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# How learning progresses in an artificial organism

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**In this article the design and functioning of an artificial organism made on a computer is described. Besides giving a perspective on artificial life and intelligence, the organism (Colline) can be used to investigate the development of structures. A learning principle is suggested which relates the development of any organism to the concept of 'entropy' and 'exformation'. The learning principle suggested, makes it possible to interlink several scientific fields and aspects of life, thereby facilitating cross disciplinary communication.**

## Colline

Within the past 20 years or so, several new scientific fields have emerged: Organization theory, autopoietic systems, self-organizing systems, semiotics, cybernetics and more.

A common denominator for the fields is that they deal with *structures*. Structures that communicate, develop and have a certain complexity. The human mind, a company and a culture can all be seen as a complex of structures that grow, develop and die. The structures constitute an organism in its broadest sense.

The focus on structures brings along a need to investigate the development of these structures, which is difficult because:

- An objective examination is not possible since examining the structure influences the structure in some manner, maybe even kills it.
- The lifetime of the organism is often measured in years

These two difficulties would be circumvented if an artificial organism could be made and investigated using a computer. However, attempts to create an artificial organisms has so far not shown the necessary similarity to other real organisms in order to be useful. As far as we know, Colline is the first artificial organism to show enough similarity in behaviour to a real organism, in order for new insights to be achieved. By using a computer, Colline simulates an organism, which can be seen to grow, develop and possibly die, like any other organism. It can provide answers in a very concrete manner (e.g. by using computer graphics) to questions like: *What is a structure? When does it exist? How and why does a structure crystallize? What does an organism with inner tensions look like, compared to one without? What happens when a new complex of structures "take over" an existing complex of structures? How does an organism learn?*

By answering these questions and more, Colline can help investigate and refine these key concepts.

## Colline description

Colline is a computer simulation of how small "insects", referred to as *agents*, behave in a limited space, a *matrix*. The agents have seven kinds of behaviour, they can:

- **move** (randomly) in the matrix
- **observe** other agents

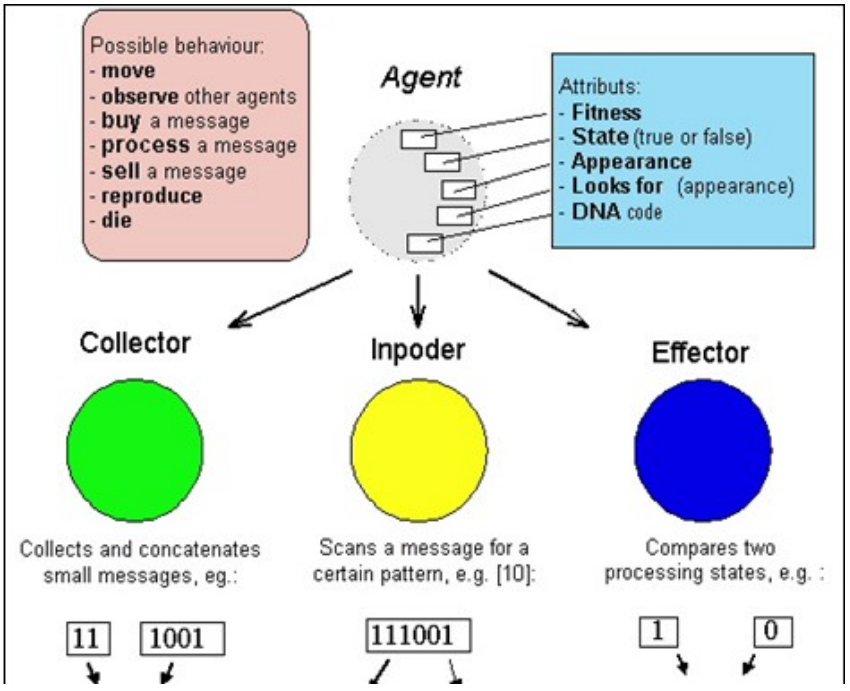
- **buy** a message using fitness points
- **process** a message
- **sell** their processed message and processing state to another agent
- **reproduce** when fitness is high
- **die** when fitness is low or maximum age is reached

A message is simply an information string (bit string). How an agent act is determined by its DNA code, which is (more or less) passed on to its offspring.

Three types of information processing occurs in the system:

1. Small messages are **concatenated** to a larger message
2. A message is **scanned** for a certain pattern and deleted if found (“eaten”)
3. Two processing states from other agents are **compared**

which gives rise to three types of agents: Collectors, inpoders and effectors. The description is summarized in the following figure:



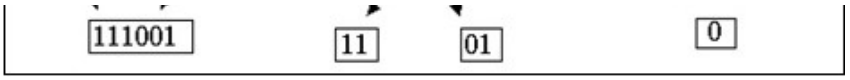



**Figure 1: Description of the three types of agents**

In short the collectors can be said to collect the information, the inpoders process the information and the effectors delivers the system response. A possible task for the system could be to recognize whether the input is a flower or not:

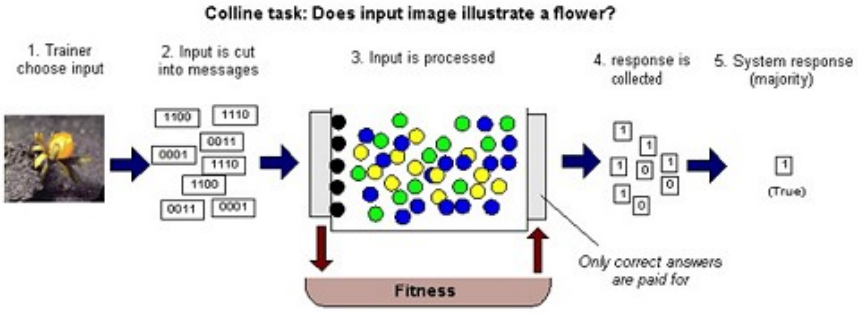



**Figure 2: The functionality of Colline. The flow of messages (data) in the system goes from left to right, whereas the fitness points (energy) paid for the messages, flows from right to left.**

The initial hypothesis behind the system is that there exist some colony of agents interacting in a certain way that will be able to solve the task. So how is this combination of agents found? … and maybe more interesting: *Is there a general method for finding this combination that can also be applied to other learning organisations or organisms?*

## Focus on structures

Before we look at the learning process for Colline, we must emphasize that our focus is now on *structures* not the agents used to manifest the structures. When an agent buys a message from another agent this is a *transaction* and represents a structure. If the agents are not able to reproduce this structure will only exist in a glimpse. On the other hand if the agents do reproduce the same type of buying and selling (transactions) will occur again and again, representing a more stable structure. By giving each type of transaction its own color, the development of the structures can be monitored on the user interface for Colline. For further focus on the transactions the individual agents can also be made invisible.

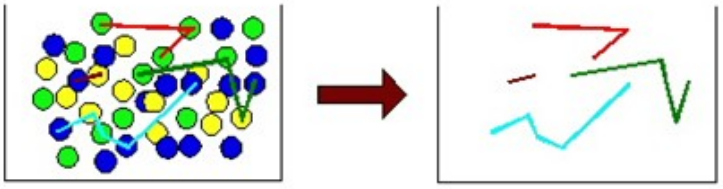


**Figure 3: By making the agents invisible, the focus shifts to structures**

Different methods can be applied when choosing how to draw the structures. In general a transaction between two agents should only be plotted if it occurs a certain number of times (*N*) in a given period of time, otherwise it is too volatile to be categorized as a 'structure'. Also the structure must be located in a certain part of the matrix. The period of time in which to count the transactions, and the size of the neighbourhood in the matrix where they must occur are fixed to some values depending on the type of system (size of the matrix, total number of agents, computer speed, etc.). Once these values are fixed the system operator can change the value *N* and thereby view the structure behaviour from different aspects. The value of *N* determines in which "resolution" the structures are viewed. If, for example, *N*=10 times, only structures that are more stable will be visible, compared to a resolution where 2 similar transaction (*N*=2) are enough for the transaction to be plotted. In the latter many more structures will be plotted since they do not have to be very persistent. We will label a view where only stable structures are drawn "*Low frequency view*" and a view where also volatile structures are drawn "*High frequency view*". In figures we will

assume that the view is low frequency if nothing else is mentioned.

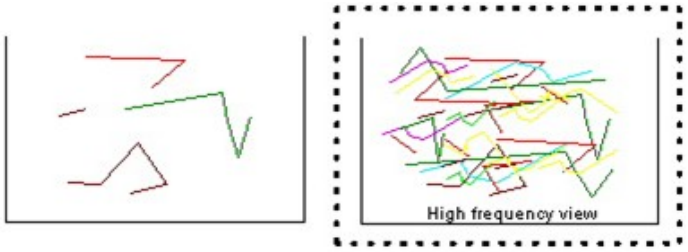



**Figure 4: Example of low and high frequency view of the same agent colony.**

A possible perspective is to see the (infinite) number of possible structures in relation to the agent colony as a *cooperation* between the two. A cooperation where the agent colony provides the constraints necessary for the manifestation of the structures. These constraints [[1]] can be steered by the trainer and thereby influence the manifested structures.

## Learning process

The training of the system starts with the trainer making a hypothesis: *A structure exists, that will be able to solve the task better than a random state.*

The objective for the trainer is now to make some structure crystalize. In a crystalized structure the underlying agents do not change, i.e. the offspring are identical to the parents. This first part of the training process can be divided into four stages:

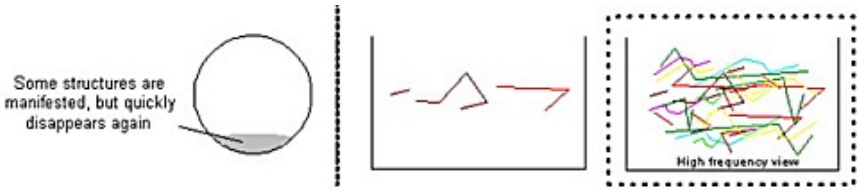
### Stage 1

When the system starts up a number of agents are born with a completely random DNA. This means that the structures that manifests will be chosen randomly from the (almost) infinite number of possible structures. This stage is illustrated with a circle. The circle is empty because structures are only manifested in a glimpse and then disappear: Observed over time no structures are manifested.


Note that at this stage, the system response is completely random, which means that the chance that the system will give the correct answer (yes or no) is exactly 50%.

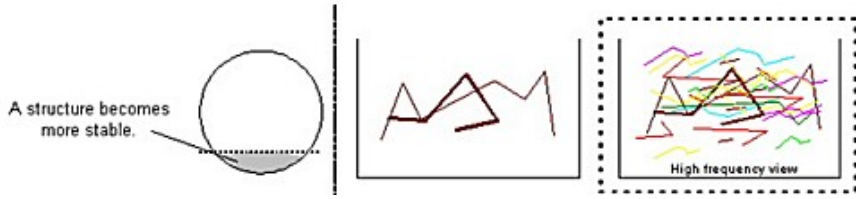
### Stage 2

Because the trainer only pay fitness to the structures that give the correct answer, some structures will start to become more stable. From another perspective some agents have, by chance, passed on their DNA code to later generations, thereby increasing the possibility for certain structures. The structures that thereby manifests are still very fragile and will easily dissolve and be replaced by others. This stage is illustrated by shading a part of the circle, the shaded part represent that some structures are manifested in a short period of time and then dissolves again.



### Stage 3

In stage 3 a certain structure starts to freeze. The agent colony is no longer as mutable as it was in stage 2: Certain types of agents are now beginning to dominate. The freezing is illustrated by a dashed line, separating the freezing structure from the "raincloud of possibilities".




### Stage 4

In stage 4 the freezing structure at stage 3, has now frozen. The agents used to manifest the structure do not change, i.e. the offspring are identical to the parents.


At stage 4 the first part of the training process has been achieved: A structure has crystalized which solves the processing task to some extent. Say it gives the correct answer in 60 out of 100 training sessions, a performance of 60%.

### Part II of the training process: Stage 4 to 7

The trainer now change focus from low to high frequency view, and thereby notice a chaotic swarm of structures also present in the matrix. The chaotic swarm is a left-over from stage 1 where all agents had a random DNA code. He notice that the performance of the chaotic swarm is very stable and unshakable (always 50%), whereas the crystalized structure is much more sensitive towards sudden variations in the input. Using an analogy, the chaotic swarm has the strength of foam rubber, whereas the crystalized structure has the strength (and weakness) of glass. It is also very apparent that the organism is divided at this stage: A division between one structure which is persistent over time and a chaotic bunch of structures that are not. And a division between total control in the crystalized structure versus total chaos in the chaotic swarm. The crystalized structure has a higher performance than the chaotic swarm (60% vs. 50%) but the price for this knowledge is a shift from a smooth and unshakable behaviour to a more tense and fragile behaviour.

The trainer now makes the hypothesis that a synthesis exists between these two extremes; a synthesis where the "volatile stability" of the chaotic swarm is preserved, but with a better performance. We will label the synthesis *complex swarm*:

| *Thesis* **Chaotic swarm** | *Antithesis* **Crystalized structure** | *Synthesis* **Complex swarm** |
|---|---|---|
| All structures are possible | One structure is possible | Some structures are *not* possible (all others are) |
| Structures are not persistent over time | One structure is persistent over time | Structures has a short persistency in time |
| Total chaos | Total control | Balance between chaos and control (selected autonomy or purged chaos) |

To make the complex swarm manifest in the matrix, the trainer decides to separate the chaotic swarm from the crystalized structure. This is done by keeping a persistency-table of the structures that manifests. The persistency-table is simply a registration of how persistent in time a structure is and is used to look up the persistency in time when a transaction occurs. If the persistency of the involved structure is low, a tendency to drift upwards in the matrix is added to the involved agents, and if the persistency of the structure is high a tendency to sink down is added to the two agents. This will cause the chaotic swarm to drift towards the top and the crystalized structure to sink towards the bottom of the matrix. An empty void is thereby created in between, where the desired complex swarm can be born.

In the chaotic swarm at the top the transactions that occur do not repeat themselves (if they do they will sink down), which means that the structures are only manifested in a glimpse. In the crystalized structure the involved structures are persistent over time (if they are not they will drift upwards). Since the complex swarm is neither totally chaotic nor totally ordered, it must necessarily manifest between these two extremes, i.e. in the middle area of the matrix. To encourage the complex swarm to manifest the trainer decides to pay more fitness to structures that manifests in this area. By adding the gravity factor and changing the fitness award this way, a “purication process” of the manifested structures begins: Only swarms where a bunch of structures cooperate will be able to keep “floating” in the high-rewarding middle area, all others will either drift up or sink down.

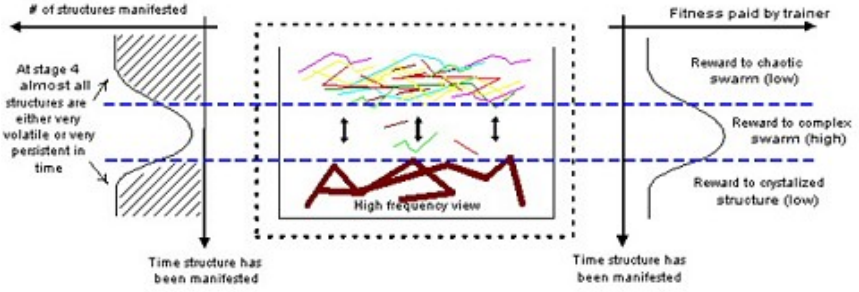
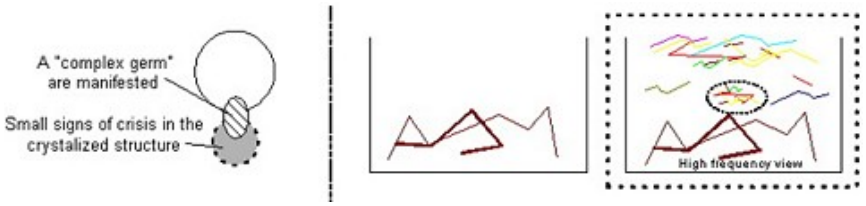



**Figure 5: By adding a gravity factor, the structures are separated according to their persistency in time. This makes it possible to encourage swarms of cooperating structures, because their location in the matrix are known.**

## Stage 5

To create the germ for the complex swarm, the trainer increases the mutation rate for the

agents. In this way mutated agents will be born in the lower area of the matrix, where otherwise only one type of agents are born. The structures that are manifested through this new mutated group of agents, will start to drift upwards since they are not persistent over time (yet). Many prospects will drift all the way up and be swallowed by the chaotic swarm above, and others will crystalize and sink down only to be choked or integrated by the omnipresent dominating structure below. But eventually (depending on the computer speed) a few structures will find a balance between chaos and control and be able to stay afloat in the middle area. These cooperating structures are the “germ” for the complex swarm.




Small signs of crisis might occur in the dominating structure because of the increased mutation rate and partly because fitness that were previously directed to this structure are now directed to structures that organize themselves around the new germ.

Figure 6 below illustrates how various structures are selected for manifestation (via the mutated agent colony) and the three possible results of the manifestation: Absorption by the chaotic swarm (1), choked by the crystalized structure (3) or they organize themselves as a complex swarm (2). The red arrows illustrates the effect of the graduated fitness award as described on figure 5.

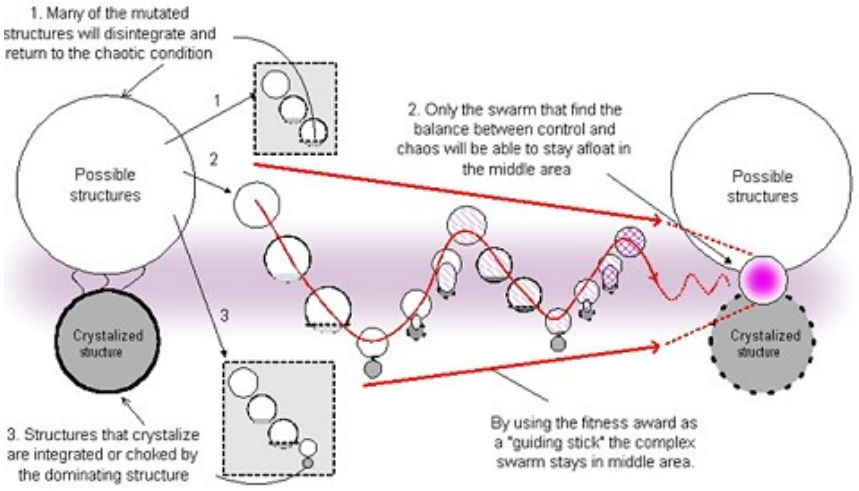
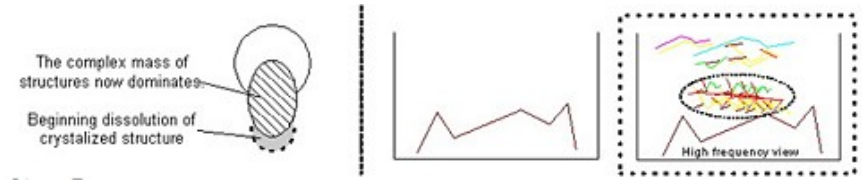



**Figure 6: Illustration of the leap from stage 4 to 5. The leap is somewhat paradoxial, in that the development is self-referential. Further details of the leap can be seen on figure 5 and 8.**

## Stage 6

If the germ in stage 5 do not incorporate new structures as it grows the gravity of the swarm will increase causing it to sink down only to be choked by the dominating structure. Only

germs that are able to incorporate new structures in the organisation as they grow will be able to maintain their gravity and keep the middle area position. Only such a germ is a true germ for a complex swarm and it will quickly grow because of the higher fitness reward it receives from the trainer.




## Stage 7

This process will lead to the extinction of any swarm not taking part in the complex swarm. Fitness that were previously tied to the crystalized structure are now released and instead used by the complex swarm. At first glance the behaviour of the swarm seems identical to the behaviour of the chaotic swarm at stage 1, however, due to the organization of the agent colony, certain structures are not possible at this stage, wherefor it deserves the name *complex swarm*.


The training process described above can also be illustrated by figure 7 and 8:

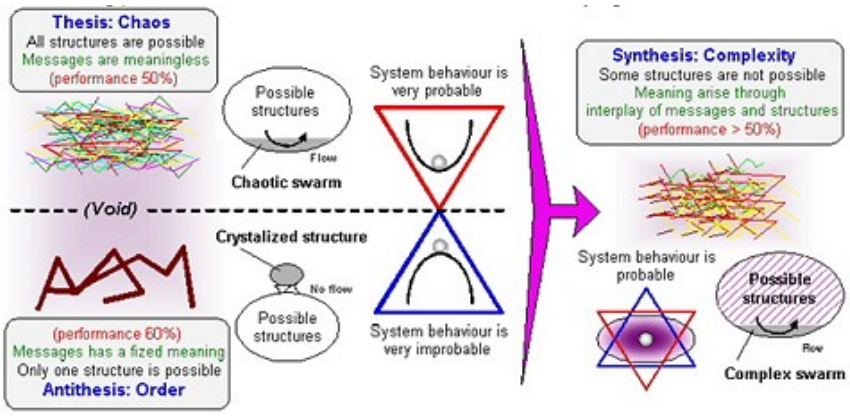



**Figure 7: The figure illustrates the chaotic swarm and the crystalized structure in relation to their synthesis: The complex swarm of structures.**

Since the complex swarm is a synthesis between a swarm with a performance of 50% and a swarm with a performance of 60% we expect that the performance will be somewhere between 50% and 60% [[2]]. Under this assumption the artificial organism has now absorbed a knowledge that was not present in stage 1, and – significantly – the knowledge is incorporated without the domination of some structures, rather some of the potential structures has been made impossible (purged out). The training process can now be repeated with this more intelligent swarm. Only this time the trainer can choose to avoid total crystalization and instead extract a swarm where a few structures cooperate. This extracted swarm serves as the antithesis to the original complex swarm and a new synthesis can be born following the same principle.

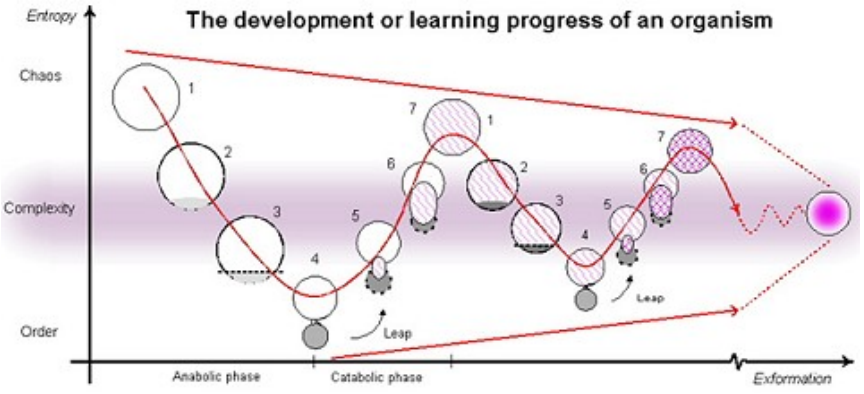



**Figure 8:In the anabolic phase of the learning progress one or more structures are selected for manifestation in time. This structure serves as the "stepstone" or catalyser for a more complex swarm in the catabolic phase. Note that the leap from stage 4 to 5 is itself characterized by the principle (see fig. 6), i.e. the progress is fractal.**

The training of the systems then interchange between a focus on crystalization (anabolic phase) and a focus on giving birth to a more complex swarm with the crystalized swarm serving as the catalyser or the necessary stepstone to take the leap to the complex swarm (catabolic phase).

The organism carries more and more exformation [[3]] as the learning progresses. In the crystalized structure the structure itself is implied in every transaction that occurs. The structure is the necessary background to make the messages meaningful. Unlike the

structure is the necessary background to make the messages meaningful. Unlike the messages in the chaotic swarm they carry information. As the crystalized structure dissolves and are replaced by the complex swarm, the information value in the messages is replaced more and more by exformation value: The messages become meaningful because of the structures they triggers to manifestation, which depends less and less on the 0's and 1's in the message and more and more on the organization (and history) of the swarm as a whole. In this way the system processing in the crystalized structure is information processing, whereas it is exformation processing in the complex swarm. The shift from the anabolic to the catabolic phase is therefore also a shift from a focus on information to a focus on exformation. On the way down to stage 4 the organism is focused on the environment (extroverted), and on the way up to stage 1/7 it is focused on its internal operating and organization (introverted). This means that at stage 4, the organism is more sensitive to what input it receives from the environment compared to stage 1/7 where it is more insensitive (at the chaotic beginning it is completely insensitive). These two extremes are brought closer and closer together as the learning progresses until the internal and external focus are perfectly balanced as illustrated on figure 8. The focus in the balancing point can be described with the psychological term "centroverted".

### Cross disciplinary aspects

The learning progress as described above and illustrated on figure 8, can also be applied to other scenarios where learning occurs. We will give a few examples.

#### Learning in general

The learning progress can be applied when a person learns something, e.g. learns how to make a speech, ride a bicycle, juggle, paint, knit, etc.. We will use the example with riding a bicycle. To learn it the person concentrates on learning the basics of riding a bicycle: Keeping the balance, not steering into obstacles, pedaling etc. Once these basics are learned the person is at stage 4 in the learning progress. At stage 4 the person can ride the bicycle but it is done in a restrained and uneasy manner because the focus is on the knowledge complex (*is the balance ok?... don't hit tree... remember to pedal,* etc.). In stage 4 to 7 the knowledge complex are integrated. The person let go of the focus on the knowledge complex and allows the knowledge to be absorbed or incorporated. The criticial issue is how long time the person should hold a firm grip on the knowledge complex: If the grip is loosened too early the crystalized knowledge complex will simply dissolve and the person will loose (forget) the knowledge. On the other hand if the knowledge complex is kept in focus too long, much time will be wasted by riding the bicycle in a tense and uneasy manner and maybe (in the worstcase) so much energy (consciousness) are directed to the knowledge complex that it becomes neurotic – the learning progress gets stuck at stage 4.

#### Science

Science, as an organization of knowledge and principles used to gain new insights, also develops according to the learning principle. The development from stage 1 to 4 describes how science in the western world started to take form: Certain methods and conventions became generally accepted, and basic natural laws were discovered. Science were, and to a certain extent still is, extroverted and focused on the environment. The 'information overload' that science deals with today, is one of the (crisis) signs that it is about to change to the phase towards stage 7. Following the learning progress, science is changing from a focus on information to a focus on exformation, from being extroverted to being introverted. An introverted science means that it deals with its own internal organization and structures. This phase is necessary before it once again can turn its focus on the environment. The transition has been ushered in by philosophers and intuitive scientists within various fields. It seems that the transitions will not be a new direction for science as a whole, rather an offspring of the traditional science will shoot out, like a rescue vessel build inside Titanic, and take the direction towards stage 7. In the analogy, Titanic is the part of science that is stuck at stage 4: The part of science that has crystalized with concepts and natural laws 'carved in stone'.

#### Psychology

The development of the individual consciousness follows the same pattern. Roughly the stages 1 to 4 corresponds to the consciousness of a baby, child, teenager and adult. It is

the progressive development of the personality, which is directly linked to deeper and deeper initiations into the realm of language. At stage 3 (teenager) the complex known as 'personality' has begun to take form. This is the 'steering tool' or vessel used by the individual to navigate in society, and leads to the extroverted adult who identifies with the personality. When the individual becomes introverted to some extent this marks the beginning of the process where a more complex vessel for consciousness are born. To nurture this germ the person must let go of the firm grip on the personality, i.e. stop identifying with it. The individual learns the blessings of self irony and solitude. As long as the rewards and punishment from the surroundings are important the person are held at stage 4, only when the person through an inner decision starts to reward and punish thoughts and behaviour in an alternative way, can the journey towards stage 7 begin. Like when learning how to ride a bicycle the critical issue is for how long the person should stick with the personality or knowledge complex that have been build since childhood. If the

person lets go too early there exists no alternative vessel for the consciousness and the person will not be able to function in society. On the other hand if the person identifies with the personality complex for too long (maybe because of an unwillingness to let go of habits) a neurotic personality is the inevitable outcome – the person is stuck at stage 4 (or is blessed with a nervous breakdown).

**Sociology**

When parents and society raise children, they use their influence to teach the children how to behave in relation to other persons. They reward the child when it behaves in a civilized manner, according to the norms and traditions in the culture. At some point the child has grown up (stage 4) and is ready to make its own unique contribution, which, since it is unique, necessarily deviates from the norms and traditions. The individual makes an inner shift in its own reward system (conscience or inner feeling of 'what is right'): Instead of rewarding the more or less crystalized structure (stage 4) it rewards unique contributions, spontanity and norm deviating behaviour in general (cf. figure 5). The social system today produces gear wheels for the social machine: It is specialized in bringing the individual to stage 4. It does not contain the sufficient complexity to handle individuals who make unique contributions. This difference between the reward system used by the individual and the one used by the social system, creates a tension: When the individual behaves according to the social norm he "dries up inside" and when the individual instead choose to follow her heart, the reaction from the surroundings range from paying no attention to condemnation. The family, the organization and the education system are in general not geared to handle behaviour that deviates from traditional behaviour, which means that new social behaviour, progress and new ideas have (sofar) been brought forth in sheer defiance of the straitjacket offered by the surrounding society. Ironically this defying behaviour, which is often described as being blissful and filled with life, are often 'rewarded' with the death penalty in many countries. The crisis we witness in the world today could very well be the birth pangs for a more complex social system (stage 5), which can handle creativity from the individual in a wiser way.

**Communication**

The cross disciplinary aspects of the learning principle, as described above, are based on the following four hypotheses:

- The learning principle can be applied to *all* organisms.
- *Everything* that exists or happens in the universe is part of some organism.
- Every organism is a suborganism of a larger one.
- The superorganism of which mankind is a suborganism is about to change from stage 4 to 5.

These hypotheses might or might not be true, the interesting thing is, in our opinion, that by assuming them to be true, *a new unifying light can be shed on the efforts made by all men and women, who endeavor to understand the meaning of our existence*.

The approach that these men and women have taken can roughly be divided into three archetypes: The scientist, the poet and the religious, giving rise to three paths towards

understanding: Science, the humanities and religion, which together embraces the human effort to understand the meaning of existence. Traditionally these three fields have had difficulties in understanding each other: The scientist views the poet as a dreaming idealist and how can the religious believe in something of which there is no proof? The poet think of science as cold and heartless and therefor turns away from it, and how can anyone set some god higher than the love of the one and only? The religious cannot believe that anything of lasting value can be found through scientific investigation of our fallen world and the poet is merely a lost soul who wanders in darkness.

The division becomes apparent through the type of language used. The language of the scientists are traditionally based on logic and rationality, the language of writers and poets are based on feelings such as love, bravery and honour, and the religious use language based on a common faith. If the three groups are to communicate a language with a common base would be very helpful, if not vital. A base where logic, feelings and faith meets and create a synthesis: The aesthetic base. The languages based on logic, feelings and faith has brought forth and shaped the world we see today. A world where humanity has learned many lessons, but also a world characterized by separation, disunion and strife. What will a language based on their synthesis bring forth? It is our hope that the ideas presented here will serve as a help in shaping this new and still fragile language.

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{{1}} The constraints are the interaction rules for the agents: How complex is the appearance of agents? At what distance in the matrix can a transaction occur? What are the reproduction rules for the agents (cross-over, cloning, mutation)? etc..

{{2}} In the current implementation of Colline, a complex swarm have not yet been manifested. One reason is that the training tasks have been too simple (due to lack of computer power) to invoke a complex swarm for their solution. Also the separation of structures according to their persistency in time has not yet been implemented. It is our conviction that, since the possibility for the complex swarm exists, it will also manifest itself when the right constrains are provided.

{{3}} Exformation is the amount of implied information in a message. It is the body of information that has been thrown away and now serves as a common background for the communication.

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**Further background material as well as the software code for Colline (version 1) can be downloaded at http://colline.dk/**