Why Two Sexes?

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Abstract

Evolutionary role of the separation into two sexes from a cyberneticist's point of view. [I translated this 1965 article from Russian "Nauka i Zhizn" (Science and Life) in 1988. In a popular form, the article puts forward several useful ideas not all of which even today are necessarily well known or widely accepted. *Boris Lubachevsky, bdl@bell-labs.com*]

1. Are males really needed?

Interesting lizards live on the mountains of Armenia, by the shore of Lake Sevan. A peculiarity of the species is that they do not have males; their females deposit non-fertilized eggs from which only females hatch.

Such a reproductive method is extremely simple and very rational: each animal can produce progeny and the difficulties of finding a "spouse" are eliminated. It turns out that the task of reproduction can be performed quite well without males.

Another interesting method of reproduction is demonstrated by silver crucian carps *carassius auratus*, inhabitants of Russian lakes. Like the Lake Sevan lizards, only females represent the species. These females do resort to the service of males, but .... of different fish species. Sperm of "foreign" males stimulates the roe to develop. However, real fertilization, i.e. the fusion of nucleus of male and female sex cells, does not occur. The males do not generate new organisms genetically and can not claim the fatherhood. A needle or certain chemicals can play the role of a father. For example, the frog roe can be stimulated to develop by the prick of a thin needle, and cell division in the eggs of certain sea species is triggered by shaking or adding certain acids or salts to the water.

In the laboratory, even such a highly organized animal as a rabbit can be born without a father. The experimenters sometimes succeed in triggering cell division mechanically or chemically in an ovum extracted from a female rabbit; the result is then placed back into the womb of the mother. Later, the mother delivers a normal live newborn "orphan" rabbit, which can become a normal adult animal. [This method should not be confused with the much publicized *in vitro* fertilization on humans where the biological father, possibly anonymous, always exists. *Translator's comment.*]

In some species the attitude toward the male is very "unfair." For example, a spider female allows the male to copulate but eats it up immediately after the "marriage." To avoid this destiny the male must fetch some tasty food to its bloodthirsty bride. Despite its name, the female of the praying mantis *mantis religiosa* behaves "godlessly." During copulation, it bites away the head of the male so that the latter has to complete its mission with no head.

This set of examples can be augmented by the habits of bees which "permit" the males to be born only in some generations, or practice their elimination immediately after the female is fertilized.

However, in the majority of species the females "keep" their males, tolerate them and treat them fairly well. Moreover, some species which "know" how to reproduce without males, e.g. some crayfish, manage without the males in summer, when it is warm and there is enough food. But as soon as the fall or a drought begins they resort to the service of males. This makes one believe that there is still a purpose in males.

Let us try to figure out this purpose.

2. Why is the crossbreeding needed?

Two main methods of reproduction exist: asexual and sexual. Only one parent organism participates in the asexual method, producing organisms similar to itself. Two parents participate in sexual reproduction. However, the principal feature is not the quantitative one: "two from one" in the first case and "three from two" in the second case. Much more important is the qualitative feature: in the asexual method no new quality appears, whereas in each instance of the sexual reproduction new qualities appear which are different from the parental ones.

The asexual method is encountered mostly in one-cell species, whereas most animals including mammals reproduce sexually. This suggests that the latter method is more progressive from the viewpoint of evolution. The evolutionary advantages of sexual reproduction usually are attributed to the recombination of genes leading to a genetic variety.

Sexual reproduction necessarily assumes crossbreeding, and, as a rule, is accompanied by splitting into two sexes. It is the crossbreeding which generates new gene combinations. But why are two *different* sexes needed?

3. Why are two sexes needed?

A method of reproduction exists in which the animals are not separated - not differentiated - into two sexes but crossbreeding still takes place. This method is used by earthworms. Each worm is both the male and the female. Oysters behave similarly: each animal first behaves as a male and then as a female.

This method seems to have many advantages. Indeed, suppose a population consists of 100 animals and each of them without exception can breed with all the other. Then the number of possible combinations is $100 \times 99/2 = 4950$. However, if the same population is split fifty-fifty into two sexes, then the number of possible combinations is about half as large: $50 \times 50 = 2500$. The division into sexes makes things worse, as it seems, because a sexually divided population sacrifices about half of the possible genetic combinations in each generation compared with a non-divided one. What advantages are received by the sexually divided population in return?

A common belief is that the advantage is the differentiation which provides two sorts of gametes, i.e., sex cells: small mobile spermatozoa, whose task is to reach the ova, and relatively big but immobile ova, which provide the future embryos with nutrients. However, a similar specialization takes place among the hermaphroditic animals (e.g., earthworms and oysters) without sex differentiation and the accompanied decrease in the genetic variety. Hence we can not explain the biological meaning of sex differentiation in this way.

Let us try to analyze the role of the sexes in the reproduction process, i.e., to elucidate their relationships to the main production criteria: quantity, quality, and variety of the product. Because each kind of mass-production is mainly characterized by these three parameters.

4. Quantity, quality, and variety of the product

Suppose 100 bisons are released into a sanctuary. How should the ratio between the sexes be chosen, how many cows and how many bulls? Obviously, this ratio depends on the goal. For example, if the goal is to maximize the *quantity*, the number of calves, then 99 cows and 1 bull is a reasonable proportion, because 99 new calves can be born in each generation. However these calves will all share the same father, and will differ only as to the mother. The number of possible parent combinations in this case is 99.

If, on the other hand, maximum *variety* of the progeny is desired, then the number of cows should equal the number of bulls. In this case, the number of possible combinations is $50 \times 50 = 2500$. However, the number of progeny decreases, because only 50 calves will be born in each generation.

Finally if the *quality* of the herd is the goal, then conditions for sexual selection should be created in such a way that part of the animals do not participate in the reproduction. For this it is necessary to have extra males. Then, the competition for the females will eliminate the representation of some of the males from the progeny. The larger the ratio of males to females, the more severe is the selection.

Thus, there exists a kind of specialization of function between the sexes in reproduction. The two sexes have different relationships with respect to the main parameters, quantity and quality of the progeny: the more females in the population, the higher the quantity, while the more males in the population, the better the selection, and the faster the changes in quality.

This asymmetry appears only on the population level; in each family, an offspring receives roughly the same quantity of genetic information from the father and the mother. The new principle becomes apparent only if we consider not a family but the entire population. (We discuss an "ideal" population, that crossbreeds randomly.)

5. A section of the channel for genetic information transmission

The specialization described above originates in the fact that the potential of a male for the transmission of genetic information is incomparably higher than that of a female. Every male might, in principle, become the father of the entire progeny of the population, whereas the ability of females in this respect is limited.

In the jargon of cybernetics, the section of the channel for transmitting male genetic information to the progeny is significantly wider than that for transmitting female genetic information. Genetically rare males, unlike genetically rare females, can play a substantial role in changing the average genotype, i.e. the quality of the population.

The difference between the two sections of the channel to the progeny also appears in that each separate male "tends" to use his ability to the largest degree and leave a maximum quantity of progeny, thus affecting the quality of the population. At the same time, every separate female "tends" to assure the best possible quality for her limited quantity of progeny.

The schematic formula looks as follows:

The number of females determines the size of the population.
Each female fights for the quality of her progeny.
The number of males determines the quality of the population.
Each male fights for the number of his progeny.

To a certain degree, this simplified formula explains the different psychologies of the sexes. Darwin gives an incisive example of this difference: "Males of the deerhound are inclined to someone else's females, whereas the females prefer the company of familiar males." [Reverse translation from Russian.] This does not mean, of course, that the females are good and the males are bad. They are simply different, and the difference has a biological foundation.

To understand the advantages of sexual specialization, we have to consider the relationship between the population and the environment. But first we will try to reveal the features of analogous mechanisms in various control systems from the point of view of cybernetics, the science of analogies.

6. What do a rocket, a soccer team, and an animal population have in common?

From the point of view of cybernetics, all three are control systems. All are characterized by the attempt to reach a goal. The goal may be the Moon for the rocket, victory for the soccer team, survival for the animal population. All three systems are subject to perturbations. The rocket is perturbed by the atmosphere and gravitational fields, the soccer team is perturbed by the efforts of the opposite team, and the animal population is perturbed by the environmental factors: climate, food, predators, parasites, etc.

Each system counteracts the perturbations to achieve stability of its motion. What is the mechanism of counteraction?

An important feature is separation of the mechanism for conservation, with the task of keeping everything as is, from the mechanism for making changes, with the task of correcting errors. In the rocket, stabilizers [fin assembly] are for conservation while rudders are for making changes in the motion. In the soccer team, these mechanisms are respectively the defense players, who try to keep the score constant, and the forwards, who try to change it in favor of their team. The same result, stability of motion, is achieved in a similar manner in different systems: by separate mechanisms for conservation and for making changes. This separation allows the system to have maximum stability of motion.

What about the animal population? Does not the differentiation of sexes relate to the analogous separation of conservation and change?

We have already shown that the females control the quantitative side of reproduction and the males define the qualitative side. In the biological categories, this means that the females largely express the tendency for inheritance, and the males largely express the tendency for change. Finally, in computer science terminology, the female represents the memory in a permanent storage for the species, whereas the male represents the memory in a temporary storage.

This separation of two types of memory gives substantial advantages to the species. To see this let us consider the relationship of the population with the environment.

7. The front between the harmful factor and the curve of mortality

The notion of environment includes the set of all physical, chemical, and biological factors which affect an organism during its lifespan. Climatic factors are part of the environment: cold and heat, humidity and drought; these also include various chemicals in the food, water, and air; and finally there are various animals of the same or different species which live nearby (predators, parasites, etc).

A characteristic feature of a living system is the ability to adapt to changing environmental conditions. The system must receive information about the change from the environment in order to adapt.

All characteristics of an organism are directly or indirectly connected with the corresponding environmental factors: the resistance to cold is connected with the low temperature, the resistance to heat is connected with the high temperature, the resistance to drought is connected with the humidity etc. Connections with other factors of the environment may be less evident; however, it is beyond doubt that the optimal, average values for the characteristics of an organism are, in the end, determined by the corresponding factors or combinations of factors of the environment.

For expository simplicity let us choose a factor-characteristic pair, say temperature and the resistance to temperature, and represent graphically in Fig.7.1 the relation between the population and the environment for this particular pair.

In Fig.7.1, the abscissa represents the intensity of the harmful perturbation factor, say cold; at the same time, the abscissa represents the degree of resistance to the factor. The ordinate in Fig.7.1 represents the number of animals that would die for a particular value of the factor, i.e. as a result of a given temperature. The curve obtained characterizes the mortality of the population as a whole. The harmful factor front is represented by a vertical line. The front cuts off the part of the population (the shaded area in Fig.7.1) which is most vulnerable to the factor. [More explanation, might be helpful. An additional dimension, time, is implied in Fig.7.1. The term "harmful factor front" suggests the "approaching"

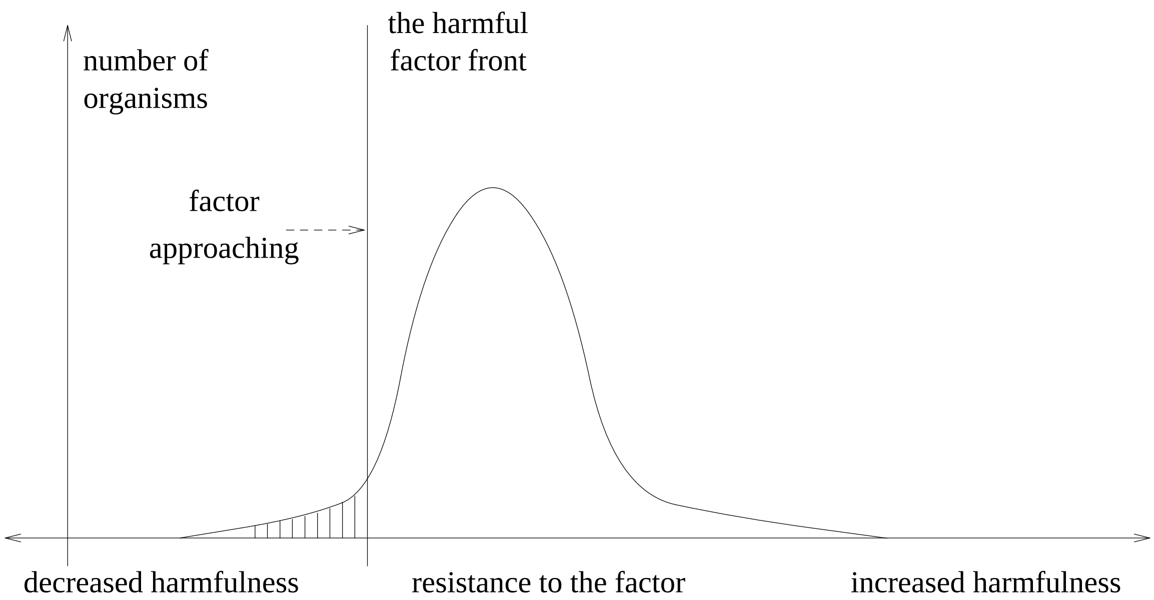

Figure 7.1:

factor, i.e. the weather is becoming colder. The vertical line called the "front" in Fig.7.1, represents the current level of the factor in this case. If, on the other hand, the factor is "retreating", i.e. the weather is becoming warmer, then the current level of the factor represents its "rear." Fig.7.1 does not represent the latter case as the factor should not to be considered harmful when it is "retreating": specimens do not die because of it. But they may start dying from the opposite factor which then becomes harmful, i.e. heat. *Translator thanks Dr. J.B. Kruskal who pointed out this and several other somewhat non-obvious spots in the original.*]

The mortality curve must be always in contact with the harmful factor front in order for the population to sense the approaching perturbation. The population must always sacrifice some quantity to receive the information which improves the population quality with respect to the factor.

This implies, for example, that even in a population living in the tropics, say, monkeys, some animals sometimes die from the cold. At the same time, even in an Arctic or Antarctic population, say, penguins or white bears, some animals sometimes die from the heat.

A tribute for the information received is necessary for the informational contact with the environment. If a population pays no such tribute, no information is received from the environment and the population is not able to adapt to it. A sudden change in the environmental condition might have caught such a population unprepared and killed it entirely.

Naturally, it is advantageous for a population to minimize the tribute of the quantity for a new quality. How is this minimization achieved?

The optimization method employs the asymmetry of the relationship of the sexes to the quantity and quality of progeny. Caused by a perturbation in the environment, losses of males or females affect progeny differently. A loss of females strongly affects the quantity of the progeny, without essentially affecting the quality. On the other hand, a loss of males during unfavorable environmental conditions does not tell on the quantity of the population but changes the quality in the proper direction.

Thus, we may say, that a loss of females during "hardships" is useless, decreasing the size of the population. A loss of males in similar conditions is useful, promoting the evolution of the species.

8. Is the "beautiful" sex really "weak"?

Poets and writers often call the female sex "beautiful" and "weak." The validity of the first attribute seems undoubted. But is the second one correct?

If by strength we understand the degree of resistance in hardships, then the female sex should be considered as the strong one. Indeed, multiple experiments on plants and animals and observation on humans show that the males die first as a result of all harmful environmental factors: heat, cold, hunger, poisons, and illnesses. Not only does the entire male organism have a lower resistance than the female organism, but its various organs, tissues and cells are also weaker than those in females.

How can this weakness and higher mortality of males be explained? Two theories explain the phenomenon. The first one says that the heterogametic sex always has a higher mortality because of recessive genes connected with the sex chromosome. [The heterogametic sex is the one with unlike sex chromosomes X and Y, as opposed to the homogametic sex which possesses similar sex chromosomes X and X. If a recessive bad gene occurs in a sex chromosome of a heterogametic specimen, the latter acquires the bad trait because there is no similar gene in the specimen's genetic set. Hemophilia is a classical example of such a trait. The gene responsible for the illness is located in the sex chromosome X. Unlike men, women carrying the hemophilia gene have a low chance of acquiring the disease because their genetic set includes another X chromosome which usually masks the sick gene with a healthy counterpart. *Translator's comment.*]

As to the second theory, it infers a higher male mortality from a more intensive metabolism.

The first theory contradicts the results of mortality studies among birds, butterflies and moths. Unlike the overwhelming majority of other species, the females of these species constitute the heterogametic sex while the males are the homogametic sex. Yet experiments show that in many species of butterflies, several species of birds and moths, male mortality is almost always higher than that of females.

The second theory, in fact, does not explain anything but substitutes one incomprehensible phenomenon of higher mortality with another no more comprehensible phenomenon of higher metabolism. If resistant females exist, why should not similarly resistant males?

9. The higher mortality of males is ... expedient

The fact that the males are biologically weaker implies the following: If, on the same graph, we draw the mortality curves for each sex separately, then we will see that only

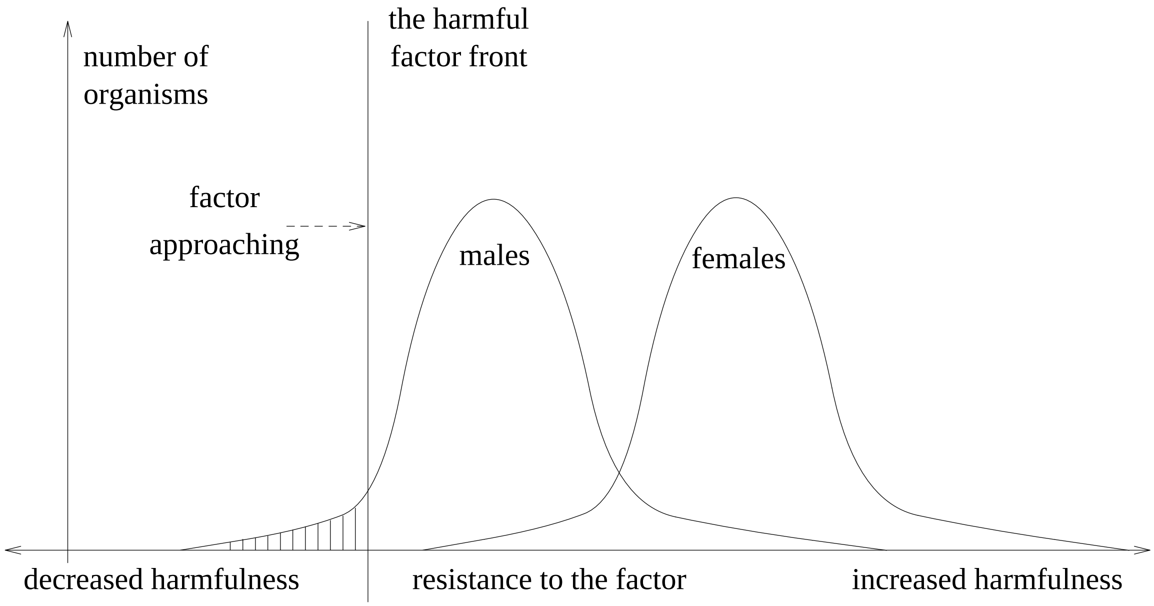

Figure 9.1:

the males' curve makes contact with the front of a harmful factor. There are two main possibilities for drawing the females' curve. The latter can either shift to the right (Fig.9.1), or it can have a smaller dispersion than the males' curve (Fig.9.2).

Taking into account our previous considerations (that the loss of males does not affect the quantity of the population but promotes adaptation of quality, and that rare specimens of males have a larger informational value than rare specimens of females; that the males are the main carriers of the information from the environment to the population), we come to the conclusion that for each characteristic considered, the males' curve must have larger dispersion than that of the females. This means that the males must have greater variety that the females in all qualities.

If we include all the males in the population in one team and include all the females in the other and arrange competitions between the two teams, then the champions in all personal competitions will be the males, whereas in a whole-team competition (where the results of all participants count) the females will be the winners. [In other words: the mean-value of the females' curve is to the right of the males' (females are the winners in a whole-team competition), while the dispersion of the females' curve is lower than of the males' (females are the losers in personal competitions). Thus, the author suggests that a combination of both tendencies takes place, the one presented in Fig.9.1 and the one presented in Fig.9.2. *Translator's comment.*]

Such a relationship of the resistances between the sexes makes it possible for the population as a whole to pay for the new information mainly with males whose loss promotes the shift of quality without changing the number of specimens. Thus, the higher male mortality is expedient for the survival of the species.

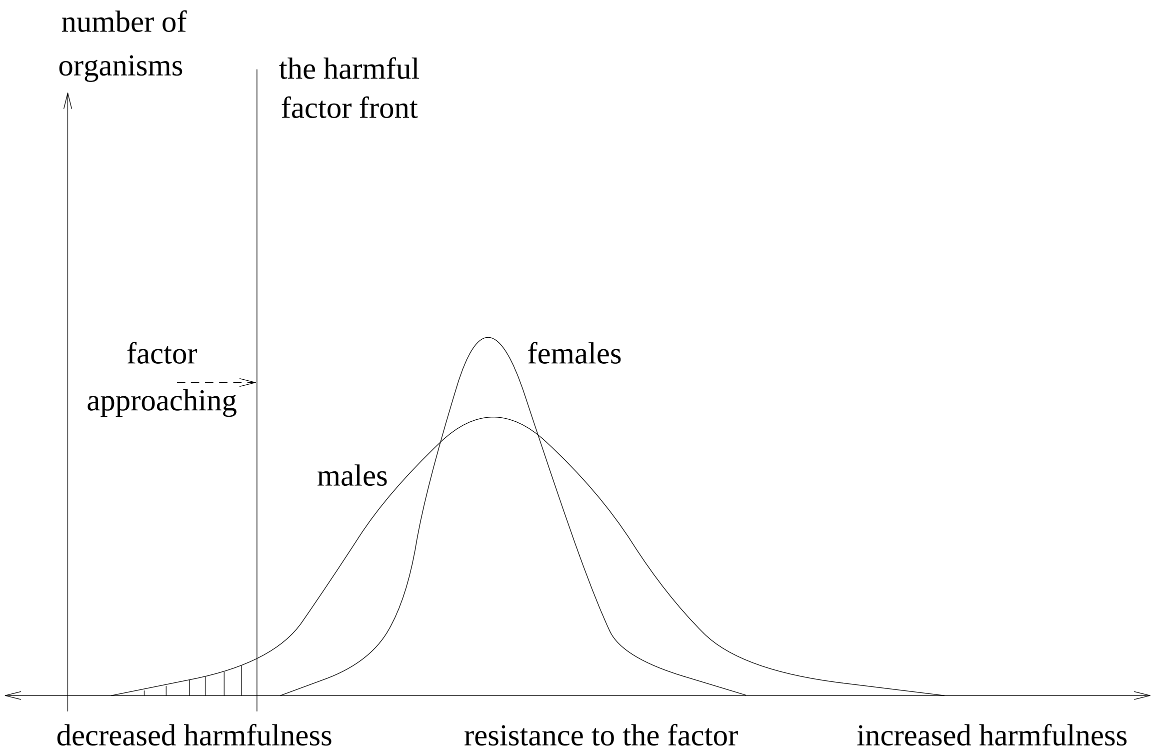
number of
organisms
the harmful
factor front
factor
approaching
females
males
decreased harmfulness
resistance to the factor
increased harmfulness

Figure 9.2:

10. The sex ratio at birth and the environmental conditions

It is now clear that the sex ratio is an important parameter of the population, connected with the hereditary conservation and changeability tendencies in the reproduction process. Therefore, the sex ratio at birth must reflect these tendencies in their dependence on the environmental conditions during different periods of the population history.

An increase of male mortality in unfavorable environmental conditions must lead to an increase of the male/female ratio at birth. An increase of this ratio may be triggered directly by a changed environmental conditions, independently of the ratio of sexes of adult animals. There are reasons to believe that in vertebrates this increase is controlled by steroid hormones of the hypophysis (pituitary gland), adrenal cortex and gonads.

To promote faster adaptation of the population, an environmental hardship should increase the male's renewal rate. The rule is that in response to *any* unfavorable environmental condition, *both* the birth and the death rates for the males increase.

Multiple facts reported and known in biology confirm this rule. Interestingly enough, the species which utilize either method of reproduction, asexual or sexual (bacteria, infusoria, some crayfish, and other), resort to sexual reproduction under unfavorable environmental conditions.

For example, among many kinds of water-fleas *daphnia genus* as well as among the aphids *aphidae*, when the conditions are favorable, usually in summer, asexual reproduction (parthenogenesis) takes place. The new fleas (only females) hatch out of the summer soft-membrane eggs. When less favorable conditions strike, some of the females produce a quantity of males, which then copulate with the females. The fertilized females deposit the hard-shelled winter eggs, which can stay alive for a long time in unfavorable conditions: during cold, heat, drought, when the water reservoir dries out.

Extracting a population of female rotifers *rotifera phylum* from pond water and placing them into river or well water, or doing the reverse resettlement, the scientists observed an emergence of males on the third or fourth day after the move. The direction of the move, from the pond to the river or from the river to the pond, was unimportant: any change in the environment caused the males to appear.

Subjecting sexual animals like drosophila (fruit flies) to harmful factors, the researchers observed the simultaneous increases in both the male birth and death rates. This seemed paradoxical and unexplainable. Indeed, why should a harmful factor (no matter which: hunger, cold, heat, or a poison) act as such for male flies at all stages of the life causing them to die more intensively, except at the very beginning of the male life and, moreover, promote the birth of more males? Why are the sex theories sometimes so contradictory? For example, paying attention to the fact that during a cold year more boys than girls are born, a scientist inferred that cold promotes the birth of boys, while heat promotes the birth of girls. Later, the scientist noticed that extreme heat also promotes the birth of the boys. Then another theory appeared which explained everything in exactly the opposite way: heat promotes the birth of boys, while cold promotes the birth of girls.

Meanwhile, both phenomena are explainable easily by the rule of higher male renewal rate for any change in the environmental conditions.

Facts which confirm this rule can be found among mammals, humans including. Medical and demographic statistics show that during substantial climatic and social shifts (abrupt change of the temperature, drought, war, hunger, resettlement), that is, during an increase of mortality, a tendency to increase the ratio of boys to girls among the newborn babies is also observed. The same tendency is observed by cattle-breeders: better the maintenance conditions of the animals, more females in the progeny, even if artificial insemination is practiced and the sperm is taken from the same male.

The separation of the population into two sexes and the specialization of the sexes, wherein one sex is responsible for quality and the other for quantity leads to the situation where any information stream about environmental changes is first received by the males, which react to this information and transform the stream. In other words, new information gets first into the temporary memory of the population, where it is checked and selected, and only after this is it transferred into the permanent memory, i.e. females.

This separation, into a more inertial stable kernel and a more mobile sensitive shell, allows the population to distinguish temporary, short-term and random factors of the environment, e.g. an unusually cold winter, or an especially hot summer, from systematic changes in the same direction, say the beginning of an Ice Age. One may say that the information stream from the temporary memory gets to the permanent memory through a frequency filter. The filter lets low frequency through but blocks high frequencies. It is this filtration through the temporary memory by which the inertiality of the permanent memory is achieved.

11. Clay and marble

A good sculptor, before making a sculpture out of marble, will create many models out of clay. The nature acts similarly. Like a sculptor, it first creates a large variety of males (clay models), testing them and selecting good versions to implement later in females (marble sculpture). Thus, in a population, new qualities first appear among the males and may afterward appear among the females.

We may consider the male as the vanguard of the population, which advances to meet the harmful factors of the environment. A certain distance is kept between this vanguard and the kernel, "the golden fund" of the population. The distance is necessary for testing and selection.

The evolutionary inertiality, lagging of the females, is a payment for their perfection. Vice versa, the progressivity of the males is a benefit of their imperfection.

We can formulate the following hypothesis: a new quality in phylogeny must first become permanent among the males, and then it must be transferred to the females. In other words, the males are the "door" for the change in the heredity of the population.

Thus, if the male and the female are distinct from each other in some quality, say in the height or color, one may predict the direction of change, namely, the quality is changing in the direction from the female to the male. For example, if males are bigger than the females, then there is an evolutionary tendency for size to increase in the species. In the other case, if males are smaller than females, the species evolves to have smaller specimens.

We may conjecture that humans are becoming taller at this stage of history, because an average man is taller than an average woman. Among the spiders, the tendency must be opposite, because their males are smaller than the females. The anthropologists and entomologists believe this is the case: mankind is growing, spiders are shrinking.

Another example is the well-known connection between ontogenetic and phylogenetic emergence of the antlers in male and female deers. A strong relation exists between the extent of antlers in a species and the age when antlers appear in a specimen. Namely, the larger the extent, the earlier the antlers appear, first in males, then in females.

The suggested rule can be applied to study some concrete problem of evolution, remembering of course that this general tendency can sometimes be overlapped by other tendencies.

12. Conclusion

An application of certain general ideas and approaches of cybernetics to the formulation and solution of biological problems allows us to understand certain facts, previously mysterious. Now we know that the advantages of asexual reproduction are efficient only in short "sprinter" evolutionary distances. "Stayer" and "marathon" distances need the sexual method. The advantages of crossbreeding and differentiation are now clear, as well as the fact that these advantages can be fully realized only in an "ideal" population. This implies an insignificant sexual dimorphism in monogamous species versus a strong sexual dimorphism in polygamous species.

Returning to our first question, whether males are generally needed, we should answer: yes, they are needed mostly for adaptation to the changes in environmental conditions. This holds for animals. What about humans? It is known that social and technological progress steadily decreases the role of the biological evolution. Having learned how to change the environmental conditions, man renders himself free from the necessity to change himself. Indeed, if a new Ice Age begins, animals will grow thick hair, but man will put on synthetic fur clothes.

We conclude that social and technological progress should steadily increase the role and proportion of women in the society. [This statement which is apparently saying that men are dying out is put in such an indirect way perhaps to improve the chances of the original publication. *Translator's comment.*]