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Predation and generation processes through a new representation of the cusp catastrophe

Ph. Lacorre

Laboratoire des Fluorures, URA CNRS 449, Faculté des Sciences
Université du Maine, Avenue Olivier-Messiaen, 72017 Le Mans Cedex, FRANCE

ABSTRACT

A new formulation of the cusp catastrophe is used to model the fundamental biological functions of predation and reproduction. This new representation lies on the decomposition of the overall cusp potential in two component potentials individualising the conflicting pregnancies. It results in a more accurate and less problematic description than the original proposition by R. Thom, mostly due to the use of parameters with strong physical and evocative power. For instance, it gives a very suggestive account for such biologically significant processes as digestion and assimilation, or pregnancy and delivery. Two couples of parameters are used in the new representation of the cusp: one defines the exact shape of the conflicting attractors which symbolises genetic coding, the other controls the deformation of -and interaction between- the two attractors and represent hormonal effects. This new description strikingly echoes Heidegger's philosophical thought on ontological difference, by giving a representation of the distinct concepts of *entity* and *Being*. It thus precludes a previous criticism concerning the impossibility for catastrophic models to depict the *entity* level. Such a type of representation might be useful in translating syntactical-semantic models of catastrophe theory into computer language.

Introduction

In a previous article (Lacorre [1996]), the conflict between two single-well, single-variable, convex potentials has been studied through its effect on the stability of a system submitted to these potentials. Depending on the sign of the potential's third derivative, conflict generates either stability or instability, but it is always solved smoothly. The introduction of a concave segment in the otherwise convex potentials qualitatively changes the behaviour by generating discontinuities and bifurcations.

Such behaviour is reminiscent of what happens in catastrophe theory. As a matter of fact, it was shown in (Lacorre [1996]) that it is possible to define a new representation of the cusp catastrophe by using a new parameter set describing the conflict between two single-well potentials. This new set of control parameters, consisting in the relative strength and distance between individualised attractors, has a more physical significance than the original and purely mathematical control set of catastrophe theory. For this reason, it was anticipated that the new representation of the cusp has more evocative power, which could be of interest for some application of this catastrophe. The aim of this article is to give an illustration of the usefulness of such a representation by considering applications borrowed from biological sciences, concerning the vital functions of predation and reproduction. The core of this paper will be divided into five sections. In the first one, Thom's interpretation of animal psychism and his description of the predation loop within the cusp catastrophe model will be recalled. In section II, a new model for the predation loop will be presented, which takes advantage of the new representation of the cusp. The third section will be devoted to another illustration of the same model, applied to the reproduction loop. An application of the model to linguistics will be presented in section V. In the last main section, more philosophical questions will be tackled, and we will see how the new representation of the cusp can be used to give account of Heidegger's ontological difference within the scope of catastrophe theory.

I - René Thom's predation loop

Predation is an important biological function since it permits the survival of the predator by restoring its energy. It is ruled by the conflict between two individual animals, the predator and the prey, whose interaction end up by a fundamental singularity, the capture and ingestion of the prey by the predator. For this reason, R. Thom attempted to describe it by using catastrophe theory, more particularly the cusp catastrophe which seems best suited.

Although any description of animal psychism is conjectural, Thom advanced that animal consciousness could be described as a local map of the environment, which contains the images of the organism itself, and for which senses provide forms of the biologically significant animals such as preys, predators and mates (Thom [1983]). Such forms, which trigger important hormonal and behavioural changes are called "pregnant" by Thom, and the associated quality is "pregnance". Thom wonders whether (Thom [1981]) the source forms of pregnancies could be genetically coded. He argues that it seems difficult to understand how a visual, geometrical shape could be biochemically coded, but a biochemical coding of pregnancy gradients is more easily conceivable, leading to a distortion of the environment map. Thom regards pregnancies as "black holes" within the individual's local maps, representing the subject's self and the other biologically significant organisms. Such maps can conveniently be modelled by the use of potential functions, with the interaction of pregnancies being described by catastrophe theory. For instance, the double-well potential in figure 1 represents the interaction

between the predator and its prey in the predator's local map of predation. The bimodal process of predation is well described by the cusp catastrophe. The cyclic character of this fundamental biological function is represented by a closed loop within the control plane (u, v), centred on origin O , which has been called by Thom "predation loop" (Thom [1972], p.294). The potential distortion along the loop represents the interrelation between the predator and prey during the predation. Abrupt, catastrophic changes such as the capture of the prey, occur when the trajectory crosses the cusp bifurcation set and one of the minima disappears. The whole process (Thom [1986]) is described as follows (see figure 1):

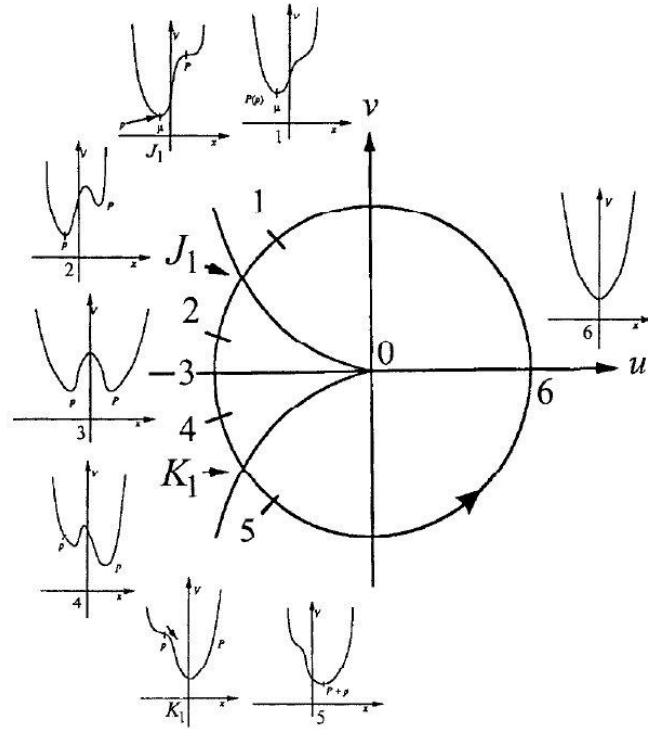


Fig. 1 : Catastrophic theoretical model of the predation loop according to Thom (adapted from [Thom, 1990] pp.223-224). The crossing of the cusp bifurcation set by the circular trajectory corresponds to the perception (J_1) and capture (K_1) catastrophe. See text for more details.

At point **1**, the single minimum represents the famished predator (P), alienated by the prey image. At J_1 (perception catastrophe) the predator (P) meets its prey (p) associated with the emergence of a new minimum. Then, the prey (p) drives the predator out of the global minimum it used to occupy toward the other, metastable minimum. The remaining two-minima sequence (**2-3-4**) represents the chase of the prey, which ends up with the capture of the prey by the predator (K_1 , capture catastrophe) where the prey's minimum disappears. At **5** the predator, after having swallowed the prey, is in the digestion phase. The semicircle $u > 0$ corresponds to the sleeping period, during which the predator (**6**, single minimum) passes from satiety to hunger.

The previous description poses two problems:

1) One wonders why the predator, alienated by the prey image, occupies the minimum of the prey, before being driven out by the prey during the perception catastrophe (J_1). Thom himself considers such a situation as paradoxical, and has made attempts to solve the problem in several different ways. For instance he argued that the alienated predator actually considers itself as prey (Thom [1972], p.299). He also proposed a tunnelling effect (Thom [1988], pp.81-86) or a double cusp (Thom [1988], pp.72-73). None of these explanations seems to be really convincing, even to Thom himself (Thom [1994]).

2) The second problem is more subtle, and representative of the ambiguities originating in a purely mathematical representation of catastrophe theory. It concerns a difficulty in the interpretation of the crossing of the bifurcation set. In a remarkable article on catastrophe theory applied to linguistics (Thom [1970]), Thom describes action verbs as trajectories in the control plane of catastrophes, while subject and objects in the sentence are the potential attractors, represented by its minima. For instance, the two main sections of the cusp catastrophe at $u=cs$ and $v=cs$ correspond to the archetypal morphologies of verbs **[TO BECOME]** and **[TO CAPTURE]**, respectively. In subsequent papers however, such as those referring to the predation loop, only the signification **[TO CAPTURE]** is kept whatever the section. The confusion is probably due to the strong similarity between the potential shapes along both main sections, as can be seen in figure 2.

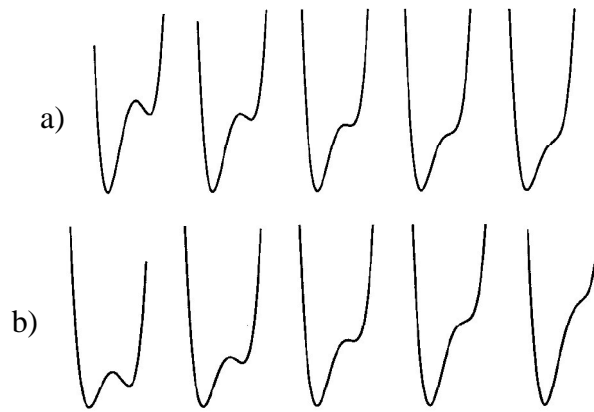


Fig. 2 : Potential distortion while crossing the cusp bifurcation set by increasing u at $v = cs$ (a) and by increasing v at $u = cs$ (b).

In the next section, it will be shown how the new representation of the cusp introduced in (Lacorre [1996]) permits a new description of the predation loop, which clears up the two difficulties above mentioned.

II - Proposition for a new representation of the predation cycle

II.1 - New formulation of the cusp

First it is necessary to come back to the new formulation of the cusp proposed in (Lacorre [1996]). It has been shown in this paper that it is possible to decompose the cusp potential $x^4 + ux^2 + vx$ in the summation of two contributions, each of them being a single-well potential. The characteristics of these potentials lie in the presence of a concave segment in the otherwise convex well. The exact shape of the two conflicting potentials is defined by the coordinates $(\alpha, \pm\beta)$ of their representative points in the control plane (u, v) . Two new control parameters a and c are defined as the relative strength of the two individual attractors (a) and the distance between them (c). They are related to the traditional control parameters (u, v) . by the following relationships:

$$u = \frac{3}{2}(1 - a^2)(2m(\alpha, \beta) - c)^2 + \alpha$$

$$v = ((1 - a^2)(2m(\alpha, \beta) - c)^3 + \beta)a ,$$

with $m(\alpha, \beta)$ a real such that $4m^3 + 2\alpha m - \beta = 0$.

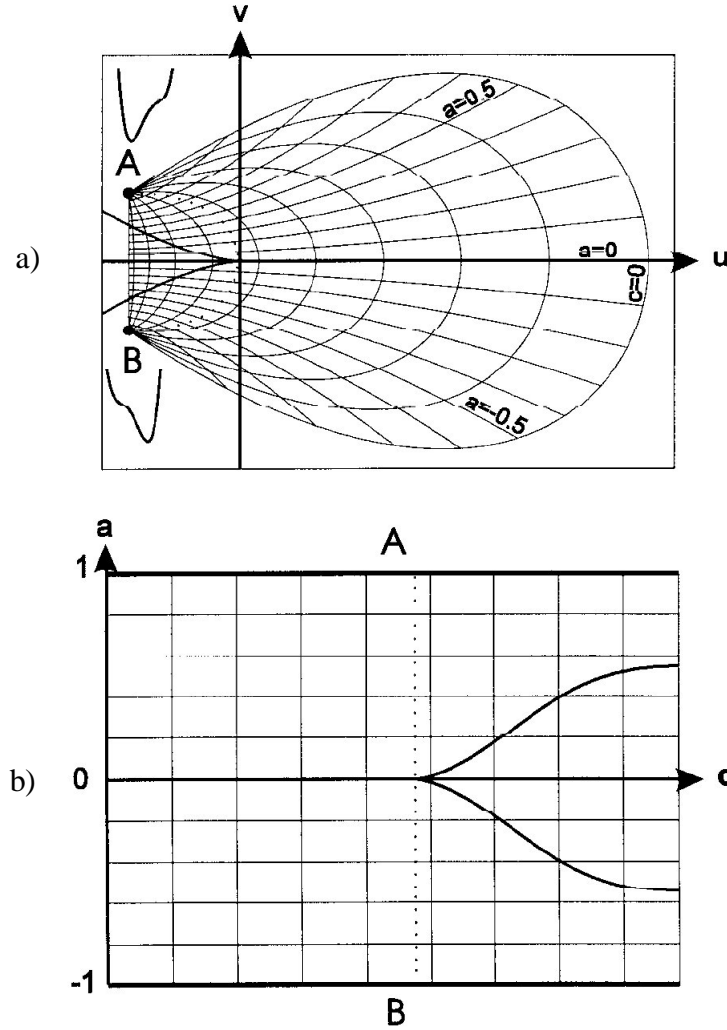


Fig. 3 : Mapping of the new representation of the cusp as a function of the conflict c between two individual potentials A and B of relative strength a . Note that points A and B representing conflicting pregnancies in the traditional (u, v) control set (a) become facing segments in the new (a, c) reference frame (b). Iso- c lines join A and B while iso- a lines do not.

When a and c are varied, the control point in the traditional set (u, v) belongs to the mapping region shown in figure 3a, which includes parts of all original four quadrants. Points A and B represent the pure archetypal shape of each individual conflicting potential and attractor at full strength. Their coordinates $(\alpha, \pm\beta)$ in the traditional control set, are chosen symmetrical about the u axis for convenience; they determine the exact nature of the concave bias. Points A and B could be located anywhere within each of the two quadrants $u < 0$, outside the cusp bifurcation set in order to ensure the uniqueness of the attractor. Each point within the mapping region represents the conflict between two attractors of the type A and B , whose relative strength is determined by parameter a and distance between them by conflict parameter c , according to the relationship:

$$P(a, c, x) = \frac{1+a}{2} p\left(\frac{c}{2} + x\right) + \frac{1-a}{2} p\left(\frac{c}{2} - x\right),$$

where P represents the overall potential and p the individual archetypal potential of points A and B .

Within the mapping (see figure 3a), the lines joining points A and B are iso- c lines, with c varying from 0 and $2m$ (m being a real root of the equation $4m^3 + 2\alpha m - \beta = 0$), and the lines which do not pass through A and B are iso- a lines, with a varying between -1 and $+1$. Figure

3b represents the cusp bifurcation set within the new reference frame (\mathbf{a}, \mathbf{c}).

One of the interests of this new representation lies in the evocative power of physical concepts such as strength (parameter \mathbf{a}) and distance (parameter \mathbf{c}) compared to the much more abstract and purely mathematical parameters \mathbf{u} and \mathbf{v} . It allows an easier description of the cusp catastrophe by using a kind of "natural language" as advocated by Thom, thus enabling a clearer representation in some applications, such as the predation cycle.

II.2 - A new representation of the predation

The new representation of the predation cycle naturally takes advantage of the salient features of the new cusp mapping shown in figure 3. For instance, the two points \mathbf{A} and \mathbf{B} represent the two conflicting pregnancies, namely predator and prey.

The great power of the catastrophe formalism lies in its independence of any substrate which makes it usable, through analogy, in a number of similar situations belonging to different domains. Even in a unique narrow domain such as predation, interpretation can be carried out at four different levels:

- biological level: the conflicting pregnancies are the vital pregnancies of predator and prey. Since we will adopt the predator point of view, the vital pregnancy of the prey corresponds to a food or nutritive pregnancy;
- psychic level: the two conflicting pregnancies are here what could be called the ego or self pregnancy (self-consciousness) and the alter-ego pregnancy (consciousness of the other, the desired being, here the prey);
- physical level: the bodies of the predator and prey (saliencies in Thom's terminology) occupy and materialise the attractors defined by the corresponding biological pregnancies. They move and interact in the usual tridimensional space;
- semantic level : the conflicting pregnancies define words and the trajectory in the control space define verbs which characterise the interaction between words.

In this section, we will concentrate on the three first levels; the semantic level will be considered later on since its application domain is much wider.

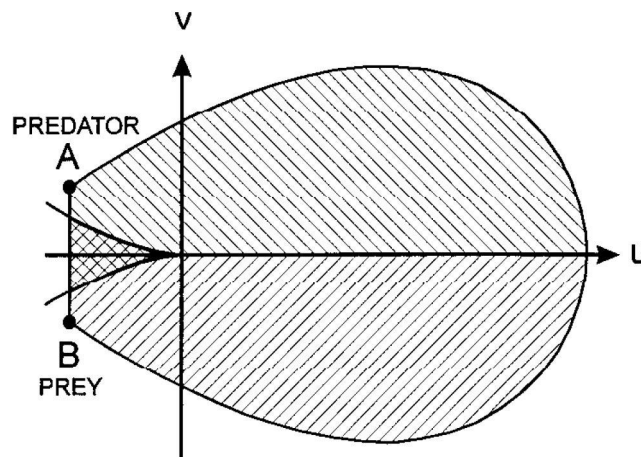


Fig. 4 : The couple predator/prey as the two conflicting poles \mathbf{A} and \mathbf{B} of the new representation of the cusp. The vital zones of the two animals are hatched differently. An encounter between the two live animals can only take place within the cusp bifurcation set.

The whole new mapping region for the couple predator/prey is shown in figure 4. It will be considered from the side of the predator, which survives to the predation process. Point \mathbf{A} represents the vital pole of the predator, the point at which it experiences total

fullness, plenitude. Any move away from this point, for instance under the influence of hunger, corresponds to a weakening of its vital pregnancy. The predator will try to compensate it and restore its vital energy by chasing and ingesting its prey, which will tend to move its representative point back toward point **A**. In figure 4, the vital zones of predator and prey are highlighted, hatched differently. At the biological level, the "falling-off" of an animal from its vital zone (the zone where its vital pregnancy defines an attractor) corresponds to the death of the animal. Note that it does not mean that the animal's body and "nutritive energy" have disappeared, but only that the animal is dead. The frontiers defined by the semi-cubic parabola (the folds of the cusp) determine the extent of the viability zone of the predator and prey. An encounter between the two living animals can only take place inside the shared region, within the parabola. Predation then consists in an excursion of the predator in the common part of their viability zones, from which it will be able to "extract" the prey.

Before detailing the new proposition for the predation loop, it is important to make some remarks on the nature of the different parameters used in the new representation of the cusp. Since point **A** determines the intrinsic characteristics of the predator, independent from its environment, it seems natural to ("see") interpret the coordinates of this point (parameters α and β , which determine the exact shape of the archetypal potential and gradient of pregnancy) as resulting from a biochemical genetic coding. On the other hand, fluctuating parameters **a** and **c**, which control the relative strength and distance between pregnancies, directly related to variables such as hunger or desire, are more likely governed by hormonal factors.

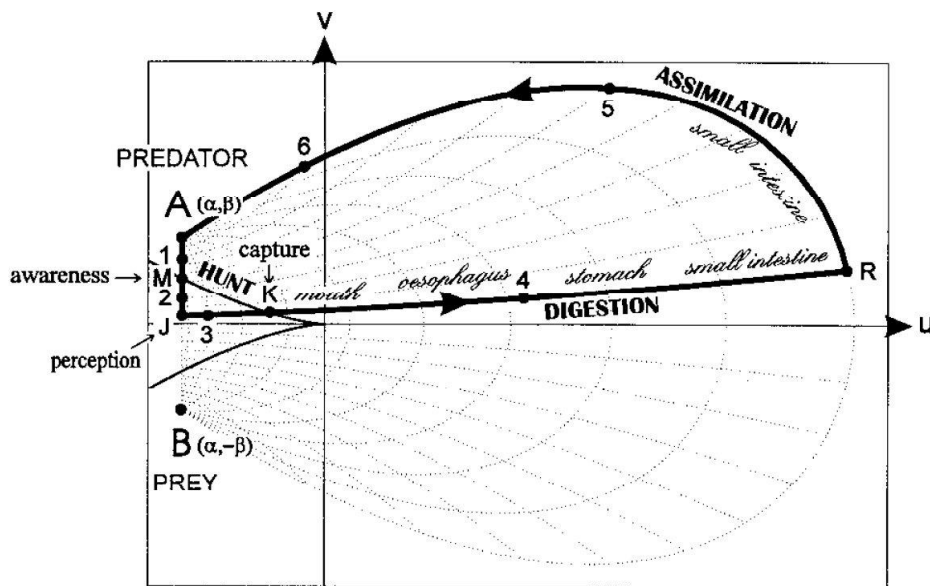


Fig. 5 : Proposition for a new representation of the predation loop, within the traditional control set (u, v) . Organs of the predator's digestive tract are added in italics, as approximate indicators of the prey's progression inside the predator's organism. The potentials shape for the points of the trajectory are shown in figure 6.

Let us now give a more detailed description of the new predation cycle. In this interpretation, the trajectory in the control plane (u, v) is no longer a circle around the organising centre 0 , but a closed circuit with 3 segments along iso-**a** and iso-**c** curves of the mapping. As mentioned above, the starting point is point **A**, representing the fulfilled predator in all its plenitude. The cycle trajectory within the control plane (u, v) is shown in figure 5, and the same cycle within the new control plane (a, c) is displayed in figure 6. In this last presentation, the segments of the trajectory are straight lines (note also that points A and B become here facing segments). The potentials shape for selected points along the trajectory are displayed around the cycle on figure 6.

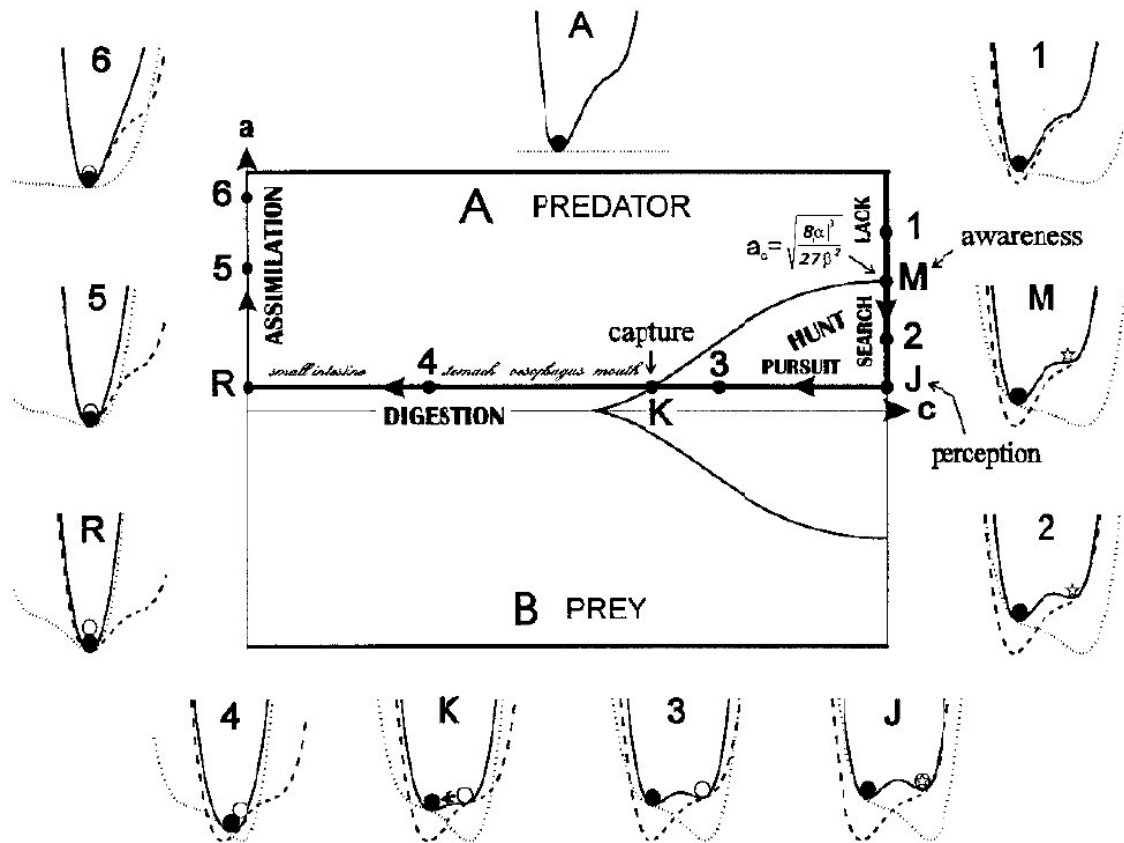


Fig. 6 : Same as figure 5, within the new control set (a, c) . The overall (full line) and component (predator=dashed, prey=dotted) potentials for a selection of points along the trajectory are shown. At the psychic (*resp.* biological) level, the component potentials represent the predator's self-pregnance (*resp.* vital pregnance) and alter-ego pregnance (*resp.* prey vital pregnance or nutritive pregnance). The star materialises the unoccupied attractor, while predator and prey saliencies are represented by full and open circles, respectively.

The 3 segments of the trajectory are called **AJ** ($c=cst=c_{max}$, a decreases), **JR** ($a=cst$, c decreases) and **RA** ($c=0$, a increases). Although all the levels of interpretation apply for all segments, one of them dominates each segment, namely the psychic level for the first segment, the physical level for the second, and the biological level for the last one. Each segment will now be examined successively.

Segment AJ

This segment concerns the predator only, and the psychic and biological transformation occurring under the influence of hunger, which moves the representative point away from plenitude. At **A**, the predator has full self-consciousness. Then slowly, under the influence of hormonal factors (parameter a decreases) of hunger, it progressively becomes aware of a lack, of a missing alter-ego. The consciousness of another self, symbolised by the appearance of the alter-ego pregnance, is first vague (point **1**) then strengthens to the prejudice of self-pregnance (a decreases). At **M**, the alter-ego pregnance is strong enough to give rise to a second attractor in the local map. It is probably at this point (when the trajectory crosses the bifurcation set) that the predator becomes fully aware that what it misses is actually prey. Point **M** represents what could be called the "awareness catastrophe", which will trigger a change of behaviour, the start of the chase phase, the search for prey. Although some movement might be triggered, this part of the chase phase is not very active, and mostly driven by sight and smell.

In the new representation of the cusp, point M is characterised by a specific, critical value

of parameter \mathbf{a} , $\mathbf{a}_c = \sqrt{\frac{8|\mathbf{a}|^3}{27\mathbf{b}^2}}$. As can be seen, this value is only a function of parameters α

and β , which are supposedly defined by genetic coding. This gives a clear image of what happens during this process: under the action of hormonal factors controlled by hunger, parameter \mathbf{a} diminishes, intensifying alter-ego pregnancy up to a critical value, predefined genetically, which triggers the search for prey. This search part can last for a while, during which (point **2**) alter-ego pregnancy keeps on reinforcing to the prejudice of self-pregnance. It ends up when the predator actually meets a prey (point **J**).

At the biological level, the increase of hunger originates from a weakening of the predator's vital energy expressed by the decrease of parameter \mathbf{a} . The lost energy will only be compensated by gaining some external energy in the form of nutritive pregnancy, which for the moment exists only as a latency.

To finish with this portion, it should be noticed that the part of the predator organism which controls this segment is the nervous system, first through psychism, then through sensory organs. We shall go back to this point later on.

Segment **JR**

Point **J** corresponds to the perception of prey by the predator. From this point, two beings are now present and a direct action can be carried out by the predator in the physical space, which was impossible while it was alone. This new perspective finds expression in a change of direction of the trajectory (see fig. 5 and 6): \mathbf{a} now stays constant while \mathbf{c} diminishes. At the physical level, the two animals occupy the two attractors of the overall (summation) potential. As \mathbf{c} diminishes, the two attractors come closer. It is the second phase of the chase: the active part of the hunt. The predator goes after the prey, the distance between the two attractors symbolising the spatial distance between the two animals. This distance shortens (point **3**). The capture of the prey by the predator occurs when the prey attractor disappears by collision with the predator attractor (point **K**, capture catastrophe). Only one animal survives the catastrophe: the predator. However the prey saliency persists all along the segment.

At the biological level, perception (point **J**) corresponds to the appearance of the prey in the predator's field of vision. Instantly, the prey saliency is invested by the nutritive pregnancy. From there, the predator identifies the nutritive pregnancy with the prey vital pregnancy. The pursuit phase corresponds to the closing up between the two vital pregnancies, which will allow the predator to get the missing vital energy back and to restore its own archetypal vital pregnancy. The capture point **K** corresponds to the death of the prey, since it leaves its vital domain.

An important and yet very interesting point is the following: at the capture (point **K**) the two vital pregnancies do not coincide (the conflict parameter \mathbf{c} is non-null); the real coincidence of the two component attractors only occurs at point **R**, the end of the segment. How can this part of the trajectory between point **K** and **R** be understood? The most simple and natural interpretation is the following: this portion of the segment corresponds to the digestion phase, with nutritive pregnancy passing through the alimentary canal of the predator (mouth, oesophagus, stomach) up to the biological centre of the predator's vital pregnancy, the small intestine. This digestion phase includes an ingestion step and a dissolution step of the nutriment (stomach, small intestine).

At the psychic level, the previous biological phase probably couples with a similar psychic evolution, with a progressive merging of alter-ego and self pregnancies, which fills the lack felt by the hungry predator.

As a final remark, it can be noted that segment **JR** is mostly governed by the muscular system of the predator, which enables first, the motion in order to catch the prey, then, the digestion by swallowing it.

Segment **RA**

The last part of the cycle, with return to point **A**, essentially concerns the biological level. At point **R**, the prey is already digested, liquefied by gastric juices into chyle. However the "biological energy" of the prey has not been transferred to the predator organism yet: it is the purpose of this last step. It takes place within the small intestine. Here, the chyle is absorbed by the intestinal villusities. The substance of the prey is transferred to the predator, and restores its vital energy: the prey "becomes" the predator, in the real sense this time.

This ultimate step, called assimilation, is perfectly described by the segment **RA** of the trajectory (see figures 5 and 6). Conflict is null ($c=0$) and parameter a increases: nutritive pregnancy (originally prey vital pregnancy) is progressively absorbed (points **5** and **6**) by the predator vital pregnancy, until the archetypal vital pregnancy of the predator is reconstituted (point **A**). The cycle is now closed, with predator in a biological fullness state, satiety.

This last segment is thus controlled at the biological level by intestinal tissues.

As for the previous segment, this biological step probably couples with a similar psychic step with assimilation of the alter-ego pregnancy by self pregnancy, and fusion with the desired being, leading to psychic fullness. A new cycle can now start again, with a new prey.

II.3 - Comments

Compared to the original proposition by Thom, the new representation of the predation cycle seems to offer several advantages:

i) it solves the paradoxical situation with confusion between predator and prey. If a comparison is made between the first segment **AJ** and its equivalent in Thom's predation loop, it can be seen that the crossing of the first branch of the bifurcation set has a different meaning: "perception catastrophe" in Thom's description, "awareness catastrophe" here. Moreover, Thom extends the cycle up to the second branch of the bifurcation set, leading to the paradox. This is hardly conceivable in the new representation, since it would mean the biological death of the predator. A reinforcing of the alter-ego pregnancy to the point it overrides the self pregnancy is here very unlikely, but it could occur, for instance when the predator starves to death.

ii) it restores the original characteristic of the capture catastrophe, whose trajectory should be parallel to the u axis, rather than to the v axis.

iii) it gives a clear and natural representation of the fundamental biological functions such as digestion and assimilation.

iv) it suggests a distinction between parameters of genetic (α, β) and hormonal (a, c) origins.

v) it is in perfect adequacy with Thom's thoughts, who expressly points out that "actants" regulation catastrophes express the survival manoeuvres of a system submitted to adversary constraints which force it to leave its characteristics (quoted in Petitot [1992], p.378, as a private communication from R. Thom). Even better than the original proposition by Thom, the new representation of the predation exactly follows such a scheme: the system's characteristics are represented by point **A** and the adversary constraints which make it leave its characteristics by segment **AJ**, while the survival manoeuvres are described by segments **JR** and **RA**. Enlarging the original scope, J. Petitot [1992] presents intentionality as schematised by an homotopy class of trajectories going from an excited multi-actantial state towards the basis mono-actantial state. Here, point **J** represents the excited multi-actantial state, while point **A** is the basis mono-actantial state.

vi) it provides a vivid illustration of Thom's fundamental hypothesis that actants

catastrophes convert the functional significance of tissues differentiated by embryogenesis catastrophes (Petitot [1992], chapter VI). Hence the identification between triploblastic differentiation and predation through the cusp archetype. We have already pointed out that each segment of the new predation cycle is associated with some specific part of the predator organism, namely the nervous system for segment **AJ**, the muscular system for segment **JR** and the intestinal tissues for segment **RA**. Now during embryogenesis, these organs originate from the original triploblastic differentiation in the following way: the nervous system comes from the ectoderm, the muscular system from the mesoderm and the intestine from the endoderm. Thus the new representation of predation clearly shows that this fundamental regulation effectively realises, one after the other, three main functions associated with the original triple differentiation during gastrulation, also modelled by Thom using cusp catastrophe (Thom [1990], p.196-198).

Other interesting consequences of some of the points presented here will be developed later on.

III - The generation process: re-examination of the reproduction loop

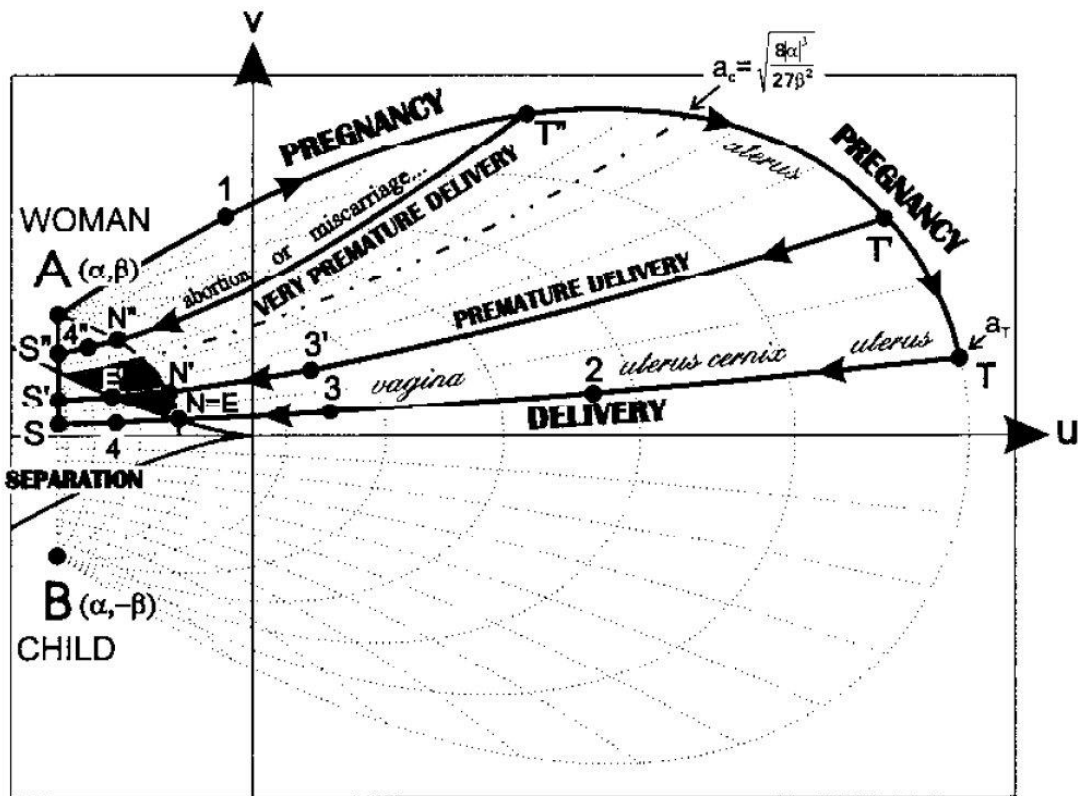
René Thom used the circular trajectory of the predation loop to represent another fundamental biological function, that of reproduction (Thom [1972], pp.300-302). Such a reproduction cycle is looped backwards compared to the predation loop. The capture catastrophe thus becomes an emission catastrophe, which corresponds to birth.

III.1 - A new reproduction cycle

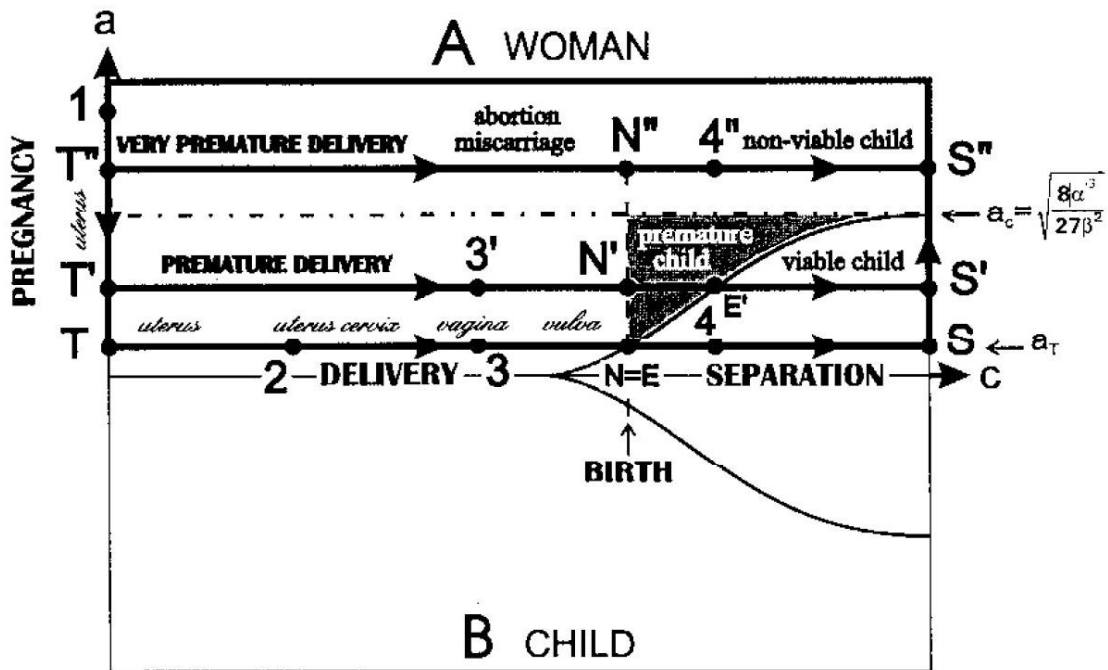
Here, the new model of the predation cycle presented above has been used to give a more precise account of the generation process, which uses the full potential of the new representation of the cusp. The trajectory used is basically of the same kind as that used for predation, except that the cycle is looped backwards.

The current interpretation concerns mostly the biological level, although interpretations at the psychic and physical levels are also possible. Here the couple predator/prey of the predation cycle is replaced by the couple woman/child, whose archetypal vital pregnancies are represented by points **A** and **B** of the new representation, respectively. The vital zones of woman and child are identical to those of predator and prey, respectively, as shown in figure 4. In terms of local map, it is now that of generation in human being.

As in the case of predation with a predator, a part of the trajectory takes place within the woman's body, the predator's digestive tube (mouth, oesophagus, stomach, intestine) being replaced by the female genitalia (vulva, vagina, uterus). The whole trajectory is presented on figure 7, and special potentials configurations on figure 8. The three segments of the cycle are now called **AT**, **TS** and **SA**. As for the predation cycle, we will start the trajectory at point **A**, which represents the archetypal vital pregnancy of the woman.



a)



b)

Fig. 7 : New representation of the generation process, within the traditional (u, v) reference frame (a) and the new (a, c) control set (b). Organs of the female genitalia, in italics, give an approximate indication of the baby's positioning during delivery. The potentials evolution along the trajectory is presented on fig. 8.

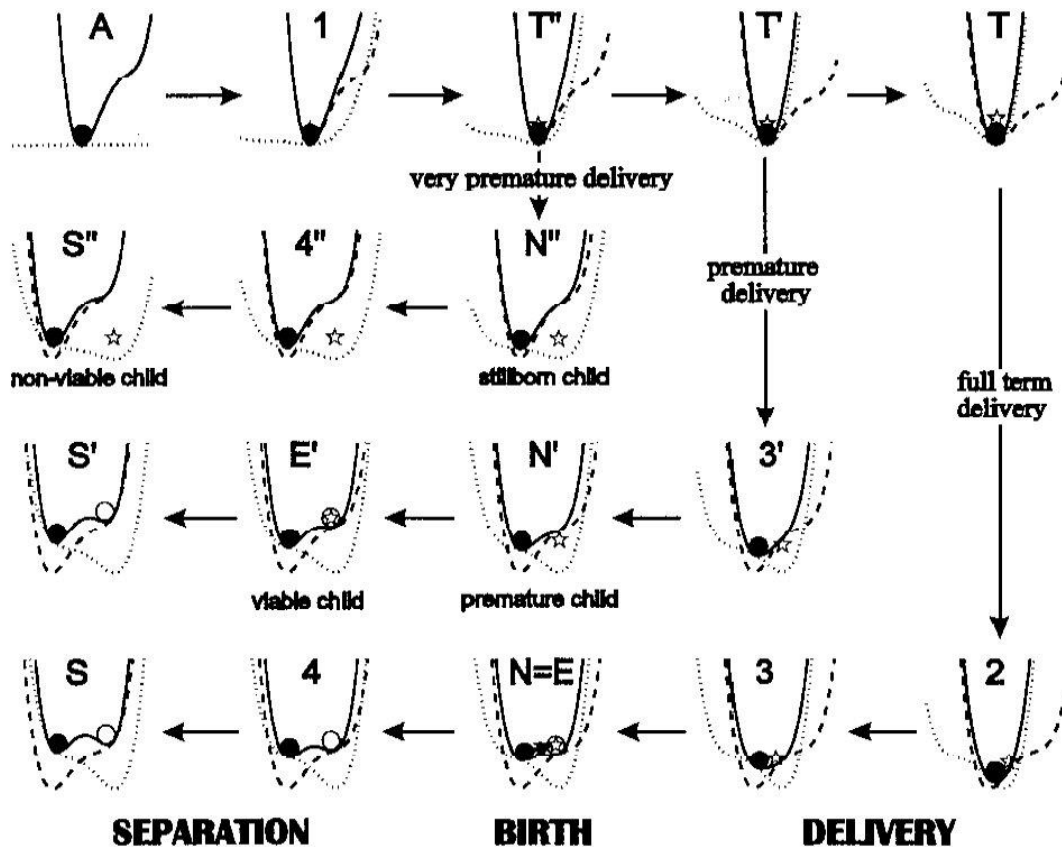


Fig. 8 : Evolution of the global potential (full lines) and relative strength and position of the component potentials (dashed=woman's vital pregnancy, dotted=child's vital pregnancy) along the trajectories presented on figure 7. The star symbolises the foetus in the womb, or outside when non-viable. The woman and child saliencies are represented by full and open circles, respectively.

Segment **AT**

Point **A** symbolises a woman in her whole sexual fullness. We will consider her just after having been fertilized. Segment **AT** corresponds to the diminution of strength parameter **a**, with **c** remaining null. The conflict parameter **c**, representing the distance between vital pregnancies of the mother and the child, is zero. It means that what is happening along this segment takes place at the biological centre of the generation process ($c=0$), namely the woman's uterus. Going from point **A** towards point **T** means that the child's vital pregnancy strengthens to the detriment of the mother's: this is pregnancy, when embryo development "pumps" energy reserves from the woman. Thus parameter **a** is a development parameter. If the pregnant woman reaches full term, this step lasts nine months, until point **T**. Cases of premature delivery will be examined later on.

It is clear that such a simple, general model does not enter into the detail of embryogenesis. Thom has already described such an evolution within the scope of catastrophe theory, at a slightly lower organisational level (Thom [1972]).

Segment **TS**

At point **T**, the foetus has reached its maximum development, and development parameter **a** is at its optimum a_T . It will remain constant while **c** increases, symbolising the separation between the mother and her child. The first part of the separation takes place within the woman's organism: this is confinement, delivery, while the baby passes through the uterus cervix, then the vagina. This step is the backwards equivalent of digestion in the predation cycle. Childbirth corresponds to the crossing of the semi-cubic parabola branch of the

bifurcation set (emission catastrophe, point **E**). The subsequent part of the segment out of the woman's body up to point **S** represents the separation, at the biological, psychic and physical levels, between the mother and her child.

Segment **SA**

The interpretation of this segment seems less obvious than the previous ones. Two interpretations can be given, depending on the adopted viewpoint. This ambiguity comes from the fact that two actants are present at the origin **S** of the segment (woman and child) but only one at the end **A** (woman). One has to assume that only one of the two actants is concerned by this segment (as it is the case for predation). The double interpretation reflects the two possibilities.

The first interpretation is to consider that the reproduction cycle is pertaining to one individual only, as is the predation cycle. If such is the case, the remaining actant should be the woman. Here the cyclic character of the generation process is less stringent than for predation, since a woman only gives birth a few times during her life, and it is not essential to her survival. By analogy with segment **AJ** of the predation cycle, a psychic interpretation can be found to segment **SA**: it can represent the satisfaction of the desire to have a child. This desire, or lack, is equivalent to hunger in predation, and symbolised by the existence of an alter-ego pregnancy, that of the child **B** (point **S**). This segment is proceeded backwards compared to **AJ**, thus corresponding to the satisfaction of the desire, like the prey assimilation step **RA** in predation. At the biological level, segment **SA** could thus represent the fecundation (crossing of the bifurcation set), the "biological" satisfaction of desire through sexual intercourse.

The other interpretation, closer to Thom's original idea, is to consider the cycle as relevant to the species, not to the individual. Then, the cyclic character is essential to the species' survival. In this case, the remaining actant has to be the child, not the mother (the child survives the mother), and the child has to be a girl. Segment **SA** would thus correspond to the girl's psychic and biological development, and her transformation into a woman. The crossing of the bifurcation set ($a=a_c$) symbolises puberty. Point **A** represents the new woman in all her sexual fullness, and fecundation triggers the first step of the next cycle.

III.2 - Comments

As can be seen, this type of cycle gives a relatively simple and clear representation of the generation process. Such a description can even be pushed a little bit further by considering cases of premature delivery.

First let us come back to birth itself. The emission catastrophe (point **E**) corresponds to the stabilisation of a second attractor (minimum) of the global potential, to the entering of the child's vital zone. This entering coincides with the exit from the mother's body, that is birth (point **N**). Besides, birth corresponds to a specific value of separation between the child and the mother, to a specific conflict rate materialised by the dashed line on figure 7. At the biological and physical levels, everything happening on one side of this line occurs within the female's body (genitalia), and on the other side, outside female's body.

Let us now assume that the foetus did not reach its optimal development rate a_T at delivery. Two possibilities can occur: either parameter a reached a value such that the delivery trajectory crosses the bifurcation set (segment **T'S'**), or it does not (segment **T''S''**). In this last hypothesis, the foetus will never reach the child's vital zone: such a trajectory **T''S''** encompasses cases of abortion and miscarriage, and some cases of stillborn children. In the other hypothesis (segment **T'S'**), the child's vital zone will be reached (point **E'**), although later than the birth itself (point **N'**): this includes the cases of premature children. The separation between these two possibilities (chain-dotted line on figure 7) corresponds to a critical development rate a_c of the foetus. Parameter a_c can be computed from the

coordinates of archetypal point **A**, α and β , in the same way as point **M** of the predation loop (note however that the values of parameters α and β have nothing in common with those of predation, since we are now considering the case of human reproduction), that is $a_c = \sqrt{\frac{8|a|^3}{27b^2}}$. On a temporal scale, parameter a_c corresponds approximately to the 6th month of

the foetus' development. We now have a somewhat clear overview of the situation: the newborn child will have a chance of survival only if the foetus reaches a critical rate of development whose value, under our assumption, is genetically coded, since it depends upon parameters α and β .

If the foetus has a development rate between a_c and a_T at delivery, the child will thus be premature. On segment **T'S'**, as c increases while a remains constant, birth (point **N'**, leaving the mother's body) no longer coincides with the emission catastrophe (point **E'**, entering the child vital zone). This can be interpreted as follows: in general, premature babies require special medical care (incubator, ...), all the more intensive as they are premature. These treatments, symbolised by segment **N'E'**, allow the new-born baby to reach his vital zone. Therefore, the real emission catastrophe no longer corresponds to birth (point **N'**), but to the end of medical care (point **E'**) without which the baby could not survive most of the time. One can clearly see here the importance of medical assistance for the premature baby: it increases his vital zone (dark area on figure 7).

IV - Application to linguistics

IV.1 - Verbal production

The previous scheme of the reproduction cycle can be used to model other generation processes, such as for instance language production.

We can assume that deep and surface structures of linguists are related to the existence of preverbal thought, whose language is expression. Verbal production can be seen as a generation process identical to the reproduction cycle described above, with the couple preverb/verb replacing the couple woman/child. It is interesting to note how easily common language has assimilated the analogy between the biological reproduction function and the verbal production process, as can be seen for instance in the following expressions: "to conceive an idea, a plan", "a plan that miscarried", "to bring forth, to give birth to a concept", and so on.

The trajectory (see figure 9) is decomposed in three segments.

Segment SA

By analogy with the reproduction analogue, this segment can be seen as symbolising the "fecundation" of thought by speech, the assimilation of alien concepts.

Segment AT

This is the conception step: the formation and development of the concept within the fecundated preverbal thought. The biological equivalent of this maturation step is embryo development (pregnancy).

Segment TS

The concept will be emitted (will pass from the preverbal to the verbal stage) only if a critical development rate a_c is reached. If not (segment **T"S"**) the concept cannot be formulated, since the trajectory **T"S"** does not cross the bifurcation set corresponding to the emission catastrophe: aborted concept. If the critical development rate is overrun, the concept will be emitted, all the easier as it will have ripened longer (compare the relative length of

segments $T'E'$ and TE). Portion TE symbolises the uplift of the concept from the deep to the surface structure (language automatisms) with verbal emission (speech) at point E . The biological equivalent of word emission is birth in the previous example.

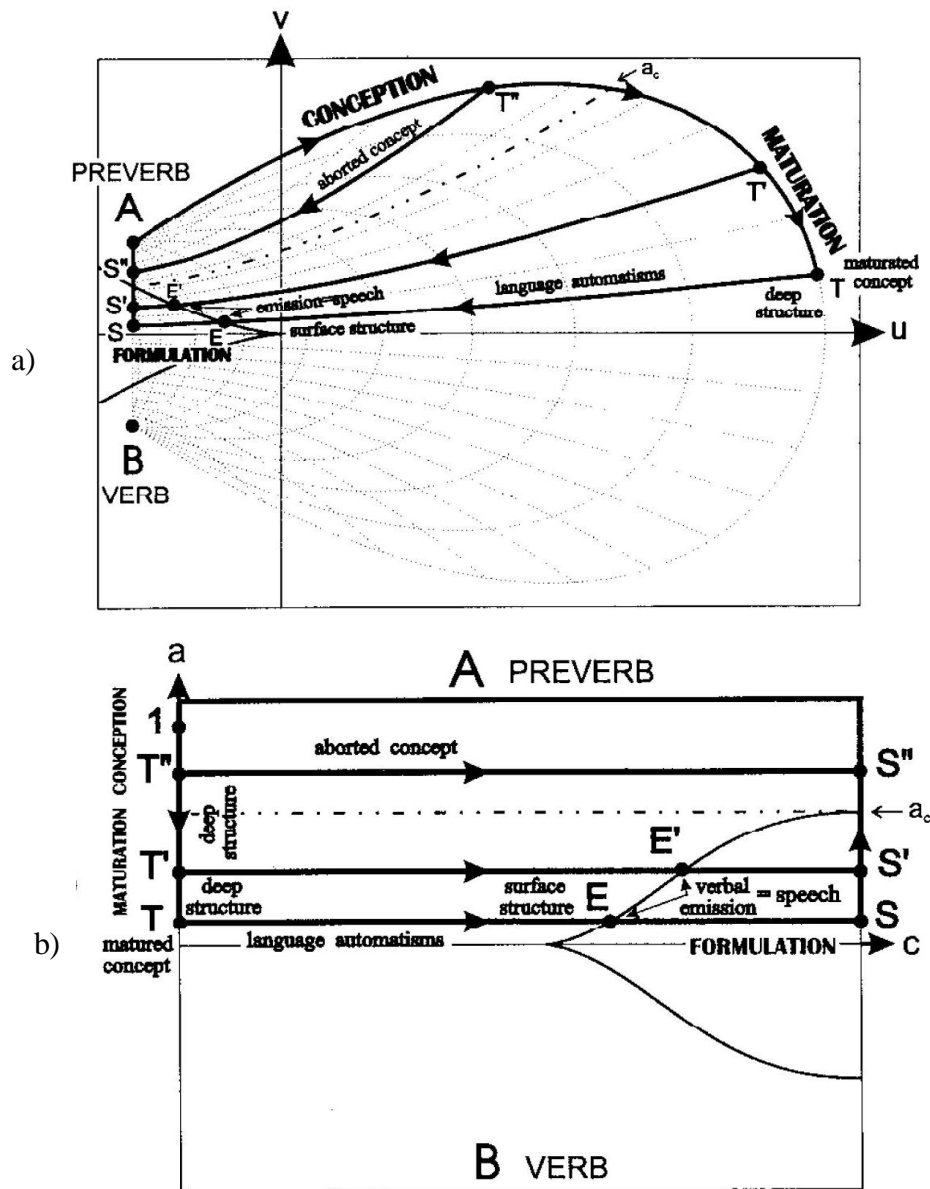


Fig. 9 : Representation of the verbal production process, by analogy with that of generation:
a) within the traditional control plane (u, v) ,
b) within the control plane (a, c) of the new representation of the cusp.

IV.2 - The cusp archetypal morphologies

As evoked earlier (section I), Thom envisions a sentence as represented by a bifurcation of a dynamic system describing neurologic activity, whose attractors represent names and separation surfaces between attraction basins represent the verb (see also comment by E.C. Zeeman in Thom [1990], pp.358-359). For instance (Thom [1970]), he defined archetypal morphologies of verbs **[TO BECOME]**, **[TO CAPTURE]** and **[TO EMIT]** by the main sections of the cusp catastrophe: u =negative constant and v =constant with increasing u or decreasing u , respectively. He called these sections 12α , 12β and 12γ , respectively. By using the new representation of the cusp and specific trajectories of the mapping (parameters a and c), it is possible to define sub-

categories to these three main categories. Such a classification attempt is presented in Table I.

Table I

main section	constant parameter	variable parameter	variation domain	actants number	signification under-category	main signification
12	$c = 0$	a increases	$[-1,1]$	2	to assimilate, satisfy	to become
	$c = 0$	a decreases	$[-1,1]$	2	to conceive, ripen	
	$c < c_c$	a decreases	$[-1,1]$	1	to change continuously	
	$c > c_c$	a decreases	around a_c	1	to change abruptly	
	$c \neq 0$	a decreases	$[-1,1]$	1	to desire, want	
12	$a < a_c$	c decreases	$c > c_c$	2	to pursue, overtake	to bring closer
	$a < a_c$	c decreases	around c_c	2	to capture, catch, enter	
	$a < a_c$	c decreases	$c < c_c$	2	to swallow, ingest, digest	
12	$a < a_c$	c increases	$c < c_c$	1 or 2	to deliver, express	to move away
	$a < a_c$	c increases	around c_c	1 or 2	to emit, appear	
	$a < a_c$	c increases	$c > c_c$	1 or 2	to separate, part, throw	
	$a > a_c$	c increases	$[0, c_m]$	1 or 2	abort, miscarry	

In this table, the reference pregnancy is supposed to be A ($\beta > 0$). Critical values a_c and c_c correspond to those values of a and c at which the trajectory crosses the bifurcation set, for fixed values of c and a , respectively. In the most general case, these values are complex functions of parameters α , β and c for a_c , of α , β and a for c_c . In certain specific cases as those presented in the previous sections, parameter a_c can be simply expressed as a function

of α and β (explicitly, $a_c = \sqrt{\frac{8|a|^3}{27b^2}}$).

V - New representation of the cusp and ontological difference

Heidegger's ontological difference is the difference between "entity" or "being", in the sense "what is" (German "seiend", French "étant") and "Being" in the sense "the fact of being" or "to be" (German "Sein", French "Etre"). In a recent article, J.M. Salanskis [1993] studied the representation of the philosophical concept of ontological difference in three theoretical constructions used in cognitive sciences, among which is Catastrophe Theory. Namely, he utilises the catastrophist representation of the verb **[TO ENTER]** in linguistics, as proposed by J. Petitot [1991], to illustrate the "defect" of the thomian figuration compared to the heideggerian model. Now it seems to me that the new cusp formulation, of which some applications have been presented here, can remove the objection.

In his article, J. Petitot uses the capture archetypal morphology of R. Thom (cusp main section **12β**) to represent the verb **[TO ENTER]**. J.M. Salanskis notes the difference between the verbs **[TO ENTER]** and **[TO CAPTURE]** in the traditional representation of the cusp (figure 10a):

" at the end of the potential distortion, one has no more access to the "entered" minimum, this minimum has disappeared. One must merely admit that, if its basin would have subsisted, it would be within the other minimum basin, the one which remains. It follows that the *being-in* is not at all represented; and if it could be, it is only with a considerable interpretative complement from the model maker" (Salanskis [1993], translated by the author).

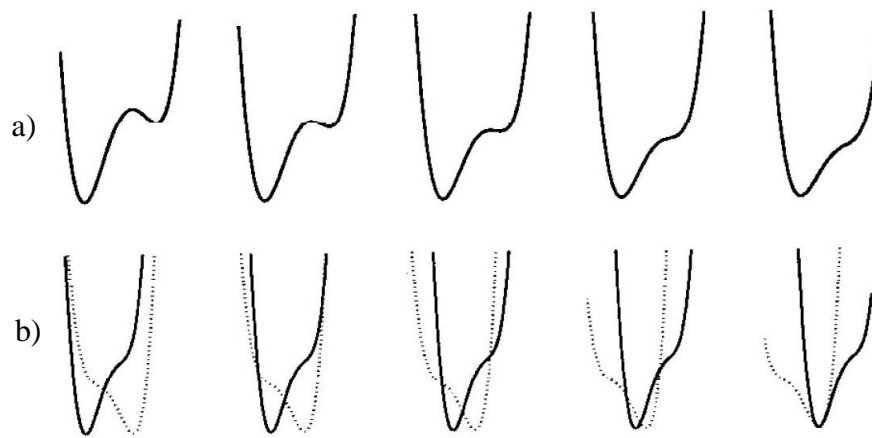


Fig. 10 : Crossing the bifurcation set of the cusp catastrophe as a representation of the verb **[TO ENTER]**:
a) potential evolution within the traditional cusp representation (section 12β , u increases at $v=cst$)
b) component potentials in the new representation (c decreases at $a=cst$)

The author considers that it is the same problem as that of ontological difference; he notices that the potential representation favours the *Being* level to the detriment of the *entity* level. Taking into account the exact signification of the verb **[TO ENTER]** would necessitate the "marking of the two protagonist entities", which is not the case in the traditional representation of the cusp. However, it is clear that such a "marking" is actually realised in the new representation of the cusp: by points A and B, which are the poles of the representation (see figure 3). One can thus consider that this new representation is the kind of "interpretative complement" or "device amelioration" evoked by Salanskis, which gives access to the "entered" minimum (see figure 10b).

According to Heidegger, *entity* has a rather static, inert character, while *Being* has a dynamic, eventful nature (Heidegger [1954], as commented by Salanskis [1993]). The new representation of the cusp makes a clear distinction between these two aspects:

- the static, inert part is accounted for by parameters (α, β) , the coordinates of points **A** and **B** which are the static poles of the representation;
- the dynamic part is taken over by parameters (a, c) which control distortions and positioning.

Such a difference is particularly well expressed in the biological applications of the new representation of the cusp presented in this article: a clear distinction is made between parameters which are biochemically coded (α, β) by essence originally fixed, and hormonal parameters (a, c) by nature evolutive.

The new representation of the cusp unravels the double level of *entity* and *Being*, with *entities* represented by archetypal conflicting potentials with coordinates (α, β) of points **A** and **B**, and *Being* expressed by the trajectory in the control plane, the way parameters a and c change thus reflecting *entities* interaction. By comparison, the traditional representation does not clearly make the distinction, since parameters (u, v) express the dynamical part only, that of *Being*, hence the difficulty to account for the concept of ontological difference. The new representation of the cusp seems closer to the heideggerian model.

The problem discussed here is not only of philosophical relevance but can also have practical interest. It is undeniable that, beyond Heidegger's controversial positions in contemporary history, his philosophical thought directly or indirectly inspires a new generation of specialists in Artificial Intelligence (see Winograd [1993] and some other articles in *Intellectica* 17 (1993)). The late recognition of Thom's avant-garde role on these

topics should be added to that (Visetti [1990], Salanskis [1993]). Indeed the stake is of consequence, since the matter is to find new computing structures which should be able to reproduce human cognitive capacities. Actually J.Y. Visetti [1990] evoked recently the difficulty to translate syntactical semantic models of Catastrophe Theory in computers language. He noticed that one way to get through it would be to give up "the principle *one actant = one attractor*, and represent several actants together under the form of one single complex attractor". This would necessitate the "beforehand disposing of attractors capable of coding a collection of actants, that is to say *already* structured themselves in a certain way". As a matter of fact, it is exactly this type of structuration which is proposed by the new representation developed in this article.

VI - Conclusion

In this article, a new interpretation of the fundamental processes of predation and generation have been presented, within the scope of catastrophe theory. A new representation of the cusp catastrophe has been used, which allows a more detailed description than the original proposition by R. Thom. This new representation also seems to be in better agreement with some philosophical ideas such as Heidegger's ontological difference. One can wonder whether the new formulation could be a useful tool for other biological applications of catastrophe theory. For instance, considering the problem of cellular differentiation in embryology, parameter c gives a very suggestive image of the differentiation concept, of a separation between pregnancies. First the separation occurs softly, continuously, until a critical rate of separation beyond which differentiation is abrupt, with creation of a frontier which stabilises.

More generally, the success of some applications of the new representation of the cusp as those presented in the current article is an incitement to undertake the "marking" of more complex catastrophes. This should allow the definition of a general framework for a structuration of attractors within each member of the series of catastrophe potentials, which could be of interest in connection with the computer coding of syntactical-semantic models of catastrophe theory.

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