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Dynamic Construction of Visual Ecosystems to Interact with Complex Systems

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ABSTRACT

Visualization of natural complex systems is essential to analyze their dynamics, in order to design artificial systems with analogous characteristics. It is also fundamental to visualize industrial complex systems in order to control and command their functioning. Furthermore, the properties of such systems may be used in artistic creation as a means to introduce unpredictability and endless novelty in computer-generated artworks. In this article, we describe a versatile multiagent platform, designed for the real-time visualization of complex data streams. The platform has been used for the creation of the computer-art work called *The Garden of Chances*, which virtually recreates the meteorological ambience of a distant place. We study in this article the relevance of the artistic stance to build synthetic representations of complex situations and try to see how it may be applied in scientific and industrial contexts.

Keywords: complex systems, visualization, multiagent systems, art, ecosystems.

1. INTRODUCTION

Since complex systems are composed of interacting entities whose organization is dynamic and whose evolution is emergent or chaotic and therefore potentially unpredictable, generally they cannot be observed directly as a coherent whole. As in the case of natural ecosystems, only small elements of the global picture can be seen at any given time. Furthermore, only local interactions can be observed, leaving the global dynamics out of sight. In many different contexts, however, it is desirable and necessary to grasp the complexity of the whole thing in a way that is both natural and intuitive. We can classify these contexts in at least three categories:

- In a scientific context, the visualization of a simulated complex system may foster the understanding of its internal dynamics by completing quantitative statistical analysis with qualitative visual analysis. As a result, it can also help design artificial systems with similar global properties.
- In an industrial context, visualization techniques are used as a means to control the functioning of real complex systems such as airplanes or nuclear plants, in order to help operators detect local or global failures. In return, it helps them to make appropriate decisions in the command of the system [10].
- Finally, dynamic and emergent properties of complex systems may be used in an artistic context as a source of endless novelty. The unpredictability of the system becomes a valuable property that the artist will try to retain, while at the same time constraining the evolution of the system to keep it meaningful.

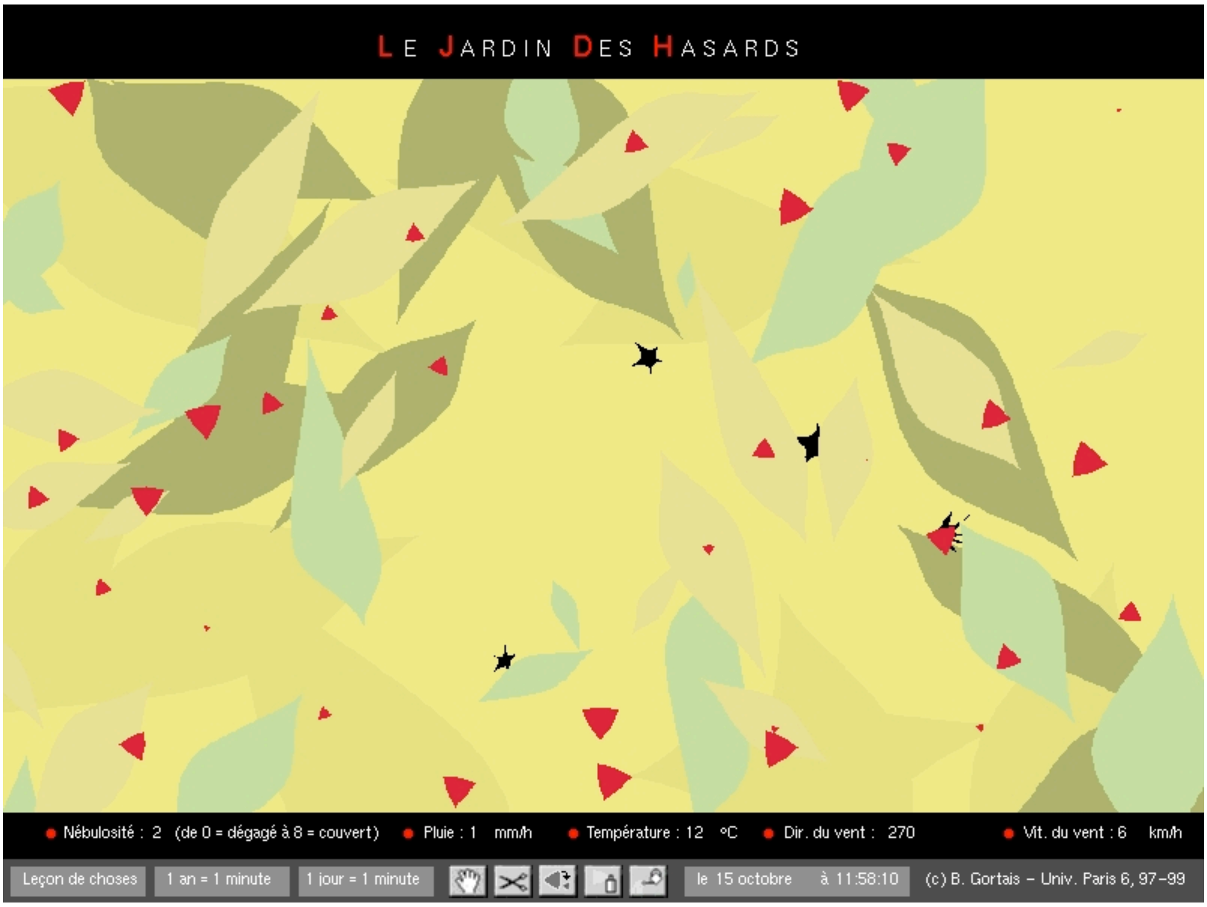
The question of the visualization of complex systems is addressed here from this artistic point of view, with the strong intuition that it may be of great value when switching back to scientific or industrial contexts. This has led to the design of the interactive computer-art work called *The Garden of Chances* (*GoC* for short) [8], that is presented in section 2. Section 3 discusses its value, not from an artistic point of view but from the point of view of visualization, by describing experiments carried out to assess its efficiency and expressiveness as a representation of meteorological conditions. Finally, section 4 develops the implications of this art work for the design of human-complex system interfaces in applied contexts and suggest future lines of research.

2. *THE GARDEN OF CHANCES*: A VISUAL ECOSYSTEM

This work was carried out as a collaboration with the multimedia artist Bernard Gortais. It has been designed both as computer-art work and as a versatile complex data visualization system.

The Artistic View

From an artistic point of view, the aim was to build an ever-changing view of the weather conditions of a distant place (see figure 1). Periodically retrieved through Internet, simple meteorological data such as temperature, wind conditions, cloud coverage and rain are used to give life to a graphical ecosystem of abstract colored shapes. The evolution of these shapes is driven by two complementary principles: on the one hand, they react like plants growing in a garden, developing or decaying with the more or less favorable conditions; on the other hand, they combine to restitute the global climatic ambience of distant places, thus changing in aspect along with temperature or cloud coverage, moving in different ways along with wind conditions, appearing or disappearing in reaction to rain.



● Nébulosité : 2 (de 0 = dégagé à 8 = couvert) ● Pluie : 1 mm/h ● Température : 12 °C ● Dir. du vent : 270 ● Vit. du vent : 6 km/h

le 15 octobre à 11:58:10 (c) B. Gortais - Univ. Paris 6, 97-99

Figure 1. A view of The Garden of Chances during fall. Weather conditions are as follows: the temperature is 12°C, the wind is blowing from the west at 6km/h, the sky is partly clouded with no rain

The Technical View

The whole thing relies on a versatile multiagent platform that was designed to make the interface between complex systems and humans, be they users, operators or spectators. Thus, the platform is not specific to the *GoC* and will first be described on a general level before being explained with the *GoC* implemented on it.

Agents of the platform have two main functions: retrieving the data then filtering and organizing it before presenting it to the spectator or user on the other hand (see figure 2).

A set of agents, let's call them 'information agents', are in charge of gathering all the data needed to describe the functioning of the complex system being represented. There can be one or more of them, collecting data from fixed or variable sources depending on their availability. Agents can be added or removed dynamically if necessary. The user, too, is considered as a complex system whose functioning it may also be important to take into account. For this reason, supplementary agents may be added to observe the user's behavior, for example actions using the keyboard or mouse.

In the *GoC*, there are as many such information agents as different places from where we wish to display meteorological information. The simplest case is when only one place is represented; the role of the agent is merely to ensure that the required data is available on the default meteorological server or else to find another one that may be able to provide the same service. The keyboard and mouse agents allow the user to interact with the representation system.

This representation system is composed of another set of agents, let's call them 'representation agents'. Their role is to display the information collected in the most suitable way so as to make it intelligible to some user. The data is made available through a shared memory in which information agents and representation agents can read or write independently, just like on a blackboard. Representation agents were designed together as a multiagent simulation system, similar in its principles to Starlogo [11]. Agents are placed in a simulated environment in which they evolve and through which they can interact with each other. They are characterized by internal resources; they are able to propagate signals in their environment or to communicate directly by exchanging messages; they can move in their environment in various ways; they may reproduce with each other or die; finally, they may emit sounds or change their graphical appearance on the screen, modifying their shape, size or color, or alternating between pictures, polygons or text. A scripting language is used to specify the different behaviors of the agents.

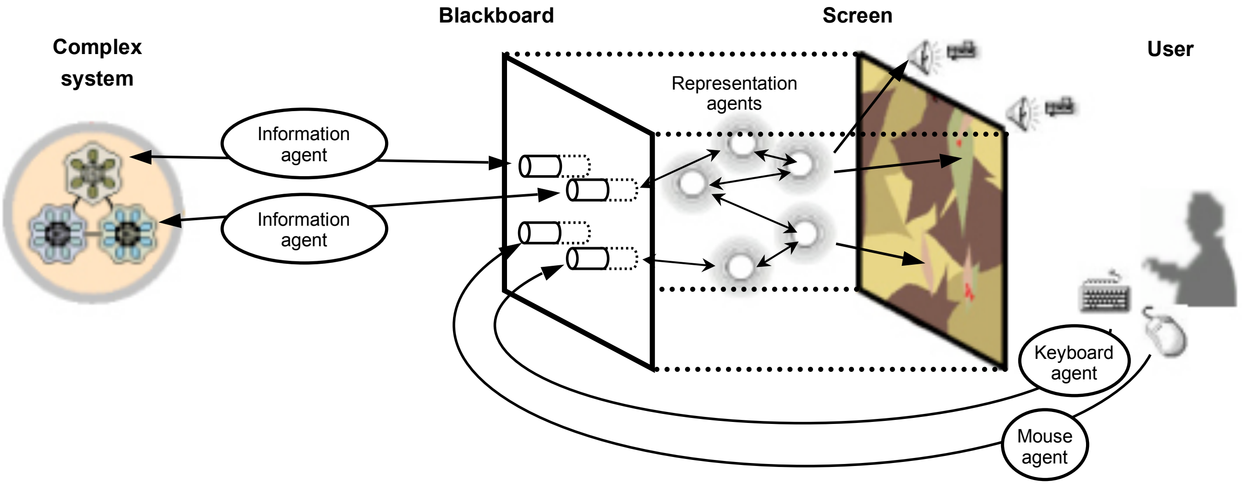


Figure 2. General architecture of the representation system. The information agents are responsible for retrieving the data describing the functioning of some complex system. The representation agents then filter the data and organize it hierarchically before presenting it to the user (complex system picture from [3])

In the *GoC*, various types of agents can be distinguished: 'leaf' agents which will gain all the more energy that meteorological conditions are close to ideal, and will duplicate when they have accumulated enough energy; 'herbivorous' agents which move randomly and feed from *leaves*; 'carnivorous' agents which are attracted by the previous ones and try to catch them, 'cloud' agents which grow and duplicate as the sky turns overcast; 'rain' agents which appear in greater number when it is raining. Some of these agents will be swept along by the wind; some will turn darker as clouds increase in number; some will have their color turn unsaturated as the temperature drops. The global result is a 'visual ecosystem' whose aspect and dynamics are highly evocative of the current weather conditions of the distant place from which the data has been retrieved.

3. QUALITY OF THE ARTISTIC REPRESENTATION

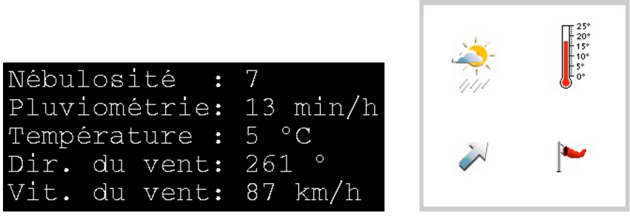
To confirm this intuitive feeling, several experiments have been designed in order to assess the quality of the artistic representation of the meteorological conditions.

Accurate Perception

The first thing is to know if the *GoC* would provide an accurate perception of the five meteorological variables (temperature, rain, cloud coverage, wind speed and direction) used to build the representation. To this end, the *GoC* was presented to ten subjects who were told how the picture evolved in relation with the variables. The subjects were given five minutes to get accustomed to the representation, during which they could change the values of the variables freely. After that time, the values of the variables were chosen randomly by the computer and the corresponding representation of the *GoC* was shown. The subjects were asked to guess the values of rain, temperature, cloud coverage and wind conditions. The test was done ten times in a row for each of the ten subjects and the results (for each variable, the difference between the actual value and the guessed value) have been averaged. The mean error was 3°C for temperature, 1 unit for cloud coverage (for a scale that goes from 0 to 8), 6 min/hour for rain (for a scale that goes from 0 to 60), 10 degree angle for wind direction and 20 km/hour for wind speed. For the same experiment, my own results were significantly better (respectively 2°C, 0.3, 3 min/h, 5° and 15 km/h), showing that some kind of learning is possible.

Decision Making

The problem is that one can't say that the representation is good or bad independently of what it is supposed to be used for. As an artistic representation, the results are clearly good enough. But what if the representation is to be used to make practical decisions? To assess this second point, a second experiment was designed in which the perception of the current meteorological conditions had to be used to decide whether to take an umbrella, a raincoat, gloves, a fan or sun lotion. Each of the five choices is constrained by the values of one or more of the variables. For example, gloves should be taken if the temperature is less than 10°C, and a raincoat or an umbrella if the rain lasts (e.g. more than 20 min/hour) but the raincoat will be a better choice if the wind is blowing (e.g. more than 50 km/h), and so on.



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Nébulosité  : 7
Pluviométrie: 13 min/h
Température : 5 °C
Dir. du vent: 261 °
Vit. du vent: 87 km/h
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Figure 3. Text and pictograms views used for comparison with the *GoC* representation

In this experiment, the criteria were to make correct decisions and also to respond as quickly as possible. To be able to compare the *GoC* representation with more classical representations, the same experiment was done with a simple textual view of the five variables, and with a pictorial view (see figure 3). The results clearly reveal three different modes of perception: while perception using the textual representation is precise but very slow, it is very fast with the *GoC* but rather imprecise (we already knew this), and it is both precise and fast with pictograms.

Continuous Operation

However, the previous experiment has at least two limitations: first, decisions are made one at a time and not continuously as is generally the case when controlling an industrial complex system; in addition, a choice is either right or wrong with no gradation between the two which is not necessarily a valid assumption. The experiment is therefore an extension of the previous one in which the meteorological conditions are continuously changing, requiring that choices be revised to take these new conditions into account. Starting with an initial credit, penalties are given whenever a choice is inadequate, the penalty being heavier the further the guessed conditions are from the actual conditions (e.g. if gloves are not taken, the penalty is greater if the temperature is 0°C than if it is 9°C). The experiment ends when the initial credit is exhausted.

What the experiment revealed is that the *GoC* representation needed considerably less concentration and efforts than the other two. Textual and pictorial representations are fragmented and require constant attention on each individually represented item of information. On the contrary, the *GoC* representation is global and the corresponding perception it makes possible is also global. Being natural and intuitive, it doesn't require the user to focus all of his attention on it. It may therefore be useful as a complementary visualization tool to more classical items such as counters or graphs. The latter are based on focalized perception while the *GoC* relies on ambient perception [6].

4. SCIENTIFIC AND INDUSTRIAL EXTENSIONS

The preliminary results obtained using the art work naturally lead to extensions in the scientific and industrial contexts mentioned in the introduction.

Scientific Visualization

When simulating complex systems, visualizing the simulation process may have at least two main functions. The first one is to assess the validity of the simulation, the second one to reveal some of the dynamic properties of the system. The appropriate visualization form is different in each case. When used as a validation tool, visualization offers a qualitative comparison between the dynamics of the real and simulated systems. In this context, the visual aspect of the simulation should be made as natural and close to the real system as possible, so that a visual evaluation may be made quickly. In order to use it as an analysis tool, however, the representation has to be adapted to transcribe in a visual form not only the individual properties of the various entities but also their local interactions, and the dynamic constitution and dissolution of groups.

In this second context, several strategies can be used. First, both the properties of the entities composing the system and their behavior, can be shown using visual primitives such as color, shape, size or movement. For example, one may link the internal energy of a simulated organism to the size of its visual representation; or one may relate the activated behavior (e.g. feeding, moving randomly, fleeing from a predator) of the organism with the color of its representation.

But the important thing, when studying complex systems, is also to understand the mutual relations between these entities. To this end, Gestalt principles may be used [1] which describe how shapes are visually associated, either because they are similar or because they are different. Several shapes are visually clustered by the observer either because they are similar, or because they are close to one another or because they are arranged in a continuous fashion. Similarly, two shapes can be visually associated because they have contrasting features (e.g. color, size or shape).

Based on these complementary principles of similarity and contrast, it is possible to represent interactions between agents by changing their graphical properties. An interaction is generally an asymmetric relationship between two agents. The aim of the visualization is therefore to show that these two agents have something in common and also that they have a different role in the interaction. For example, we could represent a fleeing prey and the corresponding attacking predator with the same color, the two species being differentiated by distinct shapes. Similarly, when a group is created dynamically, the agents composing the group share similar properties, one of them sometimes being responsible for the creation of the group, thus having a particular status. For instance, if a predator leads a pack after a prey, the predators of the pack and the leader may be given identical colors, the latter being bigger in size.

Industrial Visualization: *Data Gardens*

These simple ideas may be transposed for the visualization of industrial complex systems but they have to be adapted to the distinct needs specific to this context. What is most important when visualizing the functioning of real complex systems is to detect any abnormal situation, and to be able to make a diagnosis about what's going wrong to suggest what correction should be made. Compared to simulation, the main difference is that the functioning of the system is supposed to be perfectly known. The difficulty is that a great number of variables must be checked, not all of them being equally important for the safe operation of the whole system. The following ideas are developed in the industrial project called *Data Gardens*.

The use of multiagent techniques is justified in this context of dynamic, heterogeneous and distributed data, and it should allow the construction of versatile and adaptive computer-human interfaces. The basic idea is to have agents in charge of the visual representation of small items of information. In order to build a global coherent whole, we must give these agents the necessary knowledge so that they can cooperate with each other. The visualization process becomes a matter of dynamic organization of a whole society of representation agents.

The aim is to handle the problem of the hierarchical ordering of data depending on their importance, that is, depending on the priorities given by the operator. The secondary problem this approach may also handle is that of the interference between data of equal importance occurring simultaneously. Agents in charge of the different items of information have to negotiate in order to build together a collective synthesis, a coherent visual composition showing, at any given time, only the information that is most relevant to the current situation.

In addition, the 'agent' structure of the interface system allows for a very modular construction. Information or representation agents can be added or removed dynamically, depending on the current needs. Finally, it is possible to modify the behaviors of the agents, either manually or automatically, using machine learning techniques which will eventually lead to an adaptive interface system evolving along with different operators or different data types, and adapting dynamically when data evolves or when priorities change.

5. CONCLUSION

These last possibilities are not yet sufficiently developed to be described in more detail but they show the potential interest of transversal studies such as the one initiated with the artistic project *The Garden of Chances*. For this project, the properties of complex systems were used to produce works of art with endless novelty, always the same but always different. The artistic quality of the project has been recognized, as can be seen by the many exhibitions in which it has been shown. But from a computer scientist's point of view, it would be meaningless to work on artistic projects if it wasn't with the hope of learning something from it, or of getting new ideas to be applied in one domain or another. In this respect, too, this research is very promising. The extensions presented in this paper are only the main ones, those which have led to the definition of well formalized research projects. A lot of other developments are still to be explored, associating more closely the picture and the user/operator/spectator in complex interactions.

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