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### Multi-modal modelling with multi-module mechanics

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*Publication date:*  
1992

*Document Version*  
Publisher's PDF, also known as Version of record

[Link to publication in Tilburg University Research Portal](#)

*Citation for published version (APA):*  
Powers, D. M. W. (1992). *Multi-modal modelling with multi-module mechanics: Autonomy in a computational model of language learning*. (ITK Research Report). Institute for Language Technology and Artificial Intelligence, Tilburg University.

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RESEARCH  
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ITK Research Report  
february 1992

**Multi-Modal Modelling with  
Multi-Module Mechanics:  
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Model of Language Learning**

David M.W. Powers

No. 33

1992/33

This is an invited chapter for "Autonomy" (Scott Delancey & John Goldsmith, eds.) to be published by Chicago University Press (Linguistics Editor, Geoff Huck). The work was initiated whilst a guest researcher at the German AI Institute (DFKI), Kaiserslautern GERMANY, and completed during a visiting fellowship at the Institute for Language Technology and Artificial Intelligence (ITK), Tilburg The Netherlands.

ISSN 0924-7807

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# Multi-Modal Modelling with Multi-Module Mechanisms: Autonomy in a Computational Model of Language Learning

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January 30, 1992

## 1 Introduction

Autonomy has been the subject of many claims, and what is needed most urgently is a summary and analysis of the major claims. Only once we have established what is meant by 'autonomy', and what is claimed under this rubric, can we hope to decide a question which relate as much to the Philosophy of Science as to Empirical Science *per se*.

Nonetheless, the philosophy which guides our science can have considerable impact on the results of our research, not to mention the short shrift which we may give, or meet from, those working within other paradigms. This is the context in which this volume has arisen.<sup>1</sup>

With this in mind it may be helpful to reveal the biases which lie behind this essay, and the directions in which it will seek to influence the field. The perspective is that of a (hopefully not too impertinent)<sup>2</sup> Computer Scientist seeking the gems throughout Cognitive Science which might be useful in his ambition of building a Language Learning system (Powers: 1983, 84, 85, 89, 91).

Machine Learning of Natural Language and Ontology (MLNLO), or simply Natural Language Learning (NLL), is pursued from two perspectives: the artificial intelligence or engineering perspective and the psycholinguistic or scientific perspective. In the present Chomskian era of linguistic claims of the autonomy of language, a new slant emerges: NLL may help provide answers to the philosophical, teleological and neurological questions of whether language is learnt,

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and how; what aspects of language are learnt, and where; which language features must be designated emergent, and why. Any positive results in NLL will demonstrate what can be learnt – and support the underlying theory; whilst failures will indicate the computational weakness and (with analysis) even the infeasibility of a theory, pinpointing areas where more detailed explanation is needed.

The futures indicated here are both near and far. If we succeed in our long term goal of building a successful language learning machine, the model underlying it will provide a distinct challenge to theories which are directly opposed to the principles embodied in this machine. We are, however, not likely to realize such a machine for a few years yet! On the other hand, a number of small successes in learning aspects of language should provide a similar challenge. In this chapter, we review some of these existing results and their implications, and outline proposals for computational language learning models which may one day aspire to be this HAL (Clarke, 1972)!

## 2 Claims

### A. Claims about autonomy

1. *irreflective*: Language is NOT reflective of general conceptual organization, categorization principles, and processing mechanisms.
2. *encapsulated*: Modules are characteristically informationally encapsulated (Fodor: 1983).
3. *specific*: There is a specifically linguistic language organ encompassing specifically linguistic principles and processes (Chomsky: 1965).
4. *modular*: Vision is also modular and analogously autonomous (Fodor, 1983).
5. *empirical*: Autonomy is an empirical linguistic hypothesis.
6. *metatheoretical*: Autonomy is a metatheoretical hypothesis whose claims concern relations between theories, both linguistic and extra-linguistic.
7. *neuropsychological*: Autonomy is supported by neurological and psychological evidence.
8. *independent*: The language faculty is independent, autonomous, genetically pre-wired and non-derivative of non-linguistic cognitive abilities.

9. *submodular*: The language faculty has independent components for syntax, semantics, phonology etc. which differ in organization, structure, function and processing.

## **B. Straw claims for autonomy**

1. *universal*: ONLY specifically linguistic principles are involved in language processing.
2. *evolutionary*: What learning can't do, evolution has.
3. *knowledge-based*: The language module contains not only innate computational mechanisms but also both innate programs and data, i.e. both procedural and non-procedural knowledge.

## **C. Claimed failures of autonomy**

1. *shifty*: Autonomy merely shifts the burden of language acquisition from learning to evolution.
2. *untestable*: Autonomy has never been precisely formulated as a testable hypothesis.
3. *existential*: It's not enough to show that SOME aspects of language are autonomous.
4. *unneuropsychological*: Neurological and Psychological data don't support autonomy.
5. *redefinitive*: If anything is shown to be non-autonomous the answer is to redefine 'core' linguistics.

## **D. Claims for non-autonomy**

1. *reflective*: Language is reflective of general conceptual organization, categorization principles, and processing mechanisms.
2. *general*: Language is a product of general cognitive mechanisms of a variety of types.
3. *metaphorical*: Metaphor is such a general cognitive mechanism (Lakoff, 1987).

## E. Straw claims for non-autonomy

1. *universal*: EVERYTHING called language is a product of general intelligence.
2. *uniform*: ALL aspects of language have the same nature and the same origin.
3. *undifferentiated*: There is a SINGLE undifferentiated cognitive faculty.

## F. Claimed failures of non-autonomy

1. *irrelevant*: Theories ignore the sorts of ‘core’ linguistic behaviour that need to be accounted for.
2. *vacuous*: Functional accounts can explain just about ANYTHING, even mutually contradictory hypotheses.
3. *existential*: It’s not enough to show that SOME aspects of language aren’t autonomous.
4. *intractable*: General associative and learning mechanisms are intractable and thus inefficient and implausible.
5. *isotropic*: Theories don’t deal with Poverty of the Stimulus and the (related) Frame Problem.

## Discussion of Claims

The above (somewhat redundant) summary of views expressed in the autonomy debate is weighted towards the development of a clear picture of the view of the autonomy claim espoused by its advocates. Whilst the more specious endorsements on both sides are typically those of the opponents of a position, some proponents sail remarkably near the wind and charity has prevailed to some extent in this classification.

Where we are most likely to find problems is where strong quantifiers are used, that is where the strongest form (B1/E1, ‘*universal*’) of either position is presented, or where negation is used. If these are ‘straw men’, then C3/F3 (‘*existential*’) are ‘straw failures’. In addition, A1 (‘*irreflective*’) is as much a claim about the mechanisms, principles and organization of non-linguistic cognition as it is about language. This is what is specifically captured in claim A6 (‘*metatheoretical*’), along with the idea that we won’t agree till our science is complete.



Claims A5 (*'empirical'*) and A7 (*'neurophysiological'*) really amount to saying that linguistic research indicates that language has a unique complexity which can most parsimoniously be explained with the autonomy hypothesis, and some work in other disciplines would seem consistent with autonomy. Claims C2 (*'untestable'*) and C4 (*'unneurophysiological'*) challenge this directly, claiming paradoxically that the autonomy hypothesis is invalid because, on the one hand, it does not admit disproof and because, on the other, it has been refuted by extra-linguistic evidence.

Claims A1, A8 and A9 (*'irreflective, independent, submodular'*) are notable for their implicit universal quantification. As they are worded, these claims admit the existence of NO linguistic phenomena derivative of non-linguistic brain processing or mechanisms in common with non-linguistic cognition. This is inconsistent with argument F3 (*'existential'*) against the non-autonomy view, which suggests that demonstration of the non-autonomy of arbitrary aspects of language is irrelevant!

This is interestingly the converse of the relationship of claims D3, E1 and E3 (*'metaphorical, universal, uniform'*) to C3 (*'existential'*). The difference is that E1 to E3 are attributions of opponents, and that claims D1 to D3 say little about the extent to which language might involve mechanisms specific to language: The word "reflective" in D1 is very weak; and despite its use of the provocative word "general" (without admitting "specific"), D2 is vague about the "variety of types".

Claims C5 (*'redefinitive'*) and F1 (*'irrelevant'*) also represent an intriguing juxtaposition. Not only are we lacking a definitive characterization of what is meant by "autonomy", we have only a handful of prototypes to categorize what is and is not 'language' and 'core' linguistic behaviour.<sup>3</sup>

The main question here then is how much of language is claimed to be autonomous and not share mechanisms with other cognitive processes. It is also non-trivial to distinguish the claims of modularity and autonomy: whilst Fodor (1983) defines a battery of more or less fundamental characteristics of modules, others define the module as "an autonomous system".

So what does autonomy add to the definition of modularity, or the pursuit of linguistics? To answer apolitically, it is precisely the "unshared mechanism" claim (e.g. A1).<sup>4</sup>

### 3 Procedure

Our discussion of this list of claims has shown that there is a wide range of belief about the strength and scope of the competing hypotheses on the autonomy question. In the following, rather than merely reexamining the positions and the empirical evidence of the relevant literatures, it is considered more constructive to elaborate a model which lies at neither extreme, gives credit where credit is due, and suggests a reasonable synthesis of the views of Lakoff and Fodor.

But let us first consider a little fairy tale inspired by Fodor's (1985). This parable is intended to suggest a model of research which will become our model of language and learning in what follows.



## The Handsome Academic and the Impoverished Student

Once upon a time, not very long ago and not that far away, there lived a handsome academic. For all I know, he might well be the handsome cognitivist of the Fodor Fairy Tale, for he was indeed very handsome, quite well to do, and a charter member of the renowned ivory league.

The handsome academic was famed throughout the land, and seemed to have something to contribute on every topic. He headed up a large academic department with lots of secretaries, lots of computers and lots of photocopying, video and other high tech equipment.

He also took a class, for even the most handsome of academics must stoop to teaching occasionally. And in this class, there were naturally quite a few students, none of whom were anywhere near as handsome, or as well off – and one of whom, in particular, was so impoverished that he could hardly afford the proverbial broken pencil.

The handsome academic really had the art of research down pat. His team of secretaries would search libraries and publisher's catalogues throughout the land, and bring him abstracts and reviews and bibliographies and citations. He would then carefully look through the titles and the keywords, and give his instructions: "Yes, copy that one. Add this one to these bibliographies. Note this down for a possible paper, or better still a research proposal." But no matter how carefully he made his judgement about where to file it on the basis of the title and the keywords, he couldn't guarantee that he'd be able to find the right papers when he needed them.

But then, one shouldn't blame him if other academics couldn't come up with decent titles or perspicuous keywords.

His experimental research also made maximum use of the latest technology. His experimental subjects were videotaped and microphoned from all angles, and the whole sequence was computer controlled. This contributed all the more to his popularity as an invited speaker at conferences, for he could always be counted on to illustrate his talks with amusing (as well as scientifically edifying) video clips. Even his lectures made use of these multimedia possibilities, and the students had the opportunity not only to make copies of appropriate papers in the departmental library, but to copy the departmental videos.

Through the marvels of modern technology, this department had become a leader in terms of the amount of material available and referenced. Interestingly, nobody seemed to make any use of much other than the abstracts, introductions and tables of results, but it was all stored away and available nonetheless.

Our impoverished student, however, had poured his entire allowance for the previous years into building a personal computer. Rather than making photocopies, which he felt he couldn't afford, he would actually read the papers. You can imagine the jeering from his fellow students, and the disparaging looks from the handsome academic. He would read the papers, and only copy down with his not so trusty pencil what was absolutely essential. He also felt he was able to build up some kind of understanding of the interrelationships between different pieces of work, in his head, by rereading certain key papers. Of course, after he had built up his PC (small but expandable and really a very thrifty



investment) he started to use that to take notes, and wrote programs to compare and correlate and interrelate.

Our impoverished student discovered that if he focussed particularly on the differences and similarities of the various pieces of work, he could get much more information into his limited disk space. In fact, he found that the same techniques he used to condense his reading could also be used to condense the video input. Really not very much was happening most of the time, and the small parts of the picture where things did change could be described very economically. A bit of an electronics buff, he built some hardware which would actually allow him to automatically capture this relevant information from the handsome academic's videos, with the help of slightly modified versions of the same software he used for doing the contrast and similarity analysis of his textual data.

But one day, while the handsome academic was digressing on Plato during a discussion of the epistemological impossibility of a formal system of analysis being capable of characterizing an arbitrary symbolism as a result of the metaphysical unlikelihood of the existence of reality, the last piece of the puzzle fell into place and our impoverished student screamed "Eureka!"

After that day, the handsome academic and the impecunious student didn't meet again for many a year, for our impecunious student had realized that there was more to life than quantity of worldly possessions, whether money, photocopies, or videos. Indeed the key to success in the real world is quality not quantity, an ounce of efficiently represented information is worth a ton of arbitrarily filed data; for him how it all fitted together was everything, and once he recognized that, and only then, he understood: "Intelligence", he said, "is the ability to recognize what is important and to discard what is not, to find a parsimonious framework which can explain everything both efficiently and elegantly, and with a minimum of redundancy. Science is the art of learning."

Our hero remained ever a student, not much longer impecunious, and never again thought of himself as impoverished. He himself, moreover, became a teacher, realizing that there is no higher calling than to help others to understand. Indeed, he himself, through his subsequent writings, helped the handsome academic to realize that being handsome wasn't everything, and that being an academic needn't mean being divorced from reality.

And they all researched happily ever after.

## 4 Fodor is Right

Fodor argues (in Piatelli-Palmarini, 1979) that a system cannot become more powerful than it originally was. In the case of language, we have some cognitive mechanisms which are innate, and some sensory-motor experience. In principle this experience of the world is endowed with all the riches of the world's structure and complexity. But there are more states 'out there' than can be represented 'in here', and there are limits on how accurately we can even perceive what is going on 'out there'. Although there are theoretical physical principles constraining our perception, what is fundamental is, in the first instance, our



sensory organs.

Fodor notes further (1983) the existence of these sensory "transducers", which may be considered to be one-to-one to within a certain degree of resolution (this is incontrovertibly an innate property). But there is still more information than higher cognition can deal with, and we are faced with the problem of trying to resynthesize the physical structure of a world which has been captured only with the loss of much detail and dimensionality.

Thus our visual transduction reflects a 2-D retinal projection which loses not only the third dimension, but any representation of the structural complexity of the objects viewed, let alone causal relationships and multitudinous real properties of our world. Our auditory transduction reflects no intrinsic distinction between speech, music and noise, let alone the intentions of the speaker, composer, or whoever.

Therefore Fodor makes the point that some system, an input analysis module, he argues, must induce from the transduced data the structure which is appropriate to our needs. He proposes that up to a certain level such peripheral processing is encapsulated into modules which are domain specific and 'mandatory' {footnote Fodor means by 'mandatory' not just that the modules must be present, but that they cannot be disabled or bypassed. in-line filters, whose input-output relationships with the other processing systems are severely constrained, and in particular whose output is limited to the highest level constructs and their interrelationships, with intermediate level structure being private to the module.

Fodor suggests that these peripheral processing systems differ from central processing systems in a number of ways: Input systems are associated with fixed neural architecture - which must be interpreted to mean that relatively little learning takes place here and the process is largely innately determined. Different input systems evidence similar pathologies along with highly consistent patterns of development, and Fodor proposes that that is a result of their hardwiring into fixed specialized circuits.

By contrast, the central systems are supposed to be far more amorphous, with this being an explanation of many of the failures of AI, and in particular of the Frame Problem. He is very pessimistic about the future of research into the non-modular central processing systems and general intelligence.

The position adopted here is that logically, there is a lot of truth in this modularity hypothesis. Fodor doesn't comment on the neural substrate and the possibility that different modules can share neural or higher level building block templates (that is the design is common, but not necessarily the instance). Computers share transistors, gates, memories, adders, even processors amongst a wide range of hardwired circuits. Indeed there is a whole industry built around customizing Application Specific Integrated Circuits built around such macroscopic building blocks.

Also, Fodor doesn't say anything about the ontogenic mechanisms. Turing (1952) showed (in a chemical model) that self-organizing mechanisms could produce specific structure either in the absence of environmental influence, or responsive to such influence. Von der Malsburg (1973) and Willshaw (Longuet-Higgins, Willshaw and Buneman, 1970) separately examined different self-



organizing and associative models which could detect auto-correlation and induce structure, and together (1976) they investigated the synthesis of an ontogenic mechanism combining strongly-determined trophic mechanisms with weakly-determined trophic self-organization.

The first point here is that processes can share mechanisms without making use of the self-same instantiation of the mechanism. The second is that at some level there must be mechanisms in common between linguistic and other cognitive processes. The question is partly one of level. If they share mechanisms only at the molecular level or below, then everyone might well concede autonomy. What about such a basic neural mechanism as lateral inhibition? At what level we should draw the line?

The third point is that there is evidence that general self-organizing processes can participate in the ontogeny of Fodor's peripheral processing modules, and that to explain ontogeny given the (arguably sparse) genetic material a mix of hardwiring and self-organization is plausible. Furthermore it is not disputed that both vision and language, at the level of Fodor's modules, are influenced by environmental factors and must therefore, in some measure, be plastic or programmable. Here we must ask, at what level and how firmly should we draw the line?

It also makes sense to raise such questions at the level of submodularity (cf. claim A9): there is evidence that certain candidate subhierarchies are intricately intertwined and physically co-extensive, (e.g. in vision (Hubel and Wiesel, 1979). Similarly stereoptic and stereophonic 'reconstruction' clearly lie within the scope of Fodor's input modules, but provide challenges to his encapsulation and interface requirements.<sup>5</sup> In this case the question is primarily: how firmly should we draw the line?

The position taken here is therefore presented as a modification of Fodor's position, and it will be elaborated in terms of the different modal hierarchies, the level to which self-organizing techniques may aspire, and the intrahierarchical, interhierarchical and transhierarchical interrelationships which determine what subsystems can best be viewed as modules.

## 5 Lakoff and Johnson are Right

Johnson (1987) starts off at an analogous point to Fodor (1983): the interaction of the human with his environment. The focus however turns inward and to the functional and motor aspects of our relationship to our world. We see that our own body is the basis for many of our concepts. We have to learn about and use our bodies, just as we have to learn about and function in our environment.

Lakoff (1987) also commences with a focus at the same level of processing as Fodor: categorization, and in particular the special role of basic categories, and the influence our linguistic categories have on judgement. We see these linguistic categories, and the corresponding ontological categories, as somehow basic – in Fodor's terms, as "the interface" – to our central cognitive processing. And these categories are language, culture and environment dependent, and thus learnt.



Categorization is also the fundamental mechanism which Lakoff (1987, p182) holds up against the autonomy view:

"It is bizarre to assume that language ignores general cognitive apparatus, especially when it comes to something as basic as categorization. Considering that categorization enters fundamentally into every aspect of language, it would be very strange to assume that the mind in general uses one kind of categorization and that language used an entirely different one."

This is very concrete, as categorization has been much studied as fundamental to language, including both syntax and semantics. But it is when the mechanisms of categorization are elaborated in terms of metaphor and metonymy, imagination and non-Objectivist rationality, that misconceptions can come in as to the relevance of Lakoff's mechanisms to 'core' language processing (criticism F1). Furthermore, the arguments have been supported by *ad hoc* "Case Studies" (leading to criticisms F2 and F3).

In relation to this first area of criticism, it must be pointed out that the concepts of metaphor and imagination as used by Lakoff and Johnson transcend their normal limited scope. Metaphor is no more a literary device, but the literary device is an outworking of a fundamental cognitive mechanism for dealing with a world which is *every* time different; imagination takes on extended-Kantian proportions (Johnson 1987, p165):

"Imagination generates much of the connecting structure by which we have coherent, significant experience, cognition, and language."

Johnson's idea of a "fully adequate theory of imagination" includes (at least) categorization, schemata, metaphorical projection, metonymy and narrative structure (p171), and his non-Objectivist Cognitive Semantics requires "understanding, imagination, embodiment" (p173).

This view, particularly the "understanding", contrasts with Fodor's "I hate relativism" (1985, p5). Imagination is no longer equated with fantasy, but with the necessary associations and accommodations of schemata which Fodor characterizes as the root of all evils in our Cognitive Science and Artificial Intelligence, and in particular as the cause of the Frame Problem (1983, 1987). Understanding is no longer solely the result of our cognitive processing, but (as Fodor might put it) contaminates our input processing. Embodiment contrasts with Fodor's ignoring of output processes, notwithstanding his observation that they may also be modular.

What Fodor's modularity aims to do is insulate the input processors, including much of language processing, from the complexity problems of association within an amorphous cognitive processor. These problems are thus removed from input processing to the central processing, in relation to which Fodor is extremely pessimistic about the future of cognitive research.

Lakoff and Johnson concentrate particularly on the role of metaphor and image schema (in both cases with a generalized interpretation) in "Cognitive Semantics". This is illustrated particularly in their consideration of prepositions and other specific concepts. However, Lakoff (1987) seeks to extend the

model to “Cognitive Grammar”, to “lexical items, grammatical categories, and grammatical constructions.”

Lexical items are viewed, following Fillmore (e.g. 1977), in terms of their relationships with frames (Lakoff’s ICMs). Grammatical categories, in particular nouns and their subcategories, are viewed as founded around the lexemes corresponding to “basic-level physical objects” (Lakoff, 1987, p290f) according to a species of “prototype theory”. Grammatical structure is seen as reflecting many of the structures familiar from Cognitive Semantics, abstracted and applied at a symbolic level: thus constituent structure is characterized in terms of PART-WHOLE schemas.

A major aim of Cognitive Grammar, and conversely a major lacuna of traditional grammatical theories, is highlighted as “direct pairings of parameters of form with parameters of meaning”. This also seems, *prima facie*, to run counter to modularity and encapsulation.

The position taken here is that there is much going for this view of pervasive metaphor. However, neither Johnson nor Lakoff make any attempt to relate this to lower level mechanisms, other metaphors (than their METAPHOR AS MECHANISM metaphor), neural or self-organizing mechanisms, etc.

So our first point is that this insight (that metaphor may play a wider and more important role in language) is not an end point in itself, and we need to explain the phenomena as well as document its pervasiveness. A second point is that this ubiquity may extend beyond language, to other modalities and to general cognition. If metaphor is a consequence of low level mechanisms of wide applicability it will be significant in setting the level at which we want to argue for autonomy of language, as well as perhaps influencing what we now regard as being intrinsically linguistic phenomena.

The third point addresses innateness: it is probably uncontroversial to propose that such a basic and widespread property, if demonstrated adequately, is innate. But if it turns out to be a natural outworking of lower level mechanisms and structure, this claim becomes rather tautologous: viz. the innateness is accidental.<sup>6</sup>

In relation to innateness it should also be noted that our definition of ‘learning’ is also at issue. To quote Fodor (1985, p35f, emphases are original): “As a minimum [the nativist] denies that environmental effects on innately specified cognitive capacities are typically instances of *learning*, as opposed, say, to imprinting. ... To show effects of experience on perceptual systems is not, in and of itself, to show effects of *learning*.”

## 6 The Impoverished Student is Right

Fodor’s Wicked Behaviourist (WB) wanted to do without perceptual processes – that is he felt central processes could directly take the results of transduction. The Handsome Cognitivist (HC) and the Handsome Academic (HA) were both avid collectors (HC in (Fodor75, p1)):

“Almost nothing reduces to almost anything else. ... Only collect.”



Interestingly, the Impoverished Student (IS) picked up on something that is important to everyone, including WB, HC, HA, JAF, GL, MJ and ME: Information!

Let us start with something Fodor, Lakoff and Johnson have in common, an explicit acknowledgement that has shaped their respective theories: Information about the world is necessarily lost during each of the processes of transfiguration, transmission, transduction and transformation. Let us clarify what is meant by this family of words here, and wherein the losses lie.

*Transfiguration.* For us to detect an object or event, it is necessary for some external medium to interact with the observed situation. This could be elicitation, illumination, bumping, whatever. In this case, external means external both to the observing cognitive system and the observed phenomena. Quantum Mechanics tells us we can't observe without interacting and influencing and thus losing information of one sort or another. So the medium highlights a particular subset of the features of the situation, introducing distortions in the process.

*Transmission.* The external medium which conveys information has physical limitations which limit the bandwidth of the information. In fact, the losses here which relate to the specific medium are closely related to those of transfiguration. In the former case we note that only some features of the observed situation are captured at all, and then only with interference. Here we emphasize that even the resolution with which that information may be transmitted is limited. The medium may also be under stress from independent environmental influences, such as fog.

*Transduction.* The external medium must be converted, by some sensory organ, into the internal medium of cognitive communication. Fodor limits transduction to the conversion to neural signals which retains, in as close to a one-to-one way as the transducers allow, the information content of the external carrier. The losses here are complementary to the losses of transfiguration, and similarly there may be a mismatch – in this case between the numbers of states supported by the internal and external media.

*Transformation.* What we will still unflinchingly term the 'raw' input from our transducers, we must now bring into some form appropriate to higher levels of cognitive apparatus. Here Fodor proposes that 'hardwired' input processes do the job, abstracting the features which are necessary to the central processing. Lakoff and Johnson propose that input is compared with 'image schemata' and classified on the basis of previous experience. This abstraction, classification or categorization is a deliberate introduction of further losses, on both accounts. The additional detail which is lost is however, in both case, hoped to be less important. On the hardwired account there is less flexibility to deal with such cases – unless it is preprogrammed into the development cycle (imprinting, tuning parameters, etc.). On the schema account, learning is a continuous phenomena which hopefully will be able to adjust even to eventualities totally unforeseen (genetically).

Fodor argues that hardwiring minimizes introduction of indeterminism and uncertainty – what emerges from this stage is not influenced by what we had for dinner. Johnson builds his thesis on precisely the opposite claim: that



Objectivity is a myth, and we really have no direct idea what is going on out there. On the other hand, Lakoff and Johnson argue that extremely flexible modes of interaction are necessary to explain human adaptability, and that this is more important than a real reality.

In fact, on both counts, transformations introduce losses, at the end of a long chain of losses, so we have only a limited grip on reality. On the other hand it would be reassuring to believe that my seeing obstacles while driving home was more influenced by reality than by digestive action. Does the METAPHOR AS MECHANISM transformation provide such reassurance? Does some random evolutionary event a few million years ago? Is it even (always) true?

So, back to our Impoverished Student.

Given the emphasis on information, and the fact that we seem to have to throw so much away, it would be convenient to be able to characterize the 'usefulness' of information. It is interesting that all the fields and participants represented in this debate appear to acknowledge the relevance of information theoretic considerations, but seldom is it cogently brought to bear on this issue (Schank and Hunter, in (Fodor: 1985)).

An information theoretic usage of the term 'information' has a built in idea of relevance and redundancy. Information is conveyed only when the data we are presented with is in some sense novel. That is: 'surprise value', or 'denial of expectation', is the metric for 'information'. Attention is one correlate of this information content. We attend to the novel, and dismiss as boring the rest. But is that the only role of expectation in a module?

In fact, whilst Fodor's hyperbole sometimes seems to suggest the opposite, there is scope for expectation in his model, even within a module (and not just through selective attention). It is just that it is constrained, particularly at the boundaries of the modules and submodules: modules have a well defined, bidirectional interface – which Fodor envisages primarily as the interface between the individual module and the central processes. The point of encapsulation is that an arbitrary data point internal to one module cannot *directly* influence the processing of an arbitrary data point internal to another.

Our Impoverished Student understood information in this sense. He compared and correlated and interrelated, he focussed on the differences and similarities, he used information theoretic techniques to compress the information on his disk, not just in individual files, but across different pieces of work. Not just in relation to linguistic information, but in relation to visual data.

By comparing data, he found similarities and differences. The similarities equated firstly to redundancies, and secondly to contexts in which interesting contrasts were highlighted. This interrelation also provides the opportunity to detect consistent and inconsistent data. Surprise serves two purposes: it focuses on the important, significant and novel, and it catches errors and inconsistencies. Redundancy serves no purpose in itself, but the position of redundant information can serve purposes in relation to indicating relevance of the novel parts and in increasing confidence in the repeated data.

One more basic point. IS used his information theoretic ideas throughout both the linguistic and the visual modalities. Using the same mechanisms in different modalities and at different levels of the one modality has some interesting

consequences: the representations and structures are going to be compatible, if not similar. I can further report (personal communication) that IS has had preliminary success in finding similar structures amongst the representations of both his text and video data. He is now keen to explore whether he can automatically relate the content of the two types of data using cues from this structural similarity. But what he finds most exciting is the possibility that when the structures match closely, but not completely, postulating the relationships from one modality into the corresponding position in another might bring useful insights.

Interestingly, he has already succeeded in applying these structural generalizations across different levels of the one hierarchy.

## **7 Back to non-Objectivist Reality**

The Impoverished Student is a work of fiction, but I would be only too pleased to be accused of autobiographical pretensions in that portrayal. Alas, reality has not yet come that far. However, it does reflect the directions, if not the results, of my own and related research.

Powers and Turk (1989) present the results of a decade's grappling with these issues on the basis of an analogy with the scientific method and ideas of contrast and similarity, differential minimization and consolidation, multimodal parsing and interlevel and interhierarchical interactions, along with the rest of the interdisciplinary manifestos of Powers (1983) and Turk (1984). This program was significantly influenced by the work of Lakoff and Johnson (1980), H. Clark (1973) and E. Clark (1973, 1979).

Wolff (1991) presents compression as the basis of a theory of computation and cognition which generalizes models of grammar discovery and language acquisition (Wolff: 1978, 1982). The relevance of Wolff's work is discussed further by Langley (1991) and Powers (1992). The information theoretic learning based on compression, the differential minimization and consolidation based on unification, the application of metaphorical projection based on image schema: all serve to relate structure, to relate interrelationships.

This perspective on language and cognition can well be summed up in IC's epithets: "Intelligence is the ability to recognize what is of importance and to discard what is not, to find a parsimonious framework which can explain everything both efficiently and elegantly, and with a minimum of redundancy. Science is the art of learning."

Notice that neither metaphors nor modules come into this explicitly. But we will now dare to attempt the reconciliation of all of these proposals into a framework for a theory of cognition, of language and of learning.



## 8 Towards a Model of Learning

### The poverty of the stimulus

Any theory or model which pretends to explain the phenomena of language and its development in the child, whether or not this is regarded as largely innate and autonomous, must come to grips with the problem of 'the poverty of the stimulus'. *Neither* side does, despite the ubiquitous acceptance of this premise.

This is not the place for an adequate treatment of 'poverty', but it is worth enumerating some of the (hidden) assumptions lying behind both supposed problem and supposed solutions.

1. It is assumed that there is some objective target grammar or language to be learnt.
2. It is assumed that correction or other negative feedback is only effective if its effect is immediately obvious and correct.
3. It is assumed that natural language is not constrained in any way which negates the 'context-free' (or worse) assumption (Gold, 1967).
4. It is assumed that natural language input is not constrained in any way which meets the 'anomalous' text criterion (Gold, 1967).
5. It is assumed that selection of parameters to a universal grammar is easier than learning the grammar.
6. It is assumed that language is independent of general human cognitive resources and restrictions.
7. It is assumed that language is independent of other sensory-motor modalities.

Theories of idiolect, dialect and language change, active and passive vocabularies and sublanguages all illustrate the fuzziness of the 'objective target grammar'. Turk (1984, 1988) argued that 'anticipated correction', a phenomena by which we ourselves know when we have said something questionable, can explain some of the effects where such negative feedback as is explicitly presented to the child appears to be ignored. Powers and Turk (1989) propose that this relates to the logical separation of the recognition and production grammars, and that criticism of generated utterances by the more advanced recognition grammar and from incompletely consolidated schemas is possible.

The third assumption is met in different ways by the nativist and cognitivist theorists. The nativist claims that natural language is restricted by an innate universal grammar, whilst the cognitivist claims the restriction arises from the nature and constraints of general cognitive mechanisms. Constraints on text are implicitly introduced in the one view by trigger mechanisms which wait for particular constructs to occur at particular developmental stages. On the generalist view, the grammar (which is here the primary focus) is learnt bottom up, with learning of constructs at a new level being possible only once the

foundations at lower levels are adequately prepared. This “learning only what you already almost know” is well known in AI, and filters out examples or features which are too complex for further processing.

The problem of learning within a principles and parameters model has been addressed by Berwick (1991) and Clark (1991) using genetic learning techniques. They have had to limit the number of parameters addressed to a very small number to make it tractable, and it is ironic (considering the consigning of the ‘learning’ of the principles to evolution) that evolutionary techniques should be employed in the ‘learning’ of the parameters. The assumption does seem reasonable, and what is surprising is that learning of the parameters for an innate autonomous grammar has not always proven more tractable than learning grammars with general cognitive capabilities.<sup>7</sup>

The final assumptions are those relating to autonomy, and which are our particular focus here. We wish to investigate the contrary hypotheses: that general cognitive constraints have shaped the development of human language, and are thus responsible for the phenomena underlying a non-innate ‘Universal Grammar’, and capable of explaining language and learning; that similar mechanisms and structures exist in different modalities and levels, and between those modal hierarchies and structures.

On this view language is intrinsically tied to the interactions of our various sensory-motor modalities, and autonomy amounts merely to the observation that there may be specific (probably high level) cognitive mechanisms necessary to language. In the respect we put our money directly counter to Fodor, who tends to see the low level input processing as specific to language, and relegates the higher language levels to the dreaded central processor.<sup>8</sup>

### **Input systems constitute a natural kind**

This subheading is a direct quote (1983, p99) from Fodor’s section on property 7 (fixed architecture). His preferred term, or metaphor, is rather ‘hardwired’ than ‘innate’.

With ‘fixed architecture’, one has little choice but to agree – notwithstanding that the ‘circuit layout’ may not be complete in the early stages of language learning, we can assume that it is largely determined. But in relation to ‘hardwired’ we need a cellar of salt, as this implies absence of memory, programmability and parameterizability. Clearly Fodor would not want to exclude this triad of possibilities completely.

What we can agree on is that input systems have a well-defined architecture tunable to the constraints of environment. Perhaps the best analogy as an alternate to ‘hardwired’ is ‘PLA’, a Programmable Logic Array. In this case the building blocks of the logic ‘gates’ are hardwired, but the precise functions which will be implemented are programmed by blowing fuses (fusible links) – permanently (although erasable and reprogrammable versions are known).

The ‘gates’ of an Input PLA embody the capabilities that are necessary for the abstraction of the information required from the raw input. The permanent setting of the parameters is consistent with the difficulty adults have in reprogramming their linguistic (particularly phonological) capabilities. Clearly



this is an oversimplification, and it would be preferable to characterize the phenomena in terms of hardening, whereby the plasticity of the links reduces with age and/or experience, and we eliminate the binary links of the digital circuit in favour of analogue (more multistate) synapses.

So the real issue is the complexity of our building blocks, gates or truly hardwired submodules.

A second issue is whether output modules are somehow similar, in which case, how similar. A fundamental lacuna in Fodor's characterization of language as an input module is that it totally ignores the production side of language, the evidence for interaction between the two sides, the possibility of reversible grammars in which one representation suffices for both directions, and the evidence that particular areas of the brain (e.g. Broca's and Wernicke's) are logically associated with different (syntactic) aspects of language and physically associated most closely with one or the other of the sensory and motor cortices.

A third issue is whether the similarities between different I/O systems go further than those delimited by the modularity thesis, in particular to what extent they fly in the face of autonomy in the sense of sharing common cognitive mechanisms. We now propose some general mechanisms and seek to show that these challenge autonomy while being consistent with some form of modularity.

The point at which Fodor's concept of modularity will be weakened, and his possible reaction, can be very clearly captured in his own words (1985, p35): "What he really has in mind is a general unsharpening of edges, a process I tend to resist on temperamental and aesthetic grounds."

## Mechanisms

Let us suppose the following interrelated and vastly simplified cognitive mechanisms for all our I/O and other 'modules'.

### A. Neural level

1. Cells are in layers with feedforward and feedback synapses to and from other layers according to synaptic strength and have lateral interaction functions which excite or inhibit neighbouring cells according to distance, plane and synaptic strength. Particular layers impinge on other modules and on effectors; particular layers are impinged on from other modules and by receptors; intermediate layers are impinged on by and impinge on the layers within some small range above and below.
2. Cells have a current propensity to fire or not to fire which is a function of their firing history and their synaptic input history, whilst synapses are plastic and modified according to the correlation of the firing of the cells it links: excitatory synapses are strengthened when both cells are firing simultaneously, and are weakened when the firing cell does not succeed in exciting the stimulated cell.

## **B. Categorization level**

1. Recognizers fire in response to frequently occurring auto-associations evident in their input interface levels. Concept and context recognizers identify correspondence and differences across projections from different levels.
2. Modules can receive overlapping projections from different sources, both within and across modalities, both direct and indirect.

## **C. Homuncular level**

1. All sensory-motor modalities project to and receive projections from a homuncular module. The projections from one modality to and from the homuncular module overlap all other modalities.
2. This homuncular module just does more of the same – it is not the central process, but akin to the I/O modules.

## **Consequences**

The basic mechanisms outlined here are not intended to be exhaustively or even accurately described. In fact in the various models explored many different variations occur, including in my own research. Moreover the three levels of the models need not always be present in experiments that can demonstrate useful linguistic properties.<sup>9</sup>

The homuncular level, the highest level of abstraction considered, reflects evidence that sensory-motor modalities are mapped onto topographical maps which comprehensively cover the body, maintaining topological relationships while distorting so as to reflect the information and/or precision available to or requisite from it (Geschwind: 1979).<sup>10</sup>

This level admits the possibility of addressing the Symbol Grounding Problem (Harnad, 1987), allowing semantics to be represented in the relationships between modalities as associated using the hypothesized mechanisms, and leading to phenomena of metaphor as an emergent corollary.<sup>11</sup>

This requires explanation, and to give this explanation I must deny that individual words or constructs in the linguistic hierarchy have one-to-one correspondences with comparable patterns in the visual hierarchy, just as it could not be expected that a specific object or feature could be fully described in a single word. Rather, larger contexts (and many of them) are overlapped and consolidated to form entire frames or schema which are associated with co-occurring concepts.

This is clearly related to Lakoff's ideas of metaphor-like mechanism operating on image schema.

To understand how these mechanisms might work, and how we can still retain the advantages of Fodor's modules while skirting the problems of the 'central systems', we descend to the categorization level.

Let us distinguish a concept and a context. The concept has been recognized by the categorization mechanism at some level, and the context includes the



remainder of the data fed up from the previous levels, as well as that which might arrive from neighbouring I/O modules or the homuncular modules.

Metonymy can now be conveniently defined in terms of the occurrence of some recognized structure, the concept, which occurs within some degree of similarity in distinct contexts. Paradigm is a useful source of highly focussed information, the 'Richness of the Stimulus', in that different substructures occur in a context that is basically stable: an object moving around and taking on systematically changing configurations is a naturally occurring paradigm. Metonymy (and synecdoche) is a reflection of the insistence that concepts are associated with contexts, and contexts combine together into consolidated schema.

On this view, literal language is what is unusual and hard to define: we can vaguely associate it with the 'original' grounded concepts. Literary metaphor, and in particular the carefully crafted parable or fable, are characterized by the fact that unseen relationships in one context may be highlighted or suggested by relationships which map into them from a different context.

This '*anduction*', whereby conclusions are reached by *analogy*, is related to '*induction*', '*abduction*' and '*deduction*' in ways which are indicated by Wolff (1991). Suppose we have a history of associations of cloud cover (clear, light, heavy, dark, ...) with precipitation (dry, wet, hail, snow, ...). Association says nothing about causality, but a strong (i.e. strongly redundant) association of heavy dark clouds with rain, can be matched against (unified with) present conditions (or a query). Thus noticing that it is raining suggests it might be cloudy, while seeing a dark cloud formation indicates it is likely to rain.

Induction is represented in that associations present in the past are consolidated into schema. Deduction is represented when the association is used in the direction associated with the stronger conditional probability (or synaptic strength). Abduction would correspond with the weaker direction. Causality is quite different and can run in either direction: there might be several possible causes, or one; there might be several possible consequences, or one. Folk science and empirical science differ in their 'laws' precisely because human cognition and perception have no direct access to causality, and elucidating the laws is at best difficult.<sup>12</sup>

Note that we do appeal to some form of modularity, some form of hardwiring and encapsulation, to avoid trying to associate everything with everything.

The final wave of the hands must explain how the neural mechanisms can achieve these categorization phenomena. This is the least important part of the problem because general computing systems have been simulated in connectionist systems, and connectionist systems have been simulated in terms of computing systems. Taking some time for the question will however, hopefully, have the side effect of banishing any vestigial impression that there is a substantive symbolic/connectionist chasm, along with the related machine/meat-machine divide.

Within both Machine Learning generally and the connectionist framework in particular, two principle paradigms may be observed. The one, unsupervised, associative, self-organizing learning, almost seems too weak to warrant the title 'learning'. It has been shown to be capable of producing (with or without environmental exposure) patterns of recognizers which reflect identified neuro-



physiological structure and functionality. Moreover, exposure to stimuli will automatically produce the effect of adjusting real-estate and resolution to the information content of the relevant features (von der Malsburg (1973), Turing (1952), Kohonen (1982b), Powers (1984)). The other broad neural paradigm is characterized by supervised learning in which the desired output of the network is associated with the input. The existence of a distinguished output allows backpropagation of error. If no advantage of an input/output distinction is made, we are left with an auto-associative paradigm equivalent to the first.

The major restriction in our modules is that we limit ourselves to auto-association in the sense that there is no explicit forcing of certain distinguished inputs (actually desired outputs).

Linguistic subtasks (of the input module variety) which have already been demonstrated with auto-associative networks based on these neural principles include: categorization (identification of the class) of vowels, prosody, specifiers, sentences (sentence beginnings), nouns (and subcategorizations thereof), as well as the individual uppercase Latin characters (Powers: 1989, 91; Sukhotin: 1962, 71; Kohonen: 1989; Ritter and Kohonen: 1989; Hirai: 1980).

Note that once fairly crisp concepts are available from a number of sources, the possibility of allowing more isotropic interaction may be permitted by an increasing move toward a 'supervised' paradigm (such as backpropagation) with the supervision (i.e. distinguishing of expected outputs) being derived intermodally, and the focus being recognized primarily intramodally (through the naturally emerging concepts).

Feedback gives many further advantages in (at least) vision, speech and language, which will not be considered here<sup>13</sup>. Well-defined lines of feedback can operate within modules and between module interfaces without compromising encapsulation.

The above discussion of the power of the weaker self-organizing paradigm involved a certain sleight of hand: the association of connectionist and symbolic mechanisms referred to earlier. Some of the results cited were achieved in a more symbolic framework, some in a more connectionist framework, some in both. The distinction is essentially unimportant.

Where clustering has been achieved in a connectionist framework, particular cells act as recognizers, and the strengths of the synapses can be identified with conditional probabilities. Where clustering has been achieved through statistical techniques (such as 'bigrams'), the probabilistic basis is more explicit, and the thresholding and normalization processes also have their correlates and motivations. In this case we do not have the daunting connectionist black box, with its multiple internal layers, but a situation where we can identify the significance of the input and the categorized output of individual layers.

In fact, it should be noted that application of backpropagation black boxes to these low level linguistic tasks is overkill. The evidence from the work cited above is that our linguistic (and visual) input is sufficiently well-structured that auto-associative techniques suffice in these cases. Thus precisely the lower level processing which is most clearly in the scope of Fodor's input modules is non-autonomous, both in the sense that general weak methods suffice, and that



common methods are sufficient across different modalities and submodalities. Application of black box methods may well produce modules, but if they fail to include auto-association capabilities, these techniques can fail even though they are being trained in a strictly more powerful paradigm.

To clarify this point: the paradigm concerns how we use the black box, whether we provide only examples, *egalitarian* input, versus our provision of examples plus judgements, *distinguished* input. The judgements in the most common subparadigm of supervised learning are yes/no: positive instance or counter-example. But any other partitioning of the examples whereby we seek to force them to learn a specific classification (which we are explicitly providing) is merely a variant of the binary classification, and is of equivalent power, equally well providing 'negative information' in the sense of 'A' or 'not A' (viz. something else: 'B' or 'C').

The paradigm says nothing about what is in the black box. But given a mechanism which makes optimal use of the information available, the supervised mechanism, providing additional information in one form or another, is strictly more powerful than the unsupervised paradigm (as illustrated by the results of Gold (1967)). But if we relax this 'given best play by the black box' condition, and don't do anything useful with our input, the worst case of the two paradigms is the same: Zilch!

So far we have seen only that the neural techniques can do categorization or auto-association. But this is already the capability of recognizing that patterns are, in some automatically determined sense, either the same or different. The raw input is augmented by features which move us away from the concrete transduced input to some abstracted representation.<sup>14</sup>

The neural model has additional helpful properties: the history conditions encompass the idea of threshold as well as a form of short term memory which allows some temporal representation (it additionally permits recurrence, which can also achieve temporal/memory effects). With threshold functions we can moreover simulate a McCulloch-Pitts nets and hence an arbitrary digital circuit. In particular, if we have two images which we wish to investigate for degree of correspondence, a simplistic one-to-one 'same' (EQV) or 'different' test (XOR) is trivial and the results can also be auto-associated.

If the fields we are mapping are temporally removed versions of the same (static) visual field, we get outlines of moving objects! Similarly in other domains we get a form of focus. If the visual field (our eye or body) is in motion, in addition to proprioceptive input, auto-associated features can be used to track and correlate the fields. In addition the locus of similarity of clusters of cells, achieved by the lateral interaction function, allows slight shifts to be accommodated. At higher levels, with more feature input and lower resolution similar features in diverse areas are gradually brought together (being associated in the overlaps and interactions of neighbouring self-organized waves of association (Jacobson, 1978)).

Similarly if we exchange the retina for the cochlea's Fourier transformed frequency map, we can map features and match up, compensating for systematic frequency shifts.

In addition, one of the features of the associative structure is that the recog-



nition is in a sense holistic, and when parts are the same, missing bits will be predicted, and substitutions detected. This recognition was one of the important precursors of connectionist work, based on analogy with the hologram and 'holophone' (Longuett-Higgings, Willshaw and Buneman, 1970).

The learning of semantics can be envisaged in terms of the matching up of foci from different hierarchies, and the matching of temporal and structural relationships. The learning of syntax can be envisaged in terms of categorial grammars: we can learn categories, and add in a new feature (or non-terminal) which takes over from the contributing input features and invites similar categorization in the context with which it was associated – the new non-terminal feature also (potentially) participating in the formation of new categories. This is similar to the 'distituent grammar', approach proposed by Marcus (e.g. 1991), and investigated by Magerman and Marcus (1991) at the word class to phrase level, as well as to work by Powers at the same level (1984, 1985) and at a sub-word level (1991).

It remains to say something about the expected limitations of this model and boundary of the peripheral processing modules. Fodor has mentioned 'basic categories', 'phrases' and 'sentences' in this context. The work just cited suggests that this is roughly the right level, but probably somewhat ambitious.<sup>15</sup> The categories seem to be learned bottom up, according to their degree of 'closedness'. Closed classes are indeed quite trivial to learn, and often they are conveniently associated with open classes (like article with adjective and noun). Thus as well as their semantic/pragmatic value, closed classes may be fundamental to our segmentation of language and identification of the open classes, and augment the prosodic information.

Thus we would predict that a primary function of the closed classes in speech *understanding* is the segmentation of our language input and the induction of its structure. Whereas the content of open class words is primarily semantic and can only be derived through interaction with other input modalities (which is not to deny that categorization and even some subcategorization has been demonstrated in self-organizing systems (Scholtes: 1991)), the closed class words have a primarily syntactic function and often serve the information theoretic purposes of efficiency (e.g. anaphora) in a way which is primarily relevant to speech *production*.

This is consistent with the localization of closed class words in Broca's area adjacent to the area of the motor cortex controlling the speech organs, and the identification of open class words with Wernicke's area adjacent to the auditory cortex.

The big questions which have not yet been explored in computational models (except in the most primitive and abstract of simulations) concern the learning of interhierarchical, intermodal relationships. This is related to the big associative, isotropic, Quinean cloud of central processing concerning which Fodor is so pessimistic.

An interesting insight from Pike's Tagmemic Grammar (e.g. 1977) is his division of the tagmeme into four basic components (a reduction from the original ten). These are slot, role, cohesion and filler. The slots correspond to the traditional phrase structure categories, and the fillers to what is categorized.



Role and cohesion are particularly interesting because they extend beyond the interlevel *intra*hierarchical connections internal to a module. Role captures the particular *inter*hierarchical mapping of syntactic structure onto semantic structure or ontological schemata (e.g. Subject as Actor). Cohesion captures the long range *trans*hierarchical relationships which cut across phrase structure lines (e.g. agreement).

The existing evidence for the success of the present model is almost exclusively confined to the conventional (interhierarchical) phrase (or categorial) structure, albeit with broadened scope. I would predict that cohesion, along with the functionality of closed classes – thus much of our syntax – is actually more intimately associated with generation, and that to explain language we must explain the interaction of both input and output speech modules, and seek to understand the specifications of the interface between them (evidently mediated by the *arcuate fasciculus*).

This is to suggest that the transhierarchical relationships originate in the semantics, and are stretched out across the parse structure as the intention seeks expression. The role of the input module, in comprehension, is thus to relate this back to possible intentions, as with the semantics, and the primary role of cohesion is to disambiguate by eliminating spurious predictions using the mechanisms already in place in the output module.

Role on the other hand, being interhierarchical like semantics, is perhaps falsely identified as syntactic! Is it merely that the semantics are captured not in a word, but in an inflection or an ordering relationship? I would expect role to be involved wherever semantics is involved, and in this case the identification of associations amongst input phenomena is probably primary, with the broader sensory-motor association taking place in the interactions with the ‘homuncular’ modules.

In this case we would expect understanding to be primary and expression secondary, with a consequent tendency for the role and semantics to be resolved in areas of the brain more closely associated with the input cortex, and production making use of the bidirectional relationships which are learned according to our model. Thus speech is learnt by matching practised sounds and structures (from e.g. babbling or early speech) with recognized sounds and structures. This explains the apparent lag of production behind understanding and the impenetrability of the production process to correction – as well as providing the mechanism for ‘anticipated correction’ (Turk: 1988) and the eventual attainment of performance competence.

Thus there is much of interest happening in the areas and interactions outside the input modules, and those linguists who feel that Fodor has shown that language is tractable by confirming Chomsky’s ideas of an innate language organ will be severely disappointed. For the interactions of ‘core’ language do, as the autonomists argue, fall largely within the central and intractable core of Fodor’s model.



## 9 Conclusions

I don't know what 'core' linguistics is, but the areas where the abovementioned models have already shown significant success seem clearly to fall under the mantle of language, and equally to have demonstrated applicability of techniques which first arose in non-linguistic domains.

It is interesting that linguists seem to have felt compelled to defend their territory by postulating uniqueness in such strong terms as are represented by the autonomy and innateness claims. Particularly so, as parallel to this development there was an increasing influence of the linguistic metaphor in other aspects of what was not yet Cognitive Science. This is quite clear in Computer Science: in relation to compilers, automata and formal language theory. It is, furthermore, quite explicit in Pribram's (1971) *Languages of the Brain*, and is a major theme of Powers (1983) and Powers and Turk (1989). In the latter, parsing techniques and structures, along with unification-based differential minimization, were proposed for treating the ontology of other modalities, and our experimental computer programs were written so as to be applicable in multiple (simulated) modalities.

Thus the failure of autonomy could just as well mean that ideas, mechanisms and techniques first developed in linguistics can be applied elsewhere, as that linguists are out of a job because results from (say) vision explain language as a corollary. Whilst low level visual processing is in some ways more amenable to neurological study than language, and the maps easier to read, the linguistic approach to structuring our sensory input and motor output seems to be appropriate in all identified modules, and could indeed become one of the defining attributes of modularity.

Furthermore, the existence of common mechanisms and/or components at some level doesn't obviate the explanation of how they might give rise to the higher level phenomena. Similarly, language may be essential to higher level cognition and an explanation of thought and consciousness, so that the boundaries of language and the direction of borrowing may be fuzzy.

So has autonomy failed? Assuming we take readings of the claims for and against autonomy which exclude the 'straw men' of no common general mechanism and no specific innate mechanism, we must expect eventually to find ourselves somewhere along the path that lies between: we must bridge the chasm. I expect that we will find few *mechanisms* which are not extensively reused across modular and domain boundaries.

The identification of our peripheral processing as a site of activity which is categorically different from our central processing is an important step. Moreover, consistent with the vague notion of 'core' language, the proposals here suggest that common mechanisms are responsible for this interface-level I/O processing, whilst leaving open the question of whether 'core' cognitive processing may require specific mechanisms to explain language.

The remaining question at the level of peripheral processing is to delimit the modules. The assumptions outlined above didn't impose any boundaries within the model of peripheral processing, other than the naturally occurring substructure of cells and levels, along with hierarchies based around the pro-



cessing of specific sensory-motor projections. Thus the sharpest boundary will be the level where the peripheral processing takes off and central processing takes over. Clearly much of the peripheral processing takes place in the cortex, and whether its boundaries will prove to correspond with this logical boundary, or to distinguish a subclass of modules, remains to be explored.

As to the vertical boundaries of the modules, the claim is that 'domain specificity' (Fodor's first attribute of a module) is precisely the "ipso facto" domain specificity which arises through the impinging of transduced patterns from different modalities on different regions of a structurally uniform cortex. It may well be that there are gross differences in the precise structure of the 'cortices' defined by the modal interfaces. But it is proposed that these basic mechanisms are fairly uniform, particularly in the cortical modules. Moreover, there is neuroanatomical evidence that the amount of cortical real-estate allocated to particular modalities is influenced by the information load of that modality as a function of that available via transfiguration, transmission and transduction, and sensitive to neonate disturbances in any of these, whether as a result of pathological physiological or environmental conditions.<sup>16</sup>

So autonomy survives, but relegated to the higher levels of processing; modularity survives, but with hard-wiring in the input processors limited largely to the basic common mechanisms, and the boundaries of the modules being claimed, explicitly, to be not hardwired; metaphor survives, not as the basic mechanism, but as the linguistic outworking of an information theoretic consolidation mechanism which abstracts structure and categorizes features.

Of course the whole discussion is, in large measure, premature.

## Notes

<sup>1</sup> As will no doubt be alluded to in the preface, the recent launch of the 'International Cognitive Linguistics Association' and the journal 'Cognitive Linguistics' generated a storm of protest from 'Generative Linguists' over the "usurping" of this term (see the electronic LINGUIST Discussion List, Vol. 2 #27-102 & 239). At issue was the territory associated with the name: "The formal structures of language are studied not as if they were autonomous, but as reflections of general conceptual organization, categorization principles, and processing mechanisms."

The debate which ensued is directly responsible for this volume, so in this chapter, no new "straw men" will be erected, and the unattributed claims for or against autonomy, modularity and/or innateness of language can be traced back there. However, in view of the unresolved status of such "publication", I wish not to sheet home the blame to individuals any more specifically. But those views cited occur often enough that I fully expect that they will raise their heads one way or another elsewhere in the volume, assuming they get past the referees. The "straw men" I cite in this section are claims which have, in my view, either been unfairly attributed to one side by their opposition, or inadvisedly used in support of the given position. The failures represent supposed flaws as well as evident limits on what has yet been demonstrated and attempted. All claims are either direct quotes or fair summaries.

Vested interests I have not listed, although clearly and regrettably work on both sides reflects our personal biases and background, and may even at times serve political expediency. In this volume, autonomy is the focal issue. For further documentation of the issues of modularity and innateness see Garfield (1987), Fodor (1985) and Piatelli-Palimarini (1979).

<sup>2</sup> From my perspective, we poor unfortunates who were just working away minding our own research (guilty of mining for gems in their field, but not in any way threatening to undermine it) suddenly found the big guns of Linguistics, Psychology and Philosophy telling



us that what we were trying to do was impossible because language learning was impossible and the language organ was autonomous, innate and all-encompassing.

<sup>3</sup> Our definition of what processes are intrinsically linguistic is being continually nibbled away at: from the bottom by whatever common building blocks we find; at the top by what might slip into a theory of higher-level cognition, mind or consciousness; at the side by non-acoustic language and cues; etc.

<sup>4</sup> Lakoff (1987, p181f) observes that "generative grammar is *defined* so as to be independent of general cognitive mechanisms", however his argument addresses more directly the necessity of modular encapsulation for traditional grammatical approaches.

<sup>5</sup> Marr's (1982) theory of stereo vision tends to be modular and forms the basis of Fodor's primary non-linguistic argument. "Theoretically, Marr argued that each source of information represented an independent physical processes in the world and that therefore it was possible and efficient to design computations independently. Heuristically, he argued that it was good research strategy to see how much information could be recovered from each source before leaning on the crutch of interaction with other sources. ... On the other hand, other computer vision systems show complex mixtures of modularity and cooperation. The heuristic value and the empirical substance of the modularity thesis, at least insofar as it concerns information flow, are in danger of collapsing." (Stillings, 1987)

Marr's "theoretical" argument is related to domain specificity, but the 'domain' can only be induced from the common visual input. It thus represents an autonomy argument very similar to those of linguistics, and belies parsimony to the extent that common subprocesses could be involved which are not submodules, whilst increasing the number of submodules and inter-modular interactions otherwise. The "heuristic" argument is valid, and would be the expected way of determining how modular and how interactive the processing should be. It emerges as a corollary of the strategy of Powers (1983), and Powers and Daelemans (1991), of exploring unsupervised learning techniques within individual hierarchies before attempting to make use of interhierarchical information.

<sup>6</sup> Here, unfortunately, only the less common (17th century) usage of 'accident' properly captures the intent of intrinsic external manifestation.

<sup>7</sup> Clark's result is primarily a formal result to demonstrate learnability, and the application of genetic learning without heuristics arises primarily because the algorithm is so well suited to the problem. The development of heuristics, recognition of triggers, etc. would clearly help. Berwick applies an improved genetic algorithm to basic (X-bar) syntactic structures. Drescher and Kaye (1990) achieved some relevant results in the phonological domain.

<sup>8</sup> It is not clear where Fodor draws the line - in some places it seems like the level of sentences, at others a much lower level corresponding to words, phrases and basic categories. Elsewhere (1983, p100), he acknowledges that the issues raised in his properties 7 ('fixed architecture') and 9 ('characteristic ontogeny') are "moot" and the available information "fragmentary".

<sup>9</sup> Thus, even in my own work, symbolic and connectionist approaches to the same tasks have been contrasted, and some experimental implementations have assumed a basic parser framework whilst others haven't (Powers: 84, 89, 91).

<sup>10</sup> The proposal that the homunculus is then mapped back to the individual modalities is supported from surprising quarters: I am quite ignorant of the scientific status or quackery of those who diagnose medical complaints by examining the eye, or cure them by massaging the foot, but I have seen the maps they propose and they strike me as being not without credibility. Well if Fodor can hold up Gall as his mentor, ...

<sup>11</sup> Without the homuncular level, this level of interaction can only be achieved by Fodor's dreaded 'central processes' or by a large plex of explicit module to module connections beyond what could be explained by adjacency.

<sup>12</sup> Certainty is, of course, impossible.

<sup>13</sup> e.g. Grossberg's extensive neural modelling achievements in relation to stereopsis, edge and corner detection, etc. In respect to speech and language, Fodor (1983) answers the many models and theories related to feedback and expectations in language (including speech and machine translation) with a proposal that some elementary statistical model internal to the module can provide sufficient pseudo-feedback. Although 'bigram' models are being used for this purpose in speech and machine translation systems which don't have a grounded

semantics, it seems unparsimonious to suppose that multiple cognitive subsystems should be provide such guidance, especially when the mechanisms would be so similar and the bigram model may well be the starting point for elaboration. See Brown, Cocke, Della Pietra, Jelinek, Lafferty, Mercer and Roossin (1990) in relation to Machine Translation, and Essen and Kney (1991) in relation to Speech.

<sup>14</sup> We could equally well substitute literal/metaphorical for concrete/abstract!

<sup>15</sup> Current models of vision tend suggest input processing stops short of objects or basic categories in our visual input submodules (Marr,1982), preferring output at the level of features and 3-D reconstruction of plane orientation and location. Similarly, we suggest (Powers and Daelemans, 1991) that our language learning model will reach a level somewhere between phrase and clause before intermodal interactions become significant and modularity breaks down.

<sup>16</sup> It has, of course, been impossible to cite all the relevant literature from other disciplines, and the 350 page monograph (Powers and Turk, 1989) in which I attempted this (as background and encouragement to interdisciplinary research into computational models of language learning) is already dated – and was in any case a highly condensed version of a Ph.D. dissertation (Powers, 1985) of 700 pages which had already selected for discussion and reference about a quarter of the 2000 or so references examined, which were themselves only exemplars of the decades and sometimes centuries of work in the fields which we now lump together in two words, as ‘Cognitive Science’.

A later annotated bibliography in Powers (1991a) further reduces the size of the interdisciplinary discussion, but broadens the survey of relevant computational work as well as introducing the various contributions to the symposium proceedings in which it appears. Langley (1991), in the same proceedings, is another useful review in this latter respect, as is Hill (1987).

## References

1. Berwick, Robert: From Rules to Principles in Language Acquisition: A view from the Bridge, pp16-21 in Powers, David M W and Reeker, Larry (eds): **Machine Learning of Natural Language and Ontology**, Proc. AAAI Spring Symposium, Document D91-09, DFKI Kaiserslautern FRG, 1991.
2. Peter F. Brown, J. Cocke, S. A. Della Pietra, F. Jelinek, J. D. Lafferty, R. L. Mercer and P. S. Roossin (1990), “A Statistical Approach to Machine Translation”, **Computational Linguistics** 16: 2, 79-85.
3. Chomsky, N. 1965. Aspects of the theory of syntax. Cambridge: MIT Press.
4. Eve V. Clark, 1973 “What’s in a Word? On the Child’s Acquisition of Semantics in his First Language”, pp 65-110 in Timothy E. Moore (Ed.) **Cognitive Development and the Acquisition of Language**, Academic Press: New York
5. Eve V. Clark, 1979 “Building a Vocabulary: Words for Objects, Actions and Relations”, pp 149-160 in P. Fletcher and M. Garman (Eds) **Language Acquisition: Studies in First Language Development**, Cambridge University Press: Cambridge UK



6. Herbert H. Clark, 1973 "Space, Time, Semantics, and the Child", in Timothy E. Moore (Ed.) *Cognitive Development and the Acquisition of Language*, Academic Press, New York
7. Clarke, Arthur C., 1972, *The Lost Worlds of 2001*, Sidgwick and Jackson, London UK
8. Clark, Robin: A Computational Model of Parameter Setting, pp32-37 in Powers, David M W and Reeker, Larry (eds): **Machine Learning of Natural Language and Ontology**, Proc. AAAI Spring Symposium, Document D91-09, DFKI Kaiserslautern FRG, 1991.
9. Dresher, B. E. and J. D. Kaye, "A computational learning model for metrical phonology," *Cognition*, vol. 34, pp. 137-195, 1990.
10. Essen, Ute and Ney, Hermann (S:1991) "Statistical Language Modelling using Cache Memory", Proceedings of QUALICO'91, University of Trier, September 23-27, 1991.
11. Fillmore C. J., "Scenes-and-frames semantics" pp 55-81 in A. Zampolli (ed), *Linguistics Structures Processing* North Holland 1977
12. Fodor, Jerry A., *The Modularity of Mind*, Cambridge University Press, 1983.
13. Fodor, Jerry A., 1985. "Precis of *The Modularity of Mind*", *The Behavioral and Brain Sciences* 8. 1-42. (BBS treatment including peer commentary and reply.)
14. Fodor, Jerry A., 1987. "Modules, Frames, Fridgeons, Sleeping Dogs, and the Music of the Spheres". pp25-36 in Garfield, J. L. (ed.) **Modularity in Knowledge Representation and Natural-Language Understanding**. MIT Press: Cambridge MA
15. Garfield, Jay L. (ed.), 1987. *Modularity in Knowledge Representation and Natural-Language Understanding*. MIT Press: Cambridge MA
16. Gold E. M., "Language Identification in the Limit", *Information and Control* 10:447-474, 1967
17. Harnad, Stevan (Ed.), *Categorical perception: The groundwork of Cognition*, Cambridge University Press, New York NY, 1987.
18. Jacobson, M. *Developmental Neurobiology*, Plenum Press: New York NY, 1978.
19. Johnson, Mark, 1987. *The Body in the Mind*, Chicago: University of Chicago Press.
20. N. Geschwind, "Specializations of the Human Brain", pp158-171, *Sci. Amer.* Vol. 241 (September 1979)

21. Hill, J. C. "Language Acquisition", in *Encyclopaedia of Artificial Intelligence* (1987).
22. Y. Hirai, 1980. "A New Hypothesis for Synaptic Modification: An Interactive Process between Postsynaptic Competition and Presynaptic Regulation", *Biol. Cyb.* 36 pp.41-50
23. D. H. Hubel and T. N. Wiesel, "Brain Mechanisms of Vision", pp. 130-145, *Sci. Amer.* Vol. 241 (September 1979))
24. Kohonen, T., "Self-Organized Formation of Topologically Correct Feature Maps," *Biol. Cyb.*, vol. 43, pp. 59-69, 1982a.
25. Kohonen, T., "Analysis of a Simple Self-Organizing Process," *Biol. Cyb.*, vol. 44, pp. 135-140, 1982b.
26. Kohonen, T., *Self-Organization and Associative Memory*, Springer-Verlag, BERLIN FRG, (3rd edn, 1989)
27. Lakoff, G. 1987. *Women, Fire, and Dangerous things*. Chicago: University of Chicago Press.
28. Lakoff, George and Mark Johnson, *Metaphors we Live By*, University of Chicago Press, 1980.
29. Langley, Pat: *Machine Learning and Language Acquisition*, pp104-108 in Powers, David M W and Reeker, Larry (eds): **Machine Learning of Natural Language and Ontology**, Proc. AAAI Spring Symposium, Document **D91-09**, DFKI: Kaiserslautern FRG, 1991.
30. Longuet-Higgins, H. C., David J. Willshaw, and O. P. Buneman, "Theories of Associative Recall", *Qtly Revs Biophysics*, vol. 3, no. 2, pp. 223-244, 1970.
31. Magerman, David: *Mutual Information, Deducing Linguistic Structure*, pp122a-e in Powers, David M W and Reeker, Larry (eds): **Machine Learning of Natural Language and Ontology**, Proc. AAAI Spring Symposium, Document **D91-09**, DFKI: Kaiserslautern FRG, 1991.
32. Malsburg, C. von der, "Self-Organization of Orientation Selective Cells in the Striate Cortex", *Kybernetik*, vol. 14, pp. 85-100, 1973.
33. Marcus, Mitchell: *The Automatic Acquisition of Linguistic Structure from Large Corpora: An Overview of Work at the University of Pennsylvania*, pp123-126 in Powers, David M W and Reeker, Larry (eds): **Machine Learning of Natural Language and Ontology**, Proc. AAAI Spring Symposium, Document **D91-09**, DFKI: Kaiserslautern FRG, 1991.
34. Marr, D., 1982. *Vision: A Computational Investigation into the Human Representation and Processing of Visual Information*. Freeman.



35. Piatelli-Palmarini, M., *Language and Learning: The Debate between Jean Piaget and Noam Chomsky*, Routledge and Kegan Paul, London, England, 1979.
36. Pike, Kenneth L. and E. G. Pike, *Grammatical Analysis*, Summer Institute of Linguistics (and University of Texas at Arlington), Dallas, Texas, 1977.
37. Powers, David M. W., "Neurolinguistics and Psycholinguistics as a Basis for Computer Acquisition of Natural Language," *SIGART(84)*, pp. 29-34 (June 1983).
38. Powers, David M. W., "Experiments in Computer Learning of Natural Language", *Proc. Aust. Comp. Conf.*, Sydney NSW, pp. 489-500 (Nov 1984).
39. Powers, David M. W., 1985. "A Psycholinguistic Approach to the Acquisition of Natural Language by Computers", Ph.D. Dissertation, University of NSW, Australia (condensed 1987).
40. David M. W. Powers, 1991a "Preface: Goals, Issues and Directions in Machine Learning of Natural Language and Ontology." pp1-10 in Powers, David M W and Reeker, Larry (eds): **Machine Learning of Natural Language and Ontology**, *Proc. AAAI Spring Symposium*, Document **D91-09**, DFKI: Kaiserslautern FRG, 1991.
41. David M. W. Powers, 1991b "How far can self-organization go? Results in unsupervised language learning." pp131-136 in Powers, David M W and Reeker, Larry (eds): **Machine Learning of Natural Language and Ontology**, *Proc. AAAI Spring Symposium*, Document **D91-09**, DFKI: Kaiserslautern FRG, 1991.
42. David M. W. Powers, 1992 "On learning about learning", invited column to be published in *SIGART Bulletin*, Jan 1992.
43. David M. W. Powers and Walter Daelemans, 1991, *SHOE: The Extraction of Hierarchical Structure for Machine Learning of Natural Language*, **ITK Memo 10**, University of Tilburg, Holland.
44. Powers, David M. W. and Turk, C. C. R., 1989. "Machine Learning of Natural Language", Springer-Verlag: Berlin/London.
45. Pribram, K. H., 1971. *Languages of the Brain*, Prentice-Hall, Englewood Cliffs, NJ.
46. Ritter, H. and Kohonen, T., 1989, "Self-Organizing Semantic Maps", *Biol. Cyb.* **61** 241-254.
47. Scholtes, Jan: *Learning Simple Semantics by Self-Organization*, pp146-151 in Powers, David M W and Reeker, Larry (eds): **Machine Learning of Natural Language and Ontology**, *Proc. AAAI Spring Symposium*, Document **D91-09**, DFKI: Kaiserslautern FRG, 1991.

48. Stillings, Neil, 1987. "Introduction to Part IV", pp325-332 in Garfield, J. L. (ed.) **Modularity in Knowledge Representation and Natural-Language Understanding**. MIT Press: Cambridge MA
49. Sukhotin, B.V. 1962, "Eksperimental'noe vydelenie klassov bukv s pomoshch'ju EVM." In: Problemy strukturnoj lingvistiki. 234: 198-206.
50. Sukhotin, B.V. 1973, "Methode de dechiffage, outil de recherche en linguistique." T.A. Informations. 2:3-43.
51. Turk, C. C. R., "A Correction NL Mechanism", ECAI'84: Advances in Artificial Intelligence, ed. T.O'Shea, Elsevier: Amsterdam, 1984.
52. Turk, C. C. R., "Evolutionary Methodology in the Acquisition of Natural Language by Machine Learning" in Trappl, R. (ed.) **Cybernetics and Systems '88**, Proc. of the Ninth European Meeting, Riedel: Amsterdam, 1988.
53. Turing, A. 1952, "The chemical basis of morphogenesis", Phil. Trans. Roy. Soc. London Ser. B **237**:37-72
54. David J. Willshaw and C. von der Malsburg, 1976. "How patterned neural connections can be set up by self-organization", Proc R. Soc. Lond. B 194 431-445
55. Wolff, J. G., "Grammar discovery as data compression," Proc. AISB-GI Conf. on AI, pp. 375-379, Hamburg FRG, 1978.
56. Wolff, J. G., "Language acquisition, data compression, and generalization," Language and Communication, vol. 2, pp. 57-89, 1982.
57. Wolff, J. Gerald (S:1991) "Towards a Theory of Cognition and Computing", Ellis Horwood: Hemel Hempstead, UK, 1991.



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