A Functional Anatomy of Invertebrates

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Preface

THE LAST HALF century has seen vast changes in the teaching of zoology. The selection of topics by which the student of the nineteen seventies is introduced to the subject is quite unlike that with which his father was presented. In part, this is due to the need to incorporate new ways of studying animals made possible by such techniques as electron microscopy, and to present the results of such new interests as ecology, or those derived from biology's new relations with physical science; in part, it is due to fashion, with its predilection for the novel, which operates in scientific fields with the same apparent inevitability and unpredictability as in dress or hair style. The university or college year, however, has not increased in length to keep pace with the development of new areas of study and they have been accommodated only by the restriction or exclusion of some of its previous content. This has especially affected the courses which dealt with invertebrates and vertebrates, which had, by comparison with others, an old-fashioned look that made them vulnerable to attack: in some cases they have been so severely pruned as to sink below the critical threshold at which intelligibility can be maintained, a situation which inevitably leads to loss of interest on the part of both teacher and taught.

Since Man is a vertebrate along with most of the animals which he has domesticated for work, food, sport or keeping as pets, and since the vertebrates are a zoological unity in a sense that does not apply to invertebrates, it is courses in invertebrate zoology which have come off the worse in these circumstances; indeed, brief study of invertebrates serves only to exaggerate their disunity and to bewilder the student. The average university student, in our experience, finds his courses in invertebrate zoology are those which least capture his affection and enthusiasm, despite the fact that it was a confessed interest in animals at large which attracted him to their scientific study. The reasons for this situation seem to us to be partly the over-brief treatment, partly the emphasis on dead anatomy without relation to function, and partly an over-emphasis of the anatomical bases of the taxonomy of animals about which the student otherwise knows nothing.

It is not necessary to labour the points that animals, because they are animal in nature, have activities which they must carry out to stay alive and reproduce, and that their anatomical organization is the apparatus with which they do this. But to study the anatomy without the approach of the bioengineer, without asking such questions as – What does it do? – How does it do it? – How does the structure limit and define the ways in which the function can be fulfilled? – is dispiriting and sterile, whereas with this point of view the functional study of anatomy is stimulating and rewards the student with fuller insight into each animal's way of life. It is to try to provide the answers to such questions that we have written this book.

The basic activities of animals are identical, from Amoeba to Man – all move, all feed, all respire. It might therefore seem right to describe these activities and their underlying machinery without relation to the systematic position of the animals dealt with, and this is, indeed, what many texts set out to do. Yet there is no doubt that these activities are related to the animal's position in the animal kingdom since its grade of organization determines the anatomical and histological complexity of the apparatus which it can devote to carrying them out. Before the student is in a position to appreciate the similarities and differences between patterns and to recognize their relative advantages and disadvantages, he must have the patterns themselves clear in his mind. For this reason we have, in dealing with most groups (and especially where a phylum contains animals built in diverse ways as in annelids or molluscs), reverted to the type method introduced by Huxley. Where the organization of a group is relatively homogeneous, as in nematodes or brachiopods, we have adopted a more comparative approach.

The book is not intended for the beginner since we have taken elementary ideas and knowledge of many facts and technical terms for granted. Although we hope that it is intelligible to the first year college student it is aimed at those in the later years of their course and at graduate students who need a broad view of the group in which their research interests lie. We hope too that this kind of approach to invertebrate zoology will help the ecologist (to whom, unfortunately, animals are often only so many units in the system which he he is studying) to see more clearly how the activities of each animal contribute to the whole, and will aid the physiologist to relate the particular function in which he is interested to all those which the animal performs.

We have illustrated the text with drawings which we have made as realistic as possible by basing them on animals, whole or dissected. When they have had their starting point in the work of others this fact is acknowledged in the legend of the Figure. Though most of the drawings have been made by one or other of us, we gladly acknowledge much help given by Mrs Margaret Shepherd and Miss Shirley Townend. We are also grateful for valuable textual help given by Dr Elizabeth Andrews, for the photographs in Fig. 9 prepared by Mrs Patricia Hawkins and are glad to thank Mrs Pauline Brown and Mrs Grace Smillie for the care and accuracy with which they typed our manuscript. Finally, we wish especially to thank Mrs Dorothy Sharp of Academic Press for her help in preparing the manuscript for the printer.

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Introduction

IF YOU ASK the ordinary man in the street how to tell the difference between an animal and a plant, you are likely to get a variety of answers. One will tell you that animals move whilst plants remain stationary; another that plants are green, whereas green is a relatively uncommon colour in animals; a third may say that animals are usually divisible into two halves along one line only – or, as the biologist would say, are bilaterally symmetrical – whereas plants may be similarly divided along any one of many diameters, or, are radially symmetrical; and still another may mention that whilst animals eat solid food, plants do not seem to eat at all.

All these observations are accurate so far as they go, but it is rather easy to find exceptions to most of them. You have only to mount a drop of pond water on a slide and examine it under a microscope to see many motile organisms, which are also green. Are these animals because of their mobility, or plants because of their green colour? Similarly many animals such as sea anemones exhibit a stationary habit and a radial symmetry, but catch and eat solid food. Are these plants because of their symmetry and immobility, or animals because of their feeding habits? When alleged distinctions between two contrasted groups of objects can be shown to lead to doubt as easily as this it is clear that they are not real differences but merely subsidiary features which accompany an as yet undiscovered point of contrast. And this, as is well known in the case of animals and plants, is a matter of nutrition, that is, the source of the energy by means of which the organism runs its body and carries out the multiplicity of activities which make up its everyday life. Once this fundamental distinction between the two kinds of living organism is admitted, the other differences can be seen to follow from it, though, if an organism adopts a mode of life which is unusual in some way or other, then it may not exhibit the same features as other animals or other plants.

The typical plant possesses the pigment known as chlorophyll and for that reason is green. This allows it to trap the energy in sunlight and so build up molecules of sugar from the simple inorganic substances water and carbon dioxide in a process known as photosynthesis.

$$\text{Water} + \text{carbon dioxide} + \text{energy} \xrightarrow{\text{chlorophyll}} \text{sugar}$$

To do this the plant requires a supply of water, which it obtains from the soil, a supply of carbon dioxide, which it obtains from the atmosphere, and sunlight. Lacking any of these it cannot flourish. Much of the organization of the plant body may be related directly to these requirements. The plant has no need to move about from place to place in search of fresh supplies of carbon dioxide – the continuous movement of the air brings it. Similarly it does not require to move in search of water – rainfall and capillary movement in the soil again bring it within its reach. What the plant does require is a shoot system reaching out into the air to catch the carbon dioxide and light there, and a root system permeating the soil to absorb the water, and since these substances are as likely to be found in one direction as another, the root and shoot systems grow radially from the axis of the plant equally in all directions, branching and rebranching as they go so as to tap the resources of as great a volume of air and soil as possible.

In this way, as a consequence of the mode of nutrition, the characteristic fixed and radially symmetrical body of the plant arises, its structure directly linked to its function.

The sugar manufactured in photosynthesis contains energy obtained from sunlight by virtue of chlorophyll. This may be released by destruction of the sugar molecule in a process known as respiration, which is very obviously the antithesis of photosynthesis:

$$\text{sugar} \longrightarrow \text{water} + \text{carbon dioxide} + \text{energy}$$

The waste products from this can escape by way of the leaves in gaseous form. The energy may be used by the plant for any activity. One of these will necessarily be the production of new living substance, or protoplasm, either in the process of growth, or in that of producing new plant organisms or reproduction. Both require the manufacture of protein molecules, which contain many elements such as nitrogen, phosphorus, sulphur and so on, not found in the molecules of the substances involved in the chemistry of respiration or photosynthesis in the skeletal form in which it has been represented above. The plant, however, can make proteins provided that it can get these elements as inorganic salts dissolved in the soil water which it absorbs through the root system. The addition of this activity to those already carried out by the organism, therefore, does not call for any modification of the root and shoot system adequate for photosynthesis and respiration. All the substances which a plant requires for its respiratory activities, for growth and reproduction, can be absorbed in gaseous form or in solution, and no uptake of solid food is necessary.

We have therefore been able to relate the pattern on which the body of a plant is built – its sessile habit, its radial symmetry, its uptake of food only in solution, its greenness – to one fundamental attribute of plant life, its particular mode of nutrition. Motile green organisms are still plants provided they have this method of nutrition, as are those with bilateral symmetry; but we recognize as plants (though aberrant ones) organisms which are not green and are not capable of photosynthesis (for example, moulds) by comparing their general organization with that of plants of normal structure and function.

If we now turn our attention to typical animals we find that they are biochemically less expert than plants and are incapable of manufacturing for their own use such chemical substances as the sugars which are required as respiratory substrates, or the compounds containing nitrogen (amino acids and the like) which are essential for the manufacture of new protoplasm either in growth or reproduction. If animals require these substances for such activities and yet cannot manufacture them for themselves from an inorganic starting point as plants do, how are they to obtain them? Obviously there is only one way: from the bodies of the plants which have made them, or from the bodies of other animals which have already obtained them from the same source. Thus biochemical inadequacy compels the animal to become a slaughterer of other organisms or a carrion feeder in its search for the materials which it must have for obtaining energy or the manufacture of new protoplasm. And just as its mode of nutrition forced a certain structure on the plant, this different method forces a different structure on the animal.

In the first place, it is clear that animals must move. Imagine an animal anchored to the ground in the way that a plant is. In a very short time it would eat all the food within reach and starvation would become inevitable. Animals, therefore, have locomotor organs: cilia or flagella when they are minute, but appendages of a variety of types when they become larger, worked by muscles which act upon a skeleton. These muscles have to be controlled by the animal so that they may move the body in an appropriate way in relation to the food that the creature is seeking and the environment through which it is moving. The animal must, therefore, be equipped with machinery which will allow it to recognize food, to distinguish the edible from the inedible and to move its body in relation to its external environment, This is provided in a series of sense organs, each detecting some physical or chemical factor in the environment and sending nervous messages to a central coordinating and predicting centre, the brain, which, in the light of all the information presented to it by the sense organs and its memory of what has been presented at times past, "decides" what messages should be sent to the muscles to make the locomotor activity of the animal appropriate to the moment.

The food of a plant is already in solution, ready to diffuse or be actively taken up through the surface of the body; this is not, however, true of the food of an animal, which requires preliminary treatment, digestion, before it can be absorbed. The digestive process renders the food soluble and reduces the size of its component molecules to a level at which they can pass through the membranes of the cells forming the lining of the body. Such a process is not easily carried out on the external surface of the body and the typical animal is therefore provided with an internal space, the gut or alimentary canal, into which the food is taken, often given a preliminary mechanical breaking up, and where it is digested by means of enzymes to produce a solution of substances of small enough molecular size to diffuse into the body. Not all of what is eaten responds to digestive treatment; some parts prove indigestible. These are passed to the opposite end of the alimentary tract from the mouth and escape as faeces from the anus. It is worth noting that this material has never been inside the animal's body in any real sense, but has merely passed through it, and hence has never taken part in any kind of metabolic activity.

In this way animals acquire the sugars necessary for respiration and the production of energy, as well as the nitrogenous and other compounds required for the formation of new protoplasm. These substances, however, are only just within the body of the animal, in the wall of the alimentary tract, whereas respiratory and other vital processes go on in all parts. Some transport system is called for to carry food materials from the gut to these parts, and this is normally supplied by a vascular system, a series of tubes running throughout the body filled with a fluid called blood which can dissolve the food absorbed in the gut and transport it wherever required. The motive power driving the blood along the vessels is provided by a specialized contractile part which is the heart.

Respiration calls not only for a substrate like sugar but for oxygen, which will release the energy contained in the large sugar molecule in an oxidative process. The animal, therefore, requires as regular a supply of oxygen as it does of food in order to obtain a regular supply of energy. Indeed, since most animals appear to have evolved in an environment where food might often be lacking, but where oxygen never was, they have learned to store food against emergencies but have never learned to store oxygen, and many die if their supply is interrupted for more than a very short period of time. Oxygen is taken from the surrounding medium, air or water, by way of special, thin, respiratory surfaces through which diffusion is easy, constituting the animal's lungs or gills; it enters the blood, which thus not only distributes food but also oxygen as it circulates round the body.

Every cell in every part of the body is in this way provided with food and oxygen and can carry out the process of respiration, releasing energy, which can be put to any purpose appropriate to the animal's needs at the time. In this process waste substances will be formed as well as energy released, particularly carbon dioxide and water when the substance respired is carbohydrate, as it most commonly is. These must be evacuated from the body, otherwise it might become waterlogged and too acid, and this involves the animal in the process of excretion. Some of the waste – most of the carbon dioxide and some of the water – may escape to the surrounding medium as the blood passes through the respiratory organs, but a true excretory organ is necessary to expel the rest of the water and a variety of waste products from kinds of metabolic activity other than respiration. This organ is loosely called the kidney, and it expels the waste matter by a duct leading to an excretory opening on the surface of the body, the excretory substances being extracted from the blood as it passes through the kidney. It will be noted that the urine excreted by the kidney contains substances which have been linked with the vital activities of the animal and which have often been intimately concerned in the life of the protoplasm. It is this which distinguishes waste of renal origin from faeces.

The normal animal grows. It may keep on doing so indefinitely, but usually there arrives a time when general bodily growth is replaced by the special type of growth which results in reproduction. New protoplasm is not then used to add to the body of the organism, but to make the starting point of a new individual. Whilst the most primitive organisms may have been able to carry out this reproductive process and survive themselves, it seems that increased complexity of organization brings death of the body as one of its consequences; reproduction then becomes the only way in which a stock of animals can survive. This probably represents a compromise solution to the problems confronting the animal. In order that its protoplasm function properly the surrounding physicochemical environment has to be very carefully controlled and many variable factors kept within narrow limits. As an individual animal ages this becomes more and more difficult. Rather than face the increasing physiological expense of this the individual animal is allowed to die, but meanwhile a new one made of protoplasm which has been kept apart from such contamination is brought into existence in its place, and life continues. The typical animal has, therefore, a reproductive organ which contains the gametes from which the next generation will be formed and a genital duct which leads them to the exterior. For some reason, perhaps of economy of tubes and external openings, this duct becomes joined to the excretory ducts in many kinds of animal so that the excretory and genital system become apparently one.

This rapid review of the organization of the typical animal body shows how, given the fact that an animal has to feed in a certain way, the structure of its body inevitably follows. Because an animal finds its food only in other organisms it *must* be motile, it *must* have sense organs to investigate its environment and control its movements through a brain; an alimentary canal, respiratory organs and a circulatory system are essentials of structure because of the way in which it *must* function; an excretory system and a reproductive system equally inevitably follow as factors in its make-up.

You will realize that we have been talking of the *typical* animal in this argument. If an animal lives in atypical fashion then it may not exhibit all the characteristics of the typical animal: thus sea anemones are radially symmetrical because food may come to them from any direction as it does to a plant, and they reach out equally in all directions to improve their chances of catching prey. Oysters and sea-squirts can be sessile and immobile because they have so modified their way of life as to bring food to themselves instead of chasing it as more ordinary kinds of animal do. Animals which are markedly smaller than their close relatives may often be anatomically simpler because the changed surface to volume ratio may allow diffusion to occur more readily, and so let the creature dispense with organs otherwise essential; adoption of a parasitic mode of life similarly may be reflected in a secondary simplicity of organization. But whether typical in their way of life or not the structure of the organism reflects the functions which its method of living imposes upon it.

When you dissect an animal, whatever its taxonomic position, you ought, therefore, to expect to find within its body a standard equipment of structures allowing it to carry out the standard set of functions which its animal nature imposes upon it. But though an animal must have a gut, a nervous system, an excretory system and so on – though there is this functional need to which it must conform – there is no anatomical pattern to which it must pay equal attention. An animal must have a nervous system and a gut, but it may, so to speak, choose whether the nervous system shall lie above the gut, below the gut or alongside the gut, and there is, therefore, a vast range of anatomical diversity to be found in the animal kingdom superimposed upon the functional uniformity outlined above. Further, there is a great disparity in the physical resources with which different kinds of animals carry out their physiological requirements. A protozoan such as an amoeba may carry out the same kinds of activity as a mammal, but whereas the former has to do them all with the same single piece of protoplasm, the mammal may be able to set aside several million cells for one special activity, with an inevitable increase in the efficiency and delicacy with which it can be performed. The particular pattern on which the body of an animal is constructed, therefore, conditions and may limit the ways in which it carries out its various functions. It is the purpose of the next section of this book to show how these three factors – uniformity of physiological activity, anatomical diversity and the restrictions imposed by the evolutionary grade of organization – interact in the life of a series of different animals.

The anatomical patterns on which the bodies of animals are constructed are extraordinarily varied, particularly if extinct forms are considered alongside living ones, yet similarities exist. It is these likenesses and differences that zoologists have seized upon to erect classifications attempting to categorize the immense number of organisms that constitute the animal kingdom. In pre-Darwinian days there was no very obvious reason why similarities between different kinds of animal should exist, but they are now seen as indicators of evolutionary kinship, just as brothers and sisters, because they have the same ancestry, are more like one another than they are like other members of the population. Similarly, the differences between two kinds of animal are in a general way indicative of their degree of divergence. Using such features the zoologist with an interest in systematics is able to arrange animals into a hierarchy of groups, each called a taxon – species, genera, families, classes, phyla – each member of the series containing more different kinds of animals than the preceding one. The extremes of the series are better defined than its central terms. A species is the population of animals that fruitfully interbreed, or, if limitations of space and time were abolished, could fruitfully interbreed, and it therefore corresponds to what, in nature, is ordinarily understood by a "kind" of animal. Similarly, there is little doubt about what is meant by a phylum – echinoderms are distinct from other kinds of animal and unlikely to be confused with them. Nevertheless there is attached to the word "phylum" the same uncertainty that attaches, though in greater degree, to the words "genus", "family" and the like, in that they stand for ideas in the minds of zoologists and do not correspond to anything in nature: they express a particular systematist's reaction to the animals which he has studied and are a shorthand way of stating his ideas as to their interrelationships and probable evolutionary history. Further, since life is continuous in the ever-rolling stream of time but species change these words represent only ephemeral stages. If our systematist is a good zoologist his ideas, and therefore his classification, may prove acceptable to others, but other, equally good, zoologists can produce different, and apparently equally acceptable classifications. It must be emphasized, therefore, that the classification used in this book is no more "correct" than others which might have been used and is only that classification which seemed to the authors to reflect most adequately the known interrelationships of the animals within each group. It is liable to be upset, or replaced by another, should further study require or should new animals be discovered whose anatomy disclosed new relationships. Zoologists who are systematists tend to be impressed by differences of relatively trivial nature; zoologists with more general interests may be more struck by broad resemblances. These points of view are often revealed by their choice of classification; thus malacologists interested in bivalves may put both protobranchs and lamellibranchs into a single class Bivalvia in order to express their belief in the close relationship of these animals whereas someone who wished to emphasize his belief that they represented distinct evolutionary lines might well abolish the single group Bivalvia and replace it with two taxa of equal rank: Protobranchia and Lamellibranchia.

It was pointed out above that all animals, however classified, were doing fundamentally identical things, though their equipment for this might differ in complexity or topographical layout. In this is concealed a factor which tends to confuse the systematist and may completely confound him. In the evolution of apparatus to carry out any function in which a particular set of mechanical, physical or chemical processes is involved it will frequently come about that similar devices arise, even though the starting points of their evolution may have been unlike. Thus animals which filter their food from a current of water require a mechanism to create the current, a filter and a means of transporting the filtrate. In creatures as unlike as the worm *Sabella*, a bivalved mollusc, a copepod and a sea-squirt, parts of the body are found each carrying out one of these activities, and to that extent these animals, each belonging to a different phylum with its distinctive anatomical pattern, have come to resemble one another. This phenomenon is known as convergence and, though unlikely to mislead the systematist in the example quoted, can on occasion produce structures so similar as to make him believe that the likeness must indicate close relationship and so cause him to propose a false classification. Dr Manton's work on the mandibular arrangements in arthropods (p. 273) is an outstanding illustration of how unrelated animals, in evolving a mechanism to satisfy a particular need, have produced superficially almost identical structures.

The reality of convergence has come to be more readily accepted with a change in our ideas of how the evolution of animals has taken place. It used to be generally believed that a particular group of animals had arisen from a single ancestral stock and, therefore, that there existed a relatively close cousinhood amongst all its members, which had reached their present status by an adaptive radiation. In more technical language the group was said to be monophyletic, and its evolution from its origin expressed diagrammatically as a tree. It is, however, agreed that the evolution of at least some groups may have followed a different pattern; instead of only one ancestral form taking the step which raised it from one level of organization, to another, several may have done so, with the result that the diagrammatic representation of the change would be a herbaceous plant with several uprising stems rather than a tree with one. A group with this origin is said to be polyphyletic and the relationships amongst its members are looser than are those in a group which evolved as a unit. In a polyphyletic group, however, each stock attempts an adaptive radiation and the tendency for different animals to occupy similar niches is thereby exaggerated and the probability of convergence raised. This evolutionary pattern, too, requires us to modify our ideas of what a large taxon may be. It may be less a group of blood relations and more a society of species all of which have attained a given level of organization.

Not all anatomical plans have proved equally successful in their adaptive radiation. This is implicit in the vast number of species which have become extinct, but even amongst living organisms the patterns characteristic of a few phyla and classes seem to have proved better able than others to give rise to what might be described as successful models. This is most marked in the well-known abundance of species of arthropods and, in particular, of insects, of which there are more than of all other kinds of animal put together. In 1962 Mayr put the total number of species of animals which had been described at 1 120 310, of which 923 135 were insects; more have been described since and others certainly await description. Since few people can grasp the meanings of numbers of this order of magnitude and their relationship to smaller numbers, it is worthwhile to approach the matter in a way different from a mere catalogue of the numbers of species in each phylum. Let us suppose that we are the audience in a theatre and that there is about to pass across its stage a procession of animals, one member of every known species, at a rate of one kind of animal per second. We have in prospect an uncomfortably lengthy show, since it will go on continuously for 12 days 23 hours. Of this time no less than 10 days 16½ hours will be occupied by a procession of different arthropods. If we examine this enormous arthropodan series more closely we find that 9 days 20 hours is taken up by a succession of insects and nearly three days of that period – 2 days 21½ hours – by beetles only! The molluscs, the second largest phylum, take 22 hours 13 minutes to pass and the vertebrates 10 hours 57½ minutes, of which time half is occupied by fishes. The next largest group, the protozoans, requires 8 hours 20 minutes, leaving thirteen hours for the whole of the rest of the animal kingdom: coelenterates, flatworms, round worms, annelids, echinoderms and the so-called minor phyla. Obviously, by arthropodan standards, all phyla, even the greatest, are minor.

The classifications given at the end of each chapter are not intended to do more than permit the reader to place the animals dealt with against a taxonomic background. The diagnostic characters of the various taxa are not given. The taxic levels of the groups are also not indicated since this must vary to some extent from authority to authority. Thus whilst Crofton regards the Nematoda as a class in a phylum Aschelminthes, other authorities would raise it to phyletic level; whereas Corliss calls Ciliophora a sub-phylum of Protozoa, others call it a class. We have therefore left the taxa without hierarchical label though the steps in the hierarchy are indicated by degree of indentation.

In the text, partly for brevity, partly from ignorance, not all groups have been treated. We have judged it worthwhile, nevertheless, to give the names of the taxa not described so that the reader may get an indication of how complete the treatment has been. The names enclosed within brackets [] are in this category. They are further marked with an obelus (†) if they are wholly extinct. Whilst all major subdivisions of a phylum have been listed this is not true of the minor ones: in some cases the taxon (at subordinal level or thereabouts) which has been mentioned is named with an indication that other taxa at this level exist. Without this abbreviation the lists would be too cumbersome.

2

Protozoans

SINCE LEEUWENHOEK first demonstrated their existence with his microscope the animals included in the phylum Protozoa have been studied for a number of reasons; partly because of their intrinsic beauty, partly because of their economic and medical importance and partly because their apparent simplicity seemed to suggest that they would reveal the secrets of life more easily than other animals. This impression of more intimate access to living processes is a delusion: the simplicity of protozoans is exclusively in gross anatomy, the electron microscope having revealed an overwhelming complexity in detailed construction, and their fundamental physiological processes are as elaborate as those of any other animal. There is no easy road to the understanding of life through protozoology. Because of the multiple reasons for which they have been studied and because of the chance that one animal has proved useful for the study of a particular topic, our knowledge of the group is unbalanced—much is known of parasites of medical or veterinary importance, much is known of the nutrition of a few ciliates which happen to be rewarding experimental animals, but other areas of protozoological study may hardly have been touched.

The protozoan body usually comprises a mass of protoplasm containing a single nucleus, and to that extent it compares with a single cell extracted from the body of a higher animal. For this reason the Protozoa are often described as unicellular animals or free-living cells, and the origin of the metazoans sought in the association of such to give many-celled units. Alternatively, metazoan origins may be looked for in another type of protozoan, the multinucleate type, in which several or many nuclei lie in a continuous mass of protoplasm; by supposing each nucleus and its surrounding protoplasm to become isolated from its neighbours by cell membranes, a metazoan body is produced. A protozoan of this type is, therefore, distinguished from a true metazoan in not being separated into cells, and, for some zoologists, the protozoans, even those with only a single nucleus, cannot be regarded as "unicellular" animals, but must be called "acellular", i.e. not divided into cells. To some extent arguments of this nature derive from the fact that biologists were long unable to agree as to what precisely constitutes a cell, and the same discussion has gone on in more lively fashion as to whether the word "cell" should be used to describe a bacterium. Modern research with the electron microscope allows a fresh look to be taken at this problem since it has enormously extended detailed information about cellular structure. It has, indeed, shown a near identity in both nuclear and cytoplasmic organization between Protozoa and Metazoa, and, if a line can be drawn to separate different structural patterns it is not between the protozoans and the metazoans, but between the bacteria (which are known as prokaryotic cells) and the rest (eukaryotic cells). Bacteria are cells with only one membrane around them, separating a unity which contains all the constituents of cytoplasmic and nuclear organization from the surrounding medium, whereas in the single unit of the protozoan body and in each of the multiple units of the metazoan, the nucleus lies within its own private, though perforated, membrane and a second, outer, membrane delimits the cytoplasm from the external environment. (According to some, however, the first and second membranes are both parts of the same.) On this basis there is no justification for refusing to apply the same term, cell, to the unit which is the whole protozoan body and to that which helps to form the metazoan body, except, perhaps, the semantic objection put forward by Dobell in 1911 to calling by the same name that which is in one animal a part of its body and in the other the whole body itself. Protozoa, however, are both cells and organisms; as one they parallel the metazoan cell, as the other the whole metazoan.

Classification

Before discussing some of the problems of functional anatomy which arise in the study of protozoans it is necessary to define some of the taxonomic groups to which reference will be made. It is assumed that the reader is already familiar with such protozoans as an amoeba, *Euglena* and the ciliate *Paramecium*. The commonly accepted basis for the division of the group into classes is the type of locomotor organelle which an animal possesses. The most primitive group of the phylum is one known as Mastigophora or Flagellata, which receives its name because the characteristic locomotor structure of its members is the flagellum. One, a few, or many of these may be found on the surface of the organism. The group splits itself into a division Phytomastigina, of more plant-like types, usually with the capacity of photosynthesis, though the pigment responsible may or may not be chlorophyll, and into another, the Zoomastigina, unable to photosynthetize and therefore dependent upon the uptake of organic matter, either in solution or by ingestion of solid food. Some of the commoner or more important members of the Phytomastigina, which are widely accepted as the oldest and most primitive protozoans, are organisms like *Euglena* (Fig. 2A) and *Chlamydomonas*, widely studied as examples of the phylum; the Phytomonadina or Volvocales (Fig. 3), including *Volvox*, not uncommon in fresh water; the dinoflagellates,