Chapter 12 – The Economy Model

Abstract

What is *an* Economy?

In Chapter 10 we argued that the evolution of systems, generating increasingly complex ones we've labelled CAS and CAES, has resulted in the emergence of a generic agent model archetype. In Chapter 11 we argued the same with respect to the emergence of a generic governance model archetype. Now we will complete the argument for a set of generic CAS/CAES pattern archetypes with the internals of these classes of systems, the pattern of sub-processes that constitute the whole activity of such systems. All such systems demonstrate an internal and external dynamic that we will call an economy.

This chapter stems from noticing an interesting pattern that shows up in all CASs and CAESs. Below, in the section [titled Considering a Generic Economic System] we will explore this pattern in more detail, but fundamentally it is the way in which these systems obtain resources in energy and materials, how they do internal work to maintain themselves and grow/replicate, and how they export waste materials and waste heat back into their environments. Sometimes such systems export something that is not of use to themselves particularly but is of use to some other entities in the larger supra-system in which they are embedded. In such cases we call the exported stuff "products."

What all of these systems do internally is to use the energy and material imports in work processes that build and maintain essential internal structures. Waste products are inevitable in all such processes in nature. The organization of the work processes and their on-going management (which collectively we can call the governance of the system) is the pattern of which we spoke. Whether we are talking about the internal organization and dynamics of a living cell, of a multicellular organism, of a Neolithic tribe, a single household, a complex organization, or a modern nation state, the patterns of organization and dynamics follow them. These patterns cluster under the title "economy."

The word "economy" derives from the Greek "oikonomíā" meaning the *management* of a "household." Eco (oiko) is the Greek word for "home." In order for a home to be successful (fit in the Greek society) the "master" and "matron" of the home had to plan and practice "economic" activities – raising adequate food to support the household, for example. This meant managing processes so that the household recognized an accumulation of wealth that would ultimately provide for the support of subsequent generations of the family. Greek philosophers such as Socrates, Plato, and Aristotle spent no small amount of ink pointing out that economy was an essential aspect of the good life, primarily so as to support the head of household being able to devote time to philosophy and politics (c.f. Leshem, 2016, Introduction). In order to have time to think and participate in the governance decision processes of the state, one had to make prudent decisions about how to manage one's own affairs at home.

The term 'economy' may have focused on the management of the household, but what is more important in the long-run is that the various economic activities – the work processes internal to the household – are properly organized in the first place. In this chapter we will take this focus, adding in the governance mechanisms from the prior chapter to complete the integration of the whole CAS/CAES.

Fast forward four thousand years. The management of a single household is still an issue, of course. But now that household is embedded in an extremely complex milieu of sources of income and the goods and services needed as well as the costs associated with maintaining and provisioning the next generation of family. That embedding is in something we now, casually, call *the* economy, by which we mean the aggregate of buying and selling goods and services in something called a "market."

The HSS economy is, however, not the only example of a resource-extraction-production-of-wealth-consumption management system. At an abstract level, an economy, is a fabric of transactions, a network of sub-processes of resource acquisition, transformation (value added) production, and consumption, in which biological beings are sustained. Below we will introduce the notion of different kinds of economies, operating at different scales in living and supra-living systems[1].

In the systems view, an economy is a way of managing the flows of high potential energy and of the transformation of high entropy materials into low entropy assets via work processes that use that high potential energy to do useful work. The low entropy assets support the existence and stability of the system.

For example, we observe the nature of a living cell, the fundamental unit of life. Cells have evolved to be stable (sustainable) over relatively long periods of time relative to the time scales upon which the underlying biochemical reactions occur. Molecules come and go, but the organizing pattern of a living thing persists. What is happening within the realm of metabolism – the economic system of a cell – is management of resources to benefit the whole cell[2]. That system is not perfect in the sense that it can go on forever in any single cell. Entropy has a way of catching up with a single entity eventually. But, the lifetime of a single cell relative to its

[1] Much of the work in this Part mirrors the works of Miller (1990) and Beer (1959, 1966, 1972). Using the CAS/CAES general framework many of the concepts from these two bodies of work are integrated and cover numerous kinds of systems, living, supra-living, and so-called socio-technical or hybrid artifact and human systems like the HSS.

[2] We adopt the term 'metabolism' referring to the economic system within a cell. We will use the term 'physiology' when referring to the economy of a multicellular organism. For larger-scale supra-organismic organizations such as populations, species, ecological systems, and societies we will use a variety of terms but generally refer to the complex webs of energy flow and work processes as an economy.

internal processes is impressive, to say the least. If the HSS were a cell with such a stable economic system, it could persist for many millions of years. And, including the fact that most cells replicate, achieving a kind of immortality through reproduction, some kind of HSS might persist indefinitely.

Similarly, at the scale of multicellular organisms, they have achieved an even longer time scale of stability by evolving cooperation between many different cell types within a single organization – the body, in the form of physiology[3] – a matrix or web of interacting processes in different kinds of cells, tissues, and organs. We human beings, as an example, can sometimes live for close to 100 years while the cells that make up our bodies live for only days or months. Our physiology allows our pattern of organization to persist longer than the lifespans of the cells that make us up. Physiology is to the body its mode of economy. Our bodies are designed to process energy and material inputs to support our organization of cells, tissues, organs, and so on. Most of the time the underlying economy of the body works quite well. Of course, entropy catches up with that system as well. However, not before we have had an opportunity to reproduce ourselves in the form of children who carry our characteristics forward in time. A population, and a species of beings, can persist over indefinite time so long as its economic subsystem works to achieve that.

The human brain is a unique kind of society of information processing modules. It crosses the threshold from being a CAS to becoming a CAES by virtue of its capacity to learn and even construct new knowledge over its lifetime, and knowledge (as long as it is veridical and useful) are the assets produced. The brain is a biological entity, so includes metabolism (e.g. of neurons) and physiology, as it is one subsystem in a body. But it has a new kind of dynamic that can be described as an economy of knowledge produced from information as the inputs. We will refer to this information/knowledge economic system as neuroeconomics. This is an economy of thoughts and memories. Thinking and storing memory traces takes energy as well as material (metabolism of cells) and produces waste products. The human brain produces knowledge which it shares with other human brains through language and other forms of communication. Those products, as discussed in Chapter 8, are extremely useful to other human brains. Which leads us to the subject of Chapter 8, the human economy of goods and services, transactions, technologies, etc. That, of course, is what most people think about when you use the word ‘economy.’ Most people do not realize that what we humans do in trade and commerce is really not that different in kind from what single cells, single bodies, and single brains do to manage their respective resources and modes of production.

[3] Following footnote 2, we should point out that the term ‘physiology’ actually includes many more biological activities, such as reproduction, that may or may not involve the metabolic processes that supply resources, matter and energy, to the organism and then convert those resources into useful structures and macromolecules such as proteins.

At the highest end of organization, the ecosystem emerges as a system achieving a high degree of stability through many complex feedback loops that serve to govern through mutual constraints[4]. Ecosystems are collections of multiple species engaged in a food web organized into trophic levels (primary producers, primary consumers, secondary consumers, and decomposers). In all biosystems the primary product is biomass – living cells and tissues that behave in ways that contribute to the overall stability of the particular ecosystem in which they are embedded. Decomposers (bacteria, fungi, various worms, etc.) play a particularly important role in the recycling of nutrients. In dynamic balance, an ecosystem achieves a stable state called a climax state.

Of course, the Earth system itself is always undergoing change – plate tectonics shift continents around and change climates – but life itself, in the form of cells, bodies, populations, species, and genera manage to persist. They do so because their internal subsystems of resource management and allocation are evolved to produce that result.

Our thesis is that the economy model archetype is a repeating pattern at scales from the metabolism of individual cells to the whole planet. There is a fractal-like quality in viewing different scale economies as *nested*. We discuss the significance of nested economies, that is, the cellular economy (metabolism) within a body economy (physiology), within a human population economy (what we call *the* economy) in section [Nested Economies] below[5]. First, we need to consider why we claim that all of these processes are to be called economies. For one, they all are instantiations of a generic pattern of what we described above as the progressive transformation of high-entropy materials into low-entropy materials through work processes driven by high-potential energy flow through the system. We situate this pattern as a model archetype in the context of CAS/CAESs. Coupled with the governance archetype discussed in the previous chapter we have the basis for a complete understanding of these classes of systems, and thus the basis for understanding our own CAES, the human social system.

What is Not in an Economy

In this chapter we will cover the generic model of economy as it applies to a number of CAS/CAESs and especially the hierarchy of life – cells, organisms, and societies. The reader may be surprised to learn that there are a number of topics, issues, processes, and concepts with which academic economists (particularly neoclassical economists) deal regularly that turn out

[4] The HSS should be understood as existing within the global ecosystem but with an obvious caveat. Humans create new components within their ecosystems – their cultures. They have colonized the entire planet, so act as invasive species that upset the balancing forces that had brought those ecosystems to their climax states.

[5] At the time of this writing the author began reading Smith and Morowitz (2016) and was pleased to note that they make the case for the phenomenon of life as reflecting this nested quality of biological processes. They do not use the term economy but describe the biosphere in terms of an extended complex network of metabolic activities that extend up from cellular to the ecosphere.

not to be part of a deep economic model. We will mention a few examples here to provide some scope/perspective (some of these were mentioned in Chapter 8).

In the treatment of a natural CAS/CAES economy, the archetype model, you will not find mention of many things such as profits, perpetual growth, debt-based financing or any number of modern concerns in economics. The reason is simple, these elements are not found in pre-human societies, nor even early human economies. Some of them have correlate mechanisms in the archetype, but their implementations in the modern economy appear to be distorted and misbehaving.

Financing Based on Debt

For example, the notion of financing an asset in the present based on the possibility of having a future income sufficient to pay back the debt and interest to boot appears to be derived from the practice of borrowing from excess savings (e.g. a greater amount of grain in the granary due to an extra productive harvest). Only it has gradually morphed into a habit of borrowing from future earnings on the assumption that a growing economy means there will be higher income in that future time. Recent experience in many forms of debt-financing are showing that this assumption is not valid. Economic growth has slowed considerably of late (Gordon, 2016) so the realized ability to pay back the loan, when what was once the future got here, has diminished considerably. The global finance system had to be bailed out with cash infusions by governments to prevent too many bankruptcies. Even so too many people lost significant assets (like homes) after the 2009 Great Recession. The current state of affairs in global finance, where both public and private entities rely increasingly on debt to continue operations and where banks have the ability to extend credit by digging into deposits, essentially creating money out of nothing, looks more and more like a Ponzi scheme[6].

Natural systems do not borrow from the future because incomes do not go up over time, endlessly. The global economy of the Ecos is a steady state, circular economy, materials cycle driven by the energy flow of the sun. The world is essentially materially closed (receiving a light dusting from left-over solar system formation and an occasional meteorite). Thus, the global economy has to make do with what it has. The biosphere, too, while participating in some of the grander geosphere cycles such as the water cycle and carbon cycle, recycles and reuses its stocks of biochemicals. Thus, the economy of Earth is in a long-term steady state flux with sometimes impressive deviations (e.g. Snowball Earth[7] or the End Permian Event[8]), though most of those

[6] See the Wikipedia article: https://en.wikipedia.org/wiki/Ponzi_scheme for background. Accessed 9/30/2018.

[7] See the Wikipedia article: https://en.wikipedia.org/wiki/Snowball_Earth for background on this hypothetical event.

[8] See the Wikipedia article: https://en.wikipedia.org/wiki/Permian%E2%80%93Triassic_extinction_event for background on this real event.

were quite long ago when the Earth was still evolving to its current form. By comparison the swings from ice age to interglacial seem mild.

The point is that the Ecos is not growing. It is a fixed sized pie, which means that if any one subsystem grows larger than other subsystems must diminish. For the biosphere this means biodiversity decline. The growth of the HSS has meant a loss of species for the world. It also means that the HSS economy is constrained because it depends ultimately on the rest of the Ecos being stable and able to provide its services.

Living systems exist in constantly changing environments in which resources may, from time to time, be in low supply. Life solved this problem by evolving the ability to maintain stores of resources against a time of need. For example, an animal's fat stores contain energy that can be converted from fat to sugars when carbohydrates are not available. The animal need not starve so long as eventually it finds the external resources. When it does it is motivated to take in more than it needs, strictly speaking for maintaining. It has to rebuild its store of energy against future downturns. Similarly, early societies developed methods for preserving some foodstuffs against hard times (even just seasonal variations like dry seasons).

The excess taken in during these times of abundance is not a profit (see below)! The stored resource is properly understood as savings. There will be a time in the future in which the excess will become a deficit and whatever was saved during good times will be used to maintain the steady state.

During periods of growth, an organism must take in more resource than is needed just for maintenance of their biomass at the time. They are investing those resources into new biomass as they increase in weight and develop tissues. As they reach maturity the growth rate declines and they eventually enter a routine of maintenance as suggested above.

The same is true for a social system, ordinarily. Prior to the Green Revolution[9] agriculture was only gradually improving productivity in the western world, due mainly to the uses of tractors and other farming machinery along with better breeds of food plants and animals. This meant that the supply of food in those more developed states was adequate to abundant, but this wasn't the case in the underdeveloped areas of the globe. Subsistence farming still predominated for most of the world's populations. In both cases, however, there was not such an excess.

People got used to the idea that tomorrow we would produce even more wealth than today. At some point this seemed to give reason to think that we could borrow from that future time today. We could spend today wealth that would be produced tomorrow. This is accomplished by finding those who had already warehoused excess wealth and borrow from them with the promise to pay back the loan in the future, along with interest (or dividends). Essentially, we

[9] See the Wikipedia article: https://en.wikipedia.org/wiki/Green_Revolution for background. Accessed: 9/23/2018.

believed that we would be able to do this because the future would be essentially like the immediate past in which we really had this capability because the economy was growing.

Prior to the advent of debt-based financing as described above the human socio-economic system was propelled by ever increasing recruitment of

Profit

The current study of economics includes the role of profit in economic growth. But neoclassical economics also holds the premise that growth is a normal and perpetual state of affairs, which, as argued above, is not the case. CAS/CAESs grow when developing (e.g. reaching maturity) but eventually enter into a steady state where fluxes provide temporary gains or deficits but over the lifetime of the system, it remains at its maximum size. This can best be understood in terms of the amount of some crucial stock within the system. For example, energy reservoirs, such as the glycogen stored in the liver of an animal can temporarily increase, such as after a meal, but also deplete, say after a vigorous workout.

The concept of profit is so ingrained in our thinking that it will be difficult for most to realize that it is based on a mistaken account of the dynamic fluxes of materials and energies in mature systems. While the human socio-economic-cultural system was undergoing real growth through improvements in productivity gains (technology) the excess of income over costs was real enough. The HSS could be compared with the growth and development of an animal from embryo, through neonate, through childhood, to sexually mature adult. Once that mature state is reached a negative feedback turns off the production of growth factors. The body enters a quasi-stable, steady state with some occasional need for growth, say in the storage of body fat in anticipation of lower food intake during winter months but also working down of those stores during the time of low food intake.

The origins of the concept of profit in human society is thought to be in the earliest grain-states' ability to produce excess grain over the consumption (Scott, 2017). Originally, as a biological function similar to body fat storage, the idea of excess production in any given year was to hedge against crop failures in some future year. Farmers soon learned that there were often long-term variations in climate conditions that made such a strategy prudent. Grains can be stored for long periods so afforded such a hedge (ibid). But there was no way to monitor exactly how much excess was produced in any one year nor a way to monitor what might be needed to accommodate future needs and thus strike a balance in the long-run. Thus, excesses could accumulate, notwithstanding calamities owing to major climate events like floods or droughts in various locales. Unfortunately, what this allowed is a growth in population to account for the balance. And a growth in population fueled the need to plant more crops leading to the advances of the early grain-states toward becoming empires.

Having excess foodstuffs available was always a good thing, and so became a habit of thinking and working toward. The stores of grains represented real wealth and it became necessary to account for the amounts in storage and the ownership. Thus, was born writing and numeracy. The combination of ownership (or controlled possession) and the motive to produce excesses above one's own consumption, coupled with the evolution of the accounting markings in clay to become the beginnings of a monetary system of trade, and the sense of power given to the owners of the wealth all underwrote the rise in the notion that profits, for their own sake, were good things. More profits equated with more power. The rest, as the saying goes, is history.

Until very recently the HSS was indeed developing and growing. Profits turned into progress and growth of human-controlled biomass. After the Industrial Revolution the pace of development and productivity increases due to technological improvements accelerated. Starting in the late mid-20th century, however, that acceleration slowed and by the end of the century had turned to deceleration (Gordon, 2016). From a systems perspective this looks exactly like a signal of a system approaching maturity.

Yet the notion of profit maximization, a major tenant of capitalism, remains firmly entrenched in the thinking of economists, politicians, and the common citizen.

Governments and central banks around the globe are turning to any financial sleight of hand they can think of to keep the illusion of profits for their own sake going.

Considering a Generic Economic System

Common Attributes of an Economy

A number of features of a generic economy are found in all economic systems. The objective of an economic system is to produce low entropy goods and services that are used internally to support and perpetuate the various subsystems that do the work. Some economic systems may also produce and export products (or services) that are useful to other entities in the environment (generically called 'customers'). A properly functioning economy allows a CAS/CAES to persist in its environment for time scales much longer than that of its overt behavioral dynamics.

Products and Services

An economy is based on the notion that a CAS/CAES must obtain some immediately usable resources from environmental entities (suppliers) or, more generally, construct usable resources by doing work on raw materials (energies or messages), transforming them to a point where they can be used by the system.

Organization of Work Processes

Work processes obtain their input resources, including high-power energy, do work on those resources to modify or transform them into something of greater value to export to other work processes as input resources to them. Economies are organized in chains of work processes, each able to add value to their inputs through progressive transformations toward final products.

progressive reduction in material entropy (increase in organization) from raw inputs to finished products

Energy Flow and Work

The fundamental purpose of an economic system is to channel the flow of free energy to work processes that reconfigure matter according the needs of the system as represented by the supply chain model above. The system must have means for extracting free energy from environmental sources. Whether this is ingesting sugars for metabolism or drilling for oil with refining to produce the fuels we use in the human economy, the key tactical work that is done is getting a reliable flow of free energy into the system.

Subsequently the energy must be channeled to the work process sites. Metabolism achieves this by producing a ubiquitous molecule, adenosine triphosphate (ATP) that acts as a current flowing from specialized extractors called mitochondria (described below) to various sites where the energy packet each molecule carries is used. The electric power grid does some of the job for the human economy. Below we provide more details on how these subsystems work and why they constitute a universal archetype (or sub-archetype).

Specialization of Work Processes

Materials are transformed from low organization to useful organization in steps. There are several primary kinds of transformation work that will be described below. For now, we want to call attention to the organization of the whole system as an ordered sequence of specialized processes. Specialization of work to modular or encapsulated processes is a core feature of all economies. Specialization translates into efficiency in doing work. Evolution shaped the designs of specialized metabolic processes, physiological tissues and organs, brains, and ecosystems (where member species are the specialists). Humans design organizations and machines to achieve the highest efficiencies possible under given constraints. Specialization allows the design of work to be particular to a given step in the value-adding chain.

Redundancy and multiple pathways

In a supply chain network there are generally many similar specialized work processes operating in parallel. There are many advantages to this kind of architecture. Chief among these is the advantage of redundancy. No work process can be guaranteed to work ceaselessly forever. They are subject to degradation and may fail at some point. Having a population of work processes of the same kind, in a reconfigurable network, means that there should always be some sufficient portion of that population fully at work. Of course, the processes that have failed need to be repaired or replaced and this is exactly what living systems do. It is what human organizations do as well.

At the same time, too much redundancy becomes pathological. Living systems regulate the amount of redundant capacity to just that needed to provide the backup ability required under nominal conditions. Living systems have an ability to recruit additional capacity on an as-needed basis for short-term pulses of demand (e.g. homeostasis), but they do not build additional capacity unless they experience long-term changes in the demand level that warrant the commitment of extra resources. See (Mobus, 1999) for an analysis of adaptive response and associated costs.

Internal competition and evolvability

Whenever there are multiple work processes of the same kind operating in a complex network there is the potential for competition between those processes for limited or constrained resources. At the level of cellular metabolism such competition is thwarted by a tight regulatory system that ensures that there is no excess redundancy. In a multicellular body's physiology, the situation is much more complex and though there are similar regulatory mechanisms in place to maintain a balance there are also more opportunities for competition between organs and tissues for limited resources used by all, for example glucose in the blood used by all cells as energy sources. An extreme case of competition occurs when some cells become cancerous and send signals to commandeer the blood flow; they then grow without bound and eventually consume the whole body.

Among humans as well as among human organizations, competition is viewed as the rule rather than the exception. That is the case in the current view of a neoliberal economy where all producers are free to produce their products as much as they want and to compete with each other by reducing their prices or increasing their quality. Market dynamics under capitalism and something approximating laissez-faire conditions are thought to lead to competition driving these improvements. However, it should be noted that there have been many other kinds of economic models adopted by human societies throughout history that were not based on employing competition to this extent (Polanyi, 2001 edition).

Coordination and Control

Mechanisms for making sure work processes maintain near optimal balance of flows are found in all economic systems. That is, the governance of an economy, as demonstrated in the previous chapter, is essential in order for the entire economy to work for the good of the whole system. We find this is the case in the examples of metabolism in cells, physiology in bodies, and to be generally true in family dynamics that support reproduction. The situation is less certain when we examine the economic system of societies. As pointed out in the previous chapter the governance architecture of the HSS is still in flux and the decision-making capacity of the agents is often questionable. We suggest that the evolution of a stable HSS economy is still in process. Numerous socio-economic governance systems have been tried throughout history and most (maybe all) have been *selected against* with respect to sustainability in the long-run. A short list of tried models will illustrate the point:

Communalism: Communal ownership and tribal federations

Oligarchy: Headmen, kings and emperors

Plutocracy: The few powerful rule

Democracy: Distributed decision making

These general attributes of a generic economic system, can be found in all CAS/CAESs. All such systems examined by the author and many other investigators are found to have this general pattern (suggesting that it is universal). Evolved systems such as single cells, multicellular organisms, genera, and ecosystems are long-term stable, in other words sustainable, by virtue of having well-organized and working economic processes with well-organized and working governance. This chapter will explore the archetype of a generic economic subsystem model. We start with the basic concept of a material transformation chain, otherwise known as a supply chain, because it produces products that are low-entropy configurations of materials that can be used to support the existence of the whole CAS/CAES in which the chain operates.

A Basic Supply Chain

All economies in all CAS/CAESs have a fundamental subsystem model, the archetype of which we present here. Figure 12.1 shows the basic supply chain model that is found in all economic systems. The basic model includes processes that extract resources from the environment, processes that transport materials, processes that transform the materials into useful, low entropy, products, and processes that use those products and export waste products.

The basic supply chain is a fundamental unit of an economic system. In the figure we show a simple linear chain to fix the basic ideas. An economic process exists whenever a system contains the functions performed in this figure. The subsystems that perform these functions are specialized to the functions (we will return to the concept of specialization below). Those functions are: Extraction of resources from the environment, production or configurational modification work, distribution or moving materials from point of production to point of use, and consumption or use. The whole economic activity generally moves from left to right in the figure, however we will see later that feedback loops are important in the networked supply chain covered next.

The extraction and conversion of a material good from the environment is specialized to find and import that good. A living single-celled animalcule may obtain macromolecules through a process of phagocytosis, a human being eats food and breathes in oxygen, a corporation has a purchasing department that orders and receives shipments of parts. Value is added to the imported goods through preliminary transformations. The animalcule needs to ‘digest’ the macromolecule and the human needs to do likewise to the food. A mining operation needs to break ores up for preliminary processing.

A resource material is relatively simple insofar as organization is concerned. Some resources such as metal ores are essentially rocks that contain a high concentration of the metal making it possible to refine the latter, throwing out the non-metal bits. Others, such as timber are structurally low entropy but not in a shape that is suitable for further use, so needing sawing into boards, etc.

Distribution processes are what move the various materials through the system. In a cell, for example, an elaborate network of microtubules provides a means to cart various cellular macromolecules from points of production to points of use. In animal bodies, the cardiovascular system transports nutrients (e.g. glucose), dissolved gasses (O_2 and CO_2), and numerous signaling molecules (e.g. hormones) around the body. In the human economy the train and trucking industries provide ground transportation of material goods.

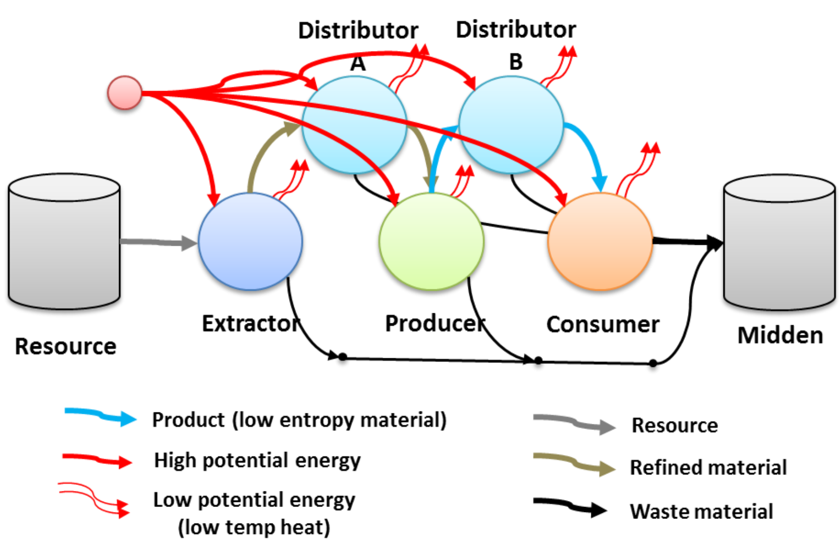

Fig. 12.1. All economies are based on a basic supply chain. Resources, such as medium entropy materials (i.e. semi-organized) are extracted by special processes and passed to producer processes, that do work to reduce the entropy of the material further (i.e. increase the organization). In turn, the product is passed to consumers. Energy is consumed by all processes as value is added. Consumers degrade the low-entropy materials through use and need to discard wastes to some environmental sink. All work processes in the supply chain produce some wastes (heat and material) because no process is 100% efficient in its uses of materials or energies.

Producers is a general category of work processes that do major transformations of material to create usable products, also called assets, for use or consumption by other processes. In a long supply chain, end products are built up in stages of production (or value added) so that a producer situated ‘downstream’ might also be viewed as a consumer of an ‘upstream’ producer’s product (the above figure only shows one generic producer but we will shortly introduce multiple stages of production). Products are classified as intermediate, i.e. component parts, or final (before being used or consumption).

Products may also be cross-classified according to their use and longevity. For example, a ribosome, in a cell, (see below) is a stable, long-term product that is, essentially, equivalent to a physical manufacturing plant in the human economy. Producers add value to materials by virtue of increasing their organization and conformation so that they may be used subsequently, either to produce tools (as introduced in Chapter 9), capital goods[10] (which are really just long-term tools), intermediate products (parts), or final products for the ultimate consumer process.

That process, the consumer, degrades the low entropy products produced by the economy and exports[11] the low-organization material to an external sink, here labeled the “Midden[12].” The concept of a consumer is a difficult one. In an ecosystem a consumer is generally an animal that eats plants (primary consumers) or animals that eat the primary consumers (secondary or carnivores). In a cell the consumer is the whole cell itself and its purpose is just to repair subsystems, stay alive, and be capable of reproducing. The same can be said for the multicellular organism. For the human economic system, the same rules apply but something quite different is at work. People need to stay alive and reproduce, certainly. But consumption in the human economy has taken on a whole new meaning that results from the inclusion of improving technologies. This is the subject of Chapter 8.

CAS/CAES Type	Extractor	Producer	Consumer
Individual cell	chloroplast/mitochondria	ribosome	whole cell/reprod
Body	alimentary canal	tissues/organs	whole body/repro
Population	individuals		
Species			
Ecosystem			

[10] In ordinary economics we make a distinction between capital goods and other long-term assets and consumables. The latter generally refer to things we use up and turn into wastes, e.g. food, paper goods. In fact, however, taking the very long-term view, we do use up long-term assets eventually. Most such assets may require maintenance, parts replacements, etc. And eventually such assets become obsolete or just wear out.

[11] Later we will add a specialized waste export function to the chain.

[12] The term ‘midden’ means a garbage or trash dump. It is generally applied to archeological sites where evidence of life styles and practices can be determined by what the local population threw away. We are using it in a more general sense to mean any sink into which waste materials of any sort are dumped by exporting processes.

The Supply Chain Network

Here we present a generic pattern for an economy[13], a network of interconnected supply chains. Figure 12.2 provides a schematic representation of the economy of a generalized CAS (we will distinguish CAESs from 'ordinary' CASs later). We have identified the internal subsystems that are operative in any economy whether of primitive humans, the current HSS, or living systems such as cells, bodies, and ecosystems.

All real CASs employ the major subsystems shown in the figure. All such systems acquire energy and material resources from their environment. Most acquire information from the sources and sinks in their environment. And they produce products and wastes (heat and material) that are exported to entities in the environment. This is a generic pattern that can be used as a basis for analysis of any CAS at any level of organization (cell, multicellular organism, societies, and the global HSS).

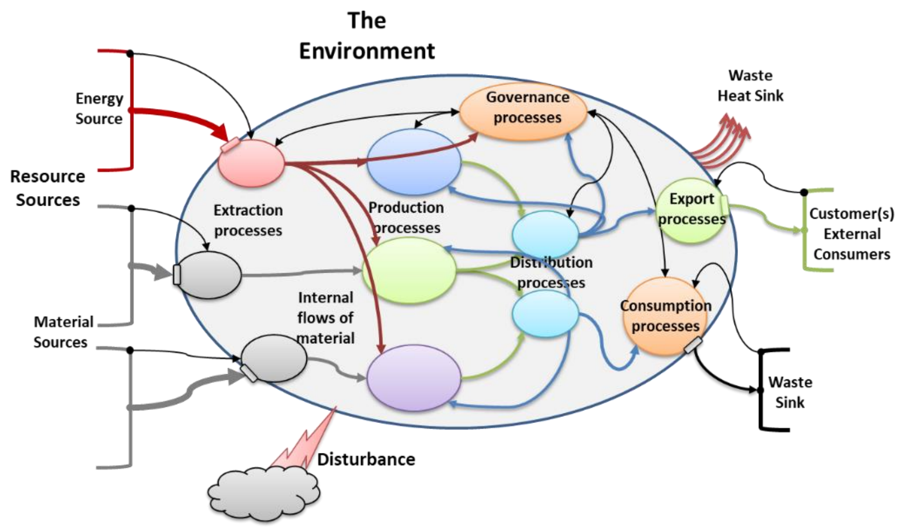

Fig. 12.2. A schematic representation of a generic economic system archetype. An economy is based on a network of interconnected supply chains. A few representative flows are shown. Thin black arrows represent message flows, red arrows represent energy flows, and other colored arrows represent various material asset flows. Extraction/Importing is shown on the left (as per the convention we established in Chapter 5). Flows internally generally go from left to right with exporting processes pushing products and wastes out into the environment. Internally some assets produced later in the general flow are sent to more forward processes for their use.

Internally, the economy consists of work processes that import and convert raw materials into progressively more usable forms; that is, organizations of matter and embodied energy that benefit other work processes downstream or, ultimately, a consumption process. Energy is

[13] This treatment suggests that an economic subsystem is a first-class ontological concept as mentioned in Chapter 2.

captured (or extracted) and converted to usable net free energy[14] to power the work processes. Work processes transform the materials to lower entropic forms, i.e. more organized and more useful to the ultimate consumption processes. Distribution processes (which are specific kinds of work processes) convey the intermediate and final products of production to internal consumption processes as well as export processes that expel products and wastes back out to the environment.

The whole system is coordinated by a governance process (see Chapter D) that manages the internal process as well as making sure the system is coordinated with the external entities in the environment (including responding to disturbances). For more evolved CAESs governance includes some aspect of strategic management, as outlined in Chapter D. Governance of an economy involves several mechanisms that help regulate the various transactions (exchanges of material and energy). For example, market transactions between entities, mediated by direct exchanges of equivalent 'value' between source and sink entities help regulate local flows of materials and energies. The signaling of value is through some kind of representation of free energy.

This generic model is what we meant before by 'systemic analogy'. No matter what kind of CAS or CAES we examine we will find these basic subsystems and interfaces with an environment at work.

This generic economy is, of course, only part of the whole picture for what constitutes a fully functional CAS or CAES. We have not yet addressed the issues of adaptability or evolvability. Those are yet to come.

Economic Agents

Chapter C explored the general decision agent model archetype. In this section we briefly consider the decision types, with reference to Chapter D, that are found distributed among the various processes participating in a typical supply chain or network.

Resource Extractors & Refiners

The task of resource extractors (as in Figure 12.1) is to locate, import through the boundary of the system, and possibly modify the raw resource in some manner to make it suitable for distribution to producers.

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[14] As a reminder, free energy, in physics and chemistry, is that portion of total energy which can be coupled with a work process to do "useful" work. The latter means work that results in a configurational change in a system, 12.g. capturing some of that energy in the form of molecular bonds. Depending on the stability of the configurational change, it might later decay, giving off the embodied energy as heat, as when molecular bonds give way to disruption and a complex molecule comes apart into simpler component molecules.

Resource Finding and Quality Testing

Photosynthesizing plants are not ordinarily thought of as 'hunting' for sunlight, but in fact many plants have growth control mechanisms that implement strategies for finding the ideal level of light. For example, understory plants make do with the dimmer light that filters through the forest canopy. At the same time, they are, generally speaking, passive in obtaining sunlight and they are subject to the luck of the draw in terms of where their seeds might land. Plants, photosynthetic autotrophs[15], possess specialize organelle in their leaf cells called chloroplasts in which photons are able to excite electrons into a chain reaction that allows the final fixation of carbon into carbohydrates, e.g. sugars and starches. The sugars are then available for oxidation processes within mitochondria that produce the energy packet ATP.

Plants obtain mineral resources such as nitrates and water from soils through roots that penetrate it and actively seek the sources underground. They obtain CO_2, as their source of carbon, from the atmosphere through pores in their leaves' undersides called *stoma*.[16]

Animals, including single celled animalcules such as *Paramecium*, generally move around in their environments to find food for ingestion[17]. They use a variety of sensory modalities to locate food sources. Many employ a prototypical foraging strategy in searching for stochastically determined food locations. For example, ant colony scouts can be seen wandering over even flat surfaces like a sidewalk in a seemingly haphazard path. The wandering is stochastic but not really purely a random walk (Mobus, 1994); it was dubbed "the drunken sailor walk" in honor of the times the author did manage to get back to his submarine somehow. Hunting, foraging, browsing, and grazing are just a few modes employed by different species in finding food. In more complex animals, gills or breathing are used to obtain ubiquitous oxygen.

The agents responsible for animal behavior in finding and eating food is, of course, modules in the brain that obtain information on the environment, looking for cues regarding the presence of food and testing the quality, e.g. the amount of food available for ingestion. Honey bees test the quality of a flower patch by sampling several flowers for nectar. If they find a very low quantity they will abandon the patch to search for more promising prospects. Taste or smell (olfaction) is another quality test for foods for many animals. If it tastes bitter, it might be poisonous.

For human organizations from families up through nations the search and quality testing of potential resources is an on-going problem. Finding food in most developed countries is

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[15] See these Wikipedia articles: https://en.wikipedia.org/wiki/Autotroph , https://en.wikipedia.org/wiki/Phototroph#Photoautotroph, and https://en.wikipedia.org/wiki/Photosynthesis for background on this most important element of the biosphere. Accessed 5/27/2018.

[16] Also used in the regulation of H_2O

[17] Of course, some parasitic varieties of organisms may simply embedded themselves in other animals bodies where they sap the nutrients from the host's tissues.

generally a matter of driving to the supermarket, at least for those who have adequate incomes. The same is true for finding fuels for transportation and cooking. The whole society is arranged around providing these resources (which we will discuss later). In under developed regions the quest for food and cooking fuel is more complicated.

Modern human economies have complex acquisition processes at the front end of the chain or network. Based on the capitalist model of corporations, companies are organized to explore for raw fuels and refine them for use in the general economy. Large industrial agricultural operations grow and supply the bulk of food to the economy. The decision agents in these organizations need not only have expertise in finding and mining or growing, they need to make decisions for how to proceed based on the need to make profits in their operations.

We might note that the profit motive for decisions and actions among human enterprises, has its roots in living systems being programmed to maximize gain so as to have resilience in the face of scarcity by saving any current excess. However, in humans, at least in the developed world, the motive has outlived its purpose since the times of want are rarer and shallow. That drive seems to have morphed into a kind of pleasure-giving motive beyond practical purposes. We will return to this issue later.

Resource Importing/Extracting

Importing and extractor processes have to have agency in actually acquiring the resource needed by the system. In cells there are complex channels embedded in the cell membrane that are designed specifically to allow the one-way passage of particular molecules into the cell cytoplasm. These channels constitute the interfaces the organism has with its environment, and the selectivity of the channels with respect to what they let in is part of the interface protocol discussed in Part 1 of the book. Single celled animalcules, as noted, may be able to ingest larger particles such as bacteria into special digestion chambers called lysosomes. There the particles are broken down into the constituent components (amino acids, sugars, and fatty acids, for example) needed as resource inputs to metabolism.

Cells, both as individual organisms and as members of a tissue in a multicellular organism, are immersed in semi-aquatic milieu in which the resources are dissolved or similarly immersed. Animalcules may actively swim (as do some bacteria) to capture their food, as noted above.

Whole organisms, in particular animals, eat. They ingest food and digest it much as is done by the animalcules discussed above. Once the nutrient molecules are broken down they enter the blood stream for distribution to various organs, 12.g. liver, for further processing.

A family goes shopping in the developed world. There are still a few hunter-gatherer societies in remote regions who continue to practice the arts of hunting game and foraging for fruit or tubers.

Farming, logging, mining, and drilling/pumping are the main resource extractors for the HSS. In Chapter 8 we explored the energy sector and the consequences of decisions about extracting finite resources like oil and coal.

Refining a Raw Resource for Use by Producers

Monitoring Demand by Producers

Producers

Consumers

Distributors

Market Dynamics

An economy is actually a plethora of producers, consumers, and distributors operating such that low-entropy goods (and service work) produced by producers gets to consumers via flows of materials and energies along multiple pathways. Those flows need to be controlled by the economic agents working together, for the most part, cooperatively via established message channels and communications protocols (signals). Consumers have to signal a distributor that they have demand for a good (or a service provider for a service). The distributor, in turn, has to signal the producer to supply the good for distribution. And the producer, in turn, has to signal the extractor or refiner, to obtain and make ready for supply the resources needed. Since there are populations of consumers, distributors, and producers, in general, the signaling mechanism must allow consumers to cast multiple signals to multiple distributors and for them, in turn, to cast multiple signals to multiple suppliers. There is a network of signaling and flow relations of the many agents resulting in a general flow from extractors to producers to consumers to waste sinks.

This network constitutes a market through which goods and services move. The marketplace of an economy has several general characteristics in all instances.

Market Characteristics

From cellular metabolism to the human societies, markets will all demonstrate the following characteristics.

Redundancy of Processes

Resilience is largely based on the redundancy of multiple kinds of processes. Multiple resource extractors, multiple producers, multiple consumers, and so on, are producing the same results, sometimes via slightly different processes. Having a multiplicity of similar processes increases the likelihood that at least some of them will continue working under varying stressful conditions. For example, in cellular metabolism there are several different cyclic pathways through which metabolites operate, all producing the same basic products, especially molecules of ATP, the cell's main power current. Tissues perform the same kind of redundancy in organs of animals. Here all of the cell types may be the same, but the massive numbers of them ensure that in spite of disease or injury, at least some of them may continue to provide services to the body. In a society of humans several individuals may possess similar skills and abilities and, thus, be able to provide alternative workers for specific jobs. In the modern social setting multiple firms may produce very similar products, with essentially the same functionality so that buyers have choices among various producers.

It should be noted that in metabolism and physiology redundancy does not necessarily imply competition between producers or between consumers. The network of producers and consumers operates more like the Internet packet switching protocols in which there is an attempt to balance throughput. Production and consumption processes need not be in synchrony. If a producer process is lagging at some time, the consumer may switch to a different source.

At the level of cellular metabolism the various product molecules, both small metabolites and large macromolecular are fairly uniform or commodity-like. Thus all of the producers produce the same basic product. Consumers of those products do not particularly care where the products came from and there is no differentiation of "brands" or consumer preferences to consider. Similarly in body physiology products of tissues are still molecular objects with no particular distinctions to be made. When we get to ecosystems, however, there are many differences in consumable biomass forms (the products), and consumers show definite preferences for one form over another. This is what constructs the food web within an ecosystem.

In the human economy the redundancy in production and consumption involves considerable variability and preference determination. In western societies in particular we find a multiplicity of toothpastes, tomatoes, and cake mixes. Presumably all toothpastes clean the teeth, all kinds of tomatoes can be used in salads, and all cake mixes produce excessive sugar-based treats. But for human consumption, variety is the spice of life[18].

Open Channels between Processes

For any market to operate efficiently and effectively there must be clear and open channels of communications between all of the processes. Certainly producers and consumers must be able to communicate things like supply and demand. At the cellular level this is accomplished by the various chemical reactions being conducted in the aqueous environment of the cytoplasm. Diffusion is the main method for propagating signals. Indeed, some very effective poisons and antibiotics work by disrupting the signaling channels.

[18] How variety of products actually creates a problem for human agents is explained in Schwartz, 2004.

In an animal's body signaling is both via blood circulation (hormones and immune system agents) and via the nervous system. Here, too, channels of communications must be open and clear.

But it isn't just communications channels that need to be maintained clear and open. The actual products need to have means of ready transport between producers and consumers. As with the diffusion of signaling and energy molecules in cell metabolism there are some metabolite and macromolecules that diffuse from points of production to points of use. In addition there is an internal network of microtubules that actively transport larger macromolecules or organelles in a guided fashion[19].

Signaling Protocols for Cooperation

Communications signals (message flows) are used intensively in economies in order to achieve as much cooperation as possible between producer and consumer parties (including extractors as producers and waste exporters as a kind of end consumer). The general pattern is to have a series of communications channels between processes from the first extraction to the last waste disposal in the supply chain. In order to effect any transaction between any two processes in the chain, a very strict protocol, both for communications and for management of the substance flow, must be in place and adhered to in order to affect transactions.

A transaction is any transfer of a product or service between a producer/provider and a consumer/beneficiary. A key aspect of a market economy is the ability for these two kinds of agents to interact directly without, as much as possible, imposed coordination from a higher-order regulator (e.g. a logistics agent per Chapter D). They must signal one another of their states (status) in terms of readiness to supply or to obtain. Such a protocol must include flow rates, onset and offset timing, etc. Highly evolved mechanisms exist to provide the communications channels (message flows) and the cooperation protocols at both ends. A basic pattern is: the consumer signals an interest in obtaining and how much (demand), the producer signals a willingness to provide and availability (supply), the consumer signals the time it is ready to accept supply, the producer acknowledges and commits to supplying quantity at the specified time, the producer signals onset of the flow (shipment), the consumer may signal readiness to accept flow, the producer signals completion of pushing the flow (quantity), the consumer signals receipt and completion of the flow at their end. This general pattern of flow control protocol can be found in metabolic cycles and the HSS economic process.

Noise Suppression of Signals

Noise is any disruption of a communication signal (used to transmit information between agents). It can be induced from the outside of the channel (e.g. electromagnetic interference) or

[19] See the Wikipedia article: https://en.wikipedia.org/wiki/Intracellular_transport for background on this mode of transportation within cells.

be inherent within the channel (e.g. thermal vibrations of the channel components). Either way, noise can disrupt the information quality of a signal and lead to process errors that would, in turn, disrupt production and transport of products (and services).

In the realm of communications, the problem of noise disruption is a constant problem. There are a number of methods that have been developed in communications engineering for suppressing noise (in a general sense) in order that the information in a message not be lost or garbled (e.g. the "signal-to-noise" ratio be kept sufficiently high). These include ways to enhance the bandwidth of the channel and of coding signals with redundancy that allows for error detection and correction. It also involve careful design (or evolution) of communication protocols (end protocols between senders and receivers as described above) that include providing retransmission of signals that have been irretrievably disrupted.

It turns out that there are very similar mechanisms operating within all economic systems. In cellular metabolism the main mechanism for noise suppression is the buffering of errors in signals, which are molecular transports (Smith & Morowitz, 2016) via cytosolic reservoirs[20]. More generally the damping of errors or noise in signals is handled by various buffering approaches.

Buffering of Movements

It should be noted in general that processes will tend to operate at varying rates at different times (asynchronous, episodic, and sporadic) due to local conditions within each. Yet to keep a supply chain/network operating efficiently it is necessary to provide temporary storage – buffering – of substances within the process subsystems in order to smooth out the overall flows. This is the case for material flows (e.g. inventories), energy flows (e.g. batteries or hydroelectric reservoirs), and also messages (computer memories used to store message packets in Internet routers). Different producers produce their products at different times and at different rates. Similarly different consumers use up these products at different times and rates. Temporary storage devices (as described in Chapter 2) are ubiquitous solutions to smoothing out the rates of flows to allow for cooperative regulation between processes being able to handle the bulk of flows and transactions.

Signaling in the Control of Consumption, Production, and Flow

Every process needs resources to do its work. It must obtain these resources from suppliers, either extractors or early supply chain producers. It needs an effective means to signal to the suppliers how much it needs and when it needs the resource. Final consumers of the final products start the process of signaling demand. Their rate of consumption and, thus, their future demands, really motivate the entire supply chain. Ultimate consumers in any economy are the

[20] Beyond the scope of this book, but covered in Mobus & Kalton, 2015, is the theory of noise filters and, in particular, the FIR filter. Think of the ability of a capacitor to buffer fluctuations in voltage changes in a circuit.

drivers for everything else that transpires in the economy. A ribosome generates a demand for tRNA+amino acids, mRNA from the nucleus, and ATP from the mitochondria. A muscle cell generates a demand for glucose from the liver as it contracts to do physical work. And a household generates demand for produce, meats (assuming non-vegetarian diets), and services as it rears children.

In cellular metabolism this signaling is accomplished at the molecular level with concentration levels of a particular molecule that, in higher concentrations, activates a production process. For example a higher concentration of ADP in the vicinity of a mitochondrion activates it to produce more ATP (which simultaneously reduces the concentration of ADP – feedback). It is an indication that the cell is actively metabolizing and needs more energy.

Signaling in multicellular organisms is still molecular but with molecules that are dispersed within the intercellular fluid (or blood). For example, when the cells in an animal take up more glucose from the blood to make more energy available within the cells, the body responds. Cells in the pancreatic islets, monitoring the blood glucose levels, and setting in motion several physiological signals that work to regulate the level. Blood glucose levels are maintained homeostatically and it is extremely important that the signals are clear and noise free. Disruption of signals (for various reasons) in this case lead to the diseases of diabetes (e.g. Type I, II).

In the HSS economy, the signaling of demand (and, indeed all signaling) has been given over to the price mechanism. Demand is signaled by what price (in monetary units) a buyer is willing to pay for a commodity, product, or service. Since buyer willingness is, itself, subject to influences that may or may not reflect actual value, we consider these signals as particularly noisy, not reliable, and the source of disruption to the long-term viability of producers. There are, of course, other disruptive factors in the use of prices to signal demand in the human economy. Some of these are mentioned in Chapter 8. Nevertheless, the price mechanism, however flawed, represents a way of signaling demand (and supply) so counts in the general archetype. Is it a good one? That remains to be seen.

Consuming processes, such as ribosomes, organs, and households are informed about supplies of resources by signals sent from the producers. Again, in metabolism and physiology these are mediated by molecular signals (i.e., concentrations in the cytosol or blood).

Cooperation signals, that is, signals that flow directly between producers and consumers to coordinate their interactions, evolved to increase the efficiency and speed with which transactions could be completed. The ATP/ADP loop mentioned above is an excellent example in cell metabolism. Similarly, the homeostatic maintenance of blood sugar levels is largely handled by cooperation between tissues directly.

In human markets most transactions are also regulated by cooperative signaling between buyers and sellers. The price system, again, is used as the mediator. Buyers and sellers agree on a price to be paid for a product or service and the transaction is completed with the buyer taking possession of the product or benefiting from the service, and the seller receiving a quantity of an abstract marker called money. The latter is a marker representing a real physical quantity, namely the capacity to obtain the inputs to production of its product in the near future. The signal here is telling the receiving producer that they should obtain those inputs in the future and produce more product because there will be buyers and demand in that future time. The producer can use those markers to become a buyer of the inputs and keep the production process going.

All human economy markets are based on an aggregate of producers and consumers who must compete on some level to obtain transactions. The signaling levels are established by allowing market dynamics generate something like an average price such that the majority of buyers and sellers are willing to make a trade (clearing the market). However, in this scheme there are some winners and some losers, thus human markets, at least in the capitalist versions, have an inherent amount of waste above and beyond that generated in cooperative and coordinated economies, such as metabolism.

This is quite different from other natural economies (metabolism or ecosystem food webs). In metabolism nothing is produced until there is a signal of need. Ribosomes do not have to compete with one another for ATP molecules, with some losing out because there aren't enough to go around. They don't have to offer higher levels of ADP in order to win the competition. Rather the mitochondria ramp up or down production according to the needs of all of the ribosomes, something like a just-in-time delivery system.

Governance Processes

Chapter D provided a description and deeper explanation of a "generic" governance subsystem as depicted in Figure 12.2. Here we provide an overview of system governance as it relates to an economic subsystem. We state categorically that every CAS or CAES involves and contains elements of a governance system to keep it doing what it needs to do to fulfill its purpose. The need for governance stems from the sheer complexity of a network of the various processes as covered above in section [The Supply Chain Network]. While it is conceivable that a simple, linear, and short supply chain, such as in Figure 12.1, might be able to operate using process to process signaling (cooperation only), given sufficient capacity of the decision agents, in the more general case of a deep network of multiple work processes some form of imposed coordination is necessary. Hence, an economy needs a coordination level of governance, at least. The more complex the system is, the more coordination is needed.

By the logic of evolution (selection) and in order to be a sustainable on-going concern a system must monitor its behaviors at every level of operations and provide control feedback whenever a subsystem is failing to do its designated job. Moreover, all of the internal subsystems must be coordinated in their behaviors so that the overall behavior is sufficiently effective[21]. Since every system is part of a larger supra-system, 12.g. a corporation is a subsystem in a larger HSS economic system or a ribosome is a subsystem of a cell, it must coordinate its behaviors in acquiring resources, exporting products (or performing services), and eliminating wastes with other entities in that larger environment (its sources and sinks). Thus, two basic forms of coordination of subsystems is required, logistical and tactical.

The governance of an economic system rests on several interrelated mechanisms, all of which are part of cybernetic loops, hence the name, *hierarchical cybernetic governance system* (or HCGS). This structure should be thought of as the architecture of governance. Management, as explained in Chapter D, is the process of agents making appropriate decisions based on where they are in the hierarchy. Governance in this architecture, can be broken into several interacting components based on the kinds of decisions and communications linkages employed.

Inter-process Communications and Cooperation

Ideally two or a small number of operational subsystems can communicate directly with one another and manage to self-coordinate on a local scale. This is possible because all of the operational decision agents share a common model and objective of what the cluster is supposed to accomplish. When this is the case, coordination is really achieved through *cooperation*. So, a primary means of managing small-scale coordination is through the sets of messages sent and received, their interpretations, and proper responses. For example, in a supply-chain model, vendors of components to be used downstream in assembly, are informed by the consuming process what is needed in some short time horizon. They respond cooperatively by making sure they can fulfill that demand, or signal back that a delay may ensue. Either way the two entities establish a cooperative interchange to manage the flow of goods.

In biological systems there are found strong hand-shaking cooperative activities, especially in metabolic processes. For example, the supply of energy in the form of ATP to various manufacturing organelle, 12.g. a ribosome, is based on a signaling process whereby the ribosome lets the local mitochondria (through diffusion) know there is need of more of that molecule. Assuming the mitochondria have enough raw material (e.g. glucose and oxygen) they can ramp up production to satisfy the needs.

Even larger scale cooperation is seen in cellular functions. For example, highly stimulated post-synaptic compartments in neurons can, through an elaborate signaling mechanism, let the genes responsible for producing the mechanism for producing various membrane channel components that these are needed to increase the sensitivity of those synapses encoding memory

[21] We would ordinarily say “optimally” effective, but as anyone who has ever tried to manage a complex organization will know, optimality is a rarely achievable ideal. Fortunately, there is generally a region around an optimum that is sufficiently close to optimum so that the organization still functions well enough not to get selected out of the ecosystem. Still a well operating management/governance subsystem is required to achieve this level of operation.

traces. This process takes place over the spatial scale of the neuron body and over a much longer time scale (see Chapter A for more details).

Operational Decision Processes

These decisions are actually distributed throughout the whole system. Each subsystem shown in Figure 12.1 contains its own governance sub-subsystem, just as the whole economic system has a governance subsystem. This pattern is recursive and self-similar at almost all scales. Even the subsystem labelled as the governance process contains a similar hierarchical structure. That is, it contains operational level decisions, i.e. the ongoing operation of the process of governance. For example, a US senator's office, or any legislator's office, has a staff of people who handle the day-to-day functions of the office, such as preparing documents for legislation. Decisions need to be made regarding what gets done and when at a low level. Other kinds/levels of decisions need to be made as well in the senator's office. We'll discuss those below.

The point is that all processes shown at the level (and below) of the governance process have internal governance sub-subsystems in their own right. And their internal operations need decision makers working at the appropriate level.

Generally speaking, operations level decisions are made in real-time and are used to correct processes that have strayed from nominal operations. This is the basic cybernetic feedback mechanism covered in Chapter D (see Figure 11.5).

Economically-relevant operations decisions involve, for example, transactions, 12.g. sales and purchases of goods and service. And here it is only managing the arrangements, say, of transfers (e.g. purchase order processing). As a rule, the determination of price and negotiating contracts, etc. is handled at a higher level of decision processing, namely the tactical level[22].

In the HSS economic subsystem, the role of consumption is generally associated with households where goods and service a primarily received and used. Consumption means using something up, leaving only wastes. The day-to-day acts of consuming are operational-level decisions based exclusively on local conditions. However, work processes are also consumers in some sense. A manufacturing operation uses up a variety of "supplies" in going about its business with the waste (e.g. paper forms) being expelled.

Market-based Decision Processes

Economic systems typically involve diffuse and distributed decision processes in which some level of flow or storage is arrived at through a kind of consensus process. That is, among a

[22] Here we have another example of the cause of fuzziness in systems. In some purchasing operations the purchasing agent handles the operational-level management (of purchase orders) and the tactical-level management of negotiating prices. Thus, one person spends some time being an operations-level agent and some amount of time being a tactical-level agent. Even when it is difficult to parse the role of a single individual, it is essential to keep in mind that one person can be a member of several classes of subsystems in the course of a few hours' time.

population of agents, the actions of individuals average over the population to assert a value that is then used in subsequent decisions. The price setting based on supply and demand in classical economics is an example of this mechanism. There are multiple constraints on the decision effectiveness of market-based coordination and its role in economic governance[23].

In the limit, a position very often taken by free-market advocates (e.g. neoliberal economists), the market mechanism is self-regulating via the supply-demand relation. The market, the average of those individual decisions, “clears” at some price where supply equals demand. Everyone who can buy the commodity does so and producers/sellers are satisfied with their incomes.

A truly “free” market is considered by most, even the advocates of lassaiz-faire, to be a (at best) useful fiction. Markets do operate to shift prices based on availability of certain commodities and their desirability among buyers. And a great advantage of a market is that it can increase the flexibility of conducting transactions and trades. However, over and over again, we have seen in history massive failures in the markets underlying, especially though not exclusively, capitalistic forms of economic systems. Many books have been written about the “causes” of market failures. But in the context of this section it should be clear that the question of governance of the market needs to be front-and-center. The market might be a useful mechanism to achieve some form of economical governance that is to say one where the overhead of governance does not unnecessarily burden the benefits of governance.

Market-based trade and distribution mechanisms ultimately depend on competition, between buyers for limited commodities and between sellers to provide those commodities at prices buyers appear ready to pay. Competition between multiple entities seeking to thrive in a constrained resource environment is, of course, a major part of evolutionary logic. Competition is seen to enhance capabilities – the most fit competitors survive by adopting “better” methods or strategies. During the formative years of economic theory in the 19th Century, the logic of competition in evolution seemed to provide the main support for the notion of free markets. Survival of the fittest was thought to be the operative rule.

Today, we realize that evolution includes a hefty dose of cooperation as well as competition (c.f. Bourke, 2011). There has to be a balance between the two for species and individuals to succeed. And while competition may work to hone skills, it is cooperation that accounts for the major transitions from simpler to more complex organizations (e.g. from multiple kinds of prokaryotes to the origins of eukaryote cells, Morowitz, 2002; Smith & Szathmáry, 1995). Cooperation among individuals of a social unit became the main mechanism for success of the human species, while competition between social units (groups) provided the impetus for improvements (Sober & Wilson, 1998).

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[23] See the Wikipedia article: https://en.wikipedia.org/wiki/Market_(economics) for general background on markets, their origins and histories.

Management (Agent) Decision Types in the HCGS

Extraction of Resources

There are three basic resources that are needed by all CAESs (and CASs). All of these systems need material resources in order to replenish their own material structures. Entropy is always at work degrading physical structures (protein denaturing or home repairs). But also, the system itself is continually consuming structures. This is the fundamental nature of life and supra-living systems. This is what we mean by dissipative systems. They are constantly needing to import materials and energy (of the proper form and power) in order to do the work of constructing structures for use. They are constantly in a battle with entropy.

Energy comes in either potential (stored but available) or kinetic (doing mechanical or chemical work) forms, for example, fossil fuels or sunlight. The generic system must have a mechanism for capturing energy and converting what it captures into a usable form – into what physicists call *free* energy or the energy available to do useful work[24]. That energy then needs to be distributed to all of the other work processes so that they can, in fact, accomplish their work.

Materials, in general, have to be acquired through active mechanisms; they need to be *imported*. Living things have to eat and digest. Society has to extract minerals from mines. The processes that do the importing work, of course, also need energy.

As energy needs to be converted to a usable form, so too, materials are generally extracted in a raw form that needs processing before it can be used in production. Digestion can convert proteins in food into amino acids that can be processed into the proteins the cell or body needs. Lumber can be sawn into planks and studs for construction. Iron ore can be smelted into iron (or steel) ingots.

Production of Useful Goods and Services

Once resources are acquired and pre-processed the system's production processes can begin constructing useful material structures for the ultimate consumer (or for export to external customers). The entire economic system is organized around the need to supply consumers with structures (and services) that they require to survive and thrive. In the living cell this is represented by the construction of enzymes and cellular organelle in tightly closed cooperative network. Cells produce metabolites that are available to other kinds of cells for many different purposes (e.g. regulation: hormones). Companies produce products and services that are used by other companies and individual consumers.

[24] In any flow of energy only a portion of the total energy can actually do work. Nicolas Léonard Sadi Carnot developed the formalism for an ideal heat engine (machines that are driven by a temperature difference). See the Wikipedia article: https://en.wikipedia.org/wiki/Carnot%27s_theorem_(thermodynamics) for background. While Carnot's result applied for heat engines doing work, the same principle applies to other forms of work.

Production, as we will see later, can be divided into several categories by who receives the products and how those products are used downstream of where they are produced. Products are considered assets. Put another way, anything that is produced from a work process that cannot be used downstream is waste and needs to be eliminated from the system. Assets are useful to someone or something in the system. They are generally categorized by their "residence time" in the system. Fixed assets such as buildings and cellular nuclei have very long lifetimes relative to that of the whole system. Fixed assets still require continuing inputs of material and energy for maintenance, meaning the work of repairs. Assets such as machinery, automobiles, or ribosomes (in cells) last for a while but eventually need replacing. The shortest lasting assets are things that get consumed completely by the processes they support; food, gasoline, plastic wrapping, are a few such items.

Distribution – Moving Atoms, Energies, and Bits

Since the various subsystems in an economy are distributed in space a fair amount of energy as well as conveyance vehicles are needed to move matter, energy, and messages, in all their various forms. The vehicles must be constructed in the production stage (above) and then powered and controlled is specialized routes (flows) to convey substances from their sources (e.g. extraction storage) to their destinations for use (e.g. production processes). All of these pathways may be described as flow networks, even when, for example, the flow is based on diffusion or convection. Things have to move or be moved through the system (essentially from left – inputs – to right – outputs in Figure 8.a). Only a few representative flow networks are shown in Figure 8.a to provide a sense of the general layout.

Consumption

Consumption, as used here, is the act of degrading a low entropy material object or a store of potential energy, in order to do other work. In a biological system food stuffs are broken down into component parts to be reassembled into structures that are useful to the consumer. This kind of process also consumes energy (e.g. to break bonds) and usually produces waste materials that need to be exported to sinks in the environment or risk toxic effects or clogging flows.

In the HSS humans living in their homes are consumers of products and services from the production sector. This consumption is oriented around the act of maintaining life (reflecting the biological mandate). Cells consume carbohydrates to produce energy stores in packets of ATP (see below). Businesses consume lots of paper, electricity, and paperclips but also human labor. All consumption results in some wastes. Energy is consumed doing work and produces waste heat.

Counted in with the consumption of material and energy (resulting in wastes) the use of intermediate-term, "hard" assets such as equipment and vehicles (or ribosomes and cell membranes) causes wear and tear that will eventually require repairs. In the modern human economy another factor that produces wastes is obsolescence of equipment such as 3-year old computers or smart phones. Owing to the complexity of these devices it is easier to replace them with newer, more up-to-date ones and scrap the old ones. We are not aware of anything analogous in cell metabolism.

Exporting Products and Wastes

Every economy must make provisions for the disposal of wastes and the exporting of products to the larger supra-system. Humans have routinely dumped their wastes into the nearest convenient hole or river. Cells exude their waste products into the surrounding intercellular medium. In a multicellular organism there are supra-systems responsible for collecting and removing such wastes (e.g. CO_2 or uric acid) such as the circulatory system.

Cells often export substances such as hormones or molecules that act as signals to other cells. These would be more in the category of products since they are actually usable in the larger supra-system. The HSS, on the other hand, does not appear to produce anything that might be of use to other systems, except, perhaps, our excrement used by bacteria as food.

Waste removal, for both material and heat, and product exporting are often active processes that require energy to be used.

A Note on Disturbances

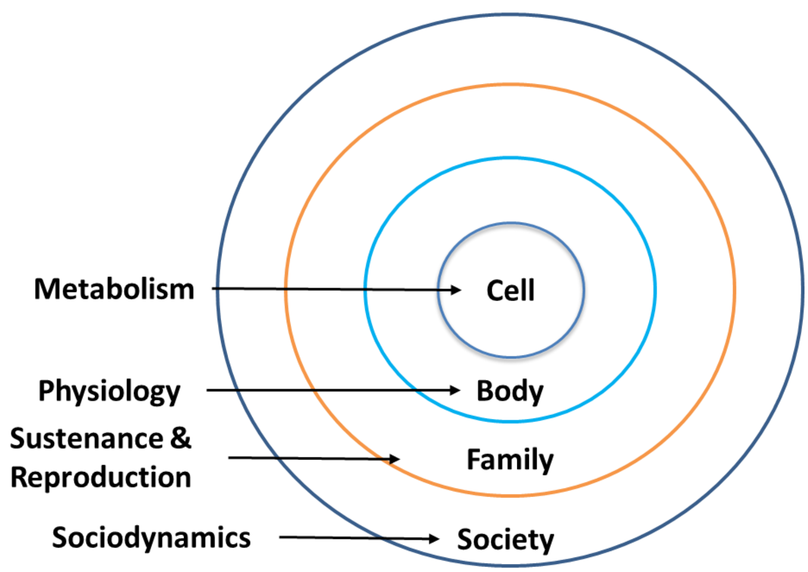
Almost by definition there is not a lot that can be said about the sources of disturbances; they tend to be spurious. There are generally no interfaces through which disturbances are "received." Their effect is felt within the system in unpredictable ways and times. Some disturbances may have internal sources such as a breakdown of a component as a result of wear and tear unmaintained. Another, and very common, internal source of disturbances, one that has been experienced by most people in the human economy, comes when a positive feedback loop in a market goes unregulated causing what is known as a "bubble" to grow. Eventually bubbles burst (or at least deflate rapidly) causing some economic pain in the process. We will examine the market mechanism, from the systems perspective, later in this chapter.

Disturbances, regardless of their source and magnitude are compensated through some regulatory mechanisms that act to restore a more stable dynamic process (see Chapter 11). In cellular metabolism this regulation is the well-known homeostasis.

Nested Economies

Above we suggested that the various forms of natural economies could be viewed as nested like concentric rings, with the simpler CAS versions in the center and more complex CAES versions outside. One can think of this as the economy of the whole HSS is comprised of families (households and the centers for reproduction). Families are comprised of individuals' bodies (physiologies), which are made up of various kinds of tissues/cells (metabolisms). The claim is that metabolism is the economy of a cell, physiology is the economy of a body. More importantly, the physiology of a body is an extension of metabolism into the "community" of cells that make up that body[25]. In other words, physiology is seen as 'exo-metabolism.' In the same way we argue that the economy of a society of bodies is an extension of physiology in the community of people[26]. Thus, we can say economies are nested with those of simpler CASs inside more complex CAESs (Figure 12.2).

This argument follows from the ontogeny of systems presented in Chapter 2, where more complex systems arise from simpler systems through the ontogenic cycle (see section 2.3.1 The Ontogenic Cycle). The history of biology has witnessed "Great Transitions" and emergences of higher levels of organization (Calcot & Sterenly, 2011; Morowitz, 2002; Smith & Szathmáry, 1995). From the origin of, relatively-speaking, primitive simple cells and early metabolism (Lee & Morowitz, 2016) to the evolution of prokaryotes to the emergence of cooperation between different varieties that led to the eukaryotes, and so on, living systems have been organizing at higher levels of complexity for, perhaps, 3.5+ billion years on Earth. At every transition the new forms displayed more complex metabolic mechanisms and increasing differentiation of cell types as specialists. With the advent of multicellular life forms new intercellular communications as well as useful metabolite production produced physiological processes and an economy of the organism. The evolution of human beings and their social systems is in direct line with this ongoing ontogeny. We, therefore, have much to learn from our progenitors.



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[25] Of course there is actually another two layers between cells and bodies – namely tissues and organs, so our treatment is not exhaustive but, we think, amply illustrative of the points.

[26] We make a similar argument for the nature of ecosystems. See section 2.2.2.6 H.T. Odum's Energese for a brief on this relation.

Fig. 12.3. "Simpler" economies are nested within more complex ones.

Metabolism

The most fundamental core process of natural CAS/CAESs is cellular metabolism. It constitutes a basic economy because it is the extraction of raw materials (carbon, water, trace elements) from an aqueous environment, the extraction of free energy from sources in that environment, the production of useful low entropy configurations of materials (i.e. macromolecules and structures) for sustaining the living state of matter, and the consumption of those materials as a dissipative system.

Anabolic processes build structures using free energy to accomplish the work. Catabolic processes break them down extracting some free energy that can be used in anabolism and degrading non-functioning molecules to their components. Both production work processes and degradation processes produce waste heat that dissipates. There are multiple possible sources of free energy. Photosynthesis is the most well-known source of energy on the surface of the planet. However, some extremophile bacteria and archaea obtain energy from inorganic reactions involving, for example, iron and sulfur compounds. In either case energy flows through the cell driving all of the processes.

Biosynthesis (anabolic) is used to produce biomass, either in the form of a growing cell (after mitosis), or as replacement of degraded structures. In the former case the production of biomass leads to population growth in unicellular organisms or individual multicellular organism's growth and development.

Metabolism[27] is an extremely complex chemical reaction network that so long as supplied appropriate resource molecules (and sunlight in the case of green plants and algae) maintains a dynamic pattern of organized processes. Everything that happens in the cell's economy is mediated at the molecular level. True, some of the molecules involved are extraordinarily complicated, such as the ribosome (below). Many molecules, such as the ubiquitous water and amino acids are relatively simple by comparison.

The workhorse molecules in metabolism are the multitude of proteins, long polymers of amino acids, just twenty of which make up the building blocks of the proteins. Proteins can act as enzymes, catalysts for various chemical reactions. They can also function as structural components and motors to move other molecules around. Many other organic molecule types as well as non-organic trace substances are used for various purposes, such as energy storage or as components in structures, 12.g. phospholipids used in building cell membranes.

Here we will provide a very general overview of metabolism as economy and only mention a few examples of implementations from the generic model archetype.

[27] For a much greater explanation of metabolism see the Wikipedia article: https://en.wikipedia.org/wiki/Metabolism. Accessed 5/18/2018.

Governance

Since the only medium available in cells is molecular all computation are done through chemical reactions. Similarly, all signaling is through molecular flows of various kinds. Even within this organization there are finely tuned feedback and feedforward loops that maintain operational level management of things like reaction rates and gradients. Most of the governance of the cell's metabolism is handled through cooperative signaling. See Chapter D for more on this subject.

Ultimately the governance of metabolism is the provenance of the genetic code. Genes determine the amino acid sequence of proteins. They also influence the secondary structure of those proteins that determines their enzymatic properties[28]. The genetic code is the ultimate decision model for all of the decision agents in living systems.

Resource Conversion

Within eukaryotes specialized energy extractors called mitochondria are good examples of resource converters. Energy comes into the cell in the form of complex macromolecules such as polysaccharides or fats. These are digested in special vesicles and broken down into simpler compounds such as glucose. The latter are then processed by the mitochondria[29], which oxidize the sugar under controlled conditions to transfer electrons and drive the synthesis of adenosine triphosphate, ATP, a molecule that is ubiquitous throughout the cytosol and is the main free energy current used in all other processes, such as synthesis (see next section) and movement. Figure 12.4 provides a diagram of this process. Note that an ATP molecule releases its energy to the work process by cleaving a phosphate, converting it to adenosine diphosphate (ADP). The latter diffuses back to the vicinity of the mitochondrion where it acts as a feedback signal – its concentration rising will ramp up the production of ATP, using the ADP as the base and adding back a phosphate. This is a good example of the governance of the activity of this process through a mechanism that looks awfully like a market.

[28] It is even more complex than this! Genes are only the beginning of the story. Epigenetic constraints are now known to have a much stronger influence on genetic expression than we had previously imagined. See the Wikipedia article: https://en.wikipedia.org/wiki/Epigenetics for more background. Accessed 9/14/2018.

[29] See the Wikipedia article: https://en.wikipedia.org/wiki/Mitochondrion for more background. Accessed 9/14/2018.

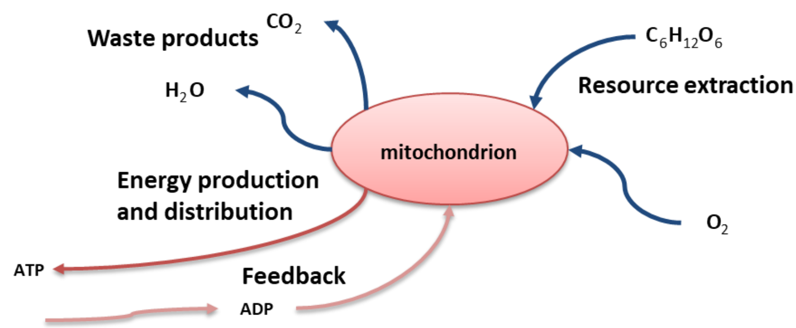

Fig. 12.4. The mitochondrion is a particular organelle that produces transportable energy packets, molecules of adenosine triphosphate or ATP, which diffuse to the work processes where the energy is consumed in doing work. See text for more explanation.

Goods Production

At the core of metabolism is the production of the various proteins that are needed throughout the system. This job is handled by a complex manufacturing unit called a ribosome[30] (Figure 12.5)

A ribosome is a complex structure composed of subunits and made from both proteins and RNA molecules. Its job is to construct a polymer of amino acids according to a specification written in a molecule of RNA (mRNA specifically) that carries the message from the nucleus to the ribosome. Essentially this is a blueprint for manufacturing a specific protein.

Amino acids are found ‘floating’ in the cellular medium, or cytoplasm, attached to another kind of RNA molecule (tRNA) that is said to ‘transfer’ the amino acids from the cytoplasm stock to the ribosome site of production. The mRNA carries a code written in triplets of the nucleotide bases, adenine (A), cytosine (C), guanine (G), and uracil (which is an RNA analog of thymine in the DNA of the genetic code).

[30] See the Wikipedia article: https://en.wikipedia.org/wiki/Ribosome for more background. Accessed 5/18/2018.

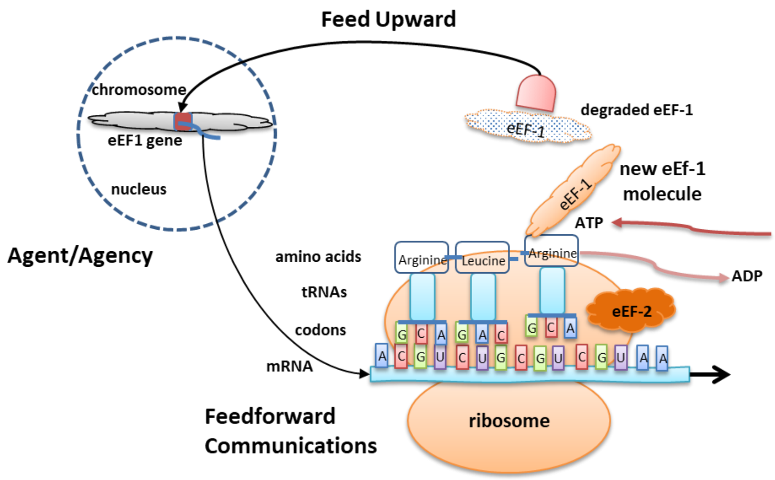

Fig. 12.5. A ribosome is a manufacturing plant to produce the proteins that can then be used for a wide array of purposes. Not shown is the input of energy from the conversion of ubiquitous ATP molecules into ADP and phosphates.

Distribution

Two large complex proteins, actin and myosin[31], function as actuators within the cell and in cell movement. They can be found in many instances of transporting materials, especially against gradients. They are ATP-dependent, working similarly to the ribosome in extracting the energy of ATP molecules which is then used to cause the molecules to contract or change conformation.

Consumption

In the context of metabolism, products that have been produced for use in the metabolic processes, macromolecules such as enzymes and the various organelle such as ribosomes tend to degrade at physiological temperatures and need continual replacement. The macromolecules, when they lose their functionality may be digested to produce some reusable metabolites and some by products are exported through the cell membrane as waste products.

Exporting Products and Wastes

All cells must excrete waste products directly into the environment. Under ideal conditions, these diffuse rapidly into what amounts to an infinite reservoir, becoming too diluted to harm the cell or other cells nearby. Cells exist in a fluid environment where currents and diffusion can be counted on to disperse waste products. But there are situations in which cells are confined to an approximately confined environment that does not allow the dispersion of wastes. For example, consider the fate of yeast cells in a wine fermentation process. The yeast cells take in sugar for

[31] See the Wikipedia articles: https://en.wikipedia.org/wiki/Actin#ATPase%E2%80%99s_catalytic_mechanism and https://en.wikipedia.org/wiki/Myosin for more background.

fuel and export alcohol (ethanol) molecules as waste products. There are actually two constraints put on the population of yeast cells. One is the availability of sugar, which is fixed and finite. The other is the toxicity of ethanol in concentration. A wine bottle or beer keg is a closed system with a finite capacity to disburse the toxin they produce. Eventually the yeast cells die of either lack of food, or toxicity of their own wastes. This condition is universal for all biological systems (all CASs) including all multicellular organisms such as *Homo sapiens*!

In multicellular organisms various cells have become specialists in that they produce export products that are of use to other cells in other tissues, either as primary resources or as signaling inputs. These cells turn out a volume of such products, which they export to the environment, but as specialists they often require specific input resources from other cells/tissues that they cannot manufacture themselves, which leads us back to resource importing functions and how metabolism is an on-going cyclical process. In a multicellular organism we find that the network of economic activities has now spanned multiple cell/tissue types that must cooperate in producing and exporting very specific resource products. The physiology of a multicellular organism is the next outer level of economics in which producers and consumers along with its own HCGS produces a coordinated CAS capable of sustaining itself for a time scale much longer than the time constants for activities at the subsystem level.

Physiology

The economic system of a multicellular organism is, essentially, a new level of organization beyond the metabolism of single cells. Such organisms are built from a set of tissues and organs that take on the role of specialists. These tissues and organs specialize in particular physiological functions that are, largely, extensions of metabolic functions at the cellular level. They can only work in the context of the whole organism but by cooperating and being coordinated by a supervisory agent they can contribute to the stability and persistence of the whole organism. All such tissues/cell types have a high degree of adaptability and are, thus, able to operate in a highly variable range of conditions within the whole organism. And, thus, the organism is able to operate in a highly variable range of conditions within its own environment.

Governance

The governance of a multicellular organism is now a matter of coordinating the activities of a huge number of interdependent cell types in a wide range of tissue types. Three main subsystems of the organisms are involved in this governance. These are the brain (in animals), the immune system, and the endocrine system. In plants the latter two are integrated as a system that acts to counter infestations by grazing insects and higher-order animals as well as disease microbes and fungi. We will focus on animal models (brains) since these are what leads to sentience and are most applicable to the human condition.

The brains of even the most primitive animals (e.g. worms) are primarily involved in sensing both internal and external stimuli and computing an appropriate response to the situation.

Brains generate behaviors that are, under the right circumstances, designed by evolution to allow the organism to survive the challenge and in so doing, procreate.

But, the brain is involved in more than just the overt behavior of the organism. By monitoring all of the internal states of the physiology, the brain acts as a primary coordinator of everything that goes on in the physiology of that organism.

In organisms higher than worms, the brain is responsible for monitoring many low-level physiological conditions (e.g. oxygen levels in the blood) and initiating responses to changes according to the dictates of the homeostatic requirements of the whole organism.

The physiology of multicellular organisms

Resource Extraction

Goods Production

Distribution

Consumption

Exporting Products and Wastes

Family Economics

Throughout the world humans have adopted a basic unit of organization that provides the basis for reproduction of the species – the family. The actual forms that families have taken can vary somewhat from society to society, but the standard model involves an adult male and an adult female who are, at least for some time, mated and responsible for the "manufacture" of more human biomass – children. Families may be extended, involving several generations of grandparents or closely related aunts, uncles, cousins, etc. There is no simple model of composition and in modern societies one even finds families based on homosexual partners who adopt children or have them via a surrogate. The only fundamental is that a society requires enough standard model families to assure replacement of those who die off.

Families do not exist in a vacuum of course. They aggregate in groups or societies, which will be explored below. But within the family, there is an economic system that constitutes the sub-processes found in the socio-economic supra-system. We can, thus, analyze a family as an intermediate unit between the simpler physiological/metabolic economies and the larger group economy. Here we outline a few considerations of how a family embodies the economy archetype.

Governance

Resource Extraction

Goods Production

Distribution

Consumption

Exporting Products and Wastes

Socio-economics

From sometime in the Mesolithic and certainly after humans adopted sedentary agricultural life styles, groups of families formed communities such as clans and tribes. Each of these occupied an amount of land that could support the whole group (this is explored more in Chapter 8).

Governance

Resource Extraction (senses)

Goods Production (percepts and concept production)

Distribution (axons)

Consumption (?)

Exporting Products and Wastes (motor commands)

The Economics of a CAS/CAES

We now examine how the generic economic subsystem situates within the context of a CAS/CAES system.

Generic Economic Archetype

Before we get into the decomposition of a ‘typical’ energy subsystem let us turn briefly to the perspective taken from a systemic biological analysis. Figure 12.6 depicts a much generalized model of a biological entity (a single individual). Shown in the figure, we have included strategic management. This is more representative of the situation for human beings who have the ability to do some strategic thinking.

Our contention is that this model depicts a basic metabolic process. Take out the strategic management process and you have a general model of all such systems, including the economic system of the HSS. Note the similarity between this model and that depicted in Figure 8.8. Here we are not showing replicated functions (work processes) but such functions are generally replicated in living systems. For example, one important work process in a living cell is the work of producing proteins done by the ribosomes. There are many ribosomes in a cell, each continually using messenger RNA (mRNA) archetypes to construct chains of amino acids into polypeptides and proteins that then become the work horses (like people supplying labor) for the metabolic activities in other parts of the cell.

A significant difference between organelle in a cell, and their contributions to metabolic activity, and entities in the economy is that they are not driven by competition. Their abundance and activities are driven strictly by demand. If the nucleus is pumping out more mRNA then the cell will turn its attention to producing more ribosomes so as to meet demand. When demand drops, some of the ribosomes will be reabsorbed to supply the raw components (e.g. ribonucleic acid molecules) for other or later use. In the economy as we understand it, driven by the idea of companies as producing profits for the owners, those companies will adapt or evolve to try and maintain their profit producing function. Competition, rather than cooperation, is the rule of the day. If demand for a product decreases in the economy, a company will attempt to adapt, perhaps by shifting its efforts to other, still-in-demand, products. Or it may try to evolve to become a different kind of company with a better position in a market. In the economy, the operating unit has become important to preserve in the sense that it is self-serving. This may be attributed to the idea that operating companies have become the main mechanism for providing support to employees through wages and profits to owners. Given the model of entities as serving the greater needs of the whole system, as organelle do, one might well ask if the economic entity model is appropriate for the working of the economy of the HSS.

Let us take a closer look at the various entity subsystems represented in the figure and begin to relate them to the economic system.

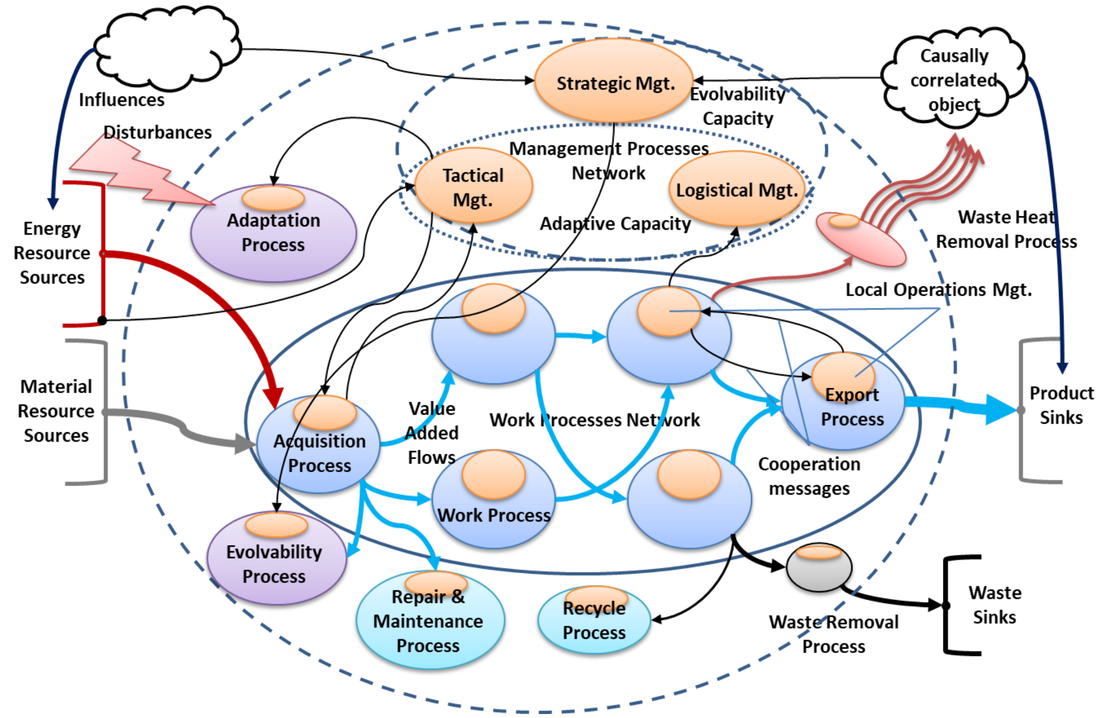

Fig. 12.6. A whole complex, adaptive and evolvable system is organized to transform resource inputs into products, expelling waste materials and heat. The system is sustainable against the vagaries of the environment by virtue of possessing both adaptive and evolvable processes (purple). Blue arrows represent value-added flows of materials transformed by work. Thin black arrows represent the flow of messages; only a small fraction of such flows are shown. The large, outer, dashed oval is the boundary of the whole system. General work processes are grouped in the center as a network of processes with value added moving from left to right. Governance processes (information and knowledge processes) are pink ovals. The whole system governance, coordination and strategic (if present) is grouped together in the smaller dashed oval. All of the other processes are auxiliary and are responsible to things like internal maintenance or recycling materials. See the text for the explanation of the "cloud" objects.

Primary Work Processes Network (blue ovals)

All processes do physical work on materials adding value to inputs for downstream work processes. In the figure we identify various work processes that have special relevance to the whole system. Special processes that interface with the environment sources and sinks are the acquisition (or import) and the export processes under coordination by the tactical management agent (see below). All other work processes provide successive transformations of materials that collectively produce the product(s) of the CAES. All processes produce some waste heat and materials. The work processes usually account for the bulk of material wastes. In general net flows go from the input streams (left side of figure) to output streams (right side of figure). Internal feedback loops may also exist (e.g. some material wastes may actually be recycled).

A typical work process in a living cell is the ribosome which assembles polypeptides and proteins from amino acids that are available due to the digestion of, for example, denatured proteins no longer able to do their own work. The ribosome is composed of ribonucleic acid (RNA) chains and some structural proteins. They receive instructions from the genes in the nucleus or in mitochondria (see below) in the form of a long messenger RNA chain that is used as an archetype for the construction of proteins, for example to be used as enzymes. The amino acids are attached to transfer RNAs that carry a specific three codon marker at one end that signifies the kind of amino acid (there are 20 amino acids but triplet codes of four nucleic acids gives a total of 64 possible codes, so many of the proteins have more than one code) being conveyed into the ribosome. The triplet codes match up to their counter parts in the mRNA strand and so the ribosome can bring in the right amino acid in the right sequence. And, through the work process new proteins are assembled for use in other parts of the cell's machinery.

There are a number of work processors in cells that conduct this kind of work.

Acquisition Processes

In the context of biological systems – eating breathing, etc.

Raw materials and energy have to be acquired through active processes such as extraction of metal ores or cutting timber. Material resources are valuable because of how they might be worked on to produce something useful such as timber being sawed to produce lumber of specified dimensions for building construction. Timber (trees) are, in principle, a renewable resource, meaning that new trees will grow to replace those extracted. But the rate of extraction cannot exceed the rate of renewal, otherwise the resource begins to act like a finite fixed one. Metal ores and fossil fuels, on the other hand, are finite and fixed resources that can get used up after extraction so that eventually that resource will run out of stock. While metals can potentially be recycled internally, this is not the case for energy which gets degraded to waste heat in doing the work. Once you burn the gasoline in your car, it is gone forever.

The value of these raw materials in or on the ground depends on the amount of work that has to be accomplished in retrieving them. Fossil fuels provide an example of how a commodity's value may be reduced. Acquisition processes such as well drilling, pumping, etc. will invariably target the easiest to obtain oil or gas. This is known as the "Best First" principle. It is simply the result of the business of oil companies that are driven by the profit motive. It gets progressively more expensive to drill and pump reserves that are deeper in the ground, or under the ocean. At the same time our civilization is absolutely dependent on fossil fuels to power industry and homes.

Export Processes

These are the processes that push waste materials and heat out into the Ecos environment. Or an export process for most CAESs that are subsystems of a larger supra-system might be to push products to "customers." At present we can find very little evidence that the HSS and its economy are producing anything of particular worth to the other subsystems in the Ecos. Nevertheless, the possibility for doing so exists. For example, the economy could do work to improve the biological support quality of soils, not just for farming but for natural ecosystems that our prior activities had degraded.

Management Processes Network (orange ovals)

The major management processes are grouped together in this network. These are the agent processes responsible for directed evolution (strategic), coordination with the entities in the environment (tactical), and coordination of the internal processes (work and auxiliary)[32]. Within all of the other processes we represent the local operational management that is in communications with each other as well as with the coordination management network. The figure only shows a few message pathways to avoid clutter. Shown are cooperation messages passing between a generic work process and the export work process (right side of figure). Tactical messages are shown between the tactical manager and the acquisition process (right side of figure) as well as from the tactical manager to the adaptive process (explained below). Finally, a message pathway is shown between the strategic management and the evolvability process (an auxiliary process).

The strategic management process is observing external entities (cloud shapes) that are not directly interacting with the system but are interacting and having influence on those entities that are (e.g. energy source and product sink). This is explained in Chapter 11 regarding the hierarchical cybernetics model.

Auxiliary Processes

These are support processes that provide services to the internal processes. Since other processes are subject to degradation or accidental structural damage a repair and maintenance process (which can repair itself!) operates on any process that incurs such damage. A waste removal management process ensures that material wastes do not clog any of the value-added channels. A similar process is needed to dispel waste heat through the system boundary. Since some materials that end up as waste might be recycled economically, some amount of recycling process is included.

The two processes that make the system adaptive and evolvable (aside from the management capabilities to make these decisions) are work processes in that they are responsible for the work accomplished in adapting or evolving a system.

Comparisons

The economy of the HSS is encapsulated within this model of a metabolic process of a living entity. But there are differences in the way we think of an economic system and the metabolic system. Therein lay the problems with our understanding of the former. What is shown

[32] Unfortunately, there is no good way to cover the subject of management without a full explication of the hierarchical cybernetic governance system model being used. That means we have to refer to Chapter 11 for a more complete handling of the model. Or we can refer to Mobus & Kalton (2015, Chapter 9). The reader is encouraged to take a pause here and refer to those chapters since we will be referencing concepts explicated there. This is the curse of systems science. Every concept depends on every other concept so we are constantly having to reference multiple chapters. Hopefully the reader will indulge us this quirk.

in Figure 8.9 is the layout of a *sustainable* CAES. We assert that the economic system within the HSS should be a sustainable CAES. But, we note that our common understanding of the economy from classical economic theory fails to recognize this and, as a result, is producing "predictions" that are wide of the mark. When we look closely at the biophysical aspects of the real economic system we will discover very different projections for the future of the HSS.

Consider a singular example of the discrepancy between the common understanding of economics and the systems perspective. In the former a "goal" of the system is to grow the production of wealth, and to do so exponentially. Growth of an assumed measure of production or income, the gross domestic product (GDP) is couched in terms of a percentage increase per annum. Like compound interest this kind of growth means the stock of wealth is consistently getting larger with each passing year. Classical economists argue that this is a necessary condition for the maintenance of the HSS. Yet, from the physics and biology of reality we know that infinite exponential growth is impossible in a finite world. Rather, a CAES grows to a limit imposed by the constraints of its supra-system and then operates in a more-or-less steady-state dynamic from that time on. The question raised by a systems perspective of economics is: what is the limit of the size of the HSS, the limits of the use of finite resources, and the limits of dumping wastes into that supra-system that will allow the HSS to function as a sustainable subsystem of the Ecos? Classical economics not only doesn't ask those questions, it doesn't even recognize the need to ask them.

The assumed need for growth begs another question: Why? Why would the economy need to grow exponentially forever? Part of the answer comes from the biological mandate and the removal of some constraints on population, namely death rates keeping the stock of people within a carrying capacity range, as with other biological systems. Technology, especially the technology of agriculture (and especially that of the "Green Revolution"[33]) along with better ways to keep ourselves safe from predation and treat the causes of diseases, has led to a seeming removal of constraints such that the population stock has grown from an estimated size of around 5 million at the dawn of the First Agricultural Revolution (also called the Neolithic Revolution)[34] to around 1 billion in 1800 to 7.5 billion today[35]. Estimates on what the carrying capacity of the planet for human beings range from several million (as in the Neolithic) to no more than 2 billion (meaning that our current population is nearly four times too large). It is not really clear that the

[33] See the Wikipedia article: https://en.wikipedia.org/wiki/Green_Revolution for background. Accessed 4/4/2018.

[34] See the Wikipedia article: https://en.wikipedia.org/wiki/Neolithic_Revolution for background. Accessed 4/3/2020. The Neolithic Revolution involved more than just the discovery of agriculture; it involved nearly every aspect of culture in general. There have been two additional agricultural revolutions in the west. The second or British Agricultural Revolution (see: https://en.wikipedia.org/wiki/British_Agricultural_Revolution for background: accessed 4/3/2020) and the third was the Green Revolution noted in the text.

[35] See the Wikipedia article: https://en.wikipedia.org/wiki/Demographic_history for background and especially see the graph of the rate of growth over the period from 10,000 years ago to today. You will see that growth rates accelerated greatly after the Industrial Revolution and even more so after the Green Revolution. Accessed 4/4/2018.

concept of carrying capacity, developed to measure populations of minimally adaptive creatures, is all that relevant to human populations. But one thing is clear. All of those people have to eat, they have to have shelter, and they have to have meaningful employment – a way to make a living. The demand for resources applied to producing food and shelters is directly related to the size of the population.

So, one answer to the question of why the economy has to grow is that it is basically the source of jobs in the modern world and each year more people are in need of jobs. There is another, more modern impetus for growth that is much more complicated. This will be discussed below as we look at the modern energy sector dynamics and how it affects the economy.

But it isn't that simple. The biological mandate doesn't just drive reproduction. It also drives the psychological propensity to want to maximize income when times are good as a hedge against when times are hard. Animals store fat when food is plentiful so they have a reserve of energy when it isn't. That is a basic biological urge. But just as technology threw off the shackles of population growth, it also contributed to eliminating or at least reducing the bad times on net. Thus the agglomeration of wealth during plenty was less and less offset by times when that wealth had to be consumed for survival. At some point in the history of modern cultures the agglomeration of wealth for its own sake coupled with increasing kinds and numbers of material goods (especially stylish goods!) became recognized as the "Profit Motive." The idea that one should constantly and forever maximize any kind of gain from economic activities such as trade came to be the dominant theme in those activities.

Living systems as CAESs only grow while maturing. Except for cancers they do not grow beyond a limit that has been established by evolutionary pressures. This doesn't mean that the biological mandate goes away. What it means is that life has found mechanism for internal regulation of growth. Tissues need to be repaired, of course. Reproduction itself is a kind of growth – but again, in nature there are external constraints that keep most biological systems in check once a population reaches its carrying capacity. Within our bodies, cells are signaled to reproduce by elaborate systems that monitor the state of maturity of the whole organism, or the states of its tissues with respect to normal functions. When growth needs to be curbed, those signals, like growth factors, are turned off and the cells obey.

Nor do cells seek to continue ingesting food (e.g. glucose) beyond their metabolic needs. It is true that specialized cells store fat but not for themselves as much as for the whole body, again as a means to survive hard times for all. Once more, there are internal signals and controls that keep living systems in balance with its environment. But the HSS has not evolved to this stage. What drives modern commerce is profits. This will be demonstrated to be one of the prime reasons for major dysfunctions in economic systems.

Markets in Cells and Economies

Demand Driven Production vs. Speculation

The counterpart to a free market capitalist economy is not a planned economy as tried under 20th century communism/socialism. Rather, it is a demand-driven non-profit economy in which the market acts as a local optimization mechanism and work processes operate on an as-needed basis. This is the case for living systems in which any excess production is either stored as a buffer against bad times, or is degraded and the components are recycled to where they might be needed for actually demanded production.

In the human economy a different mechanism underlies how a market operates. Producers are dependent on income from the sale of their products and that income is the basis of their livelihoods. They cannot afford to be unproductive just because there is a lull in the demand (though of course, they may end up being so once their product inventory fills up). Laying off workers is a poor option but necessary under these circumstances. In the worst case a firm goes out of business for lack of sales. Living systems work processes operate under a different paradigm. Processes are supported at a minimal subsistence even when demand for their products is low. Muscles may atrophy but they never actually go away. As soon as demand picks up, these processes rebuild capacity in proportion to the demand (both in terms of magnitude and longevity).

Another complication in the human market place is the requirement for firms to be profitable. Not only must they use their sales amounts as a signal signifying demand, they must include some kind of price premium that goes above and beyond covering their costs of production. This is the capitalist free market where competition to supply demand leads to more than just redundancy. It can lead to wastes. It is also the force underlying the impetus to use additional communications channels – advertising – to boost demand.

The Role of Energy

In any economy the general pattern is for the system to import relatively high entropy (low organization) materials along with low entropy (high potential) energy along with messages from sources and sinks that inform the system of the state of the environment. The energy is consumed in the process of doing transformative work on the materials, reducing their entropy by increasing their organization. Iron ore, coke, and other raw materials are mined and eventually out comes an automobile. Amino acids or low weight polypeptides are ingested by a bacterium and converted to functioning proteins in the cell. In the process the energy is degraded (becomes more entropic) in the form of unusable waste heat that is carried off to the environment.

The second law of thermodynamics is not violated in any of these processes because the waste heat contributes to the rise in entropy of the larger supra-system (or the Universe as a whole).

Looked at in another way, the production of wealth (cars and proteins) requires the expenditure of energy on work processes throughout the CAS/CAES. The imported energy must be at the right potential and of the right form (high temperature heat versus electricity) for specific kinds of work processes (internal combustion engine versus electric motor).

The central problem for an economy is how to channel and direct the right amount of energy to the right points of use at the right times. For example, the human economy electrical distribution system uses wires from the power source to the homes and businesses that use electricity. Power companies have to maintain peak capacity generation in order to handle peak loads that can occur at the points of use, sometimes unpredictably.

As an economy operates over time decisions need to be made about the distribution of the appropriate power capacities. Work processes (points of use) operate at rates that are often dictated by demand for their products or services. That, in turn, translates into demand for power to drive those processes (e.g. surges and wanes). The demand put on the work process needs to be forwarded and translated into demand on the energy flows to support the changes in work rates. That means an information system is needed to communicate changes to the power producers.

In metabolism the main product of the citric acid cycle (also known as the Krebs cycle) is the molecule adenosine tri-phosphate (ATP) which can be thought of as portable batteries that distribute by diffusion along concentration gradients to the various other work processes throughout the rest of the cell such as the ribosome discussed above[36]. The cycle takes place largely within the membrane bound mitochondria[37] – the power plant for cells[38]. At the point of use the ATP molecule gives up a phosphate becoming adenosine di-phosphate (ADP) and supplying 2 hydrogen ions per molecule. The local concentration of ATP declines while the concentration of ADP increases. This is what drives the gradient diffusion of these molecules cycling between the point of production and the point of use. The electron transported are the energy carriers in setting up a current that is coupled to the work process. ADP is then recycled back to the mitochondria where a phosphate is added by pumping energy into the reaction – the same energy that is removed later at another point of use.

Depending on how quickly the cell types must accomplish work there could be hundreds to thousands of mitochondria throughout the cell. The mitochondria are stimulated primarily by the concentration of ADP in their vicinity and the availability of sugar molecules. So the demand-

[36] See the Wikipedia article: https://en.wikipedia.org/wiki/Adenosine_triphosphate for details. Accessed 5/21/2018.

[37] See the Wikipedia article: https://en.wikipedia.org/wiki/Citric_acid_cycle for background. Accessed 5/21/2018.

[38] Green plant cells also have chloroplasts which capture sunlight converting water and carbon dioxide into sugars, which are then the main inputs to the mitochondria. Animals have to eat plants and other animals, digesting their more complex molecules down to sugars for input to their mitochondria.

driving work process will produce more ADP the more work it does, and this signals the mitochondria in the neighborhood to produce more ATP. The ATP/ADP currents constitute a signaling system, a communications process.

Energy flows are handled by energy-carrying channels and supply lines such as gas pipes and electricity wires. The flows are controlled by information influencing actuators, amplifiers, restrictors and other components. The information is generated by various agents that receive information, 12.g. of demand for an increase in a flow, from recipient agents. In the case of the ATP/ADP coupled production/use the mechanism is simple concentration gradients and diffusion. However there are more complex demand-driven examples of active transport of macromolecules within the cytoplasm instigated by a counter transport of a molecular signal that activates the one conveying the macromolecule. In the body of a multicellular organism the examples of informational signals generated by decision agents that then cause recipient agents to apply control activation to material or energy flows are abundant. For example the increased activities of neurons in a specific region of the brain supplies a cascade of molecular signals to the local blood supply which responds by increasing the flow of oxygen and glucose to that region to support its increased activity.

In the human economy we also find a signaling system needed to guide the flow of energies to appropriate work processes. And like the ATP/ADP cycle (which is its own signal), it is driven by supply and demand. But an external messaging processes is used. This is what we call money. Money in some nominal form is used to make purchases, which is actually a signal to the producer that their product or service is in demand. This kind of signaling and response is ubiquitous but not universal. There are several alternative models of economies being more direct and based on different premises other than, 12.g. profit making. Sharing or gift economies are also able to manage the distribution of goods and services (and energy) without the intermediary role of money. However a monetary signaling economy seems to be by far the most prevalent so we will primarily focus on those (e.g. in Chapter 8).

Competition

Cooperation

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