Types of problem solving activity in a complex environment: Steps towards modeling by a cusp-catastrophe

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Accepted, May 6, 2002
International Scientific Journal of Methods and Models of Complexity – An interdisciplinary journal for research of complexity

1. Abstract

A conception of the relationship among competence, qualifications, and learning is proposed as grounds for establishing a model of problem solving in complex, dynamic task environments. The conditions for testing the model are discussed in terms of catastrophe theory, which describes bifurcating systems that has not yet moved into chaos. The task environment of INTOPIA, a computer simulation of an entrepeneurial task used in our investigations, is briefly described. On this background four issues are presented and discussed, leading up to a statement of conditions for testing the model. The issues are the problem solving agent, the unit of description of a problem solving course, the interpretations of sequences of units, and the identification of sense making.

Keywords: problem solving, competence, qualifications, catastrophe theory, sense making, simulation, dynamic problems.

2. Introduction

The aim of the research program *Simulation Studies of Competence and Qualifications* (SIMCOM) is to investigate the relationship between competence and qualifications, and to elucidate the development of leadership, by investigations of problem solving in complex, dynamic environments.

In this article, we outline some issues in modeling problem solving activity by means of catastrophe theory, more particularly modeling activity by a cusp-catastrophe. A cusp-catastrophe describes parameter dependent, bifurcation determined states of stability and instability, which under specific conditions can move into the realm of chaos. Thus, models of 'catastrophes' and 'chaos' belong to the same family: Bifurcation Theory (Abraham and Shaw 1983; Abraham and Shaw 1988). In order to understand chaotic behaviour, which is deterministic but unpredictable behavior, it is necessary to understand its preconditions, viz. stable forms of bifurcation behaviour. The conditions for testing a catastrophe model are presented in a number of steps. First, we state our basic ontological assumptions. On this foundation, a conception of the concepts and phenomena of competence and qualifications, and learning is stated. Thirdly, our attempt to apply catastrophe theory is described, emphasizing the relation between hypotheses about control parameters and problem solving activities.

Fourthly, the task environment used is briefly described, and the types of data collected are presented. One of the data types is the problem solving agent's flow of talk. As described below, the problem solver is a team of two cooperating persons, and their verbal exchange during the problem solving course is recorded. Issues arising out of this type of data, such as agency, unit of description of problem solving course, interpretation of data, and sense making are discussed, leading up to an analysis of the conditions for testing the hypothesis of problem solving in complex, dynamic environments being explained by a cusp-catastrophe.

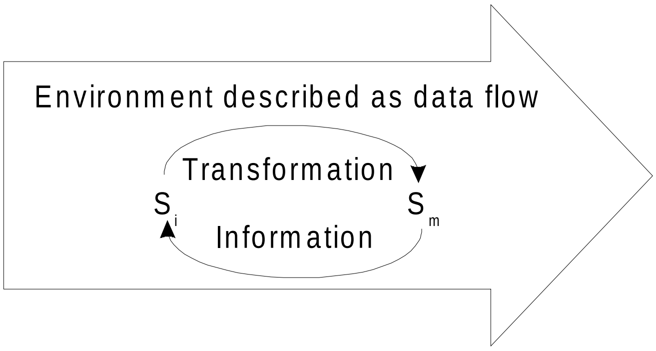
3. Basic ontological assumptions

The first assumption asserts that it is impossible to describe the performance of a living organism without concurrently describing the object that is subjected to the activity of the organism.

The *intentional subject* and the *subject matter* constitute an *ecological unity* and have to be analyzed as such. Thus, the ontology is based on the assumption that a specific natural stratum exists within the objective world, which can be described as a contra lateral unity constituted by a transformation process and an information flow. The transformation/information keeps the functionally inseparable but analytically distinguishable parts of the unity together. This unity is different from other objective phenomena, because it can be understood as meaning, vide Figure 1.

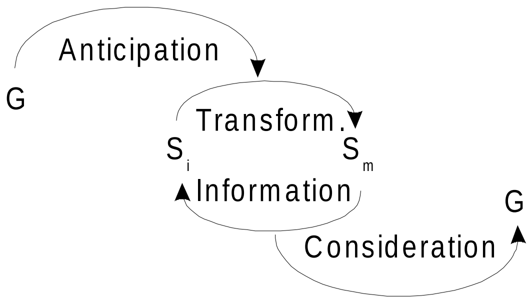
To understand the relation between the unity and the environment in which it is embedded, the environment has to be regarded as a materially generated data flow, which the subject transforms into information. Thus, subject matter is a material subjective construction, but a construction that is causally generated by the objective environmental data flow (Kugler and Turvey 1987; Rasmussen 1997). The subject generates forms of subject matter according to circumstances that are specified by the flow of data. Subject matter is not, however, a mental image; it is, so to speak, a material phenomenon loaded with ideas.

Figure 1. The fundamental relationship between the intentional subject (S_i) and subject matter(S_m) embedded in an environmental data flow.



The contra lateral unity may face incongruities between type of information and ways of transformation. If there is no incongruity between the transformation process and the information flow, the unity is stable. However, if an incongruity exists, the unity is unstable and the subject has to negotiate the incongruity. Thus, any unstable transformation/information dynamism has to be negotiated, which means that the incongruity must be transformed into congruity. In other words, the unit of meaning must change in order to 'survive'. The creation of congruity is partly a refle xive activity that takes place by means of concepts, which are categories loaded with ideas. Within the reflexive process the unity is constrained by a conceptualization process, as is illustrated in Figure 2.

Figure 2. Embedding the (S_i / S_m) unity in the reflexive agent



The subject/subject matter relationship is embedded in the anticipation/consideration relationship, thereby meeting the fundamental assumption of the agent being reflexive. The concept of agent includes the unity and a generating function (G). As 'generator', the agent is able to create stability by containing the unit of meaning within a set of constraints, where the agent as subject creates meaning in the situation. This interplay between generating function and subject is equivalent to the reflexive exercising of competence and the enactment of qualifications: a sense making process.

If the agent is unable to make sense of the situation and by that transform incongruities, he or she must 'flee' or 'succumb'. However, if incongruity is successfully negotiated, subject matter is restructured.

4. A conception of the relationship between Competence, Qualifications and Learning

The term *competence* – both in its singular and plural form – nowadays, appears to have replaced terms like capacity, ability, aptitude, skill and qualification. This use of *competence* seems to confound a basic distinction of people's behavior, viz. setting of goals and acting in order to achieve a goal. The distinction implies that people are able to comprehend a situation and the possible problems inherent in it, and are capable of figuring out ways and means to solve such problems.

To make this distinction clear, we suggest that competence and qualifications, respectively, should be used.

4.1. Competence

This basic concept we define as follows:

> **Competence: A subject's aptitude for handling complex subject matter and by that establishing and changing the unit of meaning.**

When a certain disorder arises in subject matter, the subject attempts to establish a new order, which – by the generator function – is expressed as decisions about what to do, in a very general sense. To comprehend the process, one must realize that the new order that the subject creates is not identical with objective reality, but nonetheless fundamentally dependent upon this reality. The term *subject matter* denotes a subjective reality that is fundamentally dependent on an objective reality, as presented in the following definition:

> **Subject matter is the form in which an objective reality is subjectively cast.**

In other words, an objective material reality emits a stream of data that becomes a stream of information when the agent *acts* within the objective reality. The totality of data transformed by the subject into information constitutes subject matter as being loaded with ideas, where

> ***an idea is the set of information which delimits one form of subject matter from another.***

As said above, the exercising of competence is constrained by the anticipation/consideration process, which generates *problem setting* and *decision*. Problem setting entails the notion that something might be different, and decision indicates the establishment of a state that includes a number of options regarding where and how efforts may be made to change the state.

Subject matter can be complex and we define it as follows:

> **Subject matter is complex when it is necessary to generate new categories and a new order to make action possible.**

An agent who experiences subject matter as complex will, as generator, try to establish new ideas and a new order to be able to make category based decisions. To be able to act, the agent must create new ideas and a new order of the field. Thus, at a time t_0 the order X exists; at time t_1 information has become so extensive that a new order Y has to be established. However, although subject matter may be complex, it is not entirely disordered. There must always be known or recognizable elements present that function as a kind of bootstrap for the exercising of competence.

4.2. Qualifications

If the agent as subject 'survives' he or she is considered to be capable of enacting qualifications. This type of 'survival' is defined as the ability to reproduce the unit of meaning in 'similar situations'. In other words, the subject is capable of reproducing the unit of meaning in a variety of situations that form the basis of the original creation of meaning. A prerequisite for the enactment of qualifications is that they are developed through the exercising of competence. Thus, it is possible to enact qualifications only when subject matter is no longer complex. When subject matter has been apprehended by the necessary ideas, and a new order has been established, the agent can – via the generating function – set goal-defined questions and choose among options. In other words, complex subject matter is transformed – by competence – into complicated subject matter. The meaning of this term is as follows:

> **Subject matter is complicated when it is necessary to abstract and organize available categories to make action possible.**

The meaning of qualifications then is as follows:

> **The ability to handle complicated subject matter, and by that, adjusting the unit of meaning.**

Enactment of qualifications are constrained by the anticipation/consideration process, which generates *problem identification* and *a set of options* from which a *choice can be made*. Problem identification comprises a problem, which is a goal-defined question situated in complicated subject matter. Thus, problem setting and problem identification are two components of problem solving activity based on the exercising of competence and qualifications.

Although a subject creates a new order in a complex field, thereby transforming it into a complicated one, immediate action is not possible. Organizing categories of subject matter is necessary in order to create goals and select among options. This process is realized by a set of tools, which includes ideas and procedures that constitute the basic material in a continual exercising of competence. The main point is that the exercising of competence develops qualifications, and the qualifications are embedded in the competence as ready-to-use components.

4.3. Learning

Given this conception, learning is now defined as follows:

> **The transformation of competence and qualifications that takes place by problem setting and problem identification.**

Competence, and thereby qualifications, may develop throughout life. Thus, competence varies among people. The variability of competence is manifested by the degree of complexity people are able to handle, manifesting itself in a set of decisions. Qualifications likewise vary, and the variability is manifested by the degree and nature of knowledge and skills about tools, techniques, communication skills, and analytical procedures that can be employed.

5. Making a model of problem solving activity types

Our modeling attempt is directed by the assumption that the phenomena we are interested in must be understood in terms of 'complexity theory'. In this section we briefly describe the general approach of catastrophe theory and our specific attempt to apply it.

5.1. The general approach

The goal of catastrophe theory is to describe the origin of forms, what Thom, the inventor of the theory has described as 'morphogenesis' (Thom 1972). The theory builds on topology, which is

> "…involved because underlying forces in nature can be described by smooth surfaces of equilibrium; … when equilibrium breaks down …catastrophes occur." (Zeeman 1976).

The theory is based on an assumption about structural stability, appearing by 'recurrent identifiable elements' (Woodcock and Davis 1978). Hence, it can be said the theory is concerned with qualitative regularity or stability, in our case: Human cognitive processes.

5.2. Outline of our specific attempt at application

In order to adequately structure a set of ideas, expressed in the sense making process, which encompasses the reflexive exercising and development of competence and qualification, the sense making process is hypothesized to be constrained by the 'anticipation/consideration process' manifesting itself as two control processes: *tracking-control* and *goal-control*. It is further hypothesized that tracking-control and goal-control can be split into conflicting parameters. Tracking-control is split into two conflicting control parameters: *efficacy and ruggedness*. Efficacy is a measure of being the master of one's own action, while ruggedness is a measure of the obstacles in the environment. Thus, tracking-control is the manifestation of the agent's negotiating the route towards the goal. Finally, it is hypothesized that goal-control is constituted by two conflicting control parameters: *achievement* and *availability*. Achievement is measured by the degree of manifestation of progress, while availability is measured by the manifestation of exploiting potential means of the environment. Thus, goal-control is the degree to which the agent is closing in on a solution (Bang and Rasmussen 2000).

If the control parameters, achievement/availability and efficacy/ruggedness, do interact in a conflicting and non-linear way, and if the interacting control parameters give rise to relatively stable forms of performance, between which sudden discontinuities can occur, it is possible to model the connection between control parameters and performance by means of a catastrophe.

Dörner's results (Dörner, D., H. W. Kreuzig, Reither, F., & Stäudel, T. 1983), as well as eyeball inspection of our own data, lead us to follow Zeeman's advice, which goes like this:

> "…the deep classification theorem of catastrophe theory … permits us to enunciate the general principle that whenever we observe one of these five qualities in nature {bimodality, inaccessibility, sudden jumps, hysteresis, divergence}, then we should look for the other four, and if we find them then we should check whether or not the process can be modeled by the cusp-catastrophe." (Zeeman 1977),

or, a little less demanding:

> "If any one of them {the qualities} is apparent in a process, the other four should be looked for, and if more than one is found, then the process should be considered a candidate for description as a cusp catastrophe." (Zeeman 1976).

We have informally observed bimodality, and the research literature reports a number of cases of divergence (Dörner, Kreuzig et al. 1983; Dörner 1996).

Given that it is possible to substantiate the claim that an agent does control the goal, tracking control will be the interesting parameter, and the relevant catastrophe is the so-called cusp-catastrophe (see Figure 8.). A few features characterize this catastrophe. One is that behavior is *bi-modal* over part of its range and characteristic jumps are observed from one mode of behavior to another. Another feature is that of *hysteresis*, which means that a jump from behavior A to B happens by values of parameters that are different from those of the jump from behavior B to A. A third feature is that of *divergence*, which means that a small perturbation in initial state of a system may lead to a large difference in its final state.

6. Experiment One

The task environment complying with the demands and implications of the previous sections must be complex, dynamic and involve feedback. An extended discussion of such requirements has been presented elsewhere (Jensen and Rasmussen 2001).

In this section we present a brief description of the task environment, the types of data collected, and the types of data for discussion.

6.1. The task environment

A task environment simulating entrepreneurial enterprise is presented to three teams of two persons. The tasks comprise plant construction, production, product development, and selling of goods (computers and chips) on the world market consisting of three areas (US, EU and Brazil) each with their own currency. The firm operates from headquarters situated in Liechtenstein (currency: Swiss Franc). Manuals provide the conditions for operation, and further, some of these conditions are changed during the course. The environment is an adapted version of the INTOPIA task (Thorelli, Graves et al. 2000). The task runs over eight periods distributed over four full days' work.

Data types comprise 1) recording of ongoing conversation between team members for every period, 2) the choices made by the end of each period, 3) written statement(s) from each team about the 'concern policy', 4) a written log book from each team, obtained at the end of each period, about essential problems, and ways of dealing with them, 5) the emails exchanged during the course among teams and among teams and the 'administrator'.

6.2. Data analysis

The theory of the relationship of competence and qualifications points to three coherent areas of interest: the subject's aptitude for handling complex subject matter, the developing meaning, and the resulting performance. Achievement is then assessed by the degree of coherence among problem solving activity, sense made and final results for each team. In this article we want to discuss the principles of the tool for analysis of 'sense making', the PERTEX program (Helmersson 1992; Bierschenk 1993), and the tools for analysis of problem solving forms ('complexity tools').

7. Issues from Experiment One

In this section we present four issues, three of them concerning description and analysis of problem solving activity, and one of them concerning description of sense making. The issues about problem solving activity concern the agent of problem solving, the unit of description of the course of events and the interpretation of sub-parts of the course of event.

7.1. The problem solving agent

In Figure 1. and 2. our conception of the reflexive agent is depicted. The agent of our present experimental setup is, however, not the person but the dyad of two persons, in the sense: two coordinated homologous systems, considered as one system. In other words: the agent of problem solving activity is assumed to be the dyad. The assumption rests on an analogy to what Kugler and Turvey arrive at in their study of motor coordination (Kugler and Turvey 1987). They analyze how the phenomenon of two physical, soft wired systems can be coordinated by information from their common environment and be considered as one system (cf. also the proverbial phenomenon of 'the grandfather clocks'). By this analogy 'the subject' of Figure 2. is hencefo rward to be regarded as the two persons of each of the teams of our experiment.

As said, this is our assumption. It has to be argued; we think it can be argued, but we are not prepared to fulfil the requirement at this moment. It is accepted for the time being.

7.2. Unit of description of a problem solving course

The data type involved in this issue is the agent's flow of talk. The anal ysis concerns the ways the agent (i.e. the team) acts in the environment and the objectives of its thinking.

7.2.1. Partitioning a stream of talk into text blocks

The flow of talk is an expression of the ($G(S_i / S_m)$) system (vide Fig. 2 above and corresponding text). The flow of talk is transcribed and then partioned into text blocks comprising a particular category of activity and one or more objectives of thought, according to rules described in the next section.

7.2.2. Coding a text block

A text block is characterized by two variables, 'activity' and 'subject ma tter'. The first variable of the coding is established on the basis of an elementary conception of 'the ideal course of problem solving'.

The 'ideal course of problem solving' has been conceived as a s equence of activities, comprising

tracing → clarifying → adapting → structuring → analyzing → modeling → establishing choice alternative → judging → determining → evaluating,

the meaning of each term being specified by a lexicon of terms for categorizing activities.

By 'ideal' is meant something analogous to econo mics' 'rational h uman agent', in other words not something to be observed. Nevertheless this fiction serves a purpose, viz. identifying the types of activity in the verbal exchange, albeit not observed in the strict order that defines the 'ideal'. 'A ctivity' refers to the materialization of the reflexive, constrained *transformation/information* process that constitutes our basic unit of description and analysis.

Most of the activities can be differentiated in subactivities, e.g. 'adapting' for which we dist inguish among elucidate, calculate, verify, and adjust. Such subactivities will be useful when an analysis in depth of qualifications is to be made. In this presentation, however, we confine ourselves to presenting our proposal for analysis at the activity level.

The second variable that determines the text block is that of 'subject matter' manifested by e xpressions referring to which features of the environment are being dealt with, as 'data' *to be transformed into information*, at a given moment. One problem for discussion is how fine-grained one chooses to register the verbal exchange, another one, commented on below, is the degree of content connection among forms of subject matter.

7.2.3. Description of the flow of talk

The description of the agent's flow of ta lk appears as a series of coded alternating activities and forms of subject matter. Table 1. shows an example of three consecutive text blocks.

Table 1. Example of coding of text blocks.

ser. nr.	text block	activity	subject matter
1	p11. We must produce some plans for what we actually want to sell p12. Yes, that's what we have to…	clarifying	product plan
2	p11. We cannot stake exclusively on production and sale of chips. p12. No, unfortunately.	adapting	production of chips sales of chips
3	p11. We must find out whether we should produce our own chips or buy them some place p12. Yes.	establishing choice alternative	production of chips purchase of chips

The example shows that the verbal flow starts with the activity 'clarifying' and the subject matter 'product plan'. In the next block adapting is exercised, while subject matter shifts to chip production and chip sale. The entire verbal flow is coded like that. This coding is the basis for analysis of forms of problem solving activity.

7.3. Interpreting sequences of text blocks

According to the theory, the generator function G controls the states of the fundamental subject/subject matter unity. Primarily, the generating function enables the unity to shift its state either by directing attention to different forms of subject matter or by changing the forms of activity. As stated above, different activities exist, e.g. tracing or adapting. The generating function can arbitrarily activate any of these forms of activity, and direct attention to any available subject matter. In doing so, a continuous set of different states is generated, constituting the world line of the generating function/subject/subject matter system, that is, the trajectory of the system.

7.3.1. Patterns of activity/subject matter

Subsequences of text blocks form patterns according to certain systemic aspects of activity and subject matter.

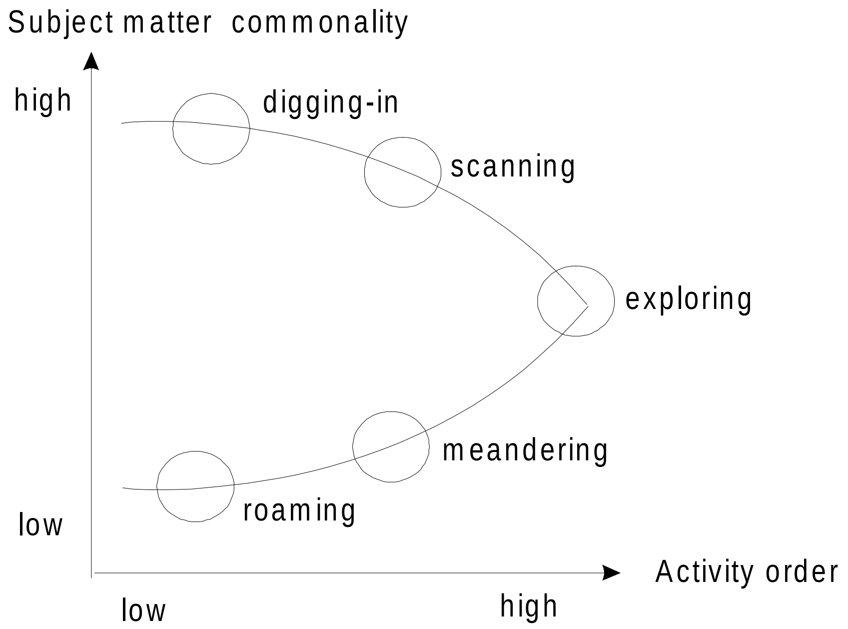
7.3.1.1. Identification of problem solving activity types

If a particular set of activities agrees with a subpart of the 'ideal course of problem solving' – e.g. tracing → adapting → structuring or structuring → modelling/analyzing → establishing choice alternative – the set is said to be *coherent*. If a particular set of text blocks is constituted as one coherent set of activities, the activity *order* is determined as high. If a particular set of text blocks encompasses no coherent set of activities, the activity *order* is determined as low.

If subject matter is clustered around a specific topic, e.g. chip_production, chip_production_capacity, and chip_product, the set is said to be *continuous with respect to content*. If a particular set of text blocks forms a continuous set of subject matter, subject matter *commonality* is determined as high. If a particular set of text blocks holds no continuos set of subject matter, subject matter *commonality* is determined as low.

This line of reasoning leads to a determination of types of problem solving activities tentatively denoted as: digging-in, scanning, exploring, meandering and roaming.[1] The relationship among these types with respect to the order and commonality is illustrated in Figure 3.

Figure 3. The relation among types of problem solving activities.



The determination of types of problem solving activities is – it must be said again – tentative. However, what is being argued here is that the determination of types of problem solving activities should be made independently of the determination of control parameters, as these independent determinations form the foundation for testing the hypothesis of modelling by the cusp-catastrophe.

The problem solving activities will be part of the reflections on testing the model, vide below.

7.3.1.2. Identification of *control parameters*

As stated above (vide section 'Making a model…'), the generating fun ction controls the exercising of the system trajectory by means of the tracking control parameters: *efficacy* and *ruggedness*. It is hypothesized that the number of words devoted to producing a specific type of problem solving activity indicates efficacy. If the number of words is large, efficacy is determined as high. The hypothesis is based on the assumption that if the sense of efficacy is high, the team will put a greater effort into the problem solving activity.

It is further hypothesized that the number of subject matter 'controlled' within a specific type of problem solving activity indicates ruggedness. If the number of subject matter is large, ruggedness is determined as low. The hypothesis is based on the assumption that if the sense of ruggedness is low the team will include more subject matter into the problem solving activity without reflecting too much on any of them.

[1] Dictionary meanings run as follows: digging-in: to work hard or laboriously with an overly restricted subset of the environment; scanning: to glance from point to point of often hastily, casually, or in search of a particular item; exploring: to travel over (new territory) for adventure or discovery; meandering: to follow a winding or intricate course; roaming: to go from place to place without purpose or direction.

7.4. Identification of sense making

In this section we provide some suggestions for analysis of the data type 'concern policy' and 'log book'. Eac h team is required to make a written statement of their overall policy in dealing with the task, possibly revised during the course of events. They are likewise required to submit a written statement at the end of each period about their deliberations in that period.

7.4.1. Sense making of different scopes

A crucial element of our theory of competence/qualifications is the conception of competence as the aptitude for establishing and changing meaning (sense making). To make sense of a situation is equivalent to making a mental model comprising significant aspects of the situation and the relations among these aspects. Situations may, of course, be of different scope, comprising more or less aspects and relations.

But sense making may also take place on different levels of generality. Transposed to our context of INTOPIA, the agent is required to make sense of the whole enterprise, how to manage eight periods of decision making, as well as the particular period, and even of subparts of a particular period. The issue then concerns how to find the meaning, or sense, that the agent establishes for a particular situation of a particular level of generality.

In this presentation, we want to discuss how meaning of the whole enterprise appears, as it is conveyed by the agent's written statements of concern policy and log book. Our tool for this e n-deavour is the computer program pertex, a program for analyzing text (Helmersson 1992; Bierschenk 1993).

7.4.2. Some assumptions of language

A fundamental assumption is that the trajectory of the (G(S_i / S_m)) system is mapped by the linguistic processes.

By claiming that the trajectory of the (G(S_i / S_m)) system is mapped by natural language, it is simultaneously claimed that the result of these processes, the control of the (G(S_i / S_m)) system, and the result of the production of natural language, the text, are isomorphic. According to Bierschenck, text production is *intentional* and *oriented*, which means that any text production is governed by a functional mechanism that encompasses an intention function **int**(A), a functional constant (a), and an orientation function **ort**(O): ((*int*(A)) *a* (*ort*(O))). Thus, the mapping relation exists between (Aao) and (S_i / S_m), and between Aa(Aao)) and (G(S_i / S_m)).

7.4.3. Principles of PERTEX

In technical terms a string of graphemes encompasses patterns in the form of grammatically determined *clauses:* (AaO) - that is an agent (A) an activity (a) and an objective (O) that are put together into *sentences:* (Aa(AaO)). A set of clauses and sentences constitutes a *text string*. A text string unfolds in time and has a specific start and ending.

The simplest form of a text string is a single clause that follows the (AaO) schema. An example from a protocol is the following:

> the other company produces third generation PCs in EU with second generation chips for the sake of competitive advantages,

which is formalized as follows:

(A) the other company
(a) produces
(O_f) third generation PCs

(O_e) in EU
(O_m) with second generation chips
(O_g) for the sake of a competitive advantage

When an agent produces a text string, the string is organized by means of a verb, into an agent-objective connection, AaO, the 'A' signifying the agent, the 'a' the acting, and the 'O' the object. O may encompass four parts, the *focus*, the *embedment*, the *means*, and the *goal*.[2] Thus, the objective is organized by means of prepositions into four different forms: the *focus* (O_f), the *embedment* (O_e), the *means* (O_m) and the *goal objective* (O_g).

Thus, any clause can – in terms of PTA – be written as $AaO_{(f,e,m,g)}$. The O-index should be conceived as an index with four slots, one of which must be filled and the others might be filled.

When a text string is built up, a concept that appears as a focus at one place in a text can appear as a means or a goal at another place. Furthermore, agent concepts can become concepts of objective. It is not in any way determined which concept takes which position in the functional $AaO_{(f,e,m,g)}$ clause. The only determinants of the clause are the verb that organizes agents and objectives, prepositions that determine the focus, embedment, means and goal positions, the sentence markers ('.', '?', '!') that determine the length of a sentence, and the clause markers (',', ':', ';', 'and', 'that' etc.) that determine the length of a clause.

Given a dictionary that lists verbs and forms of inflection, prepositions, sentence and clause markers, it is possible by way of the PERTEX program to transform any text into functional $AaO_{(f,e,m,g)}$ clauses.

Sometimes the functional clauses are 'well-formed' textual clauses as described in the above noted example, but, more often, this is not the case. Although, for example, an objective obviously has no immediate agent, as in 'keep off the grass', the agent still exists in the mind of the text producer. Because the ((int(A)) a (ort(O))) schema governs text building every objective without an agent is bound to one in the preceding text, while any agent without an objective is bound to one in the succeeding text. Within the text string, the same agent can bind more objectives lying ahead in the text, and, complementarily, the objectives are bound recursively to an agent until a state has been reached at which every agent is linked to an objective and every objective is linked to an agent.

By means of the synthetic part of PERTEX, it is possible to describe the content of sense the team makes of the situation, which means that we have an expression of competence.

However, making sense of a situation does not imply a specific form of problem solving activity. What characterizes a specific form of problem solving activity is the trajectory of the ($G(S_i / S_m)$) system, which is the specific succession of forms of activity and subject matter.

7.4.4. Example of a sense made

In this section we offer an example of the gist of a PERTEX-analysis.

A particular text is subjected to a coding, which splits the text into objectives, *focus* (O_f), *embedment* (O_e), *means* (O_m) and *goal objectives* (O_g). These objectives are then subjected to a cluster analysis.

Finally, the cluster analysis is organized into a topological web that forms the basis for the interpretation of the result of analysis.

[2] Certain terminological changes relative to Bierschenk's terminology (and possibly conception) have been made for our purposes.

7.4.4.1. Description of the organized clusters of a text

An excerpt from a statement of concern policy might look like this:

> Again, we… we are not that preoccupied with novelties; that is, we still want… that is, we want to stake on the American market and produce a modern, new, combined as high tech concept… technologically placed on the… stake on the American market, produce a small but economical one, staking on the latest computers, especially low end, and then we transfer the sale of the rest of the computers; well, we have our introduction in US, and then we move them to the European market. Yes, and then goes on.

In order to comprehend the *content* of the structures, the first step is to describe the clusters. When describing the clusters, the objectives included in each cluster are systematized at a level of generalization that unifies the objectives of the cluster.

For example, the first cluster of the focus structure encompasses the following objectives:

> not so preoccupied
> again we we
> we
> still this again we we
> again, we on the American market
> a modern new combined

and the description arrived at is:

`not preoccupied with novelties on the US-market.`

The description picks up the most significant concepts of the cluster ‘preoccupied’ and ‘on the US-market’ and transforms the statement ‘a modern new combined’ into ‘novelties’. While the description cannot be considered the result of a rigorous procedure, it is nevertheless sufficiently constrained to be intersubjectively reliable to a satisfactory degree.

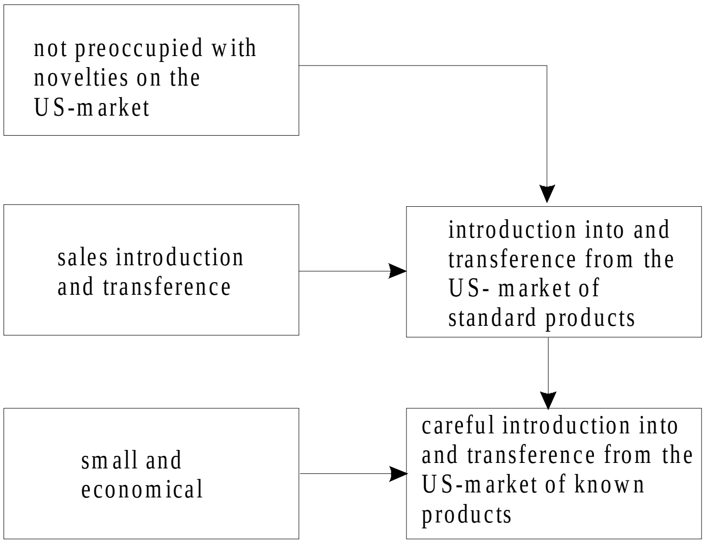
The next step in describing is the merging of clusters into a set of synthetic states, which constitutes the nodes of the topological web. For example, the first cluster, ‘not preoccupied with novelties’, is transformed by the second cluster, ‘sales introduction and transference’, into the synthetic state

`introduction into, and transference from the US-market of standard products.`

The argument for the merging of states is this: If something has to be introduced for sale and transferred, it has to be a product, at least in this game. If they are ‘not preoccupied with novelties on the US-marked’, they must be ‘preoccupied’ with standard products, and therefore it is their standard products that have to be introduced into the American market and transferred to other markets.

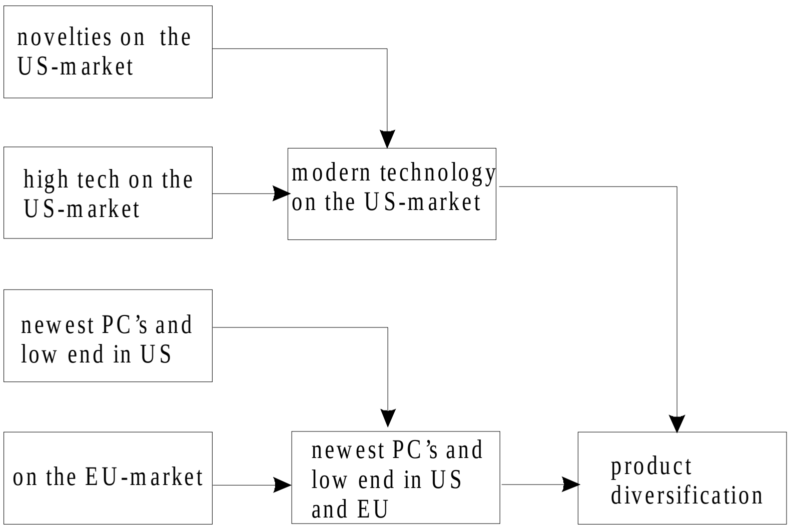
The entire focus structure of the excerpt is depicted in Figure 6.

Figure 6. Focus structure



A corresponding picture of the embedment structure of the excerpt is shown in Figure 7.

Figure 7. Embedment structure



7.4.4.2. The sense of the text

Essentially then, the sense of the text is expressed in the *focus*

`'Careful introduction into and transference from the US-market of known products'`

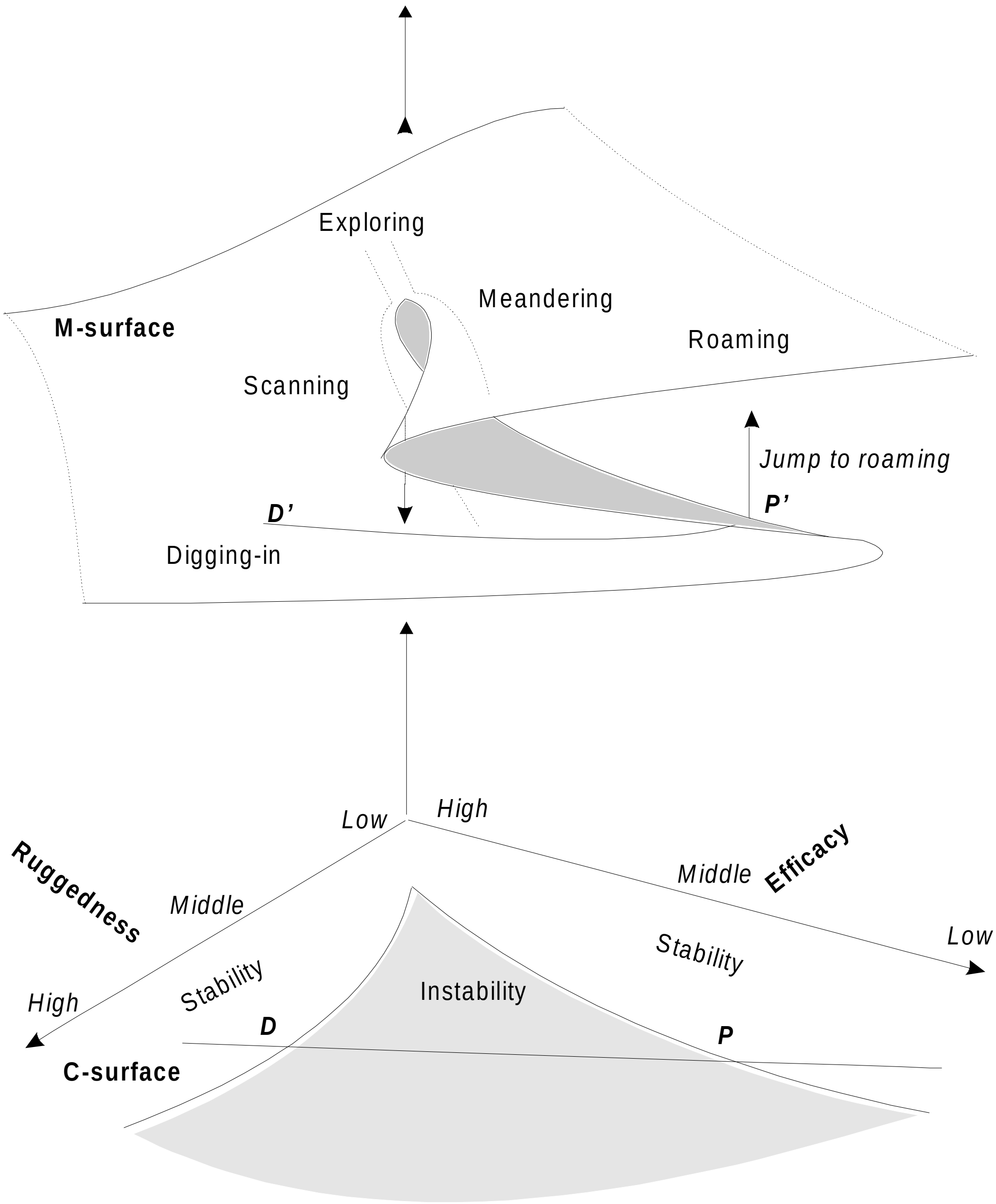
embedded in a conception of

`'product diversification'.`

7.5. Testing the model: control parameters and types of problem solving activity

Our specific hypotheses may now be expounded by means of Figure 8. If ruggedness and efficacy vary over the C-surface, which is the set of paired values of the control parameters, the forms of problem solving activity will be mapped as shown on the M-surface. On this surface, the fold curve (marked grayish) depicts an inaccessible area, signifying that two different forms of problem solving activity cannot exist simultaneously. Each point on the M -surface, except the area of the fold curve, represents a stable state, a form of problem solving activity, corresponding to a particular set of values of control parameters; jumps appear when stability breaks down by the edge of the cusp, corresponding to particular pairs of values of the control parameters. In other words, breakdowns occur when the values of the control parameters reach the edge of the area of instability, as shown on the C-surface by the cusp, which is the projection of the M-surface fold.

Figure 8. The relationship between ruggedness, efficacy and problem solving activity modeled as a cusp-catastrophe.



The M-surface shows that a continuous change in the relation between the control parameters ruggedness and efficacy may result in a continuous change of the problem solving course, from digging-in over scanning to exploring, and hence over meandering to roaming. Further, the dotted line running alongside the edge of the fold curve indicates that starting from exploring, a minor difference in the relationship between ruggedness and efficacy may result in quite different forms of problem solving activity, viz. either scanning or meandering (the *divergence* feature of a catastrophe).

Correspondingly, the model shows that under certain relations between efficacy and ruggedness – for example when a agent manifests digging-in – a minor change may result in an abrupt jump to roaming: Tracing line D-P in the C-surface, indicating that efficacy and ruggedness concurrently change from high/high (digging-in) towards low/low (roaming), shows that it cuts the projection at point P. Correspondingly, in the M-surface the line starting at D' cuts the 'catastrophic' edge at point P': the problem sol ving form jumps from digging-in to roaming.

Thus, the model shows that the relation between efficacy and ruggedness may move so far towards low/low that roaming should be expected earlier in the course; but because the agent may seem fixated, so to speak, in digging-in, the prevailing form of problem solving activity remains until still a minor change results in a jump. If a linear relation prevailed, a continuous change should be seen, but because of non-linearity, the change will appear as a jump. The change may occur as a jump from digging-in to roaming, or a jump from scanning to meandering, by tracing a similar line, and vice versa (the *hysteresis* feature of a catastrophe).

The model shows finally that the same fundamental control parameters with small quantitative variations are able to generate quite different forms of performance.

As said above, testing of the model implies observation of certain specific relations between sets of 'values' of control parameters and types of pro blem solving activity. For such observations to be instances of answers to a genuinely empirical question, the 'values' of control p arameters and the types of problem solving activity must be specified independently of each other. This having been done, the question of relation can be answered from two angles: 1) based on an identification of problem solving activities, the question concerns the value of the control parameters. 2) for a particular subset of values of the parameters, will the corresponding subsequence of activities display a pattern of types?

If successful, the model of problem solving performance will demonstrate that by means of catastrophe theory, and the concept of sense making, it is possible to move from categorizing performance to modeling performance.

8. Summary

The project Simulation studies of competence and qualifications investigates the relationship between competence and qualifications by studying complex, dynamic problem solving. A task environment simulating construction, production, product development, and selling of goods (computers and chips) on the world market are to be managed by teams of two persons.

A conception of competence, qualifications, and learning is presented, and the conditions for interpretation of the concepts by catastrophe theory are stated.

Four issues concerning the data obtained by the verbal exchange between team members are discussed, and the hypothesis that variations of problem solving forms and values of control parameters can be explained by a cusp-catastrophe is examined. The discussion displays that the main problem in our modeling attempt is how to operationalize the control parameters and the problem solving forms. This problem will be pursued in further analyses.

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