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# SEMANTIC DESCRIPTION IN THE FRAMEWORK OF CATASTROPHE THEORY

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In the last few years there have been various mathematical models proposed for the treatment of semantic problems (generative models, logical systems, fuzzy and probabilistic systems). Our approach differs from all these prior approaches by the fact that it does not derive its mathematical tools from algebra and logic. We rather pick up the suggestions made by René Thom for "topological semantics" (cf. THOM 1970) and for the treatment of basic semantic problems in the framework of catastrophe theory (cf. THOM 1973).

The famous French mathematician René Thom (he received the Field Medal in 1957) did not rest content with the new mathematical structures he had found; he developed the concept of "general morphology" which should deal with all processes of form-giving (morphogenesis) in living beings. Even in 1968 when the draft of his book "Stabilité structurelle et morphogénèse, Essai d'une théorie générale des modèles" was completed, he had the idea that linguistic structures could be one of the most developed morphologies (in the general sense of this term derived from biology).

While the applications of catastrophe theory promoted by the British mathematician Christopher Zeeman were widely recognised, the linguistic intuitions of René Thom were almost exclusively developed by himself. Meanwhile the situation in semantic research has radically changed. Most of the algebraic models have been shown to be psycholinguistically irrelevant and therefore



without explanatory power. A new generation of holistic models appeared (dependency grammars, the case approach of Fillmore, frame- and -scenes semantics of FILLMORE 1976, 1977 and those models proposed recently in the domain of artificial intelligence research, for instance MINSKY, 1974 and 1979). The development of semantic theories in the seventies has thus reached Thom's intuitions without being influenced by them.

On the other hand the rapid successes of Zeeman's models have been shadowed by the "catastrophe controversy" (initiated by the critique of Sussman and Zahler). Although many of these criticisms have been refuted meanwhile, it seems that catastrophe theory is more apt to the deeper and more abstract models in the line of Thom's proposals.

If one considers current research in semantics including the approach presented in this article, one can systematically differentiate between those semantic theories which stand in the tradition of logical semantics - we call them Fregean - and those relating to Thom. The former are strictly hierarchically structured and conform to the Frege principle, according to which the semantic whole must be constructed from the semantic components by means of simple logical operations. In Thom's semantics we consider rather dynamic wholes ("gestalts") which can be contracted to singular points (they contain the structural information *in nuce*). When we refer in the following to gestalt semantics we mean this type of Thom semantics. We cannot go into the complex interconnections between topology and gestalt philosophy. Frege's semantics are to a certain extent conservative concerning the development of modern mathematics (cf. TODT 1977).

The two types of semantics are, however, not diametrically opposed. If the logician concentrates on the features of quantification and inference, and the topologist looks rather at the ultimate semantic constituents, both paradigms are outside the "conflict zone" (cf. Fig. 4 as a model of this methodological "field"). The area between these two domains is, however, too large to be neglected. Future research must therefore clarify how the two paradigms can interact in the middle area.

We shall restrict ourselves in this short article to outlining the general structure of "gestalt semantics" and to deriving a set of propositional gestalts from the elementary catastrophe called "cusp". For further details cf. WILDGEN 1979a.

## 1. PROPOSITIONAL GESTALTS AND THE STRUCTURE OF GESTALT SEMANTICS

The usual notions of the term proposition refer to logical or quasi-logical descriptive tools which are believed to make the description of meanings possible. They exclude assertion, negation, mood, and tense (cf. FILLMORE 1968); some of them also exempt quantification (cf. BREKLE 1976: 50f). Similarly, the propositional gestalt includes only very fundamental structures of an utterance; the additional term 'gestalt' is meant to indicate that instead of dissecting the proposition into functions and their arguments we shall regard a proposition as a dynamic whole with strong interdependence among its parts.

In fact, the concepts of case frames in Fillmore's theory and of "conceptual frames" in "artificial intelligence"-research already comprise the idea of gestalt. In the concrete formulation of models, however, atomistic logical instruments have been used over and over again for want of an alternative. The recent history of generative semantics is an illustration of this development. As a result of its interdisciplinary orientation this model has come into conflict with the extremely rigid logical instruments it has chosen. It has on the one hand been prevented from pursuing a more consequent innovation; on the other hand, because of its loose formalization, it has been dismissed as pseudo-logical.

We believe that the theory of elementary unfoldings is the appropriate mathematical instrument to describe and tentatively



explain especially those propositional gestalts whose forms are universal and relatively elementary. The following concepts are of central importance for modelling with the help of catastrophe theory.

(a) Structural stability. The propositional gestalt is largely independent of changes in situation and context.

(b) Irreducibility. The elementary propositional gestalts contain only those structures which are constitutive for them.

The concepts of "structural stability" and "irreducibility" are central concepts of catastrophe theory, the main traits of which will be described in the next chapter. Before we go into mathematical details we want to sketch the overall structure of the semantic model which we intend to develop.

We do <u>not</u> assume, as logical semantics does, that the universe is given as a system of individuals, attributes, and facts. The basic scope of semantics is represented by <u>processes</u> such as perception, recognition, and storage by the human organism; the recognition of qualitative change and of movements representing a <u>central field</u>. Since semantics portrays a relatively deep level of operation, we may expect particularly sharp pattern selection. For the purpose of clarity, one may imagine <u>semantics as an arsenal of abstract images</u> which function either as invariants of perceived patterns or as invariants of selfevoked stimuli from the memory. Semantics, therefore, is not language substitute, as all semantic theories have in effect contended up to now; it is not language insofar as it distinguishes itself essentially from the level of realization, which is exposed to completely different restrictions by the efferent mechanisms. In a wider sense, one might also speak of iconic, or representational semantic theory.

We assume a stratification of gestalt semantics, which indirectly reflects different evolutionary strata.

(a) Semantic <u>archetypes</u>:

They comprise a small number of elementary propositional gestalts together with a hierarchy which allows inferences, metaphors and reductions in special contexts. The semantic archetypes contain minimal interpretations of biologically fundamental dynamic principles. We can call it the evolutionary "germ" of our language capacity. The minimal interpretation does <u>not</u> depend on specific cultural traditions, it constitutes rather a pragmatic universal of language and action.

(b) Semantic attributions.
The term "attribution" refers to "attribution theory" (cf. HEIDER 1958, JONES et al. 1971 and HARVEY et al. 1976). Attributions are typical results of sociopsychological processes. The classification of interpersonal relations (HEIDER 1958), of motions, colors, the production of value judgements, stereotypes, attributions of motivation, responsibility and causation are typical examples. Together these structures constitute our supraindividual, social knowledge. The conventional and symbolic aspects of our languages have to be described at this level.

(c) Semantic elaboration and higher levels of text organization.
The phenomenon of elaboration has been investigated in WILDGEN, 1977a. A certain degree of elaboration is conventionalized by our grammars and by the lexicon. We call it minimal elaboration. It may, however, also be controlled by the speaker according to the situation (cf. WILDGEN, 1977b). If the elaboration does not correspond to the standards of the language (making sentences ungrammatical) we speak of reduction or ellipsis. In the second case the context implicitly contributes to the elaboration, in the first case the hearer must reconstruct the communicative intention of the speaker using his knowledge.

Our analyses refer exclusively to the level of semantic archetypes. The other levels require analytical tools that transcend those of catastrophe theory. They rather refer to psycho- and sociolinguistic theories.



## 2. SOME FUNDAMENTAL NOTIONS OF CATASTROPHE THEORY

As this article is conceived to be an initial introduction to catastrophe-theoretical semantics we shall only attempt to explain the most important concepts. The appendix contains some further information on catastrophe theory.

The simplest dynamical systems can be described by monomic functions such as: $f(x) = x^2$, $f(x) = x^3$, ... , $f(x) = x^n$. The first important result says that only $f(x) = x^2$ is <u>structurally stable under small deformations</u> (it is "Morse"). The other functions are unstable but there exist structurally stable "evolutions" of these functions after deformation; these are called <u>unfoldings</u> of the function. The original function is called the <u>germ</u> of the unfolding. In this article we shall only deal with those propositional gestalts which can be derived from the cusp (see below). The classification of elementary functions and their unfoldings are given in the appendix. The complete set of propositional gestalts has been derived in WILDGEN 1979a (cf. for preliminary lists: THOM 1970: 248 and THOM 1977a: 312).

The germ of the <u>elementary catastrophe</u> (cf. the appendix) called the <u>cusp</u> is $f(x) = x^4$. The variables in the germ are called <u>internal variables</u> (in our example we have only one variable: x). The space of the internal variables $\{x_1,\dots,x_n\} \in \mathbb{R}^n$ is called the <u>behaviour space</u>; the effects of processes are represented as values of the coordinates of this space. If the germ is unstable as in our case (small deformations change the critical points of the dynamic system and hence its basic character) we must additionally consider the space of those variables which control the evolution of the system under deformation. This space is called <u>control space</u> or space of <u>external variables</u>. It is contained in $\mathbb{R}^k$ (k-dimensional space of real values); in many applications it is a model of factors governing the process. The function $f_u(x)$ with $x = (x_1,\dots,x_n) \in R^n$ at the points $u = (u_1,\dots,u_k) \in \mathbb{R}^k$ is called a <u>potential</u>.

The applications presented below presuppose that the dynamic system seeks to locally minimalize the potential $f_u(x)$. This presupposition is common to many physical systems and can be best illustrated in the case of gravitational forces. One can postulate, therefore, a gradient differential equation which describes just the force exercised at different points towards minimal values of $f_u(x)$, the potential of the field. As the minimalization refers exclusively to the effects of the dynamic, it affects only the space of internal variables, $\mathbb{R}^n$.

The unfolding of a germ is a function f defined on $\mathbb{R}^n \times \mathbb{R}^k$ and taking values which belong to $\mathbb{R}$ (real numbers), i.e. $f(x,u)$: $\mathbb{R}^n \times \mathbb{R}^k \longrightarrow \mathbb{R}$. An unfolding is called universal, if it is irreducible, i.e. if there exists no allowed transformation of the system of coordinates such that the number of unfolding parameters can be reduced. The correspondent equivalence relation is called diffeomorphism.

In the case of the germ $f(x) = x^4$ the universal unfolding is: $f(x,u,v) = x^4 + ux^2 + vx$; the internal variable is x, the external (unfolding) variables are u and v. (The unfoldings of the other elementary germs are summarized in the appendix).

If we consider a specific point of the control-space (u,v); P, we can compute the potential function $f_{u,v}(x)$ at this point. The minimalization of the potential $f_{u,v}(x)$ at P can be described by the vector field defined on the internal space $\mathbb{R}^n$, in our case on x. Fig. 1 shows the vector field, which can be classified into orbits, at a point P in the (u,v)-plane, where $u > 0$.

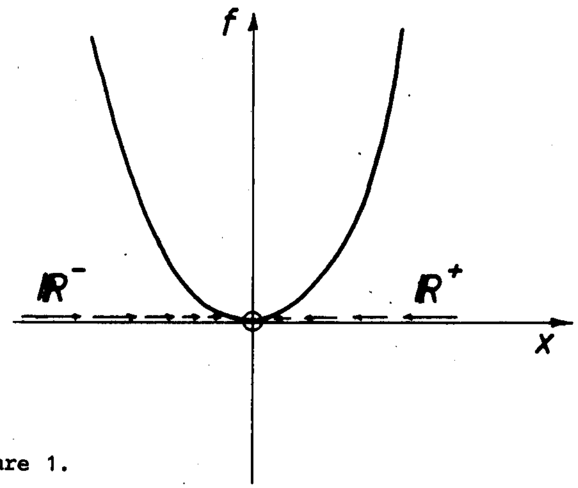


Figure 1.



This vector field is defined by the gradient of $f_u(x)$: grad $f_u(x) = \frac{\delta f u}{\delta x}$. As Fig. 1 already shows we can qualitatively characterize the flows of the dynamical system by considering its critical or stationary points. These are given by equation (1):

$$\text{grad } f_{u,v}(x):\ 4x^3 + ux + v = 0 \tag{1}$$

Fig. 2 gives the graph of this function which is also called the catastrophe map of f (cf. ZEEMAN 1973: 11).

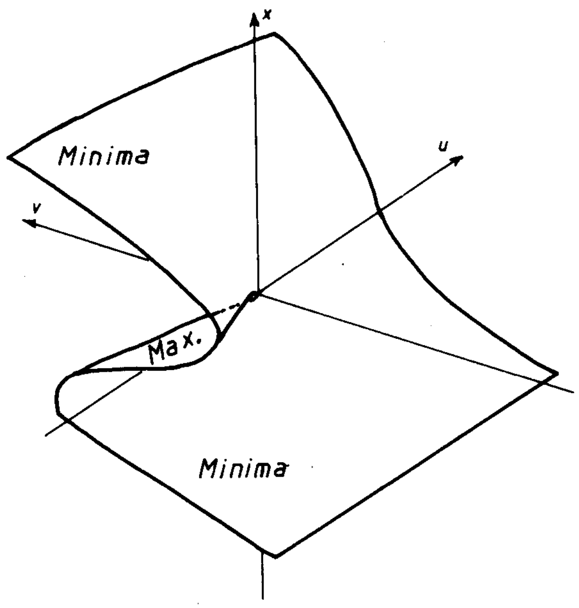


Figure 2.

If we consider next a point in the control space (u,v) where three surfaces overlap (cf. Fig. 2 above), we get a graph of the potential $f_u$ dependent on x which is qualitatively different from that shown in Fig. 1.

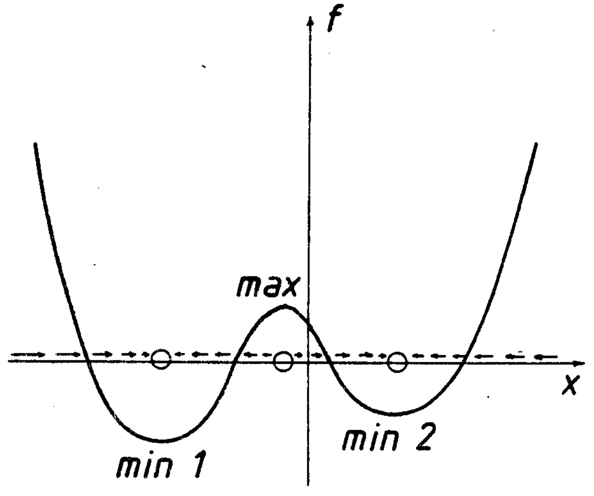


Figure 3.

The domain where f(x) has qualitatively the shape of the graph in Fig. 3 is bordered by two lines or edges. These are called bifurcation lines, as the minima existing outside of the area delimited by this line split up into two different minima, if the bifurcation line is crossed. The bifurcation points on these lines are points of destabilization or irregular (catastrophic) points. The function $f_{u,v}(x)$ is degenerate at these points.

In the case of the cusp the set of degenerate points is defined by equations (1) and (2):

$$\frac{\delta^2 f}{\delta x^2} : 12x^2 + u = 0 \qquad (2)$$



The bifurcation set is defined as the set of points of the control space (u,v) such that equations (1) and (2) hold.

The solution of the equations (1) and (2) gives us equation (3) which describes the Neill parabola (or semi-cubic parabola). It is the graph of (3) which gave the name to the unfolding (and to the elementary catastrophe) which is discussed in this article.

$$27v^2 + 4u^3 = 0 \qquad (3)$$

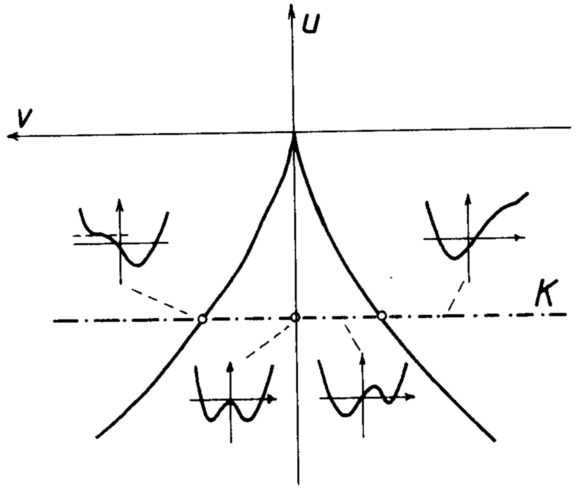


Figure 4.

The most interesting paths are those that run parallel to the v-axis where u < 0. Let K be a representative of this class of paths.

Fig. 5 shows a cut along K through the surface with the extremes (cf. Fig. 1).

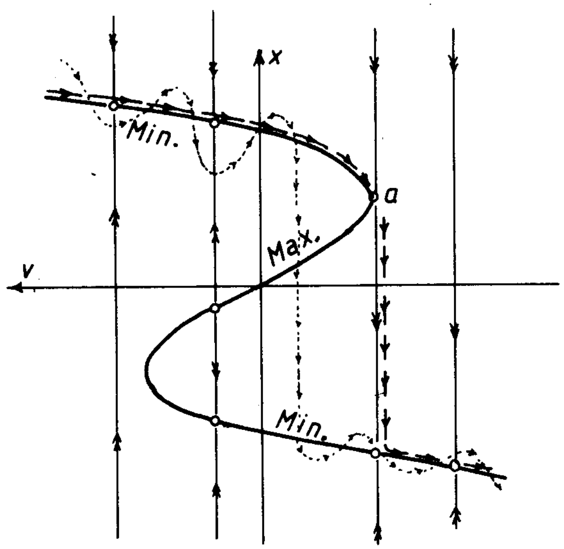


Figure 5.

We notice the slow dynamic (——➤——) 'parallel' to v: the fast dynamic, indicated by the orbit arrows (——➤➤——), stabilizes the process on the minima-surface. In (a) it is destabilized and "falls" to the other minima-surface. This course is typical for an undisturbed fast dynamic, since this dynamic is almost always localized in the minima. A "nervous", disturbed dynamic, which oscillates around the minima, can more easily overcome the barrier of the maxima-surface; therefore it falls sooner.

In the first instance, we speak of a perfect delay catastrophe, in the second instance of a Maxwell catastrophe.



## 3. SEMANTIC ARCHETYPES DERIVABLE FROM THE CUSP

The exact derivation of semantic archetypes would demand not only a semiotic legitimation of the principles of interpretation employed, it would also require a more detailed analysis of the geometry and the dynamic features of the cusp. We must refer the reader to WILDGEN (1979a: 195-307), where these tasks have been fulfilled. In this chapter we can only present the main results of our research.

Semantic archetypes are elementary and irreducible propositional gestalts. They constitute the deepest level of the organization of our communicative intents (cf. WILDGEN 1977a: 44-48) into sentences. The formal basis of semantic archetypes is constituted by those elementary process-types which can be derived as paths through the bifurcation set. The elementary processes can be filled semantically in different ways. The two main principles for the semantic "filling" of the formal process types are:

(1) The attractors of the potential are interpreted as stable domains, as qualities, as phases or as agents.

(2) The catastrophes (bifurcations and shifts of dominance) are interpreted as basic verbal structures.

In correspondence to principle (1) three types of interpretation can be distinguished:

(a) The <u>localistic interpretation</u>. The attractors are interpreted as local areas (domains).

(b) The <u>qualitative interpretation</u>. The attractors are interpreted as qualitative domains on a quality scale. The bimodality of the cusp is interpreted by the polarity of quality pairs (i.e. antonymic adjectives).

(c) The <u>interaction interpretation</u>. Both attractors are phases of an action or agents involved in an (inter) action.

The processes in (a) are processes of change of location, tho[se] in (b) are processes of qualitative change, and those in (c) describe an elementary course of interaction.

We shall briefly commentate each of the three derivations.

ad a: The bifurcation set has three zones if u < O:

- the zone of the exclusive existence of $M_1$: location A
- the zone of conflict: overlapping borders of A and B
- the zone of the exclusive existence of $M_2$: location B

The slow dynamic along the path K can now be related to a subject S, which travels on the path.

We then obtain:

(1) S moves from area A to B. We may, however, also concentrate on sub-areas of the process, thus obtaining:

(2) S leaves area A

(3) S enters area B

The realizations (2) and (3) each imply an adjoining area, that is, they are factual phases of a process, contrary to the archetype of birth/death which can be derived from the fold (cf. the appendix).

Diagram 1 illustrates the process underlying the interpretation, it should be compared to Fig. 5 (we get the diagram by the omission of the maxima line).

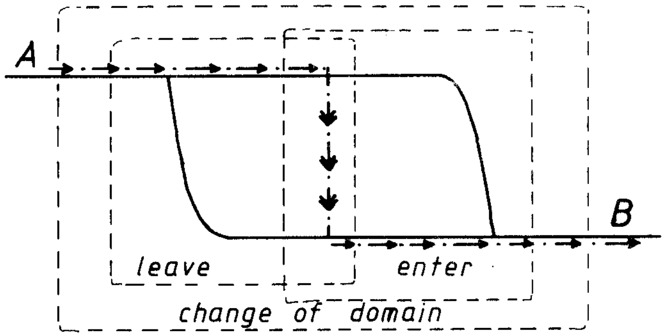


Diagram 1.



ad b: The qualitative interpretation is quite similar. Instead of local domains with overlapping borders we consider now two qualities belonging to the same qualitative scale which are in bimodal opposition. Examples are: young - old, strong - weak, calm - excited.

We shall illustrate the process underlying such oppositions by describing the pair: asleep - awake. Fig. 6 shows how the processes of awakening or of falling asleep can be reconstructed as paths in the bifurcation set of the cusp. Only the resultative aspect of the process is explicitly mentioned in the corresponding sentence.

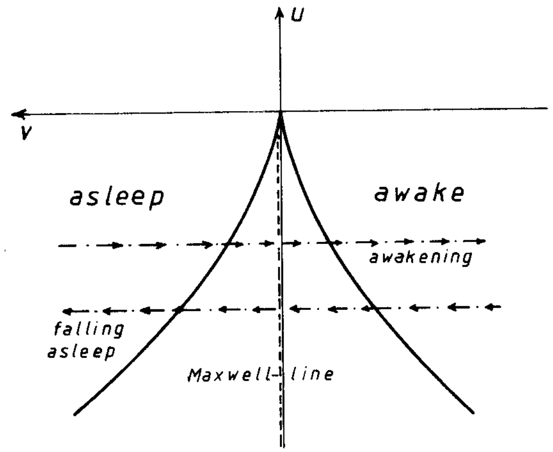


Figure 6.

Up to this point, we have applied the symmetrical Maxwell convention (the jump occurs immediately when one of the attractors grows deeper). If we apply the perfect delay convention, the initial state prevails longer so that the catastrophic jumps depend on the direction of the path. In the example of awakening - falling asleep such a delay would be rather natural. Its consideration would, however, complicate our description.

ad c: The essence of the interaction interpretation is that there are two complementary constituents of the action. We can distinguish between those interpretations in which the constituents are phases of the action, and those in which they are agents involved in the action.

(1) The phase-interpretation

We have a neutral state of relaxation and a marked state of contraction. As Zeeman has shown, the heartbeat can be qualitatively described using the cusp-catastrophe. We need, however, an additional control, the so-called pacemaker, which cyclically substitutes the respective states of stability. We shall simply assume a cyclical path in the bifurcation set of the cusp which replaces the straight paths considered up to now. $b_o$ and $b_1$ are the points where the path changes its direction (cf. ZEEMAN, 1971: 25).

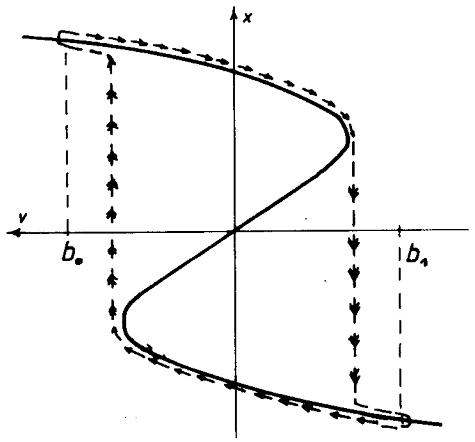


Figure 7.

Rather simple realizations of this archetype can be found in sentences like:



S waves, wags

More generally, it may be said that most movements such as walk, run, dance ... are perceived as combinations of such "beating" processes (cf. JOHANSSON, 1976, 1977).

The two phases can also be interpreted as two states of possession or control $M_1$ and $M_2$:

$M_1$: $A_1$ has/holds/possesses/controls an object O

$M_2$: $A_2$ ———————————— an object O

The catastrophe jumps (destabilizations) along a cyclical path (cf. Fig. 7) are interpreted as:

$A_1$ loses O -------- $A_2$ takes O

$A_2$ loses O -------- $A_1$ takes O

Fig. 8 illustrates this basic process type:

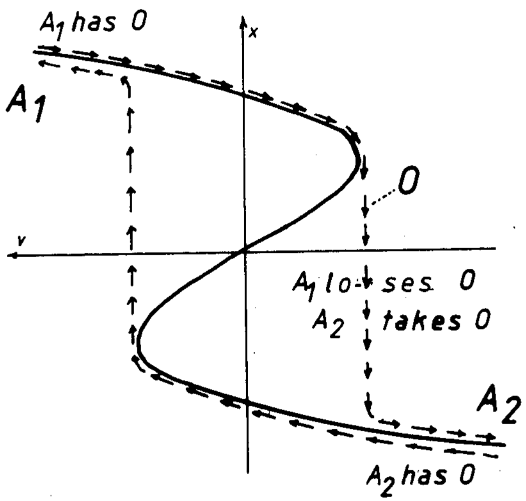


Figure 8.

We obtain the resulting or the initial state of "having" by focusing on one particular section of the process (cf. diagram 1). In this dynamic context the stative verb "to have" is integrated in a larger "scene" of change in possession.

(2) The agent (or instrumental) interpretation

This interpretation is the one which concerned René Thom the most as it shows parallels to his application of catastrophe theory in morphogenesis. The two attractors which are in conflict in the inner area of the bifurcation set of the cusp (cf. Fig. 6) are interpreted as agents ('participants' in the sense of TESNIÈRE, 1955 or 'roles' in the sense of FILLMORE, 1971).

If we consider separately the left and the right part of diagram 1 we arrive at the diagrams 2 and 3 (it would be too lengthy to derive them formally here). Diagram 2 shows how a secondary agent is "born" at the bifurcation point. We call the corresponding interpretation: the archetype of emission. Its dynamic features are realized by sentences like:

agent $M_1$ emits/throws/gives away/lets free/secretes agent $M_2$

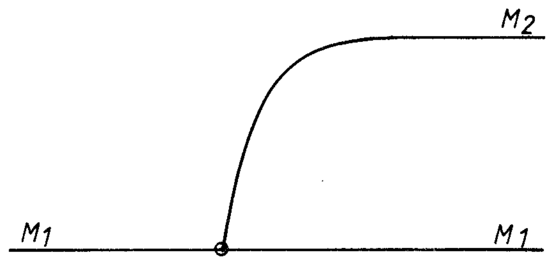


Diagram 2.



In diagram 3 the reverse process is described. A secondary agent is caught by a primary one (the primary agent is the one who survives the catastrophe). Corresponding sentences could be:

agent $M_1$ catches/takes/grasps/subjugates/ absorbs/devours/ ... agent $M_2$

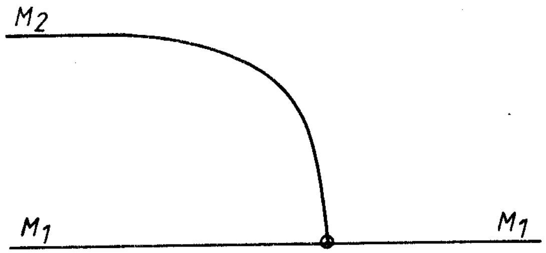


Diagram 3.

We can generalize the distinction between the archetype of capture (the name is too concrete in relation to the abstractness of the concept) and the archetype of emission. In the case of the first archetype (cf. diagram 3) a primary agent absorbs the movement/energy of a secondary agent; we can say it is affected by the secondary agent. The archetype of emission can be related to the label "effected", i.e. a secondary agent is effected by a primary one (cf. BREKLE, 1976: 70-77).

The derivations sketched in this paragraph only present a small selection from the list of propositional gestalts that can be obtained from the elementary catastrophes. A summary of the derivation of the whole set of semantic archetypes is contained in WILDGEN (1980a).

Dynamic modelling in semantics touches many other areas which were not mentioned here. The most important are: the structure of the lexicon (word semantics), phenomena of semantic reduction (in compounds, in the ellipsis, in pidgins etc.), semantic fields and semantic change. Our proposals can only be the beginning of research into the dynamic character of language and language use (cf. for further applications WILDGEN (1980a) and (1980b)).

## 4. APPROACHES TO AN EXPLANATION

As the exemplary derivation of some semantic archetypes has shown, it is possible to derive propositional gestalts from process patterns with the help of systematic principles of interpretation. The process patterns can be classified and described purely mathematically by investigating the paths through the bifurcation set of elementary unfoldings. The set of semantic archetypes that is thus obtained differs both qualitatively and quantitatively from Thom's list (cf. THOM, 1970: 248, and THOM, 1977a: 312), although counterparts can be found for each of his archetypes. In particular, we also distinguish half-elementary archetypes and higher archetypes, which result from a fibration of archetypical paths along a parameter. This systematic reconstruction of propositional gestalts on the basis of the catastrophe theory endows the approach with descriptive adequacy, but it does not yet account for the theoretical claims. Essentially, we discern three directions a possible explanation might take:

(1) Originally, the semantic archetypes take recourse to principles according to which movement and action are regulated; such principles were already developed at a very early stage (for example, territorial behaviour, patterns of hunting and feeding, bimodal manners of reaction on emotional grounds, such as escape - attack).



(2) The semantic archetypes are deep-rooted cognitive patterns, which underly the perception of processes and actions. Assuming successive selectivity in the analysis of perceptional inputs, they would have to be something along the line of a most deep and general cognitive level of analysis. Since we do not yet know much about the higher levels of brain operations, such an explanation cannot yet be put in more concrete terms.

(3) The semantic archetypes are part of the collective unconscious, i.e. they comprise evolutionary experiences, thus they would more appropriately be explained in terms of anthropology rather than biology. The hierarchy of the transfer archetype, which runs parallel to the evolution of human societies from gatherer and hunter to farmer, fabricator, and trader, indicates such connections. It is, however, not clear how such archetypes (similar to those of C.G. JUNG) can be transferred except from generation to generation.

On the whole, gestalt semantics, whose archetypical level we have to a certain degree explained, opens a broad perspective, which illustrates the biological and anthropological fundaments of language much better than logical semantics.

## APPENDIX

1. The classification of catastrophes (cf. ZEEMAN 1973b: 12 and ARNOL'D 1972: 255).

| number of internal variables | 1 | 2 | 3 | 4 | 5 | 6 and more |
|---|---|---|---|---|---|---|
| Labelling | $A_2$ | $A_3$ | $A_4, D_4$ | $A_5, D_5$ | $A_6, D_6, E_6$ | no finite classification |

2. The list of elementary catastrophes and their names

| Class | Name | Germ | Unfolding |
|---|---|---|---|
| $A_2$ | fold | $x^3$ | $x^3 + ux$ |
| $A_3$ | cusp | $x^4$ | $x^4 + ux^2 + vx$ |
| $A_4$ | swallow-tail | $x^5$ | $x^5 + ux^3 + vx^2 + wx$ |
| $A_5$ | butter-fly | $x^6$ | $x^6 + tx^4 + ux^3 + vx^2 + wx$ |
| $D_4^-$ | elliptic umbilic | $x^2y - y^3$ | $x^2y - y^3 + ux^2 + vy + wx$ |
| $D_4^+$ | hyperbolic umbilic | $x^2y - y^3$ | $x^2y + y^3 + ux^2 + vy + wx$ |
| $D_5$ | parabolic umbilic | $x^2y + y^4$ | $x^2y + y^4 + uy^2 + x^2 + wy + tx$ |

In WILDGEN (1979a) the concept of an elementary catastrophe was extended. This table gives the classical list of Thom who considered only those unfoldings with at the most four external variables (because of space-time).

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