Virtual Life in Virtual Environments

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Abstract: Virtual Environment is at the heart of Virtual Reality. High fidelity environment can become inhabited by virtual lives so that human users will feel immersed in a "real" world. With the unlimited application of VR, *Virtual Life* becomes a new and promising area. In the view of no clear definition and explanation on the notion of Virtual Life, this paper has tried to define and discuss it from a systematic view. For a true feeling of presence, virtual life should have a visual model for realistic visual shape and appearance, and a mental model for believable behaviour. This mental model should be autonomous to make decisions by itself, adaptive to promote its structure for better maintenance, and interactive to external changes, especially to human user's actions, by characteristic activities. Although virtual life derives from the real life, it is not just a simple copy of the real one. It has also its own features since its living sphere is a simulated one. The study of Virtual Life utilizes knowledge from various disciplines and intertwines with many other areas in computer science, including computer graphics, artificial life, autonomous agents and artificial intelligence. This paper reviews related areas and work and expects more attention to be paid on Virtual Life, a new field which is beginning to take shape.

Keywords: Virtual Reality, Virtual Environment, Artificial Intelligence, Artificial Life, Autonomous Agents, Computer Graphics

1 Introduction

Virtual Reality (VR) is a high-end user interface that involves real time simulation and interactions through multiple sensorial channels [8]. It uses computer graphics systems in combination with various interface devices to provide the effect of "immersion" in an interactive three-dimensional computer-generated environment, which is called a Virtual Environment (VE). VE is at the heart of VR. It is a virtual world to immerse the user and a main sphere for his activity. The more a virtual environment looks like the real world, the more immersed the user feels. Therefore, not only are lifelike static objects needed, such as sky, mountains, and buildings, but vivid lives should also be provided in a VE, such as plants, animals, and even humans. These virtual lives resemble natural lives and inhabit the virtual world subject to simulated physical laws. Like natural living things, they have both lifelike visual shapes and appearances and believable behaviours. They can receive information from the outside, make actions in the virtual world naturally, and interact with real people and other virtual lives promptly. They can have their own beliefs, desires, and intentions. They may grow, reproduce, and even die. From virtual plants to virtual creatures, from virtual insects to virtual humans, virtual lives with different complexity will have different characteristics, abilities, and intelligence. A timid virtual animal, for example, runs away when perceiving a human presence, but a virtual pet will run to the person enthusiastically, and the virtual human will talk to it with gestures and emotions. With virtual lives, a virtual environment has enhanced fidelity, and maintains the illusion in the user that it is a real one.

For the unlimited applications of VR, more and more researchers have realised the importance of Virtual Life (VL), and created a series of products, including virtual plants [28], virtual humans [35], artificial fish [34], synthetic dog [4], and virtual pets [15]. Some such systems have even been used in commercial packages. However, these virtual lives are more or less simplified for a limited environment. To construct ideal virtual lives, there is still a long way to go.

2 Related Work

In this section, we will briefly introduce related work on modeling and visualization of objects that are alive, which involve not only visual shapes and appearances but also natural behaviors.

Early work on modeling living plants can be traced back to 1962, when Ulam applied cellular automata to simulate the development of branching patterns [39]. It could be thought as an abstract representation of plants. Subsequently, Cohen presented a more realistic model operating in continuous space [9]. Smith [33] then proposed a method to describe the structure of certain plants, originally developed by Lindenmayer [17]. Nowadays extended L-system is a general framework for growing highly complex and realistic graphics models of plants, which are described as configurations of modules in space [28]. The essence of development at the modular level can be conveniently captured by a parallel rewriting system that replaces individual parent, mother or ancestor modules by configurations of child, daughter or descendant modules. By assigning numerical attributes to L-system symbols, parametric L-systems has extended the basic concept of L-systems and produced varied structures. While strings generated by L-systems are interpreted geometrically, the development of plants can be presented from birth to death. Recent study has also take the effect of the environment into consideration [22]. The plant and environment are treated as two separated processes, communicating by a standard interface. Open L-systems are introduced to specify plant models that can exchange information with the environment. This study has captured collisions between branches, the propagation of clonal plants, the development of roots in soil, and the development of tree crowns competing for light.

The modeling and visualization of living creatures is an another difficult task since it involves obvious behavior animation. This kind of animation is almost impossible to simulate by using a traditional approach (keyframe or procedural laws). The fundamental work on solving this problem has been done by Reynolds [29] which modeled flocks of birds and schools of fish by specifying the behaviour of the individual animals that made up the group. The animator only provides the leader trajectory and the behavior of other individuals relatively to it, rather than detailed frame-by-frame pose specifications. Each individual, called boid, is a point mass attached with a local 3D coordinate system and aligned with its velocity. Based on its local environment, each boid's behavioural controller computes a steering force during each iteration step of the simulation, including steering to avoid crowding local flockmates, steering towards the average heading of local flockmates, and steering to move toward the average position of local flockmates. In addition, the boid can avoid obstacles by calculating the eventual impact from the obstacles directly in front of it. The same algorithm was used to generate some behaviours of the bats in the movie *Batman II*.

Subsequent related projects have shared with Reynolds' original work on skillful manual design of physical morphology and behavioural control mechanism. Terzopolous and his colleagues [34] created faithful kinematic simulation of fish with impressive visual accuracy and realistic fish behaviour, including mating, feeding, learning and predation. The artificial fish has a physical-based animate model with internal contractile muscles that are activated to produce the desired motions. It has also some sensors (including eyes) to perceive the virtual environment, and a brain to combine the primitive reflexive behaviours, such as obstacle avoidance, into motivational behaviours whose activation depends on the fish's habits and mental states, including hunger, libido, and fear. Artificial fish can learn efficient locomotion via simulated annealing technique and abstract activation functions by Fourier basis for performing high-level tasks.

Faced with the difficulties of designing real-time and natural interactions, several researchers have drawn inspiration from biology. Blumberg [5], for example, has developed a behavioural control mechanism inspired by findings in ethology (the science of animal behaviour), including behaviour hierarchies, releasers, and fatigue. These findings are used to control a synthetic dog which inhabits a 3D software environment. This system, named ALIVE system, incorporates a tool called "Hamsterdam" to model semi-intelligent autonomous agents that can interact with one another and with the user. Hamsterdam produces virtual creatures that respond with a relevant activity on every time step, based on a predefined internal needs and motivations, past history, and perceived environment, with its attendant opportunities, challenges, and changes. Moreover, the pattern and rhythm of the chosen activities do neither dither among multiple activities nor persist too long in a single activity. They are capable of interrupting a given activity if a more pressing need or an unforeseen opportunity arises.

In Switzerland, there is an active Computer Graphics Lab directed by Thalmann, which has endeavoured to model and animate the most complex living system — human being. This group has created a group of virtual humans with impressive appearances and behaviours. These virtual humans use articulated structures as graphical and animate model. They are aware of a L-system based virtual world through visual, tactile, and auditory sensors [25]. These sensors provide information to support human behaviours such as visually directed locomotion, manipulation of objects, and response to sounds and utterances. For behaving autonomously, a brain, a visual memory and a limited reasoning system are employed [35].

In addition to academic research in institutes, there are lots of work having been done in entertainment industry. Typical examples have *Creatures* produced by Millennium Interactive Ltd [10], *SimLife* and *El-Fish* by Maxis [21], *Dogz* and *Catz* by PFMagic Inc. [27], *Fin-Fin* by Fujitsu [13], and *Galapagos* by Anark [2]. These virtual animals, acting as virtual pets, have lovely appearances and the ability to respond to the user by immediate behaviours and even emotions. These products have some autonomy and intelligence at varied levels by the utilization of intelligent techniques, such as cellular automata, genetic algorithms and neural networks. In order to achieve real-time on personal computers in home entertainment, the virtual worlds and animals are more or less simplified. *Creatures*, for example, inhabit a "two-and-a-half dimensional" world: a 2D platform environment with multiplane depth cueing so that objects can appear, relative to the user, to be in front of or behind each other [15].

3 Virtual Life

Like VR, the study of Virtual Life is a mixed branch which absorbs knowledge from various disciplines, including biology, ethology, physiology, psychology, mathematics and control theory. It also intertwines with many other areas in computer science, such as computer graphics, artificial life, artificial intelligence, autonomous agent and so on. However, an interesting phenomenon is that there is not yet a clear definition and explanation of the notion of "Virtual Life" though it has been mentioned in varied occasions. As a young and promising area, virtual life has not gotten enough attention. Here we try to give a definition to VL and analyze it from a systematic view. We hope the following discussion will evoke more concern on VL, which is beginning to take shape.

3.1 Definition

Whenever a concept involves abstraction, it would be hard to define it with absolute precision. In fact, there is even no an actual definition of "life". Many biologists try to define "life" by telling what it looks like and what it does. So here we would like to use this method to define "Virtual Life" as well.

Virtual Life is a software system which can produce graphical figures with lifelike and believable visual effect and behavioural pattern. While inhabiting a virtual environment, it can make actions autonomously, adapt to changes, and interact with the outside, especially with human user, by characteristic activities.

3.2 Structure of virtual life

For a true feeling of *presence*, convincing graphics and believable actions are both important. Realistic action can enhance the realism of graphics, while geometric and texture fidelity can make actions more intriguing. Therefore, virtual life should have not only visually realistic shape and appearance, but also natural behaviour. Although the modeling and visualization of living organisms by the computer is always a main subject in computer science, the study of realistic visual effects integrated with a mental model emerged just a few years ago. It is mainly caused by the conflict between high application requirements and laborious designing work on it, which is broadly existing in computer animation, multimedia and virtual reality. With the rapid development in computer graphics, people are no longer satisfied by visually impressive objects but with simple or foolish actions. However, when an object shows complicated behaviours, it is always completely mechanical and non-interactive and the result of a painstaking process, such as the behaviour of the dinosaurs in the movie *Jurassic Park* [20]. When facing a dynamically changing and interactive environment, it could be even impossible to design all the details in advance. Virtual environment, for example, is such a world continuously changed by the participation of active objects, including human users and virtual lives. Since the user can freely interact with the objects in the environment, it would be very hard to predict every possible action of every user and program the corresponding reaction into virtual lives beforehand. On the contrary, it should be virtual lives themselves to observe and analyse the user's behaviors and react to him by its own decisions. Virtual life with predefined and fixed behaviors can only limit its function and decrease its convincibility. Therefore, virtual life should be self-controlled and self-animated by simulating the natural mechanisms fundamental to life. To enable this, a virtual life needs receptors to perceive external information and effectors to carry on actions. Most importantly, a "brain" is required to analyse and process information, make sensible decisions, and control the body movement. Virtual life should have both visual and mental models.

3.2.1 Visual model

To produce three-dimensional (3D) lifelike organisms with realistic visual effect by the computer is always a challenge in computer graphics. It involves a number of stages:

- First, a 3D model of a virtual organism is generated by using suitable modeling methods.
- Next, viewing specifications are selected and created, such as skin texture, subtle colours, hair, and so on.
- Then, the visible parts of the organism to the user are determined and the colour values given to corresponding pixels are calculated. In addition, shadow, reflection, and transparency are counted.

- Last, an animated sequence with time-varying changes in the model, lighting, and viewing specifications must be defined.

In above procedures, selecting a suitable 3D model is a key step. A better 3D model will make the last visual effect more realistic and the implementation of the following animation much easier.

Traditional modeling technique consists of surface modeling and solid modeling. Surface modeling can produce smooth curves and surfaces when a mathematical description of the object is required. Solid modeling incorporates the representation of surface modeling into systems to represent not just surfaces, but also bounded solid volumes. These methods have been successfully used in CAD/CAM, however, they are impossibly time consuming and cumbersome when modeling natural objects which are often nonrigid, flexible and jointed. Some advanced models have been developed to overcome this problem, in which procedural model, L-system, physically based model and articulated figure are well known in modeling living things. These models have been developed for dynamic models rather than for static ones, and for modeling growth and change as well as form.

Procedural model describes objects that can interact with external events to modify themselves. This kind of procedural interaction among objects can be used to generate motions that would be difficult to specify through explicit control. Because of its ability to interact with the environment, procedural model is ideally suitable to the control of animation [1]. If embedding procedural model in, other models and control mechanisms can also be procedural in some way. In physically based systems, for example, the position of one object may influence the motion of another.

L-system is originally designed to model the development of simple multicelluar organisms. It was Smith [33] who firstly described it from the computer graphics point of view. Since then, most work in this field is based on a parallel graph grammar. Basically this is a system that specifies a construction such as a plant or a tree, as a sentence (a series of words or some other notation) in the language that the grammar defines. The grammar is specified as a set of pictorial rewrite rules and a parser based on these rules converts the sentences into the image. Algorithms that model plant developments are best described as procedures, implementing rewrite rules, but allowing complex visual attributes (e.g., a solid trunk and a system of branches decorated with leaf texture) and the stochastic rules rather than the deterministic application of the production rules.

Some biologically simple animals have been modeled by physically based methods. In 1988, Miller presented realistic models of snake and worms which are based on interaction between masses and springs, with muscle contractions modeled as changes in spring tension [23]. Similar work has been shared with the creation of artificial fishes by Tu and Terzopoulos [38]. Tu, et.al., used NURBS surfaces as 3D geometric models, mapped realistic fish textures onto them, and gave the models masses and springs for dynamic motions. These result in biomechanical models with numerous degrees of freedom and many parameters to control. By simulating the forces of interaction of a deformable body in an aquatic medium, a motor control system can achieve muscle-based, hydrodynamic locomotion.

When simulating living things with complex architectures, articulated structures are often used. An articulated figure is a structure that consists of a series of rigid links connected at joints. Early work done by Zeltze is a comparatively simple skeletal model [40]. It is the motion that make the modeling more believable. Later work of Bergeron and Thalmann are quite impressive. They built articulated humans in films *Tony de Peltrie* [3] and *Rendezvous à Montréal* [36] respectively. Both films used articulated structures or skeletons as the basis of movement animation. For articulated figure animation, kinematics and dynamics are all good tools, especially when producing short motions such as grasping a chair, etc. When producing long motions such as walking, running, and so on, they have to be used in combination with other techniques, including gaits, motion- controller, or key-frames.

Advanced modeling methods are designed with the consideration of dynamic changes, so it makes the accomplishment of the following animation much easier.

Because of the complexity of the world, it is still impossible to achieve perfect visual realism, especially in a real time simulation. Effective and fast methods are still being researched. In the conflicting requirements of realism and real time, suitable compromises must be made.

3.2.2 Mental model

3.2.2.1 Characteristics

A sound mental model is essential for virtual life to maintain a normal life in a complicated and changing world. To enable this, this mental model should at least have the following characteristics:

1. Autonomy

Autonomy is an important aspect of virtual life that is universal in living things but not confined to them. Autonomous behaviour is the one that occurs within the organism or that results from internal changes [31]. Such kind of behavior represents the capacity of the life to maintain its viability in varied and changing environments. Plants may seem motionless, but they also experience the spontaneous growth toward a place with better living conditions. Although the growth is a slow movement, there is considerable movement not only within their cells, but also from cell to cell. The need to have autonomous behaviour for virtual life arises for two considerations: the less work done by the designer and the more faithful illusion in the user that the virtual life is a real one [35]. To be autonomous, a virtual life should analyse the environment information actively, and decide how to relate its receptor information to effector actions by itself. Autonomy is necessary to make the virtual life believable. But how to realize it is still a challenge. Till now, almost all the softwares are pre-constructed by the designer. They can only do what are designed. When facing unfamiliar situations, they may not react correctly and have to stop for further help from the designer. This will cause great disappointment to the human user if virtual live "paralyses" suddenly.

2. Adaptation

Another indispensable characteristic of virtual life is adaptation, which is organised to promote itself in the environment it inhabits. Adaptation can be viewed in two aspects. In a broad view, it is to adjust genetically for a species to the changed environmental conditions. When a species reproduces, it is not just a simple copy, but a complicated transfer of the best parts (structures) to its offspring. This reproduction with changes is responsible for the evolution of life. In a narrow view, adaptation is to enhance an organism's ability by learning so as to survive in more or less unpredictable and dangerous environments. This includes how to utilize the environmental resources best and how to change the situation for its benefit. Although the broad adaptation always takes a very long time in the nature, it is not necessary in simulated environment. Virtual evolution in generations can be achieved in arbitrary time by emphasizing on only significant procedures.

3. Interaction

In real life, responsiveness is also a distinctive feature. It occurs to some extend in all living things. Organisms not only maintain themselves through environmental changes. They also respond to these changes by characteristic activities. Even plants will react to changes in sunshine, nutrition, and other environmental conditions. Responsiveness is extremely obvious in higher animals, e.g., human beings. To a virtual organism living in a virtual environment, it may be not enough that it can only react to environmental changes and actions of other virtual lives. More importantly, it should have the ability to interact with the human user, which is the main actor in virtual reality. Therefore, we rename "responsiveness" to "interaction" as a characteristic of virtual life for the coordination with VR in which interaction is an essential factor. The user in VR will extremely expect to be able to interact with virtual plants, animals, humans, and to see what response he will get. The more distinctive the responses are, the more interesting the user feels. For example, a user must be bored if he always faces a "living fossil" which has not changed for millions of years. However, he would be much satisfied and think this fossil can "understand" him if it shows its evolutionary procedures in a short time with emphasis on his interest, e.g., if his sight stays on certain parts for a long time. In this meaning, virtual life is not just a simulation of real life, even though it comes from the real one.

The above three characteristics are fundamental to virtual life. Lives at higher levels will have more features. Virtual humans, for example, still have their own personalities, consciousness, emotions, high intelligence, and so on [37].

3.2.2.2 Related areas

How to model mental models of natural creatures has been a major subject of research for many years. It has experienced the success of engineering applications of expert systems and the creation of *Dark Blue* which defeated the world chess champion. It has also failed when traditional artificial intelligence could not cope with dynamic situations. Now it welcomes a new period because of the emergence of autonomous agent and artificial life.

1. Symbolic Artificial Intelligence

Before nineteen eighties, research work in Artificial Intelligence (AI) had concentrated on symbolic artificial intelligence, which assumes the ability to symbolically represent aspects of the world is a prerequisite for all intelligent behaviours [26]. Symbolic AI is also known as deliberative AI with its concomitant need for explicit representationalism and a central executive and world model. When solving a problem, a knowledge-based system will be built in advance by the designer, which contains prior knowledge to describe objects, facts, goals, skills (rules) and so on. It corresponds to the designer's point of view about a particular domain and often reflects the limits of human expertise.

Symbolic AI has obtained great success in isolated and often advanced competences, such as chess playing and medical diagnosis. However, it is now seemed to provide "depth" rather than "width" in their competence [19]. Explicit representationalism could account for only a small part of what we call intelligence, but the rest may have nothing to do with systems of symbols [30]. Because the application domain is already defined by the designer, traditional AI systems can only accomplish predefined functions in a limited scope. An even severe problem is their fragility, they may paralyze completely when the central control unit fails in a sudden situation which is neglected or unknown by the designer.

2. Artificial Life

It is in 1987 when Christopher Langton defined the notion of *Artificial Life* (AL) on the first ALife workshop, that a new research on Artificial Life began. Nowadays, this subject has attracted researchers in all areas of contemporary science.

Artificial Life is the study of man-made systems that exhibit behaviours characteristic of natural living systems [16]. By extending the empirical foundation upon which biology rests beyond the carbon-chain-based life that has evolved on Earth, AL can contribute to the theoretical biology by locating "life-as-we-know-it" within the larger context of "life-as-it-could-be", in any of its possible physical incarnations, such as the computer. At present, it simulates lifelike behaviour by using natural principles from various views, including evolution, ecology, morphology, philosophy, and so on. The techniques developed in artificial life can greatly benefit to the study of virtual life.

Worth of mention is an active area in AL research which implements rich and robust artificial worlds for artificial life models to evolve and interact. These worlds are implicitly constructed from organisms' point of view. They allow the dynamics of the whole collection of organisms to constitute "nature" which supplies the selective pressure on lineages. Therefore, the complexity of these artificial worlds itself evolves through time, and the class of problems that this artificial "nature" poses to its constituent organisms is constantly changing over time. A typical artificial world full of competition among artificial creatures is created by Karl Sims [32]. These creatures are composed of blocks and designed to achieve certain goals, such as swimming quickly. They compete with each other for limited resources and evolve themselves for higher fitness. The whole competitive and evolutionary procedure is quite impressive.

Although these artificial worlds and lives involve important methods on simulating the nature, they have essential limitations to be used as VEs and VLs. They donot have much lifelike visual effects, besides which, their evolution procedure is very time consuming and lack of control. These make real-time interaction, a basic requirement in VR, could not be satisfied.

3. Autonomous Agent

In the mid-1980s, a new school of thought emerged strongly influenced by behaviourist psychology, which is often called autonomous agent research or behaviour-based AI as opposed to mainstream "knowledge-based AI". Autonomous agent has radical differences from symbolic AI. It denies the need of symbolic representations within the machine as far as possible, but to use only some form of representation if it is really necessary [6, 7]. It makes decisions at run-time, based on the dynamic interaction with the environment to cope with resource limitations and incomplete knowledge. Agent also refuses any central control. An agent is viewed as a collection of modules each of which has its own specific competence. These executable modules cooperate and compete with each other for the last decision. Sometimes there are redundant content among these modules. However, fast and robust behaviours have been achieved because of this distributive and parallel implementation. A conspicuous characteristic of agent is that its global behaviour is not a linear composition of the behaviours of its modules, but instead more complex behaviour can *emerge* by the interaction of the behaviours generated by the individual modules. Autonomous agent approach is argued to be appropriate for the class of problems that requires a system to autonomously fulfil several goals in a dynamic, unpredictable environment [6].

However, complex tasks requiring reasoning and/or cooperation have seldom been done in this field. Furthermore, the notion of *emerging* makes the resulting behaviour of an agent hard to understand, even harder to predict, and almost impossible to define and control [24]. In the past few years, layered architecture has been presented for supporting the integration of deliberation and reaction AI [11, 12, 18, 24]. The main idea is to construct the functionalities of an agent into two or more hierarchically organized layers that interact with each other in order to achieve coherent behaviour of the agent as a whole. While lower reactive layer monitors the outside world, the higher layer can do some complex works, such as planning, by utilizing the information obtained by lower layers. Nonetheless, new problems have appeared with the company of this architecture, such as the inconsistencies among the layers.

Above areas all endeavour to simulate living behaviours, but derive from different views.

Symbolic AI tries to study the advanced learning and reasoning techniques of human being. Autonomous Agent starts from the study of animals' reflective behaviours, and Artificial Life introduces knowledge mainly from chemistry and evolution. However, a common problem existing in these areas is that they have more or less concerned with only partial aspects of living things, but not take the whole living system, including both basic behaviours and sophisticated behaviours, into consideration. This makes simulated models could not maintain in a complex and changing environment with complete convincibility.

3.3 Comparison of virtual life with real life

As mentioned above, virtual life is not a simple copy of real life. It derives from the real life, but still has its own features since its living environment is a simulated one. To different applications, VL may have varied functions and characteristics.

An essential distinct between virtual life and real life is that the metabolism, growth and reproduction, the obvious hallmarks of real life, are not necessary in virtual life. In the nature, each organism will go through procedures from birth, development, to death. These procedures are maintained by metabolism. Though there is also information flow in virtual life, VL can have unlimited energy to survive. This means the life of a virtual organism will depend on its role and application position. A hero in a game, for example, can be mature when he appears at the first time, and will never die if the user wishes. The virtual dinosaur species may only maintain for several hours and disappear soon. In a word, the standard life period in the nature is no longer a necessity of Virtual Life.

Another obvious difference is that a virtual life may own some abilities and features which its corresponding real life does not have. Some virtual lives may even do not exist on the earth. If a user comes into a fairy computer-generated world, then trees can speak, virtual humans can fly, virtual robots can think and move, and people from other planets can visit the earth. Moreover, virtual lives can also have overstated shapes and appearances, and exaggerated behaviours for intriguing the user's interest. However, all the made-up factors should make the user think they are believable and like to interact with these lives. That is the reason "believable" is used in the definition of *Virtual Life*.

4 Conclusion

Because of the rapid development of virtual reality and its unlimited applications in entertainment, education, training, and other areas, virtual life becomes an indispensable part to compose virtual environment where both VL and the human user inhabit. Vivid lifelike virtual life can enhance the fidelity of virtual environment and intrigue the user's interest. Although much related work has already been done, there is not yet a clear definition and explanation on this new but promising area. In view of this problem, this paper tries to clarify the notion of virtual life and discuss it from a systematic view.

For a true feeling of presence, virtual life created by the computer should have faithful visual effects and believable behavioural patterns. However, it is not enough for a virtual life to have realistic appearance but predefined behaviors, like those cartoon figures. Because virtual life lives in a changing environment and no one could exactly know what will happen at next step, it is important for virtual life to be autonomous to make sensible decisions by itself, adaptive to promote its structure for better maintenance, and interactive to external changes by characteristic activities. That is, a virtual life should have a "brain" to analyse the outside information and make actions according to its own belief, character, and intention. Therefore, virtual life should have both visual and mental models.

Recently, many researchers have realized the important position of virtual life and designed many virtual organisms. In the past years, a special course has been successively held in SIGGRAPH conferences, called "Artificial Life for Graphics, Animation, Multimedia, and Virtual Reality". This course has presented the challenge of developing sophisticated graphics models that are self-creating, self-evolving, self-controlling, and/or self-animating by simulating the natural mechanisms of life. However, it should be noted that artificial life is not the only technique which could benefit the simulation of living behaviors. Other methods, including artificial intelligence and autonomous agents, can also make valuable contributions to the modeling of varied aspects of living things. Although the construction of virtual life has attracted many researchers, it is still a young field in which more work is needed. We hope above discussion would call more concerns on VL and give some help to its development.

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