

FIGURE 2.1: Three expressions of the homunculus concept. *Left*: an image from a seventeenth-century woodcut exemplifying the belief that the head of a sperm contained a preformed fetus. *Middle*: the presence of what might be described as a “plantunculus” in a bean seed. *Right*: a fanciful depiction of a homunculus constituting the functions of a person’s mind and body. Drawings from Nicolaas Hartsoeker’s *Essai de dioptrique*, Paris, 1694 (left); the author (center); cover illustration from *Allers Familj-Journal*, c. 1927 (right).

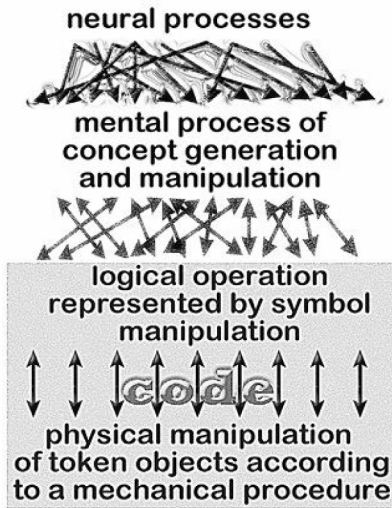


FIGURE 3.1: The relationship of computational logic to cognition. Computation is an idealization made possible when certain forms of inference can be represented by a systematic set of operations for writing, arranging, replacing, and erasing a set of physical markers (e.g., alphanumeric characters) because it is then possible to arrange a specific set of mechanical manipulations (e.g., patterns of moving beads on an abacus or of electrical potentials within a computer circuit) that can substitute for this symbol manipulation. It is an idealization because there is no such simple code-like mapping between typographical symbolic operations and thought processes, or between mental concepts and neurological events.

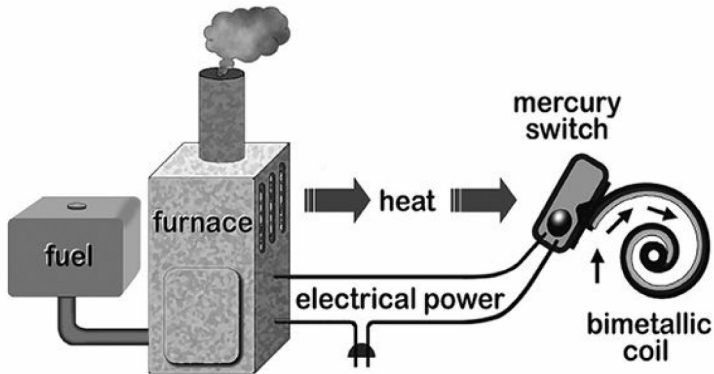


FIGURE 4.1: A diagram of a classic thermostat circuit that uses a bimetal coil and a mercury switch to turn a furnace for heating a room on and off and to maintain it at a constant temperature. Although changes of different sorts propagate around this causal circle, the circular iterations of these influences compound with themselves again and again incessantly. This causal analogue to self-reference is what is responsible for the deviation-reduction dynamics of the whole. Reversing the orientation of the mercury switch would alter the circuit from deviation reduction (negative feedback) to deviation amplification (positive feedback).

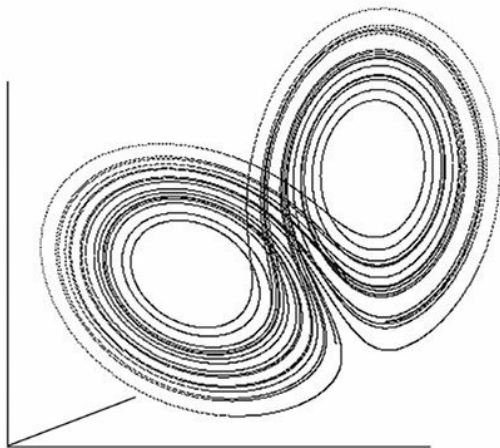


FIGURE 5.1: A plot of the Lorenz attractor produced by computing the values in three dimensions of the progressively iterated solutions of an equation that Edward Lorenz studied as a way of describing simple meteorological processes. Values from each prior solution are fed back into the equation to compute the next point on a continuous trajectory. By computing vast numbers of results a continuous curve is produced which, although it never exactly repeats the same values, tends to produce values that remain within a definite domain and trace out a sort of twisted butterfly pattern. This most probable region within which the solutions to the equation tend to lie has come to be called an attractor.

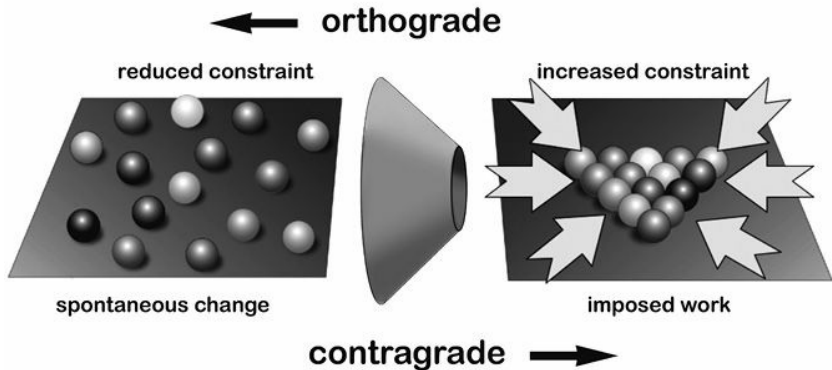


FIGURE 7.1: A cartoon characterization of the asymmetry implicit in thermodynamic change from a constrained (“ordered”) state to a less constrained (“disordered”) state, which tends to occur spontaneously (an orthograde process), contrasted with the reversed direction of change, which does not tend to occur spontaneously (a contragrade process), and so only tends to occur in response to the imposition of highly constrained external work (arrows in the image on the right).

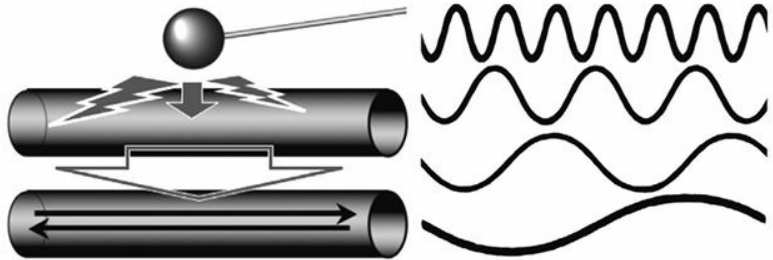


FIGURE 8.1: Resonance: a simple mechanical morphodynamic process. A regular structure that is capable of vibrating (a tubular bell: *left*) will tend to transform irregular vibrations imposed from without (depicted as a mallet striking it: *top left*) into a spectrum of vibrations (*right*) that are simple multiples of a frequency determined by the rate at which vibrational energy is transformed back and forth from one end to the other (*bottom left*). This occurs because as vibrational energy from varying frequencies “rebounds” from one end to the other, it continually interacts with other vibrations of differing frequencies. These reinforce each other if they are in phase and cancel each other if they are out of phase. Over many thousands of iterations of these vibrational interactions, it is far more likely for random interactions to be out of phase. So, as the energy is slowly dissipated, these recurring interactions will tend to favor a global vibrational pattern, where most of the energy is expressed in vibrations that coincide with even multiples of the time it takes the energy to propagate from one end to the other. This is well exemplified in a flute, where air is blown across the mouthpiece, disturbing the local internal air pressure, and this imbalance is transformed into a regularly vibrating column of air that in turn affects the flow of air across the mouthpiece. Image produced by António Miguel de Campos.

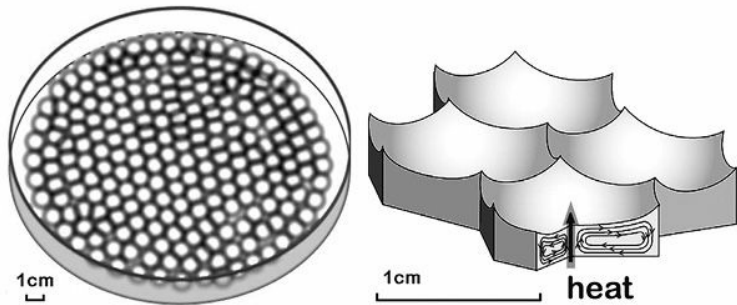


FIGURE 8.4: One of the most commonly cited forms of morphodynamic processes involves the formation of hexagonally regular convection columns called Bénard cells in shallow, evenly heated liquid. They form in liquid that is heated to a point where simple conduction of heat is insufficient to keep the liquid from accumulating more heat than it can dissipate. This creates instabilities due to density differences, and induces vertical currents due to weight differences. The heat dissipation rate increases via convection, which transfers the heat faster than mere passive conduction. The geometric regularity of these currents is not imposed extrinsically, but by the intrinsic constraints of conflicting rising and falling currents slowing the rate. These rate differentials cause contrary currents to regularly segregate and minimize this interference. Hexagonal symmetry reflects the maximum close packing of similar-size columns of moving liquid.

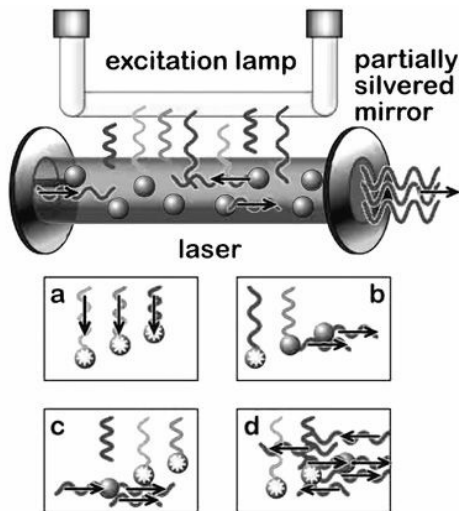


FIGURE 8.6: Laser light is also generated by a morphodynamic process that is roughly analogous to resonance. It is generated when broad-spectrum (white) light energy is absorbed by atoms (*a*), making them slightly unstable. This energy is re-emitted at a specific wavelength, corresponding to the energy of this discrete quantum level (*b*). Re-emission is preferentially stimulated if an unstable atom interacts with light of the same wavelength (*c* and *d*). The critical effect is that the emitted light is emitted with the same phase and wavelength as the incident light. If this emitted light is caused to recycle again and again through the laser material by partially silvered mirrors, this recursive process progressively amplifies the alignment of phase and wavelength of the light being emitted.

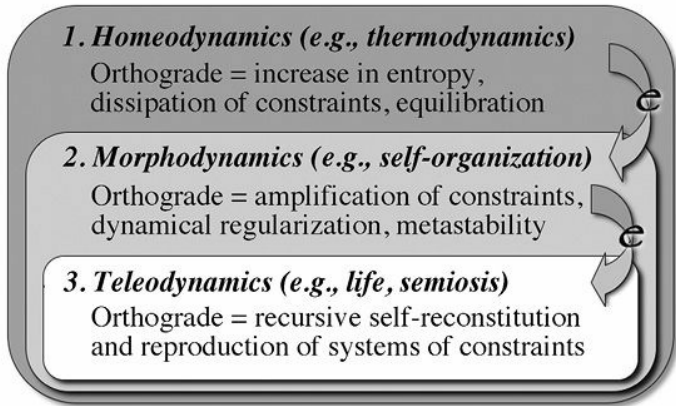


FIGURE 9.1: The nested hierarchy of the three emergent levels of dynamics; their typical exemplars; and their emergence (*e*) from subvenient dynamical processes.

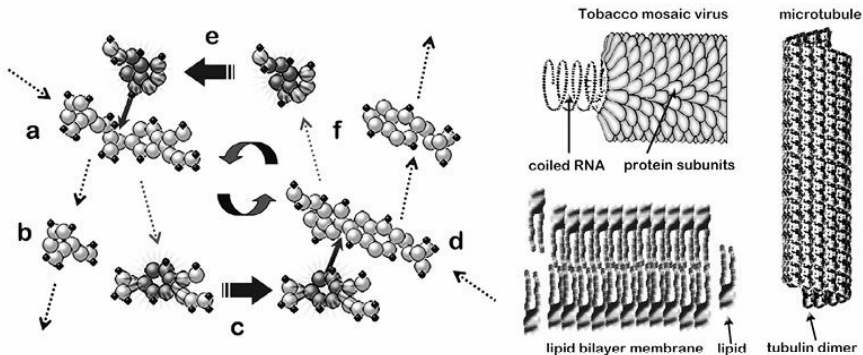


FIGURE 10.1: Two self-organizing molecular processes common to all life: autocatalysis and self-assembly. *Left:* in autocatalysis, one molecule catalyzes a reaction that produces a second catalyst as a byproduct, which in turn catalyzes the first. In this depiction, energy is released by the breaking of bonds of split substrate molecules and causes the process to be self-sustaining so long as substrate molecules are present. *Right:* three different self-assembling molecular process are depicted: self-assembly of the protein and RNA components of a virus; self-assembly of a lipid bilayer due to hydrophobic and hydrophilic affinities of these molecules' polar structure (hydrophilic “tails” are forced together); and self-assembly of tubulin molecules into a microtubule, one of the major components forming the flagella that propel bacteria and other mobile cells. Details of each of these processes are described in the text.

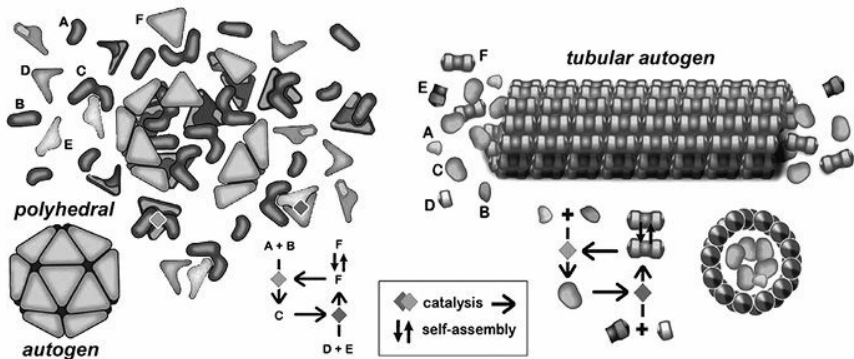


FIGURE 10.2: Two forms of simple autogenic molecular processes. *Left*: the formation of polyhedral capsules which contain catalysts that reciprocally catalyze the synthesis of each other and also produce molecules that tend to spontaneously self-assemble into these polyhedral capsules thereby likely to enclose the catalysts that generate them. *Right*: the formation of a tubular form of encapsulation, which although not fully closed will tend to restrict movement of contained catalysts along its length, but will tend to be increasingly susceptible to partial breakage and release of reciprocal catalysts as it grows longer. Both will tend to re-form or replicate additional copies if disrupted in the presence of appropriate catalytic substrates.

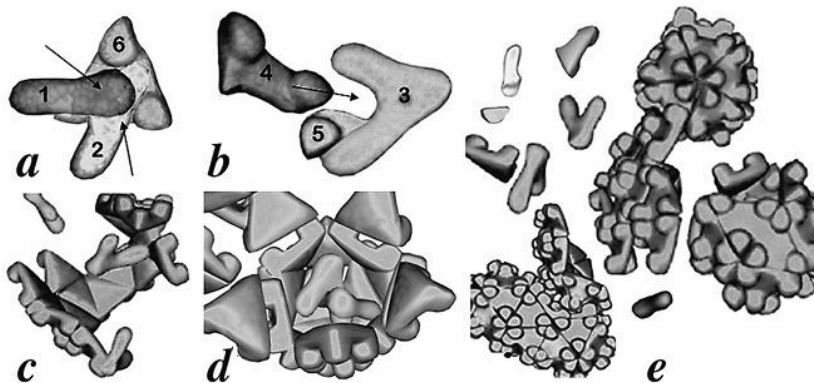


FIGURE 10.3: A cartoon depiction of various stages of polyhedral autogenic structures (as in Figure 10.2) self-assembling. The final image (*e*) shows the breakup and reassembly due to collision.

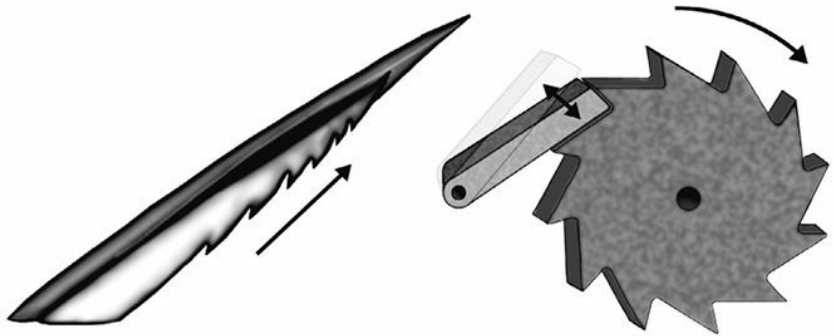


FIGURE 10.4: Typical examples of the ratchet effect. *Left:* the barb of a honeybee stinger redrawn from a scanning electron micrograph magnified 400 times. The barb structures make penetration easy in one direction and nearly impossible in the other. *Right:* the structure of a typical ratchet gear and movable catch. Clockwise rotation of the gear is easy, but counterclockwise motion is prevented; thus random forces tending to rotate the gear in both directions will only result in one direction of movement. This same logic determines that an autogenic system will tend to support the generations of constraints by morphodynamic and thermodynamic work, but will prevent their dissipation.

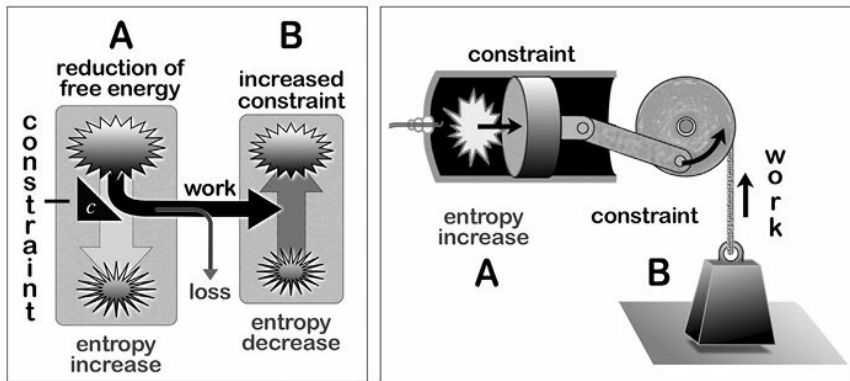


FIGURE 11.1: The left diagram schematically depicts the logic of thermodynamic work in which one physical system (*A*), which is changing in an orthograde direction (in which the reduction of free energy and the increase of entropy are depicted as an arrow from higher potential to lower potential), is coupled to another system (*B*) via constraints that cause the second system to change in a contragrade direction (depicted as a reversal of *A*). A familiar example of this relationship is depicted on the right where the exploding air-fuel mixture in a cylinder is constrained to expand in only one direction, and this is coupled to a simple mechanical device that raises a weight.

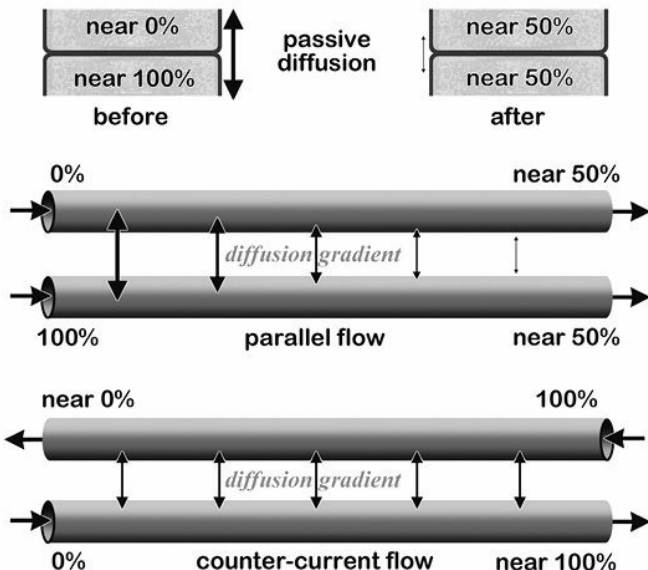


FIGURE 11.2: Countercurrent exchange demonstrates how formal constraints can be harnessed to do thermodynamic work. By causing media like coolant liquids (in a heat exchanger), or blood and environmental water (in fish gills), to flow in opposed directions, the asymmetries created can locally drive the system far beyond passive thermodynamic equilibrium (e.g., passive diffusion or parallel flow, above), so long as the movement continues. Though most naturally occurring countercurrent processes involve fluids and heat transfer, or chemical diffusion (as in fish gills and kidneys), this is a generalizable relationship. It can apply to any process involving entropy increase/decrease, including information processes.

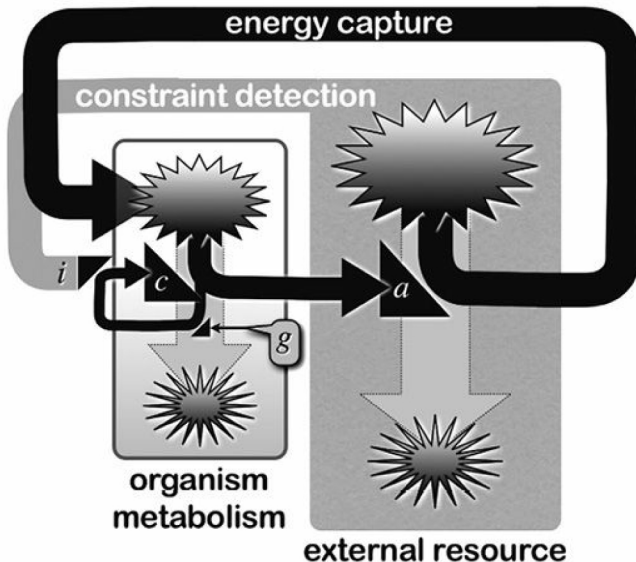


FIGURE 11.3: A diagrammatic depiction of the thermodynamic work performed by an organism to maintain its integrity with respect to thermodynamic degradation, and to support its higher-order orthograde (teleodynamic) capacity to replicate the constraints that support this process. Organisms must extract resources from their environment, e.g., by doing work (a) to constrain some energy gradient in order to access free energy to maintain their metabolisms (which maintain a persistently far-from-equilibrium state). Because the environment is often variable, they must also obtain information (i) about this variability in order to use it as a source of constraints (c) to regulate the work they perform. Constraints are depicted as right triangles deviating energy flows (arrows), and the constraints inherited genetically (g) are depicted as both within and outside the organism (since they are inherited from a parent organism).

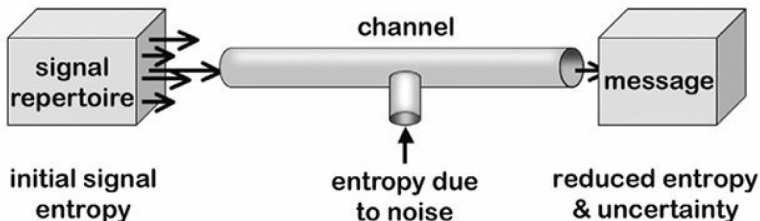


FIGURE 12.1: Depiction of the logic that Claude Shannon used to define and measure potential information-conveying capacity ("Shannon information").

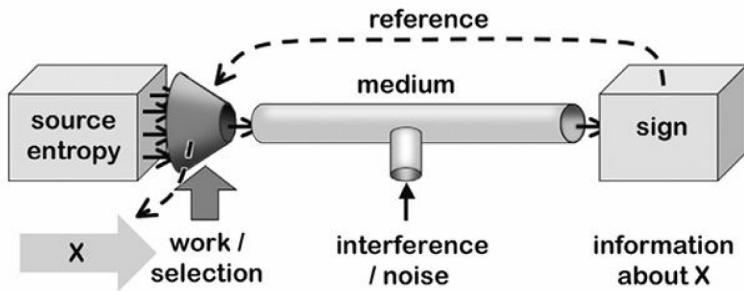


FIGURE 12.2: Depiction of the way that Shannon information depends on the susceptibility of a medium to modification by work. It derives its potential to convey information about something extrinsic to that medium by virtue of the constraints imposed on that medium by whatever is responsible for this work.

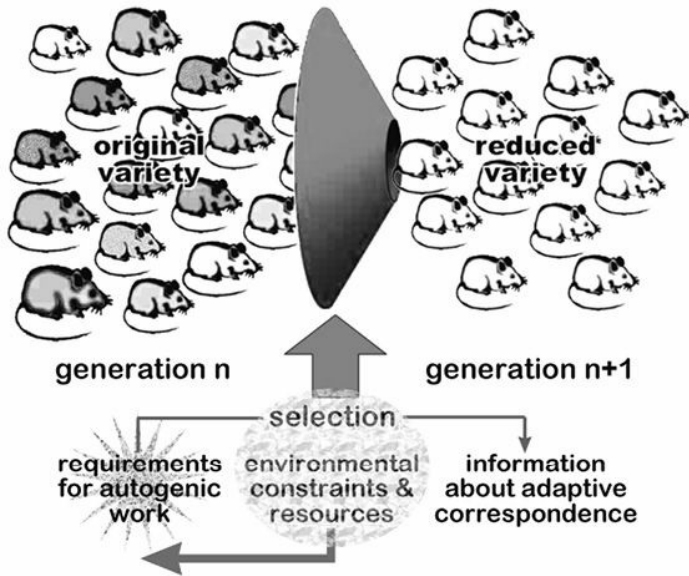


FIGURE 13.1: A cartoon depiction of the process of natural selection, showing its parallel with the logic of information generation. However, in this case the work responsible for reducing the variety is generated not by an outside influence but by the individual organisms within the population. Each organism's teleodynamic work is ultimately responsible for utilizing the constraints of the organism-environment dependency. The variety of organism traits in succeeding generations is thus reduced in ways better fitted to the environment.

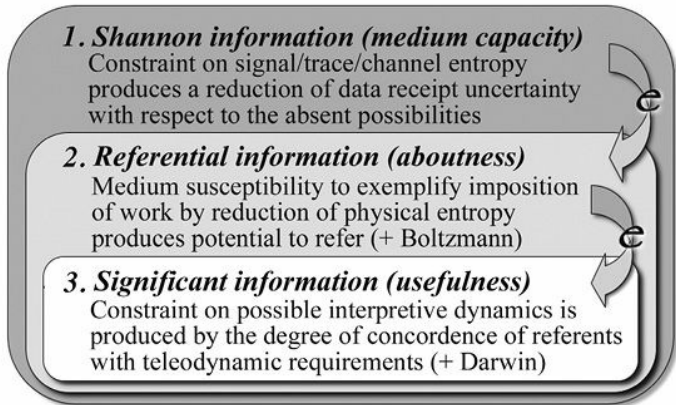


FIGURE 13.2: Three nested conceptions of information. *Shannon* information is the most minimal and the most basic. *Referential* information is emergent (*e*) from Shannon information, and *significant*—or useful—information is emergent from referential information.

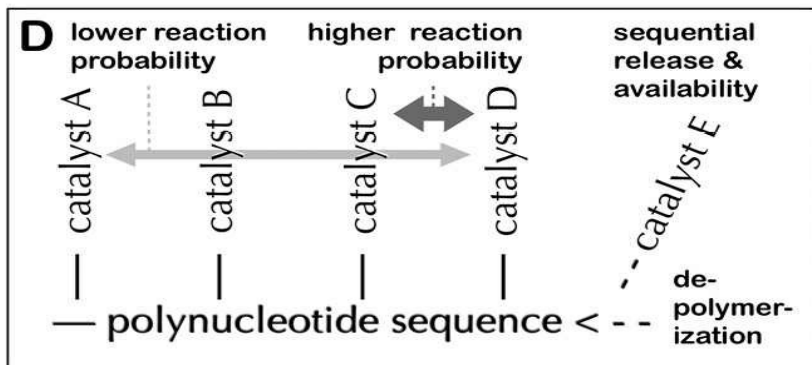
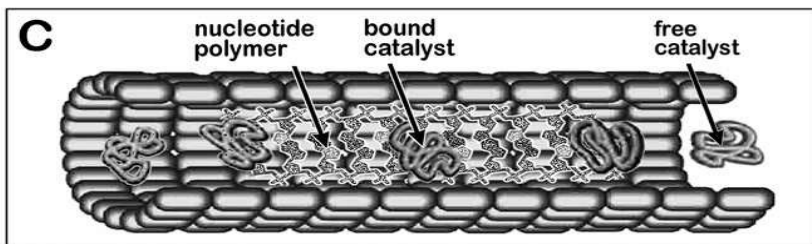
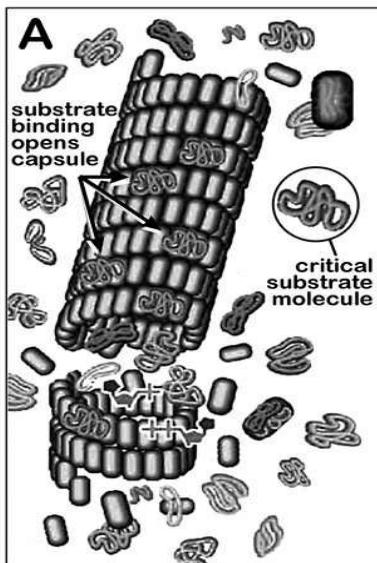


FIGURE 14.1: A speculative depiction of the possible evolutionary stages that could lead from a simple autogenic system to full internal representation of the normative relationship between autogen dynamics and environmental conditions. Though somewhat fanciful, this account provides a constructive demonstration that referential normative information is supervenient on (and emergent from) teleodynamics.

A. Depiction of a tubular autogen with a simple modification that provides the capacity to assess information indicating the presence of favorable environmental conditions. This is accomplished because the exposed structure of the autogen surface includes molecular surface structures that selectively bind catalytic substrate molecules present in the environment, and where increasing numbers of bound substrates weaken containment. This increases the probability that containment will be selectively disrupted in supportive versus non-supportive environments and thus provides information to the autogenic system about the suitability of the environment for successful reproduction.

B. Depiction of a tubular autogen that produces free nucleotides as byproducts. This might evolve in environments with high concentrations of high-energy phosphate molecules as a protection against oxidative damage, and could subsequently be exapted as a means of extracting and mobilizing energy to drive exothermic catalytic reactions.

C. Within the inert state of an autogen-diverse nucleotide, molecules could be induced to polymerize as water is excluded. This would both render phosphate residues inert and conserve nucleotides for future use. Although the spontaneous order of nucleotide binding will be unbiased, the resulting sequence of nucleotides can serve as a substrate onto which various free molecules within the autogen (e.g., catalysts) will differentially bind due to sequence-specific stereochemical affinities.

D. In this way, catalysts and other free molecules can become linearly ordered along a polynucleotide template, such that relative proximity determines reaction probability. Thus, for example, if this template molecule releases catalysts according to linear position (e.g., by depolymerization) they will become available to react in a fixed order. To the extent that this order

correlates with the order of reactions that is most efficient at reconstituting the autogenic structure there will be favored template sequences. So long as one strand of this template is preserved, as in DNA, sequence preservation and replication are possible. Since the optimal network of catalytic reactions will be dependent on the available resources provided in the environment, this template structure is at the same time a representation of this adaptive correspondence. Although this scenario has been described using a nucleotide template in order to be suggestive of genetic information, the molecular basis of such a template could be diversely realized.

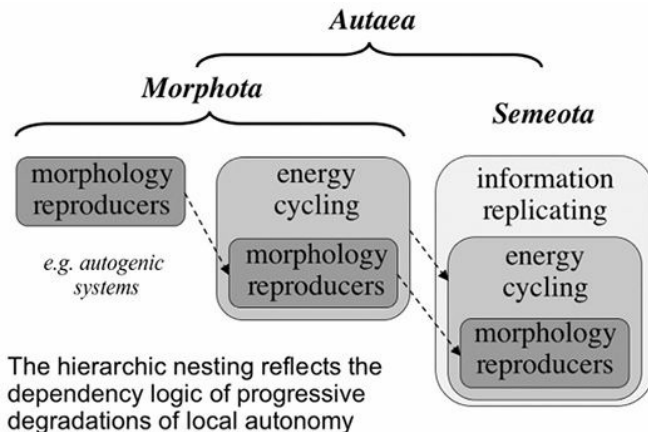
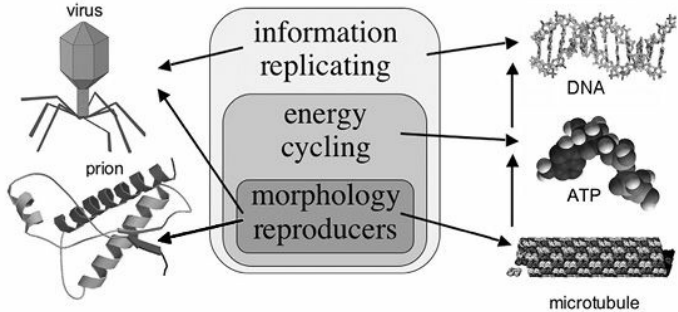


FIGURE 14.2: Depiction of an autogen thought experiment, demonstrating how a component molecule might spontaneously evolve to provide information about the production of the autogenic system of which it is a part. In this example it is assumed that variant nucleotide molecules are generated as side products of autocatalysis. In the dynamic phase of autogenesis these nucleotides could serve to capture free energetic phosphate molecules to provide generic energy for catalytic reactions (*left*). Assuming additionally that during the inert phase of the autogenic cycle free nucleotides were induced to polymerize into a randomly arranged linear molecule, different nucleotide orders would tend to provide differential substrates onto which free catalysts might tend to bind (*center*). The binding order of catalysts along the nucleotide polymer would incidentally bias interaction probabilities between catalysts by virtue of proximity and timing of release. In this way different sequences of nucleotides could come to be selected with respect to the catalytic interaction biases most conducive to autogen reproduction. The selectively favored order in this way re-presents the constraints that constitute the specific teleodynamic reaction network.



- Degenerate forms, parasitic on Semeota, reflect this logic
- Cellular exemplars with necessary hierarchic dependencies

FIGURE 14.3: The living fossil remnants of the major pre-life stages of *Morphota* evolution may still be exhibited in living systems. Some possibilities are depicted here.

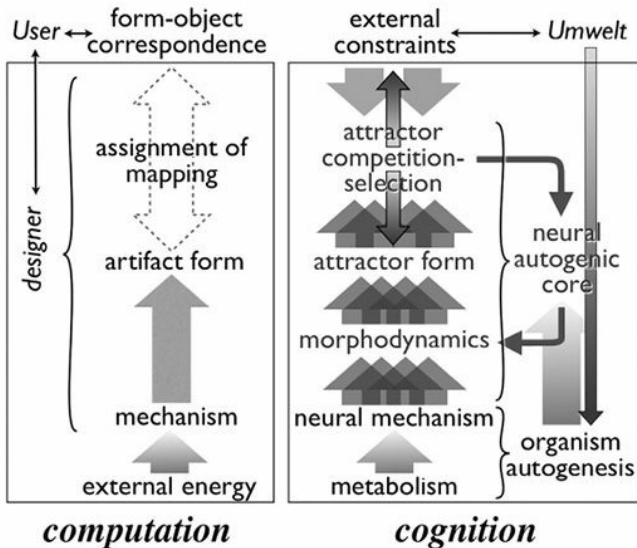


FIGURE 17.1: The formal differences between computation and cognition (as described by this emergent dynamics approach) are shown in terms of the correspondences between the various physical components and dynamics of these processes (dependencies indicated by arrows). The multiple arrow links depicting cognitive relationships symbolize stochastically driven morphodynamic relationships rather than one-to-one correspondences between structures or states. This intervening form generation dynamic is what most distinguishes the two processes. It enables cognition to autonomously ground its referential and teleological organization, whereas computational processes must have these relationships “assigned” extrinsically, and are thus parasitic on extrinsic teleodynamics (e.g., in the form of programmers and interpreters). Computational “information” is therefore only Shannon information.