

Copyright © Zann Gill, 2008
PO Box 4001
Los Altos, CA 94024
Email: zanngill@desyn.com
<http://zanngill.com>
<http://desyn.com>
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GLOSSARY

Note: This is a working glossary. No attempt is made here to cover the historic ways in which these terms have been used, nor the disagreements as to their use. My aim is simply to clarify how I use these terms in *If Microbes begat Mind* and *What Daedalus told Darwin* and to keep the definitions as simple as possible.

AI — artificial intelligence

abiogenesis — scientific term for the generation of life from inorganic matter, as distinguished from “spontaneous generation” (e.g. maggots arising spontaneously from rotting meat), which was disproven by Louis Pasteur ; today refers to hypotheses about the chemical origin of life, as from a primordial sea, via self-replicating molecules

abduction — “an inspired inference”; historically a term coined by philosophers of science William Whewell (1794-1866) and Charles Sanders Peirce (1839-1914) as another way of “thinking backward” through imagining an hypothesis which, if true, would help to explain the data. Peirce believed in an “experimental logic” that codifies how we think when we are most innovative, the art of guessing right. So Peirce’s method had three steps: abduction, through which a new hypothesis was postulated; deduction of the consequences from that hypothesis, and induction or testing of the hypothesis (through reasoning from particular instances to arrive at a general rule).

Abduction has also been defined as a heuristic procedure that reasons inductively from available empirical evidence to the discovery of the probable hypotheses that would best explain its occurrence. Both Peirce and Reichenbach developed detailed theories about the invention of such hypotheses in what is sometimes called “the logic of discovery.” The success of this enterprise may founder on the under-determination of incompatible hypotheses. See *Abduction and Induction: Essays on Their Relation and Integration*, ed. by Peter A. Flach and Antonis C. Kakas (Kluwer, 2000)

In fault diagnosis and machine learning, the technique of using certain plausible (but non-logical) inferences, e.g. to generate explanations from observations and logical sentences. Abduction is used here to characterize that third way of thinking, which is neither induction nor deduction, but the imaginative leap to generate a new idea.

acceptor strand — a strand of nucleic acid into which a piece of foreign genetic material can be placed

accident — Accident as a formal category first appeared in Aristotle’s *Categories*. For some interpreters accident is an entity, for others a predicate (i.e. action) or qualifier of something else (i.e. distinguishing between a thing and its properties). The term here is used to refer to entities and is fully defined in the context of the argument.

achiral — lacking chirality (screw-like morphology)

adaptability, somatic — organism response to environmental change, either to offset adverse effects of the environment or to increase the organism’s performance

adaptation, evolutionary — heritable change in the phenotype of an organism selected for increased reproductive fitness in a given environment

adaptive cell behavior — cell response to local environments and cell-cell signals, which can change in combinations and amounts to generate the observable phenotype

adenine (A) — one of the bases of the nucleic acids (see base)

adenosine triphosphate (ATP) — a nucleoside triphosphate consisting of adenine, ribose, and three phosphate groups; a high energy compound that releases a large amount of energy when it transfers a phosphate to an acceptor; an energy-rich phosphate ester, used as a molecular energy store in the cell. Splitting one of the bonds linking the phosphate groups releases the energy and makes it available for biochemical reactions.

adsorption — adhesion of a thin layer of molecules to the surface of solids or liquids

aerobic — organisms (aerobes) that require atmospheric oxygen for their metabolic processes

alanine — one of the twenty common naturally occurring amino acids, a basic building block of proteins

alpha-helix — one of the structures adopted by polypeptide chains of proteins; a helical (spiral-staircase) structure stabilized by hydrogen bonds between each CO group and the fourth nearest NH group

algorithm — a step-by-step problem-solving procedure, often recursive

algorithmic complexity — the shortest algorithm required to reproduce a pattern as a measure of that pattern's complexity

ALife — See artificial life.

allosteric regulation — regulation of an enzyme or protein by binding an effector molecule at the protein's allosteric site (a site other than the protein's active site)

allostery — proteins with two kinds of surface sites, one at which a function occurs, the other at which regulation of that function occurs

ambiguity — an attribute of the object we are trying to know, while uncertainty pertains to our capacity to know

amino acids — compound containing both an acidic carboxyl group (COOH) and a basic amino group (NH₂); twenty commonly occurring amino acids are the building blocks of proteins. They are all L-stereo-isomers (left-handed) and all have the same basic structure, differing only in their single, functional side chain. Using amino acids as its building blocks, each protein is composed of particular amino acids joined by peptide bonds in a particular order.

amphiphiles — molecules that have one end that is hydrophobic with the other end being hydrophilic; see micelles

anaerobic — organisms (anaerobes) that live in the absence of atmospheric oxygen with metabolic processes that do not require oxygen

analogy — a term originally used for quantitative relationships (e.g. 3 is to 6 as 4 is to 8) but now used for qualitative comparison spanning the spectrum from isomorphism to equivocation or ambiguity. Analogy can be based on partial likeness where not only similarities but also

differences between the entities compared are relevant. Inference by analogy refers to drawing conclusions in one area because of its similarities with another.

analysis — a method that emphasizes decomposition of a complex phenomenon or problem into simpler, more basic elements

analytic/ synthetic distinction — the distinction between reductive “thinking backward” and constructive “thinking forward” to assemble and integrate; the distinction between starting from premises assumed to be certain and drawing consequences and starting from uncertainty to build an emergent outcome that only gradually reveals itself

Angstrom unit — measure of length used to specify sizes on the atomic scale; one Angstrom unit equals one ten thousand millionth of a meter (10^{-10} m)

antibody — protein molecule produced in vertebrates by the immune system in defense against foreign substances (antigens)

anticodon — sequence of three nucleotides (bases) in tRNA. During the translation process the anticodon interacts with the codon (which also consists of three nucleotides) and is thus selects the correct amino acid to incorporate into the growing protein chain

antigen — a protein on the surface of a virus, bacteria or cell that can stimulate the immune system to produce antibodies as a defense mechanism

apoptosis — programmed cell death to benefit the living organism (in contrast to necrosis, which is cell death from injury)

a priori — A priori knowledge is known generally independent of experience, except to the extent that its concepts are informed by experience, and so must be justified in some other way, whereas a posteriori knowledge designates what is known “after the fact” of experience.

archaea — one of three domains: bacteria, eukarya, and archaea (discovered by Carl Woese)

artefacts — term associated with identity persisting through time, raising the question of the amount of change allowable while still preserving identity. Classic example: Repairing Theseus’ ship while sailing from Piraeus to Delos required continual substitution of new planks for old; at the end was it the same ship?

artificial Intelligence (AI) — term first coined in 1956 by Allan Newell, Clifford Shaw, and Herbert Simon that originally referred to the simulation of human behavior by computers or robots or intelligent agents. The term is used here to designate the effort to understand the nature of intelligence by attempting to synthesize it, as well as to “simulate the subjective.” Hubert Dreyfuss identifies two early schools in AI, the first dedicated to using computers to manipulate mental symbols, the second aiming to use them as a medium for modeling the brain.

artificial life (ALife) — use of human-made analogs of living systems (term coined by Chris Langton)

association — a relation between two or more ideas such that the appearance of one of them in the mind naturally leads to other(s)

antigen — usually a macromolecular protein or carbohydrate substance (as a toxin or enzyme) that triggers the production of antibodies when introduced into an organism

assimilation — heritable stabilization of somatic adaptation by genetic change

ATP — see adenosine triphosphate

attribute — used synonymously with “quality”, a characteristic of an object, seen by some as universals, by others as particulars; exemplified by properties. Attributes can be further qualified as relational, categorical, hypothetical etc.

autocatalysis — occurs when the product of a reaction is also a catalyst for the same reaction

autocatalytic set — coherent, self-reinforcing webs of chemical reactions through which a new set is produced entirely from reactions within the original set

autonomy — capacity to make independent choices, self-governing

autopoiesis — autonomous, self-producing, self-maintaining, self-directed (Maturana, Varela)

axiom — self-evident principle that does not require proof and that cannot be justified or further reduced logically

bacteriophage — viruses that attack (multiply in) bacteria; parasite which has lost its metabolic function and retains only the ability to replicate

Baldwin effect — hypothesis (James Baldwin 1896) about how individual lifetime learning can influence the course of evolution without resorting to the transmission of acquired characteristics. *The Baldwin effect*, which is based on the premise that learning is a faster method of search than random mutation, has two steps. First, if learning results in increased fitness, organisms become more likely to survive to reproduce. If they reproduce more organisms like themselves, these learned traits consistently produce fitter organisms. Second, Baldwin hypothesized that evolution will eventually find a way to reproduce those effective learned traits as innate traits. So when organisms face an altered environment, they try to respond with a somatic adaptation that will enable them to tolerate environmental change. So genetic change does not necessarily precede phenotypic change; the reverse may occur.

base — the symbols for genetic information in biochemistry, the basic components of the nucleic acids, which include: adenine (A), cytosine (C), guanine (G), and thymine (T) in DNA, with its close relation uracil (U) substituting for T in RNA.

base pairing — a specific interaction between bases, which occurs between guanine and cytosine and between adenine and thymine/ uracil

bias — predisposition or inclination influencing an outcome

binary — comprising two units; in logic a choice between two alternatives (either/ or; true, false; on, off; 1,0)

bioeconomics — application of holism and interdisciplinary methodology to bridge the empirical methodology of biology with the statistical methodology of economics

biology — used here in reference to three key concepts arising from this discipline, evolution, ecology, and ecosystems

biosynthesis — formation of organic compounds and cellular components in the living organism with the help of catalysis (enzymes)

bit — short for “binary digit”, any information associated with a binary either/ or decision

black smokers — the hottest vents, spewing out iron and sulfide

bootstrapping — after legend of Baron Münchhausen, who lifted himself out of a swamp by his own boot straps, self-starting

bottleneck — see choke point; a stage of the process impeded by a required, but unlikely, contingency, a link that might break the chain of events required to complete the process. The challenge is to identify alternative pathways, scenarios, and events that could bypass the bottleneck.

bounded variance — local variance needed to maintain global order under changing conditions

carbonaceous chondrites — class of meteorites, which contain oil-like hydrocarbons

catalysis — the acceleration of a chemical reaction

catalyst — agent that accelerates a chemical reaction, an itself emerges unchanged at the end of the reaction; this agent can be a molecule, a clay surface area (as in the montmorillonite clay hypothesis); catalysts are most frequently proteins called enzymes, but they may be either inorganic or organic molecules

categories — term first elevated by Aristotle to refer to abstract universals with which we differentiate the world

cation — positively charged ion

causality — used here to refer to any factor that brings about change. This term has stimulated philosophical debate as to whether “efficient causes” are guided by “final causes” (Aristotle’s term for goals, which later adopted theological and teleological overtones). Other philosophers, such as John Stuart Mill, restricted causality to *de facto causes*, a set of necessary conditions, e.g. to produce a forest fire.

cell differentiation — the process through which cells in a multicellular organism acquire and retain their specialized function

cellular automata (CA) — state machine that consists of an array of cells, each of which can be in one of a finite number of possible states

certainty/ uncertainty — an attribute of knowledge, which may designate absolute or relative certainty

chemoautotroph — organism whose nutrition and metabolism is based upon obtaining energy from the oxidation of inorganic substances such as sulfur, nitrogen, iron and cell carbon from CO² (carbon dioxide)

chert — chemical precipitate from groundwater creating sedimentary rock, often containing small fossils, often fine-grained and silica-rich

chert dikes — vertical rock intrusions

chirality — the “handedness” of a screw or helix (right- or left-handed); a molecule exhibiting chirality is termed “chiral”

chloroplast — particles responsible for photosynthesis, which are green due to their constituent chlorophyll

chromosome — unit of heredity containing many genes; a linear structure containing hereditary information

choice — election among options, however that election is made (the environment “chooses” what it selects as fittest to survive)

choke point — see bottleneck; event in a hypothetical scenario with lowest probability of occurrence

chondrite — a meteorite containing chondrules (from Greek chondros, grain), which are small, spherical silicate objects on the order of a millimeter in size that formed in the solar nebula before the asteroids were formed. Chondrites consist up to 80% of chondrules, embedded in a fine grained matrix.

classification — scheme for, or process of establishing, defining, and ranking taxa within hierarchical series of groups, either artificial or natural

coacervates — mixture of colloid particles that separates itself from colloidal solutions of opposite charge; colloidal droplets held together by electrostatic attractive forces; structures that segregate themselves from a water solution to form tiny droplets; these microscopic gel-like structures may be produced by lipids or other compounds, e.g. as when polymeric substances like gum arabic and gelatin are mixed with other compounds

codon — sequence of three consecutive nucleotides that code for an amino acid or for the signals “start” or “stop”

coenzymes — small, non-protein molecules required by many enzymes before they can act as catalysts, which may be bound to the enzyme and, unlike enzymes, can participate in many different reactions, e.g. ATP

cognition — the processes of consciousness through which knowledge is acquired, which include perceiving, recognizing, conceiving, reasoning, and judgment

cognitive emergence — knowledge arrived at through blurriness resolving into pattern

coherence — here used to describe any construct where the parts fit together in a compelling way. In epistemology coherence referred to the justification of a belief through its “coherence” with other knowledge already accepted as true, i.e. the description of a system whose elements stand in mutual relations of consistency and (possibly) interdependence. It also described a compelling relationship between hypothesis and evidence.

coherence-seeking behavior — contrasted with goal-directed behavior. Non-living systems do both. Robots can be pre-programmed with goals; there are many examples of coherence-seeking behavior in inanimate systems; sand on a vibrating plate will arrange itself into coherent patterns.

collaboration — particular form of cooperation in which a system of diverse entities with unique attributes and identities, is able together to accomplish a task more complex than what any entity could have accomplished alone; collaboration does not imply consciousness or anthropocentricity (e.g. the elements of an ecosystem collaborate to create that ecosystem).

collaborative autonomy — particular form of collaboration, which does not require shared ownership or consensus; each player has autonomy and ownership of his piece of the big picture.. I proposed that collaborative autonomy is a basic principle, both in the origin of life and, more generally, in evolution and the invention of novelty.

colloid — substance containing particles in a continuous medium (solvent); stable colloidal particles are organized such that the cohesive forces are directed inwards, while the particle’s surface has an affinity for the continuous medium

community — members of the more than one species that live in the same habitat

compartment — region of the embryo in which one or a few selector genes are expressed and where one or a few signaling proteins are produced, system to regulate cell differentiation

compartmentation — capacity to operate different conserved core processes at different places in the organism or embryo, and to create those places

competition — entities working together to accomplish a result that none could have accomplished alone; competition does not imply consciousness or anthropocentricity. Competition implies agreement on rules or a common basis for competition.

complementary, complementarity — a) in physics, the characterization of a system in different, independent ways that complement each other b) in biochemistry the capacity of nucleic acids to undergo specific base-pairing interactions (G-C, A-T/U)

complexity — in science the study of self-organization from simpler to more complex

complex adaptive systems — systems which are complex in that they contain diverse, multiply interconnected elements and adaptive in that they can change and learn from experience

computation — term originally used primarily to refer to numerical calculation. However, as computers have acquired higher abilities “to think”, the term’s connotation has broadened to better reflect its Latin roots: com-putare means *to contemplate things* (putare) *together* (com). Traditionally, symbolic computation consisted of systems of rules for manipulating structures built up of tokens of different symbol types. In the mid-1980s connectionist computation began to explore numerical activation across interconnected networks of abstract processing units. In the mid-1990s quantum computing and evolutionary computing drew analogy to quantum mechanics and biology respectively.

concept — one of the most debated terms in philosophy, used both to refer to the object of knowledge and to the subjective integration of sense impressions, here used to designate any mental construct that entails integrating parts into a whole. A concept is not a stereotype but an integration, a way of organizing and giving meaning to mental contents. Concepts arise from, and are dependent upon, our capacity to think and represent. As used here a concept can be defined as a generic abstraction generalized from particular instances, a seed that can produce an organic whole, a metaphor that connects disciplines, or an integration of parts into a coherent synthesis. The term “concept” has been variously used to connote a bundle of features, theory, mental representation, abstract entity, object or behavior (Margolis 1999). “Concept” as used here connotes a mental representation used to interpret, make decisions, and act. A concept “ready to test” is a hypothesis.

conservation — retention by a lineage of organisms of gene or protein sequences over long periods

conserved core processes — processes that generate the anatomy, physiology, and behavior of the organism in the course of its development. Traits are generated by different combinations of processes operating in different parts of the adaptive ranges of performance. As described by Kirschner and Gerhart, conserved core processes underlie their Theory of Facilitated Variation.

consilience — term introduced by Whewell in 1840 for the ‘jumping together’, agreement, or concurrence of two or more inductions drawn from different groups of phenomena, where each stands as an independent verification of the other (see holism); developed by E.O. Wilson in his book of that title

constraint — a limitation, restriction or guiding force; in genetics used to indicate that an organism cannot possess a particular kind of heritable phenotypic variation because it is lethal

convergence — traditionally in biology used to describe two organisms with similar structures performing similar functions that evolved independently; here used as applied to collaborative problem-solving to describe the gradual accommodation of different lines of development to produce synergy (where the whole is greater than the sum of its parts)

cooperation — cooperating entities, alike or diverse, benefit from association; cooperation does not imply consciousness or anthropocentricity, a mechanistic term and complement to the concept of competition in evolution; collaboration is one type of cooperation

correlated fitness landscape — a fitness landscape where the fitness values at one point are similar to the fitness values at neighboring points; landscapes whose slope changes gradually like landscapes in the real world

covalent bonds — also known as a polar bonds; covalent bonds are formed as a result of the sharing of one or more pairs of bonding electrons. Each atom donates half of the electrons to be shared. This sharing of electrons is as a result of the electro-negativity (electron attracting ability) of the two bonded atoms

CPSE — Collaborative Problem-Solving Environment, which consists of a "software workbench" with tools that can be configured and composed in many ways to construct simulations or to access, mine or visualize information. CPSEs are designed to:

1. visualize and analyze large amounts of data;
2. conduct collaborative simulation or problem-solving sessions in real-time;
3. enable users to search, locate, and schedule access to resources, such as heterogeneous, geographically dispersed data repositories and scientific instrument systems;
4. remotely guide laboratory experiments (e.g. on the International Space Station) in real-time or near real-time;
5. support distributed synchronous and asynchronous collaboration;
6. simulate physical and biological phenomena where experiments are not feasible;
7. simulate design proposals such that their characteristics can be studied in advance of full physical construction of the prototype.

criteria — standards or rules for judging or making a decision

crossing over — genetic exchange of material between two chromosomes, the basis of sexual reproduction

cyanobacteria — also known as blue-green algae (a misnomer because they are bacteria), a very early product of evolution; micro-organism that has the prokaryotic cell structure of bacteria and is able to carry out photosynthesis highly efficiently, liberating oxygen, in the manner of chloroplasts and (eukaryotic) plants

cytoplasm — region of the cell outside the nuclear membrane; the contents of the cell minus the nucleus; the cell contents without the organelles and cell skeleton

cytosine — one of the bases of the nucleic acids; see base

cytoskeleton — internal framework of a cell, composed largely of actin filaments and microtubules.

Darwinian evolution — theory of Charles Darwin in *Origin of Species* (published 1859) that diverse life originated on Earth through descent with modification from ancestors. According to

this view populations vary genetically, compete under pressures of the environment, and the fittest are selected by the environment to survive, reproduce and transmit their genetic inheritance, gradually strengthening the population through random variation and environmental selection.

Darwinism — as above, Darwinian theory that species originate by descent, with variation, from parent forms, through the natural selection of those individuals best adapted for the reproductive success of their kind.

decanoic acid — a ten-carbon chain producing a carboxylic acid, $\text{CH}_3(\text{CH}_2)_8\text{COOH}$, also known as capric acid. used in organic synthesis and industrially in the manufacture of perfumes, lubricants, greases, rubber, dyes, plastics, food additives and pharmaceuticals

deconstraint — reduction of constraint

deduction — deriving a conclusion by logical reasoning (inference) from premises

deltaC13 — isotopic composition of the sample being measured is expressed in parts per thousand (per mille) and represents the deviation in per mille of the sample carbon 13 content and the content of the international standard from the international standard, derived from the PeeDee Belemnite formation in the eastern U.S. The deltaC13 value for a sample can yield important information regarding the environment from which the sample originates because the isotope value of the sample reflects the isotopic composition of the immediate environment. The ratio is measured using an ordinary mass spectrometer.

deoxyribose — sugar component of the nucleotides from which deoxyribonucleic acid (DNA) is assembled; related to ribose by removal of one oxygen atom

design — the process of producing an outcome that responds to identified needs, leaving open the possibility that the method of arriving at that response may be evolutionary or interventionist. Both evolutionary design, a process of change via local adjustment, and human design can be characterized as searches for the optimal response to a given need.

detection — recognition of a signal (by any entity, living or non-living, e.g. a sensor)

developmental biology — study development of organisms, not only as embryos but through their lifespans

dichotomy — a) biology – the splitting of one genus into two species; in logic, the subdivision of a category into two sub-categories showing opposite behavior

diffusion — transport by thermo-molecular movement; mechanism for transport of molecules and atoms from regions of high concentration to regions of lower concentration

divergence — departure of lines of development caused either by an accumulation of mutations or through the accumulation and integration of new genetic material

discovery — finding and making known something previously hidden. As represented by Reichenbach “the act of discovery escapes logical analysis; there are no logical rules in terms of which a ‘discovery machine’ could be constructed that would take over the creative function of the genius” (1951:231); some artificial intelligence researchers disagree.

discriminating algorithm — procedure that determines how choices are made

discrimination — an advancement beyond detection, denoting recognition of the difference between signals in order to determine appropriate action (e.g. bacteria swimming upstream in a glucose gradient)

DNA — deoxyribonucleic acid; the molecular carrier of hereditary information; usually occurs as a double-stranded, double helical structure comprised of the four bases adenine thymine, guanine, and cytosine; DNA organization is similar to that of a language document, divided into words (codons), sentences (genes), paragraphs (operons), volume (chromosomes).

DNA polymerase — polymerase that catalyzes stepwise synthesis (polymerization) of DNA strands in the complementary copying of DNA

donor strand — strand of DNA from which a gene sequence is removed and transferred to an acceptor strand

Drake equation — an equation formulated by Frank Drake and Carl Sagan that starts with the number of stars in our Milky Way galaxy (several hundred billion), multiplied by the fraction of stars that are “plausible” (single G and K stars), multiplied by the fraction with planets with active biospheres, multiplied by the fraction of biospheres that might be “mature” enough to harbor life.

drift, genetic — progressive change in a gene due to neutral mutations, i.e. mutations that are neither advantageous nor disadvantageous in natural selection

ecology — term coined by Ernst Haeckel (1834-1919) in 1866 to describe the study of living things in relation to their environments

ecosystem — the system created by the interaction and co-evolution of living things and their environment

emergence — in philosophy the opposite of reduction, an outcome not predicted within the initial system where it later occurs, expressed as “the whole is more than the sum of its parts”

emergent variation — in contrast to random variation, the use of information resulting from self-organization and organism behavior

enantiomer — isomers whose only difference is that they are of opposite chirality (left- or right-handed)

Enceladus — moon of Saturn on which a geyser was found, making it a candidate for life

endosymbiont — symbiont living inside its host

Endosymbiotic Theory — now widely accepted theory of microbiologist Lynn Margulis that eukaryotic cells first appeared when a prokaryotic cell was absorbed into another cell without being digested. This theory also postulates that mitochondria evolved from aerobic bacteria and that the chloroplast evolved from cyanobacteria.

entropy — a) measure of the amount of energy (potential for organization) versus degree of disorganization in a system; b) thermal motion expressed in temperature; c) in information theory the concept of “negative entropy” is used to measure the amount of information needed, i.e. the number of binary bits (yes/ no decisions) required to describe a message of a given length; d) an increase in entropy is a decrease in order; the system can only become more organized through a supply of free energy (capable of doing work).

environmental selection (also natural selection) — according to Darwin's theory of evolution, how organisms best adapted to their environment survive to transmit their genetic characteristics

enzyme — biological catalyst, usually a protein, which has a particular affinity for the molecule that is to be chemically transformed

epigenesis — in biology the theory that an individual is developed by successive differentiation of an unstructured egg, rather than by simply enlarging a preformed entity, as in cell development the differentiation of stem cells differentiate to perform specialized functions; also generally, the development of new characters through differentiation of an initially undifferentiated entity.

epistemology — “theory of knowledge”, the study of the scope and limits of knowledge, its sources, methods and justification

error threshold — critical value of the mutation rate above which errors accumulate leading to loss of information (the error catastrophe); stable selection requires that the error rate be below the error threshold

essentialism — the notion that essences, like Platonic forms, provide the template that material embodiments approximate; in biology the notion of fixed perfect species of which actual individuals are imperfect representations

eukaryotes — single-celled organisms with a membrane boundary, internal membrane-bounded organelles, including a nucleus, secretory vesicles, mitochondria (or remnants) and (in plants) chloroplasts, which reproduce through mitosis (dividing); the basic cell type for complex organisms

Europa — one of the moons of Jupiter; its frozen ocean is of interest to origin of life researchers who speculate that below its frozen crust there might be an ocean habitat able to harbor life

event — an integrated action or series of actions that occur in a place or a network over a particular interval of time

evolution — originally applied to designate, following from Charles Darwin, the process of descent with modification through random mutation and selection by which living beings descend with modifications from common ancestors; now used to designate any process of change that follows these principles; the core principles and processes of evolution are under debate.

evolution by elimination — process related to hypotheses of Ernst Mayr (on gradualism in biology), and Karl Popper (on falsifiability of least fit theories in scientific method) whereby the environment eliminates those specimens least fit to survive and so controls the direction of evolution through “survival of the fittest” to reproduce their genes in offspring

evolutionary epistemology — applies Darwinian principles of natural selection to scientific theories and to knowledge, addressing issues of problem-solving and error elimination under various forms of selective pressure, e.g. the work of Karl Popper

evolvability — capacity to evolve faster or more effectively using mechanisms such as facilitated variation

exon — (abbreviation for “expressed region”) information-carrying, coded sequence of a eukaryotic gene, whose transcript appears in the completed mRNA that is expressed as a protein; frequently correlated with structural domains in the protein molecule

experience — here used simply to designate the first person perspective of the subject through time; a term which in philosophy raises arguments about the nature of knowledge and verification of truth

exploratory behavior — adaptive behavior of certain cellular and developmental core processes, wherein they generate many outcome states, select and stabilize the best-performing. Examples include microtubules contacting chromosomes at mitosis, nerve axons contacting distant target cells or organs, ants foraging for food.

exponential law — law by which a quantity is multiplied or divided by the same factor in equal time intervals (e.g. population doubling every n years)

expression — when a gene is expressed, the corresponding protein is produced

facilitated genotypic variation — theory (for which evidence is lacking) that an organism can respond to stressful environmental conditions by making directed changes in DNA sequences that result in phenotypic changes of benefit to its survival under stress

facilitated variation — theory proposed by Marc Kirschner and John Gerhart. Facilitated variation is variation that is biased to be viable, biased to give functional outcomes, and biased to be relevant to environmental conditions. It is variation that an organism uses to generate complex phenotypic change from a small number of random changes of the genotype. Conserved core processes greatly facilitate evolutionary change by reducing the amount of genetic change required to generate phenotypic novelty, and enabling reuse in new combinations and in different parts of their adaptive ranges of performance.

fatty acids — a carboxylic acid often with a long unbranched aliphatic tail (chain), which is either saturated or unsaturated. Carboxylic acids

feedback — when the end product of one phase of a process influences the next phase of that process, a critical feature in regulation and control mechanisms

feedforward — when the end product of one phase of a process cannot be evaluated until completion of the next phase of that process, a critical feature in creative mechanisms

fermentation — anaerobic metabolism producing chemical energy in the form of ATP

filter — strategy to free liquids from suspended impurities by passing the liquid through a screen or other contrivance. The term is used here more generally to designate a mechanism for selection and rejection of mental contents.

fitness — in ecology the extent to which an organism is adapted to its environment; one measure of the fitness of an individual is its ability, relative to others, to leave viable offspring

fitness landscape — a three-dimensional landscape-like graph on which fitness is plotted; higher fitness is represented by higher elevation (peaks); a metaphor used to represent how evolutionary fitness might evolve

fluctuation — in molecular physics, a small variation, the occurrence of which cannot be predicted except through stochastic (statistical) methods

formal system — an abstract system of identities and relations described by specifying a formal alphabet, a formal language over that alphabet, and a formal rule for constructing derivations of sentences in the formal language

fractals — self-similar structures whose appearance is the same irrespective of the scale at which they are observed

fusion — term introduced in psychology in the nineteenth century to refer to the sensory contents (e.g. the perception of consonance in music or harmony in the visual field) here used to refer to integration across disciplines

G stars — yellow stars with a surface temperature of 4300 to 5500 K. in the case of giants and 5000 to 6000 K. in the case of dwarfs. Our sun and Capella are best known examples.

gene — unit of heredity in the DNA double strand of the chromosome which contains the information needed to synthesize a protein

generation — production, formation

genetic algorithm — a search technique used in computing to solve optimization and search problems; evolution usually starts from a population of randomly generated individual algorithms. In each generation the fitness of each individual algorithm is assessed; individuals are selected from the current population based on their fitness and modified (mutated or recombined) to form a new population, the next iteration of algorithms.

genetic assimilation — term invented by Conrad Waddington for the heritable stabilization of somatic response

genetic code — assignment of groups of three nucleotides (triplets) to the amino acids that occur in proteins; the sequence of amino acids in each protein in the cell depends upon the sequence of nucleotides in the portion of DNA in the nucleus of that cell; transcription of the genetic code is mediated by RNA molecules

genetic drift — theory that random statistical fluctuation was more important than Darwinian selection in causing species to evolve (see Motoo Kimura)

genetic recombination — exchange of genes or segments of genes in the two parents leading to the formation of a new genome; the basis for sexual inheritance

genetic takeover — theory introduced by Graham Cairns-Smith to describe instances when earlier materials and mechanisms could have been entirely superseded by later materials and mechanisms with superior capacity to perform the original function

genetic variation — change in the sequence of DNA due to mutation, recombination, assortment of different chromosomes, and insertion of DNA from viruses and other organisms; specific variation is unlinked to the environment and independent of selection

genome — the entire DNA sequence of an organism (ordering of the four elements ATGC), also called the genotype) collective term for all the genes in a cell

genotype — genome; sum of all the genetic information present in an organism

germ line — special group of cells in a multicellular organism that produce eggs or sperm in contrast to somatic (body) cells, which are not capable of inheritance

gestalt — term originated by German psychologists Max Wertheimer (1880 – 1943), Kurt Koffka (1886 – 1941) and Wolfgang Kohler (1887 – 1967) to refer to the perception of a non-analyzable pattern as a whole (e.g. a familiar face, the pattern on a chess board)

glycine — one of twenty commonly occurring amino acids, a basic building block of proteins

goal — result or conclusion toward which an effort is directed and by which it is directed, an objective

GOF AI — Good Old-Fashioned Artificial Intelligence; popular slogan for the traditional approach to AI

guanine (G) — one of the bases of the nucleic acids; see base

guided design — method developed by Z. Gill that entails focusing and synthesis whereby a vaguely defined process gradually converges on a solution to a problem that could not have been predicted in advance; process through which a solution emerges and becomes gradually clearer and more specific; used here to describe a process modeled on the evolution of living systems, which is directed by decision-making criteria, rather than goals

halting — whether an algorithm, when executed based on initial input, halts (completes) or runs forever without halting. Alan Turing proved in 1936 that a general algorithm to solve the halting problem for all possible inputs cannot exist, proving that the halting problem is undecidable.

haploid — condition of having one set of chromosomes; complement of the sperm or egg after meiosis

heterogenesis — generation of life from inorganic matter

heterotroph — organism that feeds on other organisms

holism — the whole not reducible to its parts, such that the interaction among parts produces new properties (emergence) and the parts cannot be understood independent of the whole to which they belong

homeostasis — ability of a system to self-regulate and maintain a particular state; the process of keeping the internal environment of the body stable while the outside world changes

homochirality — all the vital biomolecules of life having the same handedness or chirality, e.g. proteins comprise almost entirely 'left-handed' amino acids, while nucleic acids, starch, glycogen etc. contain sugars that are all 'right handed.' Homochirality is a prerequisite to produce the shapes of enzymes and the DNA double helix. Since chemistry always produces a 50/50 or racemic mixture of left and right-handed forms (enantiomers), a key question for origin of life and evolutionary theorists is why this preference for right or left-handed forms arose.

horizontal inheritance — spread of genetic material by genetic recombination

Hox genes — selector genes that regulate compartment identity

Human-Centered Computing (HCC) — HCC sits on the boundary between computer science and disciplines studying human behavior. Topics of HCC research include education and development, collaboration, knowledge creation, design and cognition, and computers as tools and mediators of those activities. Through better understanding of perceptual, motor, cognitive, and social aspects of people and present-day computer systems HCC aims to improve both technology and performance.

hybrid — a new species resulting from the combination of two species

hydrogen bond — weak chemical bond between an electro-negative atom (e.g. oxygen, nitrogen) and electro-positive hydrogen which is bound to a second electro-negative atom

hyperbolic growth — where growth increases by the same factor in increasingly shorter time intervals (e.g. earth's population)

hydrolysis — breaking of a chemical compound by water; the elements of water are added to the “free ends” created by each broken chemical bond

hypercycle — term introduced by Manfred Eigen and Peter Schuster to denote a cyclic coupling pattern relating to individual reproduction; a principle of self-organization allowing integration and coherent evolution of a set of functionally coupled self-replicative entities, a precursor for genetic evolution

hypertonic cell — Having an osmotic pressure higher than that of the environment; a hypertonic cell has a higher concentration of solute inside the cell than in the environment, making the net flow of water out of the cell.

hypotonic cell — Having an osmotic pressure less than that of the environment; a hypotonic cell has a lower concentration of solute inside the cell than in the environment, making the net flow of water into the cell.

idea — an independent form or archetype of something in the material world, an abstraction. According to Plato, who first defined the term ‘idea’, the term signified the essential form of a thing, which exists independently of that thing, is an exemplary model of it and is itself an object and the terminal point of the act of intellect which exists because of being apprehended

identity — determination that x and y are one and the same, through time and/ or at a given moment in time

immune system — defense system of humans and higher animals that responds to foreign molecules (antigens) by producing antibodies to destroy them

implicit order — information or characteristics that exist as potential in a system but cannot yet be directly observed

inconsistency — an incompatibility of one fact or claim or property with another within an entity, such as an argument. In biological evolution, any mutation, whether random (i.e. unpredictable) or not, may result in inconsistency, which is discarded, or reconciled and integrated, by the self-organizing entity.

indexicality — following C.S. Peirce, words whose specific meaning must be interpreted in context, e.g. I (since “I” is different depending upon who is speaking), they, now, today

individuality — the ability to distinguish between entities belonging to the same class (e.g. all humans are individuals)

induction — the process of arriving at generalizations from particular instances; a type of inference where, given a set of sentences implied by an unknown theory and given a set which are contradictory to the theory generates the theory that is logically consistent with the sentences. Hume, in his Treatise on human nature, tackled ‘the problem of induction’, asking, What reason can anyone have for assuming that future observations will resemble past ones? For example, why should the sun rise tomorrow morning – apart from the fact that it has always done so in the past? Consequently, on what grounds can we ever accept, uncritically, those ‘laws of nature’ which are merely induced from observed facts? Karl Popper was a strong opponent of induction with his famous question: How can we say all swans are white just because we have never seen a black one?

infectivity — capable of producing infection; one method proposed for the introducing new genetic material through viral infection

inference — reasoning from an initial state toward a goal

infinite regress — the notion that any argument must be justified by another, which must be justified by another, and so on ad infinitum

information — “absolute” and “semantic” information. Absolute information, defined by probability theory, is the average number of bits needed to decipher a message. Semantic information (interpretation and meaning) is not easily defined mathematically.

information theory — science of storage, transmission, and processing of information

insertion — mutation in which one or more new nucleotides are incorporated into a nucleotide chain

instructed synthesis — synthesis according to instructions on a template, e.g. as in the synthesis of RNA or proteins

intentionality — the reference of mental objects to content. The term “intentionality”, which derives from the Latin “intendere”, meaning to point, was introduced by the philosopher Edmund Husserl, to designate mental acts that point to what is objective, i.e. phenomena that are *about* something.

intelligence — traditionally defined as mental capability to learn from experience, to adapt to new situations, to comprehend and employ abstract concepts, and to use knowledge to manipulate one’s environment. In addition, the term is used here to refer specifically to the ability to construct, connect and integrate, i.e. to synthesize.

interim result — provisional output (pro-vision, to foresee), temporary, pending achievement of the final result

interpretation — deriving logical conclusions from premises known or assumed to be true

interstellar ice — distinguished from Earth ice in lacking a crystalline structure. Ices, formed through condensation of simple molecules onto interstellar dust grains, are the building blocks of comets, so complex organics formed in within the ice could have been delivered by comets and other bombardment to primordial Earth and other habitable planets.

intron — (abbreviation for “intervening region”) non-coding intervening sequence on a mosaic gene; in contrast to an exon it carries no genetic information; its genetic function is at present unknown

introspection — derived from Latin *intro* (within) and *specere* (to look), describes a process of self-observation

intuition — insight providing knowledge that cannot be explained rationally

invention — composition that does not fit established categories

ionic bond — an electrical attraction between two oppositely charged atoms or groups of atoms. Although atoms are normally neutral and have no charge, to gain stability they sacrifice neutrality by either losing one or more of their outermost electrons to become a positive ion (cation) or gaining one or more electrons become a negative ion (anion). "Metallic" elements tend to lose electrons, while "non-metallic" elements tend to gain electrons, resulting in charged atoms that attract each other. This electrical attraction between two oppositely charged ions is an ionic bond.

irreducible complexity — attribute of a system composed of parts that collaborate to perform its basic function, such that lack of any part means that the whole system cannot function. Any

system that cannot be evolved through successive adaptation and environmental selection because it could not function (and so be selected) if it were any simpler, e.g. an eye cannot be selected for until it can see. Biochemist Michael Behe first used this expression (1996) to argue that some structures are too complex at the biochemical level to be adequately explained as a result of evolutionary mechanisms. Some scientists reject the concept out of hand because it has attracted intelligent design and creationists.

isomers — chemical compounds with the same number of atoms distributed differently in space with respect to one another

isotonic cell — relaxed, having the same concentration of solutes inside and outside

isotopes — atoms of the same element that differ in the number of neutrons in their nuclei, which have the same atomic number but different atomic weights

Isotropic variation — heritable phenotypic variation not directed toward adaptive needs of the organism. If all variation is isotropic, selection would be the creative force in evolution.

iteration — repetition of a procedure, e.g. in a cyclic problem-solving process

Jupiter — largest planet in the solar system, fifth planet from the sun, revolves around the sun in 11.86 years at a mean distance of 778 million kilometers (483 million miles), a mean diameter of approximately 142,000 kilometers (88,000 miles), and a mass about 318 times that of Earth.

K stars — orange stars with a surface temperature of 3000 to 4000 K. in the case of giants and 4000 to 5000 K. in the case of dwarfs. Best known examples are Aldeberon and Arcturus.

Kuiper belt — disk-shaped region of minor planets outside the orbit of Neptune at the edge of the solar system

Lamarckian inheritance of acquired characteristics — Though Lamarck did not originate this idea, it widely prevailed in his time, and he was blamed for it. The incorrect theory that when animals adapt physiologically or behaviorally to stressful conditions, they pass that adaptation to their offspring. See pangsesis, Darwin's version of this idea.

ligation — joining linear DNA fragments together with covalent bonds

lipids — along with proteins, principle structural components of living cells, which include fats and other compounds, generally insoluble in water, which have a tendency to pack side by side in sheets, as in cell membrane

liposomes — spherical synthetic layers of lipids, which form vesicles that enclose water, organics and other matter

Lamarckism — transmission of acquired characteristics, a concept incorrectly attributed to J.B. Lamarck

LUCA — our Last Universal Common Ancestor

macromolecule — giant molecule; a polymer such as proteins, nucleic acids, and sugars

meaning — an ideal of communication, where intention (of the communicator) and interpretation (of the receiver) are correlated, or one of the above in the absence of the other

membrane proteins — proteins that are part of biological membranes

memory — the capacity to alter behavior based upon past experience; memory exists in non-living systems: inorganic molecules can retain memory of a dye; vortices ordered by pressure gradients jump to new states based upon their history

messenger RNA (mRNA) — RNA that serves as a template for the synthesis of proteins

metabolism — the production of chemical energy (ATP) and biological useful chemicals in the cell

micelles — a class of aggregate formed by lipids or other amphiphilic molecules (most frequently, though not exclusively) in an aqueous environment. See amphiphiles.

microbe — also microorganism or germ, an organism of microscopic or ultra-microscopic size

microsphere — a primitive compartment easily formed by protein and postulated by Sidney Fox to have been the precursor of the living cell

mitochondria — organelles in the cytoplasm of all aerobic eukaryotic cells that house the enzymes of the respiratory chain and are the site of ATP production

mitochondrial Eve — the most recent common ancestor for all living humans

monomer — repeating molecular subunit of a polymer through which, by a repeated chemical reaction, the polymer is assembled

morphogenesis — development of shapes of tissues, organs and entire organisms and the positions of the various specialized cell types

multimer — a molecule with many parts, in contrast to a polymer, which suggests a regular, ordered chain

mutation — an heritable change in a chromosome

naked gene — proposed by H. J. Muller, later Carl Sagan and others, a “stripped down” definition of the minimum living entity that has the potential to evolve through natural selection, a proto-DNA molecule central to many information replicator origin theories. The “naked gene” implied that a self-replicating polymer could have arisen from the random association of its building blocks

nanobacteria — also nanobes; cell walled micro-organisms with a diameter well below the generally accepted lower limit (about 200 nanometers) for bacteria.

neo-Darwinism — also known as the Modern Synthesis; a revision (1940s) of Darwin’s theory that random mutation and environmental selection are together a sufficient and complete explanation of evolutionary change to account for modern genetics, fusing genetics with Darwin’s “descent with modification” and emphasizing natural selection as the source of evolutionary change; a gradualist view incorporating Mendelian inheritance and population genetics

neo-Lamarckism — modern variants of the theory of role of behavior and learning in evolution, which takes on new meaning in the context of evolutionary robotics and genetic engineering

nestedness — diverse usage, from ecology to agent belief structures, to describe one entity or attributed subordinate to and contained within another

niche — in evolution a isolated habitat where species can develop without the pressure of full competition

nonanoic acid — a nine-carbon chain producing a carboxylic acid, also called pelargonic acid, an organic compound used in plasticizers and lacquers and as flavorings

nucleic acids — polymers comprised of nucleotides found in all living cells, which occur primarily in the form of DNA and RNA

nucleobase — the parts of RNA and DNA that may be involved in pairing up (see also base pairs). These include cytosine, guanine, adenine, thymine (DNA) and uracil (RNA). These are abbreviated as C, G, A, T, and U, respectively; also called bases in genetics

nucleoprotein — any of several substances found in the nuclei of all living cells, consisting of a protein bound to a nucleic acid, the principal constituent of the hereditary material in chromosomes required for cell division and reproduction

nucleosides — created by adding a sugar to a base; nucleic acid condensed with a molecule of sugar ribose or deoxyribose; compounds, such as guanosine or adenosine, that consist of a purine or pyrimidine base combined with deoxyribose or ribose, found especially in DNA or RNA. Any of various compounds consisting of a sugar, usually ribose or deoxyribose, and a purine or pyrimidine base, especially a compound obtained by hydrolysis of a nucleic acid, such as adenosine or guanine.

nucleotide — created by adding an inorganic phosphate to the sugar phosphate backbone of the nucleoside (nucleoside condensed with a single phosphate group), you have a nucleotide; a molecule consisting of three parts: an organic base plus a sugar plus a phosphate ion; when nucleotides are strung together, they produce RNA or DNA polymers; the nucleotide (a monomer) is the repeating unit of nucleic acids

objectivity — that which can be verified as “truth” or “reality” in the external world independent of the knower, as opposed to “subjectivity”, which depends upon the mind of the knower (see below). Something is objective if it exists, independent of any knowledge, perception, or consciousness.

ontogenesis — development of organisms

operon — group of genes regulated together as a single unit

organelle — precursor of an organ, a differentiated structure within a cell, such as a mitochondrion, vacuole, or chloroplast, that performs a specific function.

oxidation — combination of a substance with oxygen. A reaction in which the atoms in an element lose electrons and the valence of the element is correspondingly increased. a) chemistry: originally the addition of oxygen and removal of hydrogen; now more broadly the loss of electrons through the gain of oxygen b) biology: production of useful energy by the stepwise oxidation of energy-rich matter

pangeneses — Darwin’s theory (later refuted) of the inheritance of acquired characteristics (see Lamarckism). He proposed that cells in the body produce informational particles in amounts related to their physiological use. theory Charles Darwin sought to explain the use and disuse of organs through gemmules containing hereditary information from every part of the body that coalesce in the gonads and are incorporated into the reproductive cells.

panspermia — notion that living microbes pervade the universe and that life was seeded on Earth rather than starting here

paradox —an acceptable premise or line of argument that leads (circularly) to an impossible conclusion, which expresses a fundamental contradiction; exemplified in Bertrand Russell's Theory of Types as the "vicious circle principle"; i.e. no collection of objects can be a member of itself, as in the barber who shaved all men in the town who did not shave themselves

peptides — compound formed of two or more amino acids linked by peptide bonds; short protein chains; linear molecule formed by the condensation of two or more amino acids with the expulsion of water; any of various natural or synthetic compounds containing two or more amino acids linked by the carboxyl group of one amino acid to the amino group of another.

persistence — continuing existence of an effect even after its cause is removed

perception — our internal impression related to the external world, generally through the interaction of our senses with external stimuli, i.e. sensory perception, underlying disagreement about how we acquire knowledge about the external world

Periodic Table — chemical elements arranged in order of increasing atomic number such that elements having similar properties occur at regular intervals on the list, revealing "families" of elements

phase transition — the transformation of a thermodynamic system from one state to another (e.g. ice to water).

phenotype — expression of genes in an organism; the organism itself

pheromone — chemical secreted by an animal, especially an insect, that influences the behavior or development of others of the same species, often functioning as an attractant of the opposite sex

photoautotroph — organism capable of using light for its nutrition by converting light into energy to synthesize cell material from inorganic compounds (carbon dioxide, nitrogen salts)

photolysis — chemical decomposition by the action of radiant energy

photosynthesis — process through which chemical energy is generated from sunlight: hexose carbohydrates are formed from carbon dioxide and water in the chloroplasts of living plant cells, with oxygen or sulfur produced as a waste product from the compounds water and hydrogen sulfide that provide the hydrogen

phylogeny — a) evolutionary history of all species/ b) history of the development of a particular interrelated groups of species

plasmid — independent unit of hereditary material that lives in symbiosis with a cell; some plasmids are replicated with the cell's nucleus; others proliferate independently

plasticity — capacity of organisms with the same genotype to vary phenotype in response to varying environmental conditions; or capacity to alter neural circuits and synapses of the nervous system in response to experience or injury

poised system — biological system ready to be triggered by a regulatory event

Poisson distribution — limiting case of the binomial distribution in which the probability of a particular event is very small but the number of chances of its occurrence is high; the Poisson distribution is used to calculate the number of chances that a particular mutation will occur, given the number of errors and error frequency.

polar bonds — also known as a covalent bonds; covalent bonds are formed as a result of the sharing of one or more pairs of bonding electrons. Each atom donates half of the electrons to be shared. This sharing of electrons is as a result of the electro-negativity (electron attracting ability) of the two bonded atoms

polymer — macromolecule (giant molecule) composed of monomers; four types of polymers make up the living cell: nucleic acids, proteins, sugars, and lipids, a regular, ordered chain

polymerization — the process through which simple molecules join to form complex molecules that contain repeating structural units of the original molecules, preserving their functional integrity; formation of a polymer by a succession of similar linkages between monomers; polymerization may occur either through addition in which the whole monomer is incorporated into the polymer, or by condensation, in which the linkage is formed through elimination of a small molecule (e.g. H₂O in the case of the peptide linkage)

polymerase — group of enzymes that catalyze the synthesis of polynucleotides from energy-rich monomeric nucleoside triphosphates

polypeptide — combination of peptides

population — members of the same species

possibilistic — options without specification of probabilities. In contrast to deterministic systems, possibilistic systems leave some uncertainty in the specification of future states and behavior, and so are non-deterministic.

prebiotic synthesis — synthesis of basic biochemical monomers, such as amino acids or nucleotides under conditions assumed to correspond to those that existed on early Earth, e.g. the Miller-Urey experiment.

prokaryotes — the smallest free-living organisms, the eubacteria and archaebacteria (or archaea); primitive one-celled organisms that preceded the eukaryotes; prokaryotes have a genome of circular DNA contained in the cytoplasm, but lack a membrane boundary or nucleus, e.g. bacteria. They divide asexually, some rapidly.

proposition — the object of a conscious mental act, a plan or scheme to be considered, accepted, adopted, or executed

protein — most important functional molecules of the cell, which act as catalysts (enzymes), as regulators (promoters, repressors), receptors (with lipids) and material for the construction and reinforcement of cellular structures (also with lipids); protein structure is the polypeptide chain, a polymer comprised of 100+ amino-acid monomers joined by peptide bonds. The chain folds up in a characteristic way, bringing different functional groups into close proximity and forming a catalytically active core. Some proteins (e.g. myosin) perform multiple functions. Since proteins cannot be “read” like nucleic acids, their synthesis must be “programmed” or “instructed.”

proteinoids — high molecular weight polymers; synthesized proto-proteins important in the origin of life theory of Sidney Fox, which he formed by heating mixtures of amino acids containing high proportions of aspartic and glutamic acids

protein sequence — sequence of covalently linked amino-acid monomers in a protein (also called the primary structure of a protein)

protist — eukaryotic single-celled organism, such as an amoeba or paramecium; the first protists probably arose 2 billion years ago

protobionts — transitional creatures that preceded living cells in the origin of life, the first self-replicating entities

provirus — stage in the life cycle of a retrovirus in which that virus is integrated into the chromosome of the host cell and multiplies by replication along with the host cell

purine — class of nucleic acid bases whose members are adenine and guanine

pyrimidine — class of nucleic acid bases whose members are cytosine, thymine and uracil

quasi-species — defined by Manfred Eigen as a weighted distribution of mutants centered around one or several master sequences; the target of selection in a system of replicating individuals that replicate without cooperating with one another (RNA molecules, viruses, bacteria); in evolution theory it replaces the “wild type”, which was regarded as the target of selection in the classical analyses of selection; group of species with a defined probability distribution that emerges via selection.

racemic — system containing equal proportions of left- and right-handed derivatives (enantiomers) of the same compound

random — descriptor for an event in which all outcomes are equally likely

random mutation — change of the DNA base sequence (order of A,T,G, and C) not directed to particular regions of the genome by selective conditions of the environment

rationalism — school of philosophy arising in the 17th and 18th centuries that traces its roots to Descartes and his *Discours de la méthode*, which sought certainty starting from internal mental acts and established premises followed by deduction to reach conclusions

recognition — in its simplest form, recognition exists in many non-living systems and can operate simply the way that a key “recognizes” a lock. In the study of thinking and memory, recognition is the process whereby things are identified as having been previously apprehended or as belonging to a known category, a key challenge in the design of artificial intelligence. Note that the dictionary.com definition offers eleven connotations, ten of which require human consciousness. But the eleventh gives this term the breadth required:

1. To identify as something or someone previously seen, known, etc.: He had changed so much that one could scarcely recognize him.
2. To identify from knowledge of appearance or characteristics: I recognized him from the description. They recognized him as a fraud.
3. To perceive as existing or true; realize: to be the first to recognize a fact.
4. To acknowledge as the person entitled to speak at a particular time: The Speaker recognized the Congressman from Maine.
5. To acknowledge formally as entitled to treatment as a political unit: The United States promptly recognized Israel.
6. To acknowledge or accept formally a specified factual or legal situation: to recognize a successful revolutionary regime as the de facto government of the country.
7. To acknowledge or treat as valid: to recognize a claim.
8. To acknowledge acquaintance with, as by a greeting, handshake, etc.
9. To show appreciation of (achievement, service, merit, etc.), as by some reward, public honor, or the like.
10. Law. to acknowledge (an illegitimate child) as one's own.
11. *Biochemistry, Immunology*. To bind with, cleave, or otherwise react to (another substance) as a result of fitting its molecular shape or a portion of its shape.

recombination — rearrangement of DNA to produce a new sequence by any of several means

recruitment — principle proposed by Charles Sherrington to explain how life collects and organizes matter into a pre-existent structure, but this principle is also manifest by non-life, e.g. a cyclone

recursion — a repeated procedure such that the required result at each step except the last is given in terms of the next step; in computer science the technique of defining a function (e.g. a mathematical function or a function in a program) partly in terms of itself. A base case establishes values for some parameters of the function. Recursion is suited for problems with crisply defined goals and objectives and proficient at searching through vast combinations of possibilities, such as sequences of chess moves.

reduction — the gain of electrons; opposite of oxidation; the extent to which Earth's early atmosphere was reducing is correlated with how much hydrogen it contained

reductionism — a product of rationalism, the notion that phenomena can be reduced to simpler phenomena and thereby explained. "Reductionism, like materialism, has uses that are appropriate; it can be valuable to know an object's parts and how they are joined in order to understand likenesses, differences and basic principles. But it can also be used inappropriately. It is appropriate to use reductionism as a way to understand what can be known empirically, inappropriate to use it to confront what is not empirically known or knowable. Here reductionism refers primarily to the question of whether biology (and its processes, such as evolution) is reducible and explainable by chemistry and physics.

redundancy — in information theory the repetition of information

reflexivity — that which turns back upon itself and takes account of itself, especially methods that take into account the effect of the personality or presence of the researcher on the investigation. A relation R is called \sim if for any a from its domain $a R a$.

replicase — polymerase that participates in the replication of DNA and RNA

replication — doubling the nucleic acid molecule to give two identical products, normally with the help of a catalyst (enzyme)

replicator — any individual that is self-reproducing by whatever means (DNA molecule, virus, clay etc.)

repression — blocking the reading of a gene (by a repressor)

repressor — protein molecule that blocks the reading of a gene by binding too the corresponding operator

retrovirus — family of RNA viruses that infect humans and other vertebrates. Their single-stranded RNA genome is transcribed into double-stranded DNA (a provirus). This step, the opposite of the typical direction of information transfer from DNA to RNA, is catalyzed by a viral enzyme called RNA-dependent DNA polymerase or reverse transcriptase

ribonucleic acid — RNA; differs from DNA in its use of the sugar ribose (instead of deoxyribose) and the base U (instead of T) and usually occurs in a single-stranded, rather than double-stranded structure; plays structural, functional, and information transmission roles

ribosome — readout device, not unlike a tape player, that translates the mRNA message by converting the purine/ pyrimidine language into an amino acid

ribozyme — enzyme composed of RNA that catalyzes template-directed assembly of complex RNA molecules from simpler molecules (the process called polymerization)

ribose — the sugar component of the nucleotides from which ribonucleic acid (RNA) is assembled; simple sugar molecule comprised of five carbon atoms

RNA phage — a phage (virus) whose genome is composed of RNA

RNA polymer — nucleotide

RNA polymerase — polymerase responsible for the transcription of DNA into RNA

RNA World — The discovery that RNA could both catalyze and replicate led Walter Gilbert in 1986 to coin the expression “RNA World” to designate this hypothetical stage when RNA was a precursor for the evolution of life. The “RNA World” hypothesis posits that before the evolution of proteins, RNA enzymes catalyzed the chemical reactions necessary for life, including the replication of DNA.

rRNA — RNA component of the ribosome

rules of inference — rules by which reasoning from an initial state toward a goal occurs

scientific method — accepted method for discovering knowledge. The scientific method has been defined in different ways by a range of thinkers since Plato. It has been represented both as rationalist and theoretical (following from Rene Descartes) and as materialist and empiricist/experimental (following from Francis Bacon). From the time of the Renaissance this expression has generally referred to a method characterized by starting from basic premises assumed to be true, stating an hypothesis and proceeding either through argument or experiment to reach the conclusion of proving or disproving the hypothesis.

selection by attraction — concept proposed in this book for the toolkit of origin of life theorists; a mechanism for making choices that does not require consciousness, as illustrated in the inanimate world, e.g. magnets, cyclones; a mechanism whereby Sherrington’s principle of “recruitment” could operate

selection pressure — pressure exerted by environmental conditions toward particular types of adaptation

self organization — in nature illustrated by systems that start disordered and featureless, but then spontaneously organize themselves to produce definite structures

self-organized criticality — in physics, a critical point at which a system radically changes its behavior or structure, e.g., from solid to liquid

signal transduction — the process through which a cell receives a signal at its surface and relays it through the cytoplasm through controlled internal chemical changes. See transduction (signal)

signaling (permissive and instructive) — Permissive signaling denotes a complete response built into the receiver, then internally repressed. When the signal relieves the repression, the receiver unleashes its ready-made response. In instructive signaling, the response is not built in ahead of time; the signal must provide information for generating the response.

simulation — the imitation of the behavior of some situation or process by means of a suitably analogous situation or process, especially for the purpose of research and development or training. The process of executing operations in a model resembling a real system rather than in

the system itself. The goal is to predict aspects of the behavior of the real system based on results obtained from the model.

somatic — of or pertaining to the body

specified complexity — term coined by Intelligent Design theorist William Dembski, who argues that one can rigorously show by applying so-called no free lunch theorems the inability of evolutionary algorithms to select or generate configurations of high specified complexity, though his arguments have generally been rejected by the scientific community

species — category in a classification system, a type or class. “Species” refers to the lowest level category in a classification system for living organisms; it was originally defined as comprising a breeding population of organisms able to produce offspring also capable of reproduction. But recently this definition has been questioned as it has been shown not to apply to plants and to have exceptions in animals. Species is the basic unit of biological classification the category below genus.

state cycle — term used by Stuart Kauffman to describe an attractor or cell type in his Random Boolean Network model for gene regulatory networks.

stigmergic — lacking direct inter-agent communication or a preprogrammed global blueprint of the final design; each agent’s behavior is controlled by stimuli provided by the common environment, a form of indirect communication

stigmergy — indirect communication among agents via the environment without targeting any specific recipient. In stigmergy communication is achieved by modifying the environment, as in ant pheromone trails.

stochastic — random behavior of individual participants in a dynamic (time-dependent) process characterized by statistical methods

strand displacement — the ability to displace downstream DNA encountered during synthesis. Protocols such as the isothermal amplification method Strand Displacement Amplification (SDA) exploit this activity. SDA is an isothermal nucleic acid amplification method.

subjectivity — entities that could not exist except through knowing, perceiving, believing and other mental acts

symbiosis — a long term association between species; partner sharing in symbiosis may be behavioral, metabolic, and genetic

symbiogenesis — the formation of a new organ, or a whole new organism, through mutual selection

symmetry breaking — the breaking of symmetry (geometrically-ordered repetition of elements) that sometimes characterizes a phase transition

synergetic evolution — process employing the Theory of Facilitated Variation of Marc Kirschner and John Gerhart whereby the effectiveness of behavioral choices plays a role in evolutionary direction as the target of selection improves its performance.

synergy — when the behavior of the whole is greater than the sum of its parts

system — a whole comprising an organization of parts such that the parts function in harmony to perform an integrated function. It is important to distinguish between “open systems”, which allow new input, and “closed systems”, which do not.

tautology — a statement rendered logically meaningless because it is self-dependent, e.g. the “survival of the fittest” depends on who survives

teleology — purpose or what Aristotle called “final cause” (he contended that a thing’s goal was one way to explain its behavior), the property of objects whose behavior appears to be directed toward attaining or maintaining a goal

teleonomy — term coined by biologist Jacques Monod to denote the seemingly purposeful structure, performance, and functions of biochemical mechanisms, achieved, however, without any actual goal

template — a) biology: a molecule or molecular pattern that determines how other molecules are assembled into a macromolecule, e.g. DNA and RNA molecules that contain information in a particular nucleotide sequence used to synthesize other like molecules; b) mechanics: a mould or model against which to design or compare something being fabricated; c) cognition: a pattern against which to compare and match something to be identified and recognized.

tensegrity — “discontinuous compression structures” where compression forces (the rods pushing out) are not connected, while tension forces (the cables or wires pulling in) make a continuous structural web. No rod touches any other; the rods appear to be floating in space, held in place only by the web of cables at their endpoints.

theory — an integrated mental abstraction offered to make sense of more complex data and information in a given domain

thermodynamics — science of heat, work, and equilibrium; the relationship between heat transfer and the change of state of a system; the measure of equilibrium in a given system. The first law of thermodynamics is the principle of conservation of energy. The second is the law of entropy, which states that in closed system any process (whereby heat is converted to work) will tend toward an increase in entropy.

thioesters — compounds resulting from the bonding of sulfur with an acyl group (an alkyl group attached to a carbon-oxygen double bond), with the general formula R-S-CO-R and also esters in which the ester carbonyl oxygen has been replaced with a sulfur with the general formula R-O-CS-R. Nobel laureate Christian de Duve believes that the thioester bond was critical for the origin of life and proosed that a “Thioester World” which preceded and developed into an “RNA World.”

threshold — critical value for a system at which a major change in systemic behavior will occur (e.g. error threshold)

thought experiment — conceptualization of a problem through use of analogy to visualize a situation, carry out an operation in this situation, and observe what happens. This method is typically used in science to learn about nature without empirical data, i.e. simply by thinking.

thymine (T) — one of the bases of the nucleic acids; see base.

Titan — largest of the known moons of Saturn and the only satellite known to have its own atmosphere comprised primarily of nitrogen, methane, and hydrogen with traces of hydrocarbons and nitriles; of interest to origin of life researchers because of its organic chemistry and meteorological phenomena, such as haze variations like morning fog

tolerance — in engineering, the specification of a machine part to a certain standard of accuracy to allow for a standard level of deviation, and the permitted variation parameter for a product. The term is here used to refer to the permitted level of variation or deviation from a given norm.

topology — mathematical discipline concerned with continuity and connectedness, which describes sets of points and their relations that remain unaltered under elastic deformation (homeomorphism)

transcription — rewriting of a genetic message of DNA into RNA, resulting in a transcript of the information in the DNA; the process by which messenger RNA is synthesized from a DNA template resulting in the transfer of genetic information from the DNA molecule to the messenger RNA

transduction (energy) — transfer of molecules across membranes against a concentration gradient - from low to high chemical potential

transduction (genetic) — transfer of genetic material from one microorganism to another by means of a viral agent (bacteriophage); introduction of viral gene carriers into cells for the purpose of gene transfer
energy transduction

transduction (signal) — transfer of signals so cells can respond to their environment, degrade, differentiate, divide, grow, cease growth, secrete, synthesize, and even die when the appropriate signal is given. This signal invariably is a molecule, which binds to a receptor, typically on the cell surface.

transfer RNA (tRNA) — smallish RNA molecules (c. 70 to 90 nucleotides); each binds a particular amino acid and, by means of interaction between its anticodon and the genetic message, determines the incorporation of the amino acid at the correct point in the growing protein.

transformation — in genetics a genetic modification that arises because a cell incorporates DNA from another cell or virus, or acquires a plasmid, and treats the foreign DNA in subsequent replication cycles as though it were its own

transformism — the hypothesis, or doctrine, that species arose by modification of other forms of life, or that living beings have originated by the modification of some other previously existing forms of living matter, in contrast to abiogenesis

translation — translation of a message from messenger RNA into the corresponding amino acid sequence of a protein

transposition — transfer of a piece of DNA from one place within the genome to another, which occurs relatively frequently in some DNA regions, which cannot be associated with a particular location

transposons — sequences of DNA that can move to different places in the cell genome, duplicate and excise themselves, and so are a source of mutation. First discovered by Barbara McClintock in her work on maize (1948, Nobel Prize 1983), transposons are similar in some ways to viruses and may share a common ancestor.

trigger — immediate cause of another event or chain reaction

uncertainty — Uncertainty has two connotations. In a world that we attempt to make objective, uncertainty connotes “indeterminacy” relative to quantitative domains where objective measurement is frustrated (e.g. quantum theory, Heisenberg’s Uncertainty Principle). Heisenberg used the word “uncertainty” to connote a definite quality whose actual value is not accurately known. In other words, if the clock is broken, it does not mean that time itself is uncertain. Heisenberg distinguished between uncertainty (that which we do not know accurately) and ambiguity (that which we cannot know accurately). The second connotation of uncertainty connotes more broadly the limitations of subjective perception and “doubt,” our recognition of

what we cannot know. Uncertainty pertains to our capacity to know, while ambiguity is an attribute of the object that we are trying to know.

uracil (U) — one of the bases of the nucleic acids; see base.

utility function — an internal representation of the potential fitness consequences of behavior

value peak — peak on a fitness landscape; local maximum selection value

variation — how one quality is dependent in its change upon another (e.g. the circumference of a circle varies with its diameter), and how output varies with input

vertical inheritance — inheritance of genetic material by direct descent “down” a cell line, so only direct descendants can inherit genetic material

vesicle — small vessel or pouch surrounded by a membrane, usually filled with fluid, such as water

weak linkage — in biology a regulatory connection that can be easily broken or redirected for other purposes, that is indirect, undemanding, and operates with low information. “Weak” is misleading because, from a design perspective, this is a highly tolerant “creative” connection.

widget — an unnamed gadget considered for the purpose of a hypothetical example