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From Energy Flows to Purpose and Back

Russ Abbott

Department of Computer Science, California State University, Los Angeles
russ.abbott@gmail.com

Abstract

In earlier papers (e.g., Abbott 2010) I established a taxonomy of entities one of whose categories was the dynamic entities—those that depend on a continual flow of energy to persist. This paper explores some of the consequences of the existence of dynamic entities, including (a) how energy flows establish mechanisms within entities, (b) the functional consequences of those mechanisms, (c) how functions that enhance the likelihood that the entity will survive and reproduce appear to be purposes, and (d) how functionalities that serve the needs of one entity can become, in effect, specialized energy flows that can serve the needs of others.

Introduction

In (Abbott 2010) I grouped naturally occurring entities into two categories. Static entities are those that exist in an energy well. They have less mass than their components taken separately. Examples include atoms, certain molecules, and non-organic everyday objects such as a baseball, a table, a rock, a pencil, a fork, a car, a computer, etc. These are entities that persist in the world because energy is required to pull them apart. The formation of a water molecule by combining Hydrogen and Oxygen releases energy—and hence mass—leaving the molecule with less mass than their components taken separately. To pull the components of a water molecule apart requires that the released energy be replaced.[1]

In contrast, dynamic entities have more mass than their components taken separately and require a continual flow of energy to persist. Prototypical entities in this class are biological organisms. The additional mass in these objects is the energy of ongoing activities. These entities are in continual internal motion and require a source of energy to keep those activities going. If those activities—many of which are self-maintenance—were to cease, the entities would decompose.

Energy flows

Dynamic entities exist on earth because we are blessed with a continual inflow of energy from the sun. Global warming notwithstanding, earth is relatively stable with respect to its overall surface temperature because the amount of energy received by the earth is approximately the same as the amount of energy radiated away. Ignoring the energy that is simply reflected back, the relevant energy arrives as high frequency photons and leaves as low frequency radiated heat. What is of interest is what happens to that energy as it degrades from high frequency usable energy to low frequency non-usable "waste" energy.

Much of the energy that is not radiated back is simply absorbed by the earth's physical substance. The result is the heating of that substance, which then re-radiates the energy back to space as heat. This energy is also the source of our weather. That degradation pathway is itself worth examination.

Given this perspective, the earth's weather system as whole may be understood as a large dynamic entity. Earlier, I had noted that hurricanes are dynamic entities. Now it is clear that they are dynamic entities that exist within the larger dynamic entity of the earth's weather system. We will return to the weather system as a dynamic entity—and as a source of energy for other entities—but for now, let's focus on biological entities.

Nearly all biological entities depend ultimately on energy captured by photosynthesis.[2] Photosynthesis stores some of the energy from high frequency photons in

[1] Any stable molecule has the property that energy is required to pull it apart; otherwise it would decompose spontaneously. But some molecules, for example, gasoline, carbohydrates, H_2, when supplied with enough energy to pull them apart and when the components are allowed to combine with other elements—usually oxygen—release more energy than was supplied. The products of these reactions are even more stable than the starting elements.

[2] Some bacteria are capable of releasing energy from sulfur or sulfur compounds and do not rely on energy from the sun.

chemical bonds. Molecules containing that energy may then be moved around throughout an organism and used as needed.

Each time energy is used, a bit of it is lost to entropy. Eventually it is all degraded. But what is interesting is what the energy is used to do on its way to uselessness.

In this paper I will develop a picture of a system through which energy flows and explore some of the consequences.

Mechanism

There are an enormous number of biological entities. And there are similarly an enormous number of ways in biological entities use the energy they consume. Since it is not possible to survey these possible uses what can we say?

We can say that as energy moves through (degrades through) a biological entity, it results in some chemical and physical activities. Let's refer to those activities as mechanisms. So energy powers mechanisms within biological organisms. But what is a mechanism?

The term mechanism is surprisingly difficult to define. I would define a mechanism as a collection of elements whose interactions are well understood and whose workings can be predicted in terms of that understanding. The sorts of mechanisms I have in mind are any of the standard models of deterministic computation or other intuitively mechanistic constructions.[3]

In addition, a mechanism operates only when energy is supplied. If that were not the case, it's difficult to understand how the mechanism is constructed. If the mechanism does work—in the physics sense—it must use energy. If it doesn't do work, what does it do? What does it mean to say that the mechanism operates but does no work? No mechanism is perfectly efficient. Even a mechanism with no net work loses energy through the inevitable increase in entropy.

So a dynamic entity consists of at least one or more mechanisms. An important property of a mechanism is that it characterizes the operation of an entity. It has nothing directly to do with how the entity interacts with or functions in the world. A mechanism is blind to its functionality. A mechanism simply does whatever it does in a straight-forward mechanical way.

Intuition becomes cloudy, however, when one considers mechanisms that respond to external signals. A simple (and by now very well worn) example is a heater with a thermostatic controller. Such a mechanism produces heat until its temperature sensor reaches a set level—at which point its heating process ceases—until the sensor cools off.

I resisted the temptation to write that the heater continues to heat until it senses that the temperature of the surrounding air has reached a certain level, at which point it *turns off* the heating element. I resisted that temptation because the sensor doesn't actively sense the air temperature in the common understanding of that term. It doesn't put its finger in the air and say, "Feels like about 72 degrees Fahrenheit." The sensor element—typically a bi-metallic strip—is such that it changes shape as the temperature changes. Like all other aspects of mechanisms, that change is blind. It happens just because of the physics of the materials.

Similarly, the sensor doesn't *actively turn off* the heating element in the common understanding of that term. It's not as if it says to itself, "Now that the room is a comfortable temperature, I'll turn off the heating element." It's much more direct and mechanical than that. The very change in the sensor shape breaks a circuit that is required to be unbroken for the heating element to be on—at which point the heating element loses power and stops heating.

The only reason the sensor can be said to perform functions such as "sensing the air" and "turning off the heating element" is that the mechanisms we built into it *result* in those functions being performed. It is not the case that the sensor performs its functions because it has some sort of built-in capability to perform certain functions and that in building the heater we have somehow drawn that capability out of it.

The same is true of all mechanisms, including software. Software is as blind as any other mechanism. A computer controlled by software just goes step-by-step through the instructions written by the programmer: move this value here; add this to that; etc. Those instructions have no sense of the function that the computer is intended to perform. The computer simply does whatever the programmer wrote, no more and no less. There is no implicit functionality waiting to be drawn out of a computer. Perhaps the most difficult hurdle facing beginning programming students is to come to that realization.

Michelangelo is said to have described his work by saying "I saw the angel in the marble and carved until I set him free." Poetic as that may be, there is no sensor functionality waiting to be set free in sensor components, and there is no software functionality waiting to be set free in computer programs. Mechanisms are completely lacking in functional intent—even those that interact with things outside themselves.

But …

Function

Putting materials together in certain ways often does produce a certain functionality. That's why software developers write the software they do. That's why engineers design thermostatically controlled heaters as they

[3] This definition intentionally ignores issues of non-determinacy and chaos.

do. Software developers and engineers design mechanisms so that the activities that (happen to) occur result in the functionalities we want.

Not all functionalities are the product of design; some are serendipitous. Percy Spencer, an engineer at the Raytheon Corporation, was at first surprised to find that the microwave radiation produced by a radar tube could be used for heating. But once he noticed it he was able to use that fact to design the microwave oven.[4]

A similar thing happens in evolution. Mechanisms are created randomly. Some of those mechanisms result in functionalities, and some of those functionalities improve the chances for the entities that possess them to survive and/or reproduce. Those mechanisms are retained in the genome. Often those mechanisms are refined and improved through additional random variation—where improvement means that the revised mechanism performs the function better than the original. Presumably the eye evolved from a light sensitive spot to its current sophistication by such incremental improvement. And sometimes revised designs lead to new functionality. Here are two examples.

When in a medium with a nutrient gradient the bacterium E. coli tends to move up the nutrient gradient towards the greater concentration of the nutrient. Harold (2001) explains how.

> Cells of *E. coli* are propelled by their flagella. … Despite their appearance and name … flagella do not lash; they rotate quite rigidly, not unlike a ship's propeller. … A cell … can rotate [its] flagellum either clockwise or counter-clockwise. … When the flagella turn counter-clockwise [as seen from behind] … the cell [moves] forward in a smooth straight run. … [When] the sense of the rotation is … reversed, the flagellar bundle flies apart and the cell tumbles [randomly]. [Thus *E. coli*] movements consist of short straight runs … punctuated by briefer episodes of random tumbling: each tumble reorients the cell and sets it off in a new direction.

E. coli also includes an internal mechanism that senses whether the concentration of nutrient in its surroundings is greater or less than it was a few milliseconds previously. That sensor is hooked up to the flagella in such a way that if the current concentration is greater than it had been, the straight runs are extended; if the concentration is smaller the runs are cut short. So here's the *mechanism*:

(a) Rotating flagella turn either clockwise or counter-clockwise. Clockwise rotation results in random tumbling; counter-clockwise rotation results in smooth forward motion.
(b) A sensor measures the concentration of a nutrient and compares it to the concentration a few milliseconds earlier.
(c) The sensor and the rotation mechanism are connected in such a way that counter-clockwise (forward-propelling) rotation continues for a longer period if the nutrient concentration is increasing and for a shorter period if the concentration is decreasing.

The net effect of that mechanism is the function that E. coli moves in the direction of the higher concentration of the nutrient.

Another example illustrates how a mechanism can even harness external resources to create a functionality. *D. dendriticum*, a liver lancet fluke, spends most of its adult life, including mating, in the liver of grazing animals. After flukes mate, the host excretes the fluke eggs. The eggs hatch, and after a stopover in a snail the young flukes wind up in the bodies of ants. Some of the young flukes make their way to the ants' nerve cells. Their presence there (somehow) leads the ants to climb to the tops of blades of grass and wait—as if for a bus—until the grass is eaten by a grazing animal—which returns the flukes to their site of reproduction[5].

One might imagine the flukes sitting in an ant "control room" directing the ant to climb the grass and to sacrifice itself for the sake of the fluke. Of course it doesn't happen that way. The ant climbs the grass because of how the fluke (just) happens to interact with the ant's nervous system. What's amazing is not how adept the fluke is at controlling the ant. What's amazing is that evolution managed to create a mechanism as complex as this. As in the case of *E. coli* this example illustrates how a mechanism within an organism (the fluke) results in a functionality that changes the relationship of the entity with its environment.

Purpose

What about purpose? When a functionality produces a benefit for the entity that exercises it—where benefit is defined as a change that makes it more likely that the possessor of the mechanism will persist in the world or reproduce—we often attribute intentionality to that organism. Why did the eagle swoop down on the rabbit? So that it could feed itself. The ability to swoop down on

[4] This is the story according to the Lemelson-MIT Program. http://web.mit.edu/invent/iow/spencer.html.

> [While] touring one of his laboratories [Percy Spencer] stopped momentarily in front of a magnetron, the power tube that drives a radar set. Feeling a sudden and strange sensation, Spencer noticed that the chocolate bar in his pocket had begun to melt. Spencer … did what any good inventor would—he went for some [unpopped] popcorn. … Holding the bag of corn next to the magnetron, Spencer watched as the kernels exploded into puffy white morsels.
>
> From this simple experiment, Spencer and Raytheon developed the microwave oven.

[5] See the University of Alberta Parasites Lab http://www2.biology.ualberta.ca/parasites/ParPub/text/index/plagi02i htm.

its prey is a function. The "purpose" of the function is to allow the eagle to eat and survive.

The benefit of the *E. coli* function that propels *E. coli* up a nutrient gradient is that the bacterium will be in position to make use of another bit of functionality, namely its ability to acquire energy from an external source. The benefit of the *D. dendriticum* function that leads its ant host to climb to the top of a blade of grass and wait there until eaten by a grazing animal is that the fluke is returned to a site where it can reproduce.

In both cases one might imagine the organisms that possess these functions to be exercising them purposefully—with the intent to realize the available benefit. But functions don't *have* purposes (the purpose is not built into the function) any more than mechanisms *have* functions (the function is not built into the mechanism). When a mechanism *results in* a function that *produces* a benefit, we find it convenient to think of the function—and hence the mechanism—as having a purpose, namely to provide a means to realize the *benefit*.[6]

Energy flows again

The preceding examples illustrate how functionality is always the result of harnessing an energy flow—even if the energy flow is outside the entity within which the mechanism operates. In the case of *E coli*, the energy flow harnessed was internal. Energy to turn the flagella and to sense and control their spin was supplied by the bacterium.

In the case of the liver fluke the functionality depends to a great extent on actions taken by elements external to the organism. Although the liver fluke may have had to expend some energy to move through the ant as it did, the energy flow harnessed was mainly that of the host ant (when it climbs to the top of the blade of grass) and the grazing animal (when it eats the grass and swallows the fluke). Of course even the internal energy expended by the liver fluke was supplied by the ant in the form of nutrients. The liver fluke is a parasite after all.

An ecology of functionalities

We started by noting that dynamic entities depend almost entirely on the energy flow from the sun. For the most part that energy is captured by photosynthesis and stored in the chemical bonds of carbohydrates. Animals eat plants, and animals eat animals. Food chains are built on that photosynthetic process. That's the story as we generally imagine it.

But the story is often far more complex than that. Parasites use energy that they extract from their host. But even more important, organisms depend on energy flows in forms other than food. As the liver fluke illustrates, it depends on the energy flow of the ant as a physical platform, which it harnesses and channels to place it in a position where it can be delivered to its next host. It also depends on the act of the grazing animal to ingest it. Without either of these the liver fluke's life cycle could not be completed.

There are of course a great many examples of organisms that depend on services provided by other organisms. These may be exploitative as in the liver fluke example, or they may consist of mutually beneficial services—as in the case of mutualism and symbiosis. A standard example consists of plants and their pollinators, such as bees. The bees depend on the plants for nutrition; the plants depend on the bees to transports pollen from one to another. In other words, the plants depend on an energy flow characterized by the motion of bees as part of their survival strategy. In all such cases, one organism depends on an energy flow in a specialized form made available by another organism.

In most of these cases, the relationship developed because the functionality that one organisms brought to the world could be used advantageously by another. To take the pollinator example again. Bees presumably were able to fly from plant to plant independently of the fact that doing so could be used by the plant to spread its pollen. Once that "service" became available, plants were able to take advantage of it.

In our human society we have extended this sense of an ecology of functionalities many-fold. Most of our economic activities depend on the services provided by other. Apple famously orchestrates the manufacture of its products by companies around the globe.

But we have taken it one step further. Almost all economic activity depends on the demand for services. People sell their services, either as a job or by contract. Businesses sell services and products. Some products are made; some are traded. But for the most part we now depend on selling a product or a service to survive. We now learn to provide services so that other entities will pay us to perform those services. It is no longer the case that a service provided a function for the entity that performed it. I can think of only a few "occupations" to which this doesn't apply.

- Farming—or more generally hunting and gathering. But that isn't an option for most people.
- Gambling and day trading (and arbitraging). In both of those occupations one extracts money from ones environment more or less directly.
- Thievery and its nastier cousin extortion. Again, one extracts resources from the environment directly.
- Living on welfare.

[6] Of course human beings (often) have more foresight than nature. We create mechanisms (tax codes, for example) that result in functions (tax deductions) that provide benefits (more money) to the people who lobbied for the creation of those mechanism. It makes sense in cases like that to think in terms of intent and purpose.

- Lending money—or more generally selling the use of something for which there is a reliable demand such as renting a house.
- Collecting empty bottles and cans and turning them in for the refund.
- The latter suggests a more general category: providing something for which there is a guaranteed market and no competition for selling. But I can't think of many examples other than refundable cans and bottles.

In all of these cases, one extracts energy—or money, a proxy for energy—from the environment. The function one performs has a direct value.

Conclusions

Energy flows are fundamental to an ecology of dynamic entities. In the simple cases, entities must acquire energy from the environment in order to support their internal activities. But internal activities often produce functionalities. When those functionalities produce benefits, their use can appear to be purposeful. More interestingly, some functionalities can be used by other entities for their own benefit. Such relationships can be mutualistic or parasitic. Human societies have developed to the point that almost all functionalities are now performed not for the benefit of the performer but for the benefit of another party who is willing to pay for them. When demand for our functionalities declines, most people no longer have a way of providing for ourselves directly. That's because there are very few ways available in a modern society to provide for oneself directly.

References

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