In Context

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Spring 2019

Dear Friends,

Spring is a time of new beginnings and fresh hope. We here at The Nature Institute feel this invigorating surge of life with special force now, as we enter the third decade of our activity since the Institute's founding in 1998. Our many courses – here, nationally, and abroad – are flourishing as never before, with more and more young people being drawn to them. New colleagues are being found, and with them, tantalizing possibilities for expansion of our work into new domains. Even for those of us who are "old hands," having been with the Institute from the start, our work seems to be reaching a culminating stage that carries the sense, not only of fulfillment, but also of burgeoning promise.

Actually, the sense of a new beginning is one that can fruitfully be encouraged at every moment and in every human activity. A beginning brings with it hope, as with the birth of a child. Every word released into the world is a bit like a child. Whether it is spoken in a course or to a colleague, or written in an article, or merely voiced as an encouragement to oneself, it is put forth because it is thought to carry some significance. That's what words *are*, bearers of significance. And significance always invites a response – in just the right circumstances, and for the person who is prepared for it, perhaps a life-changing response.

In this way we can healthily think that every word or gesture, every planting of a foot upon the solid earth, every action of significance (and doesn't every action carry significance?) can be the start of something new. What the world becomes will reflect all those continual beginnings and the direction in which they tend. Our own central hope is for freshening breezes in the realm of science, but human activities are always multifaceted in their significances, and it is impossible to predict the downstream consequences of one's actions. The key thing is to act in full consciousness of the grave responsibility involved in bringing new "children" into the world.

Regarding the work "now reaching a culminating stage," the briefest of mentions may be worthwhile. Henrike has written a workbook on projective geometry, *To the Infinite and Back Again*, that will be available later this spring. The book is the fruit of twenty years of Henrike's teaching on this topic in a variety of courses. It is meant for lay people as well as math teachers.

Craig, who has been pursuing whole-organism studies for many years, is in the later stage of gathering these together, revising them, and adding new material for a book of his "collected works" on whole organisms. This includes a considerable treatment of evolution, and a substantial amount of material not previously published. But, yes, you will find in the book, when it is fully finished, the "short-necked" giraffe, the elephant, the sloth, and many of the other animals we have grown to appreciate through Craig's writing over the past two decades.

Likewise, Steve is now making steady progress on his book, tentatively entitled "Whole Organisms and Their Evolutionary Intentions." Not long after you receive this issue of *In Context*, he expects to have reorganized our website's Biology Worthy of Life section, with a central focus on the book. Several draft chapters will be available, along with extensive indications of the content of several others.

Two articles in this issue, by Craig and Steve, bring you a foretaste of this work. You will certainly be hearing more about all these projects in coming issues.

Craig Holdrege — Steve Talbott

Craig Holdrege — Steve Talbott

The Nature Institute

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Scenes from a Two-Week Course in Brazil

In November, Henrike and Craig went to Florianapolis, Brazil, to give the first part of a four-week course (to conclude next November) called “Seeing Nature Whole—Foundations of Goethean Science.”

A New Challenge Grant!

A Nature Institute supporter has generously offered to donate up to $5,000 as a matching gift. If we match the grant with your help, we will use the funds to support our education programs. This will allow us to give scholarships to course participants, charge reduced fees for programs, and provide fellowships for young researchers.

So every dollar we receive by June 30 will be matched up to $5,000. You can make a gift by check or credit card using the enclosed envelope, or by credit card through our website.

(http://natureinstitute.org/friend)

Thank you!

Mentoring and Fellowships

This winter and spring we've welcomed a number of people at the Institute for mentoring and fellowships.

As many friends of the Institute will know, Craig has built up an extensive bone collection over the years, a collection that has played a significant part in his teaching about animal form and morphology. At times, Craig received those bones already cleaned and, at times, he was given the whole animal and cleaned it himself. This January and February, Erin Corrigan, an intern at Hawthorne Valley School's Earth Program, came in weekly to work with Craig and Henrike in cleaning a number of new specimens for the collection. She also participated in a study of the book, *Goethe's Theory of Knowledge*, by Rudolf Steiner. The study was led by Seth Jordan.

Gopi Krishna Vijaya, a participant in our 2018-2019 year-long program in Goethean science, joined us for the month of March as a fellow at The Nature Institute. During that time, Gopi took up an intensive study of star colors, focused primarily on the stars in the zodiac. He paid attention both to naked-eye and telescopic observations, while also studying the Institute's extensive astronomical literature that we received from the collection of the late Norman Davidson. Davidson was an educator who wrote the book *Sky Phenomena: A Guide to Naked-Eye Observation of the Stars*.

And in May, Maíra Ferraz, another participant in the 2018-2019 year-long program, joins us for three months in order to work on the completion of her Ph.D. thesis, dealing with the Goethean approach to science and its relevance for the study of geomorphology.

At Home and Abroad

This past September, we celebrated **the first two decades of our work** at The Nature Institute with a weekend talk and workshop. On Friday evening, September 22, Henrike shared memories of our founding and Craig offered a talk with slides entitled "Where Does an Animal End? The American Bison." (We've since shared this presentation online. You can find out more about it in Publications and Resources on page 6). Then, on Saturday, Craig and Henrike led a day-long workshop on "Learning to See the Animal." One highlight: spending an hour in the afternoon just sitting alongside Hawthorne Valley Farm's herd of cattle and observing as the herd grazed in the field that is neighbor to our own land.

In October, Craig traveled to Middlebury College in Vermont to make an invited presentation as part of a new, innovative course being offered on **"perennial thinking."** The class had already read Craig's book, *Thinking Like a Plant,* and his presentation led to a lively and engaging conversation with the students.

Craig traveled to Kassel, Germany, in December, where he gave four keynote talks on **"Contextual Approaches to Understanding Life"** as part of a week-long conference for Waldorf high school students. Also, Craig and Axel Ziemke, a biology teacher, gave a course on evolution for students with a special interest in biology.

During our winter course (next page), the Institute hosted a celebratory book launch for Wolfgang Schad's ***Understanding Mammals***. Both Craig and John Barnes of Adonis Press, the book's publisher in the U.S., gave presentations about Schad's work. See the feature article by Schad on page 8 to learn more about him and his work.

Early in March, Craig and Henrike were in Pasadena, California, to offer a talk and all-day workshop on **"Learning to See the Animal"** for the public and students in the teacher-training program of the Waldorf Institute of Southern California.

Later in March, Craig drove down to the Pfeiffer Center, a biodynamic farm and educational center in Chestnut Ridge, New York, to give a half-day workshop on **"Plants and Animals: Contrasting Ways of Being."**

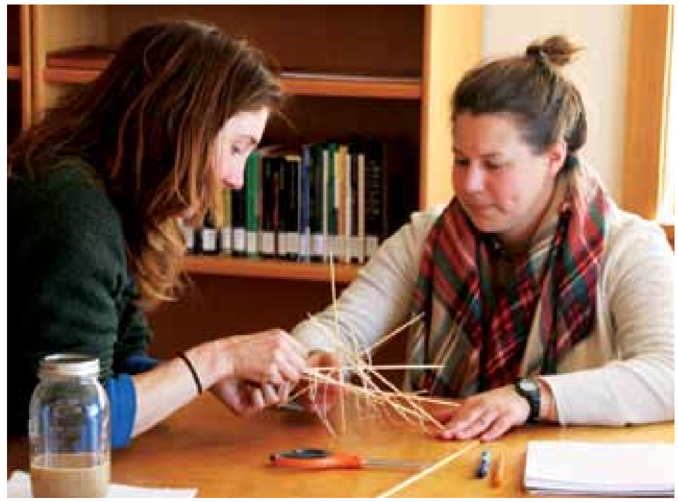
Then, at the end of March, Henrike and Marisha Plotnik, a long-time colleague who teaches at the Rudolf Steiner School in Manhattan, led a weekend workshop for class and math teachers on **"Negative Numbers and Linear Equations."** It was part of their ongoing series of *Mathematics Alive!* courses.

In early April, Craig traveled back to Kassel, Germany, this time to give a keynote talk about **the American bison** and a course on **evolution** at an International Professional Development week for Waldorf educators and teacher trainees.

Later in April, Jennifer Greene, founder of the Water Research Institute in Blue Hill, Maine, led a special weekend at the Institute, based on her phenomenological approach to understanding the qualities of water. She gave an evening talk, **"Goethean Science and the Native Science of Indigenous Peoples,"** which took up the subject of Goethean science more generally. Then she led a weekend workshop that brought participants deeper into the nature of water as an element of our experience that "serves all life without prejudice." The title of her workshop: **"Moving, Forming, and Rhythm in Water Flow: Experiencing and Understanding the Fluid Event of Water."**

2019 Winter Course

In February, we again offered a week-long winter course at The Nature Institute, this time on "The Nature of Animals and Developing Dynamic Thinking." Each morning began with exercises in projective geometry. We then shifted our focus to nature. We considered the qualities of minerals and crystals, and then plants, which helped us to see more clearly the special characteristics of animals. Through the study of animal skulls and spines, we could experience the deep wisdom that lies at the heart of animal form and learn how every part is an expression of the animal as a whole. The perception of form was enhanced each afternoon through exercises in clay modeling that Henrike guided. In reflecting on their experience afterwards, participants shared comments like those below:



Visualizing Girard Desargues' theorem about perspective triangles.

Your ability to lead students to grasp their own understandings is a breath of fresh air to a student who has only experienced conventional education systems. All I want now is to learn more. So if that is the intention of your course, you have completely succeeded. I love projective geometry and bones!

One of the things I appreciated the most was the leading nature of the lessons. It was about slowly discovering a concept or idea, piece by piece. This occurred within an individual lesson, but also over the course of the week as a whole. I appreciated how the two areas (geometry and mammals) connected in the clay sculpting of the bones. Having the time to experience the bones really opened my eyes to all sorts of small discoveries. Giving time to just looking and categorizing them in our own way developed the ability to really see the small differences in the skulls and bones. Also the tactile nature, holding the bones, feeling the teeth, etc., grounded the ideas and discoveries in a reality — the physical world — that we all experience. After the evening session when we put together the spinal columns of the animals, one being a cow, I went to the farm and looked at the backs of the cows in a whole new light. I began to imagine the internal structure that forms their bodies and recognize the internal structure within the cow as a whole. Thank you so much for the course and for sharing all your knowledge and perspectives with us!

Winter course students modeling animal bones in clay.

Still Ahead

- In June we are co-sponsoring with the Center for Social Research a talk and workshop with social scientist Christopher Schaefer on his forthcoming book, *Looking for Hope in Difficult Times.*
- This June we also begin our second year-long, low-residency foundation course in Goethean science. We are preparing for another very full group of participants and we look forward to beginning this work together!
- And in July we have the final session of our first year-long foundation course. The participants came together for the first time last summer, and since then have been studying and working with mentors on their own individual projects aimed at practicing Goethean methods.

Researching Crop Plants

Craig Holdrege and Judith Madey, a local farmer and long-time student of Goethean science, will begin a two-year research project this spring called "Learning from Plants: The Stories of Two Agricultural Plants." They will study and portray two important, widely grown crops: alfalfa, a perennial, and corn, an annual. Their project will address questions such as: What are some of the salient features of these two crops? How do they reveal to us different ways of being and ways of interacting with the larger environment? What role do they play and have they played in agriculture? How can we learn from these plants to think and act in more plant-like — that is, transformational and context-sensitive — ways?

This research is being supported by the New Perennials Project, which is housed at the Rockefeller Family Fund. The project's director, Bill Vitek, conceived the idea of comparing the qualities of a perennial plant with the qualities of an annual after conversations with Craig and Henrike. Bill is Professor of Philosophy at Clarkson University in Potsdam, New York. The New Perennials Project has roots in the work of The Land Institute in Kansas, where Craig and Bill first met. The project, like The Land Institute itself, is not about quick ecological fixes. Instead, it strives to foster the kind of far-sighted thinking that concerns itself with protecting all forms of life on earth for the long term.

The Nature Institute is very glad to have Judith Madey as a colleague in this research. She participated in a three-month course in Goethean science that we offered back in 2006, writing an article for *In Context* based on both her long experience as a cow herdswoman and her close study of cows during that course. She has decades of experience in farming. We will keep you abreast of this project in future issues of *In Context*.

Publications and Resources

An addition to our online Ronald H. Brady Archive: Ron Brady was a highly respected friend and colleague, and a professor of philosophy at Ramapo College in New Jersey for over three decades. Since his passing in 2003, we have created an archive of his papers and articles on our website, and have recently added his Ph.D. thesis to the collection. Titled "Towards a Common Morphology for Aesthetics and Natural Science: A Study of Goethe's Empiricism," it fleshes out the idea of metamorphosis in Goethe's thought and looks at historical interpretations of morphology from Linnaeus, Owen, and Darwin, to modern phylogenetic morphology. It also explores the relation between aesthetics and natural science. You will find it on our website at http://natureinstitute.org/txt/rb.

A new article in our Biology Worthy of Life Project: As Steve Talbott continues working on his new book, he is posting chapters online. You can find one of them, "The Organism's Story," on the Biology Worthy of Life page on our website. Here's how Steve describes it: "The fact of purposive activity — the obvious play of active agency, the coordination of means toward the realization of countless interwoven and relatively stable ends, and the undeniable evidence that animals perceive a world, interpreting and responding to perceptions according to their own way of life — all this tells us that every organism is narrating a meaningful *life story*."

Craig quoted in *National Geographic* online: This fall, Craig was contacted by a writer working on an article for *National Geographic's* website about new research into the spot patterns of giraffes. Craig acknowledged that the research has shown some relationship between the coat patterns of mothers and those of their young. But he also sounded a cautionary note about conjectures that such inherited patterns merely represent mechanisms for survival. You can find the article online by searching for "Baby Giraffes Get Their Spots From Mom."

And a new video — Craig's talk on the American bison: This past September at the Institute, Craig shared the fruits of his many years of research into this fascinating animal: its physical constitution, its relationship to its ecosystem, its life as an individual and as part of a herd, and its relationship to Native Americans. Through examining the American bison closely, Craig shed light on the boundaries of animals and how the demarcations aren't as clear as we might expect. You can find the video on our website at http://natureinstitute.org/media.

Thank You!

We would like to thank the group of supporters who joined forces to offer a $3,000 challenge grant in the fall — and to all who responded. Your gifts totaled over $6,000! Also, our deepest gratitude to everyone who contributed goods or services between October 1, 2018 and March 31, 2019.

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Living Form in Mammalian Biology

Excerpts from *Understanding Mammals: Threefoldness and Diversity*

Wolfgang Schad

My purpose is to place in the absolute center of inquiry the direct perception of the animals most closely related to us — the mammals — as they live in their natural environment. We shall approach them with the confidence that their lives openly and plainly convey what is essential for our understanding of them. As we recognize the unique quality of each animal form, it poses a much neglected question whose answer, like the meaningful word of an as yet uncomprehended language, can be supplied only by the living form of the animal itself.…

We know a great deal about genetic factors, basic physiological processes, predictable instinctive reactions, and the social behavior of animals. But no one can tell us why well-known hoofed mammals, like cattle, deer, and rhinoceroses, have head protuberances, while horses, donkeys, tapirs, and camels do not. Neither molecular biology nor behavioral research concerns itself with the significance of an animal's form. One view regards it as a collection of randomly acquired adaptations, while the other sees it as the result of responses to external stimuli. But we will never rid ourselves of the suspicion that a living organism's form expresses more than what is conveyed by such conventional interpretations. An animal, especially a vertebrate, is visible material substance, living form, and animated, sentient life. How are these different aspects related to each other, and how can we comprehend this relationship by observing the animal itself ? Such are the questions that always arise whenever we observe animals. [p. 2]

When we observe the human form, we immediately see that it is organized into the trunk, the head, and the limbs. The head raises itself quite distinctly above the rest of the body, while the limbs are closely connected with the trunk. Rudolf Steiner differentiated our human physical organization, however, not only in terms of its visible parts, but also according to its functional processes. Thus he grouped the processes in the abdominal region together with those in the limbs, characterizing them as a common system that constitutes a polarity with the processes in the head. Mediating in both form and function between these polarities is the chest with its organs. How do its form and function reveal their mediating role? A closer look at the polarities of the organism will provide a context for grappling with this question.

The head rests upon the body. It has little mobility within itself and is mostly solidified in the rigid bony structure of the skull. In contrast with the rest of the body, it moves but little. Above the runner's flailing limbs and panting chest, the head quietly keeps the goal in view. Most of the sense organs — those of sight, hearing, balance, smell, and taste — are gathered in the head. Through these senses the organism opens itself fully to the surrounding environment. Connected as it is with the sense organs, the nervous system, too, has its center in the head. The brain is the organ through which the organism gains the capacity to orientate itself and find its way in its environment. Thus the head is the center of what we may call the *nerve–sense system*, through which the organism perceives and adjusts itself to the requirements of the surrounding world.

In contrast to the head, the limbs and the organs of the abdominal cavity engage in strong bodily activity that is expressed both in actual physical movement and in the intense chemical activity of the metabolism. The organs of the abdominal cavity process food, which at first is alien to the body, through such dynamic chemical processes that it is transformed into the body's own substance. Thus the main function of the metabolic organs is to maintain the organism's physiological autonomy vis-à-vis the environment. The abdominal cavity, the body's largest, is also the least protected by bones; any hardenings in the soft organs it encloses (e.g., gall stones, kidney stones, and bladder stones) are a sign of disease. This fact stands in contrast to conditions in the head, where, for example, crystalloid formations within the pineal gland of the brain (brain sand) are considered normal and non-pathological.

Though the skeleton is expressed more strongly in the structure of the limbs, the placement of the limb skeleton is obviously polar opposite to that of the cranial bones. While the latter form a "shell" directly beneath the skin and serve as an external skeleton that protects the soft organs within, this relationship is reversed in the limbs. Here, arm and leg bones form the internal skeleton that is surrounded by the softer tissues. It is noteworthy that while nearly all the head bones have fused to form a single rigid structure, the limbs

HERE WE OFFER READERS of *In Context* a glimpse into a book that is the fruit of Wolfgang Schad's many decades of research into the dynamic morphology of mammals. I've met many people whose eyes were opened by Schad's work to a fundamentally new and exciting way of understanding the forms and characteristics of mammals. This was also the case for me. Moreover, he has inspired other researchers and helped them discover patterns in different groups of animals.

The first German edition of *Säugetier und Mensch* was published in 1971, when Schad was thirty-six years old. An English translation, entitled *Man and Mammals*, was published in 1977. For many years the book has been out of print and eagerly sought after as a rare used book. But Schad never stopped researching, and his ability to hold innumerable facts and then weave them into a meaningful and coherent picture is truly remarkable. In 2012, the new German edition was published — two volumes totaling 1300 pages! Truly, a lifetime achievement.

Now, through the tireless efforts of publisher John Barnes and editor Mark Riegner, we have an English translation that includes new material (Schad remains an indefatigable researcher at eighty-three!) and many new illustrations. In the scope of its treatment of mammals and in the uniqueness of approach, the book is bound to become a classic.

Animal form is usually interpreted through a Darwinian (or better said, Neo-Darwinian) view of evolution. All characteristics, whether the color or patterning of the fur or the form of the teeth, are considered in terms of survival. How do the long neck of the giraffe, the flat tail of the beaver, the larger molars of a horse, or the horns of an antelope allow the animal to survive? The beaver's teeth are good for gnawing wood, the large flat tail for swimming and as a paddle to slap against the water to alert other beavers about the presence of potential predators, and the high-set eye sockets for swimming inconspicuously with its head only slightly above the water surface. In a way, all these "explanations" make sense. But they are also quite speculative. Moreover, this way of looking leads us to mentally dissect the animal into different traits, each of which has its own type of survival value. The coherence and integrity of an animal dissolves into a collection of traits, and all its characteristics are considered solely as adaptations that secure survival.

Already long before Darwin, Goethe protested against trying to explain animal traits in terms of their utilitarian functions. He wrote, "We conceive of the individual animal as a small world, existing for its own sake, by its own means. Every creature is its own reason to be … We will not claim that a bull has been given horns so that he can butt; instead, we will try to discover how he might have developed the horns he uses for butting."* This means that we need to study the characteristics of an animal in relation to one another and see if we can discover how they fit together with the context of the animal as a whole.

In this spirit, Wolfgang Schad studies animals. From childhood onward, Schad was a keen observer of animals. When he later studied Rudolf Steiner's idea of threefoldness in the human being — of which you'll find a brief sketch in the accompanying excerpt — he formed a mental lens that allowed him to see patterns in animals that had hardly been recognized before. With this lens he has been able to build up a comprehensive picture of the diversity of mammals.

A threefold pattern in mammals is perhaps most vividly displayed in the differences between rodents, carnivores, and hoofed mammals (ungulates), which the excerpt focuses on. Of course, there are many other groups of mammals and Schad shows how the lens of threefoldness can help make sense of some of this variety. Moreover, one can see recurring themes within the different groups that otherwise remain unappreciated.

Schad is not interested in fitting the diversity of mammals into a rigid and neat system. Rather, he explores what kinds of relations the lens of threefoldness allows one to see. And many notable and surprising connections show themselves in the 1300 pages of the two volumes. Few readers will study the entire book page by page. But once you work enough with the book to gain a good sense of what Schad means by threefoldness, you can begin to see and appreciate the nuanced iterations in different groups. You begin to move in a world of dynamic connections. Then you can select individual chapters about, say, bats or whales, and not only learn interesting details about these animals, but also have your eyes opened to connections you would have never noticed on your own.

This book belongs in every good library. It will help animal lovers and educators gain a new way of looking at the diversity of mammals. *CH*

* Goethe, J. W. von. 1995. *Scientific Writings*. Princeton, New Jersey, Princeton University Press, p. 121. Goethe wrote the quoted text in 1795; it was first published in 1820.

are equipped with many joints, and their bones branch out into the multiplicity of the fingers and toes. These allow for the organism's independent mobility in its environment. This *metabolic–limb system* also includes the reproductive organs.

Between the relatively immobile nerve–sense system and the highly active metabolic–limb system, we find the organs of the chest region. Lungs and heart are rhythmically pulsating organs. In each, contraction and expansion, tension and relaxation, compression and dissolution alternate constantly. The polarities of the organism, therefore, are always present in this region; but here they do not maintain their spatial separateness; rather, they actively complement one another through their rhythmical alternation in *time*. Thus we can speak of the *respiratory–circulatory system* or the *rhythmic system*, or simply the *middle system*. [pp. 15-16]

The human organ systems are also found in all mammals. Among the mammals, however, the three main systems relate to one another in very different ways in that one or another system is especially well developed. Thus, high degrees of specialization have been attained so that, in accordance with the views of comparative morphology, we may consider many of these animals to be evolutionarily and thus physically more highly developed than the human being. In this sense, as already mentioned in Chapter 1, the rodents, carnivores, and ungulates [hoofed mammals], in particular, rank above the insectivores, primates in general, and humans. The great morphological diversity (i.e., disparity) among rodents, carnivores, and ungulates seems to defy any attempt to find guiding principles that would lead to an ordering of this extraordinary multiplicity. Yet the equally great morphological and anatomical diversity *within each organism* may itself supply the key to finding order among them all. In fact, it will be our best guide as we learn to see the extraordinary diversity of mammalian forms as a manifestation of their inherent unity.

Taking the threefold human being as our starting point, we find that the mammals demonstrate what remarkable differences are possible in the relationships among the three main organ systems. The dairy cow, with its mighty digestive processes and its prominent hoofed limbs, brings these organic systems into strong relief. Its whole organization is determined by the special qualities of the metabolic–limb system, and this emphasis is characteristic of all ungulates. Mice, in their nervous sensitivity, show the greatest possible contrast to the bovine nature. Their extremely refined sense organs so dominate the other organ systems that we may characterize the mice and all other rodents as primarily nerve–sense animals. It is

Photo: E. A. Janes

Figure 1. A wood mouse (*Apodemus sylvaticus*), which belongs to the long-tailed mice.

more difficult to generalize about the carnivores, such as cats, dogs, and seals, but I hope to demonstrate that these animals live primarily out of the processes of respiration and blood circulation.

Rodents	Carnivores	Ungulates
Sense–nerve functions predominate	Rhythmic functions predominate	Metabolic–limb functions predominate

What is brought to near perfection in the one-sided developments of the mammals yields in the human being to a delicate balance that is seen in the mammals only when they are taken together and considered within their respective environments. Only in an undisturbed landscape, when in biological equilibrium with one another and with other animals and plants, do the mammals show the balanced relationship that appears in the human body as an integrated whole.

The anatomy of the hoofed mammals shows a considerable hypertrophy of the limbs. In contrast with the five-digit type of limbs of the less specialized mammals, the ungulates' feet have regressed to a few bones, which, however, are very strongly formed. This specialization of the limbs extends even to the powerful enlargement of the nail into a hoof, which gives the group its name (i.e., ungulate). The limbs of horses and cattle support massive bodies and, in stamping and galloping, horses express the powerful animating forces within them.

Photo: W. Lynch

Figure 2. A mountain lion (*Puma concolor*).

Photo: Shutterstock

Figure 3. The African, or Cape, buffalo bull (*Syncerus caffer*).

The limbs of rodents are the polar opposite. Tiny and delicate, they hardly deviate from the original five-fingered form. Their fingers and toes are narrow and long, with nails shaped like tiny claws. The forepaws of squirrels, for example, are adept at grasping, handling, and feeling. Their limbs have clearly acquired a sensory function. Long sensory facial hairs (whiskers), and shorter ones over the entire surface of their body including their bushy tail, project beyond their warm coat and enable squirrels, fitfully twitching and hopping, to find their way in the surrounding world. In many rodents even the inside of the cheek in the mouth cavity is covered with sensitive hairs. Agile and quick in its reactions, a rodent lives in constant agitation, alarmed pauses, and rapid flight. Even in sleep, nervous spasms periodically run over its small body.

Rodents must sleep often. In all animals it is always the nerve–sense system that in the waking state so exhausts physiological functioning that this can be restored only in the unconsciousness of sleep. The organs of nutrition, which function outside consciousness, are indeed never awake, and it is for this very reason that they are able to continue functioning day and night. Thus rodents in particular, because they are so active in their senses, require frequent periods of rest even during the day, when they sleep for short intervals in order to be wakeful again.

Hoofed animals, in contrast, require little deep sleep. One or two hours, sometimes less, suffice for horses, cows, elephants, and giraffes. In these metabolic animals the processes that build up the body predominate even during the waking state, so that these animals tire much less readily than do the rodents. Contented peace and restfulness suffuse the cow's placid gaze, especially when, ruminating for hours, she devotes herself entirely to her food. Her eyes, and the eyes of all ruminants, lack the yellow spot, the *macula lutea*, which is the part of the retina with clearest sight. To the ruminants, the outside world appears diffuse. They have a stronger experience of smell and taste, senses more connected with the inner working of the metabolism than the eyes and ears. A cow is never as completely awake as a mouse; the unconscious processes of digestion predominate even in the ruminant's state of half-wakefulness.

The digestive tract of ungulates is highly developed, especially in their most characteristic group, the ruminants. A large, four-chambered stomach completely fills the anterior abdominal cavity. The intestines are extremely long: 22 times the length of the body, or about 60 m (200 ft) in cows. The principal nutritive substance of the grass, herbs, leaves, straw, and twigs eaten by the ungulates is cellulose, a food rather poor in nourishment, and extremely difficult to digest. It is thoroughly chewed twice, mixed with saliva, and fermented. Only with the help of symbiotic microorganisms that flourish in the gut, specifically the rumen, do the ruminants manage to assimilate a food so difficult to digest, and to build from it such extraordinarily powerful and large bodies. Cows can be fed nothing but straw for a period of weeks if given enough water and some urea as a source of nitrogen, resorbing the latter in their kidneys and using it to create more complex proteins. They even have a surplus of nourishing substances left over for others to utilize. From time immemorial, the ruminants have been able to serve carnivores consume the protein found in the meat and blood of their prey. This food, of course, also requires a powerful digestion, but it is much closer to the carnivores' own bodily substance than the cellulose that nourishes the ungulates. We thus arrive at the following overview of the three groups (the important role of exceptions will be discussed later):

Rodents	Carnivores	Ungulates
Nourishing food rich in energy: Fats, Oils, Starch	Foods similar to the body: Protein	Foods difficult to digest: Cellulose

There is an inverse relationship between the quality of the food ingested and the bodily size and substance of the animal eating it: in mice, rich, nourishing food is taken up by a body that contains almost no fat deposits for use as energy reserves. The opposite is true of the ungulates: they take in relatively poor food and yet develop from it substantial fatty deposits that are stored in subcutaneous tissue (producing ham in pigs), around the mesocolon, around the kidney (producing beef suet in cattle), and in humps (e.g., in camels). In diverse environments around the world, ungulates gather the substances taken from plants and, through their physiological processes, unconsciously work to enrich the energy these substances contain. While nervous constitutions characteristically break down substances, metabolic ones rebuild and augment them. The nutritive processes of the carnivores represent an intermediate state. When a leopard devours a gazelle, a true change of substance does of course take place during digestion, but the change from one form of protein to another hardly alters the chemical energy level.

The formation of the teeth is highly significant for understanding the morphology of mammals. Let us first consider our own human mouth. The most touch-sensitive part is its opening in the front: the surface of the lips and the tip of the tongue. Here, food is touched and examined, then bitten off with the incisors. (The incisors are particularly sensitive to the dentist's drill!) Next, it is thoroughly chewed and its taste fully enjoyed. The processes that follow become less and less conscious and controllable. The chewed and ensalivated food is moved back to the region of the posterior tongue and the soft palate, and the involuntary act of swallowing passes it down into the unconscious part of the physical organism. Thus the three parts of the oral cavity are arranged as follows: in the anterior part, the conscious nerve–sense pole is predominant; in the rhythmic chewing and tasting, the middle system prevails; in the unconscious throat area, the metabolic system predominates.

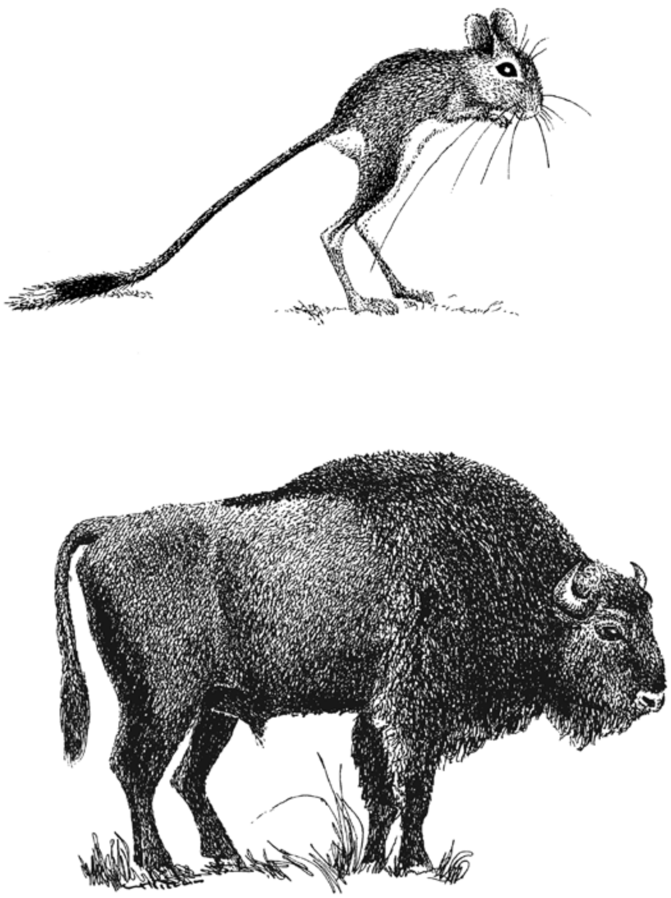


Figure 4. The lesser Egyptian jerboa (*Jaculus jaculus*) emphasizes the posterior pole as strongly as the European bison (*Bison bonasus*) emphasizes the anterior pole. (Drawings: U. Winkler)

as a source of nourishment for humans: cows, goats, sheep, reindeer, and camels have supplied milk since prehistoric times. Even their dung deserves mention as an especially valuable fertilizer for plants.

Typical rodents prefer nourishing foods high in energy. They especially like the concentrated fats and oils of nuts and seeds, as well as kernels rich in starch. They have less taste for fruits, and they will accept plant material composed chiefly of cellulose only when nothing else is available. Among the extremely sensitive rodents, the physiological capacity of the metabolism is so weak that it requires only easily digestible, energy-rich foods, substances that meet the metabolism halfway and readily support it. Such highly nutritive substances are vigorously and hastily extracted from the contents of the intestines; consequently, the desiccated, impoverished droppings that remain are composed of hard, tiny pellets that provide almost no nutrients for plants.

While the ungulates' food consists mainly of cellulose, and most rodents prefer food especially high in energy,

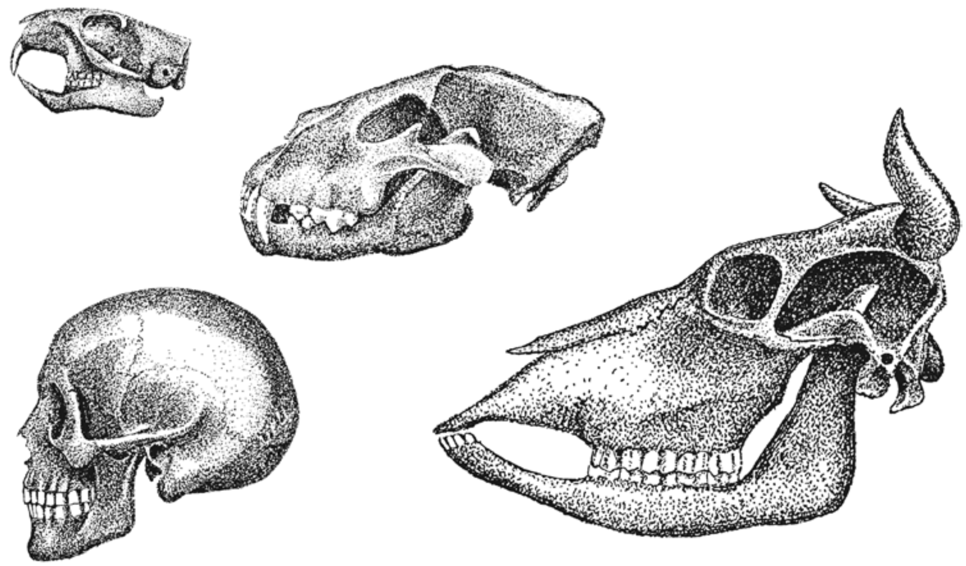


Figure 5. Dentition and skull formation of a rodent, carnivore, and ungulate, in comparison with the human skull. (Drawing: U. Winkler)

This threefold structure is expressed visually in the formation of the teeth. The incisors of humans are anterior and slender, with narrow cutting edges; the molars in the posterior are broad, with wide crowns and slightly curved grinding surfaces. In position and shape, the canines, with their rounded yet pointed (i.e., conical) structure, take their place between the other two.

The following arrangement shows the basic tripartite structure of the teeth. During development, there are two dentitions. First, the milk teeth emerge; in humans there are 2 incisors, 1 canine, and 2 molars in both sides of each jaw, making a total of 20 teeth. At the time of the second dentition, the roots are dissolved and the crowns shed. The permanent set of teeth adds 3 molars in each section of the mouth in addition to the 20 teeth that are replaced, so that the adult comes to have 20 + (4 x 3) = 32 teeth. Because of their position, the replaced posterior teeth are called premolars and the newly formed ones, molars. Molars and premolars are very similar in shape.

Kipp (1952) thoroughly studied the threefold aspect of mammalian teeth. The primarily sense-oriented rodents show a highly specialized development of the anterior incisors; they have two long gnawing teeth shaped like chisels in both the upper and lower jaws. Canines are absent. We find very few molars in typical rodents (e.g., mice, rats, hamsters), and these are indeed "molars" because they have no precursors in that milk teeth do not appear in rodents.

In carnivores the canines dominate and are often many times as long as the other teeth! The incisors are rather small, and those next to the canines are often even shaped like them, as in the African lion and the leopard seal. The molars, with their pointed crowns, also take on some of the characteristics of the canines; the largest of them is called the carnassial or "shearing" tooth. In most seals, the molars are pointed like canines.

In ungulates, in contrast, the molars are particularly well developed. With their very diverse, complicated formations of cusps and crescents, these teeth are both large and numerous in the posterior oral cavities of horses, rhinoceroses, pigs, hippos, camels, giraffes, deer, sheep, and cattle. The teeth of the ruminants are especially characteristic; in these, the processes of the nerve–sense and rhythmic systems are so completely dominated by the forces of digestion that the cow's upper jaw has no incisors or canines at all! The incisors and canines of the lower jaw form a broad, shovel-like

Incisors	Canines	Molars and Premolars
Sense-nerve oriented	Dominated by the middle systems of rhythmic processes	Metabolic-limb oriented
Rodents	**Carnivores**	**Ungulates**
Incisors accentuated	Canines accentuated	Molars accentuated

plate that cannot be used for biting, but only for tearing. The molars predominate. Thus the characteristic forms of mammalian dentition become understandable.

It is significant that all rodents and most ungulates lack canines, the intermediate tooth form. Between the incisors and molars of these animal groups is a large gap (diastema) that is usually much wider than the space fully developed canines would occupy.

Naturally, the jaw's principal direction of motion in eating is vertical — a coming together of the upper and lower teeth. Yet, in the rodents, the jaws also move forward and backward, while in the ungulates (especially the ruminants) they move more laterally. Among the carnivores this motion is entirely vertical. [pp. 37-42]

Another important phenomenon in the biology of form is the size that a living organism attains. Every plant and animal species occupies a more or less characteristic amount of space. Although its final height remains quite variable, an oak grows to a size that is different from that of a bean plant. The size of any adult animal, especially among the more highly developed ones, is relatively fixed. Does the size of an animal have a lawful relationship to its other special characteristics? Goethe touched upon this point in his osteological studies (1795):

> At this point an observation must be made that is significant for natural history in general. The question arises: Does size influence shape and form, and to what extent? ... At first sight we might assume that it should be equally possible for a lion as for an elephant to attain a length of twenty feet.… Experience shows us, however, that a fully developed mammal does not exceed a certain size, and that, when size increases, form starts to disintegrate and monsters develop.

In ordinary experience, we unconsciously take for granted that the natural size of each organism is subject to some kind of rule. To this end, I list the following representatives of the three main groups:

Table 3.1.

Representatives of the three main groups of mammals:

Rodents	Carnivores	Ungulates
Mice	Wild cats	Cattle
Rats	Lynxes	Bison
Dormice	Foxes	Deer
Squirrels	Wolves	Moose
Ground squirrels	Seals	Horses

We notice at once that each group tends to have a common size. Ungulates usually develop large bodies; rodents, extremely small ones. Once again the carnivores occupy the middle position, as do humans. For the individual structure and function of an animal, its size is apparently not a matter of indifference — it is distinctly relevant to its way of life. Strongly sense-oriented animals take up only a small space, those dominated by the metabolic-limb system fill out large forms, and representatives of the rhythmic middle system typically occupy an intermediate position in their relationship to space. Obviously, an organism's spatial dimension is of biological importance.

With our context established, it is now necessary to go beyond the general threefold classification of rodents, carnivores, and ungulates to examine the more specific animal forms of single families, genera, and species. Readers can decide for themselves whether or not the idea of threefold structure and function can shine light on the particular features of these organisms. [pp. 44-45]

The above excerpts from Chapters 1, 2, and 3 of Understanding Mammals: Threefoldness and Diversity *by Wolfgang Schad (Ghent, New York: Adonis Press, 2018) were compiled by Craig Holdrege to provide an introductory overview to this new and important book. The excerpts are published here with the kind permission of Adonis Press.*

Out of the Life of the Dairy Cow

Craig Holdrege

Photo: C. Holdrege

A grazing dairy cow from Hawthorne Valley Farm, Ghent, New York.

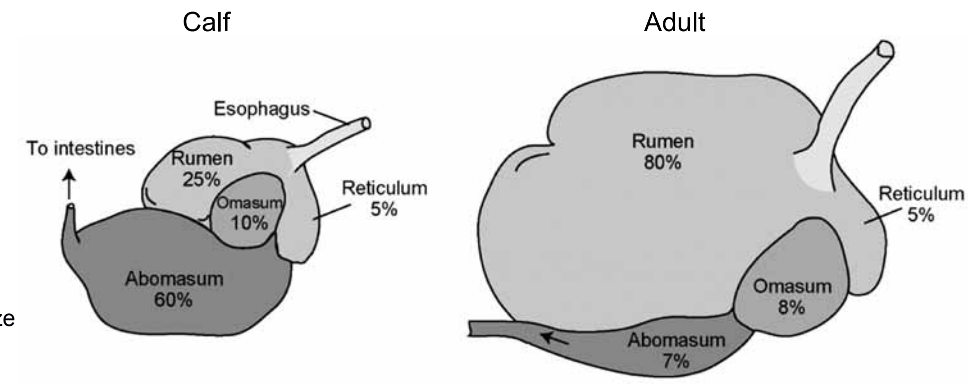
This article is a short, edited excerpt from the beginning of a much longer chapter on the dairy cow for a book on animals that Craig is writing.

As a domesticated animal, the dairy cow's past, present, and future — down into the core of its biological make-up — are directly and inextricably connected with human activity. Through thousands of years of interchange, we have become part of the cow's being, and she part of ours, in a way that goes beyond the connection we have with wild animals. Cows are deeply dependent on us and we on them.

This bond makes the question of what responsibility we have to cows (and to all domesticated animals) loom large. How do we view this relationship and how does that view guide our intentions in the way we breed and treat these animals? Do we see cows as beings who serve us and for whom we respectfully care? Do we see them as units of production whose efficiency we need to maximize? Do we manipulate them as bioreactors to produce substances we desire? You can find all of these perspectives expressed today and they all have consequences.

It is clear that, when in industrial agriculture, cows are viewed as production units, they are being considered primarily from the perspective of economic profit. Such a perspective avoids considering much of the reality of the animal's life and the way it is woven into the larger world. When we begin to turn our attention toward that larger fabric, we learn how the cow is a truly integrated organism with a very specific way of being. How can we interact with this animal responsibly without at least some understanding of its unique way of being in the world? What follows is a glimpse into some of the dairy cow's salient features.

Cows are grazers. If they are allowed to lead a life that corresponds to their nature, they live on pastures — in the midst of the food they eat — grazing on grasses and wildflowers. The cow lowers her head to the ground and touches the plants with the front end of her soft, moist snout. She does not chomp off the plants with her teeth. In fact, the cow (like the bison, giraffe, and other ruminants) has no top incisors or canines. She has, instead, a tough fibrous dental pad at the front of the hard palate. When feeding, the cow reaches out with her rough, muscular tongue, enwraps the plants, and tears them off while slightly throwing her head upward and to the side. She clearly needs to use her tongue for feeding — cattle that receive soft, fiber-poor



A schematic drawing of the development of the cow's four-chambered stomach. Only after a calf has begun feeding on grass, does the rumen develop fully in size and function.

feed begin to lick their fellow cows much more than usual to compensate for the lack of interaction with the tough, fibrous grasses and forbs. The cow needs this interaction to remain healthy.

Taking about one bite per second, the cow moves slowly through the pasture. Large glands secrete saliva while she grazes, and after taking many bites, she swallows the now moistened mass of food. She can continue grazing in a kind of flowing rhythmic persistence for a couple of hours at a time. Cows on the pasture have several such feeding periods during the 24-hour day, spending about one-third of the total day grazing. When swallowed, the food reaches the rumen, the huge first chamber of the four-chambered stomach. Occupying the entire left side of the abdominal cavity, the rumen can hold up to forty-five gallons of fluid and feed. The muscular rumen massages the food in regular contractions — about one to two per minute is a sign of a healthy cow. It is only when a calf begins to feed on grass that the rumen completes its development and becomes fully functional. You could say that grass is the environmental half of the rumen, and that the cow's anatomy and physiology only become whole through the activities of feeding and digestion.

In the rumen, forage churns around in the fluid of the saliva and any water that the cow has drunk. The rumen itself does not secrete digestive juices. When it is about half-full, a wad of partially digested forage (what we call the cud) is, via the second chamber of the stomach (the reticulum), regurgitated back into the mouth. If you are watching, you can see a bulge rapidly course up the cow's neck. When the cud reaches the mouth, the cow begins to ruminate. She grinds the food between her large cheek teeth in rhythmical, circling motions of the lower jaw. She chews a cud about 50 to 60 times before swallowing it. Soon thereafter a next cud travels up the throat and rumination continues. The saliva glands secrete copious amounts of saliva while the cow is

Photo: C. Holdrege

Dairy cows ruminating at Hawthorne Valley Farm, Ghent, New York.

Part of Hawthorne Valley Farm's dairy herd. Note the bull and a couple of calves in the foreground. A herd is only complete with cows, calves, and a bull.

feeding and ruminating — up to fifty gallons a day. Yes, that's right: fifty gallons. The drier the feed (for example, hay), the more saliva a cow secretes, and the greater the amount of water she drinks.

Cows usually lie on the ground while ruminating, often with drooping or fully closed eyelids. If you are ever in a hectic state of mind and find yourself driving through the countryside and have the luck to spot a herd of cattle lying on the ground — I know, not too likely a scenario — stop and spend a half hour attending to the herd. Expand out into it. You'll calm down. As they lie quietly in the pasture, their activity focused inward on grinding and digestion, the cows radiate centeredness and quietude. For the total of eight or so hours of rumination per day, it is as though the mixing, breaking down, exchanging, and building up of substances is telling the cow an intricate and enchanting story that she is intently listening to.

As with bison and other ruminants, digestion in the rumen is facilitated by microorganisms that break down cellulose, the main, hard-to-digest component of fresh forage and hay. The forage is churned around, and it takes a few days for it to fragment into ever smaller particles and to be broken down biochemically by the microorganisms. During this process nutritious fatty acids are released and absorbed through the rumen wall into the bloodstream. Since saliva is alkaline, it serves as a buffer and prevents the environment of the rumen from becoming too acidic. In an acidic environment, the microorganisms could not thrive.

Digestion is such a central part of the ruminant's life that even the animal's head plays a major role in breaking down the forage through about 40,000 grinding motions a day, copious salivation, and thorough chewing of the cud. As biologist E. M. Kranich suggests, you can consider the cow's mouth functionally as a fifth chamber of the stomach. After the mouth, digestion then continues in the microbial realm of the rumen. From there, the partially digested food moves into the other three chambers of the stomach that continue the process of transformation. Only the last chamber, the abomasum, is comparable to our stomach. It secretes hydrochloric acid that kills bacteria, and digestive juices that break down proteins. As if the mouth and four stomach chambers had not done enough, digestion continues in the approximately 130 feet (40 meters) long coils of the small intestine. (That's about twenty times the length of the animal!) After the cow has broken down the substances as far as possible and absorbed the many nutrients into the bloodstream, the large amounts of fluid that have been secreted as saliva and digestive juices are also reabsorbed, mainly in the last part of the digestive tract — the large intestine.

What has been digested and reabsorbed in the gastrointestinal tract then enters the blood. The blood has the unique feature of being a fluid organ that connects all organs of the body by flowing through them. It gives over substances to the organs and receives substances from them. We need to imagine the blood as changing at every moment along its pathway. In every part of the body the blood is distinct inasmuch as it is responding to what comes from the organs and what they need. And yet in all this transformation, it remains a coherent flowing organ. Through this mediating activity of the blood, what the process of digestion brings forth allows the animal to continually re-create itself.

But that is not all. Through digestion, substances arise that the cow does not incorporate into her own organism, but rather gives off into the larger world. At the front end, she exhales with every breath — as all animals do — moist, warm air that is richer in carbon dioxide than the air she inhaled. And cows also burp frequently. In the process they give off methane-rich air that has arisen through ruminal fermentation. At the back end, she releases large amounts of manure — urine and dung — into the environment. A dairy cow weighing about one thousand pounds will excrete a total of eighty pounds of manure per day.

Manure is a key element in building soil fertility. On the one hand, cows leave urine and feces on the pasture. And on the other hand, on dairy farms that are sustainably managed, manure collected in the barns is mixed with straw and other plant matter, is then composted, and finally spread on the fields. In this way the cow is an essential contributor to the fertility of the soil, helping plants to thrive that in turn serve the cows.

In contrast to the solid dung of other ruminants like sheep or goats, cows have fluid dung. The cow's large intestine does not absorb as much water out of what has been digested. In fact, we could say that from her moist snout, through all the secretions in her digestive tract, and finally in her dung, the cow embodies fluidity more than other ruminants — in a sense a paradox for such a large, heavy-boned, and stout animal. The solid bones support a massive body. And in the blood and the voluminous inner spaces of the digestive organs, continual and intense transformation occurs in the medium of fluids.

A most special fluid gift that the cow creates is milk. It provides just that nourishment her offspring need. And through domestication and husbandry, she creates more milk that we use for our consumption. Fill a glass with milk and place next to it a glass with grass in it. Two wholly different substances. The cow transforms the dry, fibrous grass into a nutritious, creamy fluid. This demands intense activity on the part of the whole physiology of the cow. Breaking down and digesting grass already places high demands on the body. For example, for every quart of saliva the cow creates, three hundred quarts of blood pass through the salivary glands. The other digestive organs are sustained by a similarly strong circulation.

The intense transformation of substances and secretion of fluids characterizing the digestive process are heightened in the formation and secretion of milk. For every quart of milk, three hundred to five hundred quarts of blood pass through the udder. The udder receives from the blood — and that means from the rest of the whole animal — the substances it needs for its mammary glands to create milk. Fine membranes separate blood and mammary glands. On the one side flows nutrient-rich blood, giving over proteins, water, fats, and carbohydrates to the mammary glands. And on the other side of the membranes, the glands fashion and secrete a creamy white fluid. It is hard not to be in awe of the cow's ability to transform substances in its quiet and steady way.

For modern consumers, milk is a packaged good that we find in the refrigerated section of a store. Most people will know that this milk comes from cows, but many children growing up in an urban environment never will have seen a cow. Most people probably don't know what kind of dairy farm the milk came from, or how the animals were fed and treated. If, by circumstance or study, we do know something about these things, then we have begun at least in our minds to free the milk from its status as an isolated product for consumption.

We can see it instead as an expression of a whole nexus of processes. The generation of milk stands as the special result of the cow's interaction with pasture, soil, sun, and weather— and, of course, with her human handlers.

The remaining chapter considers domestication; the practices of modern breeding, husbandry, and economics that have led to cows producing ever more milk; the negative health effects for the cow, farmers, and the environment of these practices; alternative practices that honor the cow as a living being; and, finally, what this all means for responsible human action.

The Sensitive, Muscular Cell

Stephen L. Talbott

The following is the fourth chapter from Steve's book-in-progress, Whole Organisms and Their Evolutionary Intentions. *It contains a number of references to material in other chapters — references that we have not removed from the text here. You can pursue many of these references in the Biology Worthy of Life section of our website.*

Throughout a good part of the twentieth century, cell biologists battled over the question, "Which exerts greater control over the life of the cell — the cell nucleus or the cytoplasm?"[1] From mid-century onward, however, the badge of imperial authority was, by universal acclaim, awarded to the nucleus, and especially to the genes and DNA within it. "Genes make proteins, and proteins make us" — this has been the governing motto, despite both halves of the statement being false (which will become ever clearer as we proceed).

The question for our own day is, "Why would anyone think — as the majority of biologists still do — that any part of a cell must possess executive *control* over other parts?" We have already caught our first glimpse of the performances in the nucleus (see Chapter 2), and these hardly testify to domination by a single, controlling agent. Now we will broaden our outlook by making a first approach to the rest of the cell — the cytoplasm, along with its organelles and enclosing membrane.

It would be well to remind ourselves before we proceed, however, that, whatever else it may be, an organism is a physical being. Its doings are always in one way or another *physical* doings. This may seem a strange point to need emphasizing at a time when science is wedded to materialism. And yet, for the better part of the past century problems relating to the material coordination of biological activity were largely ignored while biologists stared, transfixed, into the cell nucleus. If they concentrated hard enough, they could began to hear the siren call of a de-materialized, one-dimensional, informational view of life. The idea of a genetic *code* and *program* proved compelling, even though the program was never found and the supposedly fixed code was continually rewritten by the cell in every phase of its activity. So long as one lay under the spell woven by notions of information and code, problems of "mere" material causation somehow disappeared from view, or seemed unimportant.

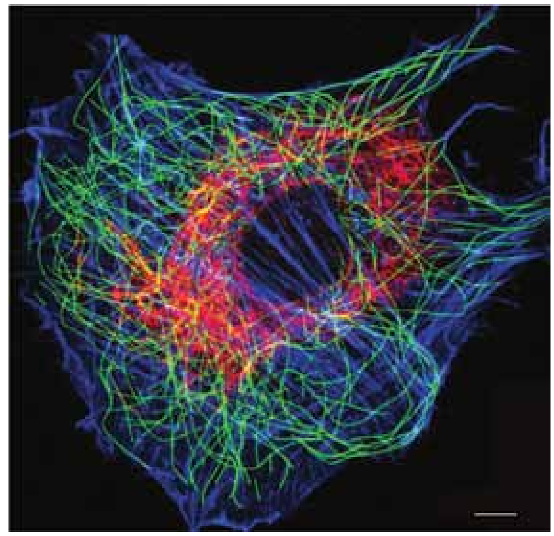


Figure 4.1. A cultured fibroblast cell, specially prepared so as to show features of the cytoskeleton in artificial color: narrow actin filaments (blue); wider microtubules (green); and intermediate filaments (red). The dark and roughly circular (spherical) region near the center is the cell nucleus.[2]

Surely genes do connect in *some* manner with the features they were thought to explain. But this just as surely means they must connect physically and meaningfully, via movements and transformations of substance testifying to an underlying narrative (Chapter 3) — not merely logically, through the genetic encoding of an imagined program. And what we saw in Chapter 2 about the movements and gesturings of chromosomes is only the beginning of the story.

Does the cell possess its own "senses" and "limbs"?

Let's continue by taking note of the cytoskeleton (Figure 4.1), which plays a key role in the cell's physical movement. It consists of many exceedingly thin molecular filaments and tubules, many of which are growing at one end and perhaps shrinking at the other end, or else disassembling altogether even as new filaments are establishing themselves. Through this dynamic activity — this constant growth and dissolution of minuscule fibers — the cell gains its more or less stable shape and organization. Cellular organelles, to which the cytoskeleton attaches, are positioned and re-positioned as the cytoskeleton responds to external stresses such as stretching or compression. Beyond that, the filaments and tubules, by dynamically managing the distribution of forces within the cell as a whole, help to enable and guide its movements so that it can find its proper place among the millions of cells in its immediate environment.

And the cells of our bodies do move. Literal rivers of cells shape the young embryo. So, too, migrating cells in and around a wound cooperate in restoring the damaged architecture. In every tiniest hair follicle niche, as well as throughout our tissues generally, cells move, replace dying neighbors, and reorganize themselves. And even while remaining in one place, cells must continually adapt their form to their immediate environment — certainly a major task in the rapidly growing embryo and fetus. But the stresses and tensions of that environment are in turn the partial result of interconnected cytoskeletal activities in all the cells of the local tissue.

The cytoskeleton not only supports cell migration, but also provides pathways for the orchestrated movement of substances within the cell. A protein molecule is not of much use if it cannot find its way to where it is required. Individual molecules and protein complexes are shifted about along these cytoskeletal pathways, as are the voluminous contents of large-capacity, membrane-bound, transport structures ("vesicles"). These latter can "bud off" from various membranes of the cell and then move, along with their cytoplasmic contents, to a particular destination where, having released their contents, they are degraded and recycled.

Such directed movements are essential to the life of the cell. Where an enzyme or signaling molecule goes in a cell is decisive for its function. Some molecules, for example, are outward-bound to, and through, the cell surface on signaling missions to distant reaches of the body. Meanwhile, others are inward-bound on different signaling missions. (Hormones, secreted by cells of a gland at the start of their journey, and then received by cells in various other parts of the body, illustrate both sorts of movement.) Some molecules produced in a cell are destined for a particular locus on the highly differentiated cell membrane, while others are targeted to any of a virtually infinite number of possible stopping places somewhere in the cell's "intricate landscape of tubes, sacs, clumps, strands and capsules that may be involved in everything from intercellular communication to metabolic efficiency."[3]

But the cytoskeleton is not just a cytoskeleton. The filaments and tubules themselves are teeming with associated regulatory molecules. As of a decade ago more than 150 proteins capable of binding to just one type of filament — actin — had already been identified. "Despite the connotations of the word 'skeleton', the cytoskeleton is not a fixed structure whose function can be understood in isolation. Rather, it is a dynamic and adaptive structure whose component polymers and regulatory proteins are in constant flux."[4]

There is scarcely any aspect of cellular functioning in which the cytoskeleton fails to play a role. On the exterior side, it connects with the cell's outer ("plasma") membrane, where it helps to import substances from the environment while also facilitating the adhesion of extracellular molecules and other cells. Through its interaction with the extracellular matrix, it contributes to the mechanical stiffness and coherence of entire tissues. On the interior side, it engages with the nuclear membrane and the "skeletal" filaments underlying that membrane. These filaments are vital regulators of gene expression. In this way the cytoskeleton links various sorts of extracellular signals, both mechanical and biochemical, to the nucleus and its chromosomes, providing a foundation for holistic behavior involving much more than the individual cell.

There are many ways to affect gene expression, and they do not all occur in the cell nucleus. For example, a key part of this expression is the translation of RNA molecules into proteins, which occurs in the cytoplasm. Evidence suggests that "the physical link between cytoskeletal and translational components helps dictate both global and local protein synthesis." But (as is all too typical) the causal effects work both ways: "specific translation factors are able to affect the organization of cytoskeletal fibres."[5]

The cytoskeleton plays many other roles, not least by ensuring the proper separation of mitotic chromosomes, the division of a cell into two daughter cells, and the correct allocation of chromosomes to those daughter cells. (See Figure 4.2, where the mitotic spindle, shown in green, consists of cytoskeletal fibers.) It is perhaps unsurprising, then, that some have seen the cytoskeleton, with its nuanced organizational "skills," as the seat of cellular intelligence or the "brain" of the cell. However, we need not invite a misleading anthropomorphism in order to acknowledge the subtle and nuanced organizational activity — the *narratively intelligible* activity (Chapter 3) — realized through the dynamics of cytoskeletal movement.

One thing is certain: neither the cytoskeleton's moment-by-moment dynamics nor the coherent and intelligible aspect of its activity can be ascribed to "instructions" from genes — or even to the physical laws bearing on cytoskeletal proteins. As the matter was summarized by Franklin Harold, an emeritus professor of biochemistry and molecular biology at Colorado State University, "One cannot predict the form or function of these complex [cytoskeletal] ensembles from the characteristics of their component

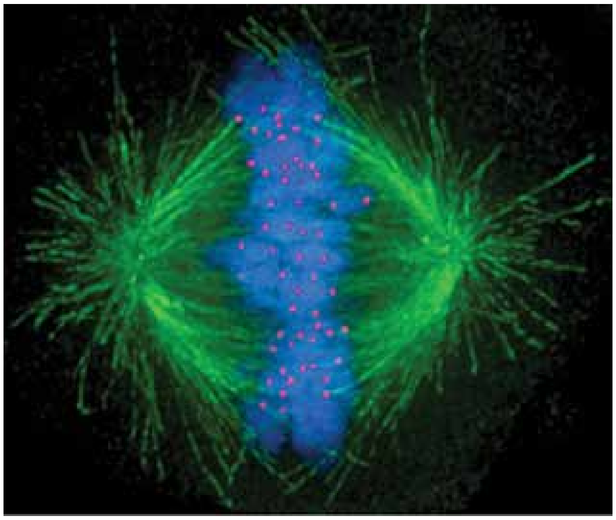


Figure 4.2. An artificially colored image of the mitotic spindle in a human cell, showing microtubules in green, chromosomes (DNA) in blue, and kinetochores in red. A kinetochore is a protein structure that temporarily holds a chromosome and its duplicate together while also providing an anchor for a "thread" of the mitotic spindle. In the following phase of mitosis, each chromosome and its duplicate will be pulled apart, destined for different daughter nuclei.

proteins." And yet, Harold went on, "When seen in the context of the parent cell the arrangement of the molecules becomes quite comprehensible." He then raised the obvious question: "How is the cytoskeleton itself so fashioned that its operations accord with the cell's overall 'plan' and generate its particular morphology time after time?"[6]

Harold answered the question merely by expressing confidence that understanding will eventually come. And surely it will. But we can be equally sure that it will not come before we have penetrated more deeply the problem: How does a living context, or whole — in this case, the cell with its "overall plan" — manage to express itself through all its parts?

In an integral, or ganic whole, we can assume the "viewpoint" of many parts in such a way as to make each one momentarily *seem* to be the coordinating "master" element. This is why the cytoskeleton, just as much as our genes, might appear to explain everything that goes on. With wonderful sensitivity it "feels out" the surfaces of the cell and all its organelles. The balance of forces maintained by the fibers shapes the cell, dynamically positions the organelles, and both guides and helps to power the critical movement of the cell within its environment. As we have seen, the cytoskeleton likewise plays a key role in moving substances to their functional locations within the cell. And it is a decisively important regulator of gene activity.

And yet, this does not make the cytoskeleton a master regulator. The truth is simply that, to one degree or another, each part of an organic whole bears that whole within itself — is informed by, and expresses, the whole. The idea of a master regulator arises only when we insist on viewing a specific part in isolation from the whole so as to identify single, local, and unambiguous causal interactions. We then say that this part *makes* certain things happen. The fact that the part is itself made to happen by the very things it supposedly accounts for then tends to be ignored. We lose sight of the fluidity and physical indeterminism of the living context — an indeterminism whose meaning and coherence become visible only when we allow particular physical causes to "disappear" into the unifying narratives, or stories, of the organism's life (Chapter 3). In much the same way, physical sounds and gestures disappear into the meaning of our speech.

The sensitive "skin" and organelles of the cell

Interestingly, the cell membrane ("plasma membrane") is likewise a highly dynamic feature that has been seen as a decisive coordinator of cellular activity, and even as a seat of cellular intelligence. It is here that we see "decisions" continually being made about which substances and signals — from among the endlessly streaming crowds passing through the neighborhood — are to be admitted into the cell and which ones are "foreign," or else unnecessary at the moment. Here, perhaps more than anywhere else, is where cellular identity is established and "self" is distinguished from "other." This happens partly by means of protein receptors ("sensors") embedded in, or attached to, the lipid matrix of the membrane. (See Figure 4.3.)

Here, too, everything flows (which is one reason why any image like the two shown here is a kind of frozen lie, despite being useful when approached with the right awareness). Molecules continually associate with, and dissociate from, the membrane, even as they undergo various modifications that redirect their functioning. They also migrate within the membrane, forming specialized communities that are in no two locales exactly the same. All the while portions of the membrane, along with cytoplasmic contents, are "pinched off" as more or less spherical vesicles that, once they are fully detached, move elsewhere, either externally to the cell or internally. At the same time, selected vesicles from external sources fuse with the membrane and release their contents into the cell's cytoplasm.

Much the same is true of all the interior membranes de-

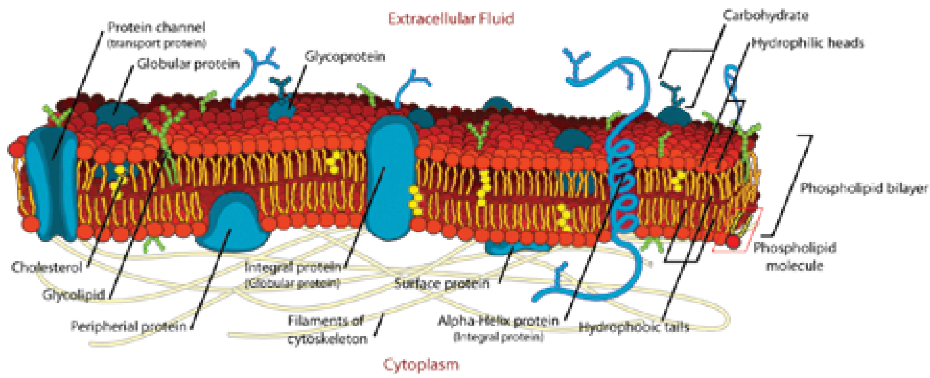


Figure 4.3 (at left). Schematic representation of a cell membrane: a lipid bilayer (red spheres with yellow tails) along with embedded proteins and other molecules. Many of the embedded proteins, which are dynamically distributed, function as "sensors" or receivers of molecular "signals."[7]

limiting the various organelles of the cell (Figure 4.4.) These, too, "harbor sensitive surveillance systems to establish, sense, and maintain characteristic physicochemical properties that ultimately define organelle identity. They . . . play active roles in cellular signaling, protein sorting, and the formation of vesicular carriers."[9]

Membranes, then, not only structure the cell into distinctive compartments and organelles, but they also "oversee" the characteristic and essential contents of those compartments and play decisive roles in managing the ceaseless and massive intercommunication among them.

All this finely discriminating activity is going on, as the eminent cell biologist, Paul Weiss, wrote in 1973, while "the cell interior is heaving and churning all the time."[10] Everything is watery movement of substances and transformation of organizational structure, and yet the cell's identity and unified character are maintained. Movement is the life of the cell and the organism. The intricately choreographed flows and chemical transactions in plasm and membrane are responsive to the ever-unpredictable conditions of the moment, and are the means by which the cell not only stays true to itself, but also remains in harmony with its larger environment.

The dynamics of this material accomplishment are a long way from the clean, informational logic commonly associated with genes. Lenny Moss, a molecular biologist who transformed himself into one of our most insightful philosophers of biology, had this to say about the relation between cellular membranes and genes:

> The membranous system of the cell, the backbone of cellular compartmentalization, is the necessary presupposition of its own renewal and replication. Cellular organization in general and membrane-mediated compartmentalization in particular are constitutive of the biological "meaning" of any newly synthesized protein (and thus gene), which is either properly targeted within the context of cellular compartmentalization or quickly condemned to rapid destruction (or cellular "mischief"). At the level of the empirical materiality of real cells, genes "show up" as indeterminate resources ... If cellular organization is ever lost, neither "all the king's horses and all the king's men" *nor* any amount of DNA could put it back together again.[11]

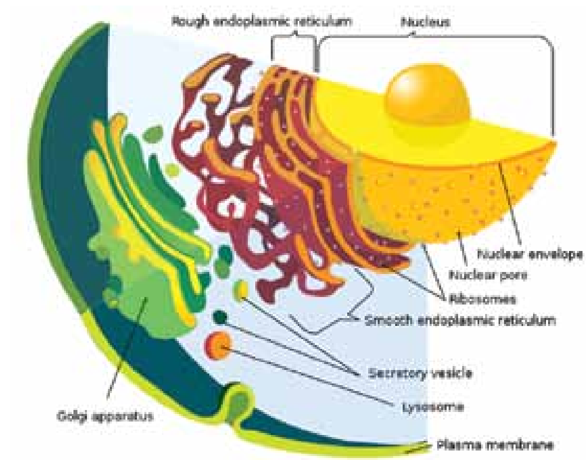


Figure 4.4. Schematic representation of the internal membrane systems of a nucleated cell.[8]

From information to life

Returning for a moment to our introductory question about the control of the cell by its genes: perhaps we have now gained our first feeling for how just about everything else in the cell and organism flexibly and contextually comes to bear upon our genes and chromosomes — a fact we will get much more specific about in Chapter 6. If we think of the genome as an almost infinitely complex informational structure, there is no reason not to think, for example, of the cytoskeletons and membranes of cells as at least equal bearers of vital information. However, it is also important to recognize the illegitimate aspects of this comparison.

In particular, the concept of information as normally applied to DNA is a quantitative one. It depends on the existence of discrete, iterated elements ("letters" of the "code"), any one of which can take on certain precise values. But everything we know about the "heaving and churning" interior of the cell — including even the coiling and looping of chromosomes we saw in Chapter 2 — tells us that we are looking at boundless and continuous variations of form and gesture whose depth of meaning is both non-quantifiable and vastly more profound than any quantifiable features we can abstract from it.

To ask about the amount of information in various aspects of the cellular performance (including the performance of chromosomes) is rather like asking about the amount of information in Mahler's fifth symphony. It would be one thing to define informational quantities in terms of some more or less arbitrary method of notation ("code") for the printed score of the symphony, and quite another to consider the expressive content of the music itself.

So, too, our means for quantifying the informational content of a genomic sequence bears little relation to the material gestures expressing the cell's life. The truth here will become even more vivid when we look (in the next chapter) at the context-dependence that biologists freely acknowledge at every turn.

Notes

1. Sapp 1987.

2. Figure 4.1 credit: Courtesy of Harald Herrmann, University of Heidelberg, Germany.

3. Kwok 2011. Here is a further description (from Plankar et al. 2012) of the various roles of the cytoskeleton:

> The cytoskeleton, in addition to its classical structural-mechanical role, integrates many signalling pathways, influences the gene expression, coordinates membrane receptors and ionic flows, and localizes many cytosolic enzymes and signalling molecules, while at the same time it represents an immense, electrically active catalytic surface for metabolic interactions. Together with cell adhesion molecules and the extracellular matrix, it forms a tensionally integrated system throughout the tissues and organs, which is able to coordinate gene expression via mechano-transduction. Given the strong relationship between mechanical and electromagnetic excitations in the microtubules (piezoelectricity) and their well-established organising potential, a weakened EM field may thus influence both cell and tissue aspects of carcinogenesis.

4. Fletcher 2010.

5. Kim and Coulombe 2010. The use of words such as "dictate" to suggest unambiguous causation is extremely common in all the literature of molecular biology. And almost as common is the immediate contradiction of this language, as we see here.

6. Harold 2001, p. 125.

7. Figure 4.3 credit: Mariana Ruiz, edited by Alokprasad84.

8. Figure 4.4 credit: Mariana Ruiz Villareal.

9. Radanović, Reinhard, Ballweg et al. 2018. Emphasis added.

10. Weiss 1973, p. 40.

11. Moss 2003, p. 95. Pages 76-98 in Moss' book provide an excellent overview of the dynamics associated with cellular membranes.

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"It seems as if the day was not wholly profane, in which we have given heed to some natural object. The fall of snowflakes in a still air, preserving to each crystal its perfect form; the blowing of sleet over a wide sheet of water, and over plains, the waving rye-field, the mimic waving of acres of houstonia, whose innumerable florets whiten and ripple before the eye; the reflections of trees and flowers in glassy lakes; the musical steaming odorous south wind, which converts all trees to windharps; the crackling and spurting of hemlock in the flames; or of pine logs, which yield glory to the walls and faces in the sitting-room,—these are the music and pictures of the most ancient religion."

Ralph Waldo Emerson, "Nature" (1844)