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Knowledge representation and search processes: A contribution to the microeconomics of invention and innovation

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Knowledge Representation and
Search Processes -
a Contribution to the Microeconomics
of Invention and Innovation

von

Frank Beckenbach

Nr. 75/05

Volkswirtschaftliche Diskussionsbeiträge

*"Forschung macht aus Geld Wissen –
Innovationen machen aus Wissen Geld"
(Volksmund)*

KNOWLEDGE REPRESENTATION AND SEARCH PROCESSES

A contribution to the microeconomics of invention and innovation

*by Frank Beckenbach**

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I. Introduction

Novelty creating processes have been mainly analysed in a 'post-revelation' situation and by taking a meso (or even macro) level perspective. One reason for this might be a methodological caveat according to which *firstly* the novelty creating process (henceforth: ncp)¹ is totally conjectural without anything to generalize and *secondly* the results of a ncp can not be anticipated leaving only room for some after-the-fact-analysis on a more or less aggregated level. Without denying these assumptions the following considerations assume that it is worthwhile to analyse the ncp from a microeconomic perspective including 'pre-revelation' situations. The subject matter of such an analysis is constituted by the following components:

- the triggering conditions for ncps,
- the constraints for ncps,
- the expectations of agents/agencies promoting ncps,
- the heuristics for ncps and finally
- the processing of the ncps themselves.

In this article I will deal with these topics by proceeding in the following manner: (1) I discuss the shortcomings of the usual analysis of ncp in evolutionary economics and pick up some hints of the cognitive sciences to overcome these conceptual shortcomings (section II). (2) I try to combine stylised facts of the microeconomic analysis of ncps with conceptual ideas about a cognitive architecture of agents and knowledge networks for getting a modelling framework. (3) I will present some preliminary simulation results for parts of this simulation model (section III).

II. Signposts of theory

II.1 Evolutionary economics

II.1.1 Neglecting the microeconomics of ncps: the Schumpeter legacy

(1) Generally the microeconomics of ncps is a neglected topic in the schumpeterian tradition of evolutionary economics. This neglect has several reasons. *Firstly*, there is a neglect of invention as a specific part of ncp. It is assumed that invention has no economic character because it has a conjectural nature. This corresponds to the focus on the entrepreneur for whom a stream of inventions is given as a basis of his selection activity. Here invention is not seen as a goal directed planned or strategic operation. Therefore it is assumed that it is not a topic of economics.

Secondly, the focus is on the entrepreneur as a person with the ability to recognize opportunities for technical, organizational and economic novelties. This person is linking a given stream of ideas, concepts and the like on one side and market possibilities on the other side. Hence, inventions are exogenous. The individual perspective in ncps is reflected only in

¹ A ncp is a process leading to an enhancement of the possibilities to act. Typically ncps can be divided in the phases of invention and innovation. Invention means the creation of a conceptual novelty. It denotes the creation of an idea or a concept, waiting for being applied in a practical context. Such a new idea or concept might be based on new knowledge which is simultaneously created with the invention ("primary inventions" in the sense of USHER 1971, pp 50) or the invention is the result of new applications of a given set of knowledge ("secondary invention", *ibid.* pp 54). Contrary to that innovation means the creation of an instrumental novelty. In many cases it is the process of applying and thereby figuring out the result of the invention process. Generally this process has to meet two requirements: The feasibility of applying the inventive idea/concept has to be shown in technical, institutional, and behavioural terms. Furthermore, a path to the marketability of this feasible application has to be demonstrated. Invention and innovation are separable (but partly overlapping) parts of the ncp. Even if some features of invention and innovation are essentially different their unification to a ncp is reasonable due to feed forward and feed back relationships between these phases, due to the possibility of identical personal in both phases and finally due to a common institutional frame work.

terms of extraordinary personal qualities (e.g. SCHUMPETER 1964) but not in terms of the normal microeconomic regularities of the ncp.

Thirdly, most of post-schumpeterian investigations of ncps is about (problems for the) diffusion of given innovations and about market dynamics as a whole (relationship between size of firm and its innovation activity). In both cases the ncp is dealt with no (or only partial) reference to the individual level.

Corresponding to that in modern Schumpeterian models of economic evolution the ncps are treated as a black box. An example is the Nelson/Winter modelling paradigm (NELSON/WINTER 1982; ANDERSEN 1994). Here r&d activities are either reduced to the expenditures they afford and in this respect determined by a given routine. Or they are disguised in a black (magic) box the access to which is determined by the expenditures and the outcome of which is given by a two step lottery. The implications of such a procedure are

- that there is a strong correlation between the level of fitness and the probability to draw such a fitness (depending on the probability distribution function),
- that there is no possibility for mapping the knowledge of inventors or innovators about possible options,
- that the local character of the search process is not depicted and finally,
- that there isn't any kind of deliberation in the search strategy.

This simplification seems to support the methodological proviso and the schumpeterian neglect of invention derived from it. Paradoxically with respect to the starting points of the Nelson/Winter line of evolutionary economic thought it is questionable if this simplification in modelling the ncp is unavoidable.

II.1.2 Approaching the microeconomics of ncps: the early Nelson/Winter legacy

(1)The starting point of the following review are two early articles of R. R. Nelson on the topic under investigation here (NELSON 1959a; NELSON 1959b). The motivation for these articles is to show that invention (including the use of basic scientific research) is a legitimate topic of economic analysis – though it has some intricacy.² It is a topic of economic analysis because what is going on in inventive processes is to a large degree influenced by expected yields and calculable costs – at least the process of invention is linked to an economic activity motivated by private goals.

The intricacy of this topic is twofold: *firstly*, even if invention is a private activity it is embedded in a public domain. The supply side of this activity is 'pushed' by (basic) scientific research because the latter is the resource of applicative specifications and instruments used in a given inventive process. The demand side of this process is 'pulled' by social needs a part of which are transformed into market demand. Hence, if invention takes place as a private process the goals of the inventors may be related to this public background (in terms of scientific insights or social needs – or both).

"Increases in scientific knowledge, by reducing expected costs, and increases in demand, by increasing expected gross revenue, act to increase the expected profitability of an invention and hence the invention effort applied. This analysis by no means implies that inventors, private or hired, are spurred exclusively by economic motives. But, if economic motives are important ones, then an 'economic' theory of invention should help to explain and predict the rate and direction of inventive effort."(NELSON 1959a, 107)

² "Invention" is used by the authors in a broad sense at least including some aspects of what has been called "innovation" in the definition given in footnote 1.

But such an economic approach to invention has to be aware of the constraints for making all basic scientific research marketable as well as of the impossibilities to transform all social needs into market demand.³ For the supply side this is expressed in the following quotation:

"It seems clear that, where the field of basic research left exclusively to private firms operating independently of each other and selling in competitive markets, profit incentives would not draw so large a quantity of resources to basic research as is socially desirable....Though the profit motive may stimulate private industry to spend an amount on applied research reasonably close to the amount that is socially desirable, it is clearthat under our present economic structure the social benefits of basic research are not adequately reflected in opportunities for private profit."(NELSON 1959b/1971, pp 159)⁴

How to determine the "socially desirable" amount of basic scientific research in a dynamic evolutionary frame work is not explained by Nelson. In microeconomic terms this intricacy is tantamount to the difficulty for the novelty creating agent to appropriate individually the yields of a successful novelty.

The *second* intricacy of invention as a topic of economic analysis is the basic uncertainty in terms of required inputs as well as in terms of direction and output of the process. This is due to the conjectural nature of invention apparent in the number of trials, experiments etc. before getting a valuable result. This conjectural nature of invention is also demonstrated by the well-documented experience that successful inventions (those leading to an innovation) are often an unintended by-product of unsuccessful attempts to get an intended result (cf. NELSON 1959a, 112, 115ff; NELSON 1959b, 154).

"Thus the evidence is that, though the expected profitability of an invention in a particular field affects the rate of inventive activity in that field, the tremendous uncertainties involved in making any major technological breakthrough preclude either the routinization of invention or the precise prediction of invention."(NELSON 1959a, 115)

Already at the time when Nelson wrote his article tremendous efforts have been made to overcome (or at least to reduce) this uncertainty by 'planning' invention in separating resources for it in r&d laboratories (ibid. pp 110). Yet there remains the necessity of a flexible organization, task assignment and task implementation in these laboratories.

"However, many laboratories have some formal project-selection plan involving the comparison of profitability of success, expected costs of the project, expected capital requirements, production costs, analysis of the market demand for the product, consonance of the product with company production know-how and sales contacts, etc. It is clear that these calculations are subject to great uncertainty and have only limited value, even when the goals of the project are well defined – developing a specific type of product for a specific use, solving a specific production problem. There seems to be wide agreement that the calculations are almost completely meaningless in areas of research where there is no specific practical goal in mind."(NELSON 1959a, 124)

Taking both intricacies (public embeddedness and strong uncertainty) together one has to conclude, that the level of inventive activities may be influenced by economic expectations but that there is no simple financial incentive scheme determining the way inventors work and hence it is impossible to guarantee a desired output.

(2)Having thus established invention (at least partially) as a topic of economic analysis, the question comes up how the very process of invention takes place. Later on R.R. Nelson in collaboration with S.G. Winter (NELSON/WINTER 1977) try to sketch an answer to this question⁵. They propose to conceptualise invention (or the generation of innovation) as a search process in a large space of possible projects. Due to their limited knowledge the inventing agents have to use space reducing heuristics. Due to the above mentioned

³ Hence the possibility of tension between the outcomes of supply-side feasibility orientation of invention and social needs on one side and the outcomes of demand-side orientation and scientific and technical feasibility on the other side.

⁴ The background for this diagnosis of a gap between the 'socially desirable' und the privately eligible basic research is a positive externality accrued to the latter. But due to time lags and uncertainties for the output of basic research (NELSON 1959b, pp 158) this externality has to be conceptualised in a dynamic context.

⁵ More precisely they are asking how the "generation of innovation" (ibid. 49) takes place.

conjectural nature of the process each step in the search process is given in probabilistic terms. A search strategy then consists of two essential steps: *step 1* is the probabilistic selection of an appealing project; *step 2* is the configuration of the project leading to a probabilistic pay off (ibid. pp 52; cf. NELSON 1982, pp252, 456).

As to the direction of this search process both the supply side and the demand side discussed above come into play:

"...(O)ne can imagine a strategy that focuses on the 'demand' side and picks out a list of inventions that if made would have a good market, for later screening according to feasibilities and costs. Or one can imagine a strategy that initially picks out projects where major technological breakthroughs seem possible, for later checks for market ability....However, if one thinks about it for a moment, both a pure demand-pull and a capabilities-push strategy would appear to be naïve. One might posit that a strategy that involves more backing and forthing between demand and supply side conditions would be more powerful."(NELSON/WINTER 1977, pp 54; cf. NELSON/WINTER 1982, pp 254)

This begs the question if there is an internal bias in orienting the search strategy due to limitations in knowledge and capabilities which implies a more or less sequential search strategy.⁶ Such a bias is e.g. given by the "technician's beliefs about what is feasible or at least worth attempting"(ibid. 57). Such a bias defines a technological regime and a multitude of "natural trajectories" compatible with it.

"The sense of potential, of constraints, and of not yet exploited opportunities, implicit in a regime focuses the attention of engineers on certain directions in which progress is possible, and provides strong guidance as to the tactics likely to be fruitful for probing in that direction."(NELSON/WINTER 1977, 57; cf. NELSON/WINTER 1982, 258ff)

Such "natural trajectories" include elements specific for a given technology as well as common elements for a wide range of industries such as e.g. exploiting scale economies, increasing mechanisation or enhancing the use of electronic equipment (ibid. 58f).

Obviously the direction and the steps of the inventive search process are both strongly influenced by the knowledge of the inventor(s). But what exactly is that knowledge and how does it evolve in the course of the inventive process? To answer this question by simply referring to the amount of money spent for r&d as 'knowledge capital' is not to the point. Contrary to this simplistic proposition NELSON (1982, pp 464) gives a threefold answer: (i) Knowledge is related to the dimensions of the search space and their correlations as well as to the availability of search heuristics. (ii) At least partly knowledge is cumulative in that the knowledge gained in one round of search influences the next round and can be conserved for a while. (iii) Knowledge consists of private and public components which are complementary in nature as regards to the evolution of knowledge.

Unfortunately the above mentioned features of novelty creation as a topic of economic analysis are not adequately translated into features of the famous Nelson/Winter models of innovation and diffusion. One reason for this incomplete transfer of Nelson/Winter's earlier ideas about the search process in their later work might be the choice of a higher level of abstraction. This would be in accordance with the distinction between a description of the search process including the "...cognitive processes typical of some identifiable group of 'searchers' in a particular economic context."(WINTER 1986, 203) on one side and the "...abstraction from the underlying technological and organisational detail"(ibid.) in economic analysis in terms of unit costs, input coefficients etc on the other side. The implicit assumption in this distinction is that there is nothing general in the cognitive features of a search process or at least that these features should not be part of economic analysis.

(3) Rejecting or accepting these doubts about the microeconomic accessibility of ncps depends on working through the research agenda on invention as a topic of economic analysis. Such an agenda is derivable from the early thoughts of Nelson and Winter about this topic. The

⁶ "Since all alternatives cannot be considered, there must be some rather mechanical procedures employed for quickly narrowing the focus to a small set of alternatives and then homing in on promising elements within that set."(NELSON/WINTER 1982, 255)

following questions (partially comprised in the works quoted above) are at the core of such an agenda:

- In what kind of economic situations do economic agents switch to inventive activities/pick up the outcomes of a r&d laboratory?
- How much money and time is spent for this activity?
- How does the ncp proceed? Are there patterns and regularities in this process or is it totally heterogeneous, contingent and stochastic? Does this process take place as a free discourse or is it dominated by command and control? Is the search local or global? Is the search sequential or parallel? What is the relationship between the virtual and real elements of search? Are there path dependencies?
- What kind of knowledge (deductive vs. inductive, public vs. private, explicit vs. implicit, declarative vs. procedural etc.) plays what role in such a process? How do the public and the private elements of knowledge interact?
- What is the influence of supply side/demand side on (i)the amount and (ii)the direction of the search process?
- How is the inventive search process determined by the institutional form (single agent, department of a hierarchical organization, cooperation) in which it takes place?
- Is a general statement about the influence of r&d expenditures on the pay off possible?

Obviously there is no frame work in which all these questions can be dealt with adequately. As already emphasized by Nelson and Winter, to catch the strong uncertainty and the conjectural nature of the ncp is beyond the scope of traditional allocation analysis. But also traditional (Darwinian) evolutionary concepts are not prepared to portray all the specificities of the ncp. Recent research has shown that especially the possibility to figure out a possible problem solution virtually and the diverse forms to communicate knowledge are hardly intelligible in the usual variation/selection/replication frame work of Darwinian evolutionary theory (cf. NELSON/NELSON 2002, pp 728; LOASBY 2002, 1230). Therefore it is appropriate to look out for other theories reflecting the features of the ncp.

II.2 Cognitive sciences

The common denominator of the cognitive sciences⁷ is the analysis of the way information is perceived, mentally mapped and manipulated as well as stored and retrieved by human agents. But beyond this common denominator the subject of cognitive sciences, especially in methodological respects, is a contested terrain. This contest is going on between 'symbolism', 'connectionism' and 'evolutionism' (cf. NELSON/NELSON 2002, pp721). In the symbolistic approach to the information processing by human agents the point of reference is the processing of symbols done by sequentially operating computers. In the connectionist approach a more holistic view is taken by reconstructing mental operations out of a parallel processing of simple mechanisms. Finally in the evolutionist approach the biological as well as the social embeddedness of the human mind and hence the biological foundations of knowledge acquisition and their further cultural development are emphasized.

In the modern mainstream of cognitive sciences there is still a bias towards the symbolistic approach but endeavours are undertaken to integrate connectionist and evolutionist ideas and concepts. The focus of this mainstream analysis of human information processing in modern cognitive sciences is on goal directed behaviour. Hence, there is a natural kinship with economic analysis. The basic assumption is that the observable actions of human beings can be explained by their (unobservable) way to perceive, to accumulate knowledge and to find

⁷ The cognitive sciences embrace parts of philosophy, psychology, linguistics, anthropology, neurosciences and artificial intelligence research (cf. WILSON/KEIL 1999).

goals (cf. WALLACH 1998, 18). In the following I will refer to cognitive psychology and to artificial intelligence for a sketch of some insights which are important for the microanalysis of ncps.

II.2.1 Cognitive psychology: clarifying knowledge and cognitive control

(1) First of all cognitive psychology can help to specify the building blocks of knowledge and to clarify the way the latter are generated and possibly destroyed. According to this view knowledge consists of a clustering of information on different hierarchical layers (cf. ANDERSON 2000). The basic level consists of a network of "propositions" which combine events, subjects and predicates to a simple statement. Depending on a given situation a number of more or less fitting propositions are activated by the human agent. According to the connections of similar propositions some spreading of activation takes place between neighbouring propositions. Hence, the basic operation of knowledge acquisition is local. On a more general level these propositions are combined to "schemata" (or "scripts" in the case of events with a temporal structure). The increase of generality is achieved by focussing on the essential features of anything in the real world, for which some elements of the propositions may be unimportant. "The premise underlying the schema notion is that information about the likely property of the environment is stored in memory in clusters that can be accessed in large units and that can serve to generate plausible inferences and problem solutions." (HOLLAND et al. 1986, 12) These schemata are built in a long term process of observation and experience whereas the next level of knowledge generalization – "mental models" – are defined by the possibility to flexibly combine schemata or scripts for the purpose of explanation or prognosis (ibid. 30). The development of these forms of explicit knowledge, i.e. knowledge which can be an element of the communication between agents, is intermingled with the development of knowledge and abilities which are at least difficult to transform into an element of communication i.e. tacit knowledge and skills (cf. ANDERSON 2000, pp 282f; DREYFUS/DREYFUS 1988, 19ff).⁸

Why is this differentiation of knowledge relevant for ncp? *Firstly*, the creation of novelties requires the highest possible level of expertise in terms of explicit and implicit knowledge as well as in terms of skills. Quick recognition of prototypical patterns, "holistic discrimination and association" (DREYFUS/DREYFUS 1986, 28), accompanied by a rich knowledge about special cases, are important features of this level. *Secondly*, the ability to explore the fuzzy borderline between explicit and tacit elements of knowledge and transferring the latter into the former is a source of novelties (cf. NONAKA 1991). *Thirdly* and most importantly, what is required is an ability to disrupt the given order of knowledge: either as enhancing the spreading activation on the levels of propositions and/or experimenting with schemata as a radical change of mental models (GUILFORD 1959).

(2) A ncp is an ambitious way to act: it requires much "cognitive effort" (cf. PAYNE et al. 1993, pp 75) in terms of perception, decoding knowledge from the long term memory and manipulating knowledge as well as actual data in the working memory. The amount of cognitive effort mobilized by an agent in a given situation depends on cognitive control procedures. Though the cognitive resources of human beings are limited ("scarce"), there is no centralized allocation procedure for them. Rather research and experiments show that there is an adaptive process between given cognitive capacities and the cognitive requirements of a

⁸ Following the work of Donald a different classification of the building blocks of knowledge and their development is proposed by NELSON/NELSON (2002, 724).

given situation going on.⁹ This adaptive process consists of conscious as well as unconscious elements (cf. KLUWE 1997; RASMUSSEN 1993, pp 166).

Two 'mechanisms' of this cognitive control process seem to be important here: (i) generating a reference level of goal attainment and (ii) establishing a motivational balance. The reference level classifying activities as "below", "equal" or "above" this level may be either simply the status quo (as in the case of prospect theory of Kahneman/Tversky) or it may be the result of assimilating experience or observing reference groups (as in the case of the concept of aspiration level of Lewin and Festinger). Especially in situations where the actual goal attainment is below the reference level there is evidence for a strong evaluative reaction and hence a willingness of the agent to enhance cognitive effort. Partly complementary and partly antagonistic to the reference orientation in allocating cognitive efforts is the balancing of motivational capacities (defined by extrinsic and intrinsic resources) and motivational requirements of a given type of activity. The willingness of an agent to increase the cognitive effort (even if the level of goal attainment is above the reference level) is given then in situations of motivational slack, i.e. if motivational capacities are larger than motivational requirements (cf. SCITOVSKY 1976).

From the perspective of this cognitive control the ncp circumscribes an extraordinary temporary mode of action – even if the inventive part of the ncp may be a continuous activity of a single person or a r&d laboratory. Hence ncp is part of an action cycle passing through different modes of action (cf. LOUIS/SUTTON 1991, 57). Switching between these different modes of action does not simply depend on how the real life situation changes but rather it depends on the cognitive mapping of the situation and the way this mapping is triggering cognitive control. The occurrence as well as the intensity of search for a novelty is therefore determined to a large part by the history of this action cycle (e.g. by setting the aspiration level and the degree of motivational balance).

II.2.2 Artificial Intelligence research: frame work of problem solving

(1) Obviously a ncp can be seen as a process "solving a problem". A conceptual frame work for dealing with this kind of processes going on in human beings in specific situations have been developed in the artificial intelligence research especially with origins in the symbolic branch of this research.¹⁰ This frame work can be used for characterizing the basic elements (and their interrelationships) relevant for ncp. Furthermore such a frame work allows for figuring out the similarities as well as the specific differences between the phases of invention and innovation and to clarify their relationship.¹¹

The starting point of the problem solving procedure is the perception of a "problem". "A person is confronted with a *problem*, when he wants something and does not know immediately what series of actions he can perform to get it.....To have a problem implies (at least) that certain information is given to the problem solver: information about what is desired, under what conditions, by means of what tools and operations, starting with what initial information and with access to what resources."(NEWELL/SIMON 1972, pp 72). Hence the essential feature of a problem is a divergence between the given and the desired state of affairs. The conditions for eliminating this divergence are on one side the well known constraints of the agent (in cognitive as well as economic terms) and on the other side the (virtual and real) transformation devices for the given state of affairs. Yet, the applicability of

⁹ The central hypothesis made by cognitive scientists about this adaptive process is that there is some kind of cognitive economizing in that for a given situation only the absolutely required cognitive resources are used by this generating some cognitive surplus which is then absorbed in more ambitious tasks (cf. ANDERSON 1993).

¹⁰ For the origins of this line of research cf. NEWELL/SIMON 1972, for the modern state of the art cf. LUGER 2002.

¹¹ In the following I refer to BECKENBACH/DASKALAKIS 2003.

these transformation devices is uncertain in that there is only a rough idea about the appropriateness of these devices. "Problem solving" then is the process of finding out a sequence of states between the initial and the desired final state under the given constraints. This process is based on a "mental representation, a mental scheme for holding information in memory and operating on it" (SIMON 1999, 674). The elements of the mental representation are (i) an interpretation of the given situation, (ii) a listing of the transformation devices (called "operators") according to this interpretation and (iii) a test and evaluation mechanism for the results of operator application. The listing of the transformation procedures within the mental representation is not complete even with reference to the agent's knowledge because not all the procedures contained in the knowledge stock are activated. This would easily lead to a combinatorial explosion of transformation possibilities which, due to cognitive constraints, would have to be dealt with only on a trial and error base. Therefore the problem solver has to restrict himself to apply more or less general search procedures (heuristics) to reduce the size of the problem space, i.e. the space which is defined by applying all available transformation possibilities to all possible states.¹²

This sketch of the seminal contribution of Simon and Newell to the analysis of the elements and process of problem solving shows, that this is a path breaking alternative to the standard model of the deliberate decision process (i) in that it focuses an open ended search behaviour divided in the statement of the given situation, the figuring out of the problem space and finally the solution of the problem; (ii) in that it integrates the assumption of bounded rationality in terms of knowledge dependent problem representation and in terms of limited capabilities of problem manipulation (e.g. by heuristics). Due to these cognitive constraints the process of problem solving becomes sticky and path-dependent.

Nevertheless – at least in its original form – the concept has a rather narrow scope. *First*, it takes only the performance dimension into account which abstracts from basic abilities of the agents as well as from individual specificities. *Second*, according to the computer oriented context in which this concept of problem solving was originally developed, it had been finally confined to clear cut ("well defined") problems. This means that the goals of the agent as well as the heuristics used for reaching this goal are specified in such a way that the results of the application of these heuristics can be unambiguously evaluated with respect to their goal-reaching capability. Furthermore it is assumed that this capability is even measurable in terms of a larger or smaller distance to the goal. *Third*, it is assumed that the definition of the problem and the finding of the problem solving devices are two separable elements and that the problem solving devices are merely instrumental for the problem itself. Thus, only these solution devices are varied during the problem solving process.

(2)By getting rid of these constraints the problem solving frame work becomes appropriate for portraying ncps. Problems to solve by ncps are usually not well defined. Sometimes even the understanding of the initial situation is not in such a way clear that it can be transformed into a mental representation. Consequently it remains vague in which way such a situation can be influenced by any kind of operator and which goals are appropriate for it. However, even if the situation is well understood it might be difficult to solve a problem because there are multiple incommensurate problem spaces and/or a lack of appropriate operators/heuristics making it intricate to find a sequence of reasonable operations. Finally, it is possible that the goal is not defined in an unanimous manner. These caveats are the background for admitting "ill defined problems" (SIMON 1977) and thereby broadening the scope of the concept of problem solving.

The inconveniences arising with ill defined problems – which do normally occur in an uncertain world – change the character of the problem solving process. *First*, it is not any

¹² These heuristics might be either explicit in that they are explicable and even programmable or they might be implicit in that a given situation includes cues about what to do for the experienced problem solver.

longer 'directed' insofar it successively reduces the gap between initial and final (goal reaching) state; rather it might circle around or even be regressive by broadening the gap. This is due to the lack of appropriate operators/heuristics and/or the goal ambiguity. *Second*, the instrumental role of problem solving devices does not hold anymore if the problems are ill defined. Under this condition heuristics and operators as emanations of the stock of knowledge are themselves influencing the way the problem is posed at every time step. Problem solving then becomes an iterative and simultaneous exploration of problems and solutions.

Ncps can be interpreted as processes solving ill-defined problems. Normally, there is no possibility for an unambiguous testing before really selecting and practicing an option. Furthermore the constructive role of operators and heuristics is unavoidable. The focus inherent in the known heuristics as well as the available operators determine the way the search for novelties takes place. Finally a feature of the ncp is a vague search space even if heuristics and operators are clear. This is due to structural uncertainties about the elements of the state space.

(5)Coming back to the research agenda for ncps some preliminary insights are worth to gather:

- The ncp is a specific mode of action for information processing and knowledge accumulating agents. This mode of action can be characterized as a search process the quintessence of which is solving (ill-defined) problems.
- Even if there might be some autonomous factors for a continuous flow of inventive activities, an economic reason for initiating ncps as a whole is given if either the pay off of the activity falls under the goal-directed reference level and/or the cognitive capacity of the agent in terms of motivation is not exhausted.
- Considered as a specific problem solving endeavour the ncp indeed has some common elements: the mental representation of the initial situation as well as of the possibilities to alter this situation strongly depend on a basic cognitive grammar in declarative terms (propositions, schemata and models) as well as in procedural terms (heuristics and operators). The 'art of search' is then constituted by making use of a stock of these elements of knowledge based on experience and observation to explore the neighbouring areas of this knowledge. Taking into account the limits for parallel cognitive processing it seems reasonable to assume that the standard form of search is a sequential local exploration divided into a virtual and a real part (feeding the latter back to the former).
- Specifying the knowledge in such a process two distinctions seem to be crucial: (i) the distinction between explicit and tacit knowledge und (ii) the distinction between declarative (domain related) knowledge and procedural knowledge (not domain specific). Generally the procedural knowledge seems to be more important in the inventive phase than in the innovative phase of ncp. Tacit knowledge is crucial in the beginning of both phases where lot of guessing and testing is indispensable.
- 'Natural trajectories' as well as general path dependencies in the problem solving search process indicate that the ncp is to a large degree dominated by the supply side: Insights of (basic) scientific research, technical feasibilities as well as behavioural and institutional possibilities are much easier to feed into the search process than the orientation of the demand side which is not unanimously signalled to this early stage of the production of commodities and services.

III. Modelling the search process

III.1 Frame work

(1)The signposts of theory for treating ncps indicate that one has to take into account a twofold nature of economic processes. The 'outer' world of observable facts is accomplished by an 'inner' world of unobservable cognitive processes. Because both worlds interact none of the worlds is explainable without referring to the other. Due to limitations, distortions and even unconscious operations in the cognitive processes constituting the inner world of the agent, the outer world as well as the inner world cannot be fully known to the agent. Hence, a full range modelling of these processes requires an artificial observer perspective (observer dummy) for which all these constraints are not given and which is therefore not accessible for any agent.¹³

Taking this observer perspective, the architecture of an agent acting in the outer world by referring to its inner world needs specification. According to what has been sketched above about the cognitive grammar and the cognitive control the way the agent operates in the outer world depends on its inner cognitive states, especially on the reference level and on the motivational balance built by previous experience. Comparing the actual pay off with the reference level and weighing the motivation absorbed by a given activity (motivational demand) against the motivational supply then determines which mode of action is selected. Corresponding to empirical observations and their theoretical analysis the following modes of action are distinguished: single routine, multiple routine, choice, imitation and invention/innovation (cf. SVENSON 1990; LOUIS/SUTTON 1991; JUNGEMANN et al. 1998; BECKENBACH 2004). Any such mode is temporally structured by evaluating the situation, checking the possible options, discriminating between the latter and finally selecting an option. Fig. 1 show how these processes can be specified for the invention/innovation mode.

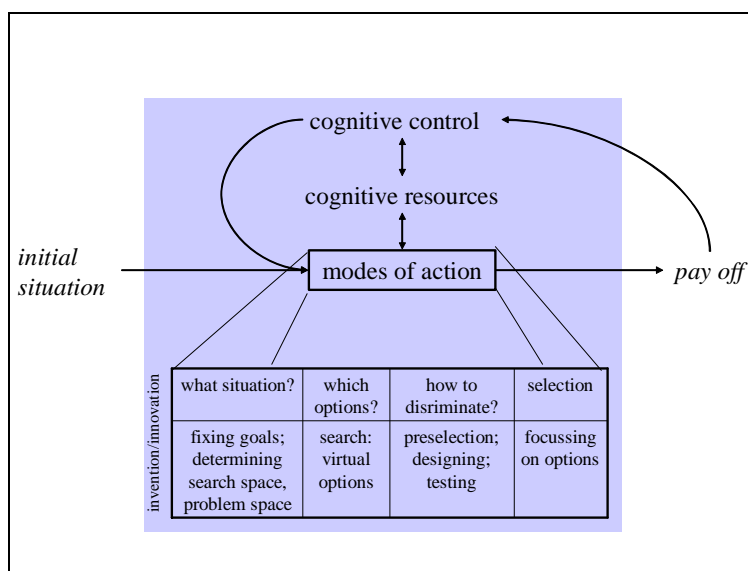


Fig.1 : Scheme of action

Inventive and innovative search processes are either triggered in the case of a strong missing of the reference level or in the case of a motivation surplus ("motivational slack"). If this search is successful, in the course of time the new option will become part of the routine or choice setting of the agent. Therefore, invention and innovation are the bygone sources of what is the usual starting point of microeconomic consideration.

¹³ Hence, contrary to rational expectation models the observer remains artificial.

(2)The signposts of theory for treating ncps as a topic of economic analysis imply some special requirements if the underlying search process shall become a part of an economic model. The major difficulty for the modelling is here that the cognitive operations are part of a process the result of which cannot be known in advance. Hence, assuming that these results of ncps are derivable (due to the dynamic setting of the model and the included iterative procedures) necessitates to use some dummy constructions. In the Nelson/Winter path of evolutionary economics this dummy construction is a two step lottery by which a given goal can be improved (cf. NELSON/WINTER 1982; ANDERSEN 1994). But this black box approach to the ncp does not pick up the features of the search process underlying the ncp sketched in section II (e.g. knowledge representation or the local path dependent nature of search). Hence, it is suggested here to give this knowledge-dummy a more plausible face.

According to this knowledge dummy perspective the state space is specified in terms of an (objective) knowledge base for the (subjective) problem space of the agents. This objective knowledge base consists of the common (scientific) knowledge as well as of the observable configurations of the instruments, the processes and the products of ncp. A part of this knowledge base is specific for the situation in which an agent starts the ncp. In a simplified modelling perspective the attributes of the artefacts under construction, the expressions for these attributes, and the interdependencies of these attributes are assumed to be the relevant dimensions of this knowledge base as regards to its serving for a given goal ('fitness'). In an evolutionary world this knowledge base is changing due to new discovered attributes and their influence on given attributes (emergence of new connections between attributes). Hence – at least in the long run – the knowledge base is an evolving system of attributes and connections. A requirement for modelling the search process in accordance with the features sketched in section II is an agent specific imperfect mental mapping of the knowledge base. Generally this subjective mapping (mental representation) is a consequence of the cognitive limitations of the agents:

- their ability to perceive the elements of the initial situation is restricted;
- one part of the knowledge stock of the agent consists of a limited number of elements of the knowledge base the coding of which is given in a reduced form (declarative knowledge);
- the other part of the knowledge stock is related to the possibility to explore the unknown elements of the knowledge: it consists of a limited number of heuristics and operators for that exploration and of some knowledge about the appropriateness of these search instruments (procedural knowledge).

Based on these cognitive limitations there is a cognitive framing in terms of interpreting a situation and in terms of a pattern building for acting in such a situation. This framing is shaped either in a process of individual socialization and/or in following domain specific path dependencies the most prominent case of which are the 'natural trajectories' mentioned in section II.1.2. Hence, cognitive framing is a prerequisite as well as a result of experience and learning (cf. FLEMING/SORENSEN 2001, 1035; GAVETTI/LEVINTHAL 2000, 114, 133).¹⁴

According to the concept of problem solving a search strategy of an agent can be understood as proceeding in the following steps: (i) transforming the mental mapping of the initial situation by using the individual knowledge stock and the search capacities in terms of heuristics and operators, (ii) changing of real world configuration derived from (i), (iii) evaluating if the requirements of a stopping rule are fulfilled and – if this is not the case – starting (i) again etc. until these requirements are met. Hence, in the search process the

¹⁴ From the perspective of complexity theory this cognitive framing as well as limited knowledge based on the latter are two forms of reducing complexity of the search space (cf. THOMKE et al. 1998, 316f).

interdependence between cognitive and real world processes are realized. The task of the search process is to use the limited knowledge about the states of the world (knowledge stock) as well as the limited knowledge about the possibilities to enhance this stock by heuristics and operators in a way that makes an improvement in terms of goal attainment as probable as possible. This kind of intelligence has to be learnt by the agents while searching in the state space.

(3)The objective knowledge base as well as the subjective search processes in that knowledge base can be approached in a modelling context by referring to the NK networks of Kauffman (cf. KAUFFMAN 1993, KAUFFMAN et al. 2000). In this framework the objective knowledge base consists of a set of options each of which is composed of the same finite number (N) of attributes which can exist in a finite number of expressions. To each of these option is assigned a fitness-value¹⁵ which – due to a lack of (observer-)knowledge – is fixed randomly in a given interval of numbers (cf. KAUFFMAN 1993, 41).¹⁶ This fitness is derived from the efficiency of the artefact the construction of which is instrumental for the achievement of an economic goal. Each of the attributes of an option contributes in a linear manner to this fitness value which is built as the mean value of these contributions (w_i/N).¹⁷ Within each option there is the possibility that an attribute's contribution to the fitness value is dependent of other attributes of the same option or even of the attributes of another option. Due to the focus on the search process (and not in the implementation of possible results of search) the connections between different options are neglected here. For the sake of simplicity it is assumed (i) that the connection within an option are 'functional' in that they are not dependent of a specific expression of an attribute, (ii) that they are ubiquitous in that they are given for the corresponding attributes in all options, (iii) that they are symmetric and finally (iv) that the number of connections is either the same for all attributes (regular graph) or is randomly distributed between the attributes if the number of connections (c) (irregular graph).¹⁸ K (K_i) is then the number of these option specific dependencies between the attributes.¹⁹ The dependencies between the attributes of the network can be expressed by a connection matrix, indicating by "x" in a row an influence on the row element coming from the element in the column (cf. fig. 3). An important feature of the NK (NK_i) network is the possibility to measure the distance (d) of the options by the number of attribute expressions in which they differ and to order the different options according to the distance they have from each other.²⁰ A set of options ordered in such a way is called here an 'option landscape'.²¹ In such an option landscape much of the required features of the objective knowledge base are depicted:

- N and K (K_i) reflect the main dimensions of this knowledge base and are both akin to portray an evolutionary change of the knowledge base (increase/decrease of both dimensions and change of the structure of K or K_i).
- The essential locality of options is captured by d .
- The sequential nature of dealing with different options in a search is respected by ignoring interdependencies between options when fixing the fitness value.

¹⁵ This fitness-value is given for a given objective knowledge base.

¹⁶ In KAUFFMAN 1996 (pp 260) the intention to formulate a general model is mentioned as a further argument for the stochastic modelling of the fitness.

¹⁷ Hence, there is no positional bias for the attribute's fitness contribution.

¹⁸ The resulting architecture of connections is important for the search strategy in general and especially for 'modularizing' as a particular search strategy (cf. BALDWIN/CLARK 2000 and section III.3.1 below).

¹⁹ For K (K_i) it holds: $0 \leq K$ (K_i resp.) $\leq N-1$.

²⁰ For d it holds: $0 \leq d \leq N$.

²¹ Because Kauffman focuses on recipes for technologies his notion is "technology landscape" (KAUFFMAN et al. 2000).

- Finally there is an artificial way to portray the search problem which is involved in every ncp in that there is a strong influence of K (K_i) on the fitness landscape. This influence can be summarized in two statements: (i) the higher K (K_i) the lower the average fitness of all options; (ii) the higher K (K_i) the more the fitness landscape becomes "rugged", i.e. the higher is the number of local fitness peaks surrounded by options with a low fitness.

This modelling architecture of the objective knowledge base is illustrated in the following example for $N = 4$ and binary expressions for the attributes (cf. fig 2). In this case a lattice order (with von Neumann neighbourhoods and continuous border conditions) for the options is possible. The minimal number of moves in the horizontal and/or vertical direction corresponds to d . Assuming $K = 3$, $K = 0$ respectively (cf. the corresponding connection matrix in fig. 3 for the attributes A, B, C and D) and $w_i \in [0,1]$ the fitness values are given in Table 1. Fig. 3 gives an impression of the different fitness structure in these two cases.

0100	1100	1101	0101
0110	1110	1111	0111
0010	1010	1011	0011
0000	1000	1001	0001

	d = 0
	d = 1
	d = 2
	d = 3
	d = 4

Fig 2: Option landscape and distance with reference option "1010"

	A	B	C	D
A	-			
B		-		
C			-	
D				-

	A	B	C	D
A	-	x	x	x
B	x	-	x	x
C	x	x	-	x
D	x	x	x	-

Fig. 3: Connection matrix for $K=0$ (left) and $K=3$ (right)

ABCD	w_1	w_2	w_3	w_4	$\sum_{i=1}^4 \frac{w_i}{N}$	ABCD	w_1	w_2	w_3	w_4	$\sum_{i=1}^4 \frac{w_i}{N}$
0000	0.45	0.63	0.67	0.4	0.54	0000	0.45	0.63	0.67	0.4	0.54
0001	0.45	0.63	0.67	0.38	0.53	0001	0.29	0.58	0.42	0.38	0.42
0011	0.45	0.63	0.7	0.38	0.54	0011	0.2	0.11	0.7	0.88	0.47
0111	0.45	0.30	0.7	0.38	0.46	0111	0.42	0.30	0.54	0.35	0.40
1111	0.94	0.30	0.7	0.38	0.58	1111	0.94	0.92	0.63	0.96	0.86
1011	0.94	0.63	0.7	0.38	0.66	1011	0.2	0.73	0.4	0.95	0.57
1001	0.94	0.63	0.67	0.38	0.65	1001	0.75	0.1	0.77	0.56	0.54
1000	0.94	0.63	0.67	0.4	0.66	1000	0.46	0.52	0.34	0.17	0.37
1100	0.94	0.30	0.67	0.4	0.58	1100	0.25	0.40	0.64	0.29	0.4
1101	0.94	0.30	0.67	0.38	0.57	1101	0.83	0.1	0.1	0.93	0.49
0101	0.45	0.30	0.67	0.38	0.45	0101	0.89	0.18	0.47	0.98	0.63
0100	0.45	0.30	0.67	0.4	0.46	0100	0.69	0.45	0.03	0.03	0.3
0110	0.45	0.30	0.7	0.4	0.46	0110	0.93	0.34	0.27	0.47	0.5
1110	0.94	0.30	0.7	0.4	0.59	1110	0.47	0.83	0.92	0.29	0.63
1010	0.94	0.63	0.7	0.4	0.67	1010	0.22	0.42	0.28	0.0	0.23
0010	0.45	0.63	0.7	0.4	0.55	0010	0.39	0.32	0.18	0.07	0.24

Tab. 1: Fitness values for $K = 0$ (left) and $K = 3$ (right)

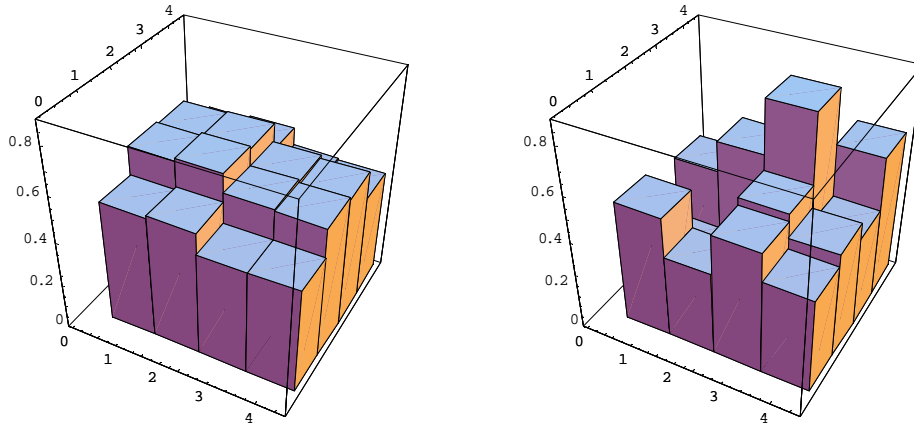


Fig 4: Option landscape for $K = 0$ (left) and $K = 3$ (right)

III.2 Elements of search

III.2.1 Knowledge representation

(1) According to the problem solving framework the knowledge stock of a search agent can be divided in declarative and procedural elements. The declarative knowledge consists of knowledge about options, attributes and connections. To a large part this knowledge is singular i.e. related to specific expressions of attributes and connections (cf. GAVETTI/LEVINTHAL 2000, 121). To a smaller part this knowledge is general in that it consists of patterns (e.g. schemata about attributes). Then the stock of knowledge of a search agent includes the following elements:

- a limited number of options ($P_R < P$) and their pay offs in the past,
- a limited number of attributes ($N_R < N$),
- a limited number of connections ($K_R < K$ and $K_{iR} < K_i$ respectively)²² and
- a limited number of schemata (S_R).²³

²² Knowing elements of N and K (K_i) does not imply a numerical specification of their respective influence on the pay off of the whole option.

The stock of procedural knowledge encompasses operators and heuristics. The former are instrumental techniques to register and to switch between given attributes and connections. The latter are tantamount to a specific focus for structuring the search process (i.e. fixing priorities and defining the steps of search). In the simulation model the following operators are used:

- a fixing operator determining an attribute's state randomly,
- a mutation operator in the form of switching from one – known – expression of an attribute to another – unknown – expression,
- an operator for checking the connections between attributes,
- an operator producing a bundling of connections by transforming the knowledge base in such a way that (almost) separable groups of connections (modules) result²⁴,
- an operator for comparing modules as regards to their fitness contribution,
- an operator for fixing a design rule²⁵,
- a discovery operator leading to new attributes²⁶,
- an assessment operator for averaging the fitness over a subspace of the state space,
- an operator for combining subspaces and finally
- a selection operator drawing a string randomly from a given subspace.

Corresponding to the mental model of the search agent there is a heuristic, i.e. a basic orientation for the search process. In the given modelling context the search agent can either focus specific attributes for research (according to some schemata) or he/she can focus on the connectedness of the attributes (or a mixture of both). A combination of operators specific to this focus as well as to the domain the agent is acting in constitutes a search strategy or search style, the main element of procedural knowledge.²⁷ These strategies are patterns of search the agent activates for constructing new artefacts if the type and amount of knowledge as well as the risk attitude are given.²⁸ Hence it is reasonable to suppose that the agent's strategies differ according to domains, situations, and personal endowments. In the following three stylised search strategies (being extracted from observable search behaviour of firms) are sketched.

(2)The first search strategy is called "*shotgun sampling*" (FLEMING/SORENSEN 2003, 19). Specific for this search style is

"...to generate an enormous number of random trials and then subject those to rigorous selection criteria. Instead of understanding the interdependencies that generate the landscape, inventors simply apply the magic of large numbers in a manner similar to the evolutionary process of natural selection. The successful implementation of this strategy of shotgun sampling requires two things: methods to generate variations cheaply and accurate tests to assess the value of those variations."(ibid. pp 19)

This heuristic makes extensive use of the mutation as well as the assessment operator. The amount of knowledge required for this search style is low; the nature of required knowledge is to a large part tacit. The focus of the r&d activity following the directive of this search method is on testing. Due to the almost blind nature of search the risk of failure for a single

²³ Relating N_R and N as well as K_R and K (K_i) respectively by an inequation means that a quantitative relationship between subjective knowledge representation and objective knowledge base is postulated. By assuming $N_R < N$ and $K_R < K$ or $(K_{iR}) < (K_i)$ the reverse case of over-complication is excluded.

²⁴ This is the operator which is most important for implementing heuristic of modularization (cf. below). In this case the operator is composed of several sub-operators like splitting, substituting, augmenting, excluding, inverting and parting (cf. BALDWIN/CLARK 2000, pp132, pp257).

²⁵ This operator is part of modular search (cf. below)

²⁶ This operator can be understood as a kind of a second order decomposition/recombination operator related to a conceptual level (cf. HOLLAND et al. 1986).

²⁷ Besides heuristic and operators the search strategy is influenced by the constraints in terms of money and time.

²⁸ According to the difference between ill-defined and well-defined problems (cf. above section II.2.2) the search processes differ in the degree of their predefined requirements in terms of quality, function, inputs and costs of the artefact.

trial is high. In terms of the option landscape this is tantamount to a low level of N_R and K_R (K_{iR}) respectively compared with N and K (K_i) of the knowledge base. In a strategic perspective this high risk of failure is compensated by a low risk to lose the advantage of a successful trial because most of the required knowledge is not communicable to competitors. – This search style was used in the Menlo Park laboratory of T. Eddison. At present examples for this style can be found especially in the pharmaceutical industry until the 1980s when the "mass screening system" was the dominant heuristic for finding new drugs (cf. FLEMING/SORENSEN 2003, 20; THOMKE et al. 1998, pp 324).

A second well-known search strategy is "*modularization*" (BALDWIN/CLARK 2000). What is primarily required are design rules about the possibilities to decompose the search space into modules the elements of which are primarily connected to each other. "Modularity is a specific design structure, in which parameters and tasks are interdependent within units (modules) and independent across them."(ibid. 88)²⁹ Hence, design rules isolate overarching connections, 'eliminate' these connections by fixing an expression for the corresponding attributes³⁰ and figure out solutions for the separable modular blocks of the knowledge base. The most important operator for this heuristic is the bundling operator. The purpose for its application is to eliminate complicated (multiple) interdependencies between attributes because a solution with a good balance between the often conflicting requirements is hard to find.³¹

"Converting an ordinary design parameter into a design rule entails both benefits and costs. On the plus side, there will be a gain in efficiency through the elimination of cycles in the design process. On the minus side, the designers will lose the ability to explore some parts of the space of designs – in effect, the architects will restrict the search, declaring some parts of the design space to be out of bounds."(ibid. 68f)

Hence, the scope of search is reduced but the risk to fail is comparatively low. The risk to lose an advantage strategically is on a medium level because the design architecture consists of explicit knowledge whereas the modular solutions are based on implicit knowledge. – The most prominent example for modularisation as a search style can be found in the computer industry. Here the modular search not only fits well to the modular architecture of the computer as a whole but also to its hardware and software components.³² Another example for modularisation of tasks and the corresponding search procedures can be found in the automobile industry (cf. PILLER/WARINGER 1999). In both cases it is obvious that there is a strong interrelationship between the style of search and the product design as well as the industry structure.

The third search strategy is called "*mapped search*" (FLEMING/SORENSEN 2003, 21). This search style requires a basic understanding of the knowledge base in terms of the attributes and their connections. If this search style should be used, either past experience and/or basic as well as applied research must have led to a comparatively rich knowledge of N and K (K_i) and corresponding schemata. The most important operator for this heuristic is the discovery operator, i.e. the use of (scientific) insight for deducing new attributes and/or connections without extensive experimentation. Hence, there is much knowledge required and the nature of this knowledge is to a large part explicit in nature. Correspondingly the focus on the search

²⁹ The emphasis of Baldwin/Clark is on the active constructivist role of agents as regards to knowledge. Hence they do not analyse the given knowledge base as a constraint for 'designing' new knowledge which conforms to their modularization postulate. Obviously they share the thesis of SIMON (1996, pp 183) that at least the hierarchical nature of complex systems allows for decomposing them into nearly independent sub-systems (cf. BALDWIN/CLARK 2000, 65).

³⁰ According to their constructivist perspective Baldwin/Clark call the attributes of the search space "design parameters".

³¹ BALDWIN/CLARK (ibid. 57) assign the notion "complexity catastrophe" to such an impossibility to find a balancing solution for multiple interconnections between elements of search. In their view such a complexity catastrophe is the reason for the inflexibility or the lock in process of a firm after the innovation has taken place.

³² E.g. the chip design or the design of operating systems (ibid. pp70, 289).

activity is now on scientific research. Due to the preliminary scientific endeavours the risk of failure is reduced but – in the case of a successful trial – the strategic risk of being caught up with by competitors is high due to the importance of communicable (explicit) knowledge.

“Specifically, companies that deploy mapped searching must pay special attention to how they manage their scientists. Engineers tend to seek career recognition within their firms and respond well to both compensation and career-based incentives. Scientists, on the other hand, often seek professional recognition through external publication and respect within the wider scientific community. Recent evidence even suggests that scientists will accept lower salaries for the opportunity to achieve such an external recognition.....Thus even if a firm’s scientists conduct their research without the rewards of external publication, the codification of their knowledge makes that information less tacit and hence more easily appropriated by other firms.”(FLEMING/SORENSEN 2003, 22).

This search style was applied in the consortia for promoting the semi-conductor industry in the USA. Another prominent example is the figuring out of the of the inkjet printer technology (cf. *ibid.* 21). Finally mapped search seems to be the dominant search style in the pharmaceutical industry after switching from the above mentioned mass screening system to either synthetic drug design or modern combinatorial chemistry systematically using scientific insights and simulation methods (cf. THOMKE et al. 1998, pp 324).

The main features of the three search styles are summarized in Table 2. In economic terms these different features are tantamount to differences in costs, yields and risks of the search process. It seems reasonable to assume that the activation of these search styles by economic agents depends on their experience as well as their endowment. Because these economic conditions are different for different agents in different times, the conclusion can be drawn that there is no dominant style in search but rather a cycle between the different styles.³³

“Unlike biological organisms, technology life-cycles do not necessarily progress in a uni-directional fashion. If we think of invention as a continuous and interdependent search process, we explicitly avoid the idea that novel technologies appear by chance and then progress monotonically through maturity and death. Instead inventors’ recombinant search efforts drive technological life-cycles. These efforts alternate continuously between new synthesis and modularization. Inventors begin the process by trying completely new combinations of components. They then discard the obvious failures and reorganise the most promising combinations and interfaces between components. This modularization of the initial synthesis decreases the effective interdependence between components. Without new syntheses, however, the modularization process eventually exhausts creative potential.”(FLEMING/ SORENSON 2001, 1037)

In the following section these – observed – search strategies will be analysed more closely from a conceptual point of view.

	<i>shotgun sampling</i>	<i>mapped search</i>	<i>modularization</i>
<i>main operator</i>	decomposition/ assessment	discovery	bundling
<i>r&d focus</i>	testing	investigating	designing
<i>knowledge</i> <i>-amount</i> <i>-type</i>	low implicit	high explicit	medium implicit/explicit
<i>risk</i> <i>-of failure</i> <i>-of imitation</i>	high low	medium medium	low high

Table 2: Features of search styles

³³ Cf. FLEMING/SORENSEN (2001, 1036) for the discussion of the shortcomings of modularisation and of the necessity to overcome these shortcomings by switching to other types of search.

III.2.2 Search strategy

(1) The search strategy³⁴ denotes the way in which the declarative and procedural knowledge of the agent is activated for conceptualising and constructing artefacts. This process of generating new knowledge includes investigating, designing, testing and implementing operations. Applying the usual economic perspective to this process is intricate: “The relative efficiency of experimentation strategies can be estimated using what is known about the topography of the solution space, and what is known about the time and money costs associated with generating and testing alternatives in the solution space.” (THOMKE et al. 1998, 318) Two intricate features of this process are to mention here: *firstly*, the way the selection process between different search styles takes place under the condition of a given risk attitude and the given limitations for the knowledge and *secondly* the stopping rules for the search process being influenced by constraints in terms of money and time.

(2) The selection of a search strategy is influenced by the knowledge base (in terms of known attributes and connections) and by the risk attitudes of the agents. These factors influencing the selection of a search strategy will change according to the experience of the agents. This reflects the importance of path dependence and knowledge representation for the search strategy. Table 3 specifies the conditions for selecting a strategy.³⁵ Only in the case of low knowledge endowment and low risk acceptance the search process will be stopped immediately in favour of less ambitious search for new options (e.g. imitation).

		<i>risk attitude</i>		
		low	medium	high
<i>knowledge endowment</i>	low	-	-	○
	medium	□	□	□
	high	□	◇	◇

Table 3: Selection criteria for search style (○ shotgun sampling, □ modularisation, ◇ mapped search)

(3) In any case the search process is a temporary operation. The rule to stop it is based on two different circumstances. On one side – at least in an economic context – there is a constraint in term of time and expenditure (expressed in money units) which might be exhausted before a useful artefact is figured out. The normal constraint for a search will be a maximum amount of money (m^*) and a maximum amount of time (t^*). Any search process has to stay within this frame, but given this quite diverse forms of combining time and money expenditures in a search path are possible. Hence, generally there is a kind of a trade off between these two kinds of constraints. Especially if the possibilities of parallel search are taken into account maintaining the same level of search effort (denoted by point A in fig. 5) by substituting search expenditure for search time (i.e. implementing more parallelism³⁶) is possible (plain curve). But this potential for parallelism is different for the various search styles: it is high for shotgun sampling, medium for modularization and low for mapped search (cf. dotted curves in fig. 5).

³⁴ The notion of “strategy” is chosen here to emphasize the deliberate and midterm orientation in this process. It is not implied that everything in this process is under conscious control.

³⁵ It is assumed that the requirements of the different strategies in terms of knowledge and risk is known by the agents.

³⁶ Increasing parallel search includes increasing expenditure due to a multiplication of a similar search operation but also due to augmented coordination requirements.

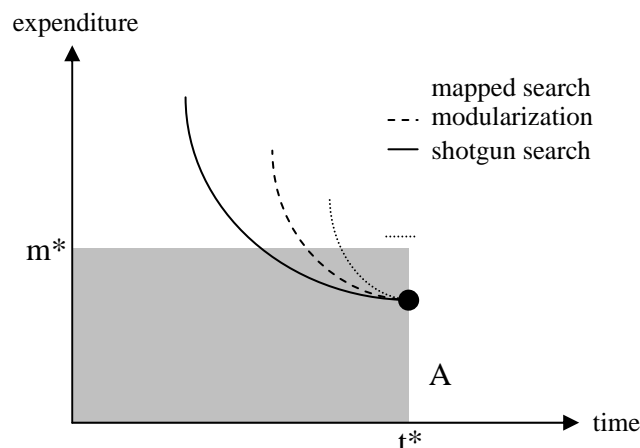


Fig. 5: Trade offs between expenditure and time for different heuristics

For all search strategies it holds, that the search costs proper are frequency and style dependent: the more often a search of an agent is successful, the lower are c.p. the costs of search in terms of money and time; but the requirements of expenditure and time for applying the various operators is quite different.

(4) Apart from this external constraint in terms of money and time there are on the other side internal states determining the stopping of the search process. *Firstly*, if the search process has been triggered by a the level of goal attainment falling below the reference level the search process stops if its results allow for expecting that the aspiration level will be met at least. But this is a sufficient condition for stopping search only if the agent is in a state of motivational balance i.e. the ‘supply’ of motivation (depending on disposable “cognitive effort” (cf. PAYNE et al. 1993 pp 75)) and the ‘demand’ for motivation (determined by cognitive effort required in the past) are about the same. If the background for switching into the search mode is a motivational surplus (i.e. supply of motivation exceeds demand for motivation) then a *second* condition for ending the search process is that this surplus has been absorbed by the cognitive effort made during the search process.³⁷

III.2.3 Exemplary specification

(1) In this section the notion of knowledge representation and the search strategies will be specified by considering a simple example in detail. The assumed background for switching into the search mode is an unsatisfied aspiration level (0.7 units). The constraints for the search process are assumed to be $t^* = 15$ and $m^* = 10$. Taking the example of a simple knowledge base of section III.1 ($N = 4$, $K = 3$) as the starting point it is further assumed that $N_R = 3$ (consisting of the attributes A, B and C; attribute D is unknown) and that $K_R = 2$ (consisting of the (A, B)- and (C, A)-connection).

Due to past experience the agent under investigation has built up a schema according to which the state of attribute B should be “1” ($S_R = \{\# 1 \# /\}$ ³⁸). The decomposition/recombination heuristic (*shotgun search*) is assumed not to be an assembly of blind trials but being biased by the schema in that the search space is oriented towards the first and third attribute of the artefact. Then the search proceeds in four steps:

- step 1: checking all options with the attribute structure $\{1 1 \# /\}$ i.e. $\{1 1 0 /\}$ and $\{1 1 1 /\}$,

³⁷ The motivational dimension of cognitive control is not yet implemented in the following model.

³⁸ In this expression “#” is symbolizing ‘under investigation’ and “/” is symbolizing ‘unknown’.

- step 2: checking all options with the attribute structure $\{0\ 1\ \#\ / \}$ i.e. $\{0\ 1\ 0\ / \}$ and $\{0\ 1\ 1\ / \}$,
- step 3: checking all options with the attribute structure $\{\#\ 1\ 1\ / \}$ i.e. $\{0\ 1\ 1\ / \}$ and $\{1\ 1\ 1\ / \}$,
- step 4: checking all options with the attribute structure $\{\#\ 1\ 0\ / \}$ i.e. $\{0\ 1\ 0\ / \}$ and $\{1\ 1\ 0\ / \}$.³⁹

The divergence between knowledge representation and knowledge base is reflected by the circumstance that every knowledge representation corresponds to multiple options in the knowledge base (e.g. the knowledge representation $\{1\ 1\ \#\ / \}$ corresponds to the knowledge options $\{1\ 1\ 1\ 1\}$, $\{1\ 1\ 0\ 1\}$, $\{1\ 1\ 0\ 0\}$ and $\{1\ 1\ 1\ 0\}$). It is assumed that due to his experimental endeavour the search agent can guess the average pay off for all knowledge options corresponding to a given knowledge representation (cf. GAVETTI/LEVINTHAL 2000, 121). Hence, taking the pay offs from the example in section III.1 the mean pay offs for the search steps 1 to 4 are 0.6, 0.46, 0.6 and 0.46 respectively. Therefore the agent combines the representation in step 1 and in step 3 and selects the option $\{1\ 1\ 1\ / \}$. The subjective knowledge about the fitness of this option is derived from the subjective knowledge about the options $\{1\ 1\ \#\ / \}$ and $\{\#\ 1\ 1\ / \}$ by building an average of the guessing about these options. Hence, the fitness of option $\{1\ 1\ 1\ / \}$ is assumed to be 0.6. These steps of knowledge representation are visualized in figure 6.

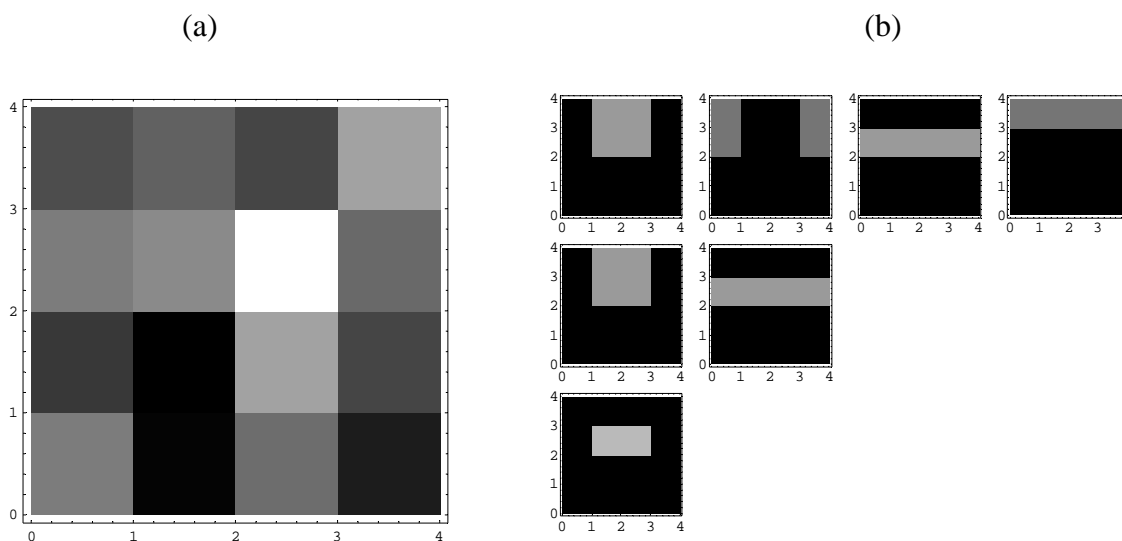


Fig.6.: (a) Knowledge base (the lighter the colour, the higher the pay off) and (b) knowledge representation during 'shot gun'- search (black colour signifying un-represented areas): sampling (first row), combining (second row) and selecting (third row)

Then the question arises if this search strategy is feasible and satisficing. Checking the feasibility requires a specification of the search effort in terms of time and expenditures (money). The search operators included in the example at stake and the corresponding pairs of time and money requirements are as follows:⁴⁰

- four assessment operators for averaging the fitness of a subspace with (1, 2) each: (4, 8),
- one operator for combining attributes (combination operator) with (1, 0.5) and

³⁹ This has been done already in step 1 and step 2.

⁴⁰ The possible reduction of time and money requirements for using the search operators due to tacit knowledge, skills and past experience is ignored here.

- one selection operator with (1, 0.5).

The sum total of required search time is 6 time steps; the sum total of required expenditure is 9 money units. Checking the satisficing ability of this search requires a comparison of aspiration level and the resulting expected pay off. In the given example the aspiration level is met (0.745 as pay off).

	A	B	C	D
A	-	x	x	/
B	x	-		/
C	x		-	/
D				-

Fig. 7: Connection matrix

(2)The *modularization heuristic* is shaped by the connection architecture. Hence the starting point is the represented connection matrix in the given example (cf. figure 7). In the first step of this kind of search modules have to be identified and design rules have to be established. In the present case the module consists of the relation between A and B; the design rule has to fix a state for the attribute C randomly. This state is assumed to be "0". Hence, the knowledge representation for further search is {# # 0 /}. The second step of this search is analysing the (A,B)-module. This is done by investigating the pay off contributions of A and B (w_A and w_B) for the combinations "0 0", "0 1", "1 1" and "1 0" for A and B given the state of C as "0". Taking the corresponding averages for w_A and w_B gives the following results:

- for option {0 0 0 /}: 0.4875,
- for option {0 1 0 /}: 0.5525,
- for option {1 1 0 /}: 0.395,
- for option {1 0 0 /}: 0.4575.

This comparison of the fitness contribution of w_A and w_B leads to the selection of the option {0 1 0 /} with the total mean pay off 0.465. This means that the analysis of w_A and w_B was insufficient because there are low contributions of w_C and/or w_D which are not investigated or not known. The corresponding knowledge representation is depicted in figure 8.⁴¹

Is this kind of search strategy also feasible and satisficing? The search operators and their requirements in terms of time and expenditure are:

- two operators checking the connections of attributes (1, 0.75) each: (2, 1.5),
- one operator fixing the design rule (1, 0.5),
- eight operators for subspace assessment with (1, 0.75) each: (8, 6)
- one operator for comparing modules (1, 2) and
- one operator for selecting an option (1, 1).

The sum total of required search effort consists of 13 time steps and 11 money units. In the present example this means that the time constraint makes it impossible to accomplish this search and furthermore that the target of the aspiration level (0.7 units) is not met.

⁴¹ The investigation of w_A and w_B is not shown.

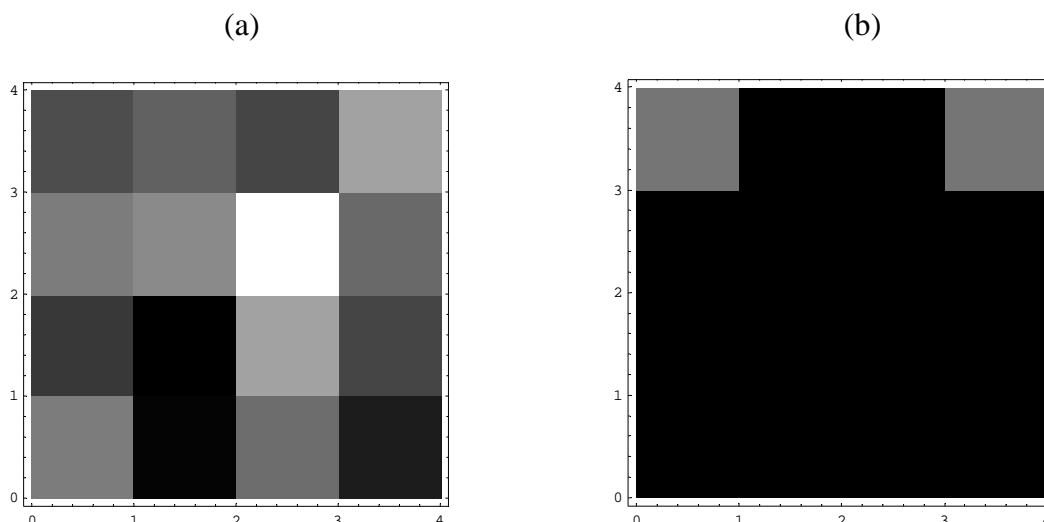


Fig. 8: (a) Knowledge base (the lighter the colour, the higher the pay off) and (b) knowledge representation of 'modularization' -search result (black colour signifying unrepresented areas)

(3) Contrary to modularization, *mapped search* takes the whole connection matrix into consideration. In the first step a discovery operator is activated the purpose of which is to discover new attributes by doing basic and/or applied research. It is assumed here that the probability to discover a new attribute is negatively correlated to the difference between N and N_R . This means that the more the knowledge is fragmentary the less probable is a new discovery in terms attributes. After this investigation all known connected attributes are taken into account for getting insights into the pay off structure. Hence, the second step of this heuristic is a simultaneous switching of all known connected attributes. The third step is a switch of all minus one known connected attributes, the fourth step a switch of all minus two known connected attributes etc. until no known connected attribute is left for switching. The resulting pay off changes – compared to initial pay off – then moulds the further search: it proceeds along the trial with the highest expected pay off by fine tuning it further in sequentially switching only one attribute.

Taking the option $\{1\ 0\ 1\ / \}$ as a starting point the expected pay off would be 0.4. Assuming that no new discovery (in terms of attribute or connection) takes place, the known connected attributes A, B and C are switched simultaneously leading to the option $\{0\ 1\ 0\ / \}$ and 0.465 as expected pay off. Switching two attributes randomly gives the option $\{0\ 0\ 0\ / \}$ and 0.48 as expected pay off. Finally switching randomly only one attribute produces the option $\{1\ 0\ 0\ / \}$ with expected pay off of 0.455. Hence, the search process gets stuck in the option $\{0\ 0\ 0\ / \}$. The graphical visualization of this process is given in figure 9.

The time and expenditure requirements of this search style are as follows:

- two discovery operators with (1, 0.5) each: (2, 1),
- two operators for checking connections with (1, 0.75) each: (2, 1.5)
- eight operators for subspace assessments with (1, 0.75) each: (8, 6)
- one operator for comparing subspaces (1, 2) and
- one selection operator (1,1).

The total amount of time required for this search is therefore 14 time steps. The total amount of expenditure is 11.5 units of money. Due to these excessive expenditure requirements this search is not feasible within the given constraints. Even if it would be feasible it would miss the goal requirements because the resulting pay off is not satisficing.

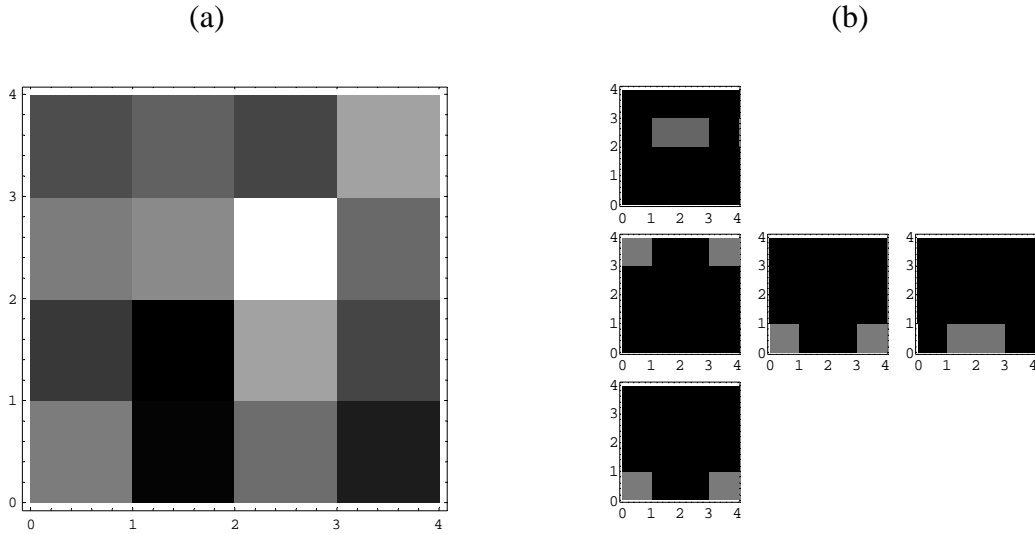


Fig.9: (a) Knowledge base (the lighter the colour, the higher the pay off) and (b) knowledge representation during 'mapped' -search (black colour signifying un-represented areas): sampling (first row), fine tuning (second row) and selecting (third row)

(4)The performance of all three search strategies is summarized in table 3. In the present example only shot gun search can be completed (is totally feasible), is satisficing and has the best yield/effort relation ($\frac{0.745}{9}$).

	<i>shot gun search</i>	<i>modularization</i>	<i>mapped search</i>
<i>time requirement</i>	6	(13)	(14)
<i>expenditure</i>	9	(11)	(11.5)
<i>expected pay off</i>	0.745	(0.465)	(0.48)

Table 4: Results of example

III.3 Simulations

(1)The modelling of the search strategies in the landscapes of artefacts (objective knowledge) is confined here to the mapping of the subjective representation of knowledge. The focus of such a model is on the way the individual search agents structure their initial knowledge in terms of heuristics and operators (the combination of which constitutes a search strategy). Hence, the encoding as well as the decoding of knowledge and the corresponding processes of memorizing and learning are neglected at this stage of analysis. What is investigated is the process between the starting with some initial (subjective) knowledge and the ending with testing and implementing an option. This process is guided by different search strategies the agents can select. The purpose of such a simulation is to get some insights about the appropriateness or even efficiency of different search strategies in different fitness landscapes.

trial	n	m	r&d	exp	u	slots	conn.	rp_shotgun	rp_modular	rp_mapped
1	10	10	10		1	2	k=0	1.437	1.246	2.284
2	10	10	10		1	2	k=1	0.840	2.617	1.018
3	10	10	10		1	2	k=2	1.222	1.875	1.452
4	10	10	10		1	2	k=3	2.293	2.203	2.347
5	20	10	10		1	2	k=3	1.651	2.088	1.822
6	10	10	10		1	2	c=2	0.969	1.274	0.756
7	10	10	10		1	2	c=3	1.050	0.473	1.187
8	10	10	10		1	2	c=4	1.198	1.401	1.339
9	10	10	10		1	2	c=5	1.992	0.97	1.646
10	10	10	7.5		1	2	c=2	1.270	1.007	1.572
11	10	10	7.5		1	2	k=3	2.106	2.185	2.397
12	10	10	10		0	2	c=2	0.937	0.997	0.968
13	10	10	10		0	1	k=3	1.878	1.357	1.069
14	10	10	10	+(sg)	0	1	c=4	1.612	1.385	0.851
15	10	10	10	+(mod)	0	1	c=4	1.589	2.827	0.945

Table 5: Simulation results for relative fitness performance of different search strategies in different knowledge landscapes (*n*: number of agents; *m*: number of periods; *r&d*: research fund; *exp*: research costs; *u*: degree of uncertainty; *slots*: number of attributes under investigation; *conn.*: degree of connection for regular [*k*] and irregular [*c*] attribute graphs; *rp*: relative fitness performance of different research strategies).

(2) In all simulations a starting point (in terms of subjective knowledge) common to all search agents is supposed. This means that there is a common reference option (standard string) for all agents upon which the search specific heuristics and operators are applied. The agents are divided in different groups according to the search strategy they activate (i.e. a group following a shotgun search strategy, a group of agents following a modular search and finally a group following a mapped search). In this set of simulations a change is assumed on two levels: *Firstly*, the structure of the artefact and correspondingly of the fitness landscape is changed in different trials. This means that the degree of the vertices of the underlying graph is changed either on a regular or on an irregular level. *Secondly*, the funds as well as the expenditure for r&d activities are changed. It will be investigated how these parameters influence the performance of the different search strategies. This performance is measured by the fitness outcome divided by the cumulated r&d expenditures (search productivity).

In table 5 the main results for the relative fitness performance of the different search strategies are summarized. This relative performance (*rp*) is measured by the difference between the sum total of the optimal fitness results (sum of global maximima over all periods) – only known to the observer – and the fitness findings of the different strategies.⁴² The basic unit of the search process is a 'period' in which a given amount of r&d fund is spent generating an outcome in terms of a fitness value.⁴³ In a first set of trials (No. 1-9) the boundary conditions in terms of number of agents, total r&d funds, and of structural uncertainty (number of unknown attributes) have been fixed and the connection architecture of the knowledge base has been changed at the beginning of each period. For both, the regular as well as the irregular connections of attributes, there seems to be a positive relationship for the degree of

⁴² The higher *rp*, the less appropriate is the search strategy.

⁴³ The way in which this generation of a fitness outcome takes place depends on the activated search strategy and – given a search strategy – on the amount of money necessary for the different steps. If the r&d fund is too small for finishing the search strategy in a normal manner, it will be abbreviated.

connectedness and the level rp .⁴⁴ This corresponds to the increasing "ruggedness" of the fitness landscape if the degree of connectedness is getting larger. Hence, the divergence between the fitness of any artefact from the optimal option is normally lower if the ruggedness is lower. In the case of a regular connectedness of the artifact's attributes the appropriate search strategy shifts from modular search to shotgun search if K is decreasing. This is not that clear in the case of irregular connectedness of attributes because here modular search as well as mapped search are only successful if they are focused on attributes with a high degree of connectedness. In a second set of trials (No 10-13) the boundary conditions of the first set of trials are varied. In the case of a lower r&d fund, the – counterintuitive – result is an increase in the performance of most search strategies for high connected landscapes and a decrease for lower connected landscapes. If the degree of structural uncertainty is reduced to "0" (i.e. all attributes are accessible for research) the general performance is improved. In trials 12 and 13 the effects of higher costs for specific search strategies are investigated. In trial 12 the scope of shotgun search is reduced and due to reduced economies some expenditures of this search strategy are assumed to be higher. Hence, the rp -indicator for this type of search is reduced giving the other search strategies (especially mapped search) a comparative advantage. The same effect takes place if modular search is getting more expensive (trial 13). These simulation results are graphically summarized in fig. 10.

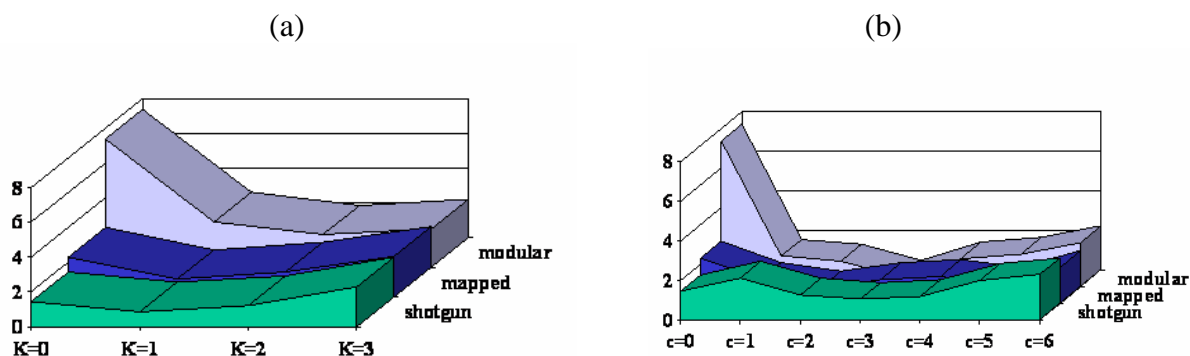


Fig.10: Simulation results as regards to relative performance of search strategies for (a) regular and (b) irregular attribute graphs.

The assessing of the performance of search strategies so far has ignored two important aspects. *Firstly*, the rp -indicator has been aggregated over all agents ignoring the variance of the results between different agents (being an indicator of the risk of the research result). *Secondly*, only the yield (in terms of fitness) of r&d have been taken into consideration ignoring the costs of the research activities. Both aspects are illustrated in fig. 11 taking trial 10 as an exemplary case. Fig. 11(a) shows the aggregated fitness results for all search strategies in each period giving the background for the aggregation underlying the calculation in table 5. Fig. 11(b)-(d) illustrate the heterogeneity of the individual search paths within each search strategy indicating that the variance of search results is different in the same period between different search strategies and in different periods within the same search strategy. The same is true if costs for r&d are included (fig. 11(e)-(g)). Finally fig. 11(h) shows that a short-term, cost oriented search perspective would take the shotgun-search as superior (best average result in 6 of 10 periods) although it is not superior in terms of fitness yields (cf. fig 11(a)).

⁴⁴ An exception from this is the case $k=0$. This is due to some detours for all search strategies being oriented towards a positive amount of connections.

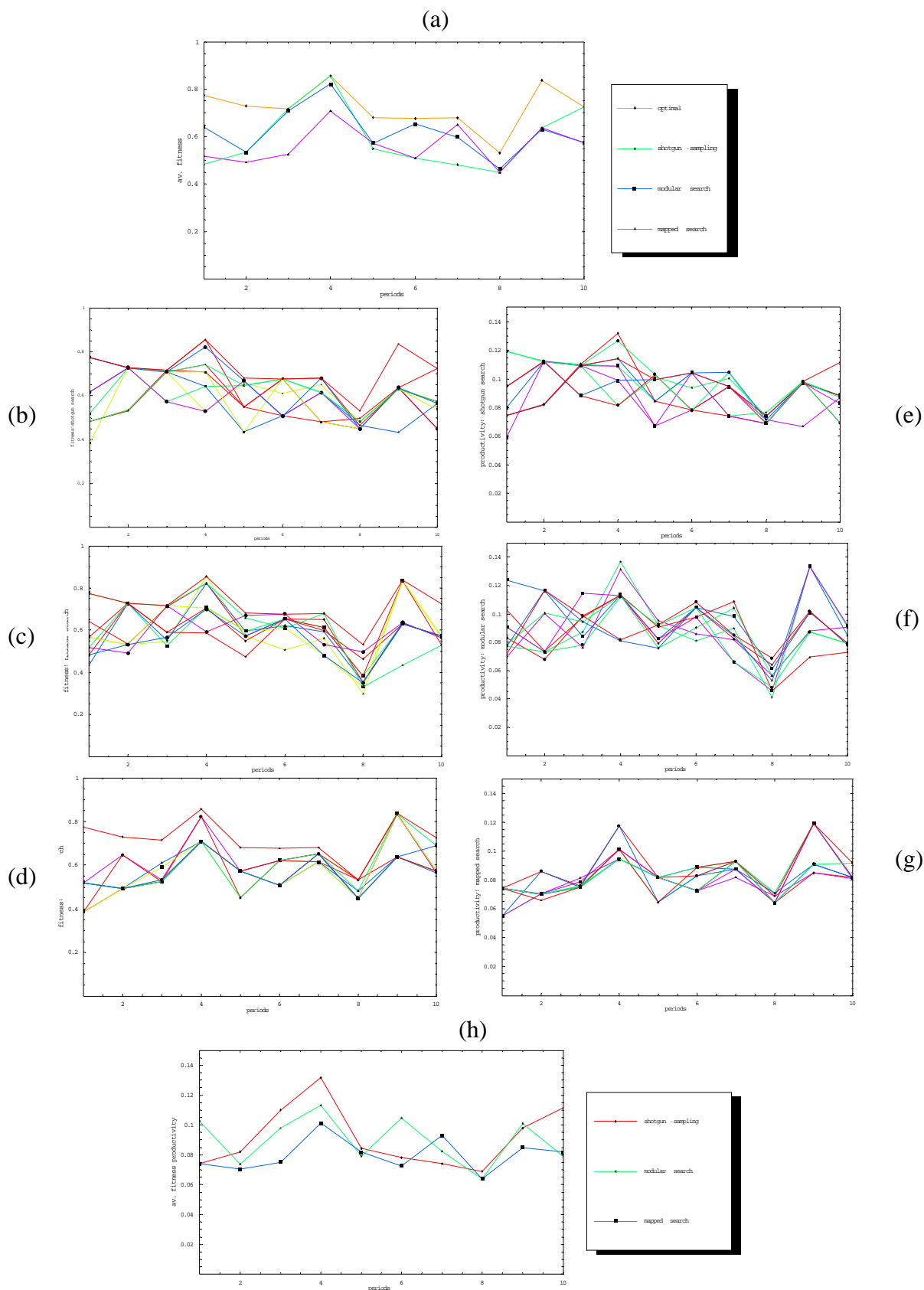


Fig.11: Simulation results for trial 10. (a) Average fitness outcomes for different search strategies (including the values for fitness optima); (b)-(d) agent-specific fitness outcomes for different search strategies (including again fitness optima); (e)-(g) agent-specific search productivity (fitness divided by r&d costs) for different search strategies (including a virtual optimal strategy); (h) average search productivity for the different search strategies.

(3) What conclusions can be drawn from this assessment of the different search strategies? Obviously the size of the r&d fund is not the only factor determining the outcome of the research process. Additionally it matters *firstly*, how this fund is allocated for different activity steps and how much money has to be paid for these different steps. Hence, a search process may produce bad results (or even may fail) due to a misallocation of money. *Secondly*, the architecture of the artefact landscape (structure of objective knowledge) is a crucial factor for the appropriateness of a search strategy. For regularly connected landscapes there seems to be a broad range of K for which shotgun search is appropriate. Contrary to that in irregularly connected landscapes only for a high number of edges (c) shotgun search seems to be appropriate because it has a broader scope (making it more probable to include important attributes with a large number of connections to other attributes). *Finally*, the importance given to the costs of r&d by the search agents may influence the selection of a search strategy. If there is a strong emphasis on short-term efficiency strategies leading to moderate results at low costs are more appealing whereas for an orientation towards long-term efficiencies a search strategy with spending all the r&d fund for finding a good fitness outcome are preferred.

IV. Conclusions and further research requirements

(1) Contrary to the scepticism often articulated against ncps becoming a topic of economic analysis the literature on enhanced (creative) problem solving, the case studies on r&d processes and some Artificial Intelligence modelling tools are seen here as a background for upgrading that topic as regards to its accessibility for (evolutionary) economic analysis. This analysis can be done on (at least) three different levels: (i) As a specification of the conditions triggering ncps: here ideas about unattained aspiration levels as well as motivational deficits come into play. (ii) As a conceptual as well as descriptive analysis of the personal and process elements relevant for novelty creation: elements of such an analysis are delivered by studies about problem solving (search space, heuristics, operators) and studies in the modern business literature about r&d processes in different domains. (iii) Finally as a modelling of the dynamic knowledge representation and search processes: such a modelling endeavour picks up the idea of a cognitive grammar (i.e. the representation of knowledge in goal directed behaviour), the essential difference between objective and subjective knowledge and the local, path-dependent and sequential nature of search processes. These search processes are seen as the outcome of multiple search strategies in which past experience is conserved. This kind of conceptualizing the search process is different from two other approaches dominating the present literature: on one side it differs from the black box approach of the Nelson/Winter tradition in which the search process is modelled as a two-step-lottery; on the other side it differs from blind search approaches considering the search paths (by opening the black box) as being determined mainly by random processes (hill climbing and genetic algorithms) without any reference to knowledge representation.

(2) The approach suggested in this article has to be embedded in the cognitive architecture of agents. This means *firstly*, that the search process has to be conceptualized as an iterative procedure. The role of acquired knowledge for further knowledge acquisition has to be specified for the different search strategies. How does the encoding and decoding of knowledge work in the different search strategies and to what degree does a corresponding learning process lead to a matching of search strategies and landscape architecture on one side and a matching of search strategies and risk attitudes of agents on the other side? *Secondly*, this opens the perspective of parallelism and recombination i.e. the possibility to follow several search strategies at the same time and possibly combining some of their features.

Furthermore *thirdly*, the suggested approach can be used to model interaction processes on the level of knowledge exchange. Partly these interaction processes take place involuntarily if the fitness generating role of some attributes or even of whole artefacts are easily accessible for others. Between simply copying and more or less sophisticated imitation there is a broad spectre for this type of knowledge spreading. Partly these interaction processes take place in a conscious manner if agents decide to cooperate in terms of sharing as well as mixing their knowledge representation and search strategies. This includes *fourthly* the possibility of a co-evolution of knowledge base (landscape) and search processes. This co-evolution takes place if the localisation of individual knowledge is clustered in certain areas of the landscape leading (via direct or indirect interaction) to a birth of new attributes and/or connections.⁴⁵ The corresponding devaluation of the fitness contribution of the old attributes might include a death of attributes (and corresponding connections) if a certain level of fitness contribution is not reached anymore.⁴⁶

(3) Such an agent architecture has to be specified further in terms of institutional and social embeddedness. Firms e.g. can be conceptualized as an organizational integration of different groups of agents each representing a repository of knowledge in terms of rules and routines. The search processes considered here can be understood as search rules for new production rules being pushed by an unsatisficing performance of the production sector of the firm and being pulled by the management sector of the firm who has the task to integrate the new discovered options into a market strategy rule. Hence, the factors for 'push' and 'pull' within the firm have to be specified. The same is true for the social embedding of the firm itself. Apart from revealing technological options (under given economic and cognitive constraints) some influence of demand (social constraints) has to be taken into consideration ("demand pull").

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⁴⁵ To formulate it the other way round: an individual endeavour for a discovery is only a necessary condition for an objective invention/innovation; sufficient for the latter is additionally a high degree of completeness of the given knowledge of the ensemble of search agents. This social nature of knowledge as a prerequisite of objective invention/innovation marks an essential difference between biological and social evolution because in biological evolution the main source of objective invention/innovation is blind random search. This difference is often ignored when the frame work of NK-network is applied to the realm of social processes (cf. e.g. EGIDI/RICOTILLI 1997).

⁴⁶ The hypothesis of Kauffman that K will be driven by natural selection to a level 'not too high' and 'not too low' because this guarantees survival in a broad range of environmental conditions (cf. KAUFFMAN 1993, pp 255) is *firstly* not well founded by micro processes and *secondly* even if true in biological processes it is not necessarily true in social processes.

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