Protocol Growth

Development of adaptable city models through self-organization

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Abstract. Protocol Growth attempts to approach the process of design in an alternative, bottom-up fashion, that is not based on master planning but instead on the development of a protocol that would allow infrastructure to 'self-organize', adapting at the same time to the conditions that it encounters. First, the concept of the protocol is explained and positioned in its historical context in order to better understand the needs that it satisfies. Then the characteristics of such an approach are illustrated through the example of a structure that aims to the development of a system that would allow for a settlement to face the rising of the water level because of global warming. The model proposed, instead of following a ‘long term’ plan adapts itself to the situation that it encounters and grows in height following an algorithm designed for that reason.

Keywords. City growth; protocol; self-organization; computation; cellular automata.

City Growth and Networks

City growth, along with the infrastructure that supports it, has been typically approached until now as an issue of planning. Expansion directions, densities, open spaces, along with highways, roads, sewers, water supply, dams and every other aspect that is employed in order to support and sustain human settlements is treated as part of a master plan that aims to satisfy the needs that arise from human activity. Such planning is always made in order to satisfy the needs for as long as possible. Therefore, since only the needs for the present point in time are definitely known, speculation, projection and statistics are employed in order for a viable solution to be achieved.

At the same time we usually tend to think about cities and infrastructure as networks. While understanding the city and its infrastructure as a network is an idea quite old, in recent years the study of networks in general is becoming all the more important for almost every scientific field. That research in network studies shows that networks are not always static; they can also be dynamic and scale-free.

In that context, ‘protocol growth’ is an attempt to propose a different model in order to study the growth of cities along with their infrastructure. According to that model, city growth and infrastructure can be understood not as the result of a master plan - of a hierarchical, top-to-bottom approach - but rather as a system that emerges through the self-organization of some basic, initial elements that interact with each other according to simple, specific rules. Infrastructure is still treated as a network,
only that now the focus is on the network’s nodes that can have the ability to re-organize, adjust and adapt to new conditions. There is a shift from a static conception of networks to a dynamic one, which, by removing any top-down hierarchical elements becomes able to self-organize.

Recent developments in biology, life sciences and network studies, make clear that systems can function in a bottom-up fashion becoming that way not only efficient, but also able to adapt to new conditions. In that context could the city be understood as a ‘living organism’ where its infrastructure is a self-organized system that is not the result of a top-down master planning, but the outcome of simple, rule-based operations? That wouldn’t mean of course that highways or power plants will be created by themselves, spontaneously and with no order. Neither does it means that design is not needed anymore. Design is still the means of an architect or a planner, only that now it is a protocol that has to be designed.

**Protocol**

Protocol of course, is not a new term. A word of Greek origins, literary means ‘first leaf’ and was originally referring to “a leaf or tag attached to a rolled papyrus manuscript and containing notes as to contents.” [1]

With time, several meanings were added to the word, from any type of correct or proper behavior within a specific system of conventions to very specific uses in fields as diverse as diplomacy or medicine. However, in recent year protocol has acquired a new meaning in the context of computer science, where it “refers specifically to standards governing the implementation of specific technologies.” (Galloway, 2004) For example the TCP/IP (Transmission Control Protocol/Internet Protocol) governs the way that the internet functions and how computers can communicate with each other. Therefore in computer science a protocol is a set of rules that allows a specific technology to be implemented.

Since digital media are holding a fundamental role in changes happening today in our society, protocol also holds a significant position. In order to better understand how protocol, in a more general and broader sense, is situated inside modern societies, it is necessary to take a wider look in the history of the modern era and its periodization: Michel Foucault (1997, 1999) in his work distinguishes what he calls the sovereign society of the 18th century and the discipline society that starts with the French revolutions and extends into the beginning of the 20th century. With this shift, the strongly hierarchical and centralized model of the former gives its place to the more decentralized organization of the later.

Gilles Deleuze (1988, 1990) extents this periodization into the 20th century and up to the present with what he calls control societies. He is also relating a specific machine with each model: “The old sovereign societies worked with simple machines, levers, pulleys, clocks; but recent disciplinary societies were equipped with thermodynamic machines presenting the passive danger of entropy and the active danger of sabotage; control societies function with a third generation of machines, with information technology and computers, where the passive danger is noise and the active, piracy and viral contamination” (1990). A different model of organizations corresponds to each society: from a centralized one in sovereign societies to the decentralized one of the discipline societies, which eventually leads us to the distributed model of the present. Alexander Galloway (2004), following the above periodization, proposes the protocol as the management style of the control society. Where management style is understood as the means to control that each society is using. According to Galloway protocol is replacing in that sense bureaucracy that in turn replaced earlier hierarchy. While the above mentioned periodization has several implications at different levels, what is important in the context of this article is the distinction between three different kinds of networks, which correspond to the three different eras and result in three different types of organization: Centralized, decentralized and distributed networks.
Centralized networks are networks with one central hub that subordinates all other nodes of the network. In decentralized networks instead of one there are many hubs that are each controlling a number of nodes. In the distributed network however there are no hubs or nodes. Each element of the network is autonomous and can be virtually connected to any other element. Protocol is providing the means that define how those separate, autonomous elements or agents of the distributed network can be connected to each other. Since there is no hierarchy in that model, a new way of organization arise: instead of a top to bottom system we have a bottom-up model where the agents are self-organized by following the rules defined by the protocol.

What would be the role of the protocol in the context of architecture and urban planning? The means to control, what Galloway calls a management style and ultimately what architects and designers are called to design. Architecture as we know it today, has been formed and defined since the Renaissance and its development has been therefore deeply affected by the models of organization described by Foucault. Consequently the architectural process has been originally understood as a centralized, top to bottom process, where at the top we have an architectural idea, that subsequently gets actualized, translated and developed until the production of the final object (either furniture, building or city plan). That initial idea is directly connected to the final result: the architect envisions what he or she wants to produce and then uses his tools (models, drawings etc) in order to bring that idea to life. But as society is changing from a centralized model of organization, through a decentralized one to an eventually distributed model, architecture could not remain unaffected. A new approach to architectural design is therefore arising: an approach that is not organized through a top-to-bottom logic but is instead following a bottom-up process. Instead of designing directly the desired outcome one can design a process that can generate several outcomes. Instead of designing objects, the architect can define some initial, basic elements, design the rules and specify the ways of interaction. Then, those initial elements, by following the rules and interacting with each other and with their environment are self-organizing giving rise to results on one hand impossible to predict in the beginning of the process, on the other hand able to satisfy the needs they are intended to. That process, designed by the architect, is what can be understood as a protocol in an architectural context.

Such a radical shift in the way we perceive architectural design, of course requires new tools in order to be accomplished. Digital media are providing those tools: code is becoming the means that architects can use in order to control information, direct their intents and create models that will test their protocols. As Anthony Bruke (2007) writes, “Design becomes the ability to schematize organizational structures and activate relationships using unique, purpose-built, and intelligent software tools.” After the ‘explosion’ of animation techniques and morphogenetic approaches that architecture went through in the ‘90s, when the computers were first used extensively for design purposes, architects start to realize that they cannot rely on commercial software and that they instead need to create their own tools that will allow them to specify any custom task necessary for their purposes. Code is becoming the means that will help the designer to design the protocol.

**City Growth and Self-Organization**

In that context the study of cities, being always closely related to the study of networks, was the first

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<th>Period</th>
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<td>Sovereign Society</td>
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to incorporate elements of self-organization and bottom-up processes. Of course there have been architects and urban designers pointing towards that direction since the middle of the previous century. For example Jane Jacobs in her book *The Death and Life of Great American Cities* (1961) is arguing that cities are characterized by an organized complexity that depends to a great extends on the local interactions of its elements, and therefore they develop not according to a centrally conceived plan but instead according to the interaction of its local elements. Christopher Alexander in his *Notes on the Synthesis of Form* (1964) is also pointing out that cities were originally organized in a bottom-up fashion where the local interaction between the residents are defining their development over time and is arguing that planning should learn how bottom-up design was executed in a simpler age, developing processes that might accomplish the kind of slow adaptation that is the image of well-developed and well-functioning buildings and towns. While those examples were truly insights into a different way of thinking about cities, what they were maybe lacking was the means that would allow them to create models in order to study how cities are behaving, if one was to follow this bottom-up approach. Those means are of course provided today by computers. And indeed there are many studies already developed in that direction through the help of the digital computer. The work of Michael Batty is one of the most impressive examples. In his 2004 book *Cities and Complexity* (which is the outcome of 30 years of research) he presents a vast number of examples where he is examining ways according which cities are self-organized and is developing models in order to fulfill and support that research. Through those examples he is reaching to a very important concusion: In order to study cities in a bottom-up fashion, one needs first to understand two important concepts, or better, two different ‘qualities’ of the individual elements that take part in the process of self organization: cells and agents: “Cities in particular and urban development in general emerge from the bottom-up and the special order we see in patterns at more aggregate scales can be explained only in that way. The way we simulate such emergence is by representing the basic elements or atoms of the city in two distinct but related ways: through cells, which represent the physical and spatial structure of the city, and through agents, which represent the human and social units that make the city work.” (Batty, 2004) Cells are giving priority at the local interactions instead of a global, centrally defined direction. It is the interaction between neighboring elements that give rise to specific modes of operation. Agents on the other hand, are making sure that, when necessary, information can travel across ‘neighborhoods’ establishing therefore communication between elements that are not necessarily close to each other. The second important outcome of Batty’s work is the importance of models, as the means to study and simulate the possibilities arising from self organization.

**Models**

A protocol is “a language that regulates flow, directs netspace, codes relationships, and connects life-forms.” (Galloway, 2004) The protocol defines the rules according to which the system will be developed and specifies the properties of the nodes of the network that will make possible for successful patterns to arise. That would create a system able not only to satisfy the current needs, but also able of adapting to new conditions and able of learning from that process, becoming that way increasingly efficient. Therefore, a protocol has to specify rules in two directions: (a) interior to the system; the simple rules that will allow self-organization to happen. (b) Rules exterior to the system; the rules that specify how the system reacts to its environment, gathers information from it and adapts accordingly. In order to evaluate, test and develop these protocols, we need to rely on models that will simulate its behavior. In that sense computer simulation is becoming, as Branden Hookway (1999) writes, the ‘signature technique’ of our period: “The simulation is not meant to
specify unknown variables in a mechanistic sense; its power lies in finding similarities or analogies across time in complex processes for which the precise actions of variables remain unknown. The simulation forsakes the unspecified interaction of constitutive variables in favor of making visible larger environmental patterns.”

While the concept of the model might seem too obvious or simple, in order to understand how we can study the self-organizational possibilities of city growth and infrastructure, and more generally how we can develop architectural protocols, it is important to understand what the use of models is offering and how models can be developed in new ways. According to John Holland (1999) the major value of models is that we “can anticipate consequences without being involved in time-consuming possible dangerous, overt actions [...] Models, above all, make anticipation and prediction possible”. Therefore models are also essential to a ‘traditional’ approach to city growth; one that is based on master planning. Statistics for example, provide a large amount of models that can be used in order to predict future needs and project a design created now to the future. Those models however are static. As already said, the understanding of networks is shifting from a static to a dynamic one. While centralized and decentralized networks can be static, distributed networks, where each node can be connected to any other node, are always dynamic. Therefore, a protocological approach to city growth and infrastructure as a dynamic network that is able to self organize, will still be heavily based on models, only that this time those models need to be dynamic in order to be able to simulate complex processes over time. Dynamic in that sense means, “models with changing configurations”. According to Holland (1999) again “the object in constructing a dynamic model is to find unchanging laws that generate the changing configurations”. In order to accomplish that, we first need to specify the states of the model and then the laws that govern the transition from one state to another through a transition function. (protocol function (a)) “The transition function assigns to each state the state that will occur next under the laws of change.” (Holland, 1999). If such is the case, for a given state and with a specific transition function we will always get the same results. Unless the system can receive ‘input’ from the outside, in which case it becomes aware of its environment (protocol function (b)), while the evolution of the system becomes impossible to predict. That is where the self-organizational properties of the model appear.

Example: Cellular Growth

The above are studied through a specific research project that examines how a protocol based approach could provide a model that will help in the design of future settlements at coastal areas threatened by the sea-level rising. The projects fundamental idea is that of a structure that grows vertically as the water level rises. As construction goes higher, the lower levels are abandoned and partially covered with water offering the possibility for sea-biotopes or fishing facilities to be developed. However, a predefined vertical growth wouldn’t necessarily meet with the actual needs arising with time. Therefore a self-organized model was developed that would grow according to the situation encountered each time a change in the configuration is needed, either because of the water level rising, or because of the population needs. Consequently the growth of the model in not predefined. It is the specification of simple interaction rules between its elements combined with the externally received input concerning the water level and the population needs that define the transition function and therefore the new formation of the system each time a new level is added.

Spatially, cellular growth consists of a three-dimensional, 30’x30’x12’ grid. The cells of the grid are the primitive units. The relations between those units/cells are the ones defining the fashion in which the system will grow. A cellular automaton algorithm is used in order for simple rules to be established, that would specify the manner in which the cells will interact. While the cellular automaton
Figure 1
Cellular Growth: A graphical representation of the protocol for cellular growth model.
algorithm is providing the necessary framework for the model in order to function, external input ‘fed’ to the algorithm is providing the system with the ability to adapt. That external input concerns: (a) The level of the water. If the water level is rising then the structure is forced to grow vertically. (b) The capacity needs of the settlement. For example, an increase of the population served from the structure would adjust the rules of the algorithm, increasing the growth rate. (c) Information deriving from the evaluation of the already existent part of the structure. Feedback is necessary for a self-organized system in order for it to be able to increase its efficiency. In other words, by evaluating itself, the system becomes able of learning, favoring for example more successful modes of growth instead of others proved less successful. The increase in the efficiency will be exponential if several structures exist in different locations. In that case, a larger, global network will also be established, with its nodes, in this scale the settlements themselves, being able to self-organize at their level.

In order for the above model to be tested and evaluated, it is necessary to encode the rules specified by the protocol in machine language so that the growth can be simulated. In that line of thought a computer program is developed so the proposed growth model can be visualized and tested. The software incorporates all the conventions specified by the protocol, the core being a cellular automaton algorithm controlling the growth according to the relationships between the cell and the ability to receive external input that will allow for the model to be aware of its environment.

The construction of the system is totally
mechanized, allowing for the process to be automated. Machines, controlled by the software, are integral part of the system and the means for the creation of the structure. Automation is an important aspect since it is necessary in order for the system to be able to self-organize.

The machines become the agents in the process of self-organization. Agents are the ‘moving’ factor, the ones that set the system in motion. In self-organized systems in general, an agent “is processing an input to produce an output” and therefore from an input state is being processed to produce an output state. “The input state is determined by the immediate environment of the agent, and the output state determines the agent’s effect on its immediate environment” (Holland, 1999). That is also the function of the machines in the growth of the system: They are equipped with a basic or primitive form of artificial intelligence, that is, being able to record the state of each cell, calculate the next state of the system and define collectively the routes that have to be followed in order for the structure to be build. The machines are the ‘bearers’ of the generative algorithm and their actions are defined precisely by the designed protocol. It is the machines that the protocol is controlling, however the control is not central but local. Each machine moves and acts individually according to that protocol and it reacts with the other machines in modes defined by the protocol.

The process described above outlines the general framework, inside which a detailed protocol needs to be created in order for the proposed model to take shape and be tested and evaluated. It is the detailed design of that protocol, as a convention that codifies rules, modes of operation and interaction relationships, that will allow for a successful model to arise, able to self organize and adapt.

Maybe the most important element of a protocological approach is that the focus of design is shifting from the final result to the process that it generates it. That process is becoming explicit and is designed directly, through coding, so that it will
Figure 4
Perspective view of a possible outcome of the cellular growth protocol
be able to provide deferent results for different situations that it encounter, becoming that way adaptable and aware of its environment.

References

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