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Insight and analysis problem solving in microbes to machines

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ABSTRACT

A key feature for obtaining solutions to difficult problems, insight is oftentimes vaguely regarded as a special discontinuous intellectual process and/or a cognitive restructuring of problem representation or goal approach. However, this nearly century-old state of art devised by the Gestalt tradition to explain the non-analytical or non-trial-and-error, goal-seeking aptitude of primate mentality tends to neglect problem-solving capabilities of lower animal phyla, Kingdoms other than Animalia, and advancing smart computational technologies built from biological, artificial, and composite media. Attempting to provide an inclusive, precise definition of insight, two major criteria of insight, discontinuous processing and problem restructuring, are here reframed using terminology and statistical mechanical properties of computational complexity classes. Discontinuous processing becomes abrupt state transitions in algorithmic/heuristic outcomes or in types of algorithms/heuristics executed by agents using classical and/or quantum computational models. And problem restructuring becomes combinatorial reorganization of resources, problem-type substitution, and/or exchange of computational models. With insight bounded by computational complexity, humans, ciliated protozoa, and complex technological networks, for example, show insight when restructuring time requirements, combinatorial complexity, and problem type to solve polynomial and nondeterministic polynomial decision problems. Similar effects are expected from other problem types, supporting the idea that insight might be an epiphenomenon of analytical problem solving and consequently a larger information processing framework. Thus, this computational complexity definition of insight improves the power, external and internal validity, and reliability of operational parameters with which to classify, investigate, and produce the phenomenon for computational agents ranging from microbes to man-made devices.

1. Introduction

Insight and analysis are two key approaches used by problem solvers for obtaining resolutions to difficult physical, logical-mathematical, intrapersonal, social, and additional kinds of dilemmas. The phenomenon of insight is oftentimes vaguely regarded as a special discontinuous intellectual process and/or a cognitive restructuring of problem representation or goal approach that culminates into alternative novel solutions, while analysis is taken as a gradual algorithmic process progressing through intermediate goal states until a final solution is found (Sternberg and Davidson, 1996). But this nearly century-old state of art devised by the Gestalt tradition to explain the goal-seeking aptitude of primate mentality tends to neglect the problem-solving capabilities of lower animal phyla, Kingdoms other than Animalia, and advancing smart computational technologies built from biological, artificial, and composite media. An inclusive and precise definition of problem-solving intelligences across phylogenetic and technological boundaries can be produced using terminology and statistical mechanical properties of computational complexity classes (Clark, 2012a, 2014b; Box 1). Applying such an information-processing framework, as done below, reveals that nonprimate computational agents, such as microbes, plants, insects, cephalopods, birds, and supercomputers, also employ both insight and analysis when solving a range of problem categories.

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Box 1
Glossary of Terminology

- *Active and Passive Observational Learning* is a set of simple and complex social (associative) learning mechanisms, whereby an observer changes its behavior upon directly witnessing a teacher, model, or demonstrator or indirectly witnessing the environmental changes brought about by such entities. Simple and complex social learning is often heavily influenced by predisposed tendencies or reflexes, such as contagious behaviors, mimesis, response facilitation, or response priming, by motivational factors, such as social facilitation, incentive, and observational aversive conditioning, and by perceptual factors, such as local enhancement and stimulus enhancement.
- *Bose-Einstein Statistics*, independently created by Satyendra Bose and Albert Einstein, predict the unrestricted distribution of a quantum mechanical system containing indistinguishable, noninteracting particles over energy ground states or quanta in thermal equilibrium. Such systems only allow two polarization states of integer spins for particles, called bosons, with identical wave functions. The thermodynamic limit, caused by critical ultralow temperatures, brings the system to a coherent or superposed macroscopic quantum state known as Bose-Einstein condensation. An analog of Bose-Einstein condensation can occur in the operation and organization of complex technological and biological networks which converge onto one computational state. The connectivity of these quantum networks obey Bose-Einstein statistics when nodal strength is described as separate fitness or energy levels and nodal links take on the identity of particle states functioning under associative-like preferential attachment rules. In such cases, control parameter T (i.e., local absolute temperature), which dictates system behavior, is often replaced with a computational annealing parameter, such as space, time, or the "critical tunneling field strength".
- *Fermi-Dirac Statistics*, independently created by Enrico Fermi and Paul Dirac, describe the distribution of indistinguishable, noninteracting particles of a quantum mechanical system in thermal equilibrium over single-particle energy levels. Such systems only allow polarization states of half-integer spins for particles, called fermions, with identical wave functions. Particles obey the Pauli exclusion principle, which states no two identical particles can occupy the same energy level. Similar to Bose-Einstein statistics, Fermi-Dirac statistics describe the connectivity and behavior of some technological and biological networks, where again nodal strength forms separate fitness or energy levels and nodal links become particle states operating under associative-like preferential attachment rules.
- *Grover's Search Algorithm* is a member of the class (or family) of procedures that implement some or all of the properties of quantum mechanics to enhance information processing capacity and speed over that achieved by standard classical procedures. Discovered by Lov Grover, Grover's algorithm relies on an initial quantum superposition of arbitrary N eigenstates to later execute nonclassical "subroutines" involving unitary phase shifts on eigenstates and to produce a root-rate gain in the algorithmic time (i.e., $O(N^{1/2})$) needed to arrive at some "target" variable x.
- *Handicap Principle* is a consumption-value argument of fitness originated by Amotz Zahavi, the handicap principle advocates honest signaling evolves along some measurable dimension, such as ornate or modest morphology or behavior, which incurs ecological cost for communicants capable of deception. The fittest communicants, known as conspicuous consumers, express their superiority to observers by flaunting their traits in disregard of potential risks, including predation, metabolic stress, and injury. In contrast, inferior communicants, known as prudent consumers, are less likely of surviving such risky, extravagant displays and emit frugal or careful signals.
- *Hebbian Learning* is nn iterative adaptive control mechanism utilizing experience- or activity-dependent bidirectional or dual-processes associative learning rules to either strengthen or weaken nodal connections of an associative (biological or technological) network. The set of learning rules (e.g., cooperativity, coactivity or associativity, synaptic or nodal efficacy/weight, etc.) governing this kind of feedback/feedforward regulation, whether at neuronal synaptic junctions or other nodal forms of computational circuitry, are named after Donald Hebb, who is largely acknowledged as the founder of such concepts.
- *Intuitive Social Logics*, as informal inferential systems used by humans, animals, and microbes, typically fail to conform to the axioms of categorical, propositional, and predicate logics and of probability calculus. The fallibility of intuitive logics was initially revealed by the groundbreaking research of Amos Tversky and Daniel Kahneman, who studied simple strategies called representativeness and availability heuristics in humans. Representativeness heuristics reduce inferential tasks to quick exemplar or similarity comparisons. When traits or events used for judgments are unrepresentative or provide only indefinite dimensions for categorization, such as level of mating fitness and availability, the heuristic may become a nonnormative guide to decision making. Availability heuristics employ readily accessible information to judge the frequency, probability, and causality of traits and events. Because decisions result from the accessibility of perceived and/or retrieved information, these simple rules of thumb may be corrupted by inaccurate trait or event base rates under the control of subjective factors. Under such conditions, like representativeness heuristics, availability heuristics become a nonnormative guide to decision making.
- *Maxwell–Boltzmann Statistics*, named after its creators, James Clerk Maxwell and Ludwig Boltzmann, describe the distribution of distinguishable classical particles in thermal equilibrium ranges with negligible quantum effects. As with quantum networks and their statistical mechanical properties, Maxwell–Boltzmann statistical properties emerge from the connectivity and behavior of technological and biological networks operating in classical computational phases.
- *Nonassociative Learning* is divided into sensitization, an exponential response increment to a repeated stimulus, and habituation, an exponential response decrement to a repeated stimulus. This form of learning may be expressed in long- and short-term durations. There are well defined criteria (e.g., failure to form associations, stimulus specificity and generalization, learning