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Physics of the City

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Complexity

Cities are the nodes of the human civilization network from Neolithic until today, when more than half of the whole world-wide population is composed by individuals that live in urban systems, from towns to metropolis. So it is obvious that many learnings from policy to aesthetics, from sociology to philosophy, from planning to architecture, from engineering to psychology, from economy to behavioural sciences have applied to understand, plan and build up the city development. In the urban stage we can see to play almost all learnings and sciences, but not physics.

It was not always the case; in the ancient times Aristotle thought that the physics (nature) of the polis (city) was the same physics of the cosmos. And more recently Karl Popper has noted that the origins of science and democracy are commons for using the same dialectical methods, with the falsification of one opinion via public critical analysis, discussions and experimentations. But at a certain moment of the history, this harmony between earth and sky, city and cosmos, was broken. From one hand there are the human sciences based on the free will and insofar which cannot be exact; from the other the natural sciences, essentially geometry, physics and astronomy, in principle exactly determinate by measuring and/or calculating, based on invariant symmetries, and whose empirical observations and experiments can be repeated by everyone wants, to verify the results. Here we are in presence of a bifurcation point from which two completely separated branches, the humanistic one and the scientific, seem to go away.

But in the last three, four decades the discover and development of complexity changed the landscape, in the double sense both that many phenomena must be investigated with a multidisciplinary approach if we want really to understand them, and that also in natural philosophy a complexity paradigm allows us a deeper knowledge of the richness and variety of nature.

From philosophy to sociology, from physics to biology, from planning to policy and so on the complexity seems the key for trying to understand many different phenomena and systems of our world that until to day appeared irreducible each other.

From the beginning of the human history the dialectic was between order and disorder, often identified with randomness. In this sense we can think the human activity over the time as a continuous struggle against natural and/or primordial chaos, to build up an order that makes possible to originate and to develop life and civilization.

Into the best logical and symbolic representations of order, we can put surely the Euclidean geometry, the Newtonian mechanics and the Keplerian astronomy, where from a set of axioms and/or principles we can deduce theorems and dynamical laws which seem to regulate the space-time evolution of natural phenomena from the infinity past to the infinity future and vice versa, the cosmos becoming a sort of perfect reversible clock.

It is the Platonic conception for which harmony and order emerge from primordial chaos through the action of the demiurge, who is a mathematician. But as matter of fact from one hand many natural events do not respect the deterministic laws neither in physics dominion, from the other one the behaviour and the evolution of human beings are almost in part governed by free will, intrinsically non deterministic. So a completely ordered world appears too much inert and lifeless, and the completely disordered one would make the life and the human culture development impossible. From any point of view the order disorder duality risks to wear us in a blind alley. Complexity can be conceived as the exit strategy invented by nature to escape from this duality, discovering that many natural phenomena are organized but not deterministic, that is also a characteristic of the social systems.

Roughly speaking complexity is a sort of no-man's-land intermediate between order and disorder, where life can survive and evolve, may be where life could be originated.

The role of information about complexity is a second crucial point that we want underscore.

The word "information" in communication theory relates not so much to what you do say but rather what you could say. The significant aspect is the freedom of choice when we select one message from a set of possible messages, and the information is a measure of this freedom. In mathematical terms, the information is a function of probabilities, if do you want the sage "daughter" of randomness.

If the information science is the theoretical framework, the high speed computers and advances in parallel distributed processing constitute the technology that allows to perform algorithms and calculations able to explore previously unimaginable orders of complexity.

So we can set up in silicon experiments to study a very wide range of complex states, that would be much more difficult to do in material experiments. At this point we must be careful that some sort of a simulation principle doesn't take precedence over the knowledge reality principle. Otherwise, we could risk building up a science of imaginary that can be beautiful and charming, but not able to intellect the natural and social phenomena.

The more recent studies in neuro and cognitive sciences show that the simulation is a basic and fundamental mechanism of learning unscripted in our biological and neuronal system, and that the data of experience are always already processed, but "As we rush to explore the new vistas that cyberspace has made available for colonization, let also remember the fragility of a material world that cannot be replaced.".

We also underline that in modern and/or post modern society, the information is not only restricted to the scientific laboratories but is present in the every day life of many peoples, so that today it is common to speak of "information society". But if the information and the information networks go from broadcast on media or fibre-optic data transmissions until to chemical or biological processes, this is a possible bridge between the humanistic culture and the natural sciences. Complexity via networks and information suggests that nature and culture evolve together and that we can construct not only translation codes from one to the other ,but common effective research programs.

Physics

Our physical world is no longer symbolized only by stable and periodic planets orbits or by the harmonic oscillator and Galilean pendulum paradigm with its reversible time, which are at the heart of classical Newtonian mechanics. A new universe of instabilities and fluctuations, which are responsible for the amazing variety and richness of the forms and structures that we see in nature, is included in the horizon of natural philosophy. Surely, if we want to understand for example the dynamics of earthquakes, the weather variations, the growing of trees, the DNA origin and structure, a pure reductionist approach appears to be powerless.

These phenomena are too complex to be analysed straightforwardly by simple application of the fundamental laws. Exactly as knowing the chemical links and molecular composition of H2O, we cannot explain the different states of matter: liquid, solid and gas.

At this frontier the watchword is not reductionism, but emergence of new unpredictable and unexpected phenomena. These emergent complex phenomena are by no means in violation of the microscopic laws, but they do not appear as logically consequent on these laws.

In a first qualitative and/or heuristic sense we establish to call this phenomenological universe “complex”, and we can define “physics of complexity” the set of experiments, models, theories, paradigms that contribute to study this type of natural phenomena and/or systems.

It should be clear at this point that until today a “theory of complexity” does not exist, in the sense that we don’t have general principles or laws or equations underlying the whole complex world, from which we could derive the behaviour of the single specific system.

Each complex phenomenon must be investigated in its proper way also if some features and models, as for instance networks or cellular automata type systems, are able to study a large spectrum of events not only in physics domains. For us a possible paradigm of complex system is an automata gas, i.e. a gas of individuals that can process information, the automata being a sort of “intelligent” atom which has not only a physical dynamics, but also a cognitive and decisional one.

At last, one question remains completely open: why our mesoscopic world appears full of so complicated phenomena from the fracture dynamics to the DNA organization, the basic physical laws at the atomic and cosmological scales being relatively simple. Or in a different view: why and from which complexity emerges. Someone answers in order to make possible the life, but it is a metaphysical and/or philosophical statement that, before becoming scientific, also needs of many experimental and theoretical steps.

Urban systems

“Aggregate of beings that hold their biological history into its borders and model it within all their intentions proper to thinking creatures, the city results at the same time by the biological generation, the organic evolution, and the aesthetics creativity. The city is contemporary a natural object and a subject of culture.” (our translation from French).

From these words of Claude Levi Strauss clearly emerges the complex nature of every urban system, that today it is generally accepted and considered in order to study the city, its development and evolution. Let’s stop for a moment to consider the city as an extremely intertwined set of flows, information and forms. The city show itself to be polymorphous, polysemic and polyglot, stratified in time and crossed by actors and objects whose dynamics are extremely different and can be conflictive, giving often a chaos sensation.

If we want to try to express the quality of this complexity in quantitative terms, using the instruments of the exact sciences, essentially the physics, without losing its texture, we must reduce the semantic, logical, syntactic and phenomenological field in which to articulate the possibilities of constructing models able to be descriptive, explanatory and, at least to some extent, predictive. These models surely will never be completely isomorphic to reality, but can simulate some of its aspects and characteristics considered salient by the observer, that plays a fundamental role in the choice of the significant observables and control parameters which obviously depend from what we want control and govern. A simple consideration can help us in the reduction process: regardless of the variety and complexity of flows, forms and information, an urban system exists insofar as it is inhabited. A city is not even definable without citizens, elementary components common to any urban system, from the Neolithic Catal Hoyuk to the modern New York, only changing over the time the complexity degree. Therefore our physics of city will be essentially physics of the inhabited city, and given the large number of elementary components, this means non-equilibrium statistical physics, because the town is a highly open system. Moreover, given that the elementary components move in urban space-time, this also means the physics of dynamic systems and since the individuals in the system have free will, we are also talking about probabilistic physics (Pascal firstly modelled the human free will by the probability function, using the game of chance as paradigm). To finish, since the elementary components have memory and are capable to draw information from the environment, processing it according to intentions, choices and decisions, the physics of the city must also be intentional, cognitive and decisional.

The cities can be also defined as adaptive complex systems. In fact the urban systems conserve coherence and persistence over a long time, nevertheless being open and far from equilibrium. If you think for example to Rome, you can see that the urbe aeterna, the eternal city, develop continuously a sort of recognizable and dynamical identity over a twenty five centuries time period adapting itself to strongly different situations, that is one of the most remarkable properties of this type of systems.

Last but not least, the physics of the city is essentially non-Newtonian, that is this physics does not respect the third principle of mechanics, the principle of action and reaction. And the third principle is fundamental in order to define a classical theory of measure. Moreover the significant material experiments and empirical observations which we can perform in the urban context generally cannot be reproducible, and so the usual Galilean truth criterion for the physics theories here lacks. In a certain sense we are in the same gnoseological situation of the astrophysics and cosmology, where the events and the objects are often unique (think for example to our sun or to our cosmos). But with two advantages, that we can visit and know directly the cities; and that we can pose to the elementary components of the systems, the citizens, the questions interesting for us.

Mobility

It seems somewhat self-evident to say that mobility conditions urban development, and vice versa. Le Corbusier posited a richer and more intriguing concept. “Man walks in a straight line because he has a goal and knows where he is going; he has made up his mind to reach some particular place and he goes straight to it. The pack-donkey (…) zigzags in order to avoid the larger stones, or to ease the climb, or to gain a little shade; he takes the line of least resistance. The Pack-Donkey’s way is responsible for the plan of every continental city.” Le Corbusier’s paradox fully unfolds in what have been defined as third-generation metropolis, in which the mobility of citizens increasingly acquires zigzagging and/or asystematic configurations. Almost as if we were all donkeys, generating the scientific problem of if-and how- this type of mobility can be modelled using dynamical equations and/or algorithmic formulations to describe, explain and, eventually, to predict some of its features and evolutions.

Over a long time, modelling and planning were inspired by an Enlightenment philosophy for which the city was naturally constituted in a rational way. If the geometry was postulated to be always Euclidean, the plan was thought as a centralist governing tool, representing a sort of intrinsic general intellect common to all urban actors. Less strongly, we can also say that the fundamental assumption was the postulated rationality as the basis of actors’ behaviour.

But social transformations drastically changed the urban picture, giving a relevant weight to the individuals’ actions and perceptions of metropolitan space-time. Henceforth a new culture of planning was arising, where the free decisions and behaviours of the citizen become significant and cannot, in general, be reduced to simple statistical averages or organized by an external authoritarian form. So we are in presence of a culture where planning and design emerge from the bottom up, where the singles citizens are in touch with the urban problems, as the liveability of city and/or the quality of life, and where the individuals contribute to drawing up the plane. The science of city must to face the problem of a new understanding in terms of how the individuals behave and the strategies/actions that they develop in order to know and modify their environment. This means that we must focus the attention at small spatial and temporal scales, modelling the microscopic urban dynamics. From this point of view the mobility is a paradigmatic problem. Where at large scales the mobility is dominated by the origin-destination schemata, what complicates the dynamics at mesoscopic and small scales are events in which the stochastic individual movements switch from one decision to another as consequence of the single free will, and of interactions with the urban space-time and with the other individuals.

E-governance

In this situation the prediction, even if partial or probabilistic, is relevant not only for the pleasure's knowledge but also for the mobility governance, for example when great events strongly attract many peoples, in order:

1. to minimize the impact of provisional city users on the town, and in particular on the mobility of local populations
2. to avoid critical and potentially dangerous crowding phenomena
3. to prefigure and plan security saving trajectories

With little variations, these points are commons to the different types of mobility, from pedestrian to the private car mobility and/or public transportation networks.

In all these cases if we want our models being useful for the E-governance, they need not only to reproduce some aspects of the factual reality but also they must be able to explore all the possible paths of the potential reality, via simulations in the corresponding virtual system. At this point we want being out a delicate epistemological problem, because the results of virtual experiments, especially for critical values of the control parameters, often cannot be compared with the corresponding empirical data. Moreover when we are studying small spatial events and microscopic dynamics, the observational data are always inadequate, i.e. our set of observables is always incomplete. And if the models break down, some unpleasant consequences could happen in the practical e-governance applications. So it is crucial to collect sufficient long time data series in order to have the better possible empirical modelling validation.