Natural Systems Engineering

Derek K Hitchins

Abstract

Natural systems have evolved on Earth over some 542MY, through trial and error, by natural selection, with such exemplary results as the human body, one of the most complex organisms on the planet.

The human body exhibits different 'levels of organization:' organization appears at each level. 'Nature's design' evidences a higher degree of coupling and mutual interdependence between structures at the same level of organization, for example between organ systems, than is the usual case for supposedly equivalent manmade systems. The human brain also exhibits levels of organization, but these do not find correspondence in manmade processing systems, while the operation of the brain's remarkable memory is still uncertain, with many clues, but conflicting ideas amongst neuroscientists.

Homeostasis in organisms can be singularly complex, with stabilizing 'mechanisms' that differ markedly from those employed by cyberneticists and engineers: could the latter learn to advantage from successful, natural systems?

Nature has also created extensive insect social systems, so-called 'super organisms.' Honeybees have existed for more than 100MY, ants over 120MY and termites over 150MY, suggesting they have a variety of successful survival strategies. Modern humans have been on the planet barely 2MY so far…and already threaten their own survival together with that of many other species.

Overall, Nature has an enviable 'track record' of evolving efficient, adaptable, effective, survivable organisms and super-organisms that exist in more-or-less mutual harmony with other organisms and super-organisms.

Biomimetics, similar to biologically inspired design, is the study of the structure and function of biological systems as models for the design and engineering of materials and machines. Together with ecology, biomimetics (Bar-Cohen, 2011) and bio-mimicry (Benyus, 1997), may also offer sophisticated models, processes and procedures for:

- systems thinking,
- systems conception,
- systems design,
- systems architectures,
- systems lifecycles,
- system survival strategies

… and many more as yet largely untapped. Can such models be employed to advantage for manmade systems, human systems, societal systems, business and industry systems, systems engineering, even economic systems? Are they applicable, can they be trusted, if they are different, *why* are they different, is their efficacy amenable to proof? These are questions to ponder, while at the same time admiring the legacy and insight the models may provide.

Levels of organization

Biologists and anatomists identify so-called 'Levels of Organization' within living things. Levels of Organization describe the way in which organisms are synthesized, starting with the cell, the smallest living entity. Cells are complex miniature factories creating proteins; they have emergent properties.

Cells of differing kinds may be organized into tissues, the next level of organization. Tissues are formed from the emergent properties of their constituent cells. Tissues are more complex than cells; they 'contain' the complexity of many interacting cells. Tissues may be: connective, muscle, nervous and epithelial.

Tissues of different kinds may come together to form organs. An organ is a collection of tissues joined in a structural unit to serve a common function. In the human body, the heart, liver, kidneys, etc., are organs, formed from the emergent properties of their constituent tissues. A kidney comprises nephrons, the principal functioning units of the kidney, filtering blood and producing urine; nephrons comprise complementary tissues made from many different cells, all set in a collagen framework or scaffold.

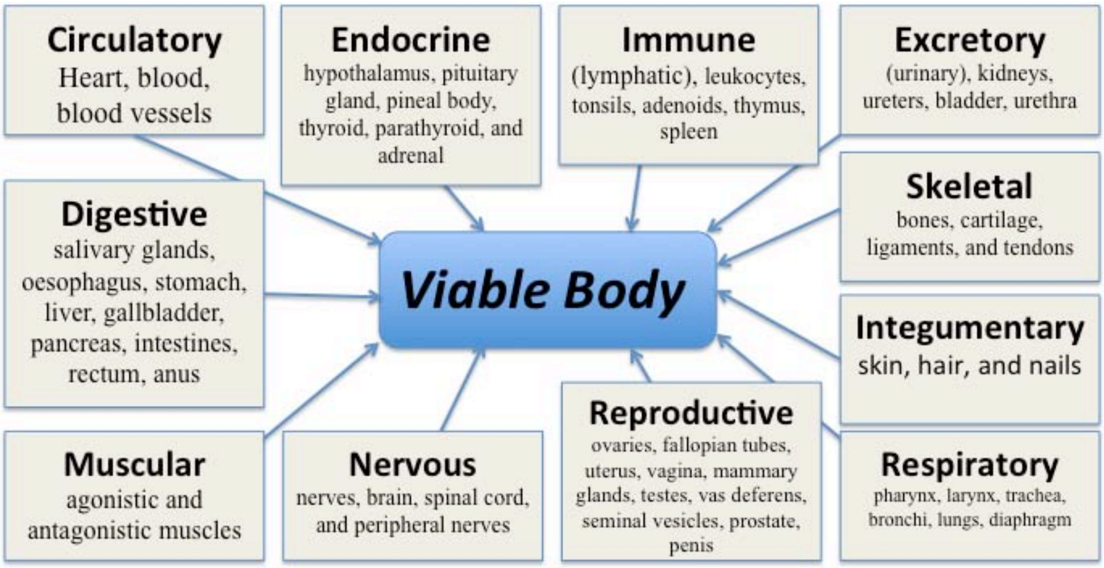

Figure 1. Organ Systems in a Viable Body

The body is comprised of organs that work together as organ systems; there are some ten to twelve major organ systems in the body, depending upon how they are counted. See Figure 1, which shows the viable body's organ systems together with their constituent organs.

Learning from Natural Levels of Organization

There are discernable levels of organization within the human body:

5. Organism   4. Organ System   3.Organ   2. Tissue   1. Cell

Each level is formed from the emergent properties of assemblages and combinations of the level below. At each level there may be many of same- or similar- kind, mutually interacting entities.

Biologists identify some 210 different human cell types. Different cell types organize into different tissues. Different tissue types organize into organs. Different organs organize into organ systems. And, different organ systems organize into the human organism. There is, however, a formative sequence within the embryo.

A human embryo grows around an axis, which will become the spine and spinal cord. The heart, brain, spinal cord and gastrointestinal tract form initially, followed by limb buds and internal organs. Each of these follows (depends upon?) the prior existence in the embryo of heart, brain and nerves; they do not appear independently and then 'join up,' as it were… so there is no reduction, only synthesis and development, with nerves, blood vessels, etc., developing within, and at much the same time as, the tissues and organs. Remembering, of course, that the embryo is developing according to a well established "master plan" in the DNA.

Extending the "Levels of Organization" Paradigm

Figure 2 shows the cell-to-organism hierarchy diagrammatically from bottom to top: cell, tissue, organ, organ system, organism and then extended beyond to population and society (and, not shown, continuing above to ecosystem and biome, both of which include non-living 'things.') At right is a supposed correspondence with manmade systems, such that Organ System corresponds with System at Level 4, Organism with Platform, at Level 5, etc.

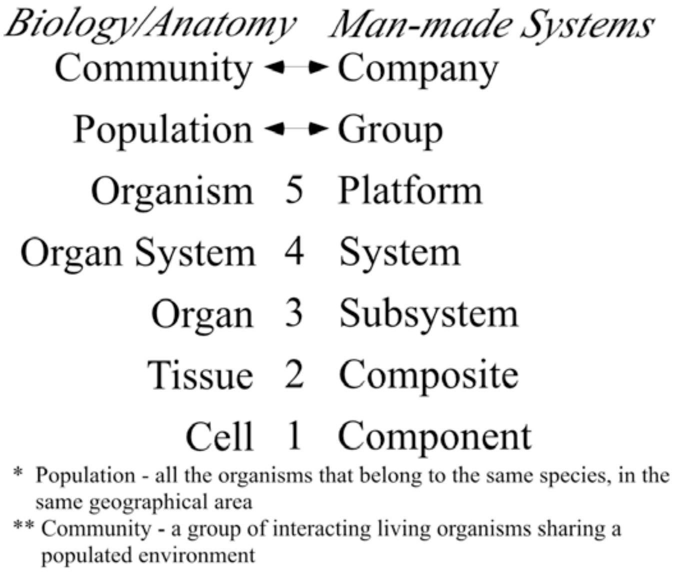

Figure 2. Levels of Organization – Organic and Manmade Systems

Correspondence at levels 1 and 2 is more questionable. While a cell is a living thing, a man-made component, an artefact, is not; neither is a composite of such inert components. However, components may be energised and may be active; for instance, a field-programmable gate array (FPGA) may be programmed to perform a variety of functions. While energized, such electronic devices/components may not unreasonably correspond with cells. Similarly, tissues may reasonably correspond with energized assemblages of such active devices, referred to as composites. Neither component nor composite, however, seems to quite merit the epithet of 'system,' since they are not 'organized coherent wholes.'

Levels 3 and 4 are more promising: an organ system corresponds sensibly with a system consisting of interacting subsystems that perform functions, and have 'organized whole' characteristics. Similarly, an organism corresponds sensibly with platform, in that a platform, like an organism, carries its organ systems around with it 'internally,' i.e., sensors, processors, etc.

Population is less clear. All workers in a hive of honeybees, for example, are sisters. Such cannot be said of humans forming a group, and the difference may be important: hive behaviour is highly motivated towards the survival of the Queen and the next generation, and this behaviour may be dependent upon their being closely related genetically, and therefore willing to supress their own need to reproduce as they are, in effect, furthering their own genes in caring for the offspring of the Queen.

The implication at community level is of different species interacting in the same populated environment, which might be less obvious for humans in interacting groups, since all humans are of the same species. Perhaps we may consider human groups with different cultures, disciplines, faiths or beliefs as corresponding conceptually with different species—at least in some degree.

One curious note presents itself; that a hierarchy of man-made systems bears such apparent similarity with that found in human biology/anatomy. Three explanations come to mind:

1. That the notion of hierarchy is simply a naturally occurring property of complex systems in that emergent properties and behaviour happen at various scales in complex systems.
2. That the hierarchy for man-made systems is innate to humans as designers and creators, and may have emerged from their subconscious
3. That the hierarchy for man-made systems has been consciously based upon the natural hierarchy found by biologists and anatomists

Then again, many of those engaged in early work on systems were biologists, one of whom was instrumental in developing General Systems Theory (Bertalanffy, 1968).

Levels of Organization and Layers of Systems Engineering

Levels of Organization indicate successive levels of complexity. Systems engineering seeks to manage complexity in the conception, design and synthesis of complex manmade systems. There is an evident correspondence between Levels of Organization, and various 'flavours' of systems engineering.

Figure 3 presents correspondence between three parallel hierarchies: levels of organization; manmade systems; and, layers of systems engineering. An 'anchor' point of correlation/correspondence is between Organ System: Level IV: System; and, Layer 2, Project Systems Engineering.

This sits comfortably above Organ: Level III: Subsystem; and, Layer 1 Product/Subsystems Engineering, where an organ is evidently a functional subsystem of an organ system, and product/subsystems engineering is evidently one level down on project systems engineering, since a project is likely to comprise a number of interacting functional products.

That leaves Business Systems Engineering addressing Company and Group; Industry Systems Engineering addressing Organizations; and, Socioeconomic /Societal Systems Engineering operating at national level.

LEVELS OF ORGANIZATION V. LAYERS OF SE

Biology/Anatomy		*Man-made Systems*	SE Layer
Nation	IX	Nation	*5. Socioeconomic/societal SE*
Region	VIII	Organization	*4. Industry Systems Engineering*
Community	VII	Company	*3.Business Systems Engineering*
Population	VI	Group	
Organism	V	Platform	*2. Project Systems Engineering*
Organ System	IV	System	
Organ	III	Subsystem	*1. Product/Subsystem Engineering*
Tissue	II	Composite	*Artefact Engineering*
Cell	I	Component	

* Population - all the organisms that belong to the same species, in the same geographical area
** Community - a group of interacting living organisms sharing a populated environment

Numbers refer to 5-layer SE Model:see Hitchins D.K. (2003) *Advanced Systems Thinking and Management,* Artech House, MA

Figure 3. Levels of Organization and Layers of Systems Engineering

The figure suggests that ‘ascending’ layers of systems engineering address ‘increasing’ levels of organization, therefore increasing degrees of complexity. Further, the figure suggests that systems engineering, at any layer, is essentially the integration of parts from the level below. So, Industrial Systems Engineering is the integration of several/many interacting businesses into a coherent Industry. Business Systems Engineering is the integration of several/many projects into a coherent business. And so on.

The figure also indicates that Business/Enterprise, Industry and Socioeconomic Systems Engineering are primarily concerned with increasingly complex *people* systems, rather than technology. As such, systems engineering will be concerned, less with technology, more with decision-making and behaviour, operations, management, organization, resourcing, training, control, contribution, coordination and cooperation, belief systems, *Weltanschauungen*, group psychology, social anthropology, etc.

Meanwhile, at the lower end, Levels II and I, the figure suggests that there is ‘less systems engineering, more conventional engineering,’ since both Components and Composites are manmade artefacts, not systems in the sense of being whole, internally-organized entities performing functions.

The potential value of this structural relationship is for a cross fertilization between the three hierarchies at each and any level. It presents a different view of systems engineering as being about integrating subsystems where each is mutually interdependent on all the others…

The Triune Brain

The Triune Brain is a model of the evolution of the vertebrate forebrain and behaviour proposed by the American physician and neuroscientist, Paul D. McLean. The Triune (‘three in one’) Brain consists of the reptilian complex, the paleo-mammalian complex, and the neo-mammalian complex (neocortex), viewed as structures sequentially added to the forebrain in the course of evolution:

1. The reptilian brain: responsible for species-typical instinctual behaviours involved in aggression, dominance, territoriality, and ritual displays.
2. The paleo-mammalian brain, otherwise the Limbic System: responsible for the motivation and emotion involved in feeding, reproductive behaviour, and parental behaviour
3. The neo-mammalian complex, or cerebral neocortex: responsible for language, abstraction, planning, and perception.

These three are less ‘Levels of Organization,’ more evolutionary overlays. The Triune Brain model has been partly overtaken by recent research, but it still offers a seductively straightforward way of regarding the human brain.

The Triune Brain does offer one potential model—that of layered processing. Instead of replacing redundant computing systems, with their accumulated wealth of software and data, perhaps these systems could be retained as a nucleus and surrounded with ‘shells’ of advanced processing permitting faster calculation, correlation, communication and control such that computing systems might interact with humans via speech and vision, rather than keyboards and mice…and might anticipate the human need for planning and presentation…

Layers in the Brain

The human brain is the most complex part of the human body, and although some may like to compare it with a computer, and/or with the software of a computer, such comparisons do not seem to offer useful models by which we might advance our manmade computing systems…so far.

The cerebral cortex is the outermost sheet of neural tissue of the cerebrum of the human brain. It is divided into left and right hemispheres, and plays a key role in memory, attention, perceptual awareness, thought, language and consciousness. It consists of up to six horizontal layers, each with a different composition in terms of neurons and connectivity.

Levels of Organization within the Brain

The brain is an exceedingly complex organ that is defying attempts to analyse and—particularly—reduce its performance and behaviour. However, there have been attempts to show levels of organization within the brain, as part of the Human Brain Project (Markram, 2012) as follows:

- **Whole Organ**, comprising some 89 billion neurons and 100 trillion interconnections (making over 1000 connections per neuron on average)
- **Regions**, mutually interacting major neural substructures: amygdala (emotions), hippocampus (memory), frontal lobes (executive control)
- **Circuits**, neural interconnections among neighbouring cells and between different brain areas
- **Cellular**, neurons, non-neuronal glial cells, dendrites and axons
- **Molecular**, parts of a neuron and its transmission of electrical and chemical signals

On the other hand, there appear to be functional ‘subsystems’ within the brain, concerned with speech, vision *(q.v.),* motor control, etc.

The Human Brain Project is undertaking an ambitious task, employing ‘synthesis biology;’ this is essentially simulating the human brain within a computer. As a test case, the project team built a unifying structure called a *cortical column:* this is described as analogous to putting a miniature apple corer through the cortex and pulling out a cylinder of tissue about one half millimetre in diameter and 1.5 millimetre in length; this would constitute a column.

The column penetrates the six vertical layers of the neocortex; the neural connections between it and the rest of the brain are organized differently in each layer. A few hundred neuron types reside in the column.

The team simulated the behaviour of a column from a new born rat, allowing the virtual neurons to connect up as real neurons would, eventually providing them with a static model of a column, as in a comatose brain. They then ‘jolted’ the column with a simulated electrical impulse: the neurons began to interact and intercommunicate. ‘Spikes,’ or action potentials, spread through the column as it began to work as an integrated circuit; this was spontaneous, not programmed behaviour. And the column stayed active after the stimulation stopped, briefly developing its own internal dynamics…

Observation. Here, then, is a fascinating, new way of looking at the way the human brain might work, and—although not its primary, medical purpose—it may afford potential for novel design of complex computing and information systems of the future.

Brain Cells for *Concepts*

Neuroscientists dispute how the brain stores memories—which it does remarkably well. Some view memories as somehow spread across the brain and interspersed with each other: others suspect that memories are stored in individual neurons, or groups of neurons. Research, particularly into the brains of those with debilitating epilepsy, is showing interesting results. (Quiroga, Fried and Koch, 2013)

Researchers have been able to insert fine probes into the brain, particularly into the hippocampus, and have discovered individual neurons firing when the subject is presented with a picture of a well-know film or TV star, or has seen their name written. An individual neuron fired for Halle Berry, again to her name written on a screen, and again to her name spoken by a synthesized voice. The same phenomenon occurred for Oprah Winfrey, and for Luke Skywalker; each appeared to have his or her own ‘neuron.’ The research team could not assert this, however, because they were able to sense only a few neurons at a time. Others could have been firing but undetected.

However, further research showed that individual neurons might fire for more than one such star. The neuron that fired for Jennifer Anniston also fired for Lisa Kudrow, her co-star on *Friends*. Again, it was sufficient to show any picture of either star, or the written name, or the name spoken with a synthesized voice. Perhaps the neuron was firing for blondes, or for the TV program *Friends?* The neuron that fired for Luke Skywalker also fired for Yoda: was there a Jedi neuron? Moreover, the neuron for e.g. Jennifer Anniston fired when shown only part of her, when wearing different clothing, etc. Such neurons, then, appeared to be firing in response to the ‘concept’ of Jennifer Anniston, or Yoda, or… how could this be?

The organization and structure of visual information in the brain is outlined in Figure 4. Top left is shown the eyeball, with the optic nerve leading to the primary visual cortex at the back of the head. Here a detailed picture is formed, such that, for every detail in the observed image, there is some correspondence in the primary visual cortex. One neuron firing does not indicate whether it is part of a tree, a wall, or a person, however, and the observer is interested in whether they are looking at an object, and if so, what object…

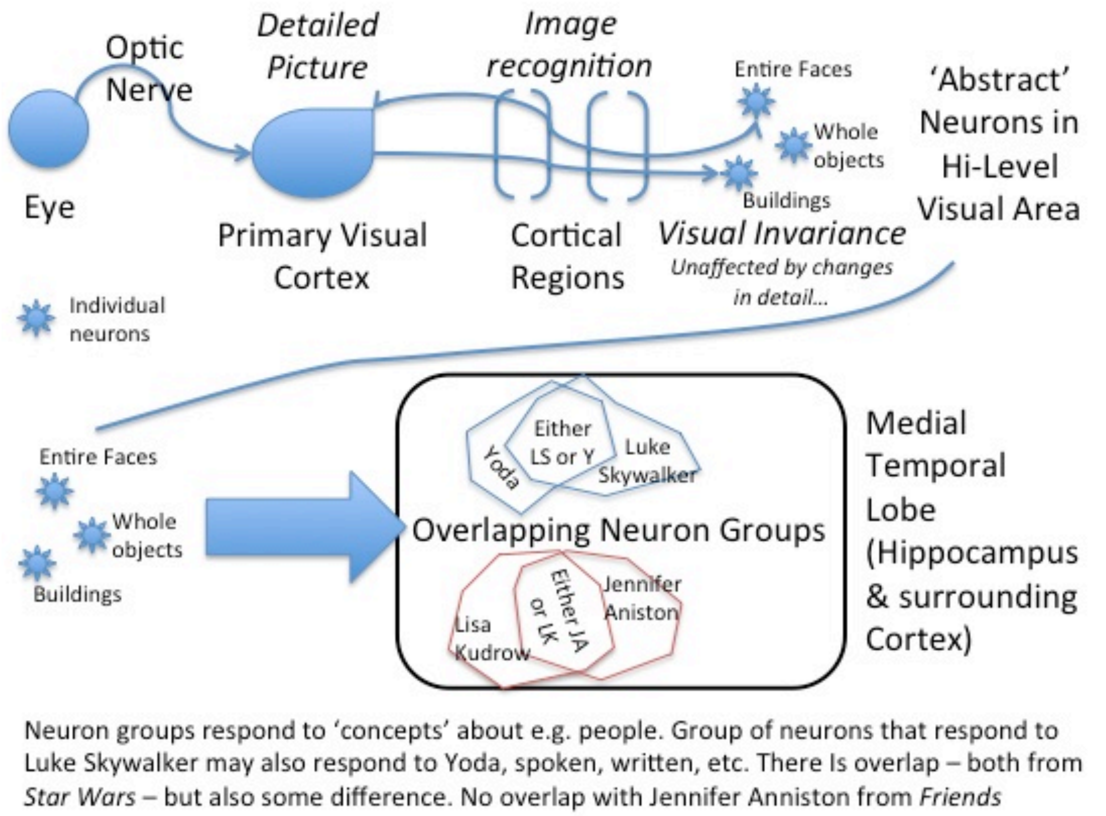

Figure 4. Concept memory

Next the visual information goes through a series of cortical regions towards the front of the brain. Individual neurons in these higher visual areas respond to entire faces, or whole objects, and not to local detail. So, minor changes in the visual scene will not affect these neurons. This is ‘visual invariance.’

Neurons in the higher visual areas send their information to the medial temporal lobe – the hippocampus and surrounding cortex – which is involved in memory functions and where the so-called Jennifer Aniston neurons were found. The response of neurons in the hippocampus is much more specific than in the higher visual cortex. Each neuron responds, not so much to an individual, as to a concept of some individual.

As the figure suggests, there may be a ‘patch’ of neurons, a relatively sparse grouping, which respond to, say, Luke Skywalker and another patch that responds to Yoda, and these two patches overlap, meaning that some of the neurons that fire are common to both memories. Similarly, neurons for Jennifer Anniston and for Lisa Kudrow may also overlap. However, there may be little or no commonality between the sets for Lisa and Jennifer from *Friends* and the sets for Luke and Yoda from *Star Wars*.

What does this all mean? Surgical removal of the hippocampus leaves the patient still able to recognize people and objects, and to remember events, but the patient can no longer make new, long lasting memories. It was as though the means of transferring from short to long-term memory had been removed, as if the 'memory folder index' had been erased.

So, the Jennifer Anniston neuron was not necessary to recognize the actress, or to remember who she was, but it was critical to bring her into awareness for forging new links and new memories about her, such as later remembering seeing her picture.

Memories are more than single isolated concepts. A full recollection of a single memory episode involving a person or thing – perhaps even a place – requires links between different but associated concepts. If two concepts are related, some of the neurons encoding one concept may also fire the other one. This hypothesis suggests how the neurons in the brain encode association.

"The tendency for cells to fire to related concepts may indeed be the basis for the creation of episodic memory (such as the particular sequence of events during an encounter) or the flow of consciousness moving spontaneously from one concept to another… A similar process may also create the links between aspects of the same concept stored in different cortical areas, bringing together the smell, shape, colour and texture of a rose." (Quiroga, Fried and Koch, 2013).

If the research is justified, an elusive aspect of the flow of human consciousness may have been explained. There are implications here for the memory systems, not only of humans, but also of autonomous machines, which will also need to associate concepts. An autonomous (robotic) peace officer,[1] for example, would need to establish concepts of people, places and things[2] on 'his' beat, together with episodic concepts of misdemeanours and crimes in progress. He would recognize individuals with past records and observe their behaviour, comparing it no doubt with models of acceptable behaviour, threatening behaviour, etc.

Observation. The above is cutting edge research, and holds out exciting prospects, not only for understanding how memory and perhaps even consciousness function, but also for conceiving advanced computing systems that learn about concepts and association between concepts for themselves.

Homeostasis

Homeostasis, dynamic equilibrium, is maintained in the body partly by negative feedback processes, and partly by dynamics in open systems. A biologist, Ludwig von Bertalanffy, developed general transport equations for open systems (Bertalanffy, 1968) as follows:

$$\frac{\partial Q_i}{\partial t} = T_i + P_i$$

[1] Sometimes used as a hypothetical test case…

[2] As does a human peace officer.

where:

Q_i = is a measure of the ith element of a system
T_i = the velocity of transport of Q_i at that point in space
P_i = the rate of production or destruction of Q_i at a certain point in space.

A system so defined may have three types of solution: first there may be an unlimited growth in the system, Q; second, a time independent state may be reached; and third, there may be periodic solutions.

In the case where a time independent solution is reached:

$$T_i + P_i = 0$$

In these two simple equation can be seen both the conservation laws of physics and the open systems stability of organisms.

An everyday example of the general transport equation might consider how a person maintains his or her weight, by eating as much food energy as is expended in basal metabolism, activity and exercise. This is homeostasis.

Control through feedback

While open system dynamics may be the principal means of establishing and maintaining homeostasis in natural open systems, many incremental feedback systems are also at work. Two well-known processes follow; one for maintaining blood sugar level, and the second for maintaining core body temperature. This ubiquitous 'opposing pairs' arrangement in natural systems is curiously at odds with engineering and cybernetic practices.

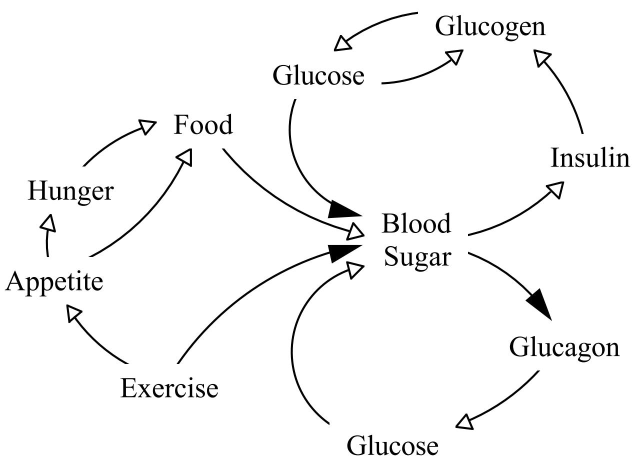

Figure 5. Maintaining Blood-Sugar Level. Open headed arrows indicate positive, supporting relationship. Solid arrows indicate a negative, detracting relationship. E.g., increasing blood sugar level increases insulin secretion (open arrowhead); decreasing blood sugar level increases glucagon secretion (solid arrowhead).

Figure 5 presents a simplified causal loop model (CLM) showing how blood sugar level is usually regulated in the human body. The upper loop is well known: excess blood sugar caused, perhaps, by eating, stimulates the secretion of the hormone insulin principally by the pancreas, which allows glucose in the blood to be converted to glucogen (and possibly to fat) in the liver and muscles, so restoring the correct blood sugar level.

The lower loop works differently. Sustained physical exercise (or starvation) might cause the blood sugar level to drop. This is also detected in the pancreas, which secretes a different hormone, glucagon, which increases (restores the level of) glucose in the blood. Together, these elements within the body's endocrine system maintain a steady level of blood sugar in a healthy human, although that level may change throughout a typical day.

At left in the figure above is shown the relationship between exercise and food ingestion, which forms part of the energy transport equation for open organic systems. In this instance—and generally—open system dynamics operate in conjunction with the feedback controls to maintain homeostasis. The complex human system also has feedback mechanisms, not shown, which encourage eating when blood sugar falls, and when food is not needed but is expected as a result of regular, habitual feeding, as opposed to eating when hungry.

Figure 6 is a second causal loop model, showing a different pair of contra-acting causal loops. The upper loop shows the well-known effect of being in a hot environment: perspiration leads to evaporation cooling to maintain core body temperature. Less well appreciated, perhaps, is what happens when the body experiences a cold environment and the surface skin and flesh cool. As the lower loop indicates, blood capillaries near the surface contract, closing off the flow of warm blood near the skin surface, so that the blood is not cooled so much. Flesh with the blood withdrawn (or not circulating as after death) forms an effective insulator, so that heat conduction through, and radiation from, the skin surface are also reduced.

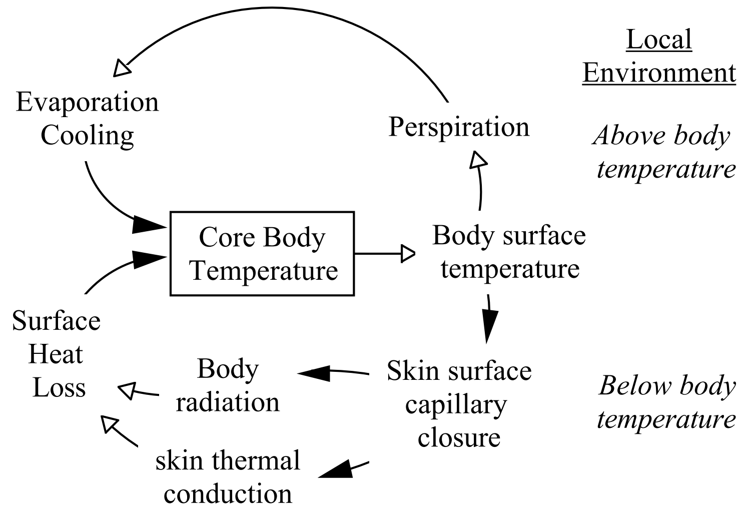

Figure 6. Maintaining core body temperature

The combined effect of these is to maintain essential body core temperature, at the expense of a cold surface skin. As in the previous figure, we see two contra-acting causal loops resulting in maintenance of a stable value of blood sugar and core body temperature respectively. Homeostasis is established and maintained with many such contra-acting feedback loops and with the open system dynamics presented earlier**.**

Observations. Natural systems such as the human body clearly find it advantageous to maintain open system homeostasis by maintaining an equable inflow/outflow regime of energy, material and information, but also by controlling short-term variations using contra-acting, incremental feedback control 'mechanisms.'

There appear to be advantages in this approach compared with the usual single-loop negative feedback technique used by engineers and cyberneticists. Equable inflow/outflow regimes allow the organism/platform to maintain homeostasis even when feedback control mechanisms are prejudiced, by changing behaviour and/or environment.

Some of these abilities are peculiarly human; we are the only members of the great apes to have subcutaneous fat, for example. This feature of human physiology may have evolved to sustain human hunters during long hunting trips where it was necessary to pursue prey over many miles under the heat of the African plains. It offers an explanation, too, for the naked ape's loss of hair covering; hair and subcutaneous fat together would have caused bodily overheating, so with fat being essential to sustain energy for the hunt, hair covering the whole body became prejudicial to survival. (Morris, 1967)

Social Insects, Social Organization

The social insects are often described as 'super-organisms.' Certainly, hives, colonies, armies, etc., do behave in a highly coordinated manner. But then, so do trained and disciplined human armies: would we describe them as super-organisms? Bertalanffy (1968) introduced the term "organismic analogy," suggesting that human systems (teams, groups, nations, even civilizations) are not organisms, but in many ways behave as though they were organisms. The organismic analogy works in both directions: human to insect; and, insect to human. So, a hive of honeybees is evidently not a single organism, but in many ways behaves as though it were…a human city is not a single organism, but in many ways it behaves as though it were.

Hymenoptera, Honey Bees

Honeybees include the well-known European honeybee (Apis *mellifera*), which often nest inside hollow trees. (Raina & Kimbu, 2005). They construct vertical wax combs with individual hexagonal cells for storing honey and rearing brood. Each hive is "ruled" by a single Queen whose only job is to lay eggs. Workers are adult females – daughters of the Queen who mates initially with between perhaps as many as fifty male drones, stores their sperm in her body and uses it throughout her life to fertilize eggs. There are, then, as many as fifty lines of workers in each hive. Their duties change upon the age of worker bees in the following order:

- Clean their own cell after eating through their capped brood cell
- Feed brood;
- Receive nectar;
- Clean hive;
- Guard hive;
- Forage.

Some workers engage in other specialized behaviours, such as:

- "Air conditioning," using their wings to move air through the hive to prevent overheating;
- "Undertaking," removing corpses from inside the hive.

Adult workers live for about six weeks during the summer, but Queens may live for several years. During cold winters, the bees cluster together, feeding on stored food reserves and sharing their body heat. As the weather gets colder, the 'ball' of bees tightens, and there is a continuous circulation of bees from the outside to the inside of the ball. This is analogous to the way chilled humans maintain core body temperature (q.v.).

The Queen secretes a pheromone to maintain calm and order in the hive. As the hive grows in numbers, there is progressively less of this pheromone to go around 'per bee.' At the same time, forager bees have to go further and further afield to fetch food for the growing numbers of bees in the hive. A mature, healthy colony may grow to as many as 80,000 workers, at which point foragers may be gathering barely enough nectar and pollen to feed, let alone expand, the hive. With so many worker bees, the Queen's pheromone becomes too diluted to maintain calm and order, and the hive may 'reproduce' by swarming, with the old Queen accompanied by many bees. A new Queen, reared within the hive, will hatch out, and restock the depleted colony.

The prime directive for the colony, or hive, is evidently propagation of the species through propagation of the hive. The survival strategy involves limiting the size of each colony to that which may be supported by local resources (flora), at which point they relocate to a new area… Hives are perennial, accumulating and storing food to survive winters in cooler climes; this appears to give the hive a fast start to the new season when the weather improves. Honeybees do not employ any technology as such, but their ability to secrete wax and to create hexagonal shaped honeycombs is surely equivalent. This 'technology' directly contributes to propagation, in being used to raise the next generation and to store food compactly for over-wintering.

Observations. European honeybee survival strategy contrasts with that of humans, who build ever-bigger and more densely populated cities. Humans create complex import-export systems to transport foodstuffs from far and wide, making their cities potentially vulnerable to breakdown in supply chains, as well as supporting populations beyond that which could reasonably be supported from locally resourced supplies. This is surely a recipe for unbounded population expansion (and eventual disaster), which is what humanity is experiencing, but which honeybees avoid by living within their neighbourhood resources, and by limiting hive population to that which the local flora will support.

Hymenoptera, Ants

Ants share a common ancestor with wasps, and there are over 8,800 species. (Höllobler & Wilson, 1990.) A typical nest contains at least one fertile egg-laying Queen, hundreds or thousands of adult female workers, a nursery for rearing eggs, larvae and pupae, a storage area for food reserves, and a disposal site for waste and dead bodies.

The size of most ant colonies is limited by their ability to forage sufficient food. Leaf cutter ants may establish lengthy supply chains to bring in their food source – although they do not eat the leaves they harvest, most of which are poisonous. Instead, they use them to feed a farm, which grows a fungus on which the ants live, an early example of symbiosis. The fungus farm is supplied with an antibiotic covering farmworker ant bodies, so preventing disease; these ants discovered antibiotics some 40M years ago.

Army ants are carnivorous nomadic predators that form bivouacs, but do not nest. Honeypot ants farm aphids, living on their excreted honeydew and moving them from plant to plant as a farmer might move cows between pastures.

Recently results from an interesting 6-year[3] study, publicized by Professor Laurent Keller, Director of Ecology and Evolution at the University of Lausanne, Switzerland, have shown that ants have a similar allocation of worker duties with age to honeybees:

- Young ants, about one third of the workers, were nurses;
- About a third were cleaners, having graduated from nursing;
- And about a third were foragers, collecting food outside the colony, having graduated from cleaning

Researchers found that ants, with lives lasting about a year, tended to socialize within their current 'profession,' e.g., nurses with nurses, foragers with foragers. It was not clear what promoted ants from one profession to the next, nor was promotion automatic: researchers found occasional old nurses and young foragers.

Observations. Between them, the many and various ant species display a wide variety of lifestyles and survival strategies. Some are carnivorous, some vegetarian. The biomass of all ant species in the world is reputed to exceed that of all humans[4]. Throughout, their prime directive is survival of their species; they limit their nest/colony size according to locally available resources, a repeated lesson, perhaps, for humans.

Recent research showing that ants progress through different 'professions' in a similar way to honeybees suggests a further instance of convergent evolution, this time of societal behaviour… Ant tendency to intra-profession socialization may suggest that these 'professions' are akin to classes or castes, although without any morphological distinctions.

Blattodea (formerly *Isoptera*), Termites

Termites share a common ancestor with cockroaches, and are universally vegetarian. (Darlington & Bagine, 1999.) Although similar in appearance to ants, they are unrelated, another instance of convergent evolution solving the same social problem. There are some 2,600 known species of termite. They eat anything from lichen and fungus to wood.

In Africa, termites create enormous mounds, with funnels to create air conditioning, particularly for the Queen's chamber, which is held at 30˚C and near to 100% humidity – not dissimilar to the breath of a mammal. These mounds can become very large, with some 35km of tunnels. The relatively huge Queen may live up to 30-45 years, supported and enabled by her king who remains virtually attached to her as she continues to lay eggs. There may be over one million termites in a mound, with the Queen as mother to all.

Like other eusocial insects, termites have castes:

- Reproductives
- Workers
- Soldiers

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[3] Read more at http://www.dailymail.co.uk/sciencetech/article-2311688/ANTS-change-job-grow-older-scientists-discover.html

[4]See en.wikipedia.org/wiki/Biomass_(ecology), extracted April 2013)

Periodically, members of the winged sexual caste take to the air, mate, and the newly fertilized young Queen seeks a new spot where she may start a new colony. So, new colonies are budded off the old, but—unlike honeybees—the old may stay put with its original Queen.

Observations. Termites, at least African termites, may be more established than their ant and bee 'cousins,' and they build strong, deep nests, mostly underground. Queens 'entertain' their king, and together they are much longer lived. Like the Hymenoptera, they live very much within their neighbourhood, foraging over the surrounding surfaces, clearing up vegetable detritus, advantageously reducing the risk of forest fires in the locale.

Do we have anything to learn from the Social Insects?

Insect societies are inherently different from human societies. We humans would find insect social behaviour intense, exceedingly tiring and beyond our ability or desire to sustain. Busy bees, for instance, literally work themselves to death. The social insects know instinctively what job they are intended to do, and they do it: no instructions, no supervision—although, failure to perform may result in summary execution.

Much of the social insects' apparent decision-making is democratic, with insects voting in preference for one option over others, as with the bees and the famous waggle dance, where the 'strongest waggle' wins. There is no control, as such. Neither is the Queen in charge, in any conventional sense; that is surely an anthropomorphic viewpoint.

There are, however, castes. While all eggs may be laid equal, the way in which they are fed may produce morphologically different results, castes:

- bees and ants have worker and reproductive castes (Queen and drone). Workers tend to progress from nursing, though cleaning to foraging. Some ant species have soldier castes where the soldiers are very much larger than the workers, and may have to be fed by those workers.
- termites have reproductive, soldier and worker castes (immature males and females (nymphs), with potential to moult into replacement soldiers or 'reproductives' if needed. Soldiers may differ from others morphologically, with 'hoses' on their heads to squirt irritating fluids at their enemies—often ants…

Castes may be compared with classes in human society, which have existed since the earliest times—the earliest probably being that of ancient Egypt. This isolated proto society was a 'pyramidal' (sic!) three-class system of a pharaoh and a few upper class nobles ('nomarchs'), a middle class of merchants, lawyers, priests, schoolteachers, doctors, scribes, etc., and a working class of very many who used their hands to till, fish, grow, tend, operate and make things. Despite efforts to eradicate, reclassify and rename class, it is still with us and seems to be as innate within human social order as it is within insect social order.

Class mobility, on the other hand, the ability to move between classes, is evident within the social insects, except where caste is morphologically determined. Within the social insects, workers progress through 'professions,' finally working outside of the colony/hive as foragers. Within human society, there is no such obvious progression…although as humans age in society they tend to accumulate knowledge and experience, (may) gain social stature, (may) own property, etc. It is not really the same…

The eusocial insect example suggests that a contemporary Western idea, that all people should be essentially equal[5], may prove difficult to achieve. People naturally fall into classes and castes: some are leaders, some followers, some develop quickly, others more slowly, and some develop degrees of social sophistication with age and experience. Attempts to destroy/discredit so-called upper classes (determined by inheritance, wealth, education and ownership) results in the creation of pseudo classes, such as celebrities—people who seem to be celebrated more for ridiculous, disgraceful, socially unacceptable behaviour than for anything meritorious.

All of the eusocial insects create societies that are closely related genetically, to promote cooperation and coordination. Humans have no obvious equivalent, outside of the family group, nor would we want or accept one. But do we have any corresponding attributes that would similarly promote cooperation and cooperation? Perhaps it would be easier with human society to identify those phenomena that prevent, or detract from these 'desirable social traits.'

- **Culture**. People of different cultures, upbringing, educational backgrounds, political persuasions, religions, etc., may behave, express attitudes and formulate decisions that differ from each other, so constraining cooperation and coordination
- **Belief Systems**. Our view of the world, our *Weltanschauung*, and our beliefs—cultural and religious—may differ radically from others, so that we are unable to see things as they do, and vice versa.
- **Training**. Intense military-style training may overcome different belief systems, such that people who have trained together will cooperate and coordinate in their actions, decision-making and will even overcome their differing natural reactions under pressure.

So, we may reasonably expect human societies where people are the same/similar background, culture, education, upbringing and beliefs to form cooperative, coordinated societies. Within those societies we may expect to find different classes. And this is generally, although far from always, the case.

Alternatively, cooperative societies may form and self-sustain where culture encourages individuals to consider themselves part of a close-knit family group. (Toyota in Japan has operated in this way, with notable success. (Womack, 1990))

What price, then, multi-cultural society? If the eusocial insects are to offer any guidance, it might be that an effective, coherent multi-cultural society is unlikely, while a complex of different side-by-side discrete cultures is more likely, with the inevitable risk of friction at the cultural boundaries.

Conclusions

Biomimetics offers a wide range of models from individual organisms and from the social insects, which may be of benefit to systems, systems thinking and systems engineering. Comparing natural and human systems engineering suggests that human systems engineering parallels natural systems engineering to a surprising degree.

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[5] Promoted by various political notions such as Political Correctness, feminism, equal opportunities, 'gay' equality and marriage, etc.

Further that, in both instances, systems engineering appears fundamentally to be the integration of functional structures from one level of organization lower—although integration may be far from simple…

Natural systems employ a more sophisticated approach to homeostasis than do engineers and cyberneticists. Nature's methods generally involve contra-acting control loops providing *incremental regulation* of open system 'flow through' of energy, substance and information: they are robust, non-linear, fast, precise, effective and tested by time. There may be much to learn here.

On-going research into the human brain is funding intriguing concepts for advancing our ability to create autonomous machines that can think like humans, which have our phenomenal ability for concept associations, and with which we may be able to interact more comfortably, since they will seemingly think and behave like us, rather than like the archetypal clumsy, inarticulate robotic machine.

Social insect societies remind us that the prime directive of all animals is the propagation of species. For hives and colonies it is quite evident that their 'business' is to raise the next generation; that is what they are preoccupied with doing, and what their equivalent of technology is dedicated toward.

Many—most—human societies, on the other hand, seem to be unaware of this prime directive, leaving people to question 'the purpose of life,' to devote their lives to accumulating wealth, to hedonism, to being continually entertained by their governments, to devote themselves to war, conflict, sport, business, work, music, etc., to decide not to have children, and many, many more ways of denying, overcoming, or supressing their nature and ignoring the prime directive. Despite this—or, perhaps *because* of it—human population continues to rise…

The eusocial insects suggest that human societies should be able to manage population size much better than we are presently doing. The hive, the colony, etc., limit their population to that which can be supported by the immediately surrounding flora and fauna, according to species. If there is insufficient food, they do not continue to multiply, but instead they swarm, or bud off, another hive or colony in another area where the resources are adequate.

The eusocial insect example does suggest that countries, or regions within countries, could easily establish whether or not they are under-populated or overpopulated.

- A place (village, town, city, nation) would be overpopulated if the existing population absorbed more resources than the immediate surrounding environment was *actually providing* for human consumption.
- Similarly, it is possible in principle to draw a circle around centres of population, with diameter sufficient to encompass the actual, productive farmland area needed to support that population: i.e., the "food resource footprint."

As a non-political observation, such concepts challenge globalization that would see populations growing unchecked, supported by global exports and imports—inevitably leading to further overpopulation… Social insects also differ from humans in maintaining their essentially agrarian lifestyle; many humans, on the other hand, have abandoned the land physically, socially and mentally, encouraged by the Industrial Revolution, which still rumbles around the planet. As human populations continue to grow and has to be fed, however, it seems possible that there will be, of necessity, a general return to a more agrarian lifestyle for many, if only to feed themselves and live in balance with, rather than progressively destroy, their supporting local environments.

Social insects also entertain class and caste, concepts that politicized western societies find objectionable. If human social history and the social insects are to be appreciated, class and caste are inevitable; attempts to demolish class will serve only to see class re-emerge under different headings. Certainly the present situation in some western societies, where it is somehow despicable to be of a high social status, wealthy and well educated, is inverted. Should we all not, rather, aspire to be like that than to denigrate it, supplant it with highly doubtful celebrity status, and degrade society in the process? Although few of us, perhaps, would want to emulate the social insect Queen, with nothing to look forward to but spending more years producing ever more eggs…

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