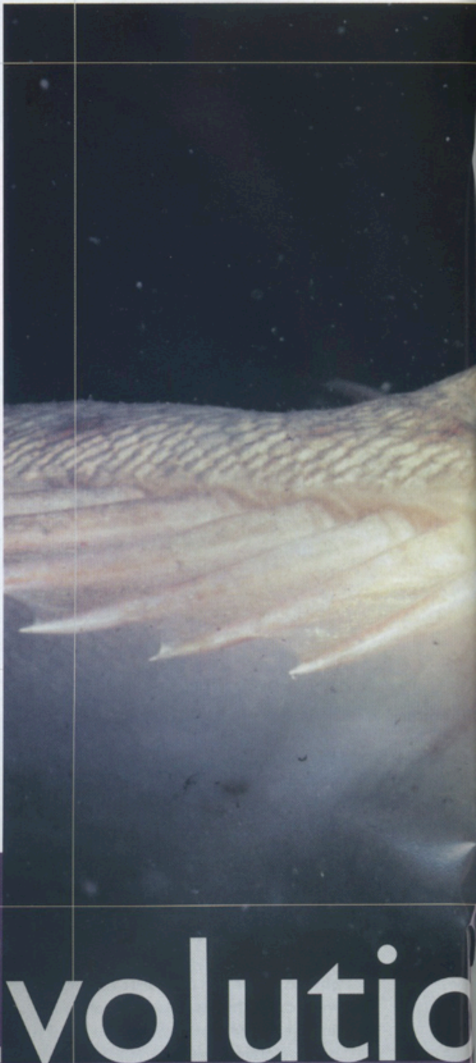
In this article, you will learn that:

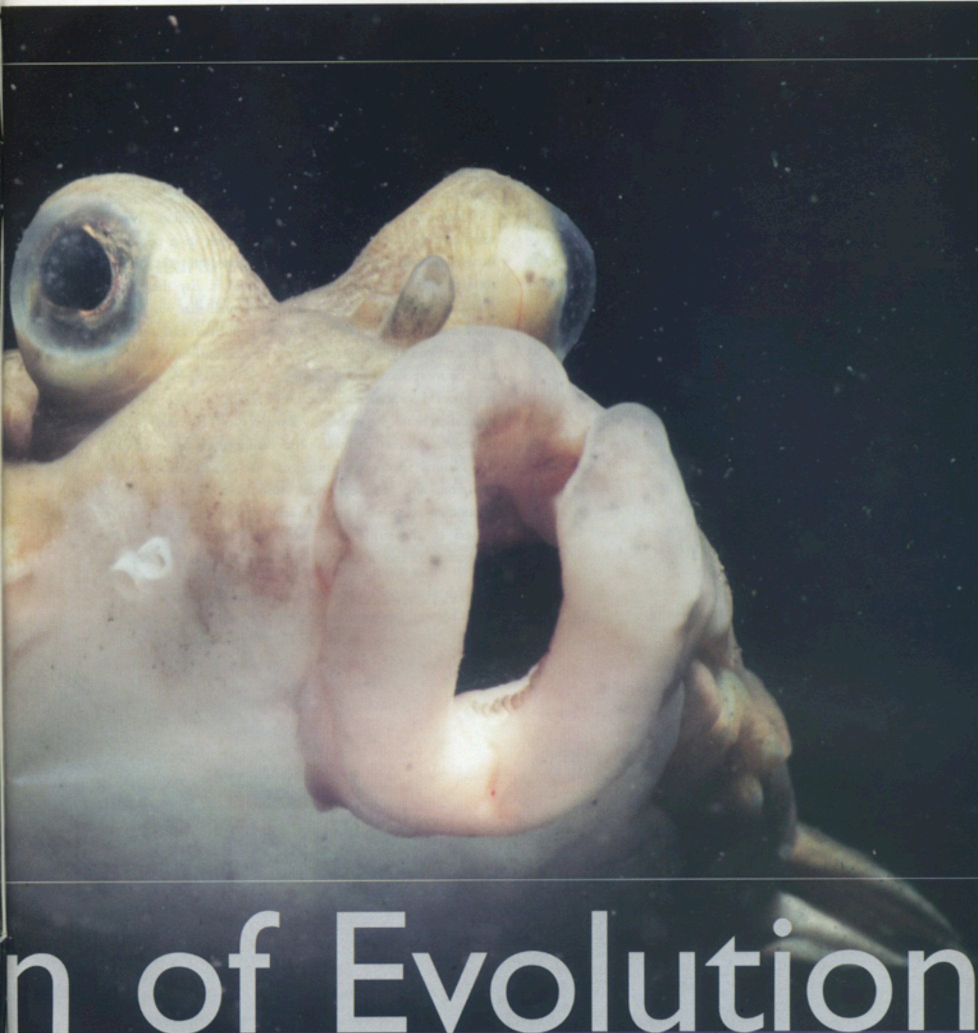
- Darwin's theory refuted evolution
- Big feet have nothing to do with sex, but a big nose might
- Death is optional
- And a host of other curious facts about how life got to be the way it is.

by Philip Johansson



The Evolutio

Flounder © Jeffrey L. Rotman / CORBIS



n of Evolution

The history of life has no plot.

Although it is often depicted as a billion-year epic drama, a steady upward march toward some semblance of "progress," the mechanisms of evolution are more opportunistic and disorderly than purposeful. One only has to look at a mudpuppy to realize this.

One of the pivotal moments in the apparent march toward progress was when certain fish evolved simple legs and lungs, and led the invasion of land by amphibians. Mudpuppies, and several other curious salamanders, like sirens and *amphiuma*, have turned history on its head by foregoing these apparent biological advancements and returning to the water for their entire adult lives. They have adopted a "simpler" form, sporting large external gills and legs that are mere vestiges of those on their landlubber ancestors. Yet they are entirely successful, arguably more so than the hundreds of land-living salamanders that have gone extinct over the past 350 million years. Mudpuppies are living proof that evolution is not about progress. It is merely about change.

When Charles Darwin finally published the *On the Origin of Species* in 1859, he had kept his theory a secret for more than 20 years for exactly that reason. What Darwin proposed was not evolution, which others of his time had already speculated on. The concept of evolutionary progress was supported by ancient and biblical teachings: lower beings evolved into higher beings, and all of biological history was an inclined plane, a "Great Chain of Being," with humans at the top, of course. All of this progress was seen as clear evidence of a divine plan, and so was taken as proof both of God's existence and his preference for us humans. Darwin's heresy was to propose a mechanism by which living forms changed not by purposeful design, but strictly in response to their environment. God was taken out of the equation, humans were no longer the crown jewel of creation, and the uproar these ideas started has continued to this day. (In fairness to Darwin, it should be pointed out that he did not intend to deny the existence of God; rather, his data simply suggested that God did not operate in so biologically straightforward a manner as tradition held.)

In God's place, Darwin gave us "natural selection." Natural selection simply means that some individuals in a population survive and reproduce more than others, based on traits inherited through their genes. That's all there is to it. Say there was a population of moles living in an environment that was growing more arid. If some of the moles in the population had a gene for longer claws, more useful for digging tunnels in the dry soils, they may be more successful at surviving and reproducing than their neighbors. This is natural selection in action, and may result in a population brimming with long-clawed moles. There is no pretense of progress here, merely moles better equipped for new conditions.

Natural selection is considered the central mechanism of evolution, and has been held responsible for a plethora of astounding anatomical and behavioral traits, from the color of flowers to the shape of a bird's beak (See "The Ultimate Adaptation"). Take a close look at fleas, for example. Fleas are

Sage Grouse © D. Robert Franz / CORBIS

adorned with a stunning variety of hairs, bristles, and spines, used to help them grasp onto the fur or feathers of their mammal or bird hosts. These anatomical accouterments are so specialized to the specific hosts that each flea species relies on, that a flea biologist can identify the exact host of any flea by its particular armature of hairs. Just as in the case of our hypothetical long-clawed moles, natural selection has favored fleas with hairs and bristles suited to particular hosts. Fleas on a golden retriever with bristles better-equipped for grasping long silky golden retriever hair survive and reproduce better than those less suited.

Unnatural selection:

But it is fair to say that natural selection is not completely responsible for every trait you can imagine, although it has been tempting for many to err in this direction. Penguins apparently evolved short wings and torpedo-like bodies for swimming in Antarctic seas by the action of natural selection. Flightlessness in penguins, on the other hand, is not the direct product of natural selection. An absence of land predators indulged this drastic modification, but did not cause it: flightlessness is merely a necessary consequence of the penguin's unique mastery of swimming.

For an example closer to home, take the squishy skull of a human baby. As in all mammals, sutures in a baby's skull allow the bones to be squeezed together during birth, much to the relief of countless mothers. These skull sutures would appear to be the result of natural selection to make birth go more smoothly, and Darwin himself pointed out their usefulness, even necessity, for this purpose. But the fact that the same skull sutures appear in young birds and reptiles, which have only to squeeze out of a broken egg, shows that this trait is a fortuitous legacy of our ancestry. Rather than being a product of natural selection, this is simply the way skulls grow in all vertebrates; mammals just have exploited this anomaly.

There are limits to what kinds of modifications can be mediated by natural selection. It can only act on variations that are already found in the population, for instance, and that have a genetic basis. Natural selection cannot "create" new variations, which only come about through the process of genetic mutation.

The Ultimate Adaptation

The evolutionary mechanisms described here are happening on a massive scale, all around us, right now. Insect populations around the globe are growing tolerant of pesticides and bacteria are becoming immune to antibiotics, through the day-to-day use of these agents. Although the selective forces at work here are less than natural, the mechanism is exactly the same as in natural selection: individuals with traits providing immunity are surviving and reproducing more successfully than others, with the inevitable outcome of supertolerant species. But the critical precedent driving this dramatic change is the evolution of death.

It's been said that the only sure things in life are death and taxes, but, in fact, death is not a prerequisite of life. Early life forms may have survived and reproduced merrily for millennia without growing old, suffering their only mortality from environmental factors or predation. But somewhere early in the history of life, organisms with the properties of senescence and death came along. Dying allowed these organisms to reproduce and then make room for the success of future generations, their progeny. Since the mechanisms of evolution rely on the relative success of genetic traits through the generations, dying afforded the opportunity for populations to adapt to new or changing environments.

In the game of evolution, the player that reproduces and dies the fastest has an edge on other players. Insects often have life cycles that can be measured in days, and bacteria replicate in a matter of hours. It is therefore no coincidence that the most dramatic evolution witnessed today is in these very successful life forms. Agricultural engineers and doctors would do well to take heed of this everyday evolution, and the significance of the evolution of death.

Male sage grouse bear no resemblance to females, particularly when they're in the mood for love. They spread out their tails in a spiky fan, swell their necks in a gaudy ruff of fluffy white feathers, and masterfully display a sequence of squeaking wings, plopping air sacs, and a vocal "wa-um-poo." *Vive la différence.*

Mutations are small random mistakes in the genetic code; they usually have a neutral effect on the individual, but, on occasion, they produce new viable variations for natural selection to act on. Natural selection is, like it says, selective. It's opportunistic rather that purposeful. It doesn't matter how advantageous longer claws might be, those moles will just have to do without them, perhaps perishing as a result, unless some genetic mutation arises for natural selection to act on.

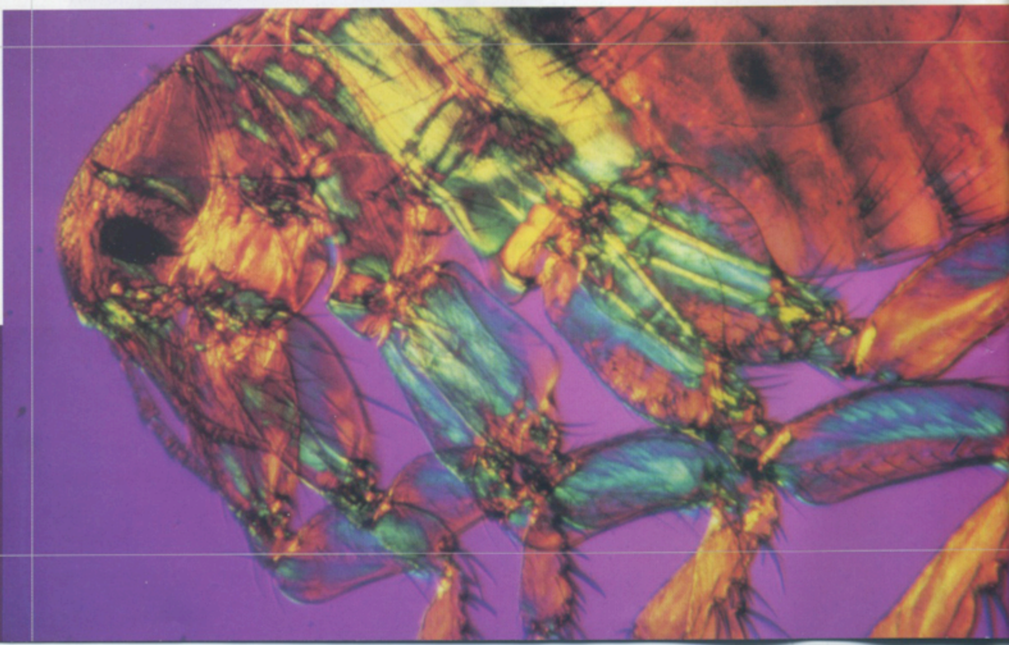
Natural selection is limited not only by the availability of variations, but by the history of the lineage and the intricate processes of development required to produce a complete living organism. For example, we don't find house flies the size of elephants (thank heavens). The breathing apparatus of all insects is an intricate system of tubes leading from tiny openings on their flanks. These tubes bring oxygen from the outside directly to the insects' tissues, a very efficient system on a small scale. But they are physiologically impossible for animals much bigger than 100 grams, about the size of the largest insects, like the Hercules beetle of South America. By the same token, we don't find mollusks with wings, or birds with shells, or mammals with six legs.

We also don't find sea turtles that lay eggs in the sea. Leatherback turtles (*Dermochelys coriacea*), for example, have navigated the world's oceans for over 120 million years, but females still return to shore every few years to lay their eggs. It is an arduous undertaking, lugging her more than 400 kilograms up onto shore and digging a nest, rife with dangers for herself and her offspring. But she is bound by a limitation of the reptilian embryo: it must develop on land where it can breath. Not even 120 million years of evolution could erase that pattern. Life on Earth is full of these quirks of history. It would be reasonable for female bats to lay eggs, as birds and flying insects do, to avoid hampering their flight with developing young. But their mammalian ancestry constrains them to internal development, so they are typically limited to one offspring per pregnancy.

Choose your selection:

But even beyond the limitations of history and development, there are many traits that can't be explained by natural selection. One of these is the distinct difference in anatomy and behavior between males and females of many species. Male sage grouse (*Centrocercus urophasianus*) of the American West bear no resemblance to the inconspicuous and demure females, particularly when they're in the mood for love. They spread out their tails in a spiky fan, swell their necks in a gaudy ruff of fluffy white feathers, and masterfully display a sequence of squeaking wings, plopping air sacs, and a vocal "wa-um-poo." *Vive la différence.* These characteristics and behaviors would appear to be very disadvantageous in terms of natural selection, especially if a coyote happens to be in the neighborhood. They are instead a product of "sexual" selection, a mechanism also posed by Darwin

Flea © Ron Boardman; Frank Lane Pictures / CORBIS



in *The Descent of Man and Selection in Relation to Sex.*

Sexual selection is called into play when individuals in a population are more or less successful in reproducing due to variations favored by courtship behavior. In the case of the male sage grouse, if his position in a group of strutting cocks is favorable, and his "wa-um-poo" robust, he is likely to fertilize a majority of females in the local population. Any variations in tail shape, ruff feathers, or courtship behavior possessed by this grouse will be well represented in the next generation. This kind of sexual selection is determined by the choices made by females in the population. Another kind of sexual selection is the direct competition between males for mating access to females, resulting in traits like the enormous horns of the bighorn sheep or the blubbery belligerence of elephant seals hoarding their harems. The fact that sexual selection often operates directly counter to natural selection, resulting in the alluring colors of many songbirds that appear to say "eat me" to any predator, suggests its importance as an evolutionary mechanism.

Another kind of trait that has been hard to explain in terms of natural selection has been altruistic, or helpful, behaviors, such as food sharing, cooperative breeding, or thwarting predators. Why would any animal accept the risk or cost involved in these behaviors if it is trying improve its own survival or reproduction? Mated pairs of Florida scrub jays (*Aphelocoma coerulescens*, studied in the 1980s by Earthwatch teams working with Dr. Jack Hailman) often enjoy the help of other jays from the population to raise their nestlings, a behavior that would appear antithetical to the survival and reproduction of the "helpers." But closer study has revealed that helpers at the nest in this and several other bird species are actually grown fledglings of the same pair, an example of "kin" selection in action.

Kin selection favors altruistic behaviors toward close relatives because those same behaviors help the survival and reproduction of genes shared by those kin. The clearest example of this is parental behavior, but it also explains the helpful behaviors exhibited by more distant relatives. While the scrub jay helpers at the nest may not be improving their own chances of survival, they are increasing the chances that genetic traits shared by their siblings in the nest will carry on. In a more extreme case, honeybee workers help raise the brood of the queen bee without ever reproducing themselves, thanks to the high level of relatedness to other members of the hive.

The Song Remains the Same

Darwin's theory of natural selection was prompted by the finches of the Galapagos islands. These birds have evolved to fill all sorts of niches on islands they originally found to be empty and have taken on the forms of other birds who fill similar niches in other places. So there are now finches that are shaped like woodpeckers and live like woodpeckers, finches that are shaped like warblers and live like warblers, and so on through 14 types.

But in 1979, Dr. Robert Bowman and his Earthwatch teams found that this mimicry went beyond shape and function: Each Galapagos finch's song is nearly identical to the type of mainland bird it resembles physically. The song of the woodpecker-like finch is practically indistinguishable from that of a red-shafted flicker in North America; the Galapagos titmouse-finch matches the plain titmouse; and so on down the line.

This situation forces us to reassess the nature of bird song. Is a bird's song related to its body shape? But how would a bird's body shape dictate the pattern of pitches and rhythms? Perhaps there's some universal bird word for "grasshopper" that all ground-feeding birds use, whether finch or flicker. Or is the song related to a bird's habitat? Bowman himself favored this explanation, hypothesizing that the relative absorption or reflectivity of the habitat dictated both the pitch and the rhythm of the song, so it could be heard at appropriate distances.

A final form of selection to consider operates on a much broader scale, at the level of the species rather than the level of the individual. Species selection means that some species within a lineage are more successful at producing more species than others. (See "Forking Evolution") This kind of selection is based on characteristics of the species rather than traits of individuals, things that improve the likelihood of producing new species or resisting extinction within the lineage. While such characteristics are hard to imagine, there are many examples. For instance, the impalas of Africa appear to be very conservative in terms of speciation,

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Forking Evolution

Natural selection and other mechanisms that shape life on Earth are only one side of the evolutionary coin. If a species underwent all the modifications in the world, it would still result in only one species, rather than the millions that populate the Earth and the hundreds of millions more that have gone extinct over time. This variety of forms has come from forks in the living lineage through a process called "speciation." Although Darwin's celebrated title was *On the Origin of Species*, the book barely addresses this subject, and it has remained one of the most controversial aspects of life's history.

Some occurrences of speciation may emerge through the processes discussed here, the result of the various forces of selection and chance operating on isolated populations over vast periods of time. If the population that is changing is isolated from others of its kind for some centuries, it could lead to a distinct species. For instance, red wolves (*Canis rufus*) of the southwestern U.S. and coyotes (*Canis latrans*) of the American west are closely related species that presumably diverged when climatic or ecological changes isolated them from each other, preventing them from interbreeding. Many other speciations are explainable in these terms, although the actual historic events leading up to the divergence are harder to pin down.

But other speciation events appear to happen over shorter periods of time, resulting in the bursts of diversification responsible for much of the Earth's astounding biological variety. These myriad-pronged forks in the evolutionary record are termed "radiations," and occurred in response to the colonization of new habitats, mass extinctions, or the introduction of biological innovations. For instance, the appearance of bony skeletons in early fishes about 300 million years ago, and swim bladders some time after, led to a radiation of bony fishes that soon dominated both fresh and salt water, resulting in over 20,000 species today. Similarly, the mass extinction of the dinosaurs 65 million years ago resulted in a massive radiation of mammals, which had been waiting on the sidelines for nearly 200 million years.

While the history of extinctions and radiations appears to follow a faltering trajectory toward progress, there is an element of luck involved here too. There is good reason to believe that the next mass extinction, the one driven by global climate change, pollution, and habitat destruction, will be hardest on the most "evolved" mammals, birds, and other organisms, including ourselves. Arthropods, other invertebrates, and protozoa accustomed to extreme environments may inherit the Earth, leading the next radiation. Although our anthropocentric view insists that evolution is a means toward and end, namely us, the only direction implied by the history of life is toward increasing diversity.

Coyote pups © Jim Brandenburg / Minden Pictures

generating only three very similar species in the last 5 million years. Meanwhile the related wildebeest tribe has speciated profusely over the same time period.

While species selection will not help explain why sage grouse "wa-um-poo," or why flea hairs are curly, it may be a potent force in determining the big picture of which evolutionary lineages persist and which do not. The extinction of thousands of species of trilobites 250 million years ago is a case in point.

Evolutionary roulette:

Far from being purposive, evolution is at best a compromise. The history of life has been a giant trade-off between the various forms of selection operating simultaneously on different traits, as well as the many confounding limitations posed by genetics, development, and history. One look at the twisted visage of the flounder—sideways mouth, eyes on one side, pectoral fins all but useless—dramatically illustrates the chaotic interplay of these forces at work. But even beyond this cacophony of mechanisms, there is an important element of chance involved in evolution. This may be the greatest heresy of all against evolutionary progress.

In the same way that natural selection can favor individuals with certain traits that are helpful in a given environment, the fickle finger of chance at times can favor certain individuals regardless of their traits. This is particularly true in small populations, such as those relegated to small patches of marginal environment or isolated islands, a process called the "founder effect." The few individuals that may colonize an island will have a random sample of traits, variations which may not be characteristic of the population as a whole, thus founding a unique population, potentially evolving into a new species. For instance, field mice (*Apodemus sylvaticus*) are uniform all over continental Europe, but there are 15 distinct subspecies found in surrounding islands. The environments on these islands are not noticeably different, but the subspecies are. These island populations were founded by mice with a random sample of traits that stowed away on Viking ships a thousand years ago—the blink of the eye in evolutionary time.

One-third of the world's fruit fly species, that poster child of modern genetics, live on the tiny Hawaiian islands, a mere one-hundredth of 1 percent of the Earth's surface. An estimated 800 species of *Drosophila* can be found there, and not just because there's a lot of fruit. Fully 98 percent of them are endemic, meaning they evolved here. The 42-million-year history of the evolving volcanic island chain has offered repeated opportunities for founder events, but, in addition, there are islands on these islands. Isolated patches of forest, called *kipukas*, are surrounded by lava flows, providing additional founder opportunities for the fruit flies. Hawai'i is a veritable fruit-fly evolution machine.

As appealing as it is to suggest that evolution is an unwavering march toward progress, as do so many popular and historical accounts, it is apparently a much messier business. Natural selection and other forms of selection are abetted by chance events and hindered by myriad limitations to result in living things that are astoundingly well-adapted, but less than perfect. The fact that 99 percent of all species that once lived on Earth have disappeared, taking with them complexities uniquely suited to their environment, should be enough to convince anyone of that. Evolutionary mechanisms mimic purposeful design in the most minute detail, but their actual lack of purpose is written in the chaotic history of life on Earth. Darwin's legacy is not evolutionary progress, but the search for mechanisms that drive this relentless change.

The question is, are we any more ready to hear Darwin's heresy today? Can we accept the meandering course of evolution and its unreasonable and capricious mechanisms as the source of the Earth's astounding biodiversity? Most biologists take this for granted in their day-to-day work, but, when it comes to communicating with lay people, it seems hard to avoid evolution's old baggage. Popular accounts of evolution are rife with references to "progress," from "primitive" to more "advanced" beings, as if describing the evolution of airplanes from the Wright brothers to the Concorde jet. The difference is that there is no Wright brothers in biological evolution. We, trilobites, humans, and indigo buntings alike, are all on our own, evolutionarily speaking. The history of life is a relentless drive toward diversity, not toward progress and the inevitable ascension of humans. The sooner we realize this, the sooner we will stop exploiting life on Earth. ■

Philip Johansson is Senior Editor of Earthwatch. For further reading on the nature of evolution, see the popular writings of Steven J. Gould, Steven Stanley, E.O. Wilson, and Lynn Margulis.

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