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Grounding Virtual Worlds in Reality

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Abstract

We suggest in this article a new paradigm for the representation of data, which is best suited for the real-time visualization and sonorisation of complex systems, real or simulated. The basic idea lies in the use of the garden metaphor to represent the dynamic evolution of interacting and organizing entities. In this proposal, multiagent systems are used to map between given complex systems and their *garden-like* representation, which we call *Data Gardens (DG)*. Once a satisfying mapping has been chosen, the evolution of these *Data Gardens* is then driven by the real-time arrival of data from the system to represent and by the endogenous reaction of the multiagent system, immersing the user within a visual and sonorous atmosphere from which he can gain an intuitive understanding of the system, without even focusing his attention on it. This can be applied to give life to virtual worlds by grounding them in reality using real world data.

1 Introduction

Let's imagine a virtual garden whose visual and sonorous aspects continuously change to reflect the passing of time and the evolution of weather conditions in a distant place. Looking at it or simply listening to its musical rhythm will make you feel just as if you where there, looking at your garden through the window. *'It's raining cats and dogs. Better stay home!'* Connected to real meteorological data, it really functions as a virtual window, opened on a distant reality. This is what the computer-art project called *The Garden of Chances* (*GoC* to make it short) [11] is all about. Beyond its artistic interest, we believe it to have very important implications for the representation of complex systems by means of visual and sonorous metaphors.

Keeping a close watch on meteorological data in order to secure airplanes landings, monitoring the physical condition of a patient during surgical operations, observing Stock Market fluctuations so as to determine the best options to chose, are three examples of situations where decisions are subjected to the real-time understanding of complex systems, respectively physical, biological, and social or economical. Those representation and interpretation issues are transposable for artificial complex systems such as multiagent systems, for which adequate real-time representation may provide insight into the inner mechanisms of the system at the agent level, or *topsight* [10] over the functioning of the system as a whole. Visualization in Scientific Computing (ViSC) has proven very efficient to represent huge sets of data, by the use of statistical techniques to synthesize and class data in a hierarchical way, and extract relevant

attributes from those sets, before presenting them to the user (Fig. 1). But it has not been so successful when dealing with distributed and dynamic systems since it is based, among other things, on a delayed treatment of the data.
The basic proposal is to consider any complex system one wish to represent as a metaphorical garden, the evolution of which reflects in real-time the evolution of the system. In this paradigm, the measures made on the system are not only stored, waiting for a further statistical processing, but they are also immediately transmitted to a *Data Garden*, a virtual ecosystem with the same global dynamics as the system to represent but with a stronger visual and sonorous appeal (Fig. 1). Indeed, the garden metaphor has the interesting property to be both very complex in its functioning, and still completely familiar to anybody, enabling a very fast and intuitive perception. Moreover, it doesn't require a sustained attention, since it relies for the most part on peripheral perception mechanisms, following the same principles as those that make us perceive weather conditions effortlessly. Finally, the *Data Garden* paradigm doesn't reduce the complexity of the system to represent but transform this complexity to integrate it into a meaningful environment, creating a visual and sonorous ambient atmosphere from which to gain a continuous understanding of the studied system.
In section 2, we present the concepts of scientific visualization and we explain why they fail to satisfy the needs of complex systems representation. By contrast, we present in section 3 *The Garden of Chances*, an artistic project which succeeds in mapping numerical meteorological data in an abstract, yet meaningful, representation of the weather. We finally extend the principles developed with this project in section 4, explaining the characteristics that *Data Gardens* should share in order to prove meaningful for complex systems representation, before concluding.

2 Scientific vs. Artistic Visualization and Complex Systems

Scientific visualization on the one hand is based on quantitative information display [22], visually in most cases but also using different modalities [4]. Fig. 1 shows the classical iteration cycle of scientific visualization whereby experiments are undertaken, during which data are collected. Only afterwards are the data analyzed and visualized, which allows to draw conclusions about the experiment and design complementary experiments. The cycle then iterates. This is well fitted for a great number of applications but doesn't qualify for the representation of complex, dynamic and distributed phenomena. Painting on the other hand, considered as a system of colored graphical elements is inherently distributed and based on the organization of those elements. According to Kandinsky, "analysis reveals that there is a construction principle which is used by nature as well as by art: the different parts become alive in the whole. Put differently, the construction is indeed an organization" [15]. Furthermore, painters try, and sometimes succeed, in transmitting complex perceptive and emotional experiences to their spectators. They so establish what J. Wagensberg [23] calls a "communication of unintelligible complexities", complexities that language and numbers cannot express since they cannot be formalized.
We're now going to analyze in further details the reasons why scientific visualization concepts appear inadequate to us for the representation of dynamic and complex data. It appears in the classical taxonomy that a processing of the data is necessary in order

to extract from huge sets of data, a restricted number of attributes that best synthesize the nature of the data. To this purpose, a great number of statistical techniques and data analysis are available that we won't detail here [3]. The results are then presented using a number of standard representations such as histograms, pie or time charts and so on. New presentation models [19] are also developed that make the visualization easier by focusing on some specific aspects of the data depending on the context. An alternative to this general scheme is when the phenomenon has physical reality and may be visualized directly or using appropriate color scales. Physical numerical simulations make a large use of this techniques, and medical visualization is a rapidly expanding domain that also exploits the same principles.

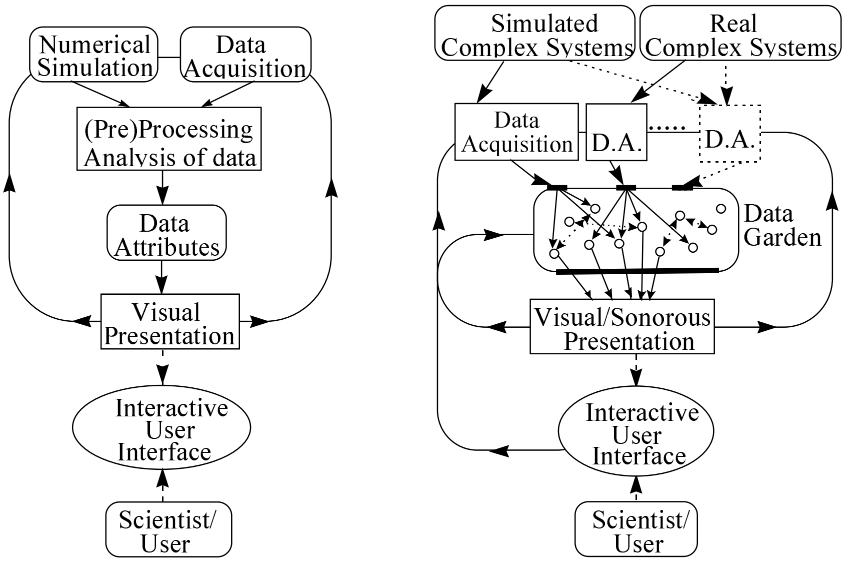

Fig. 1. Classical (partial view from [6]) vs. Data Gardens' visualization taxonomy

We propose to handle, with artistic visualization, phenomena which are both distributed and with spatial and temporal dynamicity. Our hypothesis, based on the analysis of scientific visualization techniques, is that such complex systems cannot be well represented using purely quantitative and objective means. This may be explained by the fact that we have an almost qualitative and subjective experience of such complex phenomena as meteorology, biological ecosystems, social groups, etc. Most of the knowledge that we have about those systems is derived from our everyday-life perceptions, which give us an intuitive grasp about such systems but which we don't know how to transcribe into numbers.

3 The Garden of Chances

We have explored with the computer-art *The Garden of Chances* an artistic alternative that is useful in making qualitative aspects visually or sonorously sensible in the representation of complex systems. Furthermore, the distributed aspect of complex systems is integrated as the basis of the functioning of the project and we think it qualifies as the first step in the representation of complex systems by means of colored and sonorous metaphors.

3.1 The Artistic Paradigm

The philosophy underlying this artistic work is to let the automatic generation of images be directed by a real time incoming of real world data. This has led to the development of a first computer artwork called *Quel temps fait-il au Caplan?* (*What's the weather like in Caplan?*). In this project, weather data coming in hourly from *MétéoFrance* stations were used to suggest the climatic atmosphere of a given spot (actually a small place in Britain) by means of color variations inside an almost fixed abstract image. To put it naively, rather warm tints were used when the temperature was high, dark tints when clouds appeared to be numerous, etc. In addition to meteorological parameters, the system also took astronomical ones (season and time of the day) into account, which eventually allowed very subtle variations. When functioning continuously all year long, the animation makes the computer screen become a kind of virtual window, giving access to a very strange world, both real and poetic.

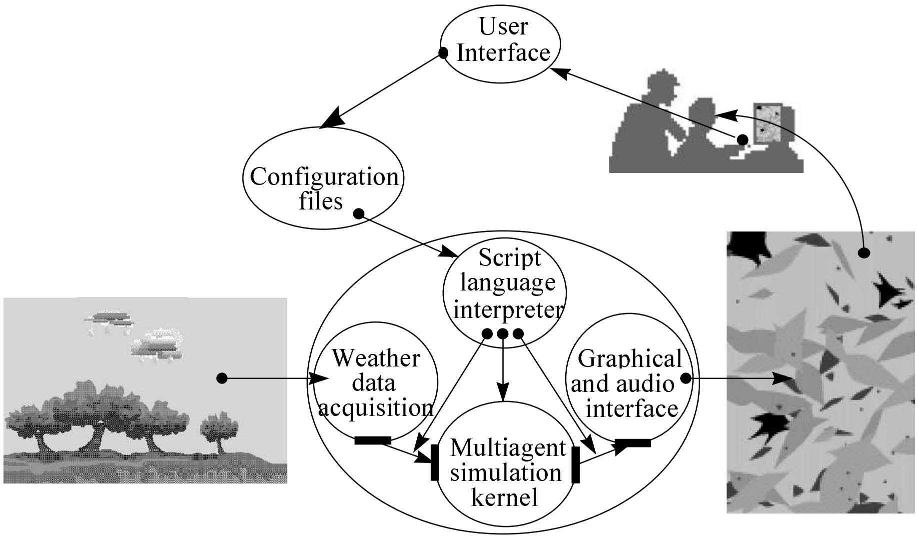

Fig. 2. The *Garden of Chances*

The *GoC* (Fig. 2) is basically designed with the same principles, namely using real data for the creation of mixed worlds, imaginary landscapes anchored in real world. In addition to colors modulations, the weather data are used to give life to a set of two-dimensional shapes, so as to create a metaphorical representation of a real garden. Thus, each graphical creature is able to grow up like a plant, benefiting from the presence of light and rain, competing against similar or other hostile shapes, reproducing and dying like any living creature. By so doing, the goal is definitely not to produce accurate simulations of natural ecosystems nor realistic pictures of vegetation. The focus is rather put on enabling the artist to experiment with lots of different abstract worlds until he obtains some imaginary ecosystem fitting his aesthetic sensitivity. The graphical space doesn't have the passiveness of coordinate systems anymore; we rather consider it as an active principle giving birth to worlds, as the raw material from which everything is created.

3.2 The Multiagent System

In agreement with artistic requirements, the system has been implemented as a programmable platform, allowing the artist to undertake a true artistic research. Capitalizing on our experience with biological simulation systems [7], we designed it as a genuine vegetal simulation platform, supplying growth, reproduction, and interaction mechanisms similar to those observed in plants. Indeed, we believe the difference between metaphorical and simulated ecosystems only resides in the perspective adopted during the experimentation process.

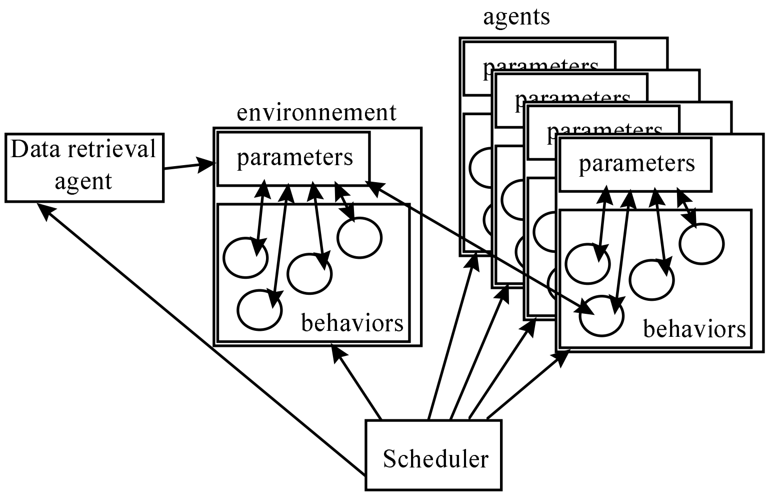

Fig. 3. The multi-agent simulation system

The core of the platform is a multiagent simulation system (see Fig. 3), representing plants as very simple *reactive agents* evolving in a simulated *environment*. Both the agents and the environment are characterized by sets of *parameters* that define their characteristics at any given time. The activity of the agents is defined as a number of *behaviors* which are programmable using a little scripting language. Those behaviors are handled by a *scheduler* which activates them whenever needed, either periodically (each n simulation cycles) or upon reception of some particular *events* (those are related most of the time to changes in one or several parameters). Finally, agents will be represented on the screen by colored shapes, which won't have necessarily something to do with plants but may be freely designed by the artist. A given still image will thus be close to his painting work, while the dynamics of the whole system will more closely rely on the artificial side of the project, i.e. the simulation of natural processes of vegetal growth.

3.3 Agents and Environment

Parameters constitute the basis for the representation of both agents and the environment. Actually, six types of parameters have been defined in order to describe the simulated world and the incoming data flow.

Agents are characterized by reserved, internal and external parameters as shown in Fig. 4. Reserved parameters are common for all agents whereas internal and external parameters may be defined specifically for each agent. Reserved parameters include information about age, speed, color, size, etc. Internal parameters describe the resources of the agent (water, glucose, etc. with the vegetal metaphor, or any other quantifiable resource). By contrast, external parameters represent any substance or information that the agent may propagate around him (chemical substances that plants release in the soil or the atmosphere, signals, etc.).

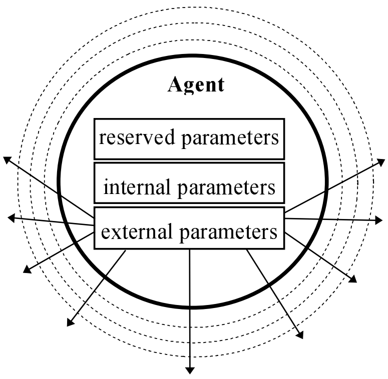

Fig. 4. Agent's parameters

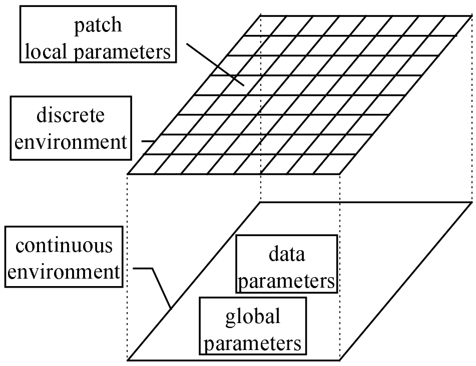

Fig. 5. Environment's parameters

The environment is characterized by local and global parameters as shown in Fig. 5. Local parameters correspond to variables whose value and evolution can be defined in a local way, i.e. for each square of the grid covering the environment (substances present in the soil, water or mineral materials for example). On the contrary, global parameters represent variables which have a nearly uniform action on the whole environment (meteorological variables, real world data, etc.). Finally, each data variable within the incoming data flow is integrated as a data parameter.

3.4 Behaviors

A little scripting language based on Tcl has been developed in order to make the programming of behaviors easier to handle from a user's point of view. In this language, one may think about agents' and environment's parameters as local and global variables, and behaviors may be thought as procedures, either with local effects when associated to agents or with global effects when associated to the environment. Within behaviors, there are only four basic actions which can be combined together using conditional statements (if ... then ... else) and iteration loops (for ..., while ..., repeat ... until). These four actions are the modification of a parameter, the death or reproduction of the agent, and the playing of a sound file. For example, if one assumes that sun-shining conditions in a distant location are available in real-time in the data-flow and we wish to make a flower grow according to this parameter, one would have to express that some flower gains energy through photosynthesis if the sun is shining, loosing a part of this energy continuously due to its metabolism, and dying if it doesn't have any energy left. The programmed behavior would simply look like the following:

```
// parameters declaration
data_param sun_shining 3
internal_param flower energy 50 0 100

// photosynthesis behavior declaration
behavior flower photosynthesis 1
  // energy parameter modification
  param_set energy {$energy - 0.01 + $sun_shining * 0.1}
  // death if not enough energy
  goc_if {$energy == 0}
    death
    sound flower_death.au
  end_if
end_behavior
```

This approach allows to describe how some parameters evolve (slow decrease of the energy of an agent to sustain its metabolism, etc.), to specify the interactions between the agents (chemical aggressions, etc.), between an agent and its environment (water drawn from the soil to feed a plant, etc.), and even between different levels of the environment (supply of underground waters by the rain, etc.).

Behaviors are triggered by a scheduler, either with a fixed periodicity or whenever a given event occurs. An event is simply defined as a special kind of behavior which periodically evaluates a condition and positions the corresponding flag of the scheduler accordingly. In agreement with the vegetal model, different behaviors of a single agent may be triggered concurrently during a single timestep. A simulated plant can thus simultaneously execute different operations such as drawing water from the soil, realizing photosynthesis, growing, releasing chemical substances, etc.

3.5 So What?

Set aside aesthetic and artistic discussions, the scientific evaluation of the quality of such a system proposing a metaphorical visualization of real data, would have to be done under two complementary points of view :

- what can the spectator say about the data that were used to generate the pictures ? In other words, does the representation used for visualizing the data make sense for the spectator ?
- what can the spectator say about the dynamics of the system that produced those data ? Does the representation succeeds in producing *topsight* ?

Since the *GoC* has originally been developed in an artistic perspective, experimental protocols have yet to be designed in order to scientifically address these issues. Our personal experience with the system is that meteorological variations are easily detected, but the *GoC* would surely prove not so well adapted for the visualization of any kind of data, especially when complex systems with no physical reality are concerned. We feel however that this artistic approach to both complex systems and data visualization may provide us with new paradigms for the visualization of complex data.

Without entering the details of painting creation, it should be underlined that painters are used to handling the problem of organizing distributed colored shapes in order to produce a given global effect. They are also used to evaluating and interpreting the produced result. Actually, they are used to communicating complex and subjective information by means of a visually distributed representation, and this expertise will be valuable in further development and experimentation steps. We're now going to formalize these intuitions to show how they should be integrated in a single effort to make complex interacting data accessible to direct visual perception, in what we have called *Data Gardens*.

4 Towards Data Gardens

The expression *Data Gardens* was coined in analogy with the artistic project and its garden metaphor. In fact, *Data Ecosystems* may be more appropriate, indicating any community of living and interacting organisms with graphical and/or sonic representation, whose individual survival is subjected to the real-time incoming of data to which they react, and to their interactions with other entities. Still, *Data Gardens* is strongly evocative and we will only use this expression in the remaining sections.

Data Gardens are an alternative proposal to standard schemes of data visualization which we think would be most efficient when applied to the representation of complex systems for purposes of diagnostic or monitoring. We explained in section 2 why we thought those standard schemes to be inadequate in the context of complex systems, and we presented with *The Garden of Chances* the outline of a possible alternative. So what are the basic features that *Data Gardens* should integrate in order to fulfill the requirement of adequately representing complex systems, that is providing the user with a global understanding of the functioning of the system. And how could this be achieved ?

- As a first thing, *DG* should rely on a *dynamic* representation, necessary get a perceptive sensation of a system's dynamics and to easily detect discontinuities. This representation should be both *visual* and *sonorous*, vision being best fitted to the perception of spatial dynamics through a parallel treatment of information while audition is more adapted to the perception of temporal dynamics through sequential treatment of information. The aim is to limit the use of high-level cognitive processes, trying to take advantage of the "peripheral", rather than active, perception capabilities of the user (many experiments in augmented reality, like in the MIT MediaLab's Ambient Room [12], rely on this approach).

  The graphical and sonorous aspects of *The Garden of Chances* have been designed so that the user can interpret the painting in the same way he could interpret his daily environment for extracting critical information. Animation on the other hand is an essential part of the *GoC*, and it carries out two different kinds of information via two different dynamics: a slow, homogeneous dynamics, intended to reorganize the whole environment during a long period of time, is used to represent the seasons. Within this dynamics, a few punctual and rapid animation of some agents or sets of agents are used to represent important short-term fluctuations of the data values.

- When representing complex systems, complexity shouldn't be reduced a priori with synthetic indices and means, but should be directly integrated in the representation system. Therefore, *Data Gardens* should be based on a *multiagent modeling* (accurate or metaphoric) of the system to represent. But because complex data are generally just too complex to represent directly, distributed principles for *organizing* and *synthesizing* the represented data must be integrated, that decrease the perceptual load of the user without significantly altering the meaning of the data.

  In *Data Gardens*, incoming data influence both the activity and the evolution of the agents. The synthesis is then realized at two levels : in the individual evolution of each agent, and in the mutual interactions they engage in. The development of an agent, which is graphically translated by a modification of its shape or color, can be the consequence of the variations of different data, like the evolution of a plant within an ecosystem.

- The representation must be *metaphorical*, that is, use cognitive categories aimed at being easily interpreted and managed by the user. This is a way of decreasing the complexity, mapping abstract data into a meaningful representation from which one can get instantaneous understanding.

  In that respect, one of the most interesting aspects of *Data Gardens* is the "garden" or "ecosystem" metaphor, already developed in the *GoC*. Analyzed at the light of the first two points we developed, the garden metaphor has the interesting property to have natural significance to anybody, while being very complex in its functioning. This functioning relies on the interactions of three types of complex systems: physical (the weather), biological (vegetal and animal) and social (social animals such as ants). This results in various audio-visual dynamics which look very familiar, from the slow evolution of vegetal landscapes to the fast interactions of animal life, and continuously changing meteorological ambiances.

- The representation should be *programmable*, at a user's level. The user must be able to express subjective choices about the representation, either to make it more significant with regards to data visualization, or to make it more aesthetically pleasing. Perception is a mostly individual and subjective feature of human cognitive functioning. The representation should therefore fit the user's own subjective conceptions of how the data are best visualized. Moreover, different types of representation of the same data may reveal different aspects of this data.

  In the *GoC*, the whole simulation system is programmable allowing the user to filter the input data, define the behaviors of the agents to make them react to the data, and choose their graphical representation. In the process, the user will need to be guided by the system, which should propose sets of dynamics and graphical vocabularies. Our collaboration with a painter in the *GoC* project has proven very useful for that particular matter, and we intend to cooperate more closely with various artists in order to define basic instances of *Data Gardens*.

- The representation should be *interactive* to allow dynamic exploration and perturbation of the multiagent system. Once a general framework has been found efficient, it must be made possible for the user to refine the representation acting as a kind of gardener by adding, removing, moving, changing agents on the fly. The user should also be able to visualize the system from different points of view. If the default functioning of *Data Gardens* exploits peripheral perception, the user may also choose to focus his attention on a specific part of the representation, getting then more detailed information about this part. Finally, the user should be integrated as a particular agent of the system, with extended capabilities, that would enable him to experiment the reactions of the system when perturbed.

  In the *GoC*, the basis for these interactions is set. The user can make agents reproduce, die or move, and one can view or change the parameters of agents or of the environment. When associating specific behaviors to a “perturbing agent” and when moving it around with the mouse, one can also visualize how the system may spontaneously reorganize.

- The system should finally be *evolutive*, taking into account the interactions of the user in order to learn something of his tastes and evolve accordingly. The reason is that a given user will most of the time be unable to express how he would like the data to be represented in the formalism of the system. But if he can't formalize it, he can point out aspects of the representation that he finds pleasing or some others that he dislikes, just as in the gardener metaphor. This last point is mostly prospective for now, since nothing like it exists in the *GoC* yet.

As a result, *Data Gardens* should be designed as "meaning operators" between the flow of data and the user, who is supposed to identify and follow, in the evolution of the system, that of the outside world. However, it must be clear that they are not intended to replace the existing environments used to track and trace data (histograms, textual presentation, curves, etc.), which are still the only way to know the precise value of a variable. They are to be viewed as complementary tools that allow an instantaneous and natural perception of complex situations and propose a global perspective on them. *The Garden of Chances* is the first of such systems we built and it should now be studied in a systematic way, and with an experimental perspective, in order to develop operational design and evaluation methodologies.

5 Conclusion

We propose with *Data Gardens* hybrid environments that graphically represent information gathered in the real world for users likely to take decisions in this real world. The goal is to let a complex and dynamic system of numeric data become visually intelligible without catching the whole attention of the user. We explained how the application of DAI concepts, along with real-time visualization, allows to compensate for some of the deficiencies of more classical approaches. In particular, it enables to handle dependent data without a priori reducing the complexity of the data but only as the result of a dynamic hierarchisation and synthesis of the different pieces of the data through the organization of a multiagent system. Furthermore, the representation is evolutive and adaptive, because of its dedicated endogenous evolutionary mechanisms, and also because of the user's actions. We presented with *The Garden of Chances*, both the artistic work that initiated the reflection on *Data Gardens*, and the first concrete application of this paradigm. But it is obvious that *Data Gardens* are not limited to given data nor graphical representation types, each application domain requiring however that the representation be adapted to specific cultures and representation habits. Further work will put the focus on systematizing this adaptation process, through the constitution of libraries proposing various dynamics, based on previous works in DAI, and various graphical and sonorous schemes, based on a collaboration with artists. The aim is ultimately to be able to interpret complex and interacting systems of data, almost as naturally as one can perceive meteorological subtle variations, which could be of fundamental importance for the interpretation of multiagent systems themselves.
'Mmm. Looks like rain has stopped. Would be perfect for a walk but it's getting cold outside and the wind has turned east. Better stay home!'

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