A Physiological Approach to the Generation of Artificial Life Forms

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Abstract

Artificial Life has been an inspiration for Virtual Reality Art, which has proposed the design of imaginary life forms and has also used Artificial Life techniques in various installations. The creation of imaginary life forms has been so far limited to the external appearance of these creatures. We introduce a novel approach to the design of artificial life forms, which enables the description of their internal physiology from first principles, by using a simulation method known as qualitative physiology, derived from a well described Artificial Intelligence technique. We illustrate this framework by revisiting early work in Artificial Life and providing these virtual life forms with a corresponding physiology, so as to obtain complete living organism in virtual worlds.

Introduction

In this paper, we present the creation of artificial life forms described by their appearance as well as their internal physiology. These can be simulated in real-time in a virtual environment in which elementary physical phenomena are also simulated, so as to recreate part of an artificial ecosystem.

We have revisited early work in Artificial Life, originally presented at the second "ALife" conference [Bec, 1991; 1998], which proposed imaginary creatures, by extending the description of these life forms to incorporate a description of their internal anatomy as well as the associated physiology. Artistic work, with a strong inspiration from Biology [Risan, 1997], is one important aspect of investigating "life as it could be" [Langton, 1989]. In the next sections, after an introduction to qualitative simulation and a presentation of the system's architecture, we describe the modelling of the artificial creature *Diaphaplanomena* that belongs to the Upokrinomena, as well as early results obtained from the simulation of the organism behaviour in its environment.

System Overview and Architecture

The system comprises a visualisation environment, which displays the real-time motion of the Diaphaplanomena, and a qualitative simulation engine controlling the simulation of both the internal physiological processes of the creature, and of physical processes in its liquid environment (such as currents, heat flows, etc.).

The visualisation component supports the real-time display of the creature in its environment and the interaction between the Diaphaplanomena and the physical world. This includes, the creature's locomotion in the 3D environment, the visualisation of its internal or external motion as real-time animations and dynamic changes in its external appearance (colour and textures).

The visualisation engine is based on a game engine, Unreal® Tournament 2003 (UT 2003). The rationale for using a game engine in research is that it supports advanced graphic rendering and animation control as well as the integration of external software modules, which makes it an ideal development environment [Lewis and Jacobson, 2002].

In addition, UT 2003 provides a sophisticated event system, which supports the real-time interaction between the Diaphaplanomena and its environment. Physical processes simulated in the environment, such as currents, turbulences and heat flows create objects (vortices, heat sources, etc.) whose direct interaction with the creature can be processed through the event system and be interpreted by the qualitative simulation module.

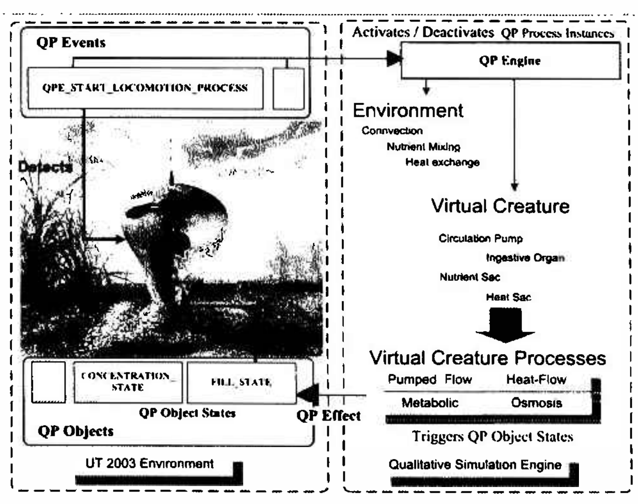

Figure 1: System Architecture

The software architecture is based on UDP communication between the qualitative simulation engine and the visualisation engine. The simulation engine passes landmark values reached by qualitative variables to the visualisation engine. These are interpreted by various scripts that control the creature's behaviour (physiological processes). In a similar fashion, physical processes in the environment such as currents, turbulences and heat flows are controlled by the simulation engine. On the other hand, dynamic interactions between the Diaphaplanomena in its environment (such as the creature entering a cold current or being hit by turbulence) generate events that are passed to the simulation engine and alter the current simulation. For instance, if the creature enters a cold current, this will eventually trigger a heat-transfer process between the current and the Diaphaplanomena, which will change its internal state (and trigger further thermal regulation mechanisms).

Artificial Physiology at the System Level: Qualitative Physiology

Modelling physiological processes has always been a major endeavour of biological modelling as it would support detailed simulations of the organism behaviour. Most models have concentrated on the numerical simulation of physiological phenomena expressed through a set of differential equations or through control theory, because of the importance of regulatory and homeostatic processes in physiology.

However, symbolic modelling is another approach which has developed more recently, mainly in medical knowledge-based systems. One advantage of symbolic reasoning is that it enables the aggregation of multiple physiological systems (even across different levels of description) and has better explanatory capabilities.

Most importantly, in the case of artificial life systems, it brings the prospect of defining artificial physiology from first principles, which opens new ways for the experimentation of artificial, alternative life forms. Previous work on Artificial Life has mostly considered molecular physiology, rather than higher level systems, with a few exceptions [Grand et al., 1997].

One of the authors has developed a technique for qualitative simulation of physiological systems [Cavazza and Simo, 2003], derived from Qualitative Process Theory (QPT), an Artificial Intelligence formalism used in qualitative physics [Forbus, 1984]. Qualitative Physiology uses the process-based formalism of QPT to represent physiological processes governed by physiological laws, and supports the real-time simulation of physiological sub-systems.

The QPT formalism is based on the concept of a qualitative variable, a discrete variable whose values correspond to the orders of magnitude of a given physical parameter. For instance, the qualitative values can be used to form a discrete set for the concentration of solute within a fluid, or for the pressure within a container. The formalism supports two basic mechanisms for updating the variables' values in the course of a process execution. Influence equations are the central mechanisms for updating variables: they correspond to abstract expressions of physical (in some cases physiological) laws. For example, in osmotic systems the transfer of solute through the semi-permeable membrane can be represented by the following influence equations.

```
I+ (Amount-of-Solute(? Substance dst)(A Osmotic-rate))
I- (Amount-of- Solute(?Substance src)(A Osmotic-rate))
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Where I+ represent a positive influence and I- a negative influence upon the first quantity by the second. The Influence equation specifies what can cause a quantity to change so we have specified that the quantity amount of solute in substance src will be decreasing with the osmotic rate and the amount of solute in substance dst will be increasing with the osmotic rate.

On the other hand, qualitative proportionalities relate variables values outside causal processes, for example stating that the mass of a liquid is proportional to its volume (hence updating the volume variable whenever the mass variable is modified, to enforce that constraint).

A qualitative process is triggered whenever its pre-conditions are satisfied; for instance, when the creature is entering a cold area (such as a cold current), the conditions for triggering a heat-exchange process between itself and the current are satisfied.

Naturally, Qualitative Simulation can also be used to simulate physical phenomena in the creature's environment, which in our case provides a unified principle for simulation.

An example process that relates the behaviour of the Diaphaplanomena to its environment is the *Propulsion* process:

Process: Heat-Sac-organ(Creature)
Individuals: ? Creature: type an virtual creature
Condition: has a Heat-Sac Sac
Preconditions:
Is_alive(Creature); Is_Active(Creature);
Quantity Conditions:
;When organ has filled with fluid
(Equal-to(Amount-in(Sac) A(Sac(volume)))
;while pressure within organ is less than
Less-than(A(pressure-In-(Sac)) A(Pr-Organ-Max))
;while Creature has energy
Greater-Than(Amount-of-Energy(?Creature)
Relations:
(Quantity ConversionRate)α(A(swim-rate)))
Influences:
I- (Amount-of-Energy(?Creature) (A(Reactionrate)))
I+ ((heat ?Sac) (A Reactionrate))

In this process, the conversion rate is dependent upon the swim rate information received from the UT 2003 environment about the detection of danger within the environment. Since the "heat sac" is used in the

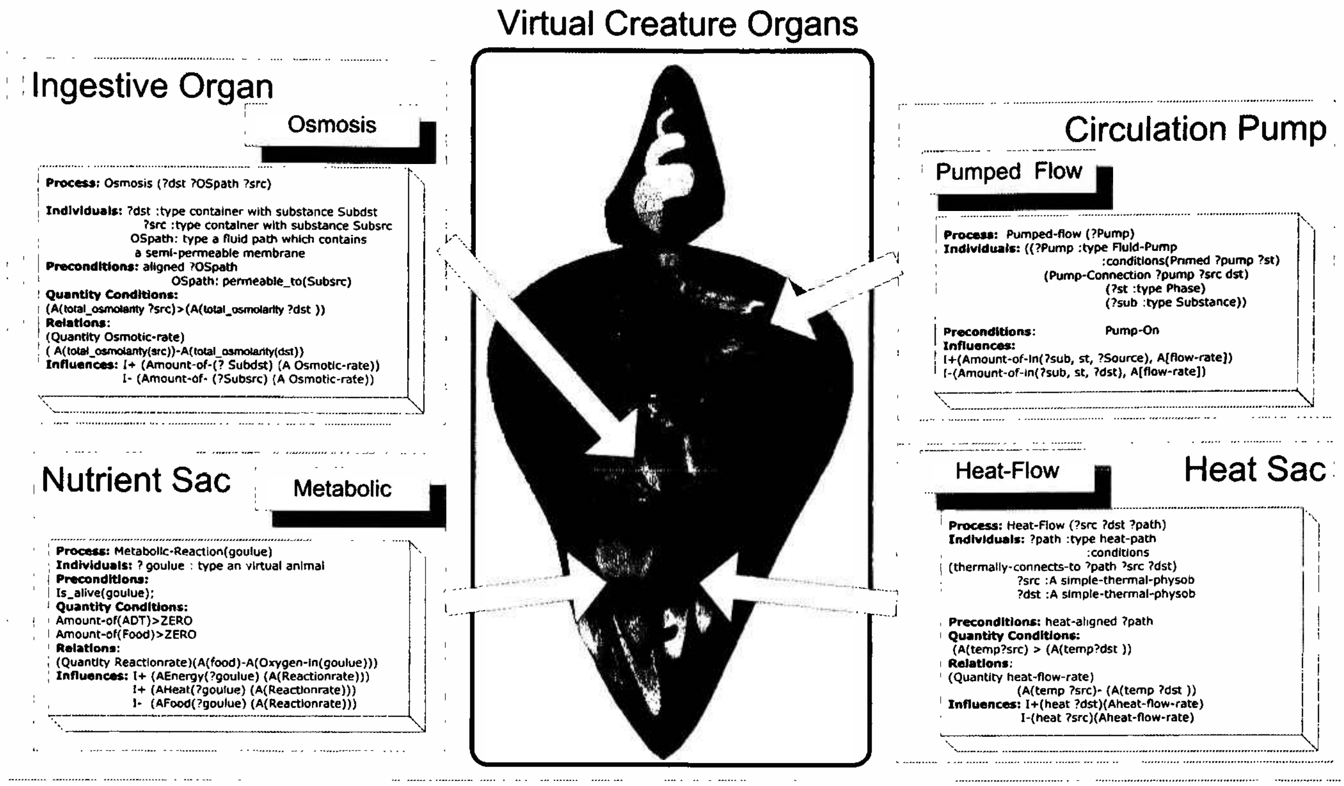

Figure 2: Diaphaplanomena Anatomy and Physiology

locomotion, the increased conversion rate allows the Diaphaplanomena to swim faster away from closer dangers.

Creating the Diaphaplanomena

The creation of the Diaphaplanomena includes the description of its anatomy and its physiology. The anatomical structure of the Diaphaplanomena is briefly outlined in Figure 2.

The visual contents have been produced using 3D modelling and animation packages such as 3D Studio Max™ and XSI™. The native 3D models as well as animations have been imported into the UT 2003 engine. This engine supports the use of key-framed animation to describe certain actions (in our case movements of internal organs, changes in shape of the creature, as well as locomotion), while retaining the interactive nature of the simulation. The actions are required to simulate interaction with the environment and/or other creatures forming a potential ecosystem.

We have modelled several physiological processes for the Diaphaplanomena, dealing with elementary physiological functions such as nutrition, locomotion, and certain homeostatic processes such as thermal regulation. An essential aspect is that these are defined altogether as an integrated system, which can further be refined through experimentation, as the process description is highly modular and processes only connect through characteristic physiological variables (e.g., concentration in nutrients, temperature in certain organs, etc.). Defining the creature using this level of description is largely a functionalist approach [Bedau, 1992], although a top-down, non-emergent one.

As far as locomotion is concerned, the Diaphaplanomena is a wandering organism, which inhabits a viscous but heterogeneous space traversed by turbulences and currents. Its locomotion is mostly dedicated to maintain stability against external perturbations as well as supporting basic chemotactic mechanisms. Its locomotion is closely related to thermal generation processes and is based on the generation of turbulences due to internal temperature gradients between "hot" and "cool" organs.

Results

This approach enables various forms of experimentation in virtual worlds. In addition, because physical processes and physiological processes are described and simulated independently of one another, it is actually possible to experiment upon the adequacy of these mechanisms for the long-term survival of the Diaphaplanomena in its environment.

This process of top-down creation of a life form has also implications for the relations between Artificial Life and real living systems [Keeley, 1997]. We have implemented

a first prototype of the system in which we have a basic set of physiological and environmental processes. The processes allow our experimentation with, and simulation of, the Diaphaplanomena and its environment.
In this section, we illustrate the system behaviour by describing some specific results from the simulation.

The Diaphaplanomena's Digestive System

A number of processes are active between the creature and the environment, when the creature is free floating. Active instances of the fluid flow and heat flow processes exist between the internal media and the environment. These two processes continuously refresh the internal media of nutrients and deprive the creature of heat respectively. The organs interact with this internal media.
The behaviour of an organ is determined by its representation. In our sample case, the organs are represented by containers and pumps which operate by using the bodily-fluids contained within them. To create the special behaviours desired to represent a specific organ, the container is given special properties. For instance, the absorption of nutrients through the nutrient sac by osmosis is enabled due to the nutrient sac's semi-permeable membrane property. In this way each organ has a direct correlation to a process or sequence of processes.
The primary behaviour processes that are active within each of the main organs are detailed in Figure 2. However, this is not a complete description of all of the processes within an organ. For instance, the osmosis process is the primary behaviour of the ingestive organ. The osmosis process transfers nutrients between the internal media and the bodily fluid in the organ. This transfer is balanced by the pumped flow from the circulation pump which is also transferring these required nutrients in bodily fluid to the attached receptive organs.
In our example creature, the nutrient rich bodily fluid in the
ingestive organ is transferred to the nutrient sac by the fluid flow process created by the circulation pump. The primary behaviour of the nutrient sac is the metabolic process that converts the nutrients in the bodily fluid to heat and stored energy. During this conversion the metabolic process decreases the concentration of nutrients in the bodily fluid, this nutrient deficient fluid in the nutrient sac is then pumped back into the ingestive organ by the circulation pump completing the cycle. In this way the processes are combined to produce the physiology for the creature.
In our example creature, the nutrient sac is given an additional behaviour of being nutrient sensitive. Changes in the nutrient concentration correspond directly to the physical colour for the organ. This mapping is caused by triggering object states in the UT 2003 engine by communication with the qualitative simulation engine.
Figure 3 illustrates the representation of nutrient concentration in an organ by using colour. The triggering of the colour object states of the "nutrient sac" organ by the qualitative simulation engine uses three qualitative process effects; these are QP_Concentration_Min, QP_Concentration_Max and QP_Concentration_Update.

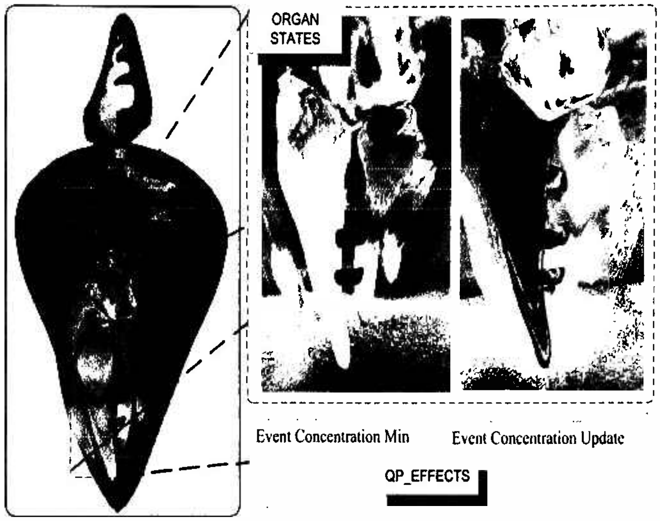

Figure 3: Changes in Internal Organs during Simulation

In the qualitative simulation engine the discretised qualitative variable that represents the concentration of nutrients in the bodily fluid that are within the "nutrient sac" is given a set of landmark values. The minimum and maximum of the landmark values are used for the respective QP_Effects, while the rest communicate using the effect QP_Concentration_Update. The distribution of the landmark values determines the responses of the organ. However, since the value of the nutrient concentration depends on the physiological processes and their associated influence equations, it is these which ultimately control the response of the organ.
The motion of the virtual creature is governed by the convection current in the environment when the creature is not under its own direct motion. As the creature is not using locomotion, the creatures Heat-sac has no active processes. The heat sac is used only to power the locomotion for the creature. In this free floating case, the creature is conserving energy and building its reserves in the nutrient sac.

The Diaphaplanomena Locomotion System

During the simulation the virtual creature may encounter the active vortices that are generated by the environment's convection process. In this case, the Touch-Vortex event will support the detection of that environmental phenomenon by the Diaphaplanomena. This will be interpreted as a danger signal and trigger its locomotion behaviour.

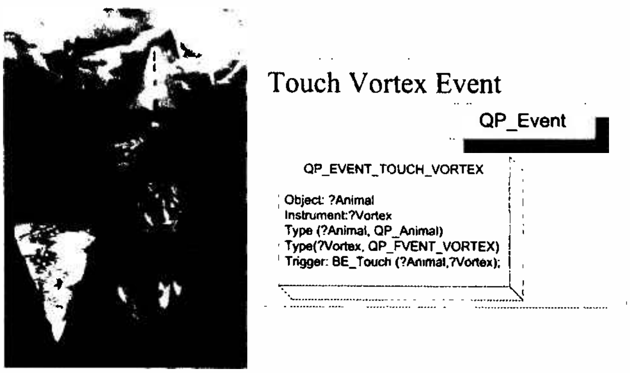

Figure 4: Interaction with the Creature's Liquid Medium

During locomotion, the internal processes affecting the virtual creature are mostly unchanged. An exception is that during locomotion, the rate at which the bodily fluids are carried around the organs by the circulatory pump, is raised due to an increase in the pump-rate. The main change is that the heat sac becomes active during the locomotion cycle.

The activation of the heat sac causes the release of the intake valve allowing it to draw fluid, via a fluid flow process. The fluid flow from the internal media into the heat sac generates the fill heat sac event, QP_Effect_Fill_Heat_Sac, which is sent to the UT 2003 engine. The fill heat sac effect specifies the rate at which the heat sac is expanded depending upon the quantity fluid flow rate of the fluid flow process into the heat sac. The primary behaviour of the heat sac is to convert stored energy from metabolic processes into heat; this conversion process creates a new heat source within the heat sac and consequently activates a heat flow from the new heat source. As temperature within the heat sac increases, the internal fluid contained also begins to heat. Qualitative proportionalities give the relationship that "heat sac" pressure increases with the heat. So, as within the heat sac increases the pressure increases. This increase in the qualitative pressure quantity triggers the landmark value within the expansion valve on the heat sac when the pressure reaches a maximum value, causing the contained media to escape. The activation of the expansion valve between the heat sac and the environment provides a fluid path between the heat sac and the environment. This fluid flow sends the event "empty heat sac", QP_Effect_Empty_Heat_Sac, to the UT 2003 engine, which changes the state for the heat sac to empting and triggers a particle effect whose rate depends upon the rate of the fluid flow (see figure 5. Propulsion effects).

The start of the event "empty heat sac" for the heat sac organ state activates the propulsion process for the creature which calculates the thrust and drag for the creature from the rate of the fluid flow, the viscosity of the fluid and the convection in the environment. The propulsion process sends the calculated qualitative thrust data to the UT 2003 engine via event "start process propulsion". This changes the velocity of the creature within the UT 2003 system.

Conclusion and Perspectives

We have presented a new method for the principled creation of artificial life forms and their real-time simulation inside their virtual environment. Its central feature is to provide a high-level representation for the creatures' physiology, which supports a more integrated description of the virtual life forms.

The use of qualitative simulation also provides a unified framework in which to simulate both the creature's physiology and the physical phenomena that affect it in its environment. This is of particular interest when exploring life forms populating alternative worlds in which laws of physics themselves could be different (a concept we have introduced as Alternative Reality [Cavazza et al., 2003]).

This "creationist" approach, which is in-line with the artistic perspective from which this work was originally developed, can however be reconciled with evolutionary approaches. One potential research direction is to link the symbolic description of physiological processes to some kind of evolutionary computation principles that would transform the creature's physiological processes. The important aspect would be to retain a link with Theoretical Biology [Noble, 1997] in the Physiological description rather than delegating it entirely to emergent processes.

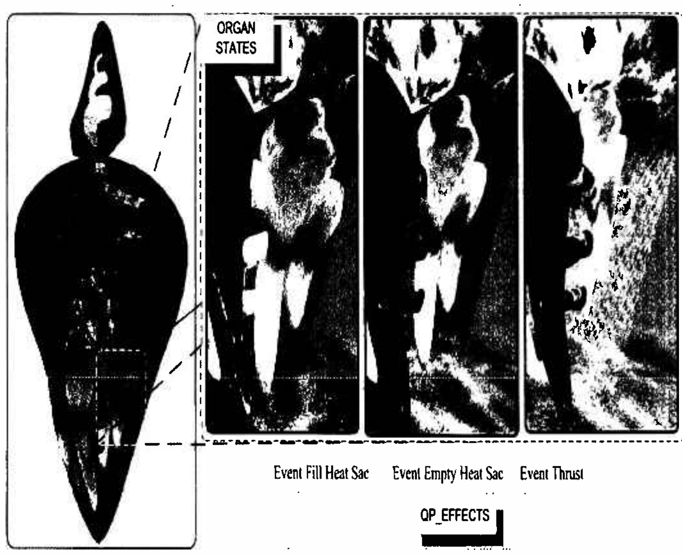

Figure 5: Propulsion Effects

Acknowledgements

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