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# The Formal Relationship between Dynamic Conceptual Semantics and Connectionist Neural Network Modelling

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In this paper a formal relationship shall be worked out between the level of experiential concepts in Dynamic Conceptual Semantics (**DCS**, Bartsch 1998) and concept formation in distributively representing connectionist neural models (**CNM**). Both are formal approaches to learning linguistically expressed concepts, and at the same time they are theories of understanding situations in perception and of understanding simple sentences that describe situations. **DCS** gives a logico-philosophical reconstruction of concept formation and understanding on the cognitive level of conscious phenomena, while **CNM** model on an abstract level of neuronal connections and activation patterns the learning of classifications and associative connections of contiguity in perception and behaviour, also linguistic behaviour, as generalisations over sequences of examples.
The background of both positions is not rationalism, rather empiricist and behaviourist philosophy, which grounds language learning in perceptual and behavioural experiences, on which the operation of abstracting, or generalising, and the structuralist operation of forming substitution classes of items within contexts are performed. The data of concept formation are situations and utterances, primarily simple sentences with their experienced satisfaction situations. Generalisation yields situation concepts or types, especially action types, on the one hand and utterance types, i.e. sentences, on the other. Substitution and contrasting within identical contexts leads to distinguishing parts of situations and utterances, as well as parts of situation types and sentences, and leads to the syntagmatic relationships within situations and within sentences, and the pradigmatic classes generalising the types of actions and relationships and their participants or roles on the levels of situation types and sentences. External relationships between situations are contiguity relationships of spatial, temporal, causal and other kinds. They give rise to sentence connectives of causal, adversative, concessive, temporal, and local

kind, and parallel to compound sentences with adverbials phrases, especially adverbial clauses. Contiguity relationships further play a role in forming historical concepts, such as concepts of individuals, actions and events, and generalisations of these. On the experiential level we form our concepts, based on growing sets of situational experiences and their delineating linguistic expressions.

On top of this situationally based linguistic stratum, which is grounded in our perception of situations, performance of actions, and reporting about these, we get the logical stratum consisting of a vocabulary of logical connectives, negation, quantifiers and modal operators of different kind. The logical vocabulary gets its meaning from the ways we organise our information in forming generalisation and existentialisation over particular information by means of general and existential quantifiers, by seeing information in conjunction or disjunction, in conditionalisation, and by seeing it as reality, as possibility, or as necessity. This stratum of the organisation of information, which makes it possible to keep information at a distance from sensory and motoric input and output, on a level of knowledge which is not directly manipulated by situational contingencies, is not captured in the discussion below, because it lies outside, or above, the treatment provided by typical connectionist modelling.

It has already been pointed out in Bartsch 1996 and 1998 that connectionist models of concept formation share with Dynamic Conceptual Semantics certain welcome properties:

1. Perception is the core and basis of concept formation

2. Sensory input is directly embedded into classificatory and contiguity content and thus understood (content addressability by input) as a perception of a situation. A situation is immediately perceived within the conceptual system available at a certain moment, which means that it is perceived as categorised and identified within the classificatory and contiguity structure established so far on the set of experienced, imagined, and reported situations. Likewise linguistic utterances are understood by directly addressing the linguistic type in contiguity relation with the type of the given context, and with this also the semantic content is addressed on the basis of the co-ordination with the parts of the expression in the respective contexts and their syntactic contiguity connections within the expression. There are efforts to work out the corresponding operations in connectionist frameworks by architectures with

recurrent fibres using vector concatenation, vector addition, and tensor products (Horgan and Tienson 1992), which will be discussed below.

3. The structures stabilise in the course of learning from experience (stabilisation).

4. The structures are flexible in accommodating new and even deviant input (flexibility).

5. Conceptual growth and change are part of the system (conceptual dynamics).

6. Traditional cognitive representations of mental contents by means of a language of thought are avoided. Representations are always in natural or formal public languages, or in pictures. As Wittgenstein has pointed out, representations always presuppose understanding if they shall be related to something they have to represent, and thus function as representations. Therefore they cannot function in establishing understanding and interpretation. They are what has to be understood. Their semantics is part of the cognitive level of perceptual and behavioural conscious phenomena in **DCS**, which are publicly co-ordinated in the intersubjective acts of acceptance of satisfaction situations for utterances. On the other hand, our ability to handle a publicly co-ordinated semantics is implicitly coded by the results of its causal effects in learning within the connection strengths between units in neuronal networks and is thus a set of potential activation patterns within a network including also the neuronal units in the sensory and motoric organs. These potential activation patterns are dispositions, or cause further dispositions to react positively or negatively to situations which satisfy or dissatisfy utterances, or bring forward actions and utterances connected to these in contiguity relationships.

7. Semantic systematicity is taken care of in part-whole relationships and union or addition of potential activation patterns in the neural nets of **CNM** on the one hand, and in inclusion and overlap relationships between sets of data in **DCS** on the other. I shall show that syntactic structuring of the process of understanding, and not so much of its result, must be crucial for semantic-syntactic systematicity.

8. Syntactic systematicity on the level of simple sentences is displayed in substitution based on contrast analysis between sets of data and between potential activation patterns, respectively, stating identity and difference between simple sentences on the one hand and between situations on the other. Structural hierarchies in semantics according to the semantically relevant syntactic hierarchies in a sentence are realised in the constructive steps in the process of construing the

set of situations into which the possible satisfaction situation of a sentence must be integratable salva stability, and in processes of successive unions or additions of pattern realisation, respectively. Hereby a stepwise specification of constraints on the set of possible satisfaction situations for the sentence is achieved in the process of understanding. (See point 2 above concerning understanding of expressions).

These shared or parallel properties between **DCS** and **CNM** point to the fact that there must be a strong structural similarity between the ways in which concepts are represented in both models. Furthermore both models share a common background assumption, namely a non-classical position in cognitive science. From the semantic properties of understanding explicated in **DCS**, which are based on principles of interpretation and truth evaluation in semantic models, conditions can be derived constraining the structures which stabilised neuronal networks must exhibit, will they be semantically successful. I shall show that there can be a result of understanding a sentence in terms of a resulting semantic representation which would be an activation pattern with a certain distribution of relative strength of activation over its units, though it cannot be stable through time. The process of activating certain neuronal patterns, which are causally related to input from previous experiences in learning processes, in certain orders is significant as the neuronal basis of sentence understanding, and it guides the interpretation in the world by providing the referential relationships to parts of the world in action and perception. Herewith architectures in neural networks, especially recurrent fibres, that let the process run in syntactic order, and can accommodate alternative routines for doing so, have to be postulated as neuro-physiological basis for the process of understanding situations in perception and action, and parallel in the process of understanding sentence utterances.

## 1. The non-classical cognitive model

Both models of concept formation treated in this paper presuppose a non-classical cognitive model. The classical model has as the centre a unit of rational reasoning, including the execution of rule application on representations in some formal language, often referred to as the language of thought. Around the centre, peripheral modules are located, namely the perceptual and the motoric module. Information comes in via the perceptual module and output goes out via the motoric module, having trespassed the central unit of rational processing, which connects the peripheral units. This model is based on ideas of rationalist philosophy, which saw the human mind as the rational core of man, getting input and securing output via peripheral sensoric and motoric modules, under influence of an emotional module, mostly competing with, and sometimes supporting the rational processing. The non-classical model, on the other hand, is rather based on empiricist philosophy, taking perception and motoric behaviour as central for cognitive ability and deriving ideas, i.e. concepts and their combinations in thinking, from perception and memory by operations of similarity and analogy in processes of abstraction and substitution, and by operations of contiguity in registering factual relationships. Speaking in terms of centre and periphery, the sensoric-motoric faculties form the centre and the rational faculties form the periphery, which is built up from out the central basis by making use of the general operational procedures just mentioned.

It has been shown in neurobiological brain research that neuronal assemblies for performing certain actions, for example grasping certain kinds of things, and perceiving these actions also when performed by others, largely overlap. Also perceiving the kind of things that regularly are grasped in this way additionally activates the neuronal assemblies for the respective actions (Fadiga and Gallese 1997). Thus not only the classification of the actions is represented together from first and third person perspectives in its perceptual and motoric aspects, but also the contiguity relationships with the type of things used in these actions are associated in activation patterns. Starting from seeing these things, grasping them is an action possibility offered straight away by the neuronal assemblies. Of course, such association by contiguity comprises much of practical reasoning and it follows the ways of performing practices while using certain things. This reminds us on Wittgenstein's example about the use of language by masons in the handling of different kinds of stones. Reasoning is not just some rational faculty innate in individuals, but it is guided in a context dependent way and organised by great amounts of practical experience, and by public norms and conventions, and therefore it is for a large part learned in education within certain types of situations.

In the way sketched above, we have perception, motoric, and emotional ability as the core of the non-classical model, while rational reasoning is rather the periphery, possibly partly due to inborn preferences for stability, conservativity, monotony. It is induced mainly through public normative and controlling behaviour, working on symbolic representations, especially in public language, and trained in schooling. This implies that rational reasoning is to some part natural to human minds, but also very much a culture bound and enforced set of constraints for control on what otherwise might be produced directly as output from the centrally encoded relationships between sensory input, emotional disposition, and motoric activity. The possibility of control is provided by our faculty of consciousness, i.e. by our awareness of others' and own behaviour, and by our awareness of previous and current perception in memory. A non-classical model is proposed, for example, by Smolensky (1989), who takes connectionist neural networks as models of the subsymbolic centre of cognition, while rules and representations are the publicly induced rational constraints, imposed from out the periphery. The latter require symbolic and especially linguistic processing on a level of logical vocabulary.

Concept formation is primarily based on the experiential level of perception and motoric activity, though it is furtheron developed on the level of linguistically explicated theoretical concepts, and constrained by public language and theory-formation. These latter are functions of the periphery of cognition which works by operations on symbolic representations, as they are made explicit in the core of classical models of cognition. These linguistically explicated, i.e. analysed, concepts form the second level of concept formation. They are theoretical concepts which are explicated by coherent sets of general sentences held true. Experientially introduced concepts can by elaborated, or even be redefined, as theoretical concepts, i.e. as linguistically explicated concepts. And in different occupations, technologies, sciences and cultural achievements different theoretical elaborations of experientially introduced concepts are possible according to their different perspectives, goals and contexts. Hereby one experiential concept might have several corresponding theoretical concepts as elaborations in different language registers and varieties.

In this paper I shall concentrate on the experiential level of concept formation, because there we can formulate a relationship between connectionist neural network models (**CNM**) and the data-based dynamic model of concept formation (**DCS**), presented in a first preliminary version in Bartsch 1990. Naturally, connectionism cannot say much about theory formation, and therefore theoretically and formally explicated concepts will not be treated here. They rather would play a role in the classical discursive component of cognition.

Of course, the similarities between concepts, their oppositions or their inclusion relationships on the theoretical level can be represented on connectionist networks, because linguistic distributions, i.e. sets of contexts of an expression in normalised sentences can be represented in these networks. Therefore the semantically characteristic syntagmatic distribution of a term X, roughly the set of sentential contexts of the universally quantified term *all X, every X, X in general*, which form a true sentence together with the universally quantified term, can be ordered such that expressions are semantically more similar the more semantically characteristic sentential contexts they have in common. Comparing the semantically characteristic distribution of two terms results in a similarity degree according to how much their distributions overlap. A subset of such a semantically characteristic distribution is a feature, which can also be part of the semantically characteristic distribution of another expression. This way terms have common semantic features and they can be classified by the features created in this way on the theoretical level. On this level similarity, opposition, and inclusion between linguistically explicated concepts is represented. By applying these linguistically explicated concepts to objects these will be classified according to the features involved, and thus will be judged similar according to common features explicated in the general sentences held true.

## 2. The relationship between Dynamic Conceptual Semantics (DCS) and Connectionism (CNM)

In the DCS-model of concept formation and understanding, concept formation on the experiential level consists in creating structures on growing sets of data. Data are pairs of utterances of simple sentences such as *The boy eats an apple, Peter drinks milk, Fred runs*, together with their satisfaction situations, which are situations that make the respective sentence true. The two types of structures that are established, are on the one hand similarity structures or classifications, i.e. similarity sets of situations formed, to begin with under certain basic perspectives such as colour, form, taste, touch, sound, form, motoric behaviour, and on the other hand they are contiguity structures, i.e. sets of situations which are connected to each other by contiguity relationships. These are factual relationships in space and time.

*Similarity structures* and *contiguity structures* on the growing sets of experienced situations are compatible in that relationships under one structure do not destroy relationships under the other structure. A situation is determined as that what it is under both structures together. A situation is always an experienced situation the borders of which are not fixed and vary with the focus of attention. A situations is not determined once and for all. Rather the result of applying one method of structuring under some perspective gives an analysis of the situation that is used further in applying the other method of structuring, and the result of this second step can be used as a new datum in applying the first method of structuring again on this datum. In this way, our set of data does not only grow, but the data also change in the manner they are understood, and in this way old data can become new data. In principle this spiral like process of understanding a situation can go on, and will practically terminate differently in different settings and different states of development, i.e. according to different structurings available under the perspectives created by different practical contexts, and available at a certain moment in the history of an understanding individual. Each termination of the process of understanding a situation, whether momentary or final, can become conscious in perception and in pictorial or linguistic representation, imagined or uttered. When such a classified and identified item has come into consciousness, whereby it has become embedded into parts of our conceptual structure, it can be kept in memory and it, or an imagined item of the same kind, can become a new input in a new round of the process of understanding. In what follows I shall formally characterise the two kinds of structures we lay on our growing sets of data, and I shall formulate what their compatibility consists in.

Furtheron, I shall work out in parallel the formal structure of the partitions on a neural network formed as potential activation patterns. The set of possible activation patterns is a set of dispositions of the network to react to input by showing activation patterns of assemblies of units or neurones. This set of dispositions is encoded implicitly in the connection strength between the units, which has been built up during the learning process. The basic idea was Hebb's 1947 conjecture that units which are repeatedly activated together by some stimulation strengthen the connections between them (elaborated in Hebb 1980). I shall formulate the formal relationships between potential activation patterns.

A problem is the delineation of a pattern because the pattern for a certain type of object, for example a chair, cannot easily be separated from all those activated parts of the net that are due to typical contiguity associations with chairs, such as sitting, table, sitting persons, properties of typical materials used, etc. However, some delineation can be achieved by contrast activation, for example by contrasting the patterns activated by perceiving standing persons, tables alone, chairs alone, whereby the parts activated by what is visually present must be activated stronger than the other parts of the patterns which correspond to what is not present in the input, but is merely associated. Also the associative correspondence with linguistic expressions uttered helps to single out a strongly activated part from other parts of an activation pattern in a contrast analysis of the patterns elicited by appropriate input. Hereby the important point is that the potential activation patterns and the relationships between them are induced in the course of learning from data, namely from the linguistic utterances together with their respective satisfaction situations.

Of course, also pre-linguistically experienced situations are ordered into similarity and contiguity structures, but language learning fixes or modifies these in accordance with the public vocabulary learned. For example, a common name strengthens the similarity relationships between its cases of application in satisfaction situations, a proper name strengthens similarity and contiguity relationships between the different occurrences of an individual object, syntagmatic relationships in small sentences strengthen contiguity relationships, as the ones between chair and sitting, dog and barking, etc. All this strengthening of class-identity or contiguity identity, for example the identity of an object, happens because in principle the use of the same expression in several satisfaction situations is an indicator of a recurrent identity. The linguistic utterances themselves are likewise partitioned and classified paradigmatically under similarity and contrast, and thus become utterance types or expressions, and they get at the same time represented in their contiguity relationships, i.e. syntagmatically within larger expressions. The linguistic and the situational systematisations on the growing sets of data constrain each other by correspondence within the data-pairs, such that situational information helps linguistic analysis, and linguistic information helps delineating linguistically expressed situational concepts.

After having formalised the structures in both types of models, **DCS** and **CNM**, we shall formulate a mapping from one to the other, which must be structure preserving with respect to the explicated formal semantics structures, shall we be able to speak in a meaningful sense of a representation of our conceptual structures in the set of dispositions or potential activation patterns implicit within the state of the connection strengths of a network. As far as these networks are designed to model important structural aspects of the brain and succeed in this task, we can then speak of an implicit representation of our conceptual structures in the brain, which becomes explicit in a set of potential activation patterns. And only with respect to the structural relationships between and within potential activation patterns we can speak of a formal relationship to conceptual semantics. In doing this we are able, in principle, to capture formally the relationship between the linguistic and perceptional data on the one hand, and the potential neuronal network activation states on the other. The first, being data that are publicly co-ordinated and agreed upon, impose constraints on the second, a person's structures between possible brain activation states. The latter have to be adjusted in learning by adjusting connection weights between neurones in such a way that important structural relationships of the first are preserved in the mapping.

## 2.1 The structure of Dynamic Conceptual Semantics (**DCS**)

A model of **DCS** is a growing set of data on which two kinds of structures, classificatory and contiguity structures, are established in the process of concept formation. The structures are compatible. Each new datum is understood by being placed into these two kinds of structures in a way that preserves the stability of the structures. This holds for the structures on the linguistic data, the utterances, as well as for the corresponding situational data, the perceived situations. What stability amounts to will be explained below.

The data are pairs (u, s), whereby u is an utterance and s its satisfaction situation. On the set of utterances U types of utterances are formed, and types of their parts are formed by contrast analysis between utterance types that are partly identical. These types are sets of utterances and sets of parts of utterances, namely sentences and parts of sentences, and sets of sentences and sets of parts of sentences as syntactic categories. They are formed as substitution classes of utterances and of their parts that can be substituted for each other in certain linguistic contexts and context types. These latter are thus similarity sets of utterances or parts of these, whereby similarity is relational, i.e. given by an identity of linguistic context. Likewise types or similarity sets, i.e. concepts, are formed on the set of situations. And as far as linguistically guided concept formation goes, types or concepts of their parts are formed by a parallel contrast analysis. This implies that for non-negated parts of simple sentences we have corresponding sets of satisfaction situations, namely the satisfaction situations of those sentences in which the expression part occurs in a non-negated fashion.

To keep a concept *stable* means that its internal similarity degree under the relevant perspective is not diminished by adding new examples. An evolving concept, a quasi-concept, expressed by *e* stabilises by growing towards a 'conceptually complete' set of satisfaction situations for *e*. It is conceptually complete in the sense that its internal similarity degree does not diminish any more by adding new examples of satisfaction situations of *e* under the relevant perspective. A conceptually complete set of satisfaction situations is a representative of the concept expressed by *e*, and the concept itself is the equivalence class of such conceptually complete sets. In dealing with concepts we just take such representative sets. A speech community has the same single concept expressed by *e* if and only if their concepts expressed by *e* can be thrown together into one equivalence class, which is the public concept expressed by *e*. This means that they accept each others' examples for the concept.

On the set of experienced situations, and especially on the growing set of satisfaction situations, and likewise on the set of corresponding linguistic utterances, a similarity based structure and a contiguity based structure are established, which are compatible. Situations are identified by their place in both structures, i.e. by similarity to other situations, especially by syntagmatic parallels in the internal contiguity between their parts which get distinguished under similarity and contrast with other situations, and by contiguity relationships with other situations.

On a set S, of course, a set structure is induced by forming the set Σ of subsets of S on which the normal operations 'union', 'intersection', 'inclusion', 'complement' $\{\cup, \cap, \subset, \setminus\}$ are declared, with the normal set theoretic axioms:

$A \cap B \subset A, A \cap B \subset B,$

$A \subset A \cup B, B \subset A \cup B,$

$A \cap B = B \cap A, A \cup B = B \cup A,$

$A \subset B \;\&\; B \subset C \rightarrow A \subset C$,

$A \cup (S \backslash A) = S$.

From all subsets those are selected that are similarity sets, i.e. have an internal similarity relationship among their elements, and those are selected that have contiguity relationships among their elements. Hereby we get a similarity based structure and a contiguity based structure on the set of situations and on the set of utterances.

*Similarity based structure*:

On the set of experienced situations we form similarity sets as subsets of S. Σ is the set of similarity sets on S. Similarity is a relationship with the following axioms:

x similar x;

x similar y → y similar x.

Similarity is graded: x can be more similar to y than to z.

A *similarity set* is a set S such that ∀xy ( x, y ∈ S → x similar y).

A similarity set has an internal similarity degree D which is the maximal similarity among all the members of the set. If $D > 0$, then there is a *perspective* **P** under which a transitive similarity relation holds between the members of the set by virtue of an identical feature or relationship that comes into view under the perspective by realising identities and differences under his perspective. *Stability* of a similarity set or class means that its internal similarity is kept constant.

A *class* is a similarity set with transitivity of the similarity relationship which defines the similarity set as a class: (1) ∀x,y,z ∈ C (x similar y & y similar z → x similar z)

A *class* is the extension of a *classical concept*. Here all elements have a common property or feature which defines the similarity as the identity of the class in opposition to other classes under the same perspective, for example under the perspective Colour, or Shape, or Behaviour, or a composition of these. A perspective provides a selection of which aspects of identity and difference may come into attention in determining similarity and contrast under the perspective. To view something under a certain perspective does not require that one is conscious of the perspective or has a concept of the perspective, and it does not presuppose that one already has concepts of the aspects that play a role in establishing categories under the perspective. Under the perspective we can become conscious of these aspects and in this way they can become concepts which function as features in a conceptual analysis. Although a perspective can become conscious and be conceptualised itself, it basically is a way of bodily orientation in activities and action by which certain channels of perception, understanding, or analysis are opened or selected. In advanced levels of gathering knowledge and in theory formation perspectives can be constructed and chosen by making conscious decisions to attend to these or that questions and aspects. A perspective can be thought of extensionally as a set of classes which stand in opposition to each other under this perspective.

X is *in opposition* to Y: $X,Y \in \mathbf{P}$ and $D(X) \geq D(X \cup Y)$ and $D(Y) \geq D(X \cup Y)$.

This means that the classes which are in opposition under a perspective have each a stronger internal similarity than their members have with other members outside the class under the same perspective. We also say that X *contrasts* with Y under **P**. The concepts under a perspective are formed by identities and contrasts.

*Complex concepts* are sets of satisfaction situations for an expression which can be analysed as unions of classical concepts that are related to each other by similarity or contiguity between their members under a common perspective. A similarity set without a class-defining identity, i.e. which is not defined by an identity which must be present in all its members and must be absent in all non-members, is a special kind of complex concept, namely one based on similarity only. These are complex concepts with at least a family relationship among the members, such as Wittgenstein's example of German *Spiel* ('play', 'game') They still have a common property, for example all plays and games are activities. However, that property is not sufficient to define the whole similarity set, because it does not discriminate this set from other contrasting ones. There are weaker organised sets of satisfaction situations for an expression which are based on similarity or contiguity (or both), but where there is no general perspective under which similarity is seen as a common identity. These have a much looser internal organisation by similarity than complex concepts; they cannot be understood as unions of classical concepts under a single perspective. Rather they merely are complexes of concepts with metaphoric or metonymic relationships between the concepts. Metaphorical relationships between concepts expressed by a single expression typically require a change in perspective under which the similarity is seen. Such complexes of concepts are *polysemic complexes*. They are chain and heap complexes; the concepts in them are related to each other as members of a chain or a heap by common similarity aspects or by contiguity between the elements of two related concepts. The more regular ones are *centralised heap complexes*, whereby each concept in the complex has common similarities or contiguities with a central concept. If a centralised complex of concepts in union forms a similarity set, then it is a prototypically organised complex concept, whereby the central concept is the prototype to which the others are each related by some common identities. The complex concept contains sub-concepts which overlap by similarity, each under a certain perspective, with the central or prototypical sub-concept.

> A *complex of concepts* is a subset $\Sigma'$ of $\Sigma$, such that there is an $A \in \Sigma'$ such that for all $B \in \Sigma'$ there is a chain of concepts $X \in \Sigma'$ from B to A whereby each two neighbouring concepts in the chain are connected by similarity or contiguity, i.e. if X and Y are neighbours in the chain for $\forall x \in X, \forall y \in Y$: x similar y or x contiguous with y in a constant contiguity relationship.
>
> A *centralised complex of concepts* contains a central class C such that $\forall X \in \Sigma'$: ($\forall x \in X, \forall y \in C$: x similar y) or (there is a contiguity relationship R such that $\forall x \in X, \forall y \in C$: x R y).

A *prototypically organised complex* is a centralised complex of concepts which is based on similarity relationships under a governing perspective and a couple of more specific subperspectives. this centralised complex is not based on contiguity relationships between its member concepts. Its central member is a class that furthermore has to each other member a stronger similarity than each other member has to all the other members together.

> A *prototypically organised complex* of concepts thus contains a central member which is a class C such that $\forall X, Y \in \Sigma'$: ($\forall x \in X, \forall y \in C$: x similar to y to degree D, and if x is similar to degree D' to all z, with $z \in Y$ and $z \notin C$, then $D' \leq D$ ).

The subperspectives under which the different member categories are formed also contain the prototypical member class such that their elements are comparable with the prototypical examples under the respective perspectives. This central member class is the prototypical concept. The union of the members of this kind of complex of concepts forms a *prototypically organised (complex) concept*, where the prototypical set is the central subset with which all the other subsets share a stronger similarity than a possible overall similarity across the whole complex.

C is a *prototype* in $\Sigma'$ if and only if $\forall X, Y \in \Sigma', \forall x \in X, \forall z \in Y, \forall y \in C$: x similar to y to degree D, and if x is similar to degree D' to all z, $z \in Y$ and $z \notin C$, than $D' \leq D$.

*Contiguity based structure*:

There is a set **R** of contiguity relationships between situations, for example spatial and temporal overlap and adjacency, which define spatial and temporal connectedness, and also distance, and ordering in spatial and temporal space, cause-effect, action-result, means-goal, and other factual relationships. Our *ontology* is due to the most general contiguity structure laid on the set of experienced situations.

m *contiguous with* n = there is a contiguity relationship $R \in \mathbf{R}$ such that mRn.

There are chains of situations formed by space-time and causal connectedness. The space time connectedness is provided by overlap and adjacency.

C is a *chain* = $\forall s \in C$: $\exists s'$ such that s connected with s', and $\forall s,t$: $s \leq t$ or $s \geq t$ or s overlaps with t.

A *continuant* can be a patch of colour lasting for some time, or a portion of stuff, or an individual, or an event which is a process or non-permanent state or an action. It has internal and relational properties which define its identity through time. An *individual* is a special kind of continuant such that there is some continuous property during its existence and other properties which are changing slowly. Often the property which defines the identity is not known, it is rather merely assumed that there is such a property. However, the individual is identified by its slowly changing properties by means of which it can be followed in space and time as a continuous bundle of states changing only slowly, and by constant relationships to other individuals. An individual in this model is its life history, and as a complete individual concept it is the complete knowledge of this life history, while the experienced individual is merely a partial individual concept, namely a part of this life history. We can have an individual concept of someone which is partially incorrect. If that incorrectness becomes evident it has to be corrected such that the partial individual concept can be part of the complete individual concept, the actual

individual. Reference to an individual via a partial individual concept means that the partial concept is assumed to fit coherently into series of steps towards completion into a complete individual concept. *Stability* of an individual concept amounts to the growth of partial individual concepts as parts coherent in one possible completion.
An *event* can be point like or can be a continuant. As a continuant it is a closed process with a temporal structure consisting of a beginning state, a couple of intermediary states, and an end state. An *action* is an event brought about by an actor due to motives and goals.
For a thorough analysis of these ontological notions a large philosophical literature is available. To take it into account here would take us too far off. What is important rather is that our ontology arises by establishing a combination of similarity and contiguity based structures on sets of experienced situations. The *compatibility conditions* for these two structures imply that in historical concepts, i.e. in individual concepts and concepts of other spatio-temporal entities, both structurings co-incide: Each situation is *categorised* by embedding the situation into similarity sets, i.e. general concepts, and it is *identified* as a specific situation by embedding it into one or more individual concepts, partial life histories, or into relational contiguity networks of other spatial-temporal entities. Both structures intersect in determining, i.e. classifying and identifying situations and more complex contiguity based entities in space and time. Both kinds of embedding a situation have to be done in a stabilising system, or salva stabilitate within an already stabilised system of general and individual concepts.

In order to understand or analyse a situation, also as far as this takes place in experiencing a situation, we place it into these two kinds of structure, the similarity based and the contiguity based structure, by integrating it into similarity sets and contiguity sets salva stability. That both structures are compatible means that situations, as that what they are for us, i.e. as experienced situations, are determined by both structures at the same time. Both structures get developed on growing sets of data, i.e. develop with growing sets of experiences of situations, by ordering each new situation by similarity and contiguity into those subsets of situations which are already built up in the previous states of experience. In the course of development the understanding of situations changes. Old experiences can be re-analysed in the light of new experiences, which give rise to new categorisations or new continuants into which they can be included.

Our sets of data grow. New data are added to old similarity sets and to old contiguity connections in a way that keeps these stable or coherent. To keep old structures stable implies to extend them by adding new similarity and contiguity sets for those data that do not fit into old sets salva stabilitate of their internal structures. This also holds for data that are nevertheless referred to by the same expressions as the old data to which they do not fit in a stability preserving manner. These newly created sets partly overlap with old sets. In correction, old structures are partly cancelled in favour of new ones.

Conceptual growth comes about with conceptual change by extending and elaborating a conceptual system. Here complexes of concepts get extended by forming new similarity and contiguity sets from old and new data that do not fit together into one of the already existing sets salva stability. Keeping old sets stable in their internal similarity and contiguity structure leads to forming new sets, based on some members of old sets and new data under similarity or contiguity, often under new perspectives. Similarity or contiguity under a new perspective leads to metaphoric or metonymic transfer of an old expression onto new data of a different kind. If the perspective remains constant we have cases of concept broadening. If the labels of the old sets are used also for these new sets, a polysemic complex of concepts is extended, or a concept is broadened under an identical perspective. If new names are devised for these new sets, the vocabulary is extended.

*Basic syntactic structure: The combination of similarity and contiguity structures in perceiving and understanding expressions and situations*

Our basic ontology, to start with, consists of experienced situations which are structured according to the impressions we have of the situations, our situational experiences. With growing numbers of such experiences they become analysed more and more by establishing more and larger similarity sets on this growing set of data. The ontology gets revised by embedding situations into both structures, similarity and contiguity sets. Contiguities give rise to further similarities, especially relationally based on. Thus a banana is classified together with apples and pears as fruit because of its similarity to these due to identities in the qualities of their contiguity relationships to eating, tasting, touching these things, and, with further experience about these things, to growing on trees and other plants. In this way we come to see situations and objects as belonging to certain classes and to the life histories of individuals or other historical entities.

Individuals are sets of situations structured by several similarity and contiguity relationships. Individuals are completions of partial individual concepts, which are sets of situations embedded into an order of situations that typically holds within life histories of the special kind of continuants which are individuals. Similarity sets are formed over individual concepts, established in this way. These are classes of individuals as there are, for example, the natural kinds we distinguish. A situation can be seen as a part of an individual concept and thus can be perceived as an action or an activity in which the individual is engaged as an actor or as an other participant, or it can be seen as a state or process in which the individual is involved in a certain role. In this way situations are perceived as being analysed according to our ontology of individuals, events, actions, states, and processes, which we have built up by combining similarity and contiguity structures in our uptake of situations. Since perception consists in embedding sensory data into these structures, the data as perceptions are already understood as such and such situations in the act of perception. With the dynamics of our conceptual systems also our perception of situations changes over time, and thus our world as perceived and understood world changes.

The two types of structures in combination with certain restrictions, holding for different kinds of entities, set up our ontology. The two structures are not only compatible but they together establish the coherent network of our historical and general concepts, as far as it is based directly on experience. Therefore a perceived situation, individual, event, action, state, or process does not only consist of parts perceived due to sensoric stimulation, which are embedded into similarity and contiguity sets and thus analysed or understood in the process of perception. Rather the perceived object contains additional aspects which are induced by the embedding of the incoming sensoric data into general concepts and into historical, especially individual, concepts in categorisation and in identification of the object. We perceive a car, although we do not really see the backside of the car. The whole object is the perceived object, whereby what is perceived is hereby ontologically categorised and identified. Perception does already contain cognition of the object. This is a Kantian and Husserlian notion of perception, which also is implied in **DCS**, and also in **CNM**. What is perceived is not just a bunch of sense data without categorisation. In perception these always are embedded into previous organisations of data. As soon as ontological concepts are established on our sets of data, perception is not anymore just a situational impression within some qualitative and quantitative categorisations by similarity and contrast and some loose space-time contiguity relations. Though at first we merely might have qualitative and quantitative categorisation of situational impressions by our senses, by combining similarity and contiguity structuring in an ontological categorisation, situations are then understood as built up by individuals being involved as participants in actions, events, states, and processes.

The primary data are basic sentence utterances and situations. From a set of basic sentences and their satisfaction situations, whereby sentences and likewise situations are related to each other by identities and contrasts, concepts of the parts of sentences and parts of situations, and especially the morpho-syntactically expressed (relational) concepts, for example the syntactic-semantic role-concepts, are constructed. An individual in a situation has a participant role, which is grammatically expressed by morphological case marking or by position in the sentence.

Construing and understanding new basic sentences and situations goes hand in hand: the structure of this process is recoverable in the structure of the result, the sentence and its satisfaction situation. In understanding a situation in perception, we can construe in parallel a sentence to describe the situation, and in parallel with understanding a sentence as a linguistic entity we understand its content by construing its possible satisfaction situation in a hierarchically organised process. The steps of the construction are, what I have called **B**-intersections in Bartsch 1998.

> A ***B**-intersection* of two concepts A and B is the intersection of a representative of A, i.e. a partial extension of A, with a representative of B, i.e. a partial extension of B, whereby the intersection is formed by adding the smallest situation s to both concepts salva stabilitate.

This means that we construe a smallest situation s which must fit into A and B without impairing the stability of A and B. This implies that the addition does not diminish the internal similarity within the similarity sets A and B under the relevant perspectives. If A or B is an individual concept this implies that there is a part of it to which we can add s such that the coherence of the partial individual concept is not impaired by adding s. This is enough for understanding s as part of a certain individual. For truth more would be required, namely that s is embeddible into the individual, i.e. into its whole life history, salva stability, which means that it is embeddible into the complete individual concept in a coherent way. Construing a smallest situation s in the intersection of two concepts is what Kant has called the synthesis by the power of imagination.

The smallest satisfaction situation of a sentence is not construable without a hierarchical structure of sentence construction. Result of understanding a sentence, and parallel of understanding a situation, is the construction of a smallest situation which is located as an element in a hierarchical architecture of sets of situations, or concepts. Some sets are classes, others are selections from individual concepts, for example the set John as Actor, a partial individual concept, is a subset of the partial individual concept of John as we know him. The latter is a subset of the set of situations that is John's life history. Within the selection expressed by *John as Actor* a step of the sentential hierarchy, for example of *John loves Mary*, is encoded. This requires that in understanding the sentence *John loves Mary* the set of *John*-situations and the set of *Actor*-situations are **B**-intersected first before this whole is **B**-intersected with the set of *love Mary* -situations. The last is construed by first **B**-intersecting the set of *Mary*-situations with the set of *Patient*-situations and then **B**-intersecting it with the set of *love*-situations. A semantically equivalent would be to first construe *John love*-situations and then form the **B**-intersection with *Mary as Patient*-situations. Likewise, but redundantly, we also could **B**-intersect the set of *John love*-situations with the set of *love Mary*-situations. Either way, the result is the same: The possible satisfaction situation for our sentence has to be a member of the set of situations that each contain the smallest situation construed by the above procedure, which is syntactically guided, though different syntactic routes lead to the same result. Of course, this procedure distinguishes *Mary loves John* from *John loves Mary.* The result of construing the smallest situation that has to be contained by all possible satisfaction situations of a sentence is dependent on syntactic structure.

Relationships, and especially actions, get classified by substitution, whereby a variation of the participants of a relationship can be achieved. We form a constant one-place predicate. By variation of the first place term, by subject variation, we get *x eat(s) bread* from sentences like *I eat bread*, *John eats bread*, *a girl eats bread*, etc. By variation of the second term, object variation, we get *I eat y* from sentences like *I eat bread*, *I eat pudding*, *I eat an apple* , etc. By variation of subject and object term we get the relationship *x eat(s) y*. The relationship in fact is a growing set of sentences with their respective satisfaction situations, whereby the sentences and likewise the situations are related to each other by such substitutions of terms in subject or in object position, or by substitutions of the respective Actor-participants and Patient-participants in the respective situations. The internal similarity of the set is given by what remains constant under substitution. In order to form the **B**-intersection between the partial individual concept John as Actor, i.e. the set of situations in which John is involved as actor, and the relational concept Love, i.e. the set of love-situations, we extend both by the smallest situation s that fits into both, salva stabilitate. This means we construe a smallest situation s that fits into the set John as Actor and into the set Love, salva stabilitate. This can be a Love-situation construed from some other Love-situation by substituting John for the Actor-participant, parallel with construing the sentence by substituting *John* for an other subject term in, for example, the sentence *Peter loves Mary.* An analogous step is taken to get the **B**-intersection between the set of John Love-situations and the set of Mary as Patient-situations, and in this way the smallest situation in which John loves Mary is construed, parallel with substituting *Mary* for possibly some other Patient-term in, for example, *John loves Greta.* We can construe new complex expressions from old complex expressions by substitution, or variation, a method also called 'projection' from old to new expressions (cf. Ziff 1960). The operation of **B**-intersection is a parallel operation to substitution in sentences, now on the level of concepts, which are represented by stabilising or already stable, but still growing, sets of situations. Substituting Mary for Greta in a situation type or situation concept such that we get the situation concept John Loves Mary amounts to forming the **B**-intersection between the concept John Loves and the partial individual concept of Mary as Patient. Such substitution is the same as a unification of Mary as Patient with the Patient-aspect in the action concept Love.

On the level of DCS the sentence *John loves Mary* is understood by construing **B**-intersections between sets of situations representing the involved concepts:

A: John, i.e. the set of John-situations that form the partial individual concept of John;

A': John as Actor, i.e. the set that is the **B**-intersection between the concepts John and Actor, which is the set of all situations that contain the smallest situation in which John is Actor;

B: John Loves, i.e. the set of all situations in which John loves somebody. It is the **B**-intersection between John as Actor and the relational concept Love, which is the set of situations that contain the smallest situation in which John is Actor and the relationship Love is realised. In construing the smallest situation the Actor-aspect of John as Actor is unified with the Actor aspect that is included in all Love situations. That the actor aspect is included in all Love situations means set-theoretically that the set of all Love-situations is included in the set of all situations in which there is an actor, i.e. in all activity situations.

L: Love, i.e. the set of Love-situations

C: Mary, i.e. the set of Mary-situations that form the individual concept of Mary;

C': Mary as Patient, i.e. the set that is the **B**-intersection between the concepts Mary and Patient, which is the set of all situations that contain the smallest situation in which Mary is Patient;

D: Loves Mary, i.e. the set of all situations in which someone loves Mary. It is the **B**-intersection between the relational concept Loves and Mary as patient, which is the set of all situations that contain the smallest situation in which the relationship Love is realised and Mary is Patient.

E: John loves Mary, i.e. the set of all situations that contain the smallest situation in which John loves Mary. It can be construed as either the **B**-intersection between B and C' or between A' and D.

E can also be construed as **B**-intersection between A' and C' followed by **B**-intersecting the result with L:

F: John as Actor and Mary as Patient, i.e. the set of situations which contain the smallest situation in which John is Actor and Mary is Patient. This set then can be

cut down further by **B**-intersection with the relation-concept Love, which gives us the situational concept of John loves Mary.
This account of alternative ways of understanding the simple sentence *John loves Mary* by construing the situational concept it expresses in forming **B**-intersections makes that the situational concept of John Loves Mary implies several set theoretical inclusions between the constituting concepts. The order relationships in the series of inclusions represent the possible alternative hierarchies of syntactic construction that all lead to the same result, the situational concept of John loving Mary:

| | |
|---|---|
| $A \supset A' \supset B \supset E$ | i.e. E = **B**(**B**(**B**(John, Actor), Love), **B**(Mary, Patient))) |
| $C \supset C' \supset D \supset E$ | i.e. E = **B**(**B**(**B**(Mary, Patient), Love), **B**(John, Actor))) |
| $L \supset B \supset E$ | i.e. E = **B**(**B**(Love, **B**(John, Actor)), **B**(Mary, Patient))) |
| $L \supset D \supset E$ | i.e. E = **B**(**B**(Love, **B**(Mary, Patient)), **B**(John, Actor))) |
| $A \supset A' \supset F \supset E$ | i.e. E = **B**(**B**(**B**(John, Actor), **B**(Mary, Patient)), Love) |
| $C \supset C' \supset F \supset E$ | i.e. E = **B**(**B**(**B**(Mary, Patient), **B**(John, Actor)), Love) |

We see that the process of construing the complex situational concept is a gathering of constraints on the set of possible satisfaction situations for the sentence at issue; in understanding the sentence step by step more and more constraints are placed on the set of possible satisfaction situations, by which the set becomes smaller. The process of understanding a sentence is thus a specification, which involves some fixed hierarchies. The concepts construed by **B**-intersection between two concepts are not empty, because either the smallest situation construed is already a member of both concept representing sets, or it is added to both sets, salva stabilitate.
We have seen that understanding a sentence follows hierarchies of constituents in performing the syntactic-semantic **B**-operations. For a simple sentence the combination between noun phrase concepts and participant role concepts has to be performed first, after that the formation of constituents can be done either way. This means that within the sentence constituents there is a fixed hierarchy, but the combinations of the sentence constituents are free, in other words, the main sentence constituent structure is flat. The traditional VP is not a necessary constituent in the built-up. The nomen-actor constituent can be connected first to the verb, and after that the nomen-patient constituent can be added. Even the nomen-actor and the nomen-patient constituent can be connected first in **B**-intersection, and

then this new concept, John as Actor and Mary as Patient in an Action, can be specified further by **B**-intersecting with the Love concept. Hereby the concept Love is unified with the general action concept. Sentence constituent order is free and can be treated differently in different languages, without a difference in the conceptual semantics of the sentences. If we would also take into account extended sentences with adnominal phrases and adverbial phrases, we would have fixed hierarchies in the comprising nominal and verbal phrases, within which the adnominal has first to be connected to the noun or noun phrase, and the adverbial has first to be connected to the verb or extended verb phrase, according to the scope it has.

## 2.2 The structural properties of connectionist network processing.

All the inclusions and non-empty intersections on the growing sets of experiences and construed situations somehow must be reflected in the relationships between potential activation patterns that come up in processing a sentence in connectionist networks. Also there we have relationships of inclusion, union, and overlap. The questions are

1. What should the relationships between potential activation patterns look like in the process of syntactic-semantic understanding?
2. Should there be an activation pattern which is the result of the process of understanding and thus would that be something like a network internal semantic representation of a sentence?
3. What should the process of understanding a sentence be in terms of network architecture and mathematical operations?

I shall deal with the questions in that order.

Conceptual Semantics, as it has been sketched in the previous section, places restrictions on what should happen in neural networks, will they have any chance to conform to their tasks in the process of relating linguistic expressions to external semantics, and generally, to being attuned to external situations and tasks performed externally. The process of understanding in **DCS** was one of gathering constraints on possible satisfaction situations, represented by **B**-intersection on concept representing sets of situations, which amounts to cutting down on the sets in a process of specification by intersection between sets or expansions of these which are stability preserving. At least some, but not many, hierarchies in constituents formation were fixed. The fixed, endocentric, constituents have to be processed first, before they as wholes can be connected to other constituents. Except for these fixed hierarchies, the processing just can proceed in any order of sentence constituents, preferably following the sequential order, whereby the internally fixed constituents, processed first, are taken as units. How can such process of sentence understanding be mirrored in connectionist networks?

*Ad question 1*: The formation of **B**-intersections should have formation of unions of activation patterns as correspondents, because the potential activation patterns can be seen as sets of micro-features, established in the process of learning and unknown to the language user, which restrict our perception of possible external semantic correspondents of the activation pattern. The greater the activation assembly or area the more restrictions or features it may represent in principle. Thus the pattern for roses should be larger than that for flowers. The rose pattern contains the flower pattern and also encodes additional more specific rose features. Likewise John as Actor should have a potential activation pattern that contains the one for John and the one for Actor. The processing thus has to be such that potential activation patterns are added to each other. For example, first the pattern for John should be activated and then, according to the case marking or position of the phrase and the kind of verb, the Actor pattern should be activated. Likewise the pattern for Mary should be activated, and to this the pattern for Patient should be added. Furthermore, the pattern for Love should be activated additionally. Internally, it always has some parts that are a generalisation of the Actor-participant, and some other parts that are a generalisation of the Patient-participant. The activation of the Love pattern will again provide some activation for the Actor pattern that had already been activated additionally to the John pattern. Likewise the activation of the Love pattern will imply some additional activation of the Patient pattern that is also activated additionally to the Mary pattern. This overlapping of activation can be seen as a unification: the Actor part within the Love pattern gets unified with the especially activated Actor part in the John pattern. How these structures might be achieved in terms of network architecture and operations on vectors will be discussed under question 3.

*Ad question 2*: Patterns of distributed representation need not be connected. They can even be distributed over several submaps. Should there, nevertheless be a unity that connects the John pattern and the Actor pattern? The unity could be that they are activated at the same time. This is not quite the case if we realise the concepts in sequence by addition. We have to assume that there is circular self activation such that the first activated pattern is still active when the second comes up. What that means for the architecture we shall discuss under question 3. When we continue this principle for the whole sentence, we get in the end all the patterns activated during the process still being active in the end stage, and we thus have a kind of result representation, in which in fact everything is mixed up. This result cannot distinguish anymore between Mary loves John and John loves Mary. But if we were able to measure the strength of activation according to the number of stimulations received in sentence analysis then the overlapping parts are measured as more strongly activated. Thus for the sentence *John loves Mary* the Actor part within the John pattern gets stronger activated than the Actor part within the Mary pattern and the Patient part within the John pattern; and the Patient part within the Mary pattern gets more activated than the Actor part within the Mary pattern and the Patient part within the John pattern.

A representation sensible to structure must be such that the semantically relevant processing steps are still recognisable in the overall pattern. Thus, either we must claim that a resulting final representation of a sentence as a potential activation pattern does not exist in a meaningful way and the syntactically structured procedure of connecting activation patterns is all that there is to sentence understanding: the path to the goal is the goal itself. The proposition then is a series of activation patterns, as in type (4) connectionist networks according to Ramsey (1992). Or we must claim that htere are connections between successive patterns which are not just the union of two patterns, but imply a modification of one by the other, as has been proposed by Elman (1990, 1993, Garson 1994). Methods for trying to do this are mentioned under 3. Note that measuring relative strength of activation due to the number of stimulations, as pointed out for the sentence *John loves Mary*, will conform to the requirement of modification: The John pattern is modified to become a John as Actor pattern by an extra stimulation of its Actor part. This purported brain activation pattern gets a conscious expression or articulation in imagining John as Actor. Perceiving John as Actor also comes down to a conscious expression of this pattern in a projective relationship to a space-time region outside. The projective relationship must be established by activations of potential brain patterns or dispositions towards routines of our bodily capacities of reaching out and moving in space and time.

We now discuss whether a finally resulting activation state that is typical, i.e. unique, for a certain proposition, is indeed necessary. I think there is no reason for this. If we want to keep some fixed representation for a proposition we could best take an inscription of the sentence itself, or some semantically equivalent sentence, or some imagined or produced picture of the satisfaction situation. The picture can be seen as an expression or articulation of the potential activation pattern which is also the result of the process of understanding the respective sentence, whereby the relative strength of activation expresses itself in seeing or imagining John as Actor and Mary as Patient in the love situation. It is not necessary to state an equivalence between such representations by pointing out an identical activation state. Rather the equivalence is found externally in what the possible satisfaction situation is like, which is conceptually represented on the **DCS**-level of growing sets of situations. There is no need for a final or single activation state of the connectionist network that should correspond to a proposition, and which would be stored as such in some memory space. To require such a representation is a relict from the traditional model where fixed mental representations were assumed to be constructed and stored in memory as something that can be used and re-used in various contexts. Still, in our memory we may be able to dig up a describing sentence or an approximate picture of a certain situation. Thus, if we do not want to assume that the network somehow makes copies of its activation states and stores them somewhere, we have to think of this network as being itself modified in its connection weights in such a way that episodes are kept in it implicitly such that the respective patterns can be activated again if some parts of them get activated by some appropriate stimulus. But within a certain state of connection weight distribution in a network we cannot find back the representation of a particular episode or a particular sentence, though it must have had some effect in strengthening some connections and not others. The weight distribution has been changed somewhat.

From the point of view of modelling understanding we can just do with modelling the process of understanding, in which brain activation patterns for the syntactic-morphological concepts and lexical concepts are run through constituentwise in connecting the sentence to brain external public situations or to imagined situations. What is then kept as a representation in our mind is the sentence itself in its, in principle, public connection with situations. That connection, in terms of gathered satisfaction conditions for the sentence, can be expressed in a semi-public fashion in DCS by operations of **B**-intersection on growing sets of situations. These structures must be somehow represented implicitly in the brain generalised as routines or procedures, but in the typical connectionist processing they merely appear in the realised procedure, which serves in connecting the sentence with the external semantic conditions by selecting the relevant aspects in the perception of satisfaction situations in a process of double activation, namely by understanding the sentence and by perceiving the situation. The procedure is not kept up in any resulting state, if there is any, something which is not really necessary. That a certain resulting momentary state with a certain distribution of relative activation strength over the pattern has been reached is equivalent to the fact that a procedure from a set of equivalent syntactic procedures had been run through. For example, if we follow the different alternative procedures of construing **B**-intersections in DCS presented above, we reach the same distribution of relative activation strength over the resultant activation pattern.

*Ad question 3*: Connectionist networks typically work with operations on vectors, which are used to represent input and output, but also can be used to represent the activation of the internal net, such that all the hidden units are represented as dimensions of a vector, which can have the values 1 or 0, depending on the state of being activated or not. An activation pattern then can be represented by such a vector, which, of course, will be very long. In this purely theoretical discussion let us assume that lexical expressions, but also compound expressions, trigger activation patterns on the neuronal networks. The patterns have been formed as dispositions or potential actiation patterns in the course of learning language in perceived situations and activities. These dispositions or potential activation patterns are implicitly encoded in the connection strengths of the network. What was discussed above already implies that for syntactically compound expressions certain operations give a structure to the built-up of the resulting semantically representing pattern, which the pattern by itself cannot exhibit, if it is merely expressed by 1 or 0 for each of its units. The structure then cannot be found back in the pattern, except in the process of reproducing it following the syntactic form of the expression. In accordance with this view we can also assume that syntactically compound expressions which have been learned as wholes in situations, may correspond to an situationally caused activation pattern which can only then be a pattern of an understood situation, if in its production a syntactically organised situational built-up is followed. - Note that this syntactically organised understanding of situations might be a speciality of human perception and understanding, not found in speechless animals. -

By contrasting complex expressions and their resulting potential activation patterns as wholes and hereby attending to identities and contrasts, a built-up of the expression pattern as well as a built-up of the situational pattern can become apparent, because then parts can trigger activation separately and the whole can be established as built up in a process from the patterns of the parts. The problem is that simple commutative and associative addition of patterns simply represented by vectors consisting of ones and zeros will lead to a mix-up, such that sentences like *Mary loves John* and *John loves Mary* cannot be distinguished. We shall now see what architecture and what operations on vectors can do, which have been proposed to deal with syntax in connectionist models.

*1. Vector concatenation with recurrent fibres*

Vector concatenation means that the vectors of two sentence parts in a sequence are fed into a net in such a way that first the vector of the first part is fed in with a certain activation result on the net. Then in the second circle, by recurrent fibres, a new vector consisting of this result concatenated with the vector of the second part is fed into the net. - See Garson 1994 and Elman 1990 for representing information built up in time. - This means that per unit on the net the activation values of all the units of the net and then the values of the units of the vector of the second part are imposed on the unit. If feeding in the vector basically means multiplying the values per unit by all the values fed in, then there is a great chance that much is cancelled out by zeros. If the activation value of a unit is separately multiplied with each dimension value of the input vector and the results are added up then the chance is better for a result that makes some sense. If we have the vector for John on the net and then concatenate it with the one for Actor and feed this concatenation into the net by multiplication and addition per value, only the positive values of John get modified. The zero values in the John-vector stay zero. The positive micro-feature values get modified by being multiplied separately with all the values of John and by being multiplied with all the values of Actor. The results are added up for a new activation value. The result consists of the new values on the pattern for John, which are all positive and thus the pattern is not changed much, except by its overall activation being strengthened by some extra firing. But this does not make much sense. There is no way to see how in this way the concept Actor is represented on the net. If Actor is already activated separately on the same net and then concatenation is performed, the John pattern as well as the Actor pattern stay and only change somewhat in the strength of activation, resulting possibly in additional firing of the units involved in the patterns. They form a union, and thus this method basically comes down to vector addition, which will be treated below.

*2. Vector addition*

Let us assume that a sentence is processed in the temporal order in which its parts are uttered. In English we have the sentence patterns of *John beats Paul* and of the contrastively used sentence *Paul, John beats*, which is used on a par with *It is Paul whom John beats*. Anyway, the position directly before the verb indicates the subject phrase. In English the verb obligatorily follows the subject phrase and thus marks the subject. In languages with a still active case system there can be very different orders, like in German *der John schlägt den Paul*, *den Paul schlägt der John*, where the rule is that in main clauses the verb occupies the second position of sentence constituents. If the respective sentence patterns have been learned then the sentence can be parsed as (*John*, Subject) *Beats* (*Paul*, Object), whereby Subject and Object are realised as Actor and Patient, respectively, in the action of beating. The Actor concept is part of the Subject concept if the verb appears in the active and not in the passive form. The activation pattern caused by the utterance part *John* causes the corresponding activation pattern on the conceptual map. The potential activation pattern for the concept of John contains subpatterns for Actor as well as Patient, because John has often been experienced as actor and often as patient. This, of course, gets generalised for all humans and also animals. By the subject marking of John in the active form sentence utterance, the Actor subpattern is additionally activated. In fact we here have an addition of the John activation pattern and the

Actor activation pattern, which can be expressed by adding the two vectors that represent the potential activation by John and the activation by Actor. The vectors have as dimensions all the units on the conceptual map, and the values in these dimensions are the activation values. By performing vector addition, in each dimension the values are added to each other with as result a new vector which is the sum from the two. On the net, the addition results in additional activation of the Actor part in the John pattern. In this way we have constructed the activation pattern for John as Actor.

The Beat activation pattern has as subpattern a part that is due to the actors perceived in the set of Beat situations in the learning process, and it has a part due to the patients perceived in the same situations. By adding the vector for John as Actor to the vector for Beat the activation part for Actor is activated again additionally. We in fact have a union of the pattern for John as Actor and the Beat pattern, whereby the overlapping parts are especially activated. There is a unification of the two patterns achieved by the overlapping part, namely the Actor pattern, which is identical in both and gets by repeated activation especially activated. Likewise the activation pattern for Paul as Patient is called up by addition of the vectors for Paul and the one for Patient, and it is united with the pattern for John Beats. Here the especially activated Patient subpattern in the pattern for Paul as Patient is additionally activated by vector addition to the pattern of John Beats, where a Patient subpattern is included. The result by pattern union, or vector addition, is a pattern for the situational concept of John Beats Paul. In fact, by just looking at the activated pattern as a result we cannot distinguish John Beats Paul from Paul Beats John, because the result of pattern union does not preserve the way in which it is constructed. But if we take into account the distribution of the relative strength of activation which enhances the Actor part within the John pattern and the Patient part within the Paul pattern, and vice versa in the second sentence, the systematic semantic distinction between John beating Paul and Paul beating John can be made. The distinction is made in the process of activation according to the sequence and the case or position markings in the sentence. In assuming vector addition we have a semantically meaningful operation, whereby the process matters. The alternative processes are equivalent by resulting in the same distribution of relative activation strength within the overall resulting pattern.

There is a way of keeping the essential properties of the process of understanding in mind. That is done by having available an imagined picture due to the actual activation pattern with its distribution of relative activation strength, or just the linguistic representation in form of the sentence, or a linguistic equivalent, which can always can be understood. In the process of understanding the syntactic-morphological information as fixing a partially hierarchical built-up of the imagined or perceived situation plays an essential role additionally to the lexical information present in the pattern union.

Note that the sentence *Paul, John beats* likewise is understood simply in the temporal order of its constituents. But here first an overview of the sentence is necessary to see from the pre-verb position that *John* is the Subject. Since *John* is such marked as the Subject, *Paul* must be the Object. Then the pattern for Paul as Patient and for John as Actor are activated, and with the union of these, the pattern of Beat is united, whereby its Actor part additionally activates the already especially activated Actor subpattern of the John pattern in construing John as Actor and the Patient subpattern of the Paul pattern in construing Paul as Patient. Also here, the overall activation pattern finally resulting does not make the necessary conceptual distinctions, though the process of construction and herewith the resulting distribution of relative strength of activation within the overall activation pattern of the sentence do. The latter cannot be captures if one merely used ones and zeros in the vectors representing activation patterns. then the different distributions of activation strength cannot be expressed. One has to use finer values for representing the degree of activation of units, or has to use measurements for the strength of activation of units in terms of its duration of activation.

The classical position in cognitive science is that there must be a semantic representation, which must exist at some moment as a whole, and a copy of it can be kept and stored in an explicit memory. If we would abandon this picture of a memory as a store of semantic representations, we could be content with what is achieved, because we have pictures and sentences as fixed linguistic representations in external stores on paper, in notebooks, in computers, and in libraries, and we can call them up in imagination consciously in our minds by stimulation through tokenings of some of their parts. But that does not mean that there must be an unconscious part of our mind, as a kind of library, in which they would be stored in explicit forms. Rather they merely must be implicit in the connection strengths within our neuronal networks such that they can be called up by some appropriate linguistic or situational stimulus, resulting in an activation pattern that can become articulated in consciousness, i.e. can express itself in a mental representation, which is a sentence token or a picture in our mind. On our linguistic and pictorial representations we can do all kinds of explicit logical operations. And we have an implicit memory in the connections in our neural nets, which can come up with activation patterns in causally established connections with input from linguistic utterances or situations. Of course, the temporally ordered patterns of procedure, like all other kinds of routines, must become encoded in our neural net architectures in learning processes. Then the presentation of a fixed external linguistic or pictorial representation in perception, or the imagination of such a thing, can activate the relevant procedures of conceptual activation.

If somebody would have mainly perceived beat-situations in which John does the beating, then in forming the union between the patterns of John as Actor and of Beat, not only the Actor pattern would be additionally activated by the adding up of the values in the overlap between both patterns, but also the John pattern would additionally be activated because in the Beat pattern the concept of John is already represented fairly strongly. The situation than would again strengthen the concept of John as a notorious beater and the concept of Beat situations as situations in which typically John is actively involved.

### *3. Tensor product*

Smolensky 1990 (discussed in Horgan and Tienson 1992 and 1997) has made a proposal to treat sentences like the above by means of Tensor Products between vectors, and not by simple addition. The reason for using this more involved operation is the one mentioned above, namely that the resulting conceptual activation patterns for a sentence like *John beats Paul* cannot be distinguished from one for *Paul beats John*, if we just use pattern union or vector addition with only ones and zeros, whereby 0+0=0, 0+1=1, 1+1= 1, meaning that only activation or non-activation is registered, but not the amount of it. If the conceptual semantics of these sentence is just construed by vector addition in that coarse manner the resulting vector is finally the same. Note furthermore that the coarse method does not take into account that in the John-pattern, and generally in every Human- and Animal-pattern, also some Actor-features and some Patient-features are to some degree activated, depending on how often John, or humans and animals, were experienced as actor and how often they were experienced as patient in an action. The Actor-features become strengthened by addition of the Actor-vector representing the Actor-concept in the syntactic structure, the Patient-features of John do not become strengthened in this case. Only if we neglect all this, vector addition is an insufficient operation for syntactic composition and is rightly criticised.

In the tensor product, on the other hand, an n-place vector and an m-place vector are connected by multiplying each value of one vector with all the values of the other vector. The result is represented in a vector with n times m dimensions. Smolensky forms the tensor product of the vector for John and the vector for Subject, the tensor product of the vector for Mary and the vector for Object, and the vector additions of these with the vector of Love as verb, which is also a tensor product. The result is something like [**v**(John) x **v**(subj)] + [**v**(love) x **v**(verb)] + [**v**(Mary) x **v**(obj)]. Generally, the semantic vectors of words are tensor multiplied with a vector for the grammatical category they are used in.

The problem I see for this representation is that the tensor product does not make sense as a semantically relevant representation for John as subject, Mary as object, Love as verb. If subject, object, verb are just concepts of linguistic theory it does not make much sense multiplying the activation value in each hidden micro-feature for the concept of John with the grammatical category subject. If a semantic concept of Subject is meant, something like Actor or Carrier of a state, then each positive value of a micro-feature of John will be multiplied with that. A unit of the potential activation pattern for John can be seen as a micro-feature, and an assembly of such micro features may stand for a feature of John, as we know features. Assume that an assembly of micro-features is indicative for John's blue eyes, then also their values will be multiplied with all the Actor-features, and where the vector dimensions have the value zero, they will be multiplied with zero. That does not make any sense. The result of the tensor product will be a modification of the John pattern and of the Actor pattern, but the micro feature values of this modification result have no semantic significance. The pattern does not contain the one of John, nor the one of Actor as subpatterns, and thus the activation pattern of John as an Actor does not include the activation pattern of John, nor that of Actor. It represents nothing meaningful because it does not have causal connections to John situations, nor to Actor situations. That we can retrieve the values for the Actor vector from values of the tensor product vector and the values of the John vector does not give any semantic relevance to the tensor product. The tensor product does not have any semantic relevance to the causal connections of the potential activation patterns, established in learning, to the situations that served as input into the learning process. The tensor product is here merely a technical device without any meaning.

Criticism of this kind, besides other points which I do not follow, has also been put forward by Fodor and McGlaughlin (1990) and Fodor (1997) against Smolensky's solution to the problem of systematicity: Fodor (1997) points out that vector composition by tensor product misses the causal connection to the possible referents of the expressions in composition. In short, semantic composition is not respected by tensor products. Compositionality of representations is not kept up in constituent combination by tensor product: BROWN COW does not partly overlap with BROWN TREE, as it should. The mental representation of Brown Cow has to include the one of Brown, as has the one of Brown Tree. That is not so in Smolensky's tensor product. Fodor (1997: 114) argues that a mental representation must be causally explanatory in the sense that " a tokening of BROWN COW will include the effects of a tokening of BROWN".

Horgan and Tienson, and also Garfield (1997), do not accept that semantic compositionality should be presented in syntactic composition of vectors and they support Smolensky's syntactic structures by claiming that they need not work compositional under the point of view of semantics and causality. It is enough that it makes for a systematic change in the resultant pattern when we replace John as Actor by Mary as Actor, or Peter as Actor, etc. We therefore can abstract the Actor pattern by systematic substitution of John in the tensor product by Mary, by Peter, by Paul, and so one. Against this I want to argue, that if syntactic structure would not be semantically relevant and motivated, there would be no sense in having syntactic structures at all. In order to uphold semantic relevancy of vector composition by tensor product formation, we would have to assume that perceiving John as an Actor is already a syntactic process in which not only a John-pattern and an Actor-pattern get activated, but in the perception of a situation in which John is an actor already a syntactic step is taken such that also the result of the tensor product of both conceptual representations gets activated. Generally, the perception of a situation would then have to involve a syntactic process which is more than addition, and it would have to keep, apart from the result of the composition, additionally also the composing parts, because the result does not contain these parts anymore, but still we have to be able to automatically get all the semantic implications from a situation. This view on perception is not unacceptable per se. That perception involves a syntactic process has to be claimed also for taking vector addition instead of the tensor product, because there only the process of composition can distinguish a situation of Peter beating Paul from Paul beating Peter. But there the result still contains all the conceptual parts, though as a whole it would only be discriminative enough, if our representations of individuals does already include some Actor, Patient, and other participant aspects in actions and events generally, and if activation values would be also others than just 1 and 0, and rather would represent degrees of activation such that double activation adds up to higher values.

A formal problem of the tensor product is that the vector length is n times n if both contributing vectors represent an activation pattern in the same net consisting of n units. A vector of the length n times n does not represent a pattern in the same net but has to be represented by a larger net with n times n units. A way out would be not to take a vector but an n times n matrix as the result of the tensor product and then have an operation performed on the matrix to reduce it to an n-place vector, for example by taking the diagonal. That would mean that in each unit just the activation value for John, 0 or 1, will be multiplied with the activation value, 0 or 1, for Actor in that unit. The problem is that if in such a multiplication one of the values is zero, then in the result also the other values gets cancelled out. The result is zero. If, for example, on the assembly of micro-feature values on which the blue of John's eyes is represented nothing of the Actor-concept is represented, then it is cancelled in the product John as Actor that John has blue eyes. The pattern has the value zero at these micro-features. The blue eyes of John cannot be recovered from the pattern of John as Actor, even though in our perception of John as Actor this feature would remain stable. This way John as Actor may not be distinguishable from, for example, Peter as Actor, if such cancelling happens for several specific features of John. What remains of John in the product with the Actor-vector are merely the micro features that attribute to Actor features, and of the Actor-features only those remain that are also found in the representation of John. The vector product amounts to an intersection of features. This parallels a union of John situations and Actor-situations, which is much to broad and is inadequate for representing John as

Actor. John as Actor is rather the intersection of the John-situations with the Actor-situations. Therefore the vector product, represented in the diagonal of a matrix construed by the tensor-product of two vectors, is inadequate.
Likewise to reduce the matrix by adding up the rows of the matrix or by adding up its columns would be inadequate. By adding up the columns we would just get the vector of the first constituent, in our example the vector of John, multiplied with the number of ones appearing in the Actor-vector. By adding up the rows we would get the vector of the second constituent, i.e. the Actor-vector, multiplied with the number of ones in the John-vector. This would amount to nothing more than an additional activation of either the John-vector or the Actor-vector. It is possible to devise another reduction method of an n times n matrix to a vector of n dimensions, but all this would be rather ad hoc.

## 3. Conclusion

The result of considering these methods is that vector addition or union of activation patterns makes sense semantically, whereby unification by common parts between patterns, which thereby get more strongly activated, plays a suggestive role in connecting the conceptual implications of parts of speech. This also holds for adnominal constructions. Take, for example, *red ball.* The Red activation pattern contains parts that generalise over surfaces, because we mainly experience coloured surfaces. This is parallel to a so-called Surface-slot in a frame representation. The Ball-activation pattern does not contain a specific colour but a generalisation over colours on the surface generally, an aspect that in a frame representation would represent a Colour-slot on a ball's surface. It further contains parts for representing a round surface, including parts that represent surface with colour in general. In the union or vector addition of these patterns of Red and of Ball, these common parts get double activation, namely by the generalised Surface-parts of the Red-pattern, and by the generalised Surface parts of the Ball-pattern. In this way there is a union between the Red- and the Ball-pattern by unification of the common subpattern for surfaces. The important point is that we take into account that potential activation patterns, and likewise mental representations on the level of frames and scripts, contain parts that represent typical contexts or situations of occurrence of the phenomenon to be represented. These get especially activated in syntactic and situational composition by way of unification or overlap like in (John[Actor) Love {Patient] Mary} or in (Red[Surface)Ball], whereby Actor-features have been especially enhanced within the John representation and Patient-features within the Mary-representation by morpho-syntactic information that the Actor-concept applies to John and the Patient concept to Mary.

We can conclude that a mapping between **DCS** and connectionist networks representations in **CNM** has to map intersections between sets of situations, or **B**-intersections, in **DCS** on unions between potentially activated assemblies of units in **CNM**, and that inclusions between sets of situations have to be reversed as inclusions on the potentially activated assemblies of units. Such a mapping can analyse the potential activation patterns on a net by delineating them in their parts and by analysing the processes of understanding by a network in terms of semantically relevant steps. A resulting activation pattern, construed by pattern union or vector addition, is by itself not semantically adequate. Rather the distribution of relative activation strength on this resulting pattern has to show the result of adding up of activation strength in repeated activation of some part of the pattern, which happens in overlap between composed activation pattern. The alternative procedures of the construction, corresponding to the steps in understanding sentences, situations, or pictures, are sufficiently semantically informative, i.e. contain the syntactic-semantic information. Such a procedure is followed in vector addition, in which all concepts in the sentence realise their corresponding activation pattern, and the syntactic connections are recoverable in its result if we include typical possible syntagmatic connections within the mental frame representations, or correspondingly within the vectors standing for neural network activation patterns, and get them additionally activated by unification in the case of frame representations, or by adding up activation values in vector addition. Alternative syntactic procedures are equivalent if they lead to the same activation pattern with an identical distribution of relative activation strength over the units of the overall pattern. An activation pattern with such a contour of activation strength distribution over its units corresponds to the construed satisfaction situation of a sentence or is articulated in our mind by a picture, a perception or a description of a situation. Only these representations in our mind can be called mental representations proper, the articulated activation pattern itself is merely a brain activation pattern, if the connectionist model is approximately right in the relevant aspects. It is not a mental representation.

Understanding a sentence does not differ in structure from perceiving a situation which satisfies this sentence. Thus, if for understanding a sentence syntactic structure is necessary, it is also so for perceiving and thereby understanding a situation. Perceiving implies performing a conceptual synthesis in which **B**-intersections are formed, i.e. smallest situations are construed in a sequence of specifying the situation by classification and identification. This process runs parallel to the syntactic combination of the concepts in forming the constituents of the sentences that describe the situation. In the representation by **B**-intersections the result contains the syntactic built up. However, in the representation in terms of unions of assemblies of neurones or, equivalently, in terms of vector addition, the result is only discriminative enough if the distribution of relative activation strength is taken into account by treating overlap as strengthening in adding up the activation values of the units in the overlap. It depends on the morpho-syntactic structure of the sentence understood, or on the situation perceived. A situation is perceived by embedding the sensory input into a conceptual structure in attending to which action takes place and which individuals are involved as what kind of participants. The process of achieving the result must be available in form of such processing routines for situations, which are likewise represented by the morpho-syntactic form of the describing sentence itself and get activated by understanding the sentence.

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