Abstract

Man can in some deep sense connect speech, symbols and meaning. This is an everyday experience which we only partly understand. Linguistic theory recognizes three representational modules, phonology, syntax, and conceptual structure. In the first part we explore the relationship between the syntactic and conceptual structures. In the second part we look closer at the conceptual module and stress the importance of its intrinsic geometric structure. In the third part we explore how this geometry could emerge out of brain dynamics. We are far from an integrated account of how man connects speech, symbol and meaning. We may have opinions and stories to tell, but science consists in doing what is do-able – we conclude with some modest remarks and suggestions concerning cognitive architecture and "mid-level" representational formats.

We have in recent years seen great advances in linguistics and the related cognitive sciences. Experimental and observational techniques at all levels from basic neuroscience to the study of grammar and text have been transformed and lifted to new levels of sophistication. Modeling skills and theory have been significantly expanded using increased insights from the mathematical and natural sciences. Simulations have been extensively used to mimic cognitive behavior. But we do not yet fully understand what human beings so effortlessly can do, how to connect into one seamless unit speech, symbol and meaning.

There are no lack of general accounts and strong claims of having found the "final solutions" to this challenge. And, indeed, beyond well confirmed observations and generally accepted facts there are many plausible stories to tell. But too often we see how scientists with sound contributions within their own special domain of expertise, have to resort to a bit of wistful handwaving when sorting out the last pieces of their preferred "solution".

Not every attempt at a synthesis is handwaiving. An interesting overview of current knowledge as seen from the various perspectives of the speaker, the listener and the reader, can be found in a recent book, *The Neurocognition of Language*, edited by C.M.Brown and P.Hagoort (1999). The book also includes a review of the main components of language structure as seen from the
linguist's point of view. And there are several survey articles aiming to link the cognitive architecture of speaking, listening and reading with the neurobiological level. I shall touch upon all of these aspects. But first some remarks on grammar and the representational structure of language.

1 The deconstruction of syntax

Linguists generally recognize three main representational modules in the description of language structure, the phonological structure, the syntactic structure, and the semantic/conceptual structure. The disagreement comes when we ask about the inner structure and relative autonomy of the different parts and how the parts are bound together.

There are, indeed, many different stories being told. One version, which I in many ways find attractive, can be found in two recent books Foundation of Language by R.Jackendoff (2002) and Simpler Syntax by P.W.Culicover and R.Jackendoff (2005); see also the paper by Jackendoff in Brown and Hagoort (1999). In the latter book, starting with Chomsky's Aspects of the Theory of Syntax from 1965 Culicover and Jackendoff tell a story of how "mainstream" syntax has developed – or should develop – through various stages of the chomskian enterprise, including the current version of minimalism, ending in a final "flat" structure inspired by the attribute-value formalisms of Lexical-Functional Grammar (LFG), see Bresnan (1982, 2001), and Head-Driven Phrase Structure Grammar (HPSG), seePollard and Sag (1987, 1994). This is a piece of "deconstruction" where the elaborate tree structures and transformations of chomskian syntax are transformed into a relational form, which - and this is a central claim of the authors – is more amenable to interacting with a semantic/conceptual structure.

I would like to tell a somewhat different story – different, but with many points of similarity. Instead of Chomsky I take as my starting point the work on logic and language by K.Ajdukiewicz and A.Tarski in the mid 1930s; for fuller details see Fenstad (1978, 1996, 2004). Ajdukiewicz pioneered the modern study of categorial grammar, Tarski opened up the new field of formal semantics. In Warsaw of the 1930s they met and could have joined forces, but it remained for H.Reichenbach and H.B.Curry in the late 1940s to connect the syntax of categorial grammar and the semantics of model theory through the formalism of higher order logic. The work of Curry did not receive the attention it merited at the time, and it was the later contributions of R.Montague, see Thomason (1974), that revitalized the links between logic and linguistics. This represents, in fact, another piece of "deconstruction": The tree structure of categorial grammar is mapped into the relational form of model theory. One should not be confused by the complexities of the lambda-terms of logic. Higher order logic defines the map between the tree structure of categorial analysis (the
subject-predicate form) and the flat relational form of model theory – the higher
order logic is the tool, not the substance. This use of logic as a connecting map
has led to a number of interesting insights. Particularly important is the
structural identification between noun phrases and generalized quantifiers; see
Fenstad (1978) and Barwise and Cooper (1981).

Higher order intensional logic is a powerful and elegant mathematical tool.
But when this instrument is used to establish a map between syntax and meaning
there is a tendency to formalize too much. This was a criticism voiced, among
others, by J.Barwise and R.Cooper in their study of the relationship between
noun phrases and generalized quantifiers; see Barwise and Cooper (1981). The
Barwise-Cooper study of generalized quantifiers was an important step forward.
Further reflection on the proper semantic structure for the study of natural
languages led to the subsequent development of situation semantics; see
J.Barwise and J.Perry (1983). Language and formal semantics have been an area
of great activity. The full story remains to be told, many interesting overviews
can be found in the Handbook of Logic and Language (edited by J. van Benthem
and A. ter Meulen (1997)). The theory of generalized quantifiers and the
development of situation semantics can be seen as simplifications on the
semantic/conceptual side. What should be done on the syntactic side? And how
should syntax and the new semantics be linked?

The Center for the Study of Language and Information (CSLI) was
founded at Stanford in 1983. The logician J.Barwise and the linguist J.Bresnan
were both leading members of the Center. I happened to be present as visitor at
Stanford for the academic year 1983-84. The opening year of CSLI was marked
by a general wish to explore the connection between the many disciplines
present. LFG was the prominent syntactic theory at CSLI. Situation semantics
had a similar status on the meaning side. Syntax and semantics must be related.
Thus the question of how to interpret the functional structures of LFG in
situation semantics became urgent. The solution, simple when first recognized,
was the concept of situation schemata; see Fenstad et al. (1985, 1987). This is a
representational form derived from the f-structures of LFG. And in contrast to
the lambda-terms of Montague grammar, questions of efficient computability
was always an important concern. The technology of situation schemata was
later adopted by Pollard and Sag (1987) in their development of HPSG.

Seen in retrospect the story can be slightly rephrased. What we did in
developing the theory of situation schemata can be seen as an act of double
replacement: replacing the categorial syntax of language with the formalism of
LFG and replacing the formulas of higher order logic of formal semantics with
the situation schemata format. It is important to point out that the technology of
situation schemata is not necessarily tied to LFG and situation semantics. The
particular attributes and value slots in the schemata were in our analysis selected
Jens Erik Fenstad

for the task at hand, viz. to link LFG and situation semantics, but the technology is general as e.g. the later application to HPSG shows.

I called this an alternative story to the one told by Culicover and Jackendoff (2005). In both cases a somewhat rigid syntactic tree-structure (in one case minimalism, in the second case categorial grammar) is replaced by an LFG-like simpler structure. In both cases the simpler syntax is linked to a conceptual/semantic structure. And here is the point where the two accounts come together. The similarity between the CS (Conceptual Structures) of Culicover and Jackendoff (2005) and the situation schemata of Fenstad et al. (1985) is deep and immediate. Both are constraint-based formalisms and both allows for partiality, and their basic formats are quite similar.

For the reader who is familiar with the notions of conceptual structures and situation schemata I add the following technical remark: The basic format of a CS, as introduced in Culicover and Jackendoff (2005), is:

\[
\text{FUNCTION(ARG}_1, ... \text{ ARG}_i); \text{ MOD}_1, ... \text{ MOD}_m; \text{ FEATURE}_1, ..., \text{ FEATURE}_n.
\]

The basic format of a situation schema, as introduced in Fenstad et al. (1985,1987), is:

\[
\text{REL, ARG}_1, ...\text{ARG}_n, \text{LOC, POL}.
\]

We see the similarities, FUNCTION corresponds to REL; both formats have an ARG-list; FEATURES correspond to LOC. The MOD-list is missing from the situation schema format. This is because we at that time had the task to create a tailormade interface between LFG and situation semantics. In LFG modifiers are basically attached to either the REL, an ARG, or possibly the LOC attribute. Culicover and Jackendoff (2005) argue for a flatter syntax; see as an example the different treatment of NPs in LFG and in Simpler Syntax. The need for a semantic/conceptual representational interface is clear; its particular format will have to depend on your choice of syntax and semantic structure. We shall elaborate this issue further below, in particular, in connection with the theory of Conceptual Spaces, see Gärdenfors (2000).

Returning from technicalities to the main story let me conclude by one further remark. In Jackendoff (2002) there is a fourth component, the spatial structure (see fig. 1.1 on p. 6 of the book). Precisely how this part is linked to the others components is not explained in any detail. In Fenstad et al. (1985,1987) there is a well-defined fourth component, viz. the model structure or, in other words, the semantic/conceptual space. And there is a well-developed theory of interpreting situation schemata in the model structures; see Fenstad et al. (1987, pp. 52-76). We remind the reader once more that in this work situation
semantics defines the class of models, but the technology is general. It is to the theory of semantic spaces in general that we now turn. We shall – extending the standard approach – explore the role of geometry in understanding semantic structure.

2 The structure of semantic space

In logic we make a clear distinction between syntax and semantics. Syntax is the domain of formulas and their structure. A fundamental notion is "provability", i.e. how one formula \( \phi \) of a certain well-defined formal language \( L \) is provable from a set of formulas \( \Delta \) of the same language. Semantics deals with structures or models. Typically, a model consists of a non-empty domain \( M \) of objects, which can be finite or infinite. In addition there are sets of relations \( R_1, \ldots, R_n \) and functions \( f_1, \ldots, f_m \) defined over the domain. The basic notion in model theory is "validity", that some assertion \( R_k(a_1, \ldots, a_v) \) or a functional equality \( f_s(a_1, \ldots, a_v) = a_i \) is true in the domain. It was the great contribution of Tarski to set up a precise formalism and inductive definitions of these notions. The connecting link between syntax and semantics is the notion of "interpretation", i.e. how a formula \( \phi \) of \( L \) is assigned a meaning over the model \( M \). If \( \phi \) is a closed formula (a sentence) of \( L \), then the meaning is a truth-value, true or false.

There are two basic results in (first order) logic, the Gödel completeness theorem, which asserts that a formula \( \phi \) is provable if and only if it is valid in all domains, and the Gödel/Church/Turing incompleteness theorem, which asserts that the notion of provability is undecidable. Note that the notion of proof is algorithmic, but that provable, which asserts that there exists a proof, is not necessarily so.

This is, very briefly, the formal tools used in Montague grammar. From categorial grammar via higher order logic to the model structure we have precise constructions and well-defined maps. But there is a price to pay. The class of semantic structures consists of all models of the kind described above. And a general model of this kind is nothing but sets of lists. A first order model is essentially two lists, one list of positive facts, which are basic assertions \( R_k(a_1, \ldots, a_v) \) valid in the model, and a second list of negative facts, i.e. assertions \( R_k(a'_1, \ldots, a'_v) \) which are not valid in the model. As explained in Fenstad (1998) the standard way of extending the notion of model only leads to more lists, e.g. partial models are partial lists, possible world models are indexed sets of lists, and higher order models are just lists of lists. This may be adequate if the aim is technological applications of natural language systems, since in this case the models or semantic structures at the current level of technology are data bases, which in bare structure are nothing but systems of lists. But if the aim is cognitive science, we need something more.
This leads us back to the pairing of LFG and situation semantics discussed in the previous section. We reproduced the basic format of a situation schema above. Let us now be a bit more specific about the semantics, see Barwise and Perry (1983). The starting point is a multi-sorted structure

\[ M = (S, L, D, R), \]

where \( S \) is a set of situations, \( L \) is a set of locations, \( R \) is a set of relations and \( D \) is a set of individuals. Note that in situation semantics all basic types are primitive, which, in particular, means that a relation is not a set of n-tuples of individuals. Sets of tuples may be used to classify relations, but, as argued in Barwise and Perry (1983), this is not sufficient as an analysis in a broader cognitive context. Basic facts are either positive or negative,

\[ r, a_1, \ldots, a_n; 1 \]
\[ r, a_1, \ldots, a_n; 0 \]

where \( r \in R \) and \( a_1, \ldots, a_n \in D \). Partiality is present in the format since we do not necessarily have either \( r, a_1, \ldots, a_n; 1 \) or \( r, a_1, \ldots, a_n; 0 \), for all n-tuples \( a_1, \ldots, a_n \). Facts may be located,

\[ \text{at l: } r, a_1, \ldots, a_n; i \quad (i = 1 \text{ or } 0) \]

where \( l \in L \) is a connected region of space-time. A situation is determined by a set of located facts of the form

\[ \text{in s: at l: } r, a_1, \ldots, a_n; i. \]

The main contribution of Fenstad et al. (1985,1987) was a formal construction of a method which to every sentence of (a fragment of) a natural language (taken e.g. from some text corpus) gave an interpretation of that sentence in a system of situation semantics via its associated situation schema. From one point of view this is a piece of theoretical linguistics, but there were also some early applications of the techniques to natural language technology, in particular, to question-answering systems, see Vestre (1987), and to machine translation systems, see Dyvik (1993). Today techniques have changed and have been vastly extended, but basic insights still remain. For one example of current activity in language technology see KUNSTI (Knowledge Generation for Norwegian Language Technology), which is a research programme with main focus on machine translation and speech recognition financed by the Norwegian
Research Council (see the website www.forskningsradet.no/kunsti, where you will find further links to the individual projects).

The theory of conceptual spaces, see Gärdenfors (2000), is an attempt to provide a theory of semantic structures suitable for linguistics and cognitive science. We noted above that standard model theory is basically a theory of lists. For technological applications, where the equation "model = data base" is still the operating modus, lists may well suffice – for cognitive science it does not. We have seen a refinement in situation semantics, where the location component, representing a connected region of space-time, plays an important role. But situation theory is very much a realistic theory. There is always a given discourse situation with a speaker, an addressee, an utterance and a location – and a described situation "out there", i.e. in a suitable sense "a situation in the world" (see chapter 5 of Gärdenfors (2000) for a more careful analysis). And the meaning relation in situation semantics is a complex relation between two situations and an utterance, the latter represented, as in Fenstad et al. (1985), by a situation schema; see Barwise and Perry (1983) for an extended discussion. But even with this refinement of standard model theory situation semantics is not exactly right for the analysis of concepts, mind and brain.

The starting point of Gärdenfors (2000) is the insight that concepts should be structured relative to several domains, which form clusters well separated from each other. Color and shape are typical examples of such domains. In the case of color we usually recognize three dimensions, hue, chromaticness and brightness – thus the color domain is a three dimensional space. Concepts are usually related to several domains, "red cube" relates both to the color and the shape domains (and possibly to many others – what is the cube made of?). A property, following Gärdenfors (2000), is a concept related to one domain, e.g. "red" is related to the color domain only and can be identified with a subset of color-space.

In standard model theory properties are arbitrary subsets – there is no further general analysis. This has caused philosophers endless difficulties in their attempts to give an analysis of notions such as "natural kinds" within the framework of standard logic. The added ingredient in the theory of conceptual spaces (taking a clue from the study of perception) is geometry. Each domain carries a geometric structure, e.g. the hue dimension is represented by a circle, chromaticness and brightness are linear. In this case we have a natural geometric structure, and – to cut the story short – with this insight the property red is immediately seen to be a convex subset of color space. The analysis is general and is related to the analysis of properties as prototypes, see E.Rosch (1978). To sum up, we can now define, following Gärdenfors (2000), a conceptual space M as a collection of one or more domains D_1, ..., D_n, where each D_i represents a quality dimension of the total space.
From one point of view the analysis presented by Gärdenfors can be seen as an extension or enrichment of standard model theory. In standard model theory there is a perfect match between syntax and semantics, every relation and function on the model domain has a name in the language. In the theory of conceptual spaces red as a region in a quality domain has an intrinsic geometry, whereas red as a syntactic entity has no geometry. Many years ago I argued for the need to enrich standard model theory with geometry, see Fenstad (1978), and pointed to the analysis of R.Thom (1970,1973), but I did not pursue the matter further at that time. In situation schema theory the LOC attribute may hide some geometry not visible in the syntax, see the analysis of prepositional phrases by E.Colban in Appendix A of Fenstad et al. (1987). There are close connections between the theory of conceptual spaces, cognitive grammar, and the geometric approach to semantics by R.Thom, see the discussion in Gärdenfors (2000) and Petitot (1995).

The theory of conceptual spaces lies in the middle ground between language stucture and brain dynamics. From the linguistic side we seem to have the technology available to connect a syntactic analysis in an LFG format to the semantics of conceptual spaces, using an attribute value formalism extending the approach used in connection with LFG and situation semantics – we note that refinements such as multi-dimensionality of domains and geometry are no serious technical obstruction. Explicit constructions, however, need to be supplied to turn this opinion into a solid fact. But far more challenging is the interface between conceptual level and actual brain. How is the geometry of conceptual spaces generated by an underlying brain dynamics?

3 Beyond simplicity

If we are to succeed in the task of explaining how meaning and mind are grounded in the physical brain, we first of all need detailed models of brain structure and functioning. This is a very active area of research. Much is now known about structures, less about functions.

Out of a vast literature let me mention a few general surveys which may be useful as a background to our speculations about grammar, geometry and brain: G.Marcus (2004), *The Birth of the Mind. How a Tiny Number of Genes Creates the Complexities of Human Thought*; P.Gärdenfors (2003), *How Homo became Sapiens. On the Evolution of Thinking*; and M.Donald (2001), *A Mind So Rare. The Evolution of Human Consciousness*. The books all report many facts and observations. They all try to weave this information into a coherent story connecting mind and brain. The stories may be plausible, but it is not "hard" science. Current research is regularly reviewed in journals such as *Nature* and *Science*. Some recent examples are: "Language Development", *Science* vol. 303, February 2004; "Neuroscience: Higher Brain Function", *Science* vol. 2306,
October 2004; and "Neuroscience: System-Level Brain Development", Science vol. 310, November 2005. At regular intervals we have handbook-type comprehensive reviews, of special relevance is M.S.Gazzaniga (2004).

Closer to our immediate concern are the review articles in the book The Neurocognition of Language, Brown and Hagoort (1999). Of particular interest are the reviews in the section on the neurocognitive architecture of language, dealing with the basic brain architecture underlying the process of written and spoken word forms, the functional and neural architecture of word meaning and the neurocognition of syntactic processing. As the word architecture indicates, we are here dealing basically with structure. Other sources deal with the dynamics of brain modeling; we may mention D.J.Amit (1989), Modeling Brain Function. The World of Attractor Neural Networks, A.Scott (2002), Neuroscience – A Mathematical Primer, and C.Eliasmith and C.H.Anderson (2005), Neural Engineering: The Principles of Neurobiological Simulation. These books are attempts to model brain and cognitive behavior in general. One attempt aimed directly towards language behavior, is D.Loritz (1999), How the Brain Evolved Language. Loritz uses systems of non-linear reaction equations to model linguistic behavior. He has some successes with phonology and certain morphological and syntactic phenomena, but is rather vague when moving from syntax to semantics. In this area there is a recent attempt by C.Eliasmith (2000), How Neurons Mean. A Neurocomputational Theory of Representational Content. This is noteworthy, but it is fair to say that we are only in the very early stages in our quest for understanding.

Let me for a moment retreat to simplicity and some early attempts to model language and brain based on neural network models. One example is the work by J.Elman on recurrent networks for grammatical discrimination; see the review of this work in P.M.Curchland (1995) and, for further references, the comprehensive survey of network models in P.S.Churchland (2002). Let me also recall a proposal within the context of optimality theory, A.Prince and P.Smolensky (1997), "Optimality: From Neural Networks to Universal Grammar", in Science vol. 275, March 1997. This is interesting reading, but details have, as far as I know, not yet appeared in print. There has been a heated debate between rule-based approaches versus network models. Stated in a very crude way the proponents of the first approach want to extend chomskian type syntactic rules into the brain, whereas the network camp believes that recurrent networks do indeed model brain in a faithful way and that language structure can be explained as an emergent behavior of such networks.

Some years ago I sketched an attempt to close the gap between meaning and brain, the missing link being geometric structure, see Fenstad (1998). Via a more gently executed rule-based approach we are now in a position to move from phonology and syntax to a conceptual structure; see the first section above.
The conceptual part has two components, first, the representational form in the form of an attribute-value matrix (e.g. a situation schema), and, second, the model structure, where we have opted for the format of conceptual spaces. A conceptual space is a collection of domains, where each component domain is a standard model structure enriched with an intrinsic geometric structure; see the second section above.

And it is geometric structure which points to a link between concept and brain, see Fenstad (1998). We spell this out in some detail: A natural kind is, as explained above, a property related to one of the domains of a conceptual space, more specifically a natural kind is a convex region of a domain. This is the view from the language side. Seen from the brain modeling side we recognize that the various dynamic processes in the brain have associated geometric constructs. This was explicitly used by Thom in his early attempts towards a topological semantics for language, Thom (1970, 1973). Thus similar to the prototypes and convex regions in the domains of a conceptual space we have attractors and domain of attraction in the "potential surfaces" of topological semantics. If one identifies the two, and there are certainly mathematical theorems to prove in this connection, a link is established between language, concept and brain. Note, that this is an account very much consistent with the discussion in P.M.Churchland (1995) of coding and pattern recognition. There is also some recent research on attractor dynamics and memory which can be taken to support our account, see T.J.Wills et al. (2005). But one need to be extremely careful in choosing the "right" geometrical representations on both the conceptual side and the brain side to make sense of the connection.

At this point we need to return from simplicity to the real world. Much of current global brain modeling employ neural network models. But despite their rich mathematical structure – see Amit (1989) – they are too simple to catch the complexity of a real brain – see the critical discussion in Scott (2002). Doubts about this simplicity do not only concern the structure and dynamics of the network models, it extends even to the choice of basic unit, the neuron, see the recent critical assessment article by T.H.Bullock et al. (2005). The cognitive neurosciences have, indeed, made rapid progress. And this includes sophisticated modeling of structures and functions on many levels. But what we really need, and what some popular texts pretend to supply, is a connected story – with experiments and mathematical models at the level of Hodgkin and Huxley (1952) – reaching from basic anatomical structure up through the various stages of complex cognitive behavior, and ending up with high-level phenomena such as attention, consciousness, and speech.
4 Representations at mid-level

Science consists in doing what is do-able. We will, therefore, abstain from further speculations, scale down the grand visions, and conclude with a few simple remarks on cognitive architecture and representational formats.

A convenient starting point for these remarks is the "neurocognition of language" book edited by Brown and Hagoort (1999). The surveys in this book separate into three levels. At one end we see the perspective of the linguist, which rests on a long research tradition in the classical disciplines of phonology, syntax and semantics. At the other end we have the perspective from the neuroscience research community, which by now is in command of a vast and extremely detailed knowledge of brain structures. But when the linguists try to reach deeper into mind and brain and the neuroscientists try to explain how higher cognitive functions emerge out of bare structure, we are in a somewhat uncertain middle ground. The two middle parts of Brown and Hagoort (1999) survey various attempts to bridge this gap. In one part the linguistic analysis is supplemented by an account of cognitive architecture, building on a rich research tradition in cognitive psychology. Here we find mid-level blueprints of the speaker, the listener and the reader. In a second part we find a survey of steps towards a neurocognitive architecture of language, aiming to connect the blueprints of cognitive psychology with basic brain structure. What is particularly attractive with the Brown and Hagoort (1999) book is the effort to spell out the interaction between the different parts. On the one side the blueprints are so constructed to be consistent with the linguistic analysis, and on the other side the blueprints serve as guiding principles in the identification of the basic neural architecture.

Language, blueprints and structure bear some analogy to our discussion in the first part of this paper. We have advocated the use of an LFG type syntactic format. This is very much consistent with the grammatical analysis used by J.M. Levelt (1999) in his blueprint for the speaker, where a unification-based grammar formalism is a tool in the transformation of meaning into speech. This unification-based analysis was first developed by G.Kempen and T.Vosse (1989); see also the account in Fenstad (1998). But at mid level there are many structures interacting, not only meaning and speech. Placed in a particular context you may listen, observe, speak and write. All of this interact at many levels in the brain to create meaning and response. To fix ideas let us return to an early example of language technology, a question-answering system developed by E.Vestre (1987 – in Norwegian); see the exposition in Fenstad et al. (1992). The basic architecture follows a familiar pattern:
This is a technology application based on the simple assumption that "model = data base". The system can be updated by new facts as indicated by the left column. Sentences are represented by situation schemata, and a special algorithm was developed to extract basic facts from the schemata and to add them to the data base. A question is asked resulting in an incomplete schema. This schema acts as a query to the data base and produces an answer in form of a complete schema, which in turn generates the appropriate response.

If we are allowed a brief moment of speculation, we could argue that at a very general level this architecture can also be used in a cognitive context. The right column will then have to be modified to represent a "blueprint" for a speaker or, more generally, an actor. The left column must in a similar way be modified to "blueprints" for the reader or the listener. And we must in addition make allowance for visual and other types of perceptual inputs. The middle column will represent some "attention mechanism" and will determine the appropriate context and form of response. The main move would be to replace the data bases of simple language technology with the category of conceptual spaces. And, as a consequence, the situation schemata need to be enriched to a suitable attribute-value matrix form. We could even entertain the thought that this is a possible architecture for memory recall, pointing to the similarity between recall and the above sequence: questions – incomplete representational form – data base – inference – answer.

But this is speculation and yet far from respectable theory. As pointed out above we seem best prepared at either end, we are at a loss in the middle ground. But we are slowly gathering the tools in our quest for a deeper understanding. On the brain side we have seen interesting mathematical models; I want, in particular, to point to various forms of neuronal assembly theories, see Scott (2002), and to the approach in Eliasmith and Anderson (2005); see also the recent book, _Neuromimetic Semantics_, H.Howard (2004). The aim is not necessarily to build global brain models, but to model specific functions at their appropriate level. On the other side we have the theory of conceptual structures. It is now necessary to study specific examples and try to understand how the intrinsic geometry in these examples can be generated by brain mechanisms, themes in color and vision come immediately to attention; for vision see
E.T.Rolls and G.Deco (2002). I submit that proper attention to the larger architectural structure is needed to guide this quest.

At mid-level we also need a more detailed study of the space of representational forms, in particular, its dynamical structure; see the unification spaces of Kempe and Vosse (1989) for some early algorithms, see also the discussion in Fenstad (1998). Algorithmic concerns should always be a focus of attention; we need to exploit the fact that the representational level is the interface between the linear processing of speech and the parallel processing of brain; see Donald (2001, chapter 5) for a general discussion.

To take command of the middle ground is, in my view, the main challenge. We can, as we did above, argue for this within a cognitive science context. But barriers to progress in language technology – in machine translation and speech recognition – tell us with equal urgency that we need to conquer the middle ground. Incremental progress in current language technology is still important for viable applications. But real progress in the technology needs an understanding that is far beyond theory today. No amount of wistful handwaving can hide this fact.

References


T. J. Wills et al. (2005): 'Attractor Dynamics in the Hippocampal Representation of the local Environment', *Science* **308**.