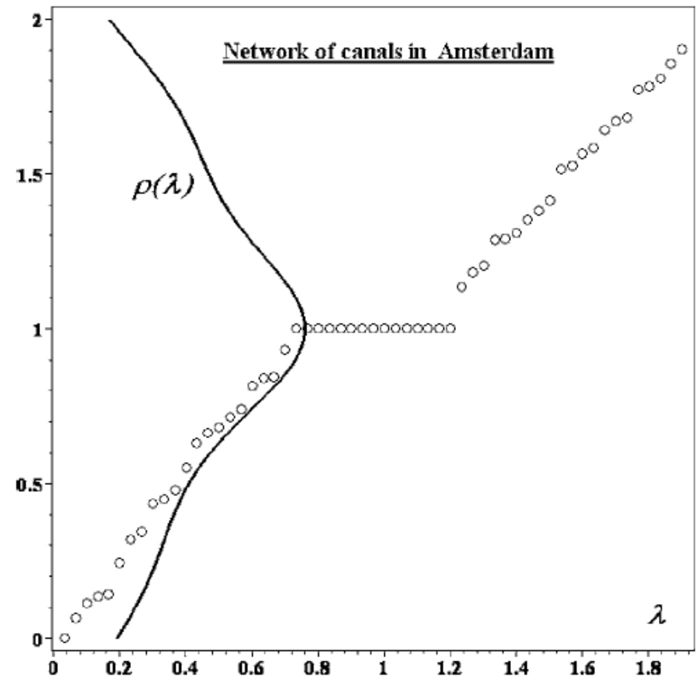
The 3D-image of a dynamical segmentation of Venetian canals built for the first 8 eigenmodes. The structural differences between the historical city districts of Venice are clearly visible.

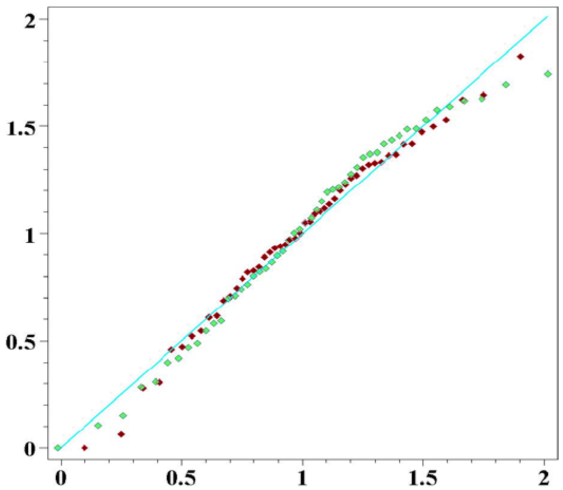
SPECTRAL PROPERTIES OF URBAN NETWORKS

Spatial networks of human settlements are not random. No matter whether they are organic or not, they take form of a complicated highly inhomogeneous structure that emerges due to trade-offs, the optimization problems between the multiple, complicated and probably conflicting objectives.

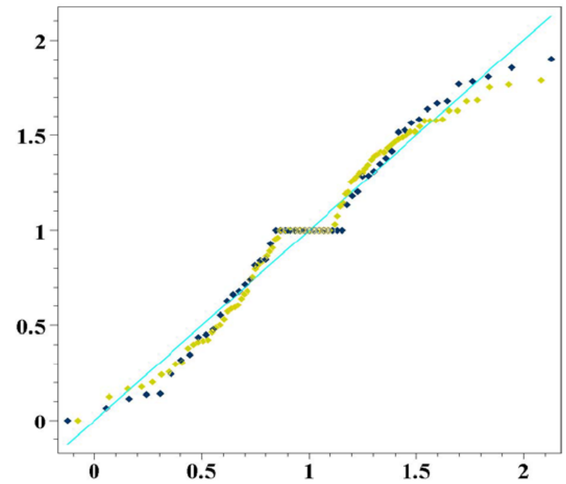
The spectra of human settlements are close to ***normal distribution***, but not to the Poisson one that was typical for random graphs.



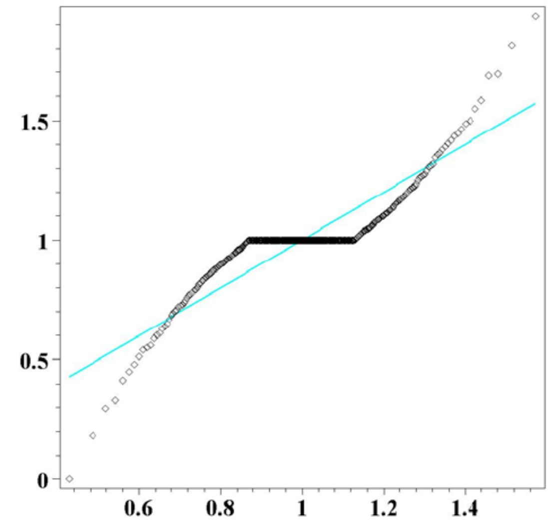




The probability-probability plot of the normal distribution (on the horizontal axis) against the empirical distribution of eigenvalues in the city spectra of German medieval cities, Bielefeld and Rothenburg o.d.T. The coincidence line $y = x$ is set for a reference.



The probability-probability plot of the normal distribution (on the horizontal axis) against the empirical distribution of eigenvalues in the spectra of the city canal networks in Venice and Amsterdam.



The probability-probability plot of the normal distribution (on the horizontal axis) against the empirical distribution of eigenvalues of the spatial graph of Manhattan.

The accumulation of eigenvalues close to ***1*** is an evidence in favor of that the city graphs have good expander property, i.e. they constitute the economical robust networks in which the number of edges growing approximately linearly with size, for all subsets.

RANDOM WALKS ON DIRECTED AND INTERACTING NETWORKS

Random walks and diffusions can be considered on directed and interacting networks. However, they are not uniquely determined.

For instance, on a strongly connected directed graph, the probabilities of moving into a node and of leaving it are not equal. Therefore, we can define ***forward-time (P)*** and ***backward-time ($P^{\dagger}$)*** random walks that are not equivalent to each other. Nodes in directed networks can be easy to reach but difficult to leave, and vice versa.

Bus (N_1) and Train (N_2):

Take a bus – $\mathbf{P}^{(1)}$

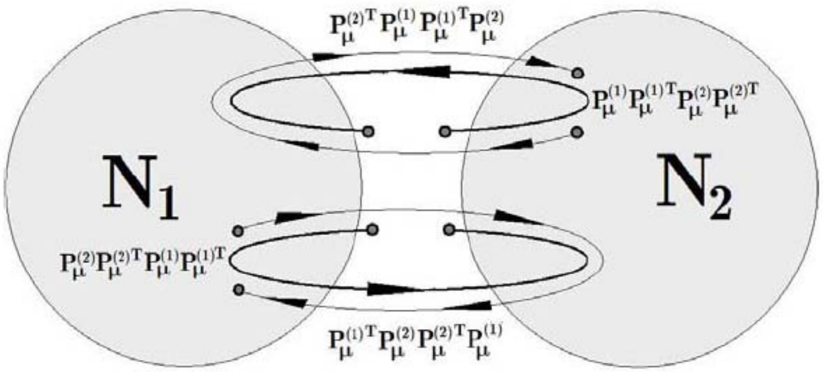
Take a train - $\mathbf{P}^{(2)}$

Leave the bus - $\mathbf{P}^{(1)^{T}}$

Leave the train - $\mathbf{P}^{(2)^{T}}$

Different "strategies":

"Take a train-Leave the train-Take a bus -Leave the bus",
"Leave the train-Take a bus-Leave the bus -Take a train",
"Take a bus-Leave the bus-Take a train -Leave the train",
"Leave the bus-Take a train- Leave the train -Take a bus".



In general, given $\boldsymbol{n}$ different interacting networks, we can define $\boldsymbol{2^n}$ different diffusion processes on them. Nodes that have a good access in one network can be relatively isolated in others. Structural diversification of nodes and subgraphs can be of the essential practical interest. The city locations related to public processes of trade, exchange, and government tend to occupy those places which can be easily reached from everywhere. Alternatively, the hidden nodes constitute the optimal location for a residential area where the occasional appearance of strangers is unwilling.

AFTERWORD

Urbanization has been the dominant demographic trend in the entire world, during the last half century. The essentially fast growth of cities in the last decades urgently calls for a profound insight into the common principles stirring the structure of urban developments all over the world.

There is a strong positive link between national levels of human development and urbanization levels.
However, even as national output is rising, the implications of rapid urban growth include increasing unemployment, lack of urban services, and overburdening of existing infrastructure that result in a decline of the quality of life for a majority of population. The essential attention should be given to the cities in the developing world where the accumulated urban growth will be duplicated in the next 25 years.

We often think that we have much enough time on our hands, but do we? This is upon us whether or not the city welcomes these people.

The need could not be more urgent and the time could not be more opportune, to act now to sustain our common future.

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