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'Small-World' Networks and the Fractal City

Biological and digital networks offer important lessons for planners as they design cities for the 21st century.

By Nikos Salingaros

Oct 06, 2003



Living cities have intrinsically fractal properties, in common with all living systems. The pressure to accommodate both the automobile and increased population growth led twentieth-century urbanists to impose anti-fractal geometrical typologies. The fractal properties of the Traditional City were erased, with

disastrous consequences for the urban fabric. I will use lessons learned from the evolution of biological systems and the Internet to discuss the distribution of sizes, inverse-power scaling laws, and 'small-world' networks. These concepts show us that extreme densities favored in contemporary urbanism--suburban sprawl on the one hand, and skyscrapers on the other--are pathological. The challenge for the Contemporary City is how to superimpose competing connective networks in an optimal manner.

'Small-World' Networks and the World-Wide Web

In talking about urban connectivity, it is necessary to consider the length of links (i.e., the different paths) so as to establish a hierarchy of connections according to their geometry. There is an optimum distribution of sizes: the paths are going to satisfy some distribution according to their length, width, or capacity.

A 'small-world' network is one where nodes are connected by both long and short links (Barabási, 2002; Salingaros,

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[The Sky Is Not Falling On Cities](#)

By *Carol Coletta*

2001). Starting from a set of nodes with only nearest-neighbor interactions, add a few longer links at random. The result is a drastically improved overall connectivity. This is measured by how many links it takes to get from node A to node B for any two nodes chosen at random. If the nodes are connected only via nearest neighbors, then one is required to go through all the intermediate nodes between A and B. Just a few longer connections provide sufficient shortcuts to improve the connectivity. What has happened is that a system with only nearest-neighbor (shortest) connections has been transformed into one that is closer to having an inverse-power distribution of paths.

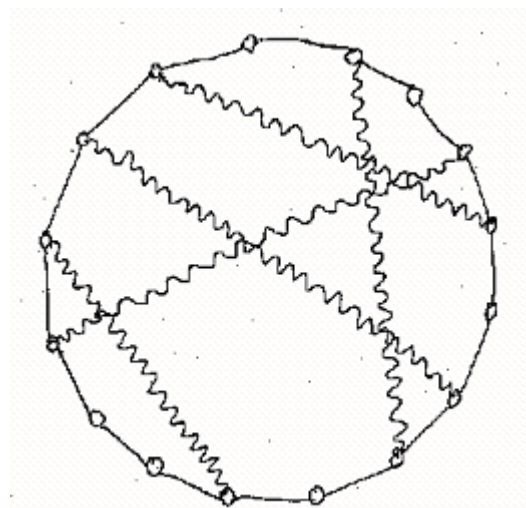


Figure 1. A minimally-connected set of nodes with only nearest-neighbor links is made into a 'small-world' network by adding a few longer links.

We have started at the smallest scale and have built up to the largest scales. In urban structure, this progression corresponds to the dynamic growth of a village into a town, at which point it loses its initial small-scale connectivity. To regain it, it needs to cut new roads as "shortcuts" that connect spatially-separated regions. As it grows, a city requires larger and larger roads. A NETWORK IS ALWAYS DRIVEN TO ADJUST ITS COMMUNICATION INFRASTRUCTURE TOWARDS AN INVERSE-POWER HIERARCHY. This is the reason why the Medieval City-- with short-range pedestrian connections-- could not survive unchanged.

Aug 25, 2005

Cities aren't in decline. The way population change is "measured" by the Census Bureau leaves much to be desired, writes Carol Coletta in this week's Op-Ed. But even if cities were in decline, a city's population is no longer tied to its economic success. What is ironic about these estimates and the misleading story of decline that has been spun around them is the fact that cities no longer have to grow big to grow wealthy. For the first time, according to research from CEOs for Cities, a city's population is no longer tied to its economic success.

[From NIMBYs To DUDES: The Wacky World Of Plannerese](#)

By Ric Stephens

Jul 26, 2005

Ric Stephens has compiled a list of some of the wackiest -- yet at times quite realistic -- urban planning words, in a vocabulary he has dubbed 'Plannerese.' This week's Planetizen Op-Ed includes a selected glossary of the terms, in addition to 'A Modern Fairy Tale in Plannerese,' which looks at a typical planning issue through the humorous lens of planning jargon.

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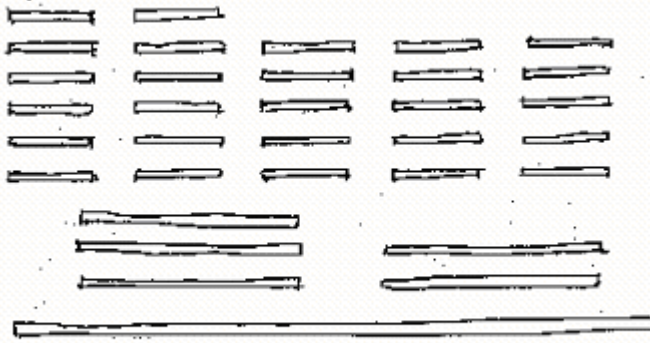


Figure 2. Inverse-power distribution of sizes.

For the same reason, however, the Modernist City, which is artificially biased towards longer connections, was an unrealistic planning model. The Car City that emerged in place of the Modernist City requires many short car trips, hence parking lots everywhere. Contrary to what Le Corbusier decreed, people have never used their car to drive solely between their house in a garden suburb and their downtown office. The car is now used for every little chore of everyday life. Not surprisingly, once we have the sedentary connective freedom offered by the car, we demand a direct car connection to every urban node. This powerful force generates commercial suburbia, erasing the compact urban fabric in the process.

Our craving for direct car connections among every urban node makes the Car City differ from the Modernist City. The Twentieth-Century City is a combination of Suburban Car City and Modernist City. In theory, we can connect by car directly to any other point, as long as there is parking, and no other cars want to use the network at the same time. The car increases a person's reach to tens of kilometers. Even more important is the transport and delivery of goods by truck. The price for car accessibility, however, is to sacrifice 50% of a city's surface to roads and parking, and to make our economies hostages to petroleum supplies. Le Corbusier wanted to amalgamate the paths in a Modernist City into one superpath (Salingaros, 1998). His method was to force all residences together into a few giant high-rise buildings, and all offices together into downtown skyscrapers.

The web of public transport that includes subway, trams/streetcars, and light rail was an invention of cities growing rapidly in the nineteenth century. It became

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necessary to introduce shortcuts between regions of the pedestrian city that were too far apart to connect. The ideal solution was a superimposed transportation network that does not compete with the existing pedestrian and vehicular (early motor and horse-drawn) traffic, hence it was built either underground or raised overhead. The Metro/Subway should be interpreted as an extension of the PEDESTRIAN web, since it links regions of the city that are themselves parts of the pedestrian web. Altogether, it's a small-world network that improves its connectivity by introducing a few longer connections.

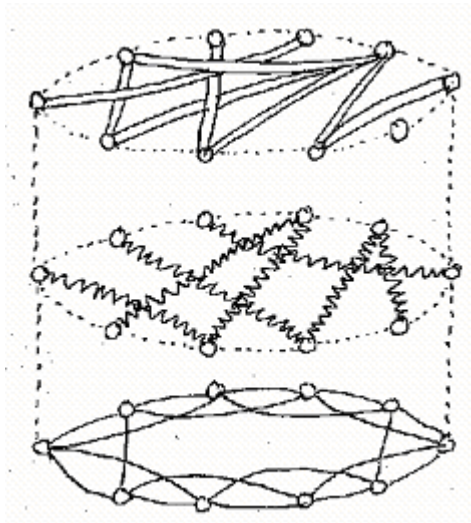


Figure 3. Three different competing connective networks shown separated into layers.

Failure to understand this causality (i.e., what action drives another action) has led to disappointment when car cities introduce a subway. Just because Paris has a subway, post-war commuter suburbs-- with an existing road grid built for cars-- unrealistically expect that a piece of 19th century European urban fabric will miraculously develop around new subway stops. This has failed to materialize. In a Car City, the forces are overwhelmingly focused on the need for parking around a metro station. Forces that would generate a pedestrian network are simply not present, and the actual needs may prevent any pedestrian web from ever forming there.

Urban morphology is a product of the particular transportation system laid down by the government when the city was initially built. Later modifications to the transportation system lead to changes in city structure. Today, governments lay down exclusively car cities (by legislating the road network and infrastructure before

anything can be built), or come in and destroy an existing Pedestrian City in order to transform it into a Car City. In the second instance, pieces of the old Pedestrian City might survive to provide at least some remnants of urban life (if the state machine is truly efficient, nothing will be left). For this reason, it is extremely difficult to transform a post-war Car City or suburb into a Pedestrian City -- one has to rebuild a new pedestrian network into the Car City.

The World Wide Web itself has grown and has self-organized according to a self-similar, small-world structure (Barabási, 2002). That is, it obeys an optimal distribution of sizes for connective links. None of this structure has been imposed-- it has all grown incrementally. Here we have an excellent example of self-organization, the process by which forces manage to act in balance to grow a complex system into a stable working structure. This process is analogous to the miracle of biological growth, as seen in the development of an embryo. A combination of code (in the DNA) and chemical fields leads to the formation of a wondrous complex whole.

When 'small-world' networks were first introduced, it was discovered that the nervous systems of invertebrates (which are simple enough to be mapped) indeed obey such a distribution. The need for efficient signal connectivity via a nervous system has evolved exactly this type of network in animals. A city should evolve the same type of network connectivity, but unfortunately it cannot do this automatically. It is necessary to allow both self-generation of urban fabric on the small scale, as well as deliberate intervention on the large scale. This is in fact a central problem of urbanism-- the competition between top-down imposed design, and bottom-up self-generated design. Both processes are misunderstood nowadays.

The City of the Future

If we can get over the ideological blinders imposed on the world by otherwise well-meaning but false ideas about "modernity", then we can begin to understand how the urban fabric forms itself and changes dynamically. We can then build new cities that incorporate the best characteristics of traditional cities, while utilizing the latest technology to facilitate instead of frustrating human interactions. At the same time, we can regenerate older cities, which already contain physical structures that would today be impossible to duplicate economically. Those

buildings and urban spaces are being sacrificed to an intolerant design dogma, to be replaced by faceless and lifeless rectangular slabs, cubes, and parking lots.

Pathological components of the city can be selected against. Either an underconcentration, or overconcentration, of nodes strains the infrastructure and resources of the city. Two extremes are suburban sprawl, and skyscrapers. Individuals desire the first, whereas governments and corporations want the second. Neither is acceptable. The first of these urban typologies uses up most of the automobile fuel in the city for the simplest transportation needs. The second typology concentrates non-interacting people into one building, drawing resources from the rest of the city. The urban forces generated by the overconcentration of a skyscraper tend to erase the urban fabric in a significant area around it. Skyscrapers feed off the rest of the city, and require more infrastructure and larger expressways to maintain them.

The Electronic City offers help in two distinct ways. Firstly, it replaces many "dirty" connections of the older city, freeing up infrastructure and fuel consumption. It makes pedestrian pockets in the city much more attractive and practicable than ever before. Secondly, its very structure offers us a template to follow in rebuilding the urban fabric. I mentioned that the Internet follows the same structural laws as the Traditional City. This should be enough reason to finally discard the misguided, simplistic twentieth-century models of urbanism that did so much to damage our cities. IF WE NEED TO CONNECT THE ELECTRONIC CITY TO A PHYSICAL CITY, THEN THE PHYSICAL CITY MUST FOLLOW THE SAME STRUCTURAL LAWS. By selectively applying successful prototypes from the past, together with insights from the science of networks, we can generate an entirely new type of living contemporary city.

NOTE

This essay consists of extracts from a longer article, presented as a Keynote speech at the 5th Biennial of towns and town planners in Europe (Barcelona, Spain, April 2003). The original article entitled "[Connecting the Fractal City](#)" is available on-line.

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