Developing Evolutionary Adaptative Systems to Negotiate the Mind-Body-Environment Relations

Erwan Le Martelot
Institute of Ophthalmology
University College London
11-43 Bath Street
London EC1V 9EL
rone56@free.fr

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Abstract

This project is part of a larger research project[1] the aim of which is to create an interactive video art installation between spectator and computer, and an artwork which lies between art and science. The interface between them is driven by an open-ended "Artificial Intelligence" computational system that evolves in response to the autonomic reactions of arousal of a subject, rather than the consciously controlled processes which characterize most interactive art.

This project merges interests in art, neuroscience and computer science and is born from a collabaration between these fields.

This paper presents the achieved work to create an intelligent system able to provide concrete results highlighting the the mind-body-environment relations.

Introduction

The last decades have seen a significant rise in Human-Computer Interaction (HCI). Becoming more and more powerful, computers makes possible

[1]The project was initiated by Sarah Rubidge (artist) and Beau Lotto (neuroscientist)

this interaction evolution and thus became a lot more than “computing machines”. In the past computers could make short work of a heavy computing task which previously required a huge quantities of computation work for humans. Now they can learn, recognize, make decision, assist and even replace humans in many tasks. All those applications always require more power to be improved but that way computers are progressively becoming more “intelligent”.

The first aim of my research, within this global framework, was to create an open-ended AI computational system which analyses body responses, uses those responses to evolve itself, and in this way creates the desired psychological state in the subject.

The second aim was to use my system to create ‘interactive” installations, crossing between computer science, art and psychophysiology, which sets up some conditions for a human subject to understand intuitively the more subtle psycophysical aspects of the nature of its “being in the world”. This installation works as an infinite interaction between a subject and a computer where the intelligence in the computer provides a more and more physiologically arousing experience to a subject.

In what follows I will first describe the engine, how it relates to the global project, and then the two applications which were created. The first one aims to make a subject react to sequences of pictures. The second provides totally abstract evolving imagery from a real-time evolving artificial life system. I will thereafter discuss about the limitations of the actual systems and the possible improvement needed to be realized in a near and in a further future to achieve the original objective.

1 Global Theoretical Principle

The system works with cycles of interaction. Each cycle works according to three steps as shown on figure 1:

1. Perception : the subject is presented with a stimulus by the computer,
2. Response : a sensor on the body transmits the unconscious physiological response of the subject to that system,
3. System evolution : the system adapts according to that response.

This installation, by virtue of its topology, should be able to work with any kind of input-output dynamic. Thus we can imagine several types of perceptions and responses:

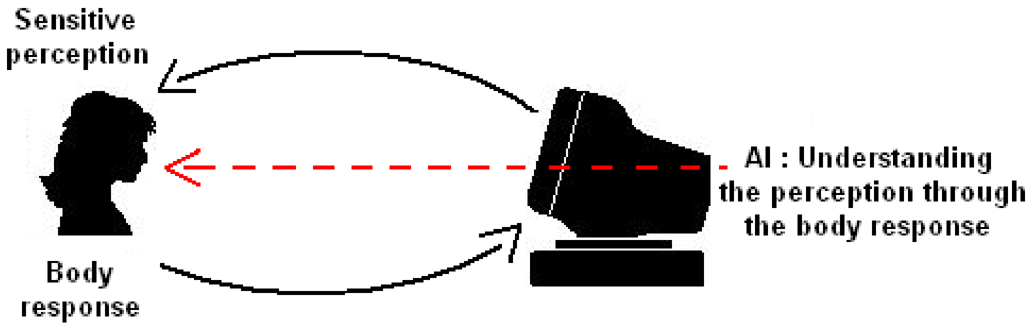

Figure 1: Experiments Global Theoretical Principle

- Sensory perception : Vision, Sound, Taste...
- Subject's response : Heart rate, Galvanic Skin Response, Brain cell response...

The artificial intelligence involved in this system processes the response, self-evolves and learns (figure 2) to increase its aptitude to distinguish between significant and insignificant responses. Beyond the physiological experience of the subject, it then generates results that can be interpreted by the artist and the neuroscientist to beter understand art and perception. It is important to notice that the aim of this system is not to understand the emotion, or what people like or dislike, but to understand which kind of response counts as a relevant arousal, and which does not, and then with that to provide the subject for instance with a more and more arousing experience using this programme. These are the results which are processed to understand the behaviour of the human biology allowing some associations between for example an arousal and an emotion.

2 Global Technical Principle

Such a system is based on the subject's response. Since any kind of body response can be expressed with an analog signal I considered the input, whatever it comes from, as an analog signal. From that, I needed to process this signal to extract the features out of it that are the best indicators of arousal.

But at this point a fundamental problem occurs. Depending on the nature of the input and on the nature of what we want to observe, we may at the very beginning have no information nor even an assumption about the nature

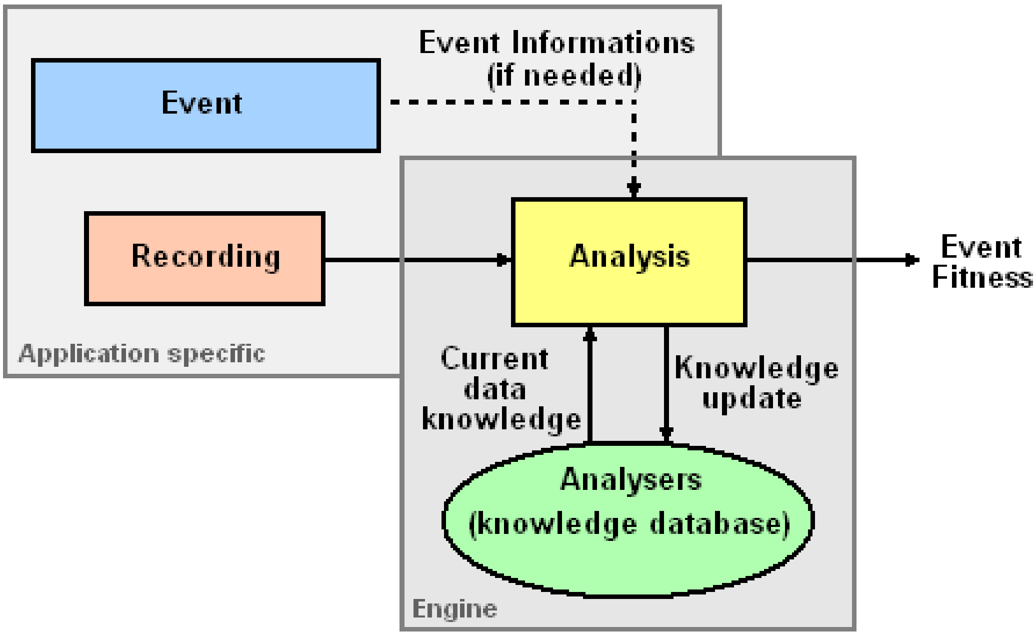

Figure 2: System Working Principle

of the relevant phenomena to observe. Let's say for example that we observe the subject's heart rate, we may want to focus on frequency, on amplitude or on variance, and from there want to observe a maximization, a minimization or a constancy. Consequently a certain flexibility of the system is required at this stage to be able to set up the experiment according to these possible choices. This brought us to define an outline of the signal processing thus:

$$Signal \Rightarrow Processing \Rightarrow Analyse \Rightarrow Interpretation$$

The processing stage extracts desired features like frequency, amplitude or variance and the analysis stage analyses them according to the changes we want to observe like maximization, constancy, or minimization (figure 3).

Each time a feature is analysed, the engine analyser improves its knowledge updating some relevant data, depending on the application. For example if I want to study the evolution of the feature on a short period I can use the first or second derivative. If I want to compare the scale of these features for different stimulus I can use the average, the minimum and the maximum value. The system is designed to use any kind of analyser "plug-in". Consequently there is no limitation concerning the analysers a user may need. Thus an important feature of the system is its flexibility : the user can write his own plug-in and give it to the engine when setting up a new experiment

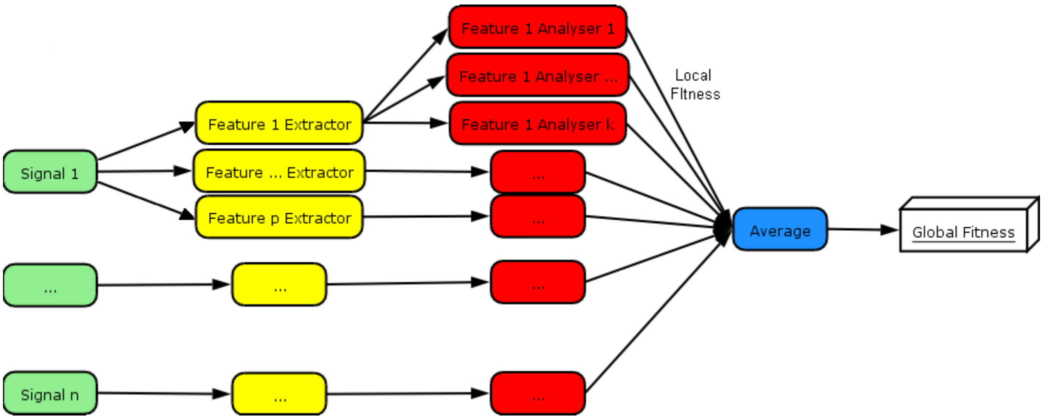

Figure 3: Engine working outline : A number n of signals are given in input, each signal is processed to extract several features from it. Then these features are analysed to give a local fitness value. Finally an average of these local fitness gives the final global fitness which is nothing else than the application event fitness.

application system.

I chose a fitness value as the reponse of the analysers, which expresses the relevance of the associated stimulus. The fitness values from all the analysers are then averaged. Using this overall fitness value, the system, using the engine, evolves itself. In this way the system learns to distinguish good stimuli from bad stimuli.

Another important abstraction of this system is that this engine is generic, thus the fitness value can be used to modulate any kind of stimulus output. I thus built a system which lies as far as possible from any specific application and thus can adapt to any one.

According to that, any experimental application has its own way of using the engine. Hence I will explain in detail the evolving process of these experiments once their principle is presented.

3 Experimentations

The first experiments I ran concerned visual perception. The subject is placed in front of a LCD screen, in a dark room, with a heart rate monitor sensor on a finger. The screen is a large 42 inch LCD screen with a 16/9 ratio, since larger screens have a stronger effect on physiological responses than smaller ones [6].

3.1 Evolving Image Displaying System

3.1.1 Presentation

The first experiments are based on displaying images, each image being a picture belonging to a set. The aim is to compare different sets of images, each set providing the same kind of pictures. Sets we used include “landscapes”, “machines”, “art”, “colours”, “food”, “people”, “plants”. We also used more physiologically arousing sets (“erotic” or “horror” images).

The subject knew as little as possible about the experiment so that the results would be unbiased. However in the case of potentially disturbing images the subject were warned prior to the experiment what the range of content is to allow him or her to give informed consent.

3.1.2 Principle

The experiment begins with a black screen displayed for a few seconds to give the subject time to relax. Then we display a sequence of “frames”, each one being displayed for a few seconds. A frame can contain several pictures, in which case the screen is divided. In the experiment descibed here, only one picture was displayed at a time. During each frame displaying time, responses are recorded within a flexible “recording window” (figure 4) allowing experimenters to focus on specific moments. Let’s say that the body response to a frame occurs one second after that frame is displayed and will be strong for a few seconds, only the relevant signal can be recorded by adjusting this window.

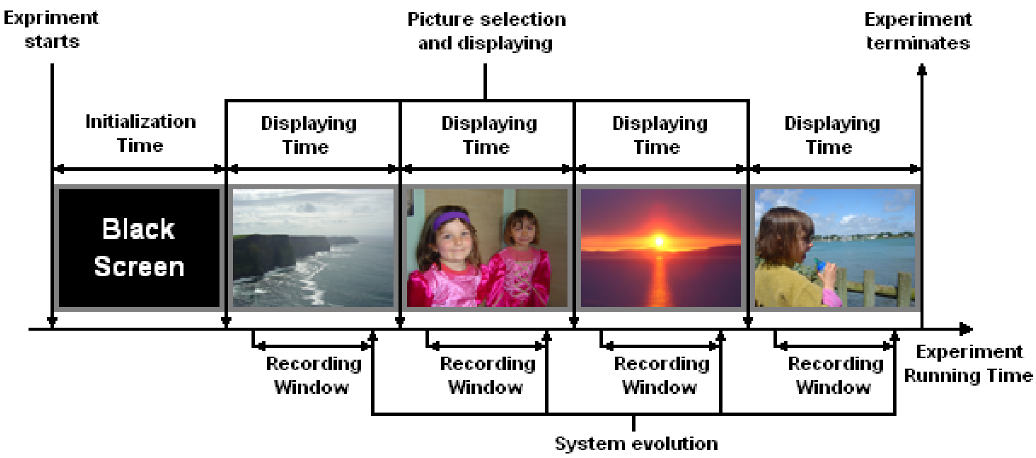

Figure 4: Evolving Image Displaying Experiment Outline

3.1.3 Implementation

The computational method used to select pictures is the "bag method". Each image set has a fitness value which determines the size of its bag, which is a fraction of an overall number set. A random number within that number set is then selected. With the affect that the bigger the bag (fraction of the number set), the more probable a particular image category will be selected (figure 5).

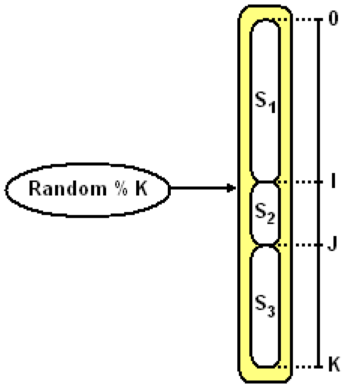

Figure 5: Bag Method on 3 sets S_1, S_2, S_3 with $P(S_1) > P(S_3) > P(S_2)$ and $P(S_1) = \frac{I}{K}, P(S_2) = \frac{J-I}{K}, P(S_3) = \frac{K-J}{K}$

At the beginning of the experiment, all sets have the same probability, but once the signal is recorded for a picture, it can be processed according to the chosen features for this specific experiment and the engine will provide a fitness value. This value will be used as a fitness change for the concerned sets, meaning it will be added to the current set's fitness value. We chose for that the range [-1; 1], "1" meaning a very strong response according to the set up, and "-1" a very strong one in the opposite direction. "0" is therefore a neutral value meaning that the response doesn't provide any relevant information. Using that information, the system can make the fitness evolve for each set of pictures, changing thus their probability to be selected (figure 6). Note that I use both terms of "fitness" and "probability" because even if the probability directly comes from the fitness, the fitness is the value the system works with (processed in the bag method). So, the notion of probability is not directly used in the system but is omnipresent through the concept of fitness.

Now, thinking about the practical experiment conditions, we must be aware at first that the measures are not perfectly precise, and then that the response on a display event can be irrelevant for some reason. The response

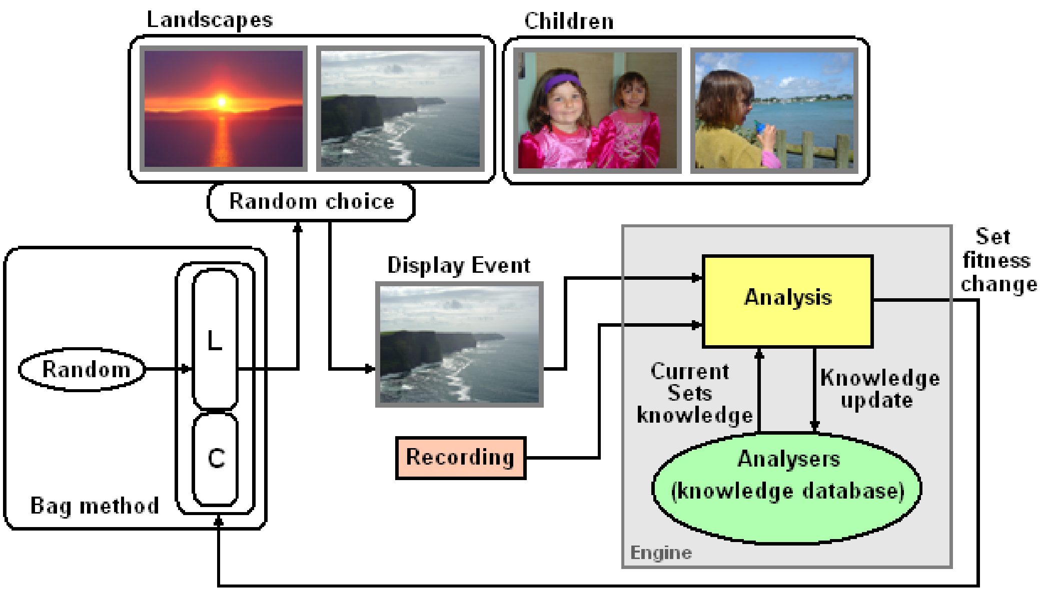

Figure 6: Evolving Image Displaying Working Principle with two sets "Landscapes" and "Children", "L" and "C" being the expression through the bag method of "Landscapes" and "Children" sets probability

given by the engine to this kind of signal can therefore be called "noise". To avoid noise causing too much perturbation in the evolving process, the returned fitness values are quite small. To change the probability of a set so that its consituent images appear more often are needed a certain number of picture-displaying events (40 or more). The more often a set is selected the more opportunities it has to prove its consistency in term of arousal. Therefore, the experiment should be long enough in duration to provide any relevant final result.

3.1.4 Example

Let's now unpack the experiment outline with an example. Consider the two sets "Landscapes" and "Children" with the aim of maximizing frequency.

Initially we start with :

Sets	Fitness	Frequency	Knowledge
Landscapes	1.0		-
Children	1.0		-

We will now follow the sequence of the figure 4 and explain how the post display analysis will process :

1. First image (landscape) : the system doesn't have any previous data for a comparison, therefore it will update the knowledge of the frequency but won't be able to give a fitness. It thus returns 0. Let's say we got 70 for the heart rate frequency. Now the state is :

Sets	**Fitness**	**Frequency Knowledge**
Landscapes	1.0	70
Children	1.0	-

2. Second image (children) : the system is now able to compare the frequency data with "Landscapes". Let's say we got a frequency of 75, the knowledge will be updated for "Children" and the system is able to say that the arousal is better on this time for "Children" than for "Landscapes" thus the fitness change will be positive (let's say 0.3). Now the state is :

Sets	**Fitness**	**Frequency Knowledge**
Landscapes	1.0	70
Children	1.3	75

3. Third image (landscapes) : Let's say we got a frequency of 72 and a fitness change in response of -0.2. We update the frequency knowledge according to the maximization therefore put 72 instead of 70. Now the state is :

Sets	**Fitness**	**Frequency Knowledge**
Landscapes	0.8	72
Children	1.3	75

4. Fourth image (children) : Let's say we got a frequency of 74 and a fitness change in response of 0.15. We update the frequency knowledge according to the maximization thus we keep 75. Now the state is :

Sets	**Fitness**	**Frequency Knowledge**
Landscapes	0.8	72
Children	1.45	75

Now if we pursue this same experiment, as the fitness of "Children" is becoming stronger than the fitness of "Landscapes", we expect "Children" pictures will be more likely selected. If the frequency differences we observed stay quite constant during the experiment, after 40 iterations the fitness values of the two sets will be very different and the frequency of "Children" pictures displaying should be significantly greater than the "Landscapes" picture.

3.1.5 Results

I will now present some results and thus show how this system contributes to artistic and neuroscience researchs.

As I explained above, a result is consistent only if the experiment is long enough. If we get a consistent result on an experiment, we can expect that if we run it again we get a quite close result. This is unfortunately not always the case. Moreover the success of an experiment can be very subject dependant. A very sensitive person will give stronger responses and is therefore a good subject.

The appendix A.1 presents the results of an experiment run twice on a same subject. This experiment involved two sets : "Animals" and "Erotic" pictures. In the first experiment, the features used were the frequency, the amplitude and the variance of the heart rate whereas in the second one only the frequency was used. In both, we looked for a maximization of these features. Looking at their evolution we can observe that in both experiment the "Erotic" set gets a stronger and stronger fitness when the "Animals" set gets a smaller and smaller one. The response provoked by "Erotic" pictures is therefore clearly stronger and consistent. From that, we can suppose that this subject is consciously or even unconsciously more sensitive to "Erotic" pictures than to "Animals" pictures. We can also make the assumption that the maximization of the frequency is a relevant measure.

Another experiment we ran on several subjects is the "Black screen" experiment. Its aim is to study the moment the arousal is provoked. We can use a set with variant and strong colours, like "Landscapes", with a grey or black screen as the other set. We assume first that the image set (like "Landscapes") will provide a subsequent stronger response than the black screen (see appendix A.2). It was the case in most of the experiments we ran, therefore this assumption seems to be reasonable. From that we can then try to setup the displaying and/or recording durations to see if the response is delayed. We can obtain that way a response delay information which can be very useful to setup properly the other experiments to get precise, accurate and relevant results.

For all the types of experiments we also got some negative results, which sometimes gave the same global response for the sets or sometimes the opposite of what we were expecting. To get a good database, running several experiments on several subjects is required since the results are not always very relevant and being aware that the results can be very subject dependant.

From the analysis of many different experiments, the artist and the neuroscientist expect to be able to extract more subtle and abstract features. Studying the results should allow both researchers and subjects to understand intuitively what a set of images consciously or unconsciously represents to the subjects and so to understand suble aspects of the nature of their “being in the world”.

3.2 Evolving Abstract Image System

3.2.1 Presentation

With the power increase of processors and graphic cards, the Human-Computer Interaction is offered more and more graphical possibilities. Complex abstract imagery can be generated in real-time providing new kind of virtual abstract animations.

In addition, the artist I am working with wished to use colour and motion only as the stimulus.

Therefore, the idea was to create a graphical system providing real-time evolving abstract imagery.

Since the two fundamental aspects of the imagery dwells in the abstraction and the evolution of the image, I had to create a constantly evolving system easily usable to generate colour motion animation sequences.

I developed in this context an artificial life based system which was then applied to colour motion.

3.2.2 Principle

I needed to create a constantly fluctuating and unpredictable system. Also, this system needed to be evolutionary, thus had to be able to change its state from the inside.

The system I chose was an “atom” system, named “Critter”. It is made of “atoms”, which are points with a mass, linked to each other by links which can behave like springs or elastics depending on the context (figure 7).

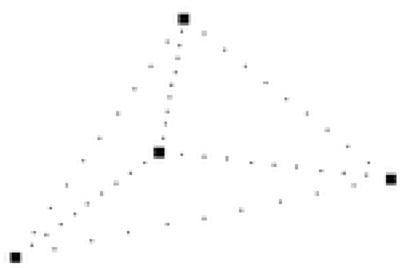

Figure 7: Critter with 4 atoms and complete linkage

This system is governed by Newtonian physics. Thus in an empty space, this system preserves its energy. The way it moves depends both on the links and on the atoms. Each link has a stable length. If the current length is smaller, the link is compressed and thus behaves like a spring, conversely if the current length is larger, the link behaves like an elastic. Therefore if a link reaches the stable length it doesn't provide any force. This link force is the only one provided by the system itself. Atoms are moved according to their mass and to these link forces. In an empty space the initial state of the links determines the quantity of energy injected in the system. Then this energy remains the same until an external interaction perturbates the state.

The second law of Newton (equation 1) is the fundamental law in this system.

$$\sum \vec{f} = m.\vec{a} \tag{1}$$

The forces applied to an atom are function of the location relatively to the neighbour's atoms, which is function of the time since it's constantly moving (equation 2).

Let's define :

$$\sum \vec{f}(\vec{L}(t)) = \vec{F}(t) \tag{2}$$

then 1 becomes :

$$\vec{F}(t) = m.\vec{a}(t)$$

$$\vec{F}(t) = m\frac{d\vec{v}(t)}{dt} \ ; \ dt \to 0$$

$$d\vec{v}(t) = \frac{1}{m}\vec{F}(t).dt \tag{3}$$

The system is evolving in a three dimensional space providing a very flexible and fluid motion from a two dimensional space projection perspective like the screen. A screenshot of the evolving system is shown in figure 8.

3.2.3 Rendering

I have explained the kind of system I was using. Now I will explain how to render an interesting evolving abstract image with it.

This system has been designed to create colour and motion changes. Since one aim of the artist is to study the influence of colours and fluid motions which resemble that of dancers, the system is designed to evolve fluently. Therefore I needed to express the system through colours with the same fluidity.

As the system evolves in a 3D-space I chose to project its motion on the 3D RGB colour space. To express the motion I am using the atoms' velocity.

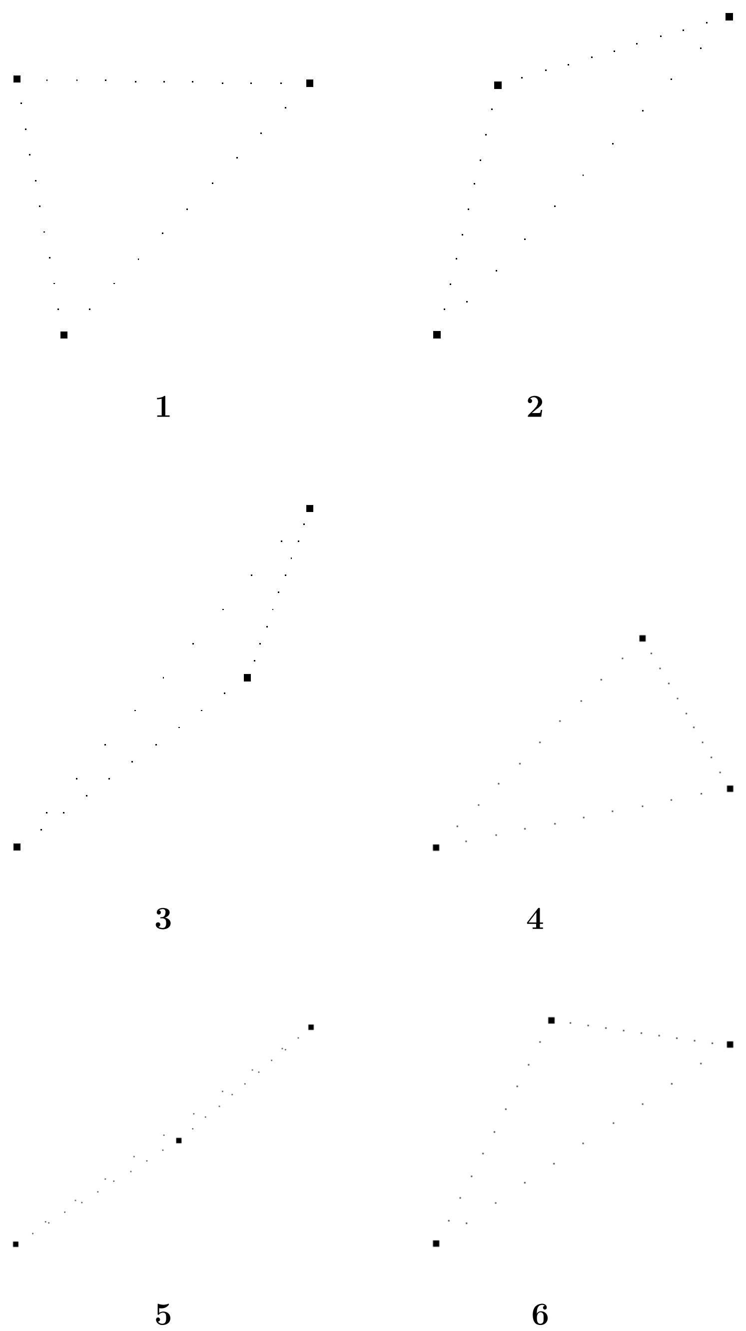

Figure 8: Three atoms critter evolving in an empty space, with z value to zero, and without any exterfal force

The velocity on an axis is projected on the matching axis in the RGB space.

Therefore though the evolving space is boundless and the RGB space is not, the use of the speed which is naturally quite bounded by the system makes a good projection feature.

The choice I made for the projection is red for the x-axis, green for the y-axis and blue for the z-axis. If the speed is positive on any axis, the colour value increases, otherwise it decreases. Note that these choices are completely arbitrary.

Now the rule to project a colour is quite simple :

Let's take C a variable in $\{$R,G,B$\}$ (representing any axis colour), for each pixel (x, y) the variation ΔC of the colour C is :

$$\Delta C_{x,y} = A_C \sum_{critter=1}^{c} \sum_{atom=1}^{a} \frac{m_{atom}.v_{atom,C}}{d_{atom,(x,y)}} - D_C \tag{4}$$

with

- A_C the change amplitude allowing small or big changes at the update,
- D_C the color decay, removing the given quantity of colour at the update,
- m_{atom} the mass of the atom,
- $v_{atom,C}$ the velocity of the atom on the axis corresponding to C,
- $d_{atom,(x,y)}$ the distance between the atom and the pixel.

It means that the change in colour for any pixel is the sum, on all the atoms from all the critters, of the mass of the atom times its velocity on the colour axis divided by its distance to the pixel. For the distance I consider the z location of the screen to be zero and thus I can compute a distance from point to point in the 3D space. The distance function used in 4 can be any type of distance. I chose the squared Euclidian distance. Firstly, Euclidian distance because I wanted a spherical distance around a pixel and secondly the squared distance to avoid the calculation of the squareroot which is quite expensive to compute.

The distance between two points is now defined as

$$d(p_1, p_2) = (p_1.x - p_2.x)^2 + (p_1.y - p_2.y)^2 + (p_1.z - p_2.z)^2 \tag{5}$$

therefore for the distance between an atom "a" and a pixel "p" equation 5 becomes

$$d(a, p) = (a.x - p.x)^2 + (a.y - p.y)^2 + a.z^2 \tag{6}$$

Note that according to equation 6 the z-axis is processed in a different way, consequently the colour on this axis is not treated equally with the others.

Setting up the amplitude and the decay can be used in the experiment system to counterbalance this effect.

A render of the critter used in figure 8 is shown on figure 9. Note that as the z-axis is set to zero there is no blue interaction.

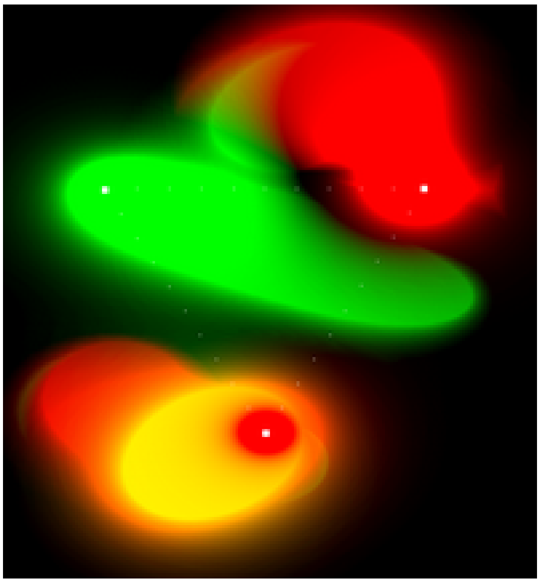

Figure 9: Critter in motion with colour rendering

A render of the critter used in figure 7 is shown on figure 10. Now you can observe the inplication of the blue.

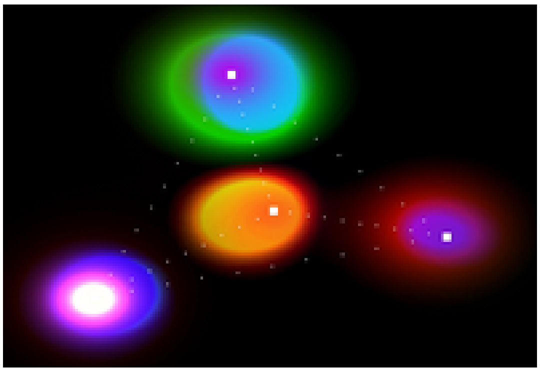

Figure 10: Critter in motion with colour rendering

3.2.4 Implementing link to the engine

Now I will explain how I linked this system to the generic engine in order to provide a new subject's experience system.

For that we need first to observe the caracteristics of the system. It is a system extending and compressing itself at the same time, each link being behaving like a spring or like an elastic. It means that each motion can be in a way reversible. Therefore it is meaningless to try to maximize a motion indefinitely.

On the other hand the subject is expected to respond to colour changes and motions, in other words to the state of the system as it evolves at a given moment, in a certain way.

Consequently it is more relevant if we get a strong response, assuming that what happened at this moment provided a strong arousal, to try to amplify this state so as to provide the same colours and motions for longer, and eventually stronger (figure 11). Recording the response at this moment allows to see if indeed the arousal is kept and even amplified. According to that correlations between the arousal of the subject and the shown abstract evolving motion shown can be extracted.

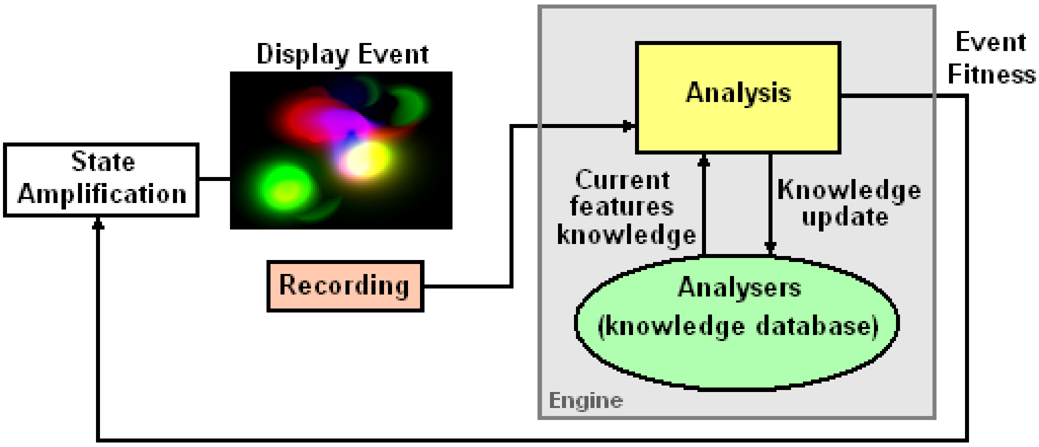

Figure 11: Evolving Abstract Image System Working Principle

Amplifying the state means to keep the fastest atoms moving and to make the static atoms quieter. To do this the speed of the fastest atoms is increased and their mass is decreased, and the speed of the slowest atoms is decreased and their mass is increased. The stronger the response is, the stronger the amplification is. Thus I get an amplification since the colour is an expression of the system's motion.

However, this type of processing introduces new forces in the system provoking its destabilization. Indeed, before, the initial energy was conserved according to the energy preservation law and thus the system was stable around its "centre of energy", but now it's no longer true since new external energy has been introduced.

The system thus needs some new forces able to help it to come back around the centre of the space (projected as the centre of the screen), otherwise a possible scenario is that the critter moves far away from the centre and the distance becomes big enough to prevent any colour change, which makes the experiment lose its sense.

Two forces are provided to resolve this :

- Friction force,
- Attraction force.

The aim of the friction force is to proportionally reduce the speed at each system update. It works in a way like air replacing the emptiness of deep space and providing resistance. This force slows the increase of the speed but doesn't stop it, it is just a way of preventing the system from expanding too much. To really make the system come back to the centre of the space the attraction force is used. For this force, the space centre works like a sun in a solar system, and the force attracts the atoms as soon as they get far from the centre, and the further they are, the stronger is the attraction.

The attraction function (see figure 12) is a function of the type :

$$Attraction(a) = A \ . \ e^{\ I \ (\ d \ (\ a, \ centre \ ) \ - \ P \ )} \tag{7}$$

where :

- a is the atom subject to the attraction force,
- A is the amplitude of the force
- $d(,)$ is the distance function
- I is the scale of distance importance
- P is the perimeter of week force

However, this force can be seen in an other way. Indeed, this force may go against the prolonging state when there is speed increase in the atoms, taking them away faster and further from the centre. In that specific case, this force can be a way to measure the strength of the response, the emotion or even the will of the subject.

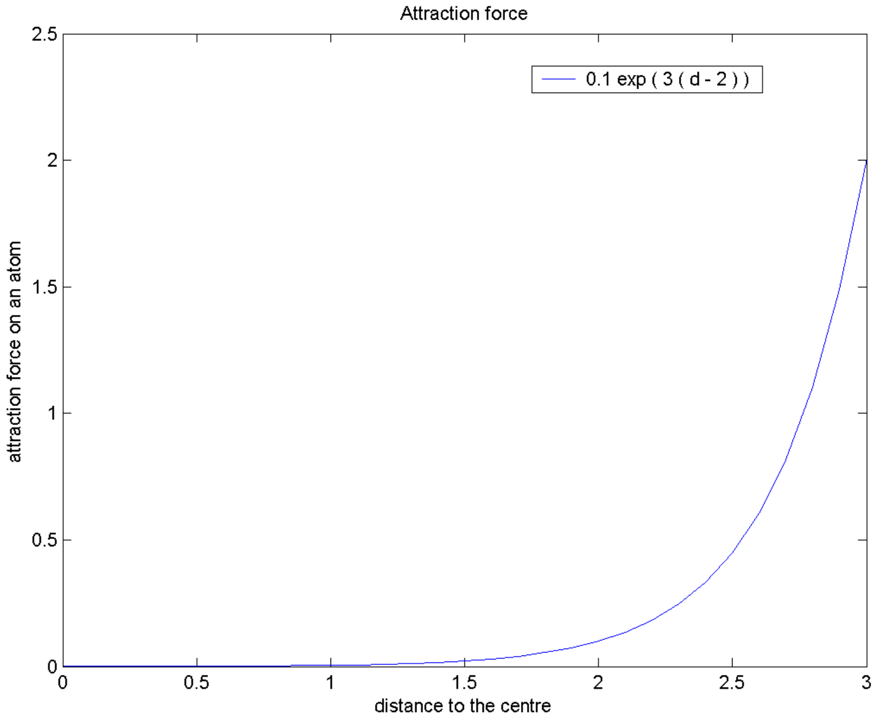

Figure 12: Attraction force example, chosen knowing that a distance of "1" is the screen border (diameter = 2) and that the speeds are computed in that scale, therefore are values very smaller than "1"

3.2.5 Interest of previous system experiments

Since this system is real-time, ideally it needs a response in real-time to evolve. It wouldn't make any sense to get a response a second later to amplify a different state from the one a second ago which provided the arousal.

For that, the usefulness of the measures done with the evolving image displaying system in the "black screen" experiment dwells in the delay which may have been measured between the image displaying time and the response time.

3.2.6 Newtonian physics

I will now come back to the physical model to explain how I used discrete time starting from the physical continuous time laws.

Indeed, I explained that the system was mostly destabilized by the evolution part therefore I need a stable model which preserves itself in an integer way if no external forces are provided. The problem I encountered was that the Newtonian laws work in continuous time but computers don't. Moreover, computing such a system with the rendering is too expensive for a computer to approach in real-time. Thus I had to deal with a reasonable discrete time.

With a time interval θ not especially stretching to zero, the equation 3 becomes :

$$\vec{v}(t+\theta) - \vec{v}(t) = \frac{1}{m}\int_t^{t+\theta} \vec{F}(\tau).d\tau$$

$$\Leftrightarrow \vec{v}(t+\theta) = \vec{v}(t) + \frac{1}{m}\int_t^{t+\theta} \vec{F}(\tau).d\tau \tag{8}$$

The problem is that is impossible to compute the integral in 8. As an approximation, I chose to use the continuous time laws, but in discrete time. I use θ as if $\theta \to 0$.

This means that instead of computing 8 I compute the approximation

$$\tilde{\vec{v}}(t+\theta) = \vec{v}(t) + \frac{1}{m}\vec{F}(t).\theta \tag{9}$$

So between 8 and 9 I make the error :

$$Err = \vec{v}(t+\theta) - \tilde{\vec{v}}(t+\theta) = \frac{1}{m}\Big[\int_t^{t+\theta} \vec{F}(\tau).d\tau - \vec{F}(t).\theta\Big] \tag{10}$$

The mass being a parameter of the evolution process I cannot use it to reduce the error.

Thus in 10 I want to minimize :

$$\Big|\int_t^{t+\theta} \vec{F}(\tau).d\tau - \vec{F}(t).\theta\Big|$$

because the law of energy preservation is broken with that error. To keep a system as stable as possible I need to strech to zero as much as possible.

This error can indeed make the system gain a lot of energy, breaking all the laws, and becoming completely unstable. This state must be avoided.

The error is varying according to :

- the time interval θ
- the forces $\vec{F}$

To get a fairly stable system, an error as small as possible is needed. Therefore,

- if the forces are small, the time interval doesn't have to be too small, but small forces won't make the system move a lot,
- if the forces are strong, the time interval has to be small, but now, even if there is motion, the computer computes it more slowly (may require a lower resolution).

Consequently, if the computer is not powerful enough to make the computing as fast as needed, a balance between the time interval and the forces is needed and must be defined according to the experiments requirements .

Conclusion

In the paper I presented the system I designed to create a prototype for an art installation studying the mind-body-environment relations. This first attempt can be improved in many ways and levels.

First, the signal processing could be improved by using more features, or the same ones in a more precise way, for instance using several main frequencies and therefore more amplitudes and variances. This would provide more subtle informations allowing to compute a more accurate fitness value.

Another future improvement could be to give more autonomy to the engine which is at the moment quite basic. A second engine generation would be to create an intelligent system, as a second layer over the first one (the first being the actual engine), able to determine by itself the accurate features and measures on them. This kind of learning and evolving system could be implemented using neural networks or genetic alorithms, their principle fitting fairly well to the idea of finding new relevant features for a specific experiment. Analysing the responses and trying to find the main evolutionary axis in the classical extractable features and even in other "unknown" features would improve the accuracy of the measures, and consequently the relevance of the experiments. Thus we would still have to set up the experiment conditions but the results would be a lot more instructive since they would present the relevant features and give their implication.

Concerning the evolving image-displaying system, an idea which would improve the response of the subject, and therefore help the computer to analyse the signal, would be to show video sequences instead of pictures. The intervention of motion and sound would give more access to the subject sensitivity thus giving stronger and especially more precise responses, assuming that the videos would provide very different experiences from one to another and would therefore provoke differientiable responses.

Concerning the evolving abstract image system, my assumption is that the heart rate may be inappropriate for that kind of experiment. The system being real-time and quickly and constantly evolving, the heart rate measure can be too slow to give a fast enough response letting the system sometimes evolve in a meaningless way. An improvement would be to be able to extract the relevant instants and thus avoid this unwanted "noise", which is due to bad syncronicity and perturbs the results.

The conditions of the experiments can also be improved. Ideally a dark room with a giant spherical screen would be the best conditions as the subject would be immersed in the stimulus. It would provide stronger responses, helping the computer to be more precise. It would also provide good conditions for an eventual eye tracking interface which can provide more precision on the relations between what is shown and the response.

To summarize, this work, even if still in a basic state, provided promising results and has many ways to be improved. The obtained results have been variously surprising, or expected, or sometimes negative. That is where the interest of the improvements dwells, as much in the system intelligence itself as in the body response measurement, and even in the starting experiments assumptions.

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A Evolving Image Displaying System Appendices

Glossary :

- **Number of frames** : Total number of frame to display
- **Frame displaying time** : Time each frame is displayed
- **Number of images per frames** : Number of image displayed at the same time in a frame
- **Initialization time** : Duration of the black screen at the beginning
- **Window delay** : Delay after the frame display before recording the input signal
- **Window duration** : Duration of the recording window

A.1 "Animals" - "Erotic" experiments

A.1.1 First experiment : Frequency & Amplitude & Variance

Number of frames	50
Frame displaying time	7
Number of images per frames	1
Initialization time	7
Window delay	0
Window duration	7

The evolution of the fitness of each set is given in figure 13.

The final result was :

Set	**Final fitness**	**Nb Occurences**	**Display Frequency**
Animals	-0.77762	22	0.44
Erotic	1.15568	28	0.56

A.1.2 Second experiment : Frequency only

Number of frames	50
Frame displaying time	7
Number of images per frames	1
Initialization time	7
Window delay	0
Window duration	7

Figure 13: Evolution of the fitness of the "Animals" - "Erotic" using frequency, amplitude and variance maximization

The evolution of the fitness of each set is given in figure 14.

The final result was :

Set	Final fitness	Nb Occurences	Display Frequency
Animals	0.223088	23	0.46
Erotic	1.59715	27	0.54

A.2 Black screen experiments

Number of frames	40
Frame displaying time	7
Number of images per frames	1
Initialization time	10
Window delay	1
Window duration	5

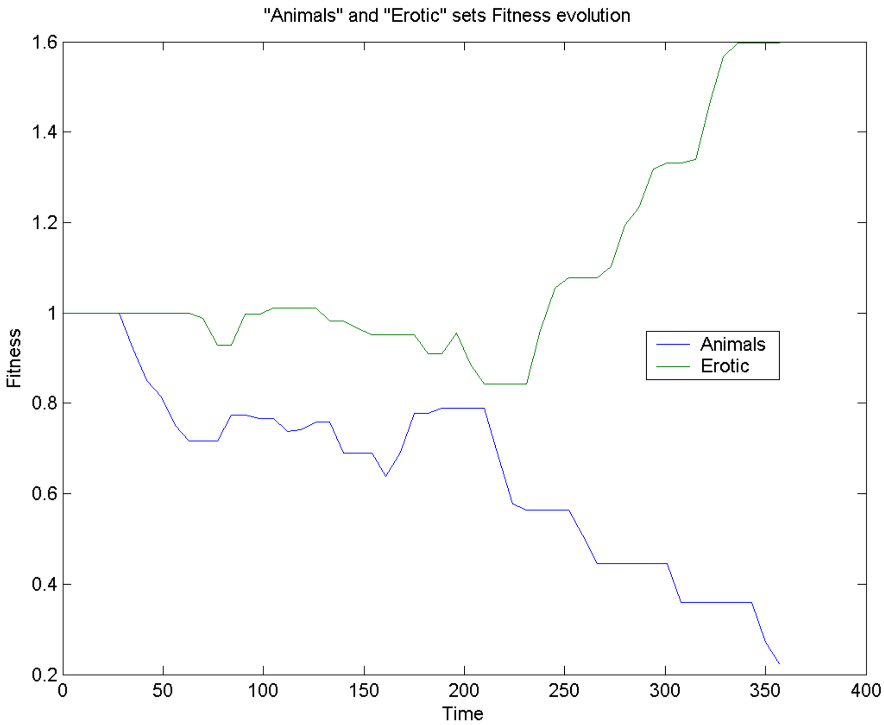

Figure 14: Evolution of the fitness of the "Animals" - "Erotic" using only frequency maximization

The evolution of the fitness of each set is given in figure 15.

The final result was :

Set	**Final fitness**	**Nb Occurences**	**Display Frequency**
Lanscapes	1.50368	28	0.7
Grey	0.231807	12	0.3

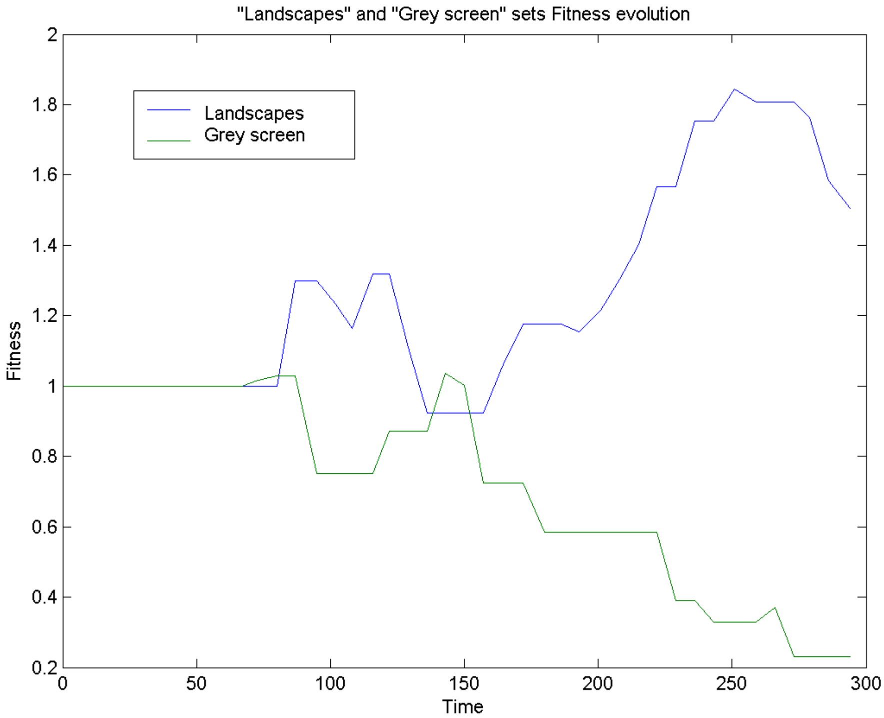

Figure 15: Evolution of the fitness of the "Landscapes" - "Grey screen" using frequency, amplitude and variance maximization