Novel Tools at the Service of Old Ideas

Jablonka, Eva & Marion J. Lamb. 2005. *Evolution in Four Dimensions*. Cambridge, MA: MIT Press.

By Massimo Piattelli–Palmarini

I wholeheartedly endorse one central idea in this book and the motivation behind it. Eva Jablonka and Marion J. Lamb (henceforth J&L) make it very clear that a multiplicity of stunning advances in biology and in evolutionary theory in the last several years have so completely reshaped the standard neo-Darwinian picture that, indeed, cognitive scientists should pay attention and re-think many of their ideas about the evolution of cognition. The main facts and ideas of this new biology are explained very well by J&L, as they are in two recent excellent books, also fully accessible to a lay audience (Kirschner & Gerhart 2005 and Carroll 2005). There is a lot to be learned in this essay about new ideas in biology and in modern evolutionary theory. Having said this, I wish to trace a sharp divide between J&L's excellent exposition of biology and their objectionable picture of language evolution. Before I explain why, I need to insert one important consideration.

1. A Missing Dimension (the 5th?)

All the ideas and experiments in biology that are detailed in this book are the right ones. There is not one of them that I would have liked to see left out. There is, however, a glaring lacuna: no mention of the powerful return of the laws of form in biology, of the central role that physico-chemical and computational factors play in the optimization of biological functions and assemblies. J&L's pages dedicated to Waddington could have been the right entry into this domain, but they are focussed on Waddington's interesting ideas about development and complex patterns of selection. Emphasis on global invariants and on the morphogenetic power of the laws of physics and chemistry goes back to Wentworth D'Arcy Thompson and Alan M. Turing (Thompson 1917/1992, Turing 1952), but it has come back in force in the last few years. In J&L's tally, it should be conceived as the fifth dimension in evolution.

There is only so much that the 25,000 or so genes in the human genome *can* do to assemble a human being. Sure, as J&L explain in detail, there are multiple gene regulations and networks of interactions, and morphogenetic attractors, and epigenetic modifications, and a complex interaction with culture. But this is far from being enough. Among other complex structures, tens of millions of kinds of

ISSN 1450–3417
Biolinguistics 2.2–3: 236–245, 2008
http://www.biolinguistics.eu

antibodies have to be produced, and 10^{11} neurons and 10^{13} synapses to be developed and fixated, and about 60,000 miles of veins, arteries and capillaries to be exactly placed in each of our bodies. Christopher Cherniak has introduced the notion of "non-genomic nativism" and has shown by means of extensive computer calculations that the wiring of the cerebral cortex is the most efficient among, literally, billions of conceivable alternatives (see Cherniak *et al.* 2004, Cherniak 2005). The maximization of connection density in the cerebral cortex is even better than in the best industrial micro-chips.

On a different, but converging, front, West, Brown & Enquist (1997, 1999) have shown that the "multiples of 1/4th" power laws that govern the scaling of metabolic activities, membrane fluxes, heart beat, blood circulation lifetime, and life span, from unicellular organisms all the way up to whales, can only be explained by universal fractal laws. Symptomatically, they also used, years before J&L, in their title, the expression "4th dimension of life", explaining that natural selection has exploited variations on this fractal theme to produce the incredible variety of biological form and function. There are genes, of course, but also severe geometric and physical constraints on metabolic processes.

A brief list of discoveries in this fast progressing sector must also include the work by Bejan & Marden (2006) on universal invariants of locomotion. Starting with general principles of physics and engineering, they have shown that the optimal speed and frequency of locomotion (be it walking, swimming, crawling, or flying), for unit of biological energy spent, scales linearly with the size of animals from fruit flies to whales. Other interesting applications of general physical principles to biological functions and structures cover optimal foraging in bees (Dechaume–Moncharmont *et al*. 2005), the neuronal regulation of singing in birds (Trevisan, Mindlin & Goller 2006), and the optimal character of the genetic code. Among thousands of possible alternatives, the genetic code as we know it is optimal for minimizing the effect of frame-shift mutations and minimizing the energy wasted in synthesizing the start of anomalous protein sequences (Itzkovitz & Alon 2007). It is perhaps ungracious to reproach a lacuna to the authors of such a rich and diverse book, but their complete neglect of this entire crucial dimension of evolution (the 4^{th} or 5^{th}, depending on how you count them) deserves to be signaled and lamented. Neglect of this dimension also reverberates negatively onto J&L's treatment of language and evolution.

2. Symbols? Oh, No, Please!

As of Chapter 6, I start to disagree with J&L. They follow a very old script, one that opens up with the appearance of symbolic systems. They duly acknowledge that language is special, with respect to other symbolic communication systems found in animals, essentially because of the subtlety of syntax. That is correct, but there is more to be said. Other crucial differences are to be found already at the level of the lexicon. It's not just syntax that makes human language special, but also the nature of individual words and the way they connect with each other and with the world. There are at least four major differences between words and all non-linguistic symbols: (A) aspectual reference, (B) headedness, (C) internal structure, and (D) edge features. Briefly about each one in turn:

(A) *Buy* and *sell*, *fear* and *frighten*, and a huge variety of such oppositions, in all languages, refer to a same objective, physical, filmable, state of affairs, but have transparently different meanings. The same applies to nouns (*destruction* vs. *demolition*, *gift* versus *theft*) and to adjectives (*thrifty* vs. *stingy*, *abundant* versus *excessive*, and so on). Even apparently innocent words like *city* embody an aspectual component, a point of view. Words refer only under specific itineraries of mental access (a city can be said to be chaotic, polluted, expensive, mostly Victorian, each expression obviously referring to very different objective features; cf. Chomsky 2005). Word meanings are through and through intensional. No symbol used in animal communication systems has this property. Also many non-linguistic symbols used by humans to communicate lack it, unless they are transparently parasitic on language.

(B) 'The California highway commissioner report' is a report. 'The world trade exchange bank' is a bank. 'The spy who came in from the cold' is a spy. The rightmost noun (in English, the leftmost in other languages) heads all nominal compounds. A noun with a determiner (such as *the spy*) heads the Determiner Phrase, even when the DP contains a whole sentence (*who came in from the cold*). Headedness also applies to Verb Phrases (in a more complicated way which need not detain us here; see below). The property of headedness is conserved by the syntactic derivation, from start to finish, and cannot be altered. It's a crucial combinatorial valency of lexical entries, determining the category to which they belong and how the syntactic machinery *must* treat them. There are, of course, many ways to make a certain symbol particularly salient in a string of non-verbal symbols (size, color, etc.), but headedness is unique to words.

(C) Words have a rich internal structure. Thematic roles are probably the most conspicuous such structures. There was *the destruction of Carthage by Scipio*, but there cannot be **the sleep of the bed by Scipio*. Together with headedness, thematic roles are crucial valencies for combination into larger expressions. Morphological domains within words are also central, with relations of dominance and asymmetry. Vast, subtle, and ramified consequences of this internal structures ensue for syntax and semantics (Halle & Marantz 1993, di Sciullo 2005). No other system of non-linguistic symbols has any semblance of such property.

(D) Very simply said, words are "sticky" and so are phrasal constituents obtained by merging two of them, and then merging this compound with other words, again and again, recursively and hierarchically. (The technical term for this intrinsic combinatorial power of words and phrasal constituents in the minimalist program is "edge features"; Chomsky has rightly stressed that the appearance of edge features has been one of the central events in the evolution of language.) Whole linguistic expressions, and sentences in particular, are not lists of words, not even *ordered* lists of words. The point I wish to emphasize here is that words have the intrinsic capacity to project structure "upwards" onto larger compounds. Verbs

> offer the richest case, but not the only one. Verbs project a stratification of "shells" in a fixed hierarchical order, specifying the place where to insert the actants, the auxiliaries, the checking of tense, Case and agreement, and more (ever since the seminal work of Richard Larson — cf. Larson 1988).

All in all, therefore, contrary to spontaneous intuition, contrary to the whole domain of semiotics, and contrary to what Chapter 6 and Chapter 9 of J&L suggest, there is *no gain in our understanding of language* by assimilating it to a system of symbols. Any attempt to reconstruct language evolution as the evolution of a symbolic system leads us badly astray. Words are, of course, in some sense, symbols, and they enter into the system of language, but the unique properties summarized here above make words stand radically apart from all other symbolic systems. J&L, unbeknownst to them, seal this radical separation in the last line of their table on p. 234, when they state that the "range of variation" of symbolic systems is "unlimited". I doubt that they are right even about symbolic systems, but surely this does not apply to language. The range of variation for language is quite severely limited, as J&L sketch in Chapter 8, sort of noncommittally, when speaking of the "principles and parameters" model (Baker 2001, 2003). Symbolic systems are not relevant to language, and they cannot be offered as an intermediate step in language evolution.

3. Culture and Language

J&L embrace a thesis that several other authors also have tried to promote: the shaping of language by culture and history. Their critique of the innatist, modularist, and highly specific nature of language has, as is often the case with those who adopt their position, a possibilistic attitude: Why could we not, one day, explain a lot in language by means of cultural and historical factors, communicative functions, motor control, and general intelligence? This line was offered over 30 years ago already by Jean Piaget to Noam Chomsky, in a direct debate (Piattelli–Palmarini 1980). The answer is today what it was then: No one can exclude this possibility, as a remote possibility. It is, however, eminently rational to expect that it will *not* happen. The task seems even more hopeless today than it seemed 35 years ago, because we know a lot more about language than we did then. For instance, none of the properties of words that I have sketched above can be explained in terms of culture or history, or motor control, or factors of general intelligence.

On p. 218, J&L venture into a minefield, quite similar to the one into which Michael Arbib also ventured in *BBS* recently (Arbib 2005) — a parallel between language and mathematics:

> Although the speed and ease of learning [of language by the child] may indicate that there are some preexisting specifically selected neural mechanisms, the same properties could also be due to a culturally evolved system that is well adapted to the brain, and therefore makes learning easy. For example, think how difficult it was 1200 years ago for someone in Europe to divide one number by another. Say they wanted to divide 3712 by 116 […] *[they point to the impracticality of the Roman numerals — MPP]* Today, with our Arabic notation system (and the useful zero), it would take the average ten-year-old only minutes to get the answer 32.

No genetic change, no brain change, but rather a cultural invention that has become common knowledge. J&L advocate (like Arbib and Deacon and Tomasello) a co-evolution of brain and language and do not advocate a *purely* cultural-evolution explanation of the language capacity. Well, anyway, their analogy with the numerical division is totally irrelevant. No sentence in any language requires "minutes" to be understood by a ten-year-old, or by anyone at any age. Aside from the fact that ten years is a very old age for language, sentences are processed in fractions of seconds, not minutes, today just as they were 1200 years ago, or earlier. Moreover, the number system and the rules for dividing numbers have to be explicitly and painfully taught. No three-year-old child today can make that division, while he or she can well understand quite subtle syntactic constructions, exactly like a child could already in ancient Egypt. The analogy is infelicitous, because language is in a completely different ball-park. Like this one, many analogies and thought-experiments offered by J&L in the domain of language are inconsequential or misleading, unlike those that deal with biology proper.

4. New Biology and Old Reflexes

A most puzzling aspect of this book is that, after having pleaded persuasively for a major expansion of concepts and models in evolutionary theory, J&L fall back onto a basically classic, neo-Darwinian, functionalist explanation of the evolution of language. Just as an example, on p. 339 we read:

> Two related sets of conditions seem to have pushed our ancestors along the route to language. The first was an altered ecological and social environment, which provided a strong and persistent motivation for better communication […]. The second and related set of conditions has to do with anatomy and physiology. […] It was probably the increased motor control over hand movements and vocalizations, and the ability to imitate both gestures and vocal sounds.

They are in excellent and very old company in making these hypotheses, from Darwin himself, to Jean Piaget, Philip Liberman, Steven Pinker, Paul Bloom, Michael Arbib, and Derek Bickerton, just to name a few. Yet, all that we have learned from the new biology, and from this very book, should make any such functionalist hypothesis unnecessary or even suspect. Master regulatory genes with pleiotropic effects, transposons, gene duplications, histone modification, and alternative gene splicing (just to mention a few) offer manifold evolutionary mechanisms that make progressive functional adaptation quite marginal. But J&L insist, venturing into "non-genetic inheritance" to explain how "various features of the emerging language system *that were initially culturally transmitted* were later genetically assimilated" (p. 340, my emphasis). I have no qualm with non-genetic inheritance, amply attested in experiments well explained in their own previous chapters and also endorsed by Cherniak's "non-genomic nativism" (which J&L ignore — see *supra*), but I strongly object to the cultural transmission hypothesis.

Hauser, Chomsky & Fitch (2002) have rightly insisted on the uniqueness of the capacity of humans to acquire a lexicon, and on the presence in humans of

syntactic computational powers that are conspicuously absent in other primates (Fitch & Hauser 2004). Together with the very special properties of words seen above, these are quantum changes in cognitive powers, both qualitatively and quantitatively, impossible to reconstruct by piecemeal functional adaptation. Cultural interactions among humans that are allowed by language presuppose them and cannot explain their gradualistic adaptive origin. The new evolutionary mechanisms presented in this book could have finally dispensed us from exploring again an old dead-end.

The surprising reappearance of old, standard neo-Darwinism is also to be witnessed when J&L criticize the approach promoted by Hauser, Chomsky & Fitch in an already famous (or infamous, for some; cf. Pinker & Jackendoff 2005) paper published in 2002 (Hauser, Chomsky & Fitch 2002). They surprisingly repeat *en passant* the most routine neo-Darwinian objections.

I must also point out that in Chapter 9, J&L choose to tell us the story of the chimp Kanzi and the data collected by Sue Savage–Rumbaugh, allegedly showing important continuity between the symbolic system mastered by apes (after long training) and human language. They fail to even mention the case of the chimpanzee Nim Chimpsky which led to drastically opposite conclusions. After several years of daily cohabitation and of daily sessions of several hours trying to teach Nim American Sign Language, Laura Petitto, Herbert Terrace, and Thomas G. Bever concluded that no real progress had been made. This momentous piece of work (Terrace *et al*. 1979) as well as the papers and book by David Premack (Premack 1972, 1986), that for many of us closed the chapter of the search for animal language, should at least have been presented, if only to criticize them.

5. Language

On the basis of previous work by Eva Jablonka and Daniel Dor, a variant of the co-evolution of brain and language, or rather (very importantly to J&L) language, brain, *and culture* is offered. As usual, in this kind of literature, they indulge in imagining various spiraling interactions between social organization, individual cognition, brain evolution, and language. Michael Arbib has given us his spirals, J&L now give us theirs. The problem, again and again, is that, if you take just any article at random, say, in the journal *Linguistic Inquiry* over the last 20 years or so, and look at the data, just the data (forget about the explanations), there is no hope whatsoever for J&L not only of explaining those data, but even of saying something that is remotely relevant.

While many interesting details are provided about experiments in biology, no specific data are presented in the case of language. Nowhere are we told *how* cultural transmission and the function of communication and general intelligence and motor control *can* have shaped language as we know it. On p. 305 we come as close to a specific hypothesis as their approach allows:

> […] Dror and other linguists have found [that] the grammatical structure of phrases and sentences is associated with the types of concepts the words in sentences embody […]. For example, the grammatical patterns we use depend on whether the participant in an event are active or inactive, on whether an action leads to a change in state of the object or it does not; on

> whether events are factual or hypothesized; on whether things are countable or not countable […] and so on.

J&L then point out, correctly, that "although there are endless ways of classifying things, events, properties, and so on, the categories that are reflected in differences in grammatical patterns are only a small set of all those that we could use".

It's hard to disagree with this. The paucity of syntactic theta-roles, with respect to all the things we are interested in in our life, is one of the central observations in linguistics (the most insightful and influential treatment is Hale & Keyser 1993, 2002). Several deep explanations have been given in generative grammar (theta theory, X-bar theory, the semantics of count ad mass terms, event semantics, the theory of aspect, the theory of telicity, internal structures in lexical semantics, and so on, not to mention the rich theory of concepts and of concept acquisition by the child).

The rub comes next (p. 306):

> What Dror concludes from this is that language is structurally designed to communicate some things better than others. Its design enables it to deal well with messages that are grounded in a rather constrained set of categories having to do with events and situations, their time and place, and the participants in them, *all of which are reflected in grammatical structures* [my emphasis — MPP].

Sorry, but it's not so. Just to take a few signal examples, the sources of objects, the motivations of actions, the banality versus the exceptionality of events — all things we do care a lot about — are *not* reflected in grammatical structures. The endpoint of an action and the culmination of an event are routinely and subtly encoded in syntax, but no syntactic device exists, in any language, to encode the beginning of an action or the initial event. We can talk about them, of course, but no structure in grammar "reflects" them. Grammatical structure is *only* sensitive to actor, patient (or theme, more generally) and in some cases the instrument or the modality of action. Period. *Bottle the wine, shelve the books,* and similar verbs incorporate the instrument or the modality. *Climb, hop, drag, attain* incorporate the path or the telos or the modality of motion. Marginal, but admissible, constructions like *we laughed the bad actor off the scene*, *John smiled the girl into his house*, and similar ones allow to syntactically encode modality or causality. Grammar has no place for more than this. For everything else, we have to go paratactic (use adjunctions, circumlocutions, add further separate sentences, develop a whole discourse, and so on). Grammatical structures do not "reflect" what Dror and J&L want us to believe.

Moreover, in many cases, grammar is a *hindrance* to communication. There are things we would very much like to say, but grammar does not allow us to:

(1) a. *Who was it apparent yesterday that Jay saw?
b. *Who do you wonder how solved the problem?
c. *This is the student who I wonder what bought.

It would be nice to be able to communicate such simple thoughts in such simple ways, but grammar blocks these constructions. Many examples of how different

languages manage to *overcome* these straightjackets of grammar are to be found in (Lightfoot 2000).

Another glaring case is ambiguity, a severe hindrance to communication. Not only grammar cannot resolve it in many cases, but sometimes *forces* it on us. It can do nothing to obviate the ambiguity of sentences like:

(2) To who did you say we should tell the truth?

Is the question about the saying or about truth-telling? Grammar bars the quick insertion of disambiguation. We cannot say either (3a) or (3b):

(3) a. * To who did you say to who we should tell the truth?
b. * To who did you say we should tell the truth to who?

Many other examples are abundant in all languages. The explanation of this impossibility is strictly grammatical, and deep and complex (Rizzi 2004, Folli & Harley 2006). Grammar often clashes with our needs to communicate, and so be it. Communication must bow to grammar, not vice versa. Grammar does not "reflect" the narrow sub-set of thinkables we especially care for. It shapes a further sub-sub-set of these, in ways that are proprietary, letting general thoughts, culture, and history fend for themselves.

6. Summing Up

The prima facie appealing and almost irresistible hypothesis that the need to communicate has shaped the evolution of language is countered by a huge corpus of data collected in many languages and dialects. The deep and complex and detailed (and far from final) explanations advanced for these subtle facts about language in generative grammar (but also, competitively, advanced in neighboring fields such as Head-Driven Phrase Structure Grammar, Lexical Functional Grammar, Tree-Adjoining Grammar, and even, to some extent, Culicover and Jackendoff's "Simpler Syntax") are alien to all conjectures based on cultural transmission, pressures from communicability or general intelligence.

The wonderful developments of the new biology should have suggested that something else can and should be sought. This book, alas, shows that even accurate knowledge of the new biology is not sufficient to urge a radical re-conceptualization of the evolution of language. J&L use their panoply of new evolutionary mechanisms only to try to improve the most canonical hypotheses about language evolution. It remains to be hoped that the readers of this fine exposition of the new biology will use the many eye-openers to be found in it to explore on their own quite different avenues to the evolution of language.

References

Arbib, Michael A. 2005. From monkey-like action recognition to human language: An evolutionary framework for neurolinguistics. *Behavioral and Brain Sciences* 28, 105-167.

Baker, Mark C. 2001. *The Atoms of Language: The Mind's Hidden Rules of Grammar*. New York: Basic Books.

Baker, Mark. C. 2003. Linguistic differences and language design. *Trends in Cognitive Science* 7(8), 349-353.

Bejan, Adrian & James H. Marden. 2006. Unifying constructal theory for scale effects in running, swimming and flying. *The Journal of Experimental Biology* 209, 238-248.

Carroll, Sean B. 2005. *Forms Most Beautiful: The New Science of Evo Devo*. New York: Norton.

Cherniak, Christopher, Zekeria Mokhtarzada, Raul Rodriguez–Esteban & Kelly Changizi. 2004. Global optimization of cerebral cortex layout. *Proceedings National Academy of Sciences* 101, 1081-1086.

Cherniak, Christopher. 2005. Innateness and brain-wiring optimization: Non-genomic nativism. In Antonio Zilhao (ed.), *Cognition, Evolution, and Rationality*, 103-112. London: Routledge.

Chomsky, Noam. 2005. Three factors in language design. *Linguistic Inquiry* 36, 1-22.

Dechaume–Moncharmont, Francois-Xavier, Anna Dornhaus, Alasdair I. Houston, John M. McNamara, Edmund J. Collins & Nigel R. Franks. 2005. The hidden cost of information in collective foraging. *Proceedings of the Royal Society, B: Biological Sciences* 272(1573), 1689-1695.

Di Sciullo, Anna-Maria. 2005 *Asymmetry in Morphology*. Cambridge, MA: MIT Press.

Fitch, W. Tecumseh & Marc D. Hauser. 2004. Computational constraints on syntactic processing in a nonhuman primate. *Science* 303(5656), 377-380.

Folli, Raffaella & Heidi Harley. 2006. What language says about the psychology of events. *Trends in Cognitive Sciences* 10(3), 91-92.

Hale, Ken & Samuel Jay Keyser. 1993. On argument structure and the lexical representation of semantic relations. In Ken Hale & Samuel Jay Keyser (eds.), *The View from Building 20: Essays in Linguistics in Honor of Sylvain Bromberger* (Current Studies in Linguistics 24), 53-110. Cambridge, MA: MIT Press.

Hale, Ken & Samuel Jay Keyser. 2002. *Prolegomenon to a Theory of Argument Structure*. Cambridge, MA: MIT Press.

Halle, Morris & Alec Marantz. 1993. Distributed morphology and the pieces of inflection. In Ken Hale & Samuel Jay Keyser (eds.), *The View from Building 20: Essays in Linguistics in Honor of Sylvain Bromberger* (Current Studies in Linguistics 24), 111-176. Cambridge, MA: MIT Press.

Hauser, Marc D., Noam Chomsky & W. Tecumseh Fitch. 2002. The faculty of language: What it is, who has it, and how did it evolve? *Science* 298, 1569-1579.

Itzkovitz, Shalev & Uri Alon. 2007. The genetic code is nearly optimal for allowing arbitrary additional information within protein-coding sequences. *Genome Research,* doi: 10.1101/gr.5987307.

Kirschner, Marc W. & John C. Gerhart. 2005. *The Plausibility of Life: Resolving Darwin's Dilemma*. New Haven, CT: Yale University Press.

Larson, Richard K. 1988. On the double object construction. *Linguistic Inquiry* 19, 335-391.

Lightfoot, David. 2000. The spandrels of the linguistic genotype. In Chris Knight & Michael Studdert–Kennedy & James C. Hurford (eds.), *The Evolutionary Emergence of Language: Social Function and the Origins of Linguistic Form*, 231-247. Cambridge: Cambridge University Press.

Piattelli–Palmarini, Massimo (ed.). 1980. *Language and Learning: The Debate between Jean Piaget and Noam Chomsky*. Cambridge, MA: Harvard University Press.

Pinker, Steven & Ray Jackendoff. 2005. The faculty of language: What's special about it? *Cognition* 95, 201-236.

Premack, David. 1972. Language in chimpanzees? *Science* 172, 808-822.

Premack, David. 1986. *Gavagai! or the Future History of the Animal Language Controversy* (Learning, Development, and Conceptual Change). Cambridge, MA: MIT Press.

Rizzi, Luigi. 2004. On the study of the language faculty: Results, developments and perspectives. *The Linguistic Review* 21(3-4), 323-344.

Terrace, Herbert S., Laura-Ann Petitto, R.J. Sanders & Thomas G. Bever. 1979. Can an ape create a sentence? *Science* 206, 891-902.

Thompson, D'Arcy Wentworth. 1917/1992. *On Growth and Form* [abridged edn., prepared by John Tyler Bonner]. Cambridge: Cambridge University Press.

Trevisan, Marcos A., Gabriel B. Mindlin & Franz Goller. 2006. Nonlinear model predicts diverse respiratory patterns of birdsongs. *Physical Review Letters 96* (10 January 2006), 058103-058101-058104.

Turing, Alan M. 1952. The chemical bases of morphogenesis. *Philosophical Transactions of the Royal Society* B 237, 37-72. [Reprinted in Turing, Alan M. 1992. *Morphogenesis*. Amsterdam: North Holland.]

West, Geoffrey B., James H. Brown & Brian J. Enquist. 1997. A general model for the allometric scaling laws in biology. *Science* 276, 122-126.

West, Geoffrey B., James H. Brown & Brian J. Enquist. 1999. The fourth dimension of life: Fractal geometry and allometric scaling of organisms. *Science* 284, 1677-1679.

Massimo Piattelli–Palmarini
University of Arizona
Department of Cognitive Science
& Department of Linguistics
& Department of Psychology
P.O. Box 210028
Tucson, AZ 85721
USA
massimo@u.arizona.edu