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The Ancient Greek roots of Biological Sciences[1]

I take pleasure in dedicating my talk to my friends Dimitrios Phitos and IOSEB President Eörs Szathmáry, both unfortunately absent.

There could hardly be a more appropriate subject than the present one for opening an international biological Congress in Greece – nor a more appropriate country than Greece for today's topic.

The 6th to 4th Century b.c. saw the breakthrough of humanity from myths and darkness into the daylight of reason and intellect. It happened in virtually no time in a tiny portion of our Globe, the domain of classical Greece – then extending from southern Italy and Sicily to the coasts of Asia Minor and Cyprus.

It must have been an incredibly exciting time to live in, with the shells of old conventions falling off one after the other at a breathtaking pace. Among political unrest and warfare, a few handful of brilliant minds set themselves to the task of renewing the human mind, reinventing human society, nature, and the cosmos.

The natural sciences were but a part of the domain thus renewed, albeit an important one. And as far as the living world is concerned, the breakthrough had to await the last quarter of the aforementioned period. It was to be the achievement of just two men, mentor and pupil: Aristotle and Theophrastos; and it took place in the years between Plato's death (347 b.c.) and Theophrastos's demise in 287 b.c. – a time span of 60 years or two generations.

Precursors – if so they may be named – were half a dozen people: Philosophers of the budding "think tanks" at the periphery of the Greek domain, In Asia Minor, Thrace, south Italy and Sicily. The first were Thales of Miletus and his pupil Anaximandrus, inventor of the notion of φύσις (nature): they were followed by Pythagoras of Croton, Xenophanes of Elea, Heraklitus of Ephesus and Empedocles of Agrigentum. These early protagonists of nature philosophy were all following a deductive, or one might say, speculative line of thought. They invented their own cosmologies and cosmogonies, rigorously logical,

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inferred its laws and processes, and tried to use them explaining their world. Empirical data were of little interest to them, used perhaps on occasion to disprove a competing philosophical conjecture.

Empirical facts were not of course unknown, but the observers were people of everyday life: herbalists and druggists, agronomists and farmers, often perhaps illiterate. Not that illiteracy made any great difference: The writings of those early days are for the greatest part lost, at best preserved as fragments – many of them apocryphal. Most of what we know of the early philosophers just mentioned (and of many later ones alike) came to us in the form of comments and references in the works of others. Much learned effort has gone and continues to go into the interpretation of that old testimony such as it came to us through the labour of ancient or medieval copyists, often in Latin translation.

But let us now turn to the heroes of the day. We do not posses their full biography, but many of the basic facts of their lives are known.

Aristotle was born in 384 b.c. in Stageira on the Halkidiki peninsula of Macedonia. He came to Athens at the age of 17 and entered Plato's Academy (that's a place name, still unwittingly reflected manifold in today's academic world) as a pupil the a teacher, to leave again in 347, shortly after Plato's death. During four or five years (347-343) he resided in Assos of Troad, then in Mytilini on Lesbos, after which he became the beloved teacher and mentor of to-be Alexander the Great, at the Macedonia residence of Pella and later in his native Stageira, rebuilt for the occasion. After 12 years of absence, in 335, when Alexander was about to leave for his famous war expedition, Aristotle returned to Athens where in his domain named Lyceum he founded his peripatetic school (Aristotle liked promenading while teaching – hence the school's name). Again 12 years later, in 323, he was driven from Athens during the riots following his protector Alexander's premature death in Babylon, to die that same year in Halkis on Evvia, aged 61.

Tyrtamos of Eresos, junior by 13 years to Aristotle, was born in Eresos on Lesbos in 371. Owing to his oratory talents he was later to be nicknamed "Euphrastos" (the well-spoken), eventually to become famous as Theophrastos, divine spoken. Having joined Plato's Academy at the age of 17 he soon fell to Aristotele's spell and accompanied him, still a young man, in his self-chosen exile on the Troad then on his home island Lesbos. He then disappeared from the record for three or more years – during which time some believe he travelled far, to Crete and Libya, which I personally doubt – to surface again at Aristotle's side in Stageira. From there on he never again left his master except for his short last exile, succeeding him as the headmaster of the peripatetic school until his death in 287, at the venerable age of 85. He is said to have been a congenial chap, sworn bachelor and gourmet, and to have died of the sequels of the wedding party of one of his pupils – but that's off the record.

Aristotle is known as the father of zoology while Theophrastos has claim to the paternity of botany – but matters really may be less straight forward. Firstly, both men were by no mean merely biologists: Lists of their works (most of them lost) show plenty of items pertaining to logics, rhetoric, politics and other branches of learning. Secondly, whereas indeed no botanical works of Aristotle nor any zoological ones by Theophrastos have come

down to us, both are reported to have once existed: Aristotle's "Theory of plants" (θεωρία περὶ φυτῶν) is referred to by himself elsewhere in his writings but has left no trace, nor did the seven tomes of Theophrastos's alleged work "on animals" (περὶ ζώων).

From what I have read and learnt yesterday, a likely scenario emerges. The two friends, mentor and pupil, undertook most of their scientific investigations jointly, during their sojourn in the Troad, on Lesbos and the Halkidiki. Obviously they practiced a division of labour, with Aristotle concentrating on the fauna and Theophrastos on the flora, but the exchange of information and ideas must have been intense and regular throughout. Aristotle's main zoological works, "On the parts of animals" (περὶ ζώων μορίων), "On the reproduction of Animals" (περὶ ζώων γενέσεως), and "Histories of animals" (περὶ ζώων ἱστορίαι), are likely at least in part the result of cooperative effort. Similarly, the botanical works of Theophrastos, "περὶ φυτῶν ἱστορία" ("History of plants") and "περὶ φυτῶν αἰτιῶν" ("On plant causes") – while probably posterior to Aristotle's death in their definitive version – will likely have profited from the master's input during the early stages of their genesis. Irrespective of the author to whom they have been credited, it is tempting to regards all these works as the product of their joint efforts of a lifetime, well beyond the senior partner's life span.

This being said, the differences between master and pupil must not be neglected. To their respective propensity for the animal and plant world I've already referred; but there is more. Both were genially gifted, but Aristotle was doubtless the keener theoretician. It is he who built the main frame, drew the general lines that Theophrastos willingly followed. On the reverse, while both men were keen observers, in Theophrastos the love of details, the interest in the diversity of beings and the variety of their features prevailed. While by no means unilaterally so, he represented analytical power where Aristotle contributed the synthetic drive.

However this may be, among the two they revolutionised biological thought and theory. They "invented" almost single-handedly the inductive approach in the natural sciences, whereby empiry – the observed fact – precedes synthesis in the building of theory. The old cosmologies, starting from abstract assumptions and working by logical deduction to explain the known facts, were dismantled and done with, as none could account for the newly acquired wealth of empirical data.

[In giving primacy to the observed fact, Aristotle and Theophrastos may have had one lone precursor: Demokritus of Abdera in Thrakia, of whom nothing certain is known, is said to have observed growth patterns of antlers and teeth and inferred the causes from his observations. This for the record.]

Still, Aristotle and Theophrastos could not ignore completely the spirit of their time, the generally acknowledged paradigms that framed the ways of human thought and perception. They admitted them willingly when they did not collide with empirical facts. Most noticeable in this respect – strange to us now but still widely accepted a mere three centuries ago – is the Empedoclean concept of our world consisting of four basic elements: Fire, water, air and soil, to which four all-embracing, pair-wise antagonistic qualities correspond: Hot and cold, most and dry (or: liquid and solid).

What then, in concrete terms, did the two men achieve? Time is much too limited to give you a reasonably comprehensive idea. Let me, then, pick out some salient features.

Among the two of them, Aristotle and Theophrastos mentioned or described 1000 different species (550 animals and 450 plants), most of which we can interpret in modern terms through their names and/or described features. These are huge figures when compared to what was mentioned in writing before, yet it only represents a selection of what these men actually knew. Neither of them aimed at completeness of coverage. Plant and animal species, along with their features, were the raw stuff on which their teaching was built, and indeed, their writings were essentially textbooks or lecture scripts – an interpretation that accounts for many of their peculiarities.

Whereas Aristotle's own botanical work is lost, there are several references to plants in his zoological writings, and they appear to be of particular interest to me. Let us look at some. Aristotle recognises a grade leading from dead matter through plants to animals, mentioning sponges and to a lesser extent, ascidia, as animals close to the former. He characterises life by the presence of one or more of the faculties of thought, perception, locomotion, food uptake, change in size and shape through growth and shrinking, and he associates the postulated presence of a soul with the living state; then he distinguishes three kinds of soul: The "vegetative" one governing feeding and growth, exclusive in plants; the perceptive soul, related to sensitiveness and motion; and the rational soul that, alone, is owned by the thinking humans. [Later Theophrastos, facing a report of leaf movements in an Egyptian sensitive, presumably *Mimosa pigra* L., will cast doubt on the former distinction.]

According to Aristotle, sessile organism are organised along a single, vertical axis. Mobile ones (i.e., the majority of animals) have two horizontal axes (left to right, front to back) in addition. As the orientation of the axes is derived from the human condition, the logical conclusion is that plants, which feed through their roots, grow upside down. This is a good example of the anthropocentric bias in Aristotle's philosophy (a bias much less pronounced in his pupil's work): Man, by his features, is undoubtedly closely related to animals, yet he is in a way a "value-added" animal (just as animals are "value-added" plants), to whom particular chapters of the "Histories of animals" are devoted.

Fundamental intellectual breakthroughs may be noted in the domains of sexuality, reproduction, and inheritance. At a time when egg and sperm cells were unknown and the function of pollen unheard of, Aristotle restricted (active) sexuality to the animal domain, but went on postulating that "in plants the male and female principle are united in the same organism"; and he pointed out that "there are trees in which only some individuals bear fruit, but then the other ones 'help' them in so doing". As an example, he mentioned caprification (the hanging of male branches onto fruit bearing fig trees, required in non-apogamous strains to obtain fruit set through the transfer of the symbiotic fig wasps – a process well known to Theophrastos and admirably described if partly misinterpreted by him).

Aristotle recognised the urge and necessity to reproduce as the driving force of all life. He could not rule out spontaneous generation in cases where the reproductive mechanisms were unknown – he gave the mistletoe as one example, but there, Theophrastos came to know better and rectified his master – but he definitely disliked the idea. Importantly, he

knew that species did breed true and thus were stable (no way for him, of course, to observe evolution of species empirically during his lifetime), and he postulated mechanisms by which maternal and paternal inheritance occur by equal shares – quite a revolutionary idea in the male dominated world of classical Hellas.

Aristotle also correctly established that the seed (or egg) comprises the potential of the whole diversified organism, but not its "reality", that is, not the material precursor of each individual part and organ. This is a surprisingly modern idea, especially if we translate the term that Aristotle used to designate the carrier of the heredity message, "soul", by "DNA".

Descriptive morphology is another innovative field in which both Aristotle and Theophrastos excelled. Terms and definitions were needed to express the observed facts properly and in a generally understood way. Aristotle created them for animals and in a basic way also for plants, in which latter he distinguished roots, stem, leaves, and fruits with a pericarp and seeds. These concepts were refined and clarified by Theophrastos, who for instance distinguished between a simple and double perianth, choripetalous and sympetalous corolla, superior and inferior ovary, giving appropriate examples. Significantly, foreshadowing at least part of the truth, he recognised seed and fruit as being parts of the mother plant (in contrast to animals where Aristotle, naturally, had attributed egg and embryo to the new generation).

I have left for the end that part of Aristotle's philosophy that is most central in an ICSEB context: Classification. Aristotle has outlined a hierarchical system of the animal kingdom that in many of its traits looks surprisingly modern. Theophrastos, faced with the same requirement for plants, apparently gave up in despair. He stated: "The plant is a variable, diverse organism, hard to define in general terms", then went on discussing the genera and species (the only units recognisable in his work) by ad hoc utilitarian categories such as cultivated and wild, terrestrial and aquatic, or the gross life form.

Aristotle first divided animals into two main groups: the bloodless ones and the "others" [I've got a problem of English there: If I refer to these "others" as "bloody animals", as logic appears to require, I immediately think of mosquitoes and the like, which are definitely bloodless according to Aristotle's system]. The two main groups he subdivided into major units, several of which are still in general use: Cephalopods (which he called "molluscs"), fish, birds, cetaceans may serve as examples. Further subdivision occurs, into units that may be named or unnamed. E.g., within the non egg-producing quadrupeds (i.e., the terrestrial mammals) he set off a group characterised by the presence of horns or antlers on the head, an incomplete dentition and a multiple stomach: Our ruminants. But they remained unnamed, apparently because the camel, clearly belonging here, lacks horns.

The most genial – for a systematist – about Aristotle's method of classification is the working method recommended and at least partly used by him to build a classification. [Sorry but I failed to spot the exact source of that method and must rely, not on his writings but on second-hand information.] He wrote, in divine simplicity: "Τὸ εἶδος ὁρίζεται ἀπὸ τοῦ γένους καὶ τῆς διαφορᾶς" (the species is defined by the genus and the difference). This beautiful piece of Aristotelian logics came to be the core of what has recently been misnamed the "Linnaean system" or, but marginally better, the "Linnaean classification". It can

be applied to any hierarchical classification system, irrespective of whether it uses fixed ranks (such as the Tournefortian system, earlier and more sophisticated than the much quoted Linnaean one) or indefinite ranks (as phylogenetic systematics apparently prefer).

The key to the universal applicability I claim for the Aristotelian principle of classification lies in the meaning of his terms γένος and εἶδος, usually translated as "genus" and "species". While they were indeed often used at these respective ranks by both Aristotle and Theophrastos, the customary translation does not render fully and exactly the meaning of the Greek terms. A more unbiased translation, taking into account the philological roots, might be "kin" for γένος and "aspect" for εἶδος. The crux of the matter is that both terms, taken together, stand for a hierarchical couplet of indefinite rank, in which γένος stands for the higher and εἶδος for the subordinate rank. Thus, depending on context, both terms can be used interchangeably for one and the same taxon, and they indeed were so used in the classical writings, where oaks can be a species of the genus "trees" or a genus comprising oak species. If you apply Aristotle's recipe to this given context you will see how well it functions: The species "oaks" is defined by its belonging to the genus "trees" plus the "difference", i.e., a statements of the features that, taken together, distinguish oaks from all other tree "species"; and any particular oak species is in turn defined by its belonging to the genus oaks plus a diagnosis ("difference") setting it off against the remaining oak species.

When the species in a genus are few the difference may consist of a single word, and then the result may foreshadow Linnaeus's binary nomenclature of species. It is not so strange or surprising, therefore, to find some of the species designations of Theophrastos to be all but identical with Linnaean binomials that we still use. Examples are βάτος ὁ ἴδαιος (*Rubus idaeus* L.), Κράνεια ἡ ἄρρην (*Cornus mas* L.), and Σφένδαμνος ἡ πεδιεινή (*Acer campestre* L.).

Aristotle and Theophrastos: The inventors of empirical observation as the basis of inductive theory; of the first operational definition of life; of the theory of heredity; of anatomy and descriptive morphology; and the fathers of classificatory taxonomy.

For them, the statement of the Swiss botanist Gustav Senn is as appropriate yet concise as any I might myself imagine: "They transcended nature philosophy to create the natural sciences".

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