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Natural language and natural selection

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Abstract: Many people have argued that the evolution of the human language faculty cannot be explained by Darwinian natural selection. Chomsky and Gould have suggested that language may have evolved as the by-product of selection for other abilities or as a consequence of as-yet unknown laws of growth and form. Others have argued that a biological specialization for grammar is incompatible with every tenet of Darwinian theory – that it shows no genetic variation, could not exist in any intermediate forms, confers no selective advantage, and would require more evolutionary time and genomic space than is available. We examine these arguments and show that they depend on inaccurate assumptions about biology or language or both. Evolutionary theory offers clear criteria for when a trait should be attributed to natural selection: complex design for some function, and the absence of alternative processes capable of explaining such complexity. Human language meets these criteria: Grammar is a complex mechanism tailored to the transmission of propositional structures through a serial interface. Autonomous and arbitrary grammatical phenomena have been offered as counterexamples to the position that language is an adaptation, but this reasoning is unsound: Communication protocols depend on arbitrary conventions that are adaptive as long as they are shared. Consequently, language acquisition in the child should systematically differ from language evolution in the species, and attempts to analogize them are misleading. Reviewing other arguments and data, we conclude that there is every reason to believe that a specialization for grammar evolved by a conventional neo-Darwinian process.

Keywords: biology of language; evolution; grammatical theory; language; language acquisition; language universals; natural selection; origin of language; psycholinguistics

> Language could not have begun in the form it was said to have taken in the first recorded utterance of Thomas Babbington Macaulay (the infant Lord Macaulay): Once when he was taken out, his hostess accidently spilled hot tea on him. The little lad first bawled his head off, but when he had calmed he said in answer to his hostess' concern, "Thank you, Madam, the agony is sensibly abated."
> — P. B. and J. S. Medawar

1. Introduction

All human societies have language. As far as we know, they always did; language was not invented by some groups and spread to others like agriculture or the alphabet. All languages are complex computational systems using the same basic kinds of rules and representations, with no notable correlation with technological progress: The grammars of industrial societies are no more complex than the grammars of hunter-gatherers; Modern English is not an advance over Old English. Within societies, individual humans are proficient language users regardless of intelligence, social status, or level of education. Children are fluent speakers of complex grammatical sentences by the age of three, without benefit of formal instruction. They are capable of inventing languages that are more systematic than those they hear, showing resemblances to languages that they have never heard, and they obey subtle grammatical principles for which there is no evidence in their environments. Disease or injury can make people linguistic savants while severely retarded, or linguistically impaired with normal intelligence. Some language disorders are genetically transmitted. Aspects of language skill can be linked to characteristic regions of the human brain. The human vocal tract is tailored to the demands of speech, compromising other functions such as breathing and swallowing. Human auditory perception shows complementary specializations toward the demands of decoding speech sounds into linguistic segments.

This list of facts (see also Pinker 1989a) suggests that the ability to use a natural language belongs more to the study of human biology than human culture; it is a topic like echolocation in bats or stereopsis in monkeys, not like writing or the wheel. All modern students of language agree that at least some aspects of language are due to species-specific, task-specific biological abilities, though of course there are radical disagreements about specifics. A prominent position, outlined by Chomsky (1965; 1980a; 1981; 1986; 1988a), Fodor (1983), Lenneberg (1964;

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1967), and Liberman (Liberman et al. 1967; Liberman & Mattingly 1989), is that the mind is composed of autonomous computational modules – mental faculties or "organs" – and that the acquisition and representation of language is the product of several such specialized modules.

It would be natural, then, to expect everyone to agree that human language is the product of Darwinian natural selection. The only successful account of the origin of complex biological structure is the theory of natural selection, the view that the differential reproductive success associated with heritable variation is the primary organizing force in the evolution of organisms (Darwin 1859; see Bendall 1983 for a contemporary perspective). But, surprisingly, this conclusion is controversial. Noam Chomsky, the world's best-known linguist, and Stephen Jay Gould, the world's best-known evolutionary theorist, have repeatedly suggested that language may not be the product of natural selection, but a side effect of other evolutionary forces such as an increase in overall brain size and constraints of as yet unknown laws of structure and growth (e.g., Chomsky 1972; 1982a; 1982b; 1988a; 1988b; Gould 1987a; Gould & Piattelli-Palmarini 1987). Recently, Massimo Piattelli-Palmarini (1989), a close correspondent with Gould and Chomsky, has done the field a service by formulating a particularly strong version of their positions and articulating it in print. Premack (1985; 1986) and Mehler (1985) have expressed similar views.

In this target article, we will examine this position in detail and will come to a very different conclusion. We will argue that there is every reason to believe that language has been shaped by natural selection as it is understood within the orthodox "synthetic" or "neo-Darwinian" theory of evolution (Mayr 1982). In one sense our goal is incredibly boring. All we argue is that language is no different from other complex abilities such as echolocation or stereopsis, and that the only way to explain the origin of such abilities is through the theory of natural selection. One might expect our conclusion to be accepted without much comment by all but the most environmentalist of language scientists, as indeed it is by such researchers as Bickerton 1981, Liberman & Mattingly 1989, Lieberman 1984, and, in limited respects, by Chomsky himself in some strands of his writings.[1] On the other hand, when two such important scholars as Chomsky and Gould repeatedly urge us to consider a startling contrary position, their arguments can hardly be ignored. Indeed, these arguments have had a strong effect on many cognitive scientists, and the nonselectionist view has become the consensus in many circles.

Furthermore, a lot is at stake if our boring conclusion is wrong. We suspect that many biologists would be surprised at the frequent suggestion that the complexity of language cannot be explained through natural selection. For example, Chomsky has made the following statements:

> [An innate language faculty] poses a problem for the biologist, since, if true, it is an example of true 'emergence' – the appearance of a qualitatively different phenomenon at a specific stage of complexity of organization (1972, p. 70).
>
> It is perfectly safe to attribute this development [of innate mental structure] to "natural selection," so long as we realize that there is no substance to this assertion, that it amounts to nothing more than a belief that there is some naturalistic explanation for these phenomena (1972, p. 97).
>
> Evolutionary theory is informative about many things, but it has little to say, as of now, of questions of this nature [e.g., the evolution of language]. The answers may well lie not so much in the theory of natural selection as in molecular biology, in the study of what kinds of physical systems can develop under the conditions of life on earth and why, ultimately because of physical principles (1988a, p. 167).
>
> It does seem very hard to believe that the specific character of organisms can be accounted for purely in terms of random mutation and selectional controls. I would imagine that the biology of a 100 years from now is going to deal with the evolution of organisms the way it now deals with the evolution of amino acids, assuming that there is just a fairly small space of physically possible systems that can realize complicated structures. . . . Evolutionary theory appears to have very little to say about speciation, or about any kind of innovation. It can explain how you get a different distribution of qualities that are already present, but it does not say much about how new qualities can emerge (1982a, p. 23).

If findings coming out of the study of language forced biologists to such conclusions, it would be big news.

There is another reason to scrutinize the nonselectionist theory of language. If a current theory of language is truly incompatible with the neo-Darwinian theory of evolution, one could hardly blame someone for concluding that it is not the theory of evolution that must be questioned, but the theory of language. Indeed, this argument has been the basis of critiques of Chomsky's theories by Bates et al. (1989), Greenfield (1987), and Lieberman (1984; 1989a), who are nonetheless strange bedfellows with Chomsky in doubting whether an innate generative grammar could have evolved by natural selection. Because we are impressed both by the synthetic theory of evolution and by the theory of generative grammar, we hope that we will not have to choose between the two.

In this article, we first examine arguments from evolutionary biology about when it is appropriate to invoke natural selection as an explanation for the evolution of some trait. We then apply these tests to the case of human language, and conclude that language passes. We examine the motivations for the competing nonselectionist position and suggest that they have little to recommend them. In the final section, we refute the arguments that have claimed that an innate specialization for grammar is incompatible with the tenets of a Darwinian account and thus that the two are incompatible.

2. The role of natural selection in evolutionary theory

Gould has frequently suggested that evolutionary theory is in the throes of a scientific revolution (e.g., Eldredge & Gould 1972; Gould 1980). Two cornerstones of the Darwinian synthesis, adaptationism and gradualism, are, he argues, under challenge. Obviously, if strict Darwinism is false in general it should not be used to explain the origin of language.

2.1. Nonselectionist mechanisms of evolutionary change

In a classic paper, Gould and Lewontin (1979) warn against "naive adaptationism," the inappropriate use of adaptive theorizing to explain traits that have emerged for other reasons (see also Kitcher 1985a; Lewontin 1978). The argument is illustrated by an analogy with the mosaics on the dome and spandrels of the San Marco basilica in Venice:

> Spandrels – the tapering triangular spaces formed by the intersection of two rounded arches at right angles . . . are necessary architectural by-products of mounting a dome on rounded arches. Each spandrel contains a design admirably fitted into its tapering space. An evangelist sits in the upper part flanked by the heavenly cities. Below, a man representing one of the four biblical rivers . . . pours water from a pitcher in the narrowing space below his feet.
>
> The design is so elaborate, harmonious, and purposeful that we are tempted to view it as the starting point of any analysis, as the cause in some sense of the surrounding architecture. But this would invert the proper path of analysis. The system begins with an architectural constraint: the necessary four spandrels and their tapering triangular form. They provide a space in which the mosaicists worked; they set the quadripartite symmetry of the dome above.
>
> Such architectural constraints abound, and we find them easy to understand because we do not impose our biological biases upon them. . . . Anyone who tried to argue that the structure [spandrels] exists because of [the designs laid upon them] would be inviting the same ridicule that Voltaire heaped on Dr. Pangloss: "Things cannot be other than they are . . . Everything is made for the best purpose. Our noses were made to carry spectacles, so we have spectacles. Legs were clearly intended for breeches, and we wear them." . . . Yet evolutionary biologists, in their tendency to focus exclusively on immediate adaptation to local conditions, do tend to ignore architectural constraints and perform just such an inversion of explanation (pp. 147–49).

Unconvincing adaptationist explanations, which Gould and Lewontin compare to Kipling's "Just-so stories," are easy to find. In the Science and Technology section of the Boston Globe in March 1987, an article noted that the number of teats in different mammals ought to correspond not to the average litter size but to the largest litter size that can occur for that species within some bound of probability. Because humans ordinarily bear single children but not infrequently have twins, we have an explanation for why humans have two breasts, not one. The author did not discuss the possibility that the bilateral symmetry that is so basic to the mammalian body plan makes the appearance of one-breasted humans rather unlikely.

Gould and Lewontin describe a number of nonadaptationist mechanisms that they feel are frequently not tested in evolutionary accounts: genetic drift, laws of growth and form (such as general allometric relations between brain and body size), direct induction of form by environmental forces such as water currents or gravity, the effects of accidents of history (which may trap organisms in local maxima in the adaptive landscape), and "exaptation" (Gould & Vrba 1982), whereby new uses are made of parts that were originally adapted to some other function or of spandrels that had no function at all but were present for reasons of architecture, development, or history. They point out that Darwin himself had this pluralistic view of evolution, and that there was an "unfairly maligned" nonadaptationist approach to evolution, prominent in continental Europe, that stressed constraints on "Baupläne" (architectural plans) flowing from phyletic history and embryological development. This body of research, they suggest, is an antidote to the tendency to treat an organism as a bundle of traits or parts, each independently shaped by natural selection.

2.2. Limitations on nonselectionist explanations

The Gould and Lewontin argument could be interpreted as stressing that because the neo-Darwinian theory of evolution includes nonadaptationist processes, it is bad scientific practice not to test them as alternatives to natural selection in any particular instance. However, they are often read as having outlined a radical new alternative to Darwin, in which natural selection is relegated to a minor role. Though Gould and Lewontin clearly eschew this view in their paper, Gould has made such suggestions subsequently (e.g., Gould 1980), and Piattelli-Palmarini (1989, p. 1) has interpreted it as such when he talks of Darwinian natural selection being replaced by "a better evolutionary theory (one based on 'exaptation')." The reasons why we should reject this view were spelled out clearly by Williams (1966), and have been amplified recently by Dawkins (1983; 1986).

The key point that blunts the Gould and Lewontin critique of adaptationism is that *natural selection is the only scientific explanation of adaptive complexity.* "Adaptive complexity" describes any system composed of many interacting parts where the details of the parts' structure and arrangement suggest design to fulfill some function. The vertebrate eye is the classic example. The eye has a transparent refracting outer cover, a variable-focus lens, a light-sensitive layer of neural tissue lying at the focal plane of the lens, a diaphragm whose diameter changes with illumination level, muscles that move it in precise conjunction and convergence with those of the other eye, and elaborate neural circuits that respond to patterns defining edges, colors, motion, and stereoscopic disparity. It is impossible to make sense of the structure of the eye without noting that it appears as if it were designed for the purpose of seeing – if for no other reason than that the man-made tool for image formation, the camera, displays an uncanny resemblance to the eye. Before Darwin, theologians, notably William Paley, pointed to the eye's exquisite design as evidence for the existence of a divine designer. Darwin showed how such "organs of extreme perfection and complication" could arise from the purely physical process of natural selection.

The essential point is that no physical process other than natural selection can explain the evolution of an organ like the eye. The reason for this is that structures that can do what the eye does are extremely low-probability arrangements of matter. By an unimaginably large margin, most objects defined by the space of biologically possible arrangements of matter cannot bring an image into focus, modulate the amount of incoming light, respond to the presence of edges and depth boundaries, and so on. The odds that genetic drift, say, would result in the fixation within a population of just those genes that would give rise to such an object are infinitesimally small, and such an event would be virtually a miracle. This is also true of the other nonselectionist mechanisms outlined by Gould and Lewontin. It is absurdly improbable that some general law of growth and form could give rise to a functioning vertebrate eye as a byproduct of some other trend such as an increase in size of some other part. Likewise, one need not consider the possibility that some organ that arose as an adaptation to some other task, or a spandrel defined by other body parts, just happened to have a transparent lens surrounded by a movable diaphragm in front of a light-sensitive layer of tissue lying at its focal plane. Natural selection – the retention across generations of whatever small, random modifications yield improvements in vision that increase chances of survival and reproduction – is the only physical process capable of creating a functioning eye, because it is the only physical process in which the criterion of being good at seeing can play a causal role. As such, it is the only process that can lead organisms along the path in the astronomically vast space of possible bodies leading from a body with no eye to a body with a functioning eye.

This argument is obviously incomplete, as it relies on the somewhat intuitive notion of "function" and "design." A skeptic might accuse the proponent of circularity, asking why a lump of clay should not be considered well designed to fulfill the function of taking up exactly the region of space that it in fact takes up. But the circle can be broken in at least three ways. First, biologists need posit far fewer functions than there are biological systems; new functions are not invented for each organ of each organism. Furthermore, each legitimate function can be related via a direct plausible causal chain to other functions and – critically – to the overall function of survival and reproduction. Finally, convergent evolution and resemblance to human artifacts fulfilling the same putative function give independent criteria for design. But regardless of the precise formulation of the modern argument from design (see, e.g., Cummins 1984), it is not controversial in practice. Gould himself readily admits that natural selection is the cause of structures such as the vertebrate eye, and he invokes the criterion of engineering design, for example, to rescue Darwinism itself from the charge of circularity (Gould 1977a). Presumably, this is why Gould and Lewontin concede that they agree with Darwin that natural selection is "the most important of evolutionary mechanisms."

What, then, is the proper relation between selectionist and nonselectionist explanations in evolution? The least interesting case involves spandrels that are not involved in any function or behavior, such as the redness of blood, the V-shaped space between a pair of fingers, the hollow at the back of a knee, the fact there are a prime number of digits on each limb, and so on. The mere presence of these *epiphenomenal spandrels*, that play no direct role in the explanation of any species-typical behavior or function, says nothing about whether the structures that they are associated with were shaped by selection. There are as many of them as there are ways of describing an organism that do not correspond to its functional parts.

Much more important are cases where spandrels are modified and put to use. However, in such cases of *modified spandrels*, selection plays a crucial role. Putting a dome on top of four arches gives you a spandrel, but it does not give you a mosaic depicting an evangelist and a man pouring water out of a pitcher. That would *really* be a miracle. To get the actual mosaic you need a designer. The designer corresponds to natural selection. Spandrels, exaptations, laws of growth, and so on can explain the basic plans, parts, and materials that natural selection works with – as Jacob (1977) put it, nature is a tinkerer, not an engineer with a clean drawing board. The best examples of structures produced entirely by nonadaptationist mechanisms are generally one-part or repetitive shapes or processes that correspond to simple physical or geometric laws, such as chins, hexagonal honeycombs, large heads on large bodies, and spiral markings. But, as Darwin stressed, when such parts and patterns are modified and combined into complex biological machines fulfilling some delicate function, these subsequent modifications and arrangements must be explained by natural selection.

The real case of evolution without selection consists of the use of *unmodified spandrels*. Gould (1987a) describes a kind of wading bird that uses its wings primarily to block reflections on the surface of water while looking for fish. The possibility that some useful structure is an unmodified spandrel is the most interesting implication of the Gould-Lewontin argument, because Darwinian natural selection would really play no role. Note, though, that unmodified spandrels have severe limitations. A wing used as a visor is a case where a structure designed for a complex engineering task that most arrangements of matter do not fulfill, such as controlled flight, is exapted to a simple engineering task that many arrangements of matter do fulfill, such as screening out reflections (we are reminded of the paperweight and aquarium depicted in *101 Uses for a Dead Computer*). When the reverse happens, such as when a solar heat exchanger is retooled as a fully functioning wing in the evolution of insects (Kingsolver & Koehl 1985), natural selection must be the cause.

We are going over these criteria for invoking natural selection in such detail because they are so often misunderstood. We hope we have made it clear why modern evolutionary biology does *not* license Piattelli-Palmarini's conclusion that "since language and cognition probably represent the most salient and the most novel biological traits of our species, . . . it is now important to show that they may well have arisen from totally extra-adaptive mechanisms." And Piattelli-Palmarini is not alone. In many discussions with cognitive scientists, we have found that adaptation and natural selection have become dirty words. Anyone invoking them is accused of being a naive adaptationist, or even of "misunderstanding evolution."

Worst of all, such a person is open to easy ridicule as a Dr. Pangloss telling Just-so stories! (Premack's 1986 reply to Bickerton, 1986, is typical.) Given the uncontroversially central role of natural selection in evolution, this state of affairs is unfortunate. We suspect that many people have acquired much of their knowledge of evolutionary theory from Gould's deservedly popular essays. These essays present a view of evolution that is vastly more sophisticated than the nineteenth-century versions of Darwin commonly taught in high schools and even colleges. But Gould can easily be misread as fomenting a revolution rather than urging greater balance within current biological research, and his essays do not emphasize the standard arguments for when it is appropriate, indeed necessary, to invoke natural selection.

Also lurking beneath people's suspicions of natural selection is a set of methodological worries. Isn't adaptationism fundamentally untestable, hence unscientific, because adaptive stories are so easy to come by that when one fails, another can always be substituted? Gould and Lewontin may be right in saying that biologists and psychologists have leapt too quickly to unmotivated and implausible adaptationist explanations, but this has nothing to do with the logic of adaptationist explanations per se. Glib, unmotivated proposals can come from all kinds of theories. To take an example close to home, the study of the evolution of language attained its poor reputation precisely because of the large number of silly *non*adaptationist hypotheses that were proposed. For instance, it has been argued that language arose from mimicry of animal calls, imitations of physical sounds, or grunts of exertion (the infamous "bow-wow," "ding-dong," and "heave-ho" theories).

Specific adaptationist proposals are testable in principle and in practice (see Dennett 1983; Kitcher 1985a; Maynard Smith 1984; Mayr 1982; Sober 1984; Williams 1966.) Supplementing the criterion of complex design, one can determine whether putatively adaptive structures are correlated with the ecological conditions that make them useful, and, under certain circumstances, one can actually measure the reproductive success of individuals possessing them to various degrees (see, e.g., Clutton-Brock 1983). Of course, the entire theory of natural selection may be literally unfalsifiable in the uninteresting sense that elaborations can always rescue its empirical failings, but this is true of all large-scale scientific theories. Any such theory is supported to the extent that the individual elaborations are mutually consistent, motivated by independent data, and few in number compared to the phenomena to be explained.[2]

Indeed, one could argue that it is nonadaptationist accounts that are often in grave danger of vacuity. Specific adaptationist proposals may be unmotivated, but they are within the realm of biological and physical understanding, and often the problem is simply that we lack the evidence to determine which account within a set of alternative adaptive explanations is the correct one. Nonadaptationist accounts that merely suggest the possibility that there is some hitherto-unknown law of physics or constraint on form – a "law of eye-formation," to take a caricatured example –are, in contrast, empty and nonfalsifiable.

2.3. Two issues that are independent of selectionism

There are two other issues that Gould includes in his depiction of a scientific revolution in evolutionary theory. It is important to see that they are largely independent of the role of selection in evolutionary change.

2.3.1. Gradualism. According to the theory of "punctuated equilibrium" (Eldredge & Gould 1972; Gould & Eldredge 1977), most evolutionary change does not occur continuously within a lineage, but is confined to bursts of change that are relatively brief on the geological time scale, generally corresponding to speciation events, followed by long periods of stasis. Gould has suggested that the theory has some very general and crude parallels with approaches to evolution that were made disreputable by the neo-Darwinian synthesis, approaches that go by the names of "saltationism," "macromutations," or "hopeful monsters." (e.g., Gould 1981). He is emphatic, however, that punctuated equilibrium is "a theory about ordinary speciation (taking tens of thousands of years) and its abrupt appearance at low scales of geological resolution, not about ecological catastrophe and sudden genetic change" (Gould 1987b, p. 234). Many other biologists see evolutionary change in an even more orthodox light. They attribute the sudden appearance of fully formed new kinds of organisms in the fossil record to the fact that speciation typically takes place in small, geographically isolated populations. Therefore, transitional forms, even if evolving over very long time spans, are unlikely to appear in the fossil record until they reinvade the ancestral territory; it is only the invasion that is sudden (see, e.g., Ayala 1983; Dawkins 1986; Mayr 1982; Stebbins & Ayala 1981). In any case, it is clear that evolutionary change is gradual from generation to generation, in full agreement with Darwin. Thus, Piattelli-Palmarini (1989, p. 8) expresses a common misunderstanding when he interprets the theory of punctuated equilibrium as showing that "many incomplete series in the fossil record are incomplete, not because the intermediate forms have been lost *for* us, but because they simply never existed."

Once again, the explanation of adaptive complexity is the key reason one should reject nongradual change as playing an important role in evolution. An important Darwinian insight, reinforced by Fisher (1930), is that the only way for complex design to evolve is through a sequence of mutations with small effects. Although it may not literally be impossible for an organ like the eye to emerge across one generation from no eye at all, the odds of this happening are unimaginably low. A random large leap in the space of possible organic forms is astronomically unlikely to land an organism into a region with a fully formed functioning eye. Only a hill-climbing process, with each small step forced in the direction of forms with better vision, can guide the lineage to such a minuscule region of the space of possible forms within the lifetime of the universe.

None of this is to deny that embryological processes can result in quite radical single-generation morphological changes. "Homeotic" mutations causing slight changes in the timing or positioning of epigenetic processes can result in radically new kinds of offspring, such as fruit flies with legs growing where their antenna should be, and it is possible that some speciation events may have begun with such large changes in structure. There is a clear sense, however, in which such changes are still gradual, because they only involve a gross modification or duplication of existing structure, not the appearance of a new kind of structure (see Dawkins 1983).

2.3.2. Exaptation. Exaptation is another process that is sometimes discussed as if it were incompatible both with adaptationism and with gradualism. People often wonder whether each of the "numerous, successive, slight modifications" from an ancestor lacking an organ to a modern creature enjoying the fully functioning organ leads to an improvement in the function, as if it should if the necessary evolutionary sequence is to be complete. Piattelli-Palmarini cites Kingsolver and Koehl's (1985) study of qualitative shifts during the evolution in insects of wings that are ineffective for flight below a certain size but effective as solar heat exchange panels precisely within that range. (The homologies among parts of bat wings, seal flippers, horse forelimbs, and human arms are a far older example.) Nevertheless, such exaptations are still gradual and are still driven by selection; there must be an intermediate evolutionary stage at which the part can subserve both functions (Mayr 1982), after which the process of natural selection shapes it specifically for its current function. Indeed, the very concept of exaptation is similar to what Darwin called "preadaptation," which played an important role in his explanation of "the incipient stages of useful structures."

Furthermore, it is crucial to understand that exaptation is merely one empirical possibility, not a universal law of evolution. Gould is often quoted as saying "We avoid the excellent question, What good is 5 percent of an eye? by arguing that the possessor of such an incipient structure did not use it for sight" (1977b, p. 107). (Of course, no ancestor to humans literally had 5 percent of a human eye; the expression refers to an eye that has 5 percent of complexity of a modern eye.) In response, Dawkins (1986, p. 81) writes: "An ancient animal with 5 percent of an eye might indeed have used it for something other than sight, but it seems to me at least as likely that it used it for 5 percent vision. . . . Vision that is 5 percent as good as yours or mine is very much worth having in comparison with no vision at all. So is 1 percent vision better than total blindness. And 6 percent is better than 5, 7 percent better than 6, and so on up the gradual, continuous series." Indeed, Darwin (1859) sketched out a hypothetical sequence of intermediate forms in the evolution of the vertebrate eye, all with counterparts in living organisms, each used for vision.

In sum, the positions of Gould, Lewontin, and Eldredge should not be seen as radical revisions of the theory of evolution, but as a shift in emphasis within the orthodox neo-Darwinian framework. As such they do not invalidate gradual natural selection as the driving force behind the evolution of language on a priori grounds. Furthermore, there are clear criteria for when selectionist and nonselectionist accounts should be invoked to explain some biological structure: complex design to carry out some reproductively significant function, versus the existence of a specific physical, developmental, or random process capable of explaining the structure's existence. With these criteria in hand, we can turn to the specific problem at hand: the evolution of language.

3. Design in language

Do the cognitive mechanisms underlying language show signs of design for some function in the same way that the anatomical structures of the eye show signs of design for the purpose of vision? What are the engineering demands on a system that must carry out such a function? And are the mechanisms of language tailored to meet those demands? We will suggest that language shows signs of design for the communication of propositional structures over a serial channel.

3.1. An argument for design in language

Humans acquire a great deal of information during their lifetimes. Because this acquisition process occurs at a rate far exceeding that of biological evolution, it is invaluable in dealing with causal contingencies of the environment that change within a lifetime, and provides a decisive advantage in competition with other species that can only defend themselves against new threats in evolutionary time (Brandon & Hornstein 1986; Tooby & deVore 1987). There is an obvious advantage in being able to acquire such information about the world second-hand: By tapping into the vast reservoir of knowledge accumulated by some other individual, one can avoid having to duplicate the possibly time-consuming and dangerous trial-and-error process that won that knowledge. Furthermore, within a group of interdependent, cooperating individuals, the states of other individuals are among the most significant things in the world worth knowing about. Therefore, communication of knowledge and internal states is useful to creatures who have a lot to say and who are on speaking terms. (In section 5.3, we discuss evidence that our ancestors were such creatures.)

Human knowledge and reasoning, it has been argued, is couched in a "language of thought" that is distinct from external languages such as English or Japanese (Fodor 1975). The propositions in this representational medium are relational structures whose symbols pertain to people, objects, and events, the categories they belong to, their distribution in space and time, and their causal relations to one another (Jackendoff 1983; Keil 1979). The causal relations governing the behavior of other people are understood as involving their beliefs and desires, which can be reconsidered as relations between an individual and the proposition that represents the content of that belief or desire (Fodor 1975; 1987).

This makes the following kinds of contents worthy of communication among humans. We would want to be able to refer to individuals and classes, to distinguish among basic ontological categories (things, events, places, times, manners, and so on), to talk about events and states, distinguishing the participants in the event or state according to role (agents, patients, goals), and to talk about the intentional states of ourselves and others. Also, we would want the ability to express distinctions of truth value, modality (necessity, possibility, probability, factivity), to comment on the time of an event or state, including both its distribution over time (continuous, iterative, punctate) and its overall time of occurrence. One might also demand the ability to encode an unlimited number of predicates, arguments, and propositions. In addition, it would be useful to be able to use the same propositional content within different speech acts; for instance, as a question, a statement, or a command. Superimposed on all of this we might ask for an ability to focus or to put into the background different parts of a proposition, so as to tie the speech act into its context of previously conveyed information and patterns of knowledge of the listener.

The vocal-auditory channel has some desirable features as a medium of communication: It has a high bandwidth, its intensity can be modulated to conceal the speaker or to cover large distances, and it does not require light, proximity, a face-to-face orientation, or tying up of the hands. It is essentially a serial interface, however, lacking the full two-dimensionality needed to convey graph or tree structures and typographical devices such as fonts, subscripts, and brackets. The basic tools of a coding scheme using such a channel are an inventory of distinguishable symbols and their concatenation.

Thus, grammars for spoken languages must map propositional structures onto a serial channel, minimizing ambiguity in context, under the further constraints that the encoding and decoding be done rapidly, by creatures with limited short-term memories, according to a code that is shared by an entire community of potential communicants.

The fact that language is a complex system of many parts, each tailored to mapping a characteristic kind of semantic or pragmatic function onto a characteristic kind of symbol sequence, is so obvious in linguistic practice that it is usually not seen as worth mentioning. Let us list some uncontroversial facts about substantive universals, the building blocks of grammars that all theories of universal grammar posit, either as an explicit inventory or as a consequence of somewhat more abstract mechanisms.

Grammars are built around symbols for *major lexical categories* (noun, verb, adjective, preposition) that can enter into rules specifying telltale surface distributions (e.g., verbs but not nouns generally take unmarked direct objects), inflections, and lists of lexical items. Together with *minor categories* that characteristically co-occur with the major ones (e.g., articles with nouns), the different categories are thus provided with the means of being distinguished in the speech string. These distinctions are exploited to distinguish basic ontological categories such as things, events or states, and qualities (see, e.g., Jackendoff 1983; 1990).

Major phrasal categories (noun phrase, verb phrase, and so forth) start off with a major lexical item, the "head," and allow it to be combined with specific kinds of affixes and phrases. The resulting conglomerate is then used to refer to entities in our mental models of the world. Thus, a noun like *dog* does not itself describe anything but it can combine with articles and other parts of speech to make noun phrases, such as *those dogs*, *my dog*, and *the dog that bit me*, and it is these noun phrases that are used to describe things. Similarly, a verb like *hit* is made into a verb phrase by marking it for tense and aspect and adding an object, thus enabling it to describe an event. In general, words encode abstract general categories and only by contributing to the structure of major phrasal categories can they describe particular things, events, states, locations, and properties. This mechanism enables the language user to refer to an unlimited range of specific entities while possessing only a finite number of lexical items (see, e.g., Bloom 1989; Jackendoff 1977).

Phrase structure rules (e.g., "X-bar theory" or "immediate dominance rules") force concatenation in the string to correspond to semantic connectedness in the underlying proposition, and thus provide linear cues of underlying structure, distinguishing, for example, *Large trees grow dark berries* from *Dark trees grow large berries* (see, e.g., Gazdar et al. 1985; Jackendoff 1977.)

Rules of *linear order* (e.g., "directional parameters" ordering heads, complements, and specifiers, or "linear precedence rules") allow the order of words within these concatenations to distinguish among the argument positions that an entity assumes with respect to a predicate, distinguishing *Man bites dog* from *Dog bites man* (see Gazdar et al. 1985; Travis 1984).

Case affixes on nouns and adjectives can take over these functions, marking nouns according to argument role and linking noun with predicate even when the order is scrambled. This redundancy can free up the device of linear order, allowing it to be exploited to convey relations of prominence and focus, which can thus mesh with the necessarily temporal flow of attention and knowledge acquisition in the listener.

Verb affixes signal the temporal distribution of the event that the verb refers to (aspect) and the time of the event (tense); when separate aspect and tense affixes co-occur, they are in a universally preferred order (aspect closer to the verb; Bybee 1985). Given that man-made timekeeping devices play no role in species-typical human thought, some other kind of temporal coordinates must be used, and languages use an ingenious system that can convey the time of an event relative to the time of the speech act itself and relative to a third, arbitrary reference time (thus, we can distinguish between *John has arrived*, *John had arrived* (*when Mary was speaking*), *John will have arrived* (*before Mary speaks*), and so on; Reichenbach 1947). Verb affixes also typically agree with the subject and other arguments, and thus provide another redundant mechanism that can convey predicate-argument relations by itself (e.g., in many Native American languages such as Cherokee and Navajo) or that can eliminate ambiguity left open by other mechanisms (distinguishing, e.g., *I know the boy and the girl who like chocolate* from *I know the boy and the girl who likes chocolate*).

Auxiliaries, which occur either as verb affixes (where they are distinguished from tense and aspect affixes by proximity to the verb) or in one of three sentence-peripheral positions (first, second, last), convey relations that have logical scope over the entire proposition (mirroring their peripheral position) such as truth value, modality, and illocutionary force (see Steele et al. 1981).

Languages also typically contain a small inventory of phonetically reducible morphemes – *pronouns* and other *anaphoric elements* – that by virtue of encoding a small set of semantic features such as gender and humanness, and being restricted in their distribution, can convey patterns of coreference among different participants in complex relations without the necessity of repeating lengthy definite descriptions (e.g., as in *A boy showed a dog to a girl and then he/she/it touched him/her/it/herself*). (See Chomsky 1981; Wexler & Manzini 1984.)

Mechanisms of *complementation* and *control* govern the expression of propositions that are arguments of other propositions, using specific complementizer morphemes signaling the periphery of the embedded proposition and indicating its relation to the embedding one, and licensing the omission of repeated phrases referring to participants playing certain combinations of roles. This allows the expression of a rich set of propositional attitudes within a belief-desire folk psychology, such as *John tried to come, John thinks that Bill will come, John hopes for Bill to come, John convinced Bill to come*, and so on. (See Bresnan 1982).

In *wh*-movement (as in *wh*-questions and relative clauses) there is a tightly constrained co-occurrence pattern between an empty element (a "trace" or "gap") and a sentence-peripheral quantifier (e.g., *wh*-words). The quantifier-word can be specific as to illocutionary force (question versus modification), ontological type (time, place, purpose), feature (animate/inanimate), and role (subject/object), and the gap can occur only in highly constrained phrase structure configurations. The semantics of such constructions allow the speaker to fix the reference of, or request information about, an entity by specifying its role within any proposition. One can refer not just to any dog but to *the dog that Mary sold ____ to some students last year;* one can ask not only for the names of just any old interesting person but specifically *Who was that woman I saw you with ____?* (See, e.g., Chomsky 1981; Gazdar et al. 1985; Kaplan & Bresnan, 1982.)

And this is only a partial list, focusing on sheer expressive power. One could add to it the many syntactic constraints and devices whose structure minimizes memory load and the likelihood of pursuing local garden paths in speech comprehension (e.g., Berwick & Weinberg 1984; Berwick & Wexler 1987; Bever 1970; Chomsky & Lasnik 1977; Frazier et al. 1983; Hawkins & Cutler 1988; Kuno 1973; 1974), or to ease the task of analysis for the child learning the language (e.g., Morgan 1986; Pinker 1984; Wexler & Culicover 1980). On top of that, there are the rules of segmental phonology that smooth out arbitrary concatenations of morphemes into a consistent sound pattern that juggles demands of ease of articulation and perceptual distinctness; the prosodic rules that disambiguate syntax and communicate pragmatic and illocutionary information; the articulatory programs that achieve rapid transmission rates through parallel encoding of adjacent consonants and vowels; and on and on. Language seems to be a fine example of "that perfection of structure and coadaptation which justly excites our admiration" (Darwin 1859, p. 26).

As we write these words, we can hear the swelling chorus: "Pangloss! Just-so stories!" Haven't we just thought up accounts about functions post hoc after examining the structure? How do we know that the neural mechanisms were not there for other reasons, and that once they were there they were just put to various convenient uses by the first language users, who then conveyed their invention to subsequent generations?

3.2. Is the argument for language design a just-so story?

First of all, there is nothing particularly ingenious, contorted, or exotic about our claims for substantive universals and their semantic functions. Any one of them could have been lifted out of the pages of linguistics textbooks. It is hardly the theory of evolution that motivates the suggestion that phrase-structure rules are useful in conveying relations of modification and predicate-argument structure.

Second, it is not necessarily illegitimate to infer both special design and adaptationist origins on the basis of function itself. It all depends on the complexity of the function from an engineering point of view. If someone told you that John uses *X* as a sunshade or a paperweight, you would certainly be hard-pressed to guess what *X* is or where *X* came from, because all sorts of things make good sunshades or paperweights. But if someone told you that John uses *X* to display television broadcasts, it would be a very good bet that *X* is a television set or is similar in structure to one, and that it was designed for that purpose. The reason is that it would be vanishingly unlikely for something that was not designed as a television set to display television programs; the engineering demands are simply too complex.

This kind of reasoning is commonly applied in biology when high-tech abilities such as bat sonar are discovered. We suggest that human language is a similar case. We are not talking about noses holding up spectacles. Human language is a device capable of communicating exquisitely complex and subtle messages, from convoluted soap opera plots to theories of the origin of the universe. Even if all we knew was that humans possessed such a device, we would expect that it would have to have rather special and unusual properties suited to the task of mapping complex propositional structures onto a serial channel, and an examination of grammar confirms this expectation.

Third, arguments that language is designed for the communication of propositional structures are far from logical truths. It is easy to formulate, and reject, specific alternatives. For example, it is occasionally suggested that language evolved as a medium of internal knowledge representation for use in the computations underlying reasoning. But although there may be a languagelike representational medium – "the language of thought," or "mentalese" (Fodor 1975) – it clearly cannot be English, Japanese, and so on. Natural languages are hopeless for this function: They are needlessly serial, rife with ambiguity (usually harmless in conversational contexts, but unsuited for long-term knowledge representation), complicated by alternations that are relevant only to discourse (e.g., topicalization), and cluttered with devices (such as phonology and much of morphology) that make no contribution to reasoning. Similarly, the facts of grammar make it difficult to argue that language shows design for "the expression of thought" in any sense that is substantially distinct from "communication." If "expression" refers to the mere externalization of thoughts, in some kind of monologue or soliloquy, it is an unexplained fact that language contains mechanisms that presuppose the existence of a listener, such as rules of phonology and phonetics (which map sentences onto sound patterns, enhance confusable phonetic distinctions, disambiguate phrase structure with intonation, and so on.) and pragmatic devices that encode conversational topic, illocutionary force, discourse antecedents, and so on. Furthermore, people do not express their thoughts in an arbitrary private language (which would be sufficient for pure "expression"), but have complex learning mechanisms that acquire a language highly similar in almost every detail to those of other speakers in the community.

Another example of the empirical nature of specific arguments for language design appears when we examine the specific expressive abilities that are designed into language. They turn out to constitute a well-defined set, and do not simply correspond to every kind of information that humans are interested in communicating. So although we may have some a priori intuitions regarding useful expressive capacities of grammar, the matter is ultimately empirical (see, e.g., Jackendoff 1983; 1990; Pinker 1989b; Talmy 1983; 1988), and such research yields results that are specific enough to show that not just any intuition is satisfied. Grammar is a notoriously poor medium for conveying subtle patterns of emotion, for example; facial expressions and tones of voice are more informative (Ekman & Friesen 1975; Etcoff 1986). Although grammars provide devices for conveying rough topological information such as connectivity, contact, and containment, and coarse metric contrasts such as near/far or flat/globular, they are of very little help in conveying precise Euclidean relations: A picture is worth a thousand words. Furthermore, human grammar clearly lacks devices specifically dedicated to expressing any of the kinds of messages that characterize the vocal communication systems of cetaceans, birds, or nonhuman primates, such as announcements of individual identity, predator warnings, and claims of territory.

Finally, Williams (1966) suggests that convergent evolution, resemblance to man-made artifacts, and direct assessments of engineering efficiency are good sources of evidence for adaptation. Of course, in the case of human language, these tests are difficult in practice: Significant convergent evolution has not occurred; no one has ever invented a system that duplicates its function (except for systems that are obviously parasitic on natural languages such as Esperanto or signed English), and most forms of experimental intervention would be unethical. Nonetheless, some tests are possible in principle, and this is enough to refute reflexive accusations of circularity.

For example, even the artificial languages that are focussed on very narrow domains of content and that are not meant to be used in a natural on-line manner by people, such as computer languages or symbolic logic, show certain obvious parallels with aspects of human grammar. They have needed means of distinguishing types of symbols, predicate argument relations, embedding, scope, quantification, and truth relations, and they solve these problems with formal syntactic systems that specify arbitrary patterns of hierarchical concatenation, relative linear order, fixed positions within strings, and closed classes of privileged symbols. Of course, there are vast dissimilarities, but the mere fact that terms like "language," "syntax," "predicate," "argument," and "statement" have clear meanings when applied to artificial systems, with no confusion or qualification, suggests that there are nonaccidental parallels that are reminiscent of the talk of diaphragms and lenses when applied to cameras and eyes. As for experimental investigation, in principle one could define sets of artificial grammars with and without one of the mechanisms in question, or with variations of it. The grammars would be provided or taught to pairs of communicators – formal automata, computer simulations, or college sophomores acting in conscious problem-solving mode – who would be required to convey specific messages under different conditions of speed, noise, or memory limitations. The proportion of information successfully communicated would be assessed and examined as a function of the presence and version of the grammatical mechanism, and of the different conditions putatively relevant to the function in question.

3.3. Language design and language diversity

A more serious challenge to the claim that grammars show evidence of good design may come from the diversity of human languages (Maratsos 1988). Grammatical devices and expressive functions do not pair up in one-to-one fashion. For example, some languages use word order to convey who did what to whom; others use case or agreement for this purpose and reserve the use of word order to distinguish topic from comment, or do not systematically exploit word order at all. How can one say that the mental devices governing word order evolved under selection pressure for expressing grammatical relations if many languages do not use them for that purpose? Linguistic diversity would seem to imply that grammatical devices are very general-purpose tools. And a general-purpose tool would surely have a very generalized structure, and thus could be a spandrel rather than an adapted machine. We begin by answering the immediate objection that the existence of diversity, for whatever reason, invalidates arguments for universal language design; at the end of the section we offer some speculations as to why there should be more than one language to begin with.

First of all, the evolution of structures that serve not one but a small number of definite functions, perhaps to different extents in different environments, is common in biology (Mayr 1982). Indeed, though grammatical devices are put to different uses in different languages, the possible pairings are very circumscribed. No language uses noun affixes to express tense or elements with the syntactic privileges of auxiliaries to express the shape of the direct object. Such universal constraints on structure and function are abundantly documented in surveys of the languages of the world (e.g., Bybee 1985; Comrie 1981; Greenberg 1966b; Greenberg et al. 1978; Hawkins 1988; Keenan 1976; and Shopen 1985). Moreover, language universals are visible in language history, where changes tend to fall into a restricted set of patterns, many involving the introduction of grammatical devices obeying characteristic constraints (Kiparsky 1976; Wang 1976).[3]

But accounting for the evolution of a language faculty permitting restricted variation is only important on the most pessimistic of views. Even a rudimentary grammatical analysis reveals that surface diversity is often a manifestation of minor differences in the underlying mental grammars. Consider some of the supposedly radical typological differences between English and other languages. English is a rigid word-order language; in the Australian language Warlpiri the words from different logical units can be thoroughly scrambled and case markers are used to convey grammatical relations and noun modification. Many Native American languages, such as Cherokee, use few noun phrases within clauses at all, and express grammatical relations by sticking strings of agreement affixes onto the verb, each identifying an argument by a set of features such as humanness or shape. Whereas "accusative" languages like English collapse subjects of transitive and intransitive sentences, "ergative" languages collapse objects of transitives with subjects of intransitives. Whereas English sentences are built around obligatory subjects, languages like Chinese are oriented around a position reserved for the discourse topic.

However, these variations almost certainly correspond to differences in the extent to which the same specific set of mental devices is put to use, but not to differences in the kinds of devices that are put to use. English has free constituent order in strings of prepositional phrases (*The package was sent from Chicago to Boston by Mary; The package was sent by Mary to Boston from Chicago*, and so on). English has case, both in pronouns and in the genitive marker spelled *'s*. It expresses information about arguments in verb affixes in the agreement marker *-s*. Ergativity can be seen in verb alternations like *John broke the glass* and *The glass broke*. There is even a kind of topic position: *As for fish, I like salmon.* Conversely, Warlpiri is not without phrasal syntax. Auxiliaries go in second position (not unlike English, German, and many other languages). The constituents of a noun phrase must be contiguous if they are not case-marked; the constituents of a finite clause must be contiguous if the sentence contains more than one. Pinker (1984) outlines a theory of language acquisition in which the same innate learning mechanisms are put to use in different extents in children acquiring "radically" different languages.

When one looks at more abstract linguistic analyses, the underlying unity of natural languages is even more apparent. Chomsky has quipped that anything you find in one language can also be found in every other language, perhaps at a more abstract level of representation, and this claim can be justified without resorting to Procrustean measures. In many versions of Chomsky's government-binding theory (1981), all noun phrases must be case marked; even those that receive no overt case-marking are assigned "abstract" case by an adjacent verb, preposition, or tense element. The basic order of major phrases is determined by the value of a language-varying parameter specifying the direction in which case assignment may be executed. So in a language like Latin, the noun phrases are marked with morphological case (and can appear in any position), whereas in a language like English, they are not so marked, and must be adjacent to a case-assigner such as a verb. Thus, overt case-marking in one language and word order in another are unified as manifestations of a single grammatical module. And the module has a well-specified function: In the terminology of the theory, it makes noun phrases "visible" for the assignment of thematic roles such as agent, goal, or location. Moreover, word order itself is not a unified phenomenon. Often, when languages "use word order for pragmatic purposes," they are exploiting an underlying grammatical subsystem, such as stylistic rules, that has properties very different from those governing the relative order of noun phrases and their case-assigners.

Why is there more than one language at all? Here we can only offer the most tentative of speculations. For sound-meaning pairings within the lexicon, there are two considerations. First, one might suppose that speakers need a learning mechanism for labels for cultural innovations such as *screwdriver*. Such a learning device is then sufficient for all vocabulary items. Second, it may be difficult to evolve a huge innate code. Each of tens of thousands of sound-meaning correspondences would have to be synchronized across speakers, but few words could have the nonarbitrary antecedents that would have been needed to get the standardization process started (i.e., analogous to the way bared fangs in preparation for biting evolved into the facial expression for anger). Furthermore, the size of such a code would tax the time available to evolve and maintain it in the genome in the face of random perturbations from sexual recombination and other stochastic genetic processes (Tooby & Cosmides, in press a; Williams 1966). Once a mechanism for learning sound-meaning pairs is in place, the information for acquiring any particular pair, such as *dog* for dogs, is readily available from the speech of the community. Thus the genome can store the vocabulary in the environment, as Tooby and Cosmides (1989) have put it.

For other aspects of grammar, one might get more insight by inverting the perspective. Instead of positing that there are multiple languages, leading to the evolution of a mechanism to learn the differences among them, one might posit that there is a learning mechanism, leading to the development of multiple languages. That is, some aspects of grammar might be easily learnable from environmental inputs by cognitive processes that may have been in existence prior to the evolution of grammar, for example, the relative order of a pair of sequenced elements within a bounded unit. For these aspects there was no need to evolve a fixed value, and they are free to vary across communities of speakers. In section 5.2.3, we discuss a simulation of evolution by Hinton and Nowlan (1987) that behaves in a way that is consistent with this conjecture.

3.4. Language design and arbitrariness

Piattelli-Palmarini (1989) presents a different kind of argument: Grammar is not completely *predictable* as an adaptation to communication, therefore it lacks design and did not evolve by selection. He writes, "Survival criteria, the need to communicate and plan concerted action, cannot account for our *specific* linguistic nature. Adaptation cannot even begin to explain any of these phenomena." Frequently cited examples of arbitrary phenomena in language include constraints on movement (such as subjacency), irregular morphology, and lexical differences in predicate-argument structure. For instance, it is acceptable to say *Who did John see Mary with?*, but not *Who did John see Mary and?; John broke* *the glass* but not *John breaked the glass; John filled the glass with milk,* but not *John poured the glass with milk.* The arguments that language could not be an adaptation take two forms: (i) language could be better than what it is, and (ii) language could be different from what it is. We show that neither form of the argument is valid, and that the facts that it invokes are perfectly consistent with language being an adaptation and offer not the slightest support to any specific alternative.

3.4.1. Inherent tradeoffs. In their crudest form, arguments about the putative functionlessness of grammar run as follows: "I bet you can't tell me a function for Constraint *X;* therefore, language is a spandrel." But even if it could be shown that one part of language had no function, that would not mean that all parts of language had no function. Recall from section 2.2 that many organs contain modified spandrels, but this does not mean that natural selection did not assemble or shape the organ. Worse, Constraint *X* may not be a genuine part of the language faculty but just a description of one aspect of it, an epiphenomenal spandrel. No adaptive organ can be adaptive in every aspect, because there are as many aspects of an organ as there are ways of describing it. The recent history of linguistics provides numerous examples where a newly discovered constraint is first proposed as an explicit statement listed as part of a grammar, but is then shown to be a deductive consequence of a much wider ranging principle (see, e.g., Chomsky 1981; Freidin 1978). For example, the ungrammaticality of sentences like *John to have won is surprising,* once attributed to a filter specifically ruling out [NP-to-VP] sequences, is now seen as a consequence of the Case Filter. Although one might legitimately wonder what good "*[NP-to-VP]" is doing in a grammar, one could hardly dispense with something like the Case Filter.

Because the mere appearance of some nonoptimal feature is inconclusive, we must examine specific explanations for why the feature exists. In the case of the nonselectionist position espoused by Piattelli-Palmarini, there is none: not a hint of how any specific aspect of grammar might be explained, even in principle, as a specific consequence of some developmental process or genetic mechanism or constraint on possible brain structure. The position gains *all* its support from the supposed lack of an adaptive explanation. In fact, we will show that there is such an explanation, well-motivated both in evolutionary theory and in linguistics, so the support disappears.

The idea that natural selection aspires toward perfection has long been discredited in evolutionary theory (Williams 1966). As Maynard Smith (1984, p. 290) has put it, "If there were no constraints on what is possible, the best phenotype would live forever, would be impregnable to predators, would lay eggs at an infinite rate, and so on." Tradeoffs among conflicting adaptive goals are a ubiquitous limitation on optimality in the design of organisms. It may be adaptive for a male bird to advertise his health to females with gaudy plumage or a long tail, but not to the extent that predators are attracted or flight is impossible.

Tradeoffs of utility within language are also unavoidable (Bolinger 1980; Slobin 1977). For example, there is a conflict of interest between speaker and hearer. Speakers want to minimize articulatory effort and hence tend toward brevity and phonological reduction. Hearers want to minimize the effort of understanding and hence desire explicitness and clarity. This conflict of interest is inherent to the communication process and operates at many levels. Editors badger authors into expanding elliptical passages; parsimonious headline writers unwittingly produce *Squad Helps Dog Bite Victim* and *Stud Tires Out.* Similarly, there is a conflict of interest between speaker and learner. A large vocabulary allows for concise and precise expression. But it is only useful if every potential listener has had the opportunity to learn each item. Again, this tradeoff is inherent to communication; one man's jargon term is another's *mot juste.*

Clearly, any shared system of communication is going to have to adopt a code that is a compromise among these demands, and so will appear to be arbitrary from the point of view of any one criterion. There is always a large range of solutions to the combined demands of communication that reach slightly different equilibrium points in this multidimensional space. Slobin (1977) points out that the Serbo-Croatian inflectional system is "a classic Indo-European synthetic muddle," suffixing each noun with a single affix from a paradigm full of irregularity, homophony, and zero-morphemes. As a result, the system is perfected late and with considerable difficulty. In contrast, the Turkish inflectional system is semantically transparent, with strings of clearly demarcated regular suffixes, and is mastered by the age of two. When it comes to production by an adult who has overlearned the system, however, Serbo-Croatian does have an advantage in minimizing the sheer number of syllables that must be articulated. Furthermore, Slobin points out that such tradeoffs can be documented in studies of historical change and borrowing. For example, changes that serve to enhance brevity will proceed until comprehension becomes impaired, at which point new affixes or distinctions are introduced to restore the balance (see also Samuels 1972). A given feature of language may be arbitrary in the sense that there are alternative solutions that are better from the standpoint of some single criterion. But this does not mean that it is good for nothing at all!

Subjacency – the prohibition against dependencies between a gap and its antecedent that spans certain combinations of phrasal nodes – is a classic example of an arbitrary constraint (see Freidin & Quicoli 1989). In English you can say *What does he believe they claimed that I said?* but not the semantically parallel *What does he believe the claim that I said?* One might ask why languages behave this way. Why not allow extraction anywhere, or nowhere? The constraint may exist because parsing sentences with gaps is a notoriously difficult problem and a system that has to be prepared for the possibility of inaudible elements anywhere in the sentence is in danger of bogging down by positing them everywhere. Subjacency has been held to assist parsing because it cuts down on the set of structures that the parser has to keep track of when finding gaps (Berwick & Weinberg 1984). This bonus to listeners is often a hindrance to speakers, who struggle with resumptive pronouns in such clumsy sentences as *That's the guy that you heard the rumor about his wife leaving him.* There is nothing "necessary" about the precise English version of the constraint or about the small sample of alternatives allowed within natural language. But by settling in on a particular subset of the range of possible compromises between the demands of expressiveness and parsability, the evolutionary process may have converged on a satisfactory set of solutions to one problem in language processing.

3.4.2. Parity in communications protocols. The fact that one can conceive of a biological system being different from the way it actually is says nothing about whether it is an adaptation (see Mayr 1983). No one would argue that selection was not the key organizing force in the evolution of the vertebrate eye just because the compound eyes of arthropods are different. Similarly, pointing out that a hypothetical Martian language could do passivization differently is inconclusive. We must ask how well supported specific explanations are.

In the case of features of human language structure that could have been different, again Piattelli-Palmarini presents no explanations at all and relies entirely on the putative inability of natural selection to provide any sort of motivated account. But there does exist such an account: The nature of language makes arbitrariness of grammar itself part of the adaptive solution of effective communication *in principle*.

Any communicative system requires a coding protocol that can be arbitrary as long as it is shared. Liberman and Mattingly (1989) call this the requirement of *parity;* we can illustrate it with the (coincidentally named) "parity" settings in electronic communication protocols. There is nothing particularly logical about setting your printer's serial interface to the "even," as opposed to the "odd," parity setting. Nor is there any motivation to set your computer to odd as opposed to even parity. But there is every reason to set the computer and printer to the *same* parity, whatever it is, because if you don't, they cannot communicate. Indeed, standardization itself is far more important than any other adaptive feature possessed by one party. Many personal computer manufacturers in the 1980s boasted of the superior engineering and design of their product compared to the IBM PC. But when these machines were not IBM-compatible, the consequences are well known.

In the evolution of the language faculty, many "arbitrary" constraints may have been selected simply because they defined parts of a standardized communicative code in the brains of some critical mass of speakers. Piattelli-Palmarini may be right in claiming that there is nothing adaptive about forming yes-no questions by inverting the subject and auxiliary as opposed to reversing the order of words in the sentence. But given that language must do one or the other, it is highly adaptive for each member of a community of speakers to be forced to learn to do it the same way as all the other members. To be sure, some combination of historical accidents, epiphenomena of other cognitive processes, and neurodevelopmental constraints must have played a large role in the breaking of symmetry that was needed to get the fixation process running away in one direction or another. But it still must have been selection that resulted in the convention then becoming innately entrenched.

The requirement of parity operates at all levels of a communications protocol. Within individual languages the utility of arbitrary but shared features is most obvious in the choice of individual words: There is no reason for you to call a dog *dog* rather than *cat* except for the fact that everyone else is doing it, but that is reason enough. Saussure (1959) called this inherent feature of language *"l'arbitraire du signe,"* and Hurford (1989a), using evolutionary game theory, demonstrates the evolutionary stability of such a "Saussurean" strategy whereby each learner uses the same arbitrary signs in production that it uses in comprehension (i.e., that other speakers use in production). More generally, these considerations suggest that a preference for arbitrariness is built into the language acquisition device at two levels. It only hypothesizes rules that fall within the (possibly arbitrary) set defined by universal grammar, and within that set, it tries to choose rules that match those used by the community, whatever they are.

The benefits of a learning mechanism designed to assess and adopt the prevailing parity settings become especially clear when we consider alternatives, such as trying to get each speaker to converge on the same standard by endogenously applying some rationale to predict form from meaning. There are many possible rationales for any form-meaning pairing, and that is exactly the problem – different rationales can impress different speakers, or the same speakers on different occasions, to different degrees. But such differences in cognitive style, personal history, or momentary interests must be set aside if people are to communicate. As mentioned, no grammatical device can simultaneously optimize the demands of speakers and hearers, but it will not do to talk in Serbo-Croatian and demand that one's listeners reply in Turkish. Furthermore, whenever cognition is flexible enough to construe a situation in more than one way, no simple correspondence between syntax and semantics can be used predictively by a community of speakers to "deduce" the most "logical" grammatical structure. For example, there is a simple and universal principle dictating that the surface direct object of a causative verb refers to an entity that is "affected" by the action. The principle by itself is unusable, however. When a girl puts boxes in baskets she is literally affecting both: The boxes are changing location and the baskets are changing state from empty to full. One would not want one perceiver interested in the boxes to say that she is *filling boxes* while another interested in the baskets describes the same event as *filling baskets;* no one would know what went where. However, by letting different verbs idiosyncratically select different kinds of entities as "affected" (e.g., *place the box/*basket* versus *fill the basket/*box*), and forcing learners to respect the verbs' wishes, grammar can allow speakers to specify different kinds of entities as affected by putting them in the direct object position of different verbs, with minimal ambiguity. This is presumably why different verbs have different arbitrary syntactic privileges (Pinker 1989b), a phenomenon that Piattelli-Palmarini (1989) describes at length. Even iconicity and onomatopoeia are in the eye and ear of the beholder. The ASL (American Sign Language) sign for "tree" resembles the motion of a tree waving in the wind, but in Chinese Sign Language it is the motion of sketching the trunk (Newport & Meier 1985). In the United States, pigs go "oink"; in Japan, they go "boo-boo."

3.4.3. Arbitrariness and the relation between language evolution and language acquisition. The need for arbitrariness has profound consequences for understanding the role of communicative function in language acquisition and language evolution. Many psychologists and artificial intelligence researchers have suggested that the structure of grammar is simply the solution that every child arrives at for the problem of how to communicate with others. Skinner's reinforcement theory is the strongest version of this hypothesis (Skinner 1957), but versions that avoid his behaviorism and rely instead on general cognitive problem-solving abilities have always been popular within psychology. [See *BBS* special issue on the work of B. F. Skinner *BBS* 7(4)1984.] Both Skinner and cognitive theorists such as Bates et al. (1989) explicitly draw parallels between the role of function in learning and evolution. Chomsky and many other linguists and psycholinguists have argued against functionalism in ontogeny, showing that many aspects of grammar cannot be reduced to being the optimal solution to a communicative problem; rather, human grammar has a universal idiosyncratic logic of its own. More generally, Chomsky has emphasized that people's *use* of language does not tightly serve utilitarian goals of communication but is an autonomous competence to express thought (see, e.g., Chomsky 1975). If communicative function does not shape language in the individual, one might conclude, it probably did not shape language in the species.

We suggest that the analogy that underpins this debate is misleading. It is not just that learning and evolution need not follow identical laws, selectionist or otherwise. (For example, as Chomsky himself has stressed, the issue never even comes up in clearer cases like vision, where nobody suggests that all infants' visual development is related to their desire to see or that visual systems develop with random variations that are selected by virtue of their ability to attain the child's goals.) In the case of language, the arguments of section 3.4.2 suggest that language evolution and language acquisition not only *can* differ but that they *must* differ. Evolution has had a wide variety of equivalent communicative standards to choose from; there is no reason for it to have favored the class of languages that includes Apache and Yiddish, but not Old High Martian or Early Vulcan. This flexibility has been used up, however, by the time a child is born; the species and the language community have already made their choices. Children cannot learn just any useful communicative system; nor can they learn just any natural language. They are stuck with having to learn the particular kind of language the species eventually converged upon and the particular variety the community has chosen. Whatever rationales may have influenced these choices are buried in history and cannot be recapitulated in development.

Moreover, any code as complex and precise as a grammar for a natural language will not wear its protocol on its sleeve. No mortal computer user can induce an entire communications protocol or programming language from examples; that's why we have manuals. This is because any particular instance of the use of such a protocol is a unique event accompanied by a huge set of idiosyncratic circumstances, some relevant to how the code must be used, most irrelevant, and there is no way of deciding which is which. For the child, any sentence or set of sentences is compatible with a wide variety of very different grammars, only one of them correct (Chomsky 1965; 1975; 1980; 1981; Pinker 1979; 1984; Wexler & Culicover 1980). For example, without prior constraints, it would be natural to generalize from input sentences like *Who did you see her with?* to **Who did you see her and?*, from *teethmarks* to **clawsmarks*, from *You better be good* to **Better you be good?* Children have no manual to consult, and presumably that is why they need innate constraints. [See also Lightfoot: "The Child's Trigger Experience: Degree = 0 Learnability" *BBS* 12(2)1989 and Crain: "How Grammars Help Language Learners" *BBS* (forthcoming).]

So we see a reason why functionalist theories of the evolution of language can be true while functionalist theories of the acquisition of language can be false. From the very start of language acquisition, children obey grammatical constraints that afford them no immediate communicative advantage. To take just one example, one- and two-year-olds acquiring English obey a formal constraint on phrase structure configurations concerning the distinction between lexical categories and phrasal categories and, as a result, avoid placing determiners and adjectives before pronouns and proper names. They will use phrases like *big dog* to express the belief that a particular dog is big, but they will never use phrases like *big Fred* or *big he* to express the belief that a particular person is big (Bloom 1990). Children respect this constraint despite the limits it puts on their expressive range.

Furthermore, despite unsupported suggestions to the contrary among developmental psychologists, many strides in language development afford the child no locally discernible increment in communicative ability (Maratsos 1988; 1989). When children say *breaked* and *comed*, they are using a system that is far simpler and more logical than the adult combination of a regular rule and 150 irregular memorized exceptions. Such errors do not reliably elicit parental corrections or other conversational feedback (Brown & Hanlon 1970; Morgan & Travis in press). There is no deficit in comprehensibility; the meaning of *comed* is perfectly clear. In fact, the child's system has greater expressive power that the adult's. When children say *hitted* and *cutted*, they are distinguishing between past and nonpast forms in a manner that is unavailable to adults, who must use *hit* and *cut* across the board. Why do children eventually abandon this simple, logical, expressive system? They must be programmed so that the mere requirement of conformity to the adult code, as subtle and arbitrary as it is, wins over other desiderata.

The requirement that a communicative code have an innate arbitrary foundation ("universal grammar," in the case of humans) may have analogues elsewhere in biology. Mayr (1982, p. 612) notes that

> Behavior that serves as communication, for instance courtship behavior, must be stereotyped in order not to be misunderstood. The genetic program controlling such behavior must be "closed," that is, it must be reasonably resistant to any changes during the individual life cycle. Other behaviors, for instance, those that control the choice of food or habitat, must have a

certain amount of flexibility in order to permit the incorporation of new experiences; such behaviors must be controlled by an "open" program.

In sum, the requirement for standardization of communication protocols dictates that it is better for nature to build a language acquisition device that picks up the code of the ambient language than one that invents a code that is useful from a child's eye view. Acquiring such a code from examples is no mean feat; many grammatical principles and constraints must accordingly be hardwired into the device. Hence, even if the functions of grammatical devices play an important role in evolution, they may play no role in acquisition.

4. Arguments for language being a spandrel

Given that the criteria for being an adaptation appear to be satisfied in the case of language, we can examine the strength of the competing explanation that language is a spandrel, as suggested by Gould, Chomsky, and Piattelli-Palmarini.

4.1. The mind as a multipurpose learning device

The main motivation for Gould's specific suggestion that language is a spandrel is his frequently stated position that the mind is a single general-purpose computer. For example, as part of a critique of a particular theory of the origin of language (Parker & Gibson 1979), Gould writes (1979, p. 386):

> I don't doubt for a moment that the brain's enlargement in human evolution had an adaptive basis mediated by selection. But I would be more than mildly surprised if many of the specific things it now can do are the product of direct selection "for" that particular behavior. Once you build a complex machine, it can perform so many unanticipated tasks. Build a computer "for" processing monthly checks at the plant, and it can also perform factor analyses on human skeletal measures, play Rogerian analyst, and whip anyone's ass (or at least tie them perpetually) in tic-tac-toe.

The analogy is somewhat misleading. It is just not true that you can take a computer that processes monthly checks and use it to play Rogerian analyst; someone has to reprogram it first. Language learning is not programming: Parents provide their children with sentences of English, not rules of English. We suggest that natural selection was the programmer.

The analogy could be modified by imagining some machine equipped with a single program that can *learn from examples* to calculate monthly checks, perform factor analyses, and play Rogerian analyst, all without explicit programming. Such a device does not now exist in artificial intelligence and it is unlikely to exist in biological intelligence. There is no psychologically realistic multipurpose learning program that can acquire language as a special case, because the kinds of generalizations that must be made to acquire a grammar are at cross-purposes with those that are useful in acquiring other systems of knowledge from examples (Chomsky 1972; 1975; 1980a; 1986; Pinker 1979; 1984; Wexler & Culicover 1980). The gross facts about the dissociability of language and other learned cultural systems, listed in the first paragraph of this paper, also belie the suggestion that language is a spandrel of any general cognitive learning ability.

4.2. Constraints on possible forms

The theory that the mind is an all-purpose learning device is of course anathema to Chomsky (and to Piattelli-Palmarini), making it a puzzle that they should find themselves in general agreement with Gould. Recently, Gould (1989a) has described some common ground. Chomsky, he suggests, is in the Continental tradition of trying to explain evolution by structural laws constraining possible organic forms. For example, Chomsky writes:

> In studying the evolution of mind, we cannot guess to what extent there are physically possible alternatives to, say, transformational generative grammar, for an organism meeting certain other physical conditions characteristic of humans. Conceivably, there are none – or very few – in which case talk about evolution of the language capacity is beside the point. (1972, pp. 97–98).
>
> These skills [e.g., learning a grammar] may well have arisen as a concomitant of structural properties of the brain that developed for other reasons. Suppose that there was selection for bigger brains, more cortical surface, hemispheric specialization for analytic processing, or many other structural properties that can be imagined. The brain that evolved might well have all sorts of special properties that are not individually selected; there would be no miracle in this, but only the normal workings of evolution. We have no idea, at present, how physical laws apply when 10^{10} neurons are placed in an object the size of a basketball, under the special conditions that arose during human evolution. (1982b, p. 321)
>
> In this regard [the evolution of infinite digital systems], speculations about natural selection are no more plausible than many others; perhaps these are simply emergent physical properties of a brain that reaches a certain level of complexity under the specific conditions of human evolution. (1988b; p. 22 in ms.)

Although Chomsky does not literally argue for any specific evolutionary hypothesis, he repeatedly urges us to consider "physical laws" as possible alternatives to natural selection. But it is not easy to see exactly what we should be considering. It is certainly true that natural selection cannot explain all aspects of the evolution of language. But is there any reason to believe that there are as yet undiscovered theorems of physics that can account for the intricate design of natural language? Of course, human brains *obey* the laws of physics, and always did, but that does not mean that their specific structure can be *explained* by such laws.

More plausibly, we might look to constraints on the possible neural basis for language and its epigenetic growth. But neural tissue is wired up by developmental processes that act in similar ways all over the cortex and, to a lesser degree, across the animal kingdom (Dodd & Jessell 1988; Harrelson & Goodman 1988). In different organisms it has evolved the ability to perform the computations necessary for pollen-source communication, celestial navigation, Doppler-shift echolocation, stereopsis, controlled flight, dam-building, sound mimicry, and face recognition. The space of physically possible neural systems thus can't be all *that* small, as far as specific computational abilities are concerned. And it is most unlikely that laws acting at the level of substrate adhesion molecules and synaptic competition, when their effects are projected upward through many levels of scale and hierarchical organization, would automatically result in systems that accomplish interesting engineering tasks in a world of medium-sized objects.

Changes in brain quantity could lead to changes in brain quality. But mere largeness of brain is neither a necessary nor a sufficient condition for language, as Lenneberg's (1967) studies of nanencephaly and craniometric studies of individual variation have shown. Nor is there reason to think that if you simply pile more and more neurons into a circuit or more and more circuits into a brain that computationally interesting abilities would just emerge. It seems more likely that you would end up with a very big random pattern generator. Neural network modeling efforts have suggested that complex computational abilities require extrinsically imposed design or numerous richly structured inputs during learning or both, any of which would be inconsistent with Chomsky's suggestions.

Finally, there may be direct evidence against the speculation that language is a necessary physical consequence of how human brains can grow. Gopnik (1990; in press) describes a syndrome of developmental dysphasia whose sufferers lack control of morphological features such as number, gender, tense, and case. Otherwise, they are intellectually normal. One 10-year-old boy with this disability earned the top grade in his mathematics class and is a respectable computer programmer. This shows that a human brain lacking components of grammar, perhaps even a brain with the capacity of discrete infinity, is physically and neurodevelopmentally possible.

In sum, there is no support for the hypothesis that language emerges from physical laws acting in unknown ways in a large brain. Although there are no doubt *aspects* of the system that can only be explained by historical, developmental, or random processes, the most likely explanation for the complex structure of the language faculty is that it is a design imposed on neural circuitry as a response to evolutionary pressures.

5. The process of language evolution

For universal grammar to have evolved by Darwinian natural selection it is not enough that it be useful in some general sense. There must have been genetic variation among individuals in their grammatical competence. There must have been a series of steps leading from no language at all to language as we now find it, each step small enough to have been produced by a random mutation or recombination, and each intermediate grammar useful to its possessor. Every detail of grammatical competence that we wish to ascribe to selection must have conferred a reproductive advantage on its speakers, and this advantage must be large enough to have become fixed in the ancestral population. And there must be enough evolutionary time and genomic space separating our species from nonlinguistic primate ancestors.

There are no conclusive data on any of these issues. This, however, has not prevented various people from claiming that each of the necessary postulates is false. We argue that what we do know from the biology of language and evolution makes each of the postulates quite plausible.

5.1. Genetic variation

Lieberman (1984; 1989) claims that the Chomskyan universal grammar could not have evolved. He writes:

> The premises that underlie current "nativist" linguistic theory . . . are out of touch with modern biology. Ernst Mayr (1982), in his definitive work, *The Growth of Biological Thought*, discusses these basic principles that must structure any biologically meaningful nativist theory. . . . [one of the principles is:] Essentialistic thinking (e.g., characterizing human linguistic ability in terms of a uniform hypothetical universal grammar) is inappropriate for describing the biological endowment of living organisms. (1989, pp. 203–5)
>
> A true nativist theory must accommodate genetic variation. A detailed genetically transmitted universal grammar that is identical for every human on the planet is outside the range of biological plausibility. (1989, 223)

This is part of Lieberman's argument that syntax is acquired by general-purpose learning abilities, not by a dedicated module or set of modules. But the passages quoted above contain a variety of misunderstandings and distortions. Chomskyan linguistics is the antithesis of the kind of essentialism that Mayr decries. It treats such disembodied interindividual entities as "The English Language" as unreal epiphenomena. The only scientifically genuine entities are individual grammars situated in the heads of individual speakers (see Chomsky 1986 for extended discussion). True, grammars for particular languages, and universal grammar, are often provisionally idealized as a single kind of system. But this is commonplace in systems-level physiology and anatomy; for example, the structure of the human eye is always described as if all individuals shared it and individual variation and pathology are discussed as deviations from a norm. This is because natural selection, while feeding on variation, uses it up (Ridley 1986; Sober 1984). In adaptively complex structures in particular, the variation we see does not consist of qualitative differences in basic design, and this surely applies to complex mental structures as well (Tooby & Cosmides, in press).

Also, contrary to what Lieberman implies, there does exist variation in grammatical ability. Within the range that we would call "normal," we all know some individuals who habitually use tangled syntax and others who speak with elegance, some who are linguistically creative and others who lean on cliches, some who are fastidious conformists and others who bend and stretch the language in various ways. At least some of this variation is probably related to the strength or accessibility of different grammatical subsystems, and at least some, we suspect, is genetic, the kind of thing that would be shared by identical twins reared apart. For example, Bever et al. (1989) have extensive experimental data showing that right-handers with a family history of left-handedness show less reliance on syntactic analysis and more reliance on lexical association than do people without such a genetic background.

Moreover, beyond the "normal" range there are documented genetically transmitted syndromes of grammatical deficits. Lenneberg (1967) notes that specific language disability is a dominant, partially sex-linked trait with almost complete penetrance (see also Ludlow & Cooper, 1983, for a literature review). More strikingly, Gopnik (1990) has found a familial selective deficit in the use of morphological features (gender, number, tense, etc.) that acts as if it is controlled by a dominant gene.

This does not mean that we should easily find cases of inherited subjacency deficiency or anaphor blindness. Pleiotropy – single gene changes that cause apparently unrelated phenotypic effects – is ubiquitous, so there is no reason to think that every aspect of grammar that has a genetic basis must be controlled by a single gene. Having a right hand has a genetic basis but genetic deficits do not lead to babies being born with exactly one hand missing. Moreover, even if there was a pure lack of some grammatical device among some people, it may not be easily discovered without intensive analysis of the person's perceptions of carefully constructed linguistic examples. Different grammatical subsystems can generate superficially similar constructions, and a hypothetical victim of a deficit may compensate in ways that would be difficult to detect. Indeed, cases of divergent underlying analyses of a single construction are frequent causes of historical change.

5.2. Intermediate steps

Some people have doubted that an evolutionary sequence of increasingly complex and specialized universal grammars is possible. The intermediate links, it has been suggested, would not have been viable communication systems. These arguments fall into three classes.

5.2.1. Nonshared innovations. Geschwind (1980), among others, has wondered how a hypothetical "beneficial" grammatical mutation could really have benefited its possessor, given that such an individual would not have been understood by less evolved compatriots. One possible answer is that any such mutation is likely to be shared by individuals who are genetically related. Because much communication is among kin, a linguistic mutant will be understood by some relatives and the resulting enhancements in information sharing will benefit each one of them relative to others who are not related.

We think there is a more general answer, however. Comprehension abilities do not have to be in perfect synchrony with production abilities. Comprehension can use cognitive heuristics based on probable events to decode word sequences even in the absence of grammatical knowledge. Ungrammatical strings like *skid crash hospital* are quite understandable, and we find we can do a reasonably good job understanding Italian newspaper stories based on a few cognates and general expectancies. At the same time, grammatical sophistication in such sources does not go unappreciated. We are unable to duplicate Shakespeare's complex early Modern English but we can appreciate the subtleties of his expressions. When some individuals are making important distinctions that can be decoded with cognitive effort, it could set up a pressure for the evolution of neural mechanisms that would make this decoding process become increasingly automatic, unconscious, and undistracted by irrelevant aspects of world knowledge. These are some of the hallmarks of an innate grammatical "module" (Fodor 1983). The process whereby environmentally induced responses set up selection pressures for such responses to become innate, triggering conventional Darwinian evolution that superficially mimics a Lamarckian sequence, is sometimes known as the "Baldwin effect" (Baldwin 1896; Hinton & Nowlan 1987; Maynard Smith 1987).

Not all linguistic innovations need begin with a genetic change in the linguistic abilities of speakers. Former Secretary of State Alexander Haig achieved notoriety with such expressions as *Let me caveat that* or *That statement has to be properly nuanced.* As listeners, we cringe at the ungrammaticality, but we have no trouble understanding him and would be hard-pressed to come up with a concise grammatical alternative. The double standard exemplified by Haigspeak is fairly common in speech (Pinker 1989b). Most likely this was always true, and innovations driven by cognitive processes exploiting analogy, metaphor, iconicity, conscious folk etymology, and so on, if useful enough, could set up pressures for both speakers and hearers to grammaticize those innovations. Note also that if a single mental database is used in production and comprehension (Bresnan & Kaplan 1982) evolutionary changes in response to pressure on one performance would automatically transfer to the other.

5.2.2. Categorical rules. Many linguistic rules are categorical, all-or-none operations on symbols (see, e.g., Pinker & Prince 1988; 1989). How could such structures evolve in a gradual sequence? Bates et al. (1989), presumably echoing Gould's "5% of an eye" (1989a), write:

> What protoform can we possibly envision that could have given birth to constraints on the extraction of noun phrases from an embedded clause? What could it conceivably mean for an organism to possess half a symbol, or three quarters of a rule? (p. 3) . . . monadic symbols, absolute rules and modular systems must be acquired as a whole, on a yes-or-no basis – a process that cries out for a Creationist explanation." (p. 30)

Two issues are being collapsed here, however. Although one might justifiably argue that an entire system of grammar must evolve in a gradual continuous sequence, that does not mean that every aspect of every rule must evolve in a gradual continuous sequence. As mentioned, mutant fruit flies can have a full leg growing where an antenna should be and the evolution of new taxa with different numbers of appendages from their ancestors is often attributed to such homeotic mutations. No single mutation or recombination could have led to an entire universal grammar, but it could have led a parent with an n-rule grammar to have an offspring with an $n + 1$ rule grammar, or a parent with an m-symbol rule to have an offspring with an $m + 1$ symbol rule. It could also lead to a parent with no grammatical rules at all and just rote associations to have an offspring with a single rule. Grammatical rules are symbol-manipulations whose skeletal form is shared by many other mental systems. Indeed, discrete symbol manipulations, free from graded application based on similarity to memorized cases, are highly useful in many domains of cognition, especially those involving socially shared information (Freyd 1983; Pinker & Prince 1989; Smolensky 1988). If a genetic change caused generic copies of a nonlinguistic symbol-replacement operation to pop up within the neural system underlying communication, such protorules could be put to use as parts of encoding and decoding schemes, whereupon they could be subject to selective forces tailoring them to specific demands of language. Rozin (1976) and Shepard (1986) have argued that the evolution of intelligence was made possible by just such sequences.

5.2.3. Perturbations of formal grammars. Grammars are thought to be complex computational systems with many interacting rules and conditions. Chomsky (1981) has emphasized how grammars have a rich deductive structure in which a minor change to a single principle can have dramatic effects on the language as a whole as its effects cascade through grammatical derivations. This raises the question of how the entire system could be viable under the far more major perturbations that could be expected during evolutionary history. Does grammar degrade gracefully as we extrapolate backward in time? Would a universal grammar with an altered or missing version of some component be good for anything, or would it result in nothing but blocked derivations, filtered constructions, and partial structures? Lieberman (1989, p. 200) claims that "the only model of human evolution that would be consistent with the current standard linguistic theory is a sudden saltation that furnished human beings with the neural bases for language." Similarly, Bates et al. (1989, pp. 2–3) claim that "if the basic structural principles of language cannot be learned (bottom up) or derived (top down), there are only two possible explanations for their existence: Either universal grammar was endowed to us directly by the Creator, or else our species has undergone a mutation of unprecedented magnitude, a cognitive equivalent of the Big Bang."

Such arguments are based on a confusion, however. Although a grammar for an existing language cannot tolerate minor perturbations and still be a grammar for a language that a modern linguist would recognize, that does not mean that it cannot be a grammar at all. To put it crudely, there is no requirement that the languages of *Homo erectus* fall into the class of possible *Homo sapiens* languages. Furthermore, language abilities consist of not just formal grammar but also such nonlinguistic cognitive processes as analogy, rote memory, and Haigspeak. Chomsky (1981) refers to such processes as constituting the "periphery" of grammar, but a better metaphor may put them in the "interstices," where they would function as a kind of jerry-rigging that could allow formally incomplete grammars to be used in generating and comprehending sentences.

The assertion that a natural language grammar either functions as a whole or not at all is surprisingly common. Yet it has no more merit than similar claims about eyes, wings, and webs that frequently pop up in the anti-Darwinian literature (see Dawkins, 1986, for examples), and which occasionally trigger hasty leaps to claims about exaptation. Pidgins, contact languages, Basic English, and the language of children, immigrants, tourists, aphasics, telegrams, and headlines provide ample proof that there is a vast continuum of viable communicative systems displaying a continuous gradation of efficiency and expressive power (see Bickerton 1986). This is exactly what the theory of natural selection requires.

Our suggestions about interactions between learning and innate structure in evolution are supported by an interesting simulation of the Baldwin effect by Hinton and Nowlan (1987). They consider the worst imaginable scenario for evolution by small steps: a neural network with 20 connections (which can be either excitatory or inhibitory) that conveys no fitness advantage unless all 20 are correctly set. So not only is it no good to have 5% of the network, it's no good to have 95%. In a population of organisms whose connections are determined by random mutations, a fitter mutant arises at a rate of only about once every million (2^{20}) genetically distinct organisms, and its advantages are immediately lost if the organism reproduces sexually. But now consider an organism where the connections are either genetically fixed to one or the other value or are settable by learning, determined by random mutation with an average of 10 connections fixed. The organism tries out random settings for the modifiable connections until it hits upon the combination that is advantageous; this is recognizable to the organism and causes it to retain those settings. Having attained that state the organism enjoys a higher rate of reproduction; the sooner it attains it, the greater the benefit. In such a population there *is* an advantage to having less than 100% of the correct network. Among the organisms with, say, 10 innate connections, the one in every thousand (2^{10}) that has the right ones will have some probability of attaining the entire network; in a thousand learning trials, this probability is fairly high. For the offspring of that organism, there are increasing advantages to having more and more of the correct connections innately determined, because with more correct connections to begin with, it takes less time to learn the rest, and the chances of going through life without having learned them get smaller.

Hinton and Nowlan have confirmed these intuitions in a computer simulation, demonstrating nicely that learning can guide evolution, as the argument in this section requires, by turning a spike in fitness space into a gradient. Moreover, they made an interesting discovery. Though there is always a selection pressure to make learnable connections innate, this pressure diminishes sharply as most of the connections come to be innately set, because it becomes increasingly unlikely that learning will fail for the rest. This is consistent with the speculation that the multiplicity of human languages is in part a consequence of learning mechanisms existing prior to (or at least independent of) the mechanisms specifically dedicated to language. Such learning devices may have been the sections of the ladder that evolution had no need to kick away.

5.3. *Reproductive advantages of better grammars*

David Premack (1985, pp. 281–82) writes:

> I challenge the reader to reconstruct the scenario that would confer selective fitness on recursiveness. Language evolved, it is conjectured, at a time when humans or protohumans were hunting mastodons. . . . Would it be a great advantage for one of our ancestors squatting alongside the embers, to be able to remark: "Beware of the short beast whose front hoof Bob

cracked when, having forgotten his own spear back at camp, he got in a glancing blow with the dull spear he borrowed from Jack"?

Human language is an embarrassment for evolutionary theory because it is vastly more powerful than one can account for in terms of selective fitness. A semantic language with simple mapping rules, of a kind one might suppose that the chimpanzee would have, appears to confer all the advantages one normally associates with discussions of mastodon hunting or the like. For discussions of that kind, syntactic classes, structure-dependent rules, recursion and the rest, are overly powerful devices, absurdly so.

Premack's rhetorical challenge captures a conviction that many people find compelling, perhaps even self-evident, and it is worth considering why. It is a good example of what Dawkins (1986) calls the Argument from Personal Incredulity. The argument draws on people's poor intuitive grasp of probabilistic processes, especially those that operate over the immensities of time available for evolution. The passage also gains intuitive force because of the widespread stereotype of prehistoric humans as grunting cave men whose main reproductive challenge was running away from tigers or hunting mastodons. The corollary would seem to be that only humans in modern industrial societies – and maybe only academics, it is sometimes implied – need to use sophisticated mental machinery. But compelling as these commonsense intuitions are, they must be resisted.

5.3.1. Effects of small selective advantages. First, one must be reminded of the fact that tiny selective advantages are sufficient for evolutionary change. According to Haldane's (1927) classic calculations, for example, a variant that produces on average 1% more offspring than its alternative allele would increase in frequency from 0.1% to 99.9% of the population in a little more than 4,000 generations. Even in long-lived humans this fits comfortably into the evolutionary timetable. (Needless to say, fixations of different genes can go on in parallel.) Furthermore, the phenotypic effects of a beneficial genetic change need not be observable in any single generation. Stebbins (1982) constructs a mathematical scenario in which a mouselike animal is subject to selection pressure for increased size. The pressure is so small that it cannot be measured by human observers, and the actual increase in size from one generation to the next is also so small that it cannot be measured against the noise of individual variation. Nonetheless, this mouse would evolve to the size of an elephant in 12,000 generations, a slice of time that is geologically "instantaneous." Finally, very small advantages can also play a role in macroevolutionary successions among competing populations of similar organisms. Zubrow (1987) calculates that a 1% difference in mortality rates among geographically overlapping Neanderthal and modern populations could have led to the extinction of the former within 30 generations, or a single millennium.

5.3.2. Grammatical complexity and technology. It has often been pointed out that our species is characterized by two features – technology and social relations among nonkin – that have attained levels of complexity unprecedented in the animal kingdom. Toolmaking is the most widely advertised ability, but the knowledge underlying it is only a part of human technological competence. Modern hunter-gatherers, whose lifestyle is our best source of evidence for that of our ancestors, have a folk biology encompassing knowledge of the life cycles, ecology, and behavior of wild plants and animals "that is detailed and thorough enough to astonish and inform professional botanists and zoologists" (Konner 1982, p. 5). This ability allows the modern !Kung San, for example, to enjoy a nutritionally complete diet with small amounts of effort in what appears to us to be a barren desert. Isaac (1983) interprets fossil remains of home bases as evidence for a lifestyle depending heavily on acquired knowledge of the environment as far back as two million years ago in *Homo habilis*. An oft-noted special feature of humans is that such knowledge can accumulate across generations. Premack (1985) reviews evidence that pedagogy is a universal and species-specific human trait, and the usefulness of language in pedagogy is not something that can be reasonably doubted. As Brandon and Hornstein (1986) emphasize, there is presumably a large selective advantage conferred by being able to learn in a way that is essentially stimulus-free (Williams, 1966, made a similar point.) Children can learn from a parent that a food is poisonous or that a particular animal is dangerous; they do not have to observe or experience this by themselves.

With regard to adult-to-adult pedagogy, Konner (1982, p. 171) notes that the !Kung discuss

> everything from the location of food sources to the behavior of predators to the movements of migratory game. Not only stories, but great stores of knowledge are exchanged around the fire among the !Kung and the dramatizations – perhaps best of all – bear knowledge critical to survival. A way of life that is difficult enough would, without such knowledge, become simply impossible.

Devices designed for communicating precise information about time, space, predicate-argument relations, restrictive modification, and modality are not wasted in such efforts. Recursion, in particular, is extraordinarily useful. Premack repeats a common misconception when he uses tortuous phrases as an exemplification of recursive syntax; without recursion you can't say *the man's hat* or *I think he left*. All you need for recursion is an ability to embed a phrase containing a noun phrase within another noun phrase or a clause within another clause, which falls out of pairs of rules as simple as NP → det N PP and PP → P NP. Given such a capacity, one can now specify reference to an object to an arbitrarily fine level of precision. These abilities can make a big difference. For example, it makes a big difference whether a far-off region is reached by taking the trail that is in front of the large tree or the trail that the large tree is in front of. It makes a difference whether that region has animals that you can eat or animals that can eat you. It makes a difference whether it has fruit that is ripe or fruit that was ripe or fruit that will be ripe. It makes a difference whether you can get there if you walk for three days or whether you can get there and walk for three days.

5.3.3. Grammatical complexity and social interactions. What is less generally appreciated is how important linguistically supported social interactions are to a hunter-gatherer way of life. Humans everywhere depend on cooperative efforts for survival. Isaac (1983) reviews evidence that a lifestyle depending on social interactions among nonkin was present in *Homo habilis* more than two million years ago. Language in particular would seem to be deeply woven into such interactions, in a manner that is not qualitatively different from that of our own "advanced" culture. Konner (1982) writes:

> War is unknown. Conflicts within the group are resolved by talking, sometimes half or all the night, for nights, weeks on end. After two years with the San, I came to think of the Pleistocene epoch of human history (the three million years during which we evolved) as one interminable marathon encounter group. When we slept in a grass hut in one of their villages, there were many nights when its flimsy walls leaked charged exchanges from the circle around the fire, frank expressions of feeling and contention beginning when the dusk fires were lit and running on until the dawn. (p. 7)
>
> If what lawyers and judges do is work, then when the !Kung sit up all night at a meeting discussing a hotly contested divorce, that is also work. If what psychotherapists and ministers do is work, then when a !Kung man or woman spends hours in an enervating trance trying to cure people, that is also work (p. 371).

Reliance on such exchanges puts a premium on the ability to convey such socially relevant abstract information as time, possession, beliefs, desires, tendencies, obligations, truth, probability, hypotheticals, and counterfactuals. Once again, recursion is far from being an "overly powerful device." The capacity to embed propositions within other propositions, as in [$_S$*He thinks that S]* or [$_S$*She said that* [$_S$*he thinks that S*]], is essential to the expression of beliefs about the intentional states of others. [Cf. Premack: "Does the Chimpanzee Have a Theory of Mind" *BBS* 1(4)1978.]

Furthermore, in a group of communicators competing for attention and sympathies there is a premium on the ability to engage, interest, and persuade listeners. This in turn encourages the development of discourse and rhetorical skills and the pragmatically relevant grammatical devices that support them. Symons's (1979) observation that tribal chiefs are often both gifted orators and highly polygynous is a splendid prod to any imagination that cannot conceive of how linguistic skills could make a Darwinian difference.

5.3.4. Social use of language and evolutionary acceleration. The social value of complex language probably played a profound role in human evolution that is best appreciated by examining the dynamics of cooperative interactions among individuals. [See: Caporael et al.: "Selfishness Re-examined" *BBS* 12(4)1989.] As mentioned, humans, probably early on, fell into a lifestyle that depended on extended cooperation for food, safety, nurturance, and reproductive opportunities. This lifestyle presents extraordinary opportunities for evolutionary gains and losses. On the one hand, it benefits all participants by surmounting prisoners' dilemmas. On the other hand, it is vulnerable to invasion by cheaters who reap the benefits without paying the costs (Axelrod & Hamilton 1981; Cosmides 1989; Hamilton 1964; Maynard Smith 1974; Trivers 1971). [See also Maynard Smith: "Game Theory and the Evolution of Behavior" *BBS* 7(1)1984.] The minimum cognitive apparatus needed to sustain this lifestyle is memory for individuals and the ability to enforce social contracts of the form "If you take a benefit then you must pay a cost" (Cosmides 1989). This alone puts a demand on the linguistic expression of rather subtle semantic distinctions. It makes a difference whether you understand me as saying that if you give me some of your fruit I will share meat that I will get, or that you should give me some fruit because I shared meat that I got, or that if you don't give me some fruit I will take back the meat that I got.

But this is only a beginning. Cooperation opens the door to advances in the ability of cheaters to fool people into believing that they have paid a cost or that they have not taken a benefit. This in turn puts pressure on the ability to detect subtle signs of such cheating, which puts pressure on the ability to cheat in less detectable ways, and so on. It has been noted that this sets the stage for a cognitive "arms race" (e.g., Cosmides & Tooby 1989; Dawkins 1976; Tooby & DeVore 1987; Trivers 1971). Elsewhere in evolution such competitive feedback loops, such as in the struggle between cheetahs and gazelles, have led to the rapid evolution of spectacular structures and abilities (Dawkins 1982). The unusually rapid enlargement of the human brain, especially the frontal lobes, has been attributed to such an arms race (Alexander 1987; Rose 1980). After all, it doesn't take all that much brain power to master the ins and outs of a rock or to get the better of a berry. But interacting with an organism of approximately equal mental abilities whose motives are at times outright malevolent makes formidable and ever-escalating demands on cognition. This competition is not reserved for obvious adversaries. Partial conflicts of reproductive interest between male and female, sibling and sibling, and parent and offspring are inherent to the human condition (Symons 1979; Tooby & DeVore 1987; Trivers 1974).

It should not take much imagination to appreciate the role of language in a cognitive arms race. In all cultures, human interactions are mediated by attempts at persuasion and argument. How a choice is framed plays a huge role in determining which alternative people choose (Tversky & Kahneman 1981). The ability to frame an offer so that it appears to present maximal benefit and minimum cost to the buyer, and the ability to see through such attempts and to formulate persuasive counterproposals, would have been a skill of inestimable value in primitive negotiations, as it is today. So is the ability to learn of other people's desires and obligations through gossip, an apparently universal human vice (Cosmides & Tooby 1989; Symons 1979).

In sum, primitive humans lived in a world in which language was woven into the intrigues of politics, economics, technology, family, sex, and friendship and that played key roles in individual reproductive success. They could no more live with a Me-Tarzan-you-Jane level of grammar than we could.

5.4. Phyletic continuity

Bates et al. (1989), Greenfield (1987), and Lieberman (1976; 1984) argue that if language evolved in humans by natural selection, it must have antecedents in closely related species such as chimpanzees, which share 99% of their genetic material with us and may have diverged from a common ancestor as recently as 5 to 7 million years ago (King & Wilson 1975; Miyamoto et al. 1987). Similarly, because no biological ability can evolve out of nothing, they claim, we should find evidence of nonlinguistic abilities in humans that are continuous with grammar. Lieberman claims that motor programs are preadaptations for syntactic rules whereas Bates (1976) and Greenfield (Greenfield & Smith 1976) suggest that communicative gestures flow into linguistic naming. As Bates et al. (1989, p. 8) put it, "we have to abandon any strong version of the discontinuity claim that has characterized generative grammar for thirty years. We have to find some way to ground symbols and syntax in the mental material that we share with other species."

The specific empirical claims have been disputed. Seidenberg and Petitto (Seidenberg 1986; Seidenberg & Petitto 1979; 1987) have reviewed the evidence of the signing abilities of apes and concluded that they show no significant resemblance to human language or to the process of acquiring it. In a study of the acquisition of sign language in deaf children, Petitto (1987) argues that nonlinguistic gestures and true linguistic names, even when both share the manual-visual channel, are completely dissociable. These conclusions could be fodder for the claim that natural language represents a discontinuity from other primate abilities and so could not have evolved by natural selection.

We find the Seidenberg and Petitto demonstrations convincing, but our argument is not based on whether they are true. Rather we completely disagree with the premise (not theirs) that the debate over ape signing should be treated as a referendum on whether human language evolved by natural selection. Of course human language, like other complex adaptations, could not have evolved overnight. But then there is no law of biology that says that scientists are blessed with the good fortune of being able to find evolutionary antecedents to any modern structure in some other living species. The first recognizably distinct mental system that constituted an antecedent to modern human language may have appeared in a species that diverged from the chimp-human common ancestor, such as *Australopithecus afarensis* or any of the subsequent hominid groups that led to our species. Moreover, chimpanzees themselves are not generalized common ancestors but presumably have done some evolving of their own since the split. We must be prepared for the possible bad news that there just aren't any living creatures with homologues of human language, and let the chimp singing debate come down as it will.

As far as we know, this would still leave plenty of time for language to have evolved: 3.5 to 5 million years, if early Australopithecines were the first talkers, or, as an absolute minimum, several hundred thousand years (Stringer & Andrews 1988), in the unlikely event that early *Homo sapiens* was the first. (For what it's worth, Broca's area is said to be visible in cranial endocasts of two-million-year-old fossil hominids [Falk 1983; Tobias 1981].) There is also no justification in trying to squeeze conclusions out of the genetic data. On the order of 40 million base pairs differ between chimpanzees and humans, and we see no reason to doubt that universal grammar would fit into these 10 megabytes with lots of room left over, especially if provisions for the elementary operations of a symbol-manipulation architecture are specified in the remaining 99% of the genome (see Seidenberg, 1986, for discussion).

In fact, there is even more scope for design differences than the gross quantity of nonshared genetic material suggests. The 1% difference between chimps and humans represents the fraction of base pairs that are different. But genes are long stretches of base pairs, and if even one pair is different, the entire functioning product of that gene could be different. Just as replacing one bit in every byte leads to text that is 100% different, not 12.5% different, it is possible for the differing base pairs to be apportioned so that 100% of the genes of humans and chimps are different in function. Though this extreme possibility is, of course, unlikely, it warns us not to draw any conclusions about phenotypic similarity from degree of genomic overlap.[4]

As for continuity between language and nonlinguistic neural mechanisms, we find it ironic that arguments that are touted as being "biological" do not take even the most elementary steps to distinguish between analogy and homology. Lieberman's claim that syntactic rules must be retooled motor programs, a putative case of preadaptation, is a good example. It may be right, but there is no reason to believe it. Lieberman's evidence is only that motor programs are hierarchically organized and serially ordered, and so is syntax. But hierarchical organization characterizes many neural systems, perhaps any system, living or nonliving, that we would want to call complex (Simon 1969). And an organism that lives in real time is going to need a variety of perceptual, motor, and central mechanisms that keep track of serial order. Hierarchy and seriality are so useful that for all we know they may have evolved many times in neural systems (Bickerton, 1984; 1986, also makes this point). To distinguish true homology from mere analogy it is necessary to find some unique derived nonadaptive character shared by the relevant systems, for example, some quirk of grammar that can be seen in another system. Not only has no such shared character been shown, but the dissimilarities between syntax and motor control are rather striking. Motor control is a game of inches so its control programs must have open continuous parameters for time and space at every level of organization. Syntax has no such analogue parameters. A far better case could be made that grammar exploited mechanisms originally used for the conceptualization of topology and antagonistic forces (Jackendoff 1983; Pinker 1989b; Talmy 1983; 1988), but that is another story.

6. Conclusion

As we warned, the thrust of this target article has been entirely conventional. All we have argued is that human language, like other specialized biological systems, evolved by natural selection. Our conclusion is based on two facts that we would think would be entirely uncontroversial: Language shows signs of complex design for the communication of propositional structures, and the only explanation for the origin of organs with complex design is the process of natural selection. Although distinguished scientists from a wide variety of fields and ideologies have tried to cast doubt on an orthodox Darwinian account of the evolution of a biological specialization for grammar, upon close examination none of the arguments is compelling.

We hope, however, that we have done more than try to set the record straight. Skepticism about the possibility of saying anything of scientific value about language evolution has a long history, beginning in the prohibition against discussing the topic by the Société de Linguistique de Paris in 1866 and culminating in the encyclopedic volume edited by Harnad et al. (1976) that pitted a few daring speculators against an army of doubters. A suspicious attitude is not entirely unwarranted when one reads about The Age of Modifiers, Pithecanthropus Alalus ("Ape-man without speech"), and the Heave-ho theory. But such skepticism should not lead to equally unsupported assertions about the necessity of spandrels and saltations.

A major problem among even the more responsible attempts to speculate about the origins of language has been that they ignore the wealth of specific knowledge about the structure of grammar discovered during the past 30 years. As a result, language competence has been equated with cognitive development, leading to confusions between the evolution of language and the evolution of thought, or has been expediently equated with activities that leave tangible remnants, such as tool manufacture, art, and conquest.

We think there is a wealth of respectable new scientific information relevant to the evolution of language that has never been properly synthesized. The computational theory of mind, generative grammar, articulatory and acoustic phonetics, developmental psycholinguistics, and the study of dynamics of diachronic change could profitably be combined with recent molecular, archeological, and comparative neuroanatomical discoveries and with strategic modeling of evolution using insights from evolutionary theory and anthropology (see, e.g., Barkow et al. in press; Bickerton 1981; Brandon & Hornstein 1986; Hinton & Nowlan 1987; Hurford 1989a; 1989b; Tooby & DeVore 1987). It is certain that there are many questions about the evolution of language that we will never answer, but we are optimistic that there are insights to be gained, if only the problems are properly posed.

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NOTES

1. For example, he says that "Language must surely confer enormous selective advantages" (Chomsky 1980a, p. 239; see also Chomsky 1975, p. 252), and argues that,

> . . . suppose that someone proposes a principle which says: The form of a language is such-and-such because having that form permits a function to be fulfilled – a proposal of this sort would be appropriate at the level of evolution (of the species, or of language), not at the level of acquisition of language by an individual (Chomsky 1977, pp. 86–87).

2. Dennett (1983), it is interesting to note, argues that Gould and Lewontin's critique is remarkably similar in logic to critiques of another large-scale theory, the representational theory of mind in cognitive science, by behaviorists. Dennett sees common flaws in the critiques: Both fail to account for cases of adaptive complexity that are not direct consequences of any law of physics, and both apply the criterion of falsifiability in too literal-minded a way.

3. Note also that historical change in languages occurs very rapidly by biological standards. Wang (1976) points out, for example, that one cycle of the process whereby a language alternates between reliance on word order and reliance on affixation typically takes a thousand years. A hominid population evolving language could be exposed to the full range of linguistic diversity during a single tick of the evolutionary clock, even if no single generation was faced with all humanly possible structures.

4. We thank John Tooby for pointing this out to us.

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Welcome to functionalism

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Torn between their attachment to the Chomskyan view of a set of autonomous linguistic modules and their appreciation of the central role of natural selection, Pinker & Bloom (P&B) have opted to bring their earlier linguistic persuasions (Pinker 1984) into accord with the biological facts. In doing so, they have moved, far more than they realize, into the camp of the linguistic functionalists where they are indeed welcome.

Bates and MacWhinney (1989) laid out four levels of the functionalist position, ordered by the amount and type of evidence that is necessary to make each claim go through. In Level 1 theories, communicative functions play an historical role in determining the range of forms a natural language can take – keeping in mind that the term "function" refers not only to communicative content, but also to the range of information processing constraints that impinge on communication in real time. Level 1 claims can only be substantiated indirectly, using diverse lines of evidence to reconstruct a plausible historical scenario. Level 2 theories go one step further: Communicative functions continue to play a causal role today in constraining the range of languages that a human being can process and acquire. Such claims presuppose Level 1 functionalism, but also require evidence from correlational studies of the range of contexts in which a given form or set of forms is used as well as experimental studies manipulat-