Are animals rational?

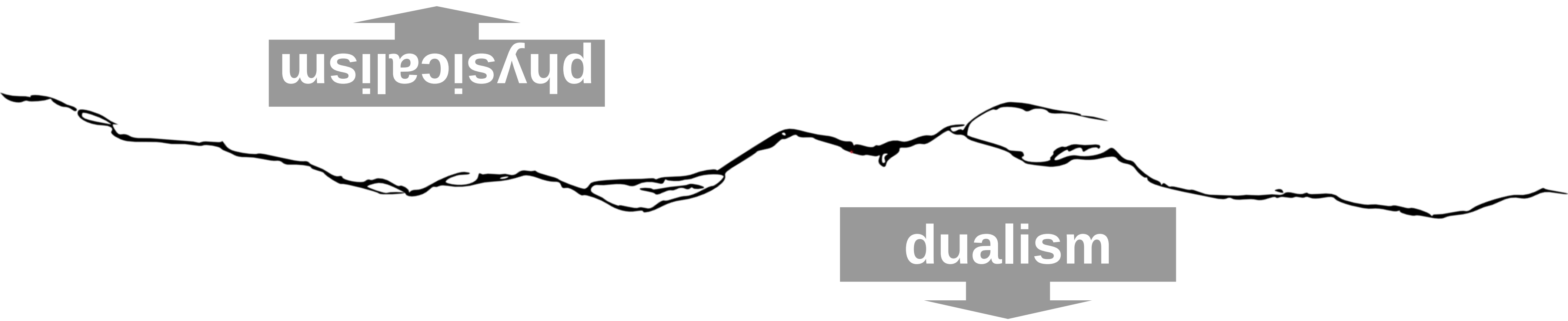
The evolution of the rational soul

Sergey Budaev
Theoretical Ecology Group, University of Bergen
> $Revision: 17920 $

- Dualism

- Plato: soul is eternal, immortal, unperishable (?) - *Phaedo*
- Aristotle: souls (*ψυχή*) is the *form* or essence of the organism (vs *matter*)
    - Vegetative soul
    - Sensitive soul
    - Rational soul

THE MIND GAP



- Descartes: mind and body are **separate** and **ontologically distinct** :: soul is immaterial => soulless automata (animals) incapable of reasoning
- *Cogito ergo sum*

- Nagel 1974
- Jackson 1982

WHAT IS IT LIKE TO BE A BAT?

CONSCIOUSNESS is what makes the mind-body problem really intractable. Perhaps that is why current discussions of the problem give it little attention or get it obviously wrong. The recent wave of reductionist euphoria has produced several analyses of mental phenomena and mental concepts designed to explain the possibility of some variety of materialism, psychophysical identification, or reduction.[1] But the problems dealt with are those common to this type of reduction and other types, and what makes the mind-body problem unique, and unlike the water-H_2O problem or the Turing machine-IBM machine problem or the lightning-electrical discharge problem or the gene-DNA problem or the oak tree-hydrocarbon problem, is ignored.

EPIPHENOMENAL QUALIA

BY FRANK JACKSON

It is undeniable that the physical, chemical and biological sciences have provided a great deal of information about the world we live in and about ourselves. I will use the label 'physical information' for this kind of information, and also for information that automatically comes along with it. For example, if a medical scientist tells me enough about the processes that go on in my nervous system, and about how they relate to happenings in the world around me, to what has happened in the past and is likely to happen in the future, to what happens to other similar and dissimilar organisms, and the like, he or she tells me — if I am clever enough to fit it together appropriately — about what is often called the functional role of those states in me (and in organisms in general in similar cases). This information, and its kin, I also label 'physical'.

- (complete) physical knowledge
- + experience

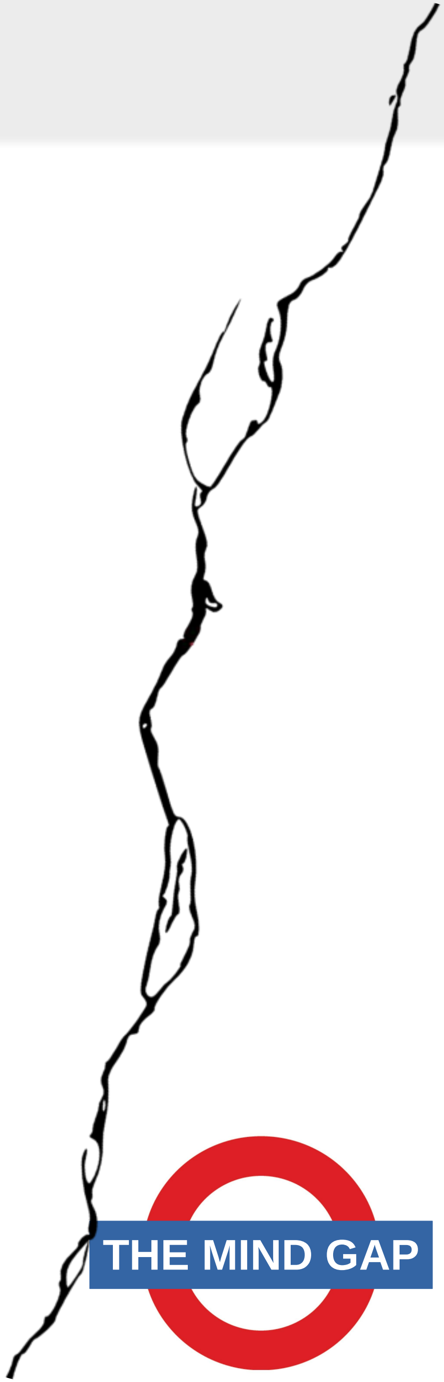
Philosophy and Phenomenological Research
Vol. LIV, No. 2, June 1994

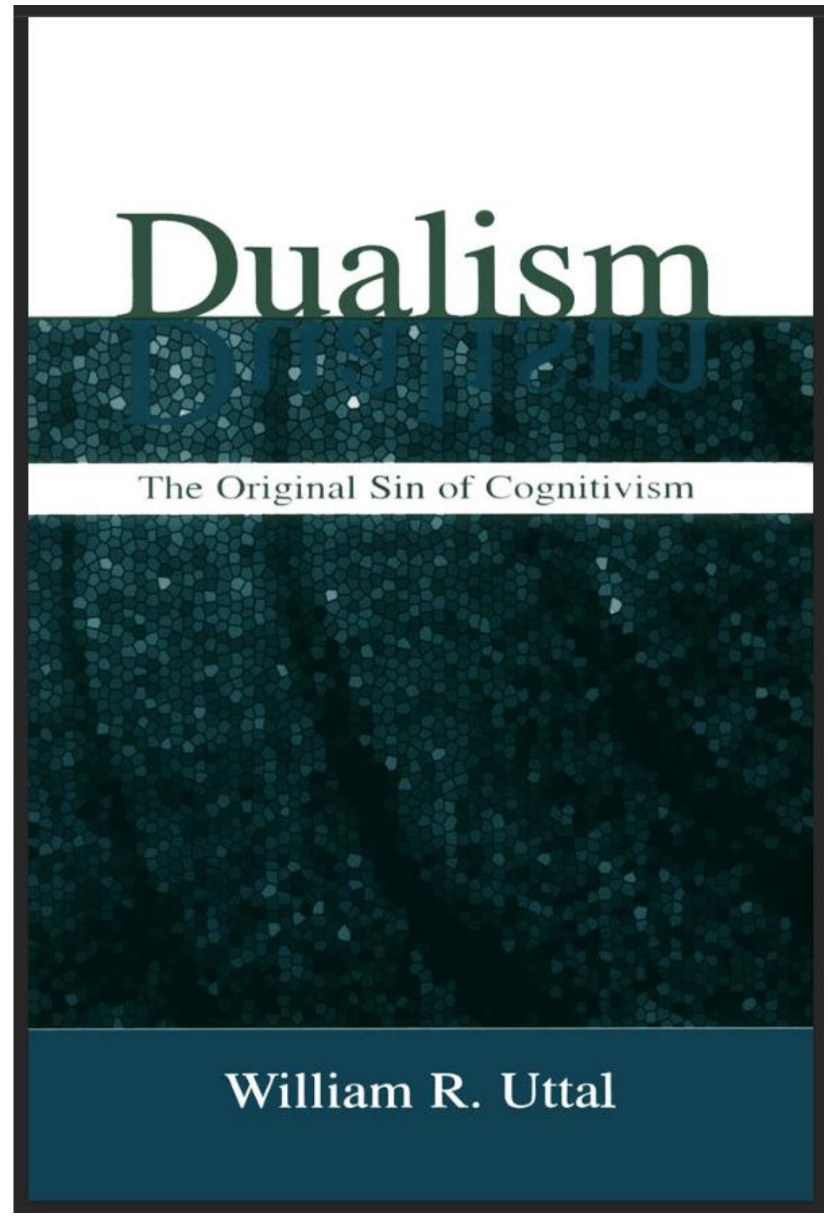
Bats, Brain Scientists, and the Limitations of Introspection

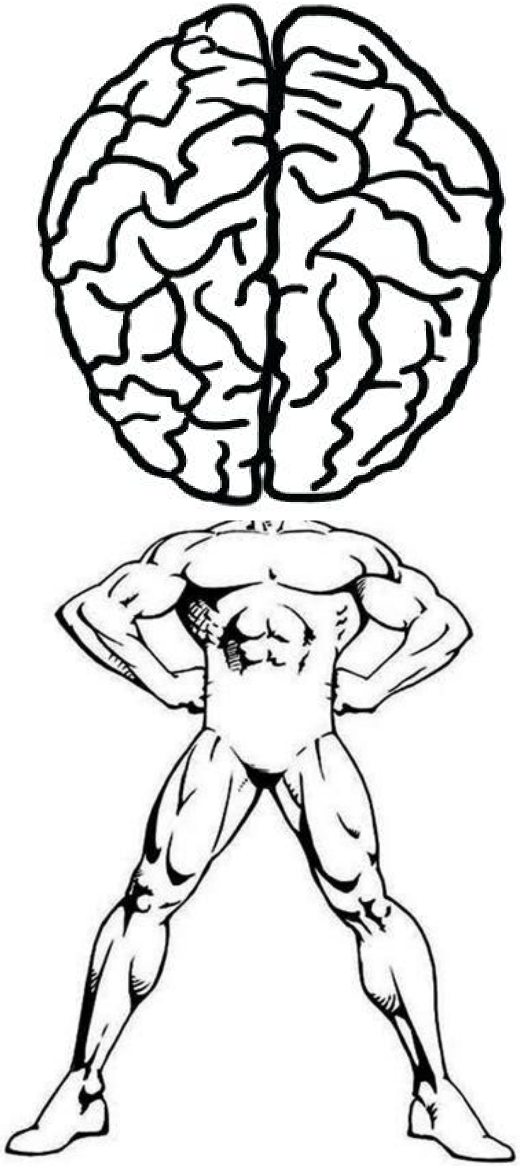
DERK PEREBOOM
University of Vermont

Thomas Nagel and Frank Jackson have advanced influential arguments designed to foil any materialist attempt to account for the mental.[1] These so-called *knowledge* arguments assume that if materialism is true, someone who possesses complete physical knowledge will know every fact about mental states there is to know. Thus, because there are facts about mental states that will not be known by someone who possesses complete physical knowledge but has never enjoyed certain experiences, it follows that materialist accounts of the mental are inadequate. In response, defenders of materi-

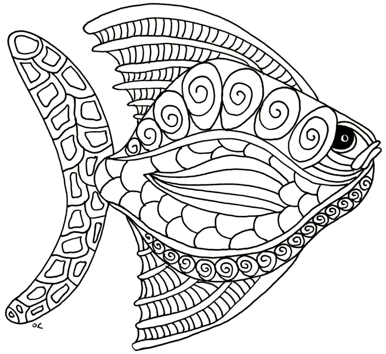
- Mind is separated
- Consciousness
- Thinking
- Inference
- Declarative ideas
- Propositionality
- Language
- Introspective communication







THE MIND GAP



- Do animals capable of **rationality**, **rational inference** in the proper sense (rather than ecological, or other “as if,” rationality)?
- Deductive inference, choice maximizing expected utility, judgement
- \- practical non-verbal inference
  \- declarative knowledge representation
  \- causal inference

THE DESCENT OF MAN

AND SELECTION IN RELATION TO SEX

BY CHARLES DARWIN

or desires. This, as Mr. Galton[49] has remarked, is all the less surprising, as man has emerged from a state of barbarism within a comparatively recent period. After having yielded to some temptation we feel a sense of dissatisfaction, shame, repentance, or remorse, analogous to the feelings caused by other powerful instincts or desires, when left unsatisfied or baulked. We compare the weakened impression of a past temptation with the ever present social instincts, or with habits, gained in early youth and strengthened during our whole lives, until they have become almost as strong as instincts. If with the temptation still before us we

ways, to risk their lives for them, and to take charge of their orphans; but they would be forced to acknowledge that disinterested love for all living creatures, the most noble attribute of man, was quite beyond their comprehension.

Nevertheless the difference in mind between man and the higher animals, great as it is, certainly is one of degree and not of kind. We have seen that the senses and intuitions, the various emotions and faculties, such as love, memory, attention, curiosity, imitation, reason, &c., of which man boasts, may be found in an incipient, or even sometimes in a well-developed condition, in the lower animals. They are

THE MIND GAP

- Davidson, D. (1982). Rational Animals. Dialectica 36: 317–327.

Rational Animals

by Donald Davidson *

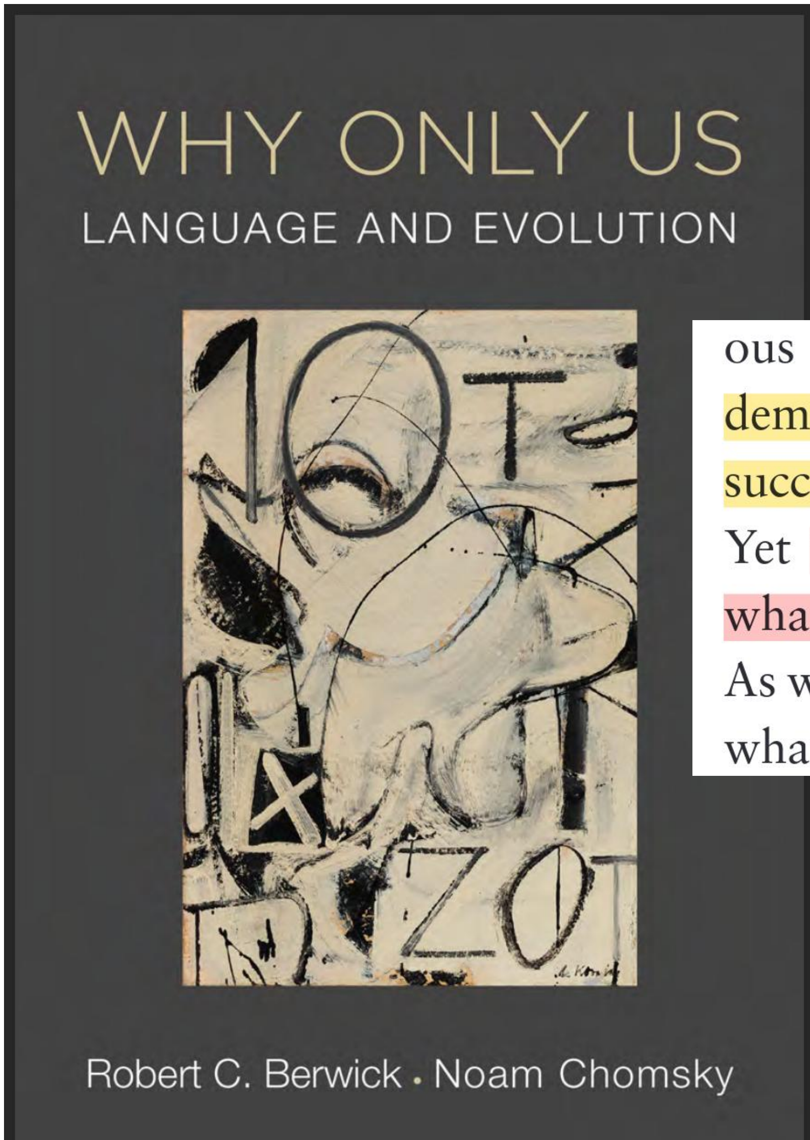
Summary

Neither an infant one week old nor a snail is a rational creature. If the infant survives long enough, he will probably become rational, while this is not true of the snail. If we like, we may say of the infant from the start that he is a rational creature because he will probably become rational if he survives, or because he belongs to a species with this capacity. Whichever way we talk, there remains the difference, with respect to rationality, between the infant and the snail on one hand, and the normal adult person on the other; this difference is discussed here.

The difference consists, it is argued, in the having of propositional attitudes such as belief, desire, intention and shame. This raises the question how to tell when a creature has propositional attitudes; snails, we may agree, do not, but how about dogs or chimpanzees? The question is not empirical; the question is what sort of empirical evidence is relevant to deciding when a creature has propositional attitudes.

It is next contended that language is a necessary concomitant of any of the propositional attitudes. This idea is not new, but there seem to be few arguments in its favor in the literature; one is attempted here.

Crucial to the considerations advanced is the idea that belief depends on having the concept of objective truth, and that this comes only with language.



ous sin. He had merely pointed out the truth: Darwinism demanded strict gradual continuity with the past—"numerous, successive, slight modifications" between our ancestors and us. Yet there *is* a yawning chasm between what we can do and what other animals cannot—language. And there lies a mystery. As with any good mystery, we have to figure out "whodunit"—what, who, where, when, how, and why.

THE MIND GAP

Darwin's mistake: Explaining the discontinuity between human and nonhuman minds

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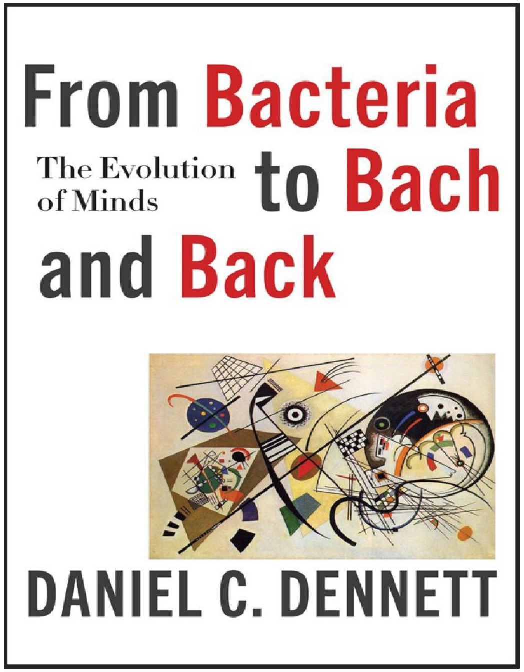
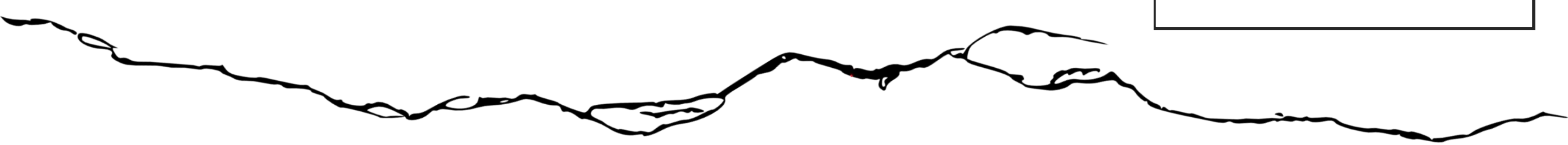
THE MIND GAP

- The **rational soul** principally differs from the sensitive soul
- It depends on compositional **symbolic** language (also capable of self-reference)
- Language evolved quickly and suddenly only in one species

- *Darwinian*: no learning or experience, random mutation and selection
- *Skinnerian*: can learn by trial and error
- *Popperian*: learn + imagine action

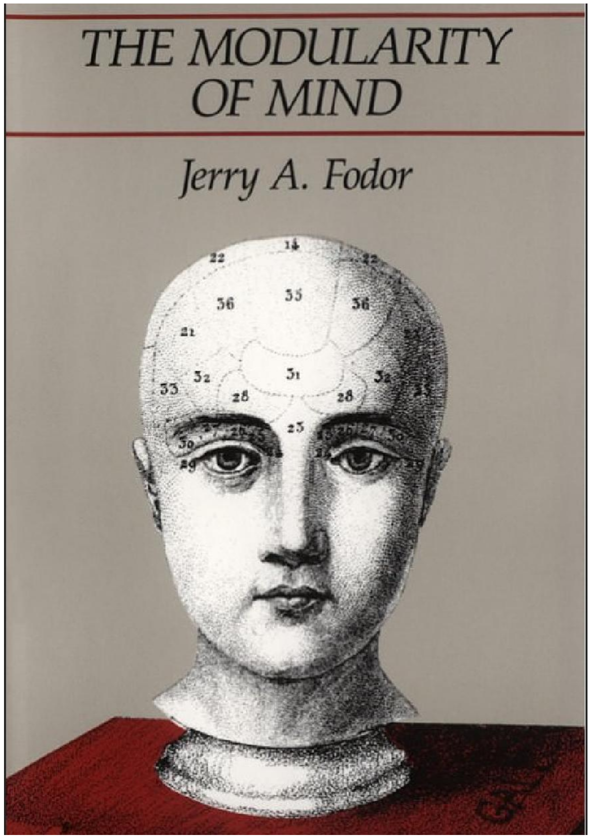




- *Gregorian*: <u>collectively</u> designed symbolic environment : language

THE MIND GAP

- **Rationality in the proper sense**: action guided by reason :: rationality is thought to be linked with ***symbolic language***
- **Chomsky**: universal grammar is linked with *I-language* that is structure of thought, actual languages – *externalization* – thought to have evolved quickly in a single big step
- **Fodor**: LOT theory of cognition language of thought: cognition is *systematic*: propositional content + compositional, systematic, symbolic combinatorial architecture => language-like



1983

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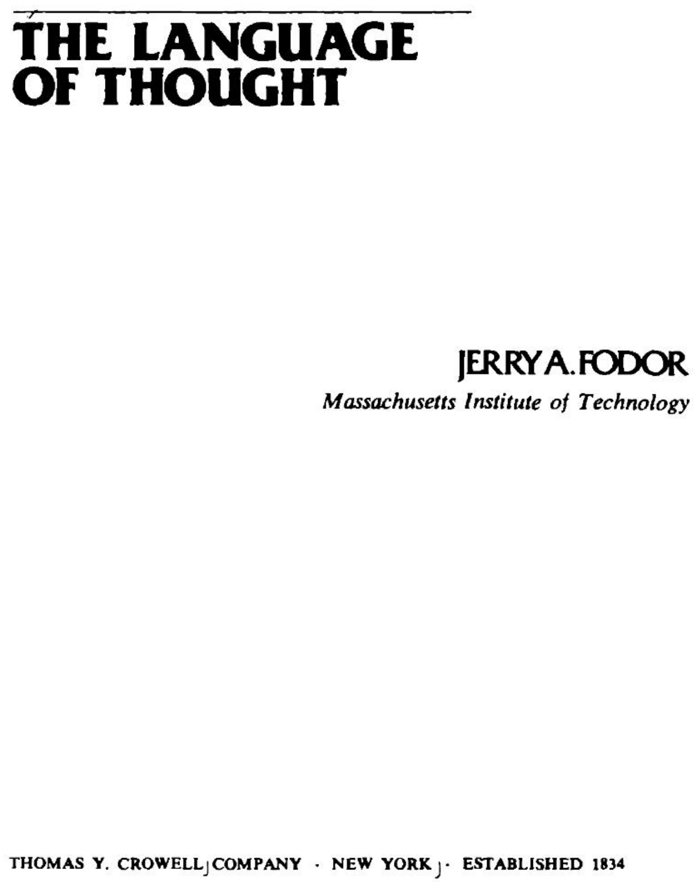
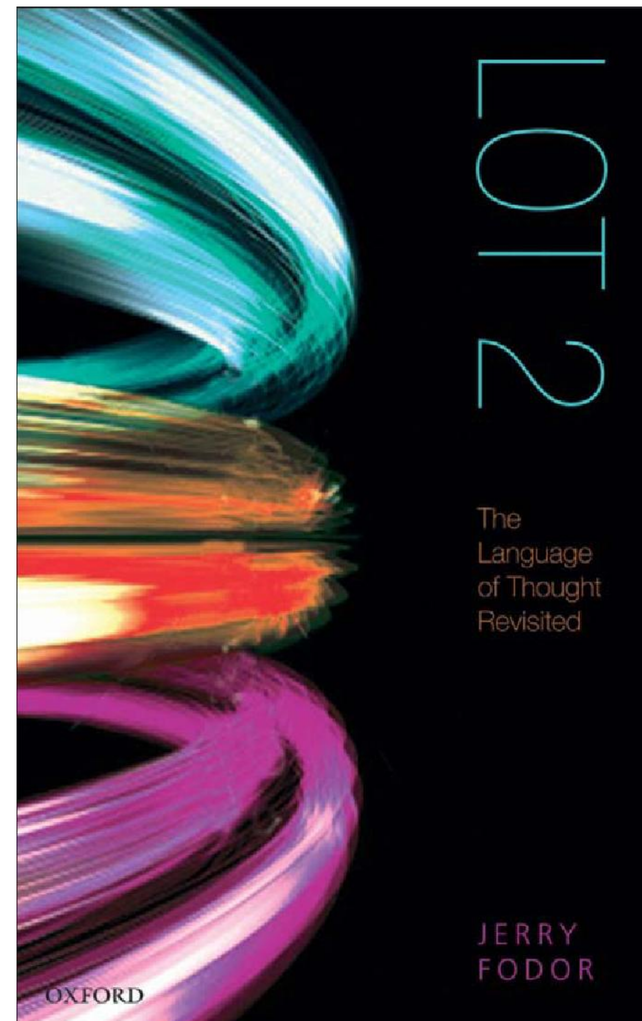


THE LANGUAGE
OF THOUGHT

JERRY A. FODOR
Massachusetts Institute of Technology

THOMAS Y. CROWELL COMPANY · NEW YORK · ESTABLISHED 1834

2008



- **LOT: Mentalese**

- Mechanistic, rule-based operations on some sort of symbols (**computational**)
- Symbols have **syntactic** structural arrangement (gammar)
- Symbols ave compositional **semantics** (meaning)

- **Systematicity**: ability to produce some thought automatically suffices the ability to produce other thoughts least some behavior is decided on.

8. The agent finds himself in a certain situation (S).
9. The agent believes that a certain set of behavioral options (B_1, B_2, B_n) are available to him in S; i.e., given S, B_1 through B_n are the things the agent believes that he can do.
10. The probable consequence of performing each of B_1 through B_n are predicted; i.e., the agent computes a set of hypotheticals of roughly the form if B_i is performed in S, then, with a certain probability, C_i. Which such hypotheticals are computed and which probabilities are assigned will, of course, depend on what the organism knows or believes about situations like S. (It will also depend upon other variables which are, from the point of view of the present model, merely noisy: time pressure, the amount of computation space available to the organism, etc.)
11. A preference ordering is assigned to the consequences.

- Galileo: “*the universe is written in the language of mathematics*”

COMMUNICATIONS ON PURE AND APPLIED MATHEMATICS, VOL. XIII, 001–14 (1960)

The Unreasonable Effectiveness of Mathematics in the Natural Sciences

Richard Courant Lecture in Mathematical Sciences delivered at New York University, May 11, 1959

EUGENE P. WIGNER
Princeton University

“and it is probable that there is some secret here which remains to be discovered.” (*C. S. Peirce*)

There is a story about two friends, who were classmates in high school, talking about their jobs. One of them became a statistician and was working on population trends. He showed a reprint to his former classmate. The reprint started, as usual, with the Gaussian distribution and the statistician explained to his former classmate the meaning of the symbols for the actual population, for the average population, and so on. His classmate was a bit incredulous and was not quite sure whether the statistician was pulling his leg. “How can you know that?” was his query. “And what is this symbol here?” “Oh,” said the statistician, “this is π.” “What is that?” “The ratio of the circumference of the circle to its diameter.” “Well, now you are pushing your joke too far,” said the classmate, “surely the population has nothing to do with the circumference of the circle.”

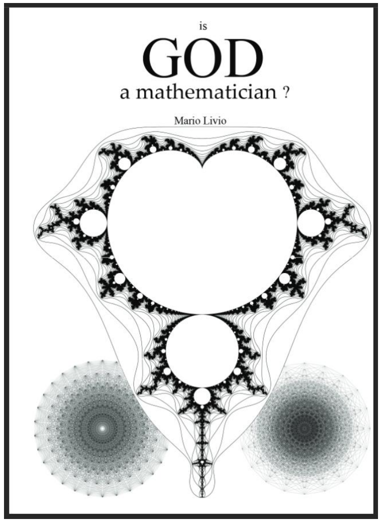
THE UNREASONABLE EFFECTIVENESS OF MATHEMATICS

R. W. HAMMING

Prologue. It is evident from the title that this is a philosophical discussion. I shall not apologize for the philosophy, though I am well aware that most scientists, engineers, and mathematicians have little regard for it; instead, I shall give this short prologue to justify the approach.

Man, so far as we know, has always wondered about himself, the world around him, and what life is all about. We have many myths from the past that tell how and why God, or the gods, made man and the universe. These I shall call *theological explanations.* They have one principal characteristic in common—there is little point in asking why things are the way they are, since we are given mainly a description of the creation as the gods chose to do it.

Philosophy started when man began to wonder about the world outside of this theological framework. An early example is the description by the philosophers that the world is made of earth, fire, water, and air. No doubt they were told at the time that the gods made things that way and to stop worrying about it.



Theology and Science, Vol. 9, No. 1, 2011

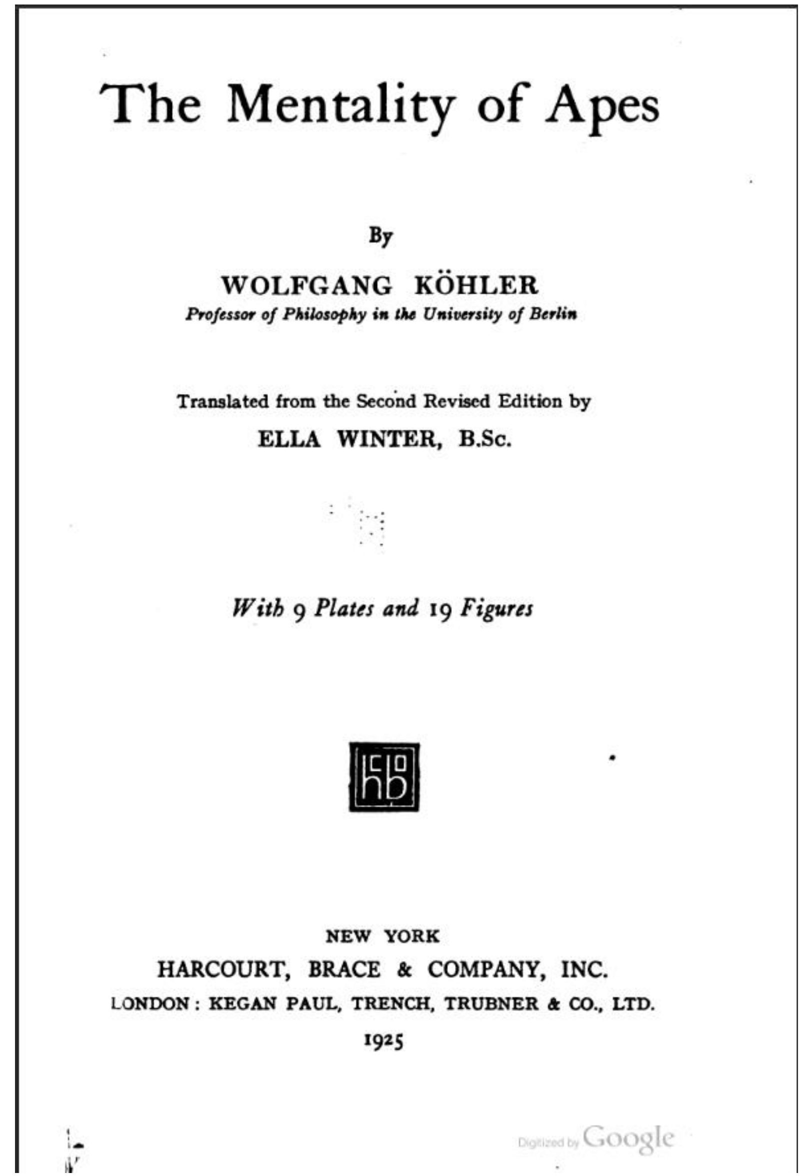
Theism and Mathematics

ALVIN PLANTINGA

Abstract *The author investigates the connection between God and mathematics, and argues (1) that the “unreasonable effectiveness of mathematics” makes much better sense from the perspective of theism than from that of naturalism, (2) that the accessibility (to us human beings) of advanced mathematics is much more likely given theism than given naturalism, (3) that the existence of sets, numbers, functions and the like fits in much better with theism than with naturalism, and (4) that the alleged epistemological obstacles to knowledge of mathematics offered by the abstract character of numbers, sets, etc., disappear from the point of view of theism.*

- Do animals capable of **rationality**, **rational inference** in the proper (symbolic, proximate) sense (rather than “ecological rationality”)?
- Deductive **inference**, choice maximizing expected utility, **judgement**
- Non-verbal (intuitive?) rationality/inference
  - practical non-verbal inference
  - **declarative** knowledge **representation**
  - **causal** inference

- Köhler’s insight
  - incubation
  - illumination (Aha!)
  - verification+use!



The Mentality of Apes

By

WOLFGANG KÖHLER

Professor of Philosophy in the University of Berlin

Translated from the Second Revised Edition by

ELLA WINTER, B.Sc.

With 9 Plates and 19 Figures

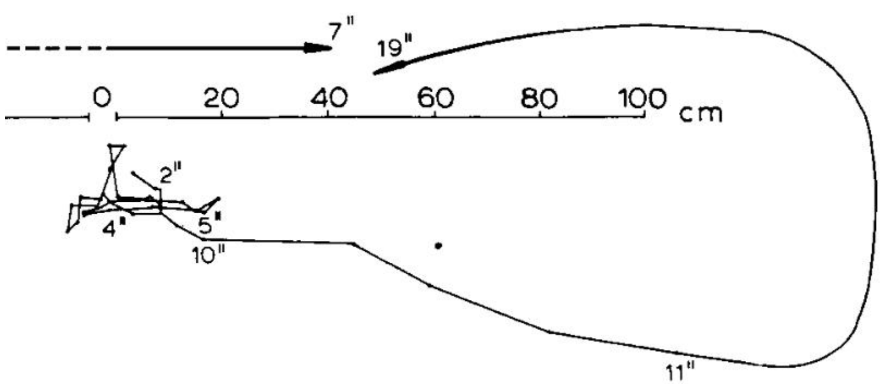
NEW YORK

HARCOURT, BRACE & COMPANY, INC.

LONDON: KEGAN PAUL, TRENCH, TRUBNER & CO., LTD.

1925

Krushinsky, L.V. (1965). Solution of Elementary Logical Problems by Animals on the Basis of Extrapolation– In: Progress in Brain Research. Elsevier, Vol. 17, p. 280–308.



Solution of Elementary Logical Problems by Animals on the Basis of Extrapolation

L. V. KRUSHINSKY

Laboratory of Pathophysiology at the Chair of Physiology of Higher Nervous Activity, Moscow State University, Moscow (Russia)

All physiological investigations, which are of importance for cybernetics, are characterized by their tendency to elaborate schemes representing the circulation of information in the process of work of the nervous system. A possibly complete and exact description of the functioning of the nervous system on all of its levels is an indispensable pre-condition for disclosing the algorhythms on the basis of which information is retained and processed by the nervous system.

The purpose of this work is to investigate the hitherto insufficiently elaborated question concerning the ability of animals to apprehend, on the basis of express-information* (without any special preliminary training), the elementary relationships between the elements of the environment and to determine the elementary laws of

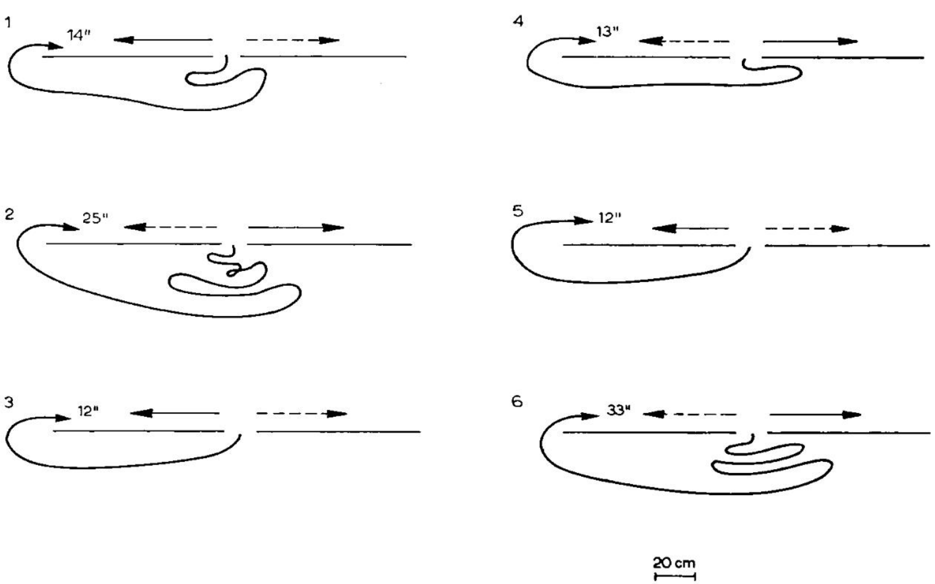


Fig. 8. Scheme illustrating the movement of the crow 'Fomka' during the first experiment. 1-6: ordinal numbers denoting the presentations of the problem. Denotations as in Fig.2.

- **Inference**: drawing conclusions from indirect evidence using rules
- Central for decision-making, reasoning and understanding

ELSEVIER

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Current Opinion in Behavioral Sciences

Inference as a fundamental process in behavior

Ramon Bartolo and Bruno B Averbeck

In the real world, uncertainty is omnipresent due to incomplete or noisy information. This makes inferring the state-of-the-world difficult. Furthermore, the state-of-the-world often changes over time, though with some regularity. This makes learning and decision-making challenging. Organisms have evolved to take advantage of environmental regularities, that allow organisms to acquire a model of the world and perform model-based inference to robustly make decisions and adjust behavior efficiently under uncertainty. Recent research has shed light on many aspects of model-based inference and its neural underpinnings. Here we review recent progress on hidden-state inference, state transition inference, and hierarchical inference processes.

Address

information is available, allowing the animal to infer various environmental features using *model-based* learning strategies. Because environmental regularities occur, and these can be used to build priors, actively making inferences about the state-of-the-world is often the best solution.

Inference from incomplete information occurs at multiple levels of cognition. At the perceptual level, percepts are formed by combining noisy or incomplete information with prior beliefs (i.e. models), through experience, to infer features of a sensor Inference increases processing speed and red energy necessary to make perceptual decisio Moreover, perceptual errors (e.g. hallucinations y pe

Article

Disjunctive inference in preverbal infants

Milad Ekramnia,[1,2,3,*] Jacques Mehler,[2,4] and Ghislaine Dehaene-Lambertz[1]

SUMMARY

Can preverbal infants utilize logical reasoning such as disjunctive inference? This logical operation requires keeping two alternatives open (A or B), until one of them is eliminated (if not A), allowing the inference: B is true. We presented to 10-month-old infants an ambiguous situation in which a female voice was paired with two faces. Subsequently, one of the two faces was presented with the voice of a male. We measured infants' preference for the correct face when both faces and the initial voice were presented again. Infant pupillary response was measured and utilized as an indicator of cognitive load at the critical moment of disjunctive inference. We controlled for other possible explanations in three additional experiments. Our results show that 10-month-olds can correctly deploy disjunction and negation to disambiguate scenes, suggesting that disjunctive inference does not rely on linguistic constructs.

Research Article

Secret Agents

Inferences About Hidden Causes by 10- and 12-Month-Old Infants

R. Saxe,[1,2] J.B. Tenenbaum,[2] and S. Carey[1]

[1]*Department of Psychology, Harvard University, and* [2]*Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology*

ABSTRACT—*Considerable evidence indicates that preverbal infants expect that only physical contact can cause an inanimate object to move. However, very few studies have investigated infants' expectations about the source of causal power. In three experiments, we found that (a) 10- and 12-month-old infants expect a human hand, and not an inanimate object, to be the primary cause of an inanimate object's motion; (b) infants' expectations can lead them to infer a hidden causal agent without any direct perceptual evidence; and (c) infants do not infer a hidden causal agent if the moving object was previously shown to be capable of self-generated motion.*

object to go into motion when and only when contacted by another moving object (Ball, 1973; Cohen et al., 1998; Kosugi et al., 2003; Kotovsky & Baillargeon, 2000; Oakes & Cohen, 1990, 1994; Spelke, Phillips, & Woodward, 1995; Wang, Kaufman, & Baillargeon, 2003), and that these expectations are suspended if the patient object is capable of self-generated motion (Kosugi & Fujita, 2002; Spelke et al., 1995).

Adults, however, have expectations not only about the patient of a causal interaction, and about the interaction itself, but also about the causal agent. By "causal agent," we mean the entity that is the purveyor of causal force, the source of motion or change, in an interaction (Leslie, 1994). Adults both distinguish between the roles of causal agent and patient in a visible in-

Anim Cogn (2006) 9:393–403
DOI 10.1007/s10071-006-0037-4

ORIGINAL ARTICLE

Inferences by exclusion in the great apes: the effect of age and species

Josep Call

Received: 20 August 2005 / Revised: 30 June 2006 / Accepted: 3 July 2006 / Published online: 22 August 2006

Abstract This study investigated the ability of chimpanzees, gorillas, orangutans, and bonobos to make inferences by exclusion using the procedure pioneered by Premack and Premack (Cognition 50:347–362, 1994) with chimpanzees. Thirty apes were presented with two different food items (banana vs. grape) on a platform and covered with identical containers. One of the items was removed from the container and placed between the two containers so that sub-

Keywords Inferential reasoning · Animal logic · Object individuation · Behavior control by exclusion · Object representation

One of the most important functions of cognition is to deal with the problem of inconsistent or incomplete information that animals often encounter in their environment. Inferential reasoning, defined as associating a visible and an imagined

Anim Cogn (2016) 19:965–975
DOI 10.1007/s10071-016-0998-x

CrossMark

ORIGINAL PAPER

Reasoning by exclusion in the kea (*Nestor notabilis*)

Mark O'Hara[1,2] · Raoul Schwing[2] · Ira Federspiel[1] · Gyula K. Gajdon[2] · Ludwig Huber[2]

Received: 4 November 2015 / Revised: 12 May 2016 / Accepted: 14 May 2016 / Published online: 21 May 2016

Abstract Reasoning by exclusion, i.e. the ability to understand that if there are only two possibilities and if it is not A, it must be B, has been a topic of great interest in recent comparative cognition research. Many studies have investigated this ability, employing different methods, but rarely exploring concurrent decision processes underlying choice behaviour of non-human animals encountering inconsistent or incomplete information. Here, we employed a novel training and test method in order to perform an in-

the current hypotheses about the emergence of inferential reasoning in some avian species, considering causal links to brain size, feeding ecology and social complexity.

Keywords Avian cognition · Categorisation · Inference by exclusion · Touch screen · Kea (*Nestor notabilis*)

/1749-4877.12299

Introduction

CellPress

Neuron
Article

Inference-Based Decisions in a Hidden State Foraging Task: Differential Contributions of Prefrontal Cortical Areas

Pietro Vertechi,[1,7] Eran Lottem,[2,7] Dario Sarra,[1,7] Beatriz Godinho,[1,3] Isaac Treves,[4] Tiago Quendera,[1] Matthijs Nicolai Oude Lohuis,[5,6] and Zachary F. Mainen[1,8,*]
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https://doi.org/10.1016/j.neuron.2020.01.017

SUMMARY

Essential features of the world are often hidden and must be inferred by constructing internal models based on indirect evidence. Here, to study the mechanisms of inference, we establish a foraging task that

the immediate rate of reward drops below the average rate (Charnov, 1976). However, this elegant solution to the foraging problem only applies in deterministic environments (Kolling et al., 2014), in which both immediate and average reward rates are knowable to the agent. In a more realistic scenario—for example, where rewards are encountered probabilistically—

Inference by exclusion in the red-tailed black cockatoo (*Calyptorhynchus banksii*)

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[1]School of Psychology, James Cook University, Cairns, Australia and [2]School of Psychology, University of Newcastle, Callaghan, Australia

Abstract

Inference by exclusion is the ability to select a given option by excluding the others. When designed appropriately, tests of this ability can reveal choices that cannot be explained by associative processes. Over the past decade, exclusion reasoning has been explored in several non-human taxonomic groups, including birds, mainly in Corvids and Parrots. To increase our understanding of the taxonomic distribution of exclusion reasoning and, therefore, its evolution, we investigated exclusion performances in red-tailed black cockatoos (*Calyptorhynchus banksii*), an Australian relative of the Goffin cockatoo (*Cacatua goffini*), using a food-finding task. Cockatoos were required to find a food item hidden in 1 of the 2 experimenter's hands. Following training sessions in which they reliably selected the closed baited hand they had just been shown open, each individual was tested on 4 different conditions. Critical to demonstrating exclusion reasoning was the condition in which they were shown the empty hand and then offered a choice of both closed hands. The performance of all birds was above chance on all experimental conditions but not on an olfactory and/or cuing control condition. The results suggest that the birds might be able to infer by exclusion, although an explanation based on rule learning cannot be excluded. This first experiment in red-tailed black cockatoo highlights the potential of this species as a model to study avian cognition and paves the pathway for future investigations.

- Transitive inference

$$A \to B, B \to C \therefore A \to C$$

Journal of Comparative Psychology
1992, Vol. 106, No. 4, 342–349

Transitive Inference in Rats (*Rattus norvegicus*)

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Although Piagetian theory proposes that the ability to make transitive inferences is confined to humans above age 7, recent evidence has suggested that this logical ability may be more broad based. In nonverbal tests, transitive inference has been demonstrated in preschool children and 2 species of nonhuman primates. In these experiments, I demonstrate evidence of transitive inference in rats (*Rattus norvegicus*). I used an ordered series of 5 olfactory stimuli (A < B < C < D < E) from which correct inferences were made about the novel B versus D pair. Control

Behavioural Processes 92 (2013) 113–117

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Behavioural Processes

journal homepage: www.elsevier.com/locate/behavproc

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Transitive inference in jackdaws (*Corvus monedula*)

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[d] Cognitive Ethology Lab, German Primate Center, Göttingen, Germany

Vol 445|25 January 2007|doi:10.1038/nature05511

nature

LETTERS

Fish can infer social rank by observation alone

Logan Grosenick[1,2]†, Tricia S. Clement[1]† & Russell D. Fernald[1]

Transitive inference (TI) involves using known relationships to deduce unknown ones (for example, using $A > B$ and $B > C$ to infer $A > C$), and is thus essential to logical reasoning. First described as a developmental milestone in children[1], TI has since been reported in nonhuman primates[2–4], rats[5,6] and birds[7–10]. Still, how animals acquire and represent transitive relationships and why such abilities might have evolved remain open problems. Here we show that male fish (*Astatotilapia burtoni*) can success-

against intruding rivals, moving one male into a unit defended by another male always resulted in the intruder losing (see Methods). Thus, we could train each bystander on an artificial dominance hierarchy by using animals whose relative status we controlled. This ensured that there were no consistent differences in male abilities or physical characteristics—a potential confounding factor in naturally formed dominance hierarchies[14,15].

Bystander males ($n = 8$) were trained for 11 days on pairwise fights

Behavioral Ecology
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Advance Access publication 7 September 2012

Original Article

Brook trout use individual recognition and transitive inference to determine social rank

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Transitive inference (TI) occurs when information about known relationships is used to construct novel associations, for example, when an individual infers the order of 3 conspecifics in a linear dominance hierarchy (A > B > C) by watching 2 dyads (A > B and B > C). TI has been demonstrated for several species, but never for organisms with hierarchies involving many individuals whose rank order changes often. Under these circumstances, theory predicts natural selection may favor use of explicit cues to rank conspecifics, rather than TI. Here we show that brook trout (*Salvelinus fontinalis*), a species that exhibits complex, shifting

RESEARCH ARTICLE

Transitive inference in cleaner wrasses (*Labroides dimidiatus*)

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Psychology Press
Taylor & Francis Group

Core knowledge of object, number, and geometry: A comparative and neural approach

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Studies on the ontogenetic origins of human knowledge provide evidence for a small set of separable systems of core knowledge dealing with the representation of inanimate and animate objects, number, and geometry. Because core knowledge systems are evolutionarily ancient, they can be investigated from a comparative perspective, making use of various animal models. In this review, I discuss evidence showing precocious abilities in nonhuman species to represent (a) objects that move partly or fully out of view and their basic mechanical properties such as solidity, (b) the cardinal and ordinal/sequential aspects of numerical cognition and rudimentary arithmetic with small numerosities, and (c) the geometrical relationships among extended surfaces in the surrounding layout. Controlled rearing studies suggest that the abilities associated with core knowledge systems of objects, number, and geometry are observed in animals in the absence (or with very reduced) experience, supporting a nativistic foundation of such cognitive mechanisms. Animal models also promise a fresh approach to the issue of the neurobiological and genetic mechanisms underlying the expression of core knowledge systems.

frontiers in Psychology

REVIEW
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Check for updates

Numerosities and Other Magnitudes in the Brains: A Comparative View

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The ability to represent, discriminate, and perform arithmetic operations on discrete quantities (numerosities) has been documented in a variety of species of different taxonomic groups, both vertebrates and invertebrates. We do not know, however, to what extent similarity in behavioral data corresponds to basic similarity in underlying neural mechanisms. Here, we review evidence for magnitude representation, both discrete (countable) and continuous, following the sensory input path from primary sensory systems to associative pallial territories in the vertebrate brains. We also speculate on possible underlying mechanisms in invertebrate brains and on the role

PNAS RESEARCH ARTICLE | PSYCHOLOGICAL AND COGNITIVE SCIENCES OPEN ACCESS

Check for updates

Number neurons in the nidopallium of young domestic chicks

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Edited by Barbara Landau, Johns Hopkins University, Baltimore, MD; received January 19, 2022; accepted June 13, 2022

Numerical cognition is ubiquitous in the animal kingdom. Domestic chicks are a widely used developmental model for studying numerical cognition. Soon after hatching, chicks can perform sophisticated numerical tasks. Nevertheless, the neural basis of their numerical abilities has remained unknown. Here, we describe number neurons in the caudal nidopallium (functionally equivalent to the mammalian prefrontal cortex) of young domestic chicks. Number neurons that we found in young chicks showed remarkable similarities to those in the prefrontal cortex and caudal nidopallium of adult animals. Thus, our results suggest that numerosity perception based on number neurons might be an inborn feature of the vertebrate brain.

Significance

Numerosity, that is, the number of items in a set, is a significant aspect in the perception of the environment. Behavioral and in silico experiments suggest that number sense belongs to a core

frontiers in Behavioral Neuroscience

REVIEW
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CrossMark

Origins of Knowledge: Insights from Precocial Species

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Behavioral responses are influenced by knowledge acquired during the lifetime of an individual and by predispositions transmitted across generations. Establishing the origin of knowledge and the role of the unlearned component is a challenging task, given

- **Causal inference and reasoning**
- Schloegl, Christian, and Julia Fischer. Causal Reasoning in Non-Human Animals. The Oxford Handbook of Causal Reasoning. Vol. 34, 2017
- Taylor, A. H., G. R. Hunt, F. S. Medina, and R. D. Gray. “Do New Caledonian Crows Solve Physical Problems through Causal Reasoning?” Proceedings of the Royal Society B: Biological Sciences 276, no. 1655 (2009): 247–54

PNAS

Check for updates

Origins of the concepts cause, cost, and goal in prereaching infants

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Edited by Gergely Csibra, Central European University, Budapest, Hungary, and approved July 26, 2019 (received for review March 25, 2019)

We investigated the origins and interrelations of causal knowledge and knowledge of agency in 3-month-old infants, who cannot yet effect changes in the world by reaching for, grasping, and picking up objects. Across 5 experiments, n = 152 prereaching infants viewed object-directed reaches that varied in efficiency (following the shortest physically possible path vs. a longer path), goal (lifting an object vs. causing a change in its state), and causal structure (action on contact vs. action at a distance and after a delay). Prereaching infants showed no strong looking preference between a person's efficient and inefficient reaches when the person grasped and displaced an object. When the person reached for and caused a change in the state of the object on contact, however, infants looked longer when this action was inefficient than when it was efficient. Three-month-old infants also showed a key signature of adults' and older infants' causal inferences: This looking preference was abolished if a short spatial and temporal gap separated the action from its effect. The basic intuition that people are causal agents, who navigate around physical constraints to change the state of the world, may be one important foundation for infants' ability to plan their own actions and learn from the acts of others.

other people's reaches (16), grasps (18), and multistep goal-directed actions (19). These observations have prompted the hypothesis that infants learn, through their own actions, to attribute mental states and causal powers to themselves and other agents (20–25).

The motor experience hypothesis is supported by evidence that action training enhances infants' action understanding (26–31). The most striking evidence for this hypothesis comes from studies of 3-month-old infants, who do not yet reach intentionally for objects (32), and who in past research showed no sensitivity to others' goals or to the cost of their actions. Training experiments suggest that such infants learn about the goals and intentions of other agents from their own action experiences (26, 27, 30). After a few minutes of experience wearing Velcro (“sticky”) mittens that allow prereaching infants to bat at soft objects and pick them up, infants come to see other people's reaches as directed toward those goal objects, whereas untrained infants do not (26, 30). Nevertheless, 2 sets of findings from these experiments stand at odds with the motor experience hypothesis. First, infants' learning from wearing sticky mittens fails to generalize in ways that new action concepts should support.

PSYCHOLOGICAL AND COGNITIVE SCIENCES

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Cognition

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ELSEVIER

COGNITION

Apes are intuitive statisticians

CrossMark

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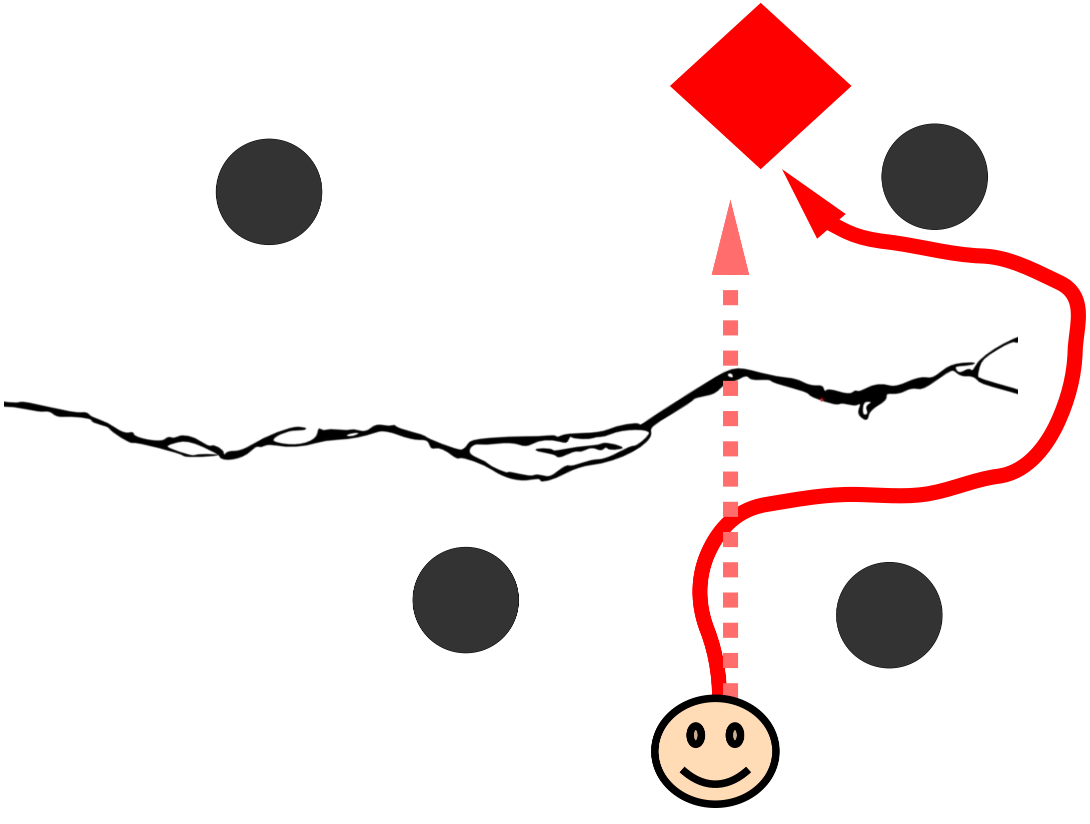
Primate cognition
Intuitive statistics
Numerical cognition

A B S T R A C T

Inductive learning and reasoning, as we use it both in everyday life and in science, is characterized by flexible inferences based on statistical information: inferences from populations to samples and vice versa. Many forms of such statistical reasoning have been found to develop late in human ontogeny, depending on formal education and language, and to be fragile even in adults. New revolutionary research, however, suggests that even preverbal human infants make use of intuitive statistics. Here, we conducted the first investigation of such intuitive statistical reasoning with non-human primates. In a series of 7 experiments, Bonobos, Chimpanzees, Gorillas and Orangutans drew flexible statistical inferences from populations to samples. These inferences, furthermore, were truly based on statistical information regarding the relative frequency distributions in a population, and not on absolute frequencies. Intuitive statistics in its most basic form is thus an evolutionarily more ancient rather than a uniquely human capacity.

- Navigation, cognitive maps: path integration



Rational psychological processes defined over spatial (“cartographic”) mental representations

Brit. J. Phil. Sci. **60** (2009), 377–407

Cognitive Maps and the Language of Thought

Michael Rescorla

ABSTRACT

Fodor advocates a view of cognitive processes as computations defined over *the language of thought* (or *Mentalese*). Even among those who endorse Mentalese, considerable controversy surrounds its representational format. What semantically relevant structure should scientific psychology attribute to Mentalese symbols? Researchers commonly emphasize *logical* structure, akin to that displayed by predicate calculus sentences. To counteract this tendency, I discuss computational models of navigation drawn from probabilistic robotics. These models involve computations defined over *cognitive maps*, which have *geometric* rather than *logical* structure. They thereby demonstrate the possibility of rational cognitive processes in an exclusively non-logical representational medium. Furthermore, they offer much promise for the empirical study of animal navigation.

Thinking without Words

José Luis Bermúdez

OXFORD
UNIVERSITY PRESS
2003

- Minimal thinking (0)
  - context-specific
  - pragmatic
  - image-based (spatial)
  - unstructured

	Applicable to Behavior Tokens	*Decision-Making*
Level 0	X	X
Level 1	√	√
Level 2	√	X

Token is **symbol**

Philosophy and
Phenomenological Research

Philosophy and Phenomenological Research
Vol. XCVIII No. 3, May 2019
doi: 10.1111/phpr.12455

Rational Inference: The Lowest Bounds

CAMERON BUCKNER
University of Houston

A surge of empirical research demonstrating flexible cognition in animals and young infants has raised interest in the possibility of rational decision-making in the absence of language. A venerable position, which I here call "Classical Inferentialism", holds that nonlinguistic agents are incapable of rational inferences. Against this position, I defend a model of nonlinguistic inferences that shows how they could be practically rational. This model vindicates the Lockean idea that we can intuitively grasp rational connections between thoughts by developing the Davidsonian idea that practical inferences are at bottom categorization judgments. From this perspective, we can see how similarity-based categorization processes widely studied in human and animal psychology might count as practically rational. The solution involves a novel hybrid of internalism and externalism: intuitive inferences are psychologically rational (in the explanatory sense) given the intensional sensitivity of the similarity assessment to the internal structure of the agent's reasons for acting, but epistemically rational (in the justificatory sense) given an ecological fit between the features matched by that assessment and the structure of the agent's environment. The essay concludes by exploring empirical results that show how nonlinguistic agents can be sensitive to these similarity assessments in a way that grants them control over their opaque judgments.

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SUBMITTED ARTICLE

WILEY

How to ascribe beliefs to animals

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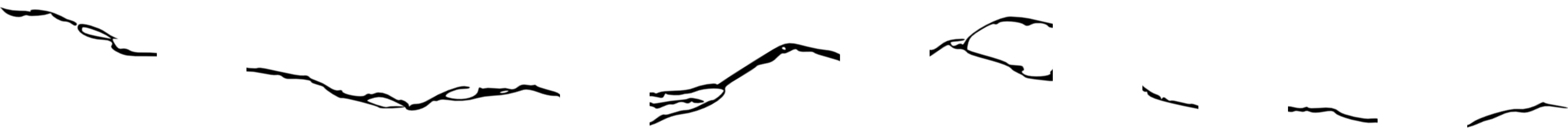
In this article, we analyze and reject two versions of the content-argument against animal beliefs, namely, the ontological argument from Davidson and the epistemological argument from Stich. One of the main defects of the strongest version of the argument is that it over-intellectualizes belief ascriptions in humans and thus sets the comparative bar for belief ascriptions in animals too high. In the second part of the article, we develop a gradualist notion of belief which captures basic beliefs as well as Davidsonian linguistic beliefs, and we specify the conditions under which belief ascriptions to nonlinguistic animals are justified.

KEYWORDS
animal belief, animal philosophy, belief ascription, comparative psychology, other minds

- Many animals (and preverbal infants) can make inferences
  - non-verbal logical?
  - number?
  - causality?
  - spatial?
- Animals *may* have belief states
- Core concepts of number, geometry
- Innate, appear early in the ontogeny
- Rationality
  - pragmatic, decision-making

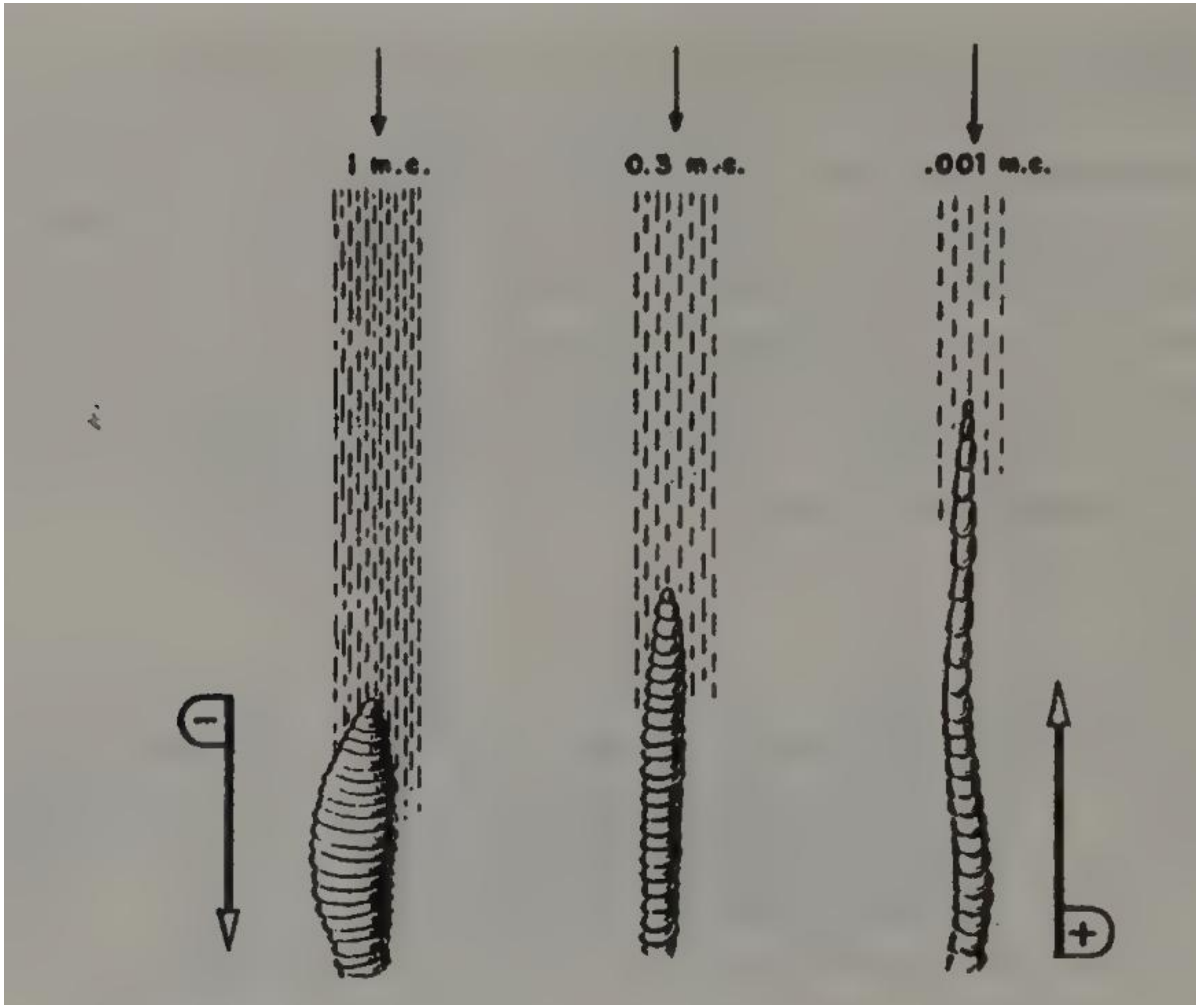
- How rational inference could have evolved?



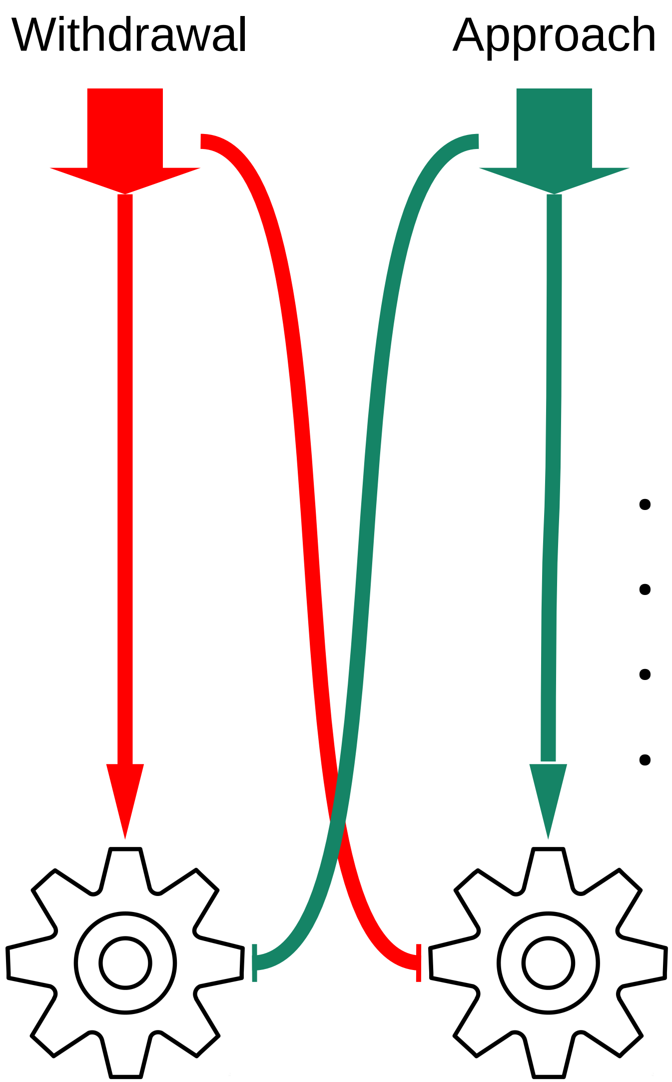
?

- *In principio erat verbum*

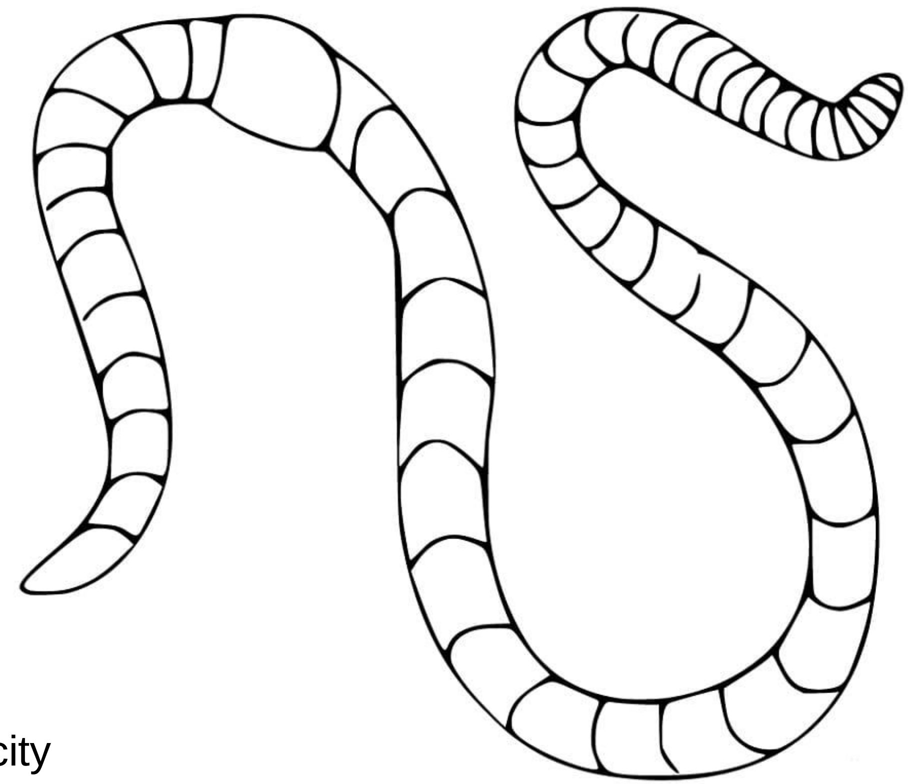
- Schneirla, T. C. (1959). An evolutionary and developmental theory of biphasic processes underlying approach and withdrawal. *Nebraska symposium on motivation*, 1959



… apud vermum?

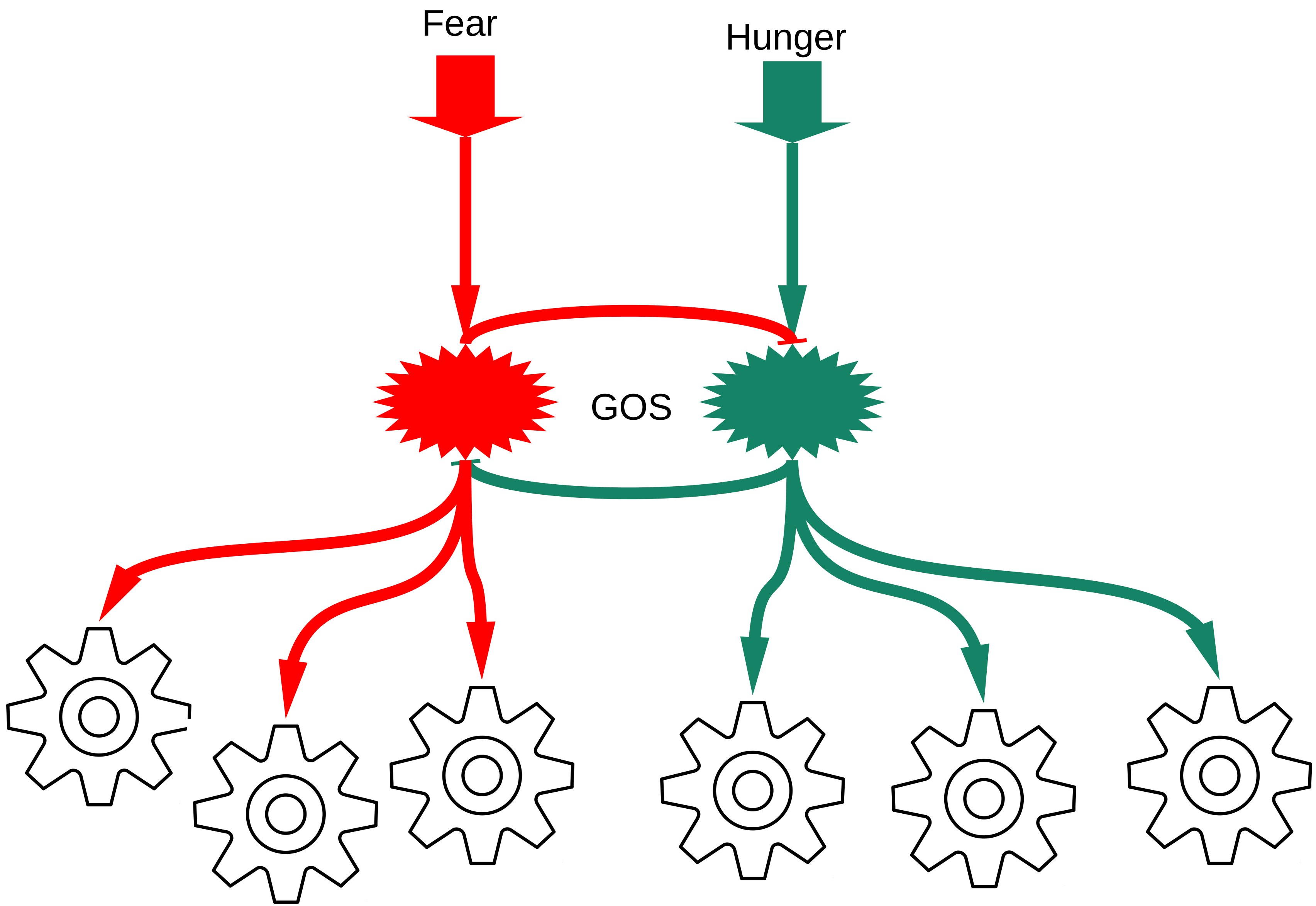


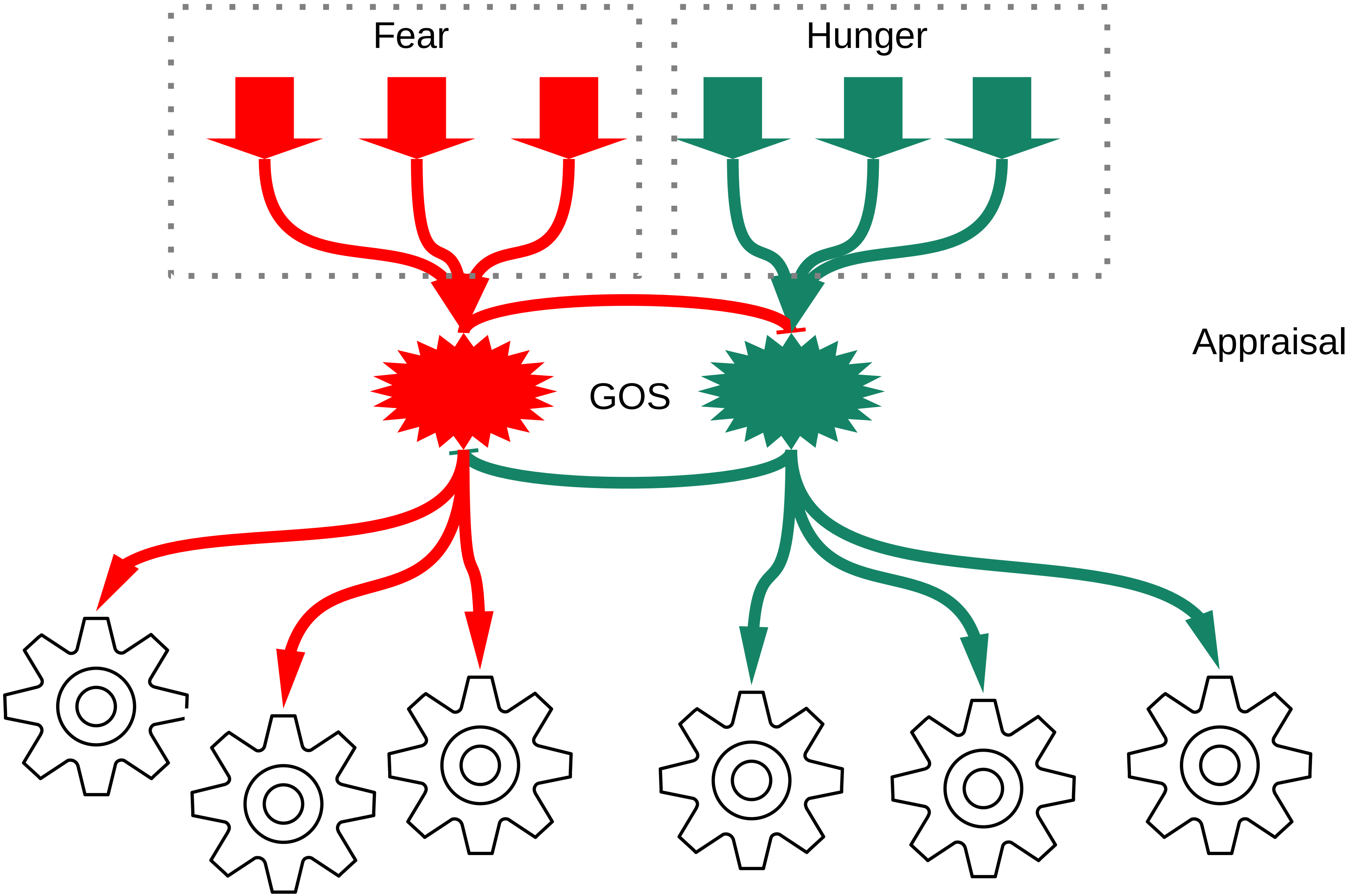
- Symbols
- Syntax
- Semantics
- Systematicity

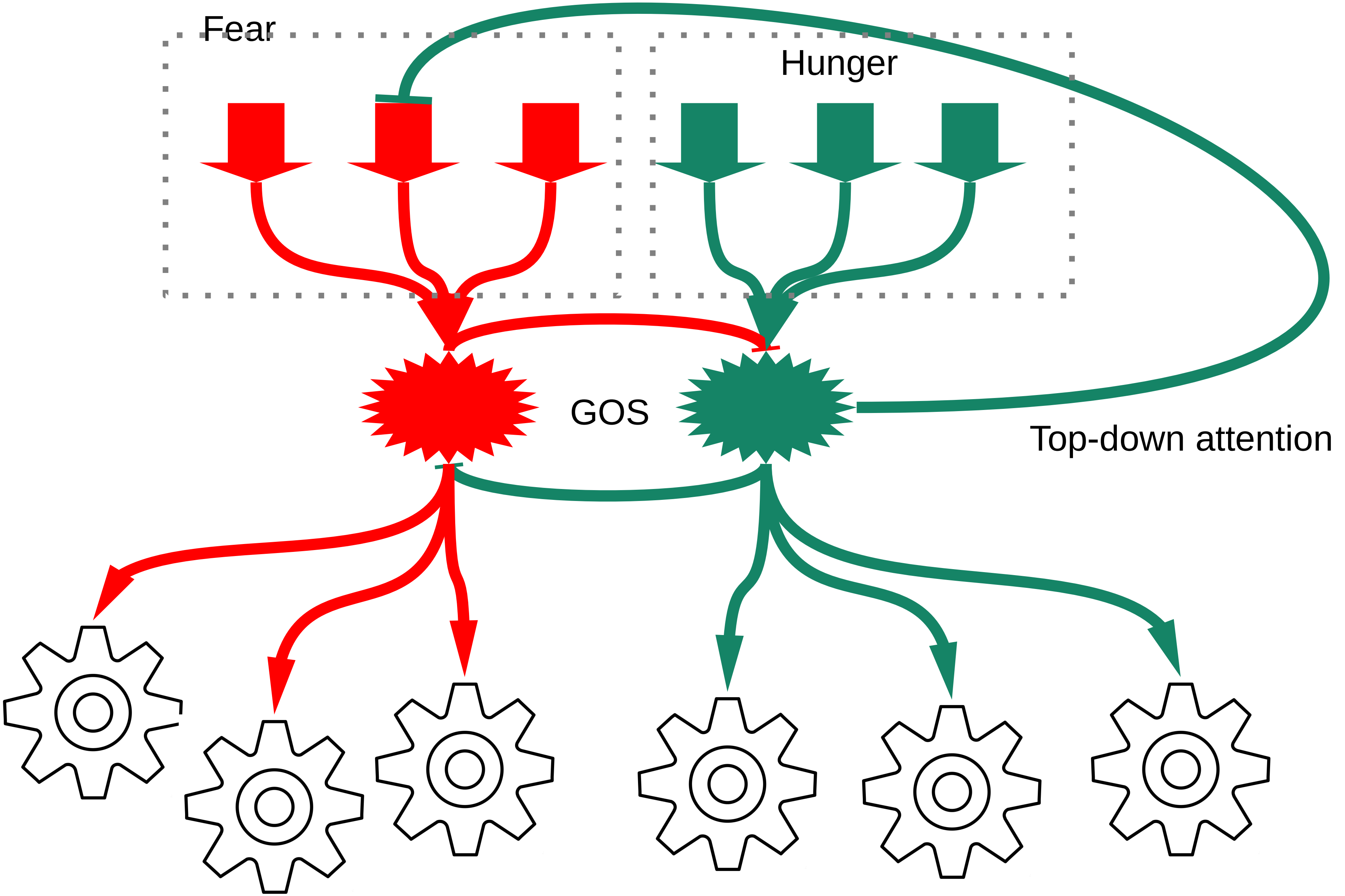


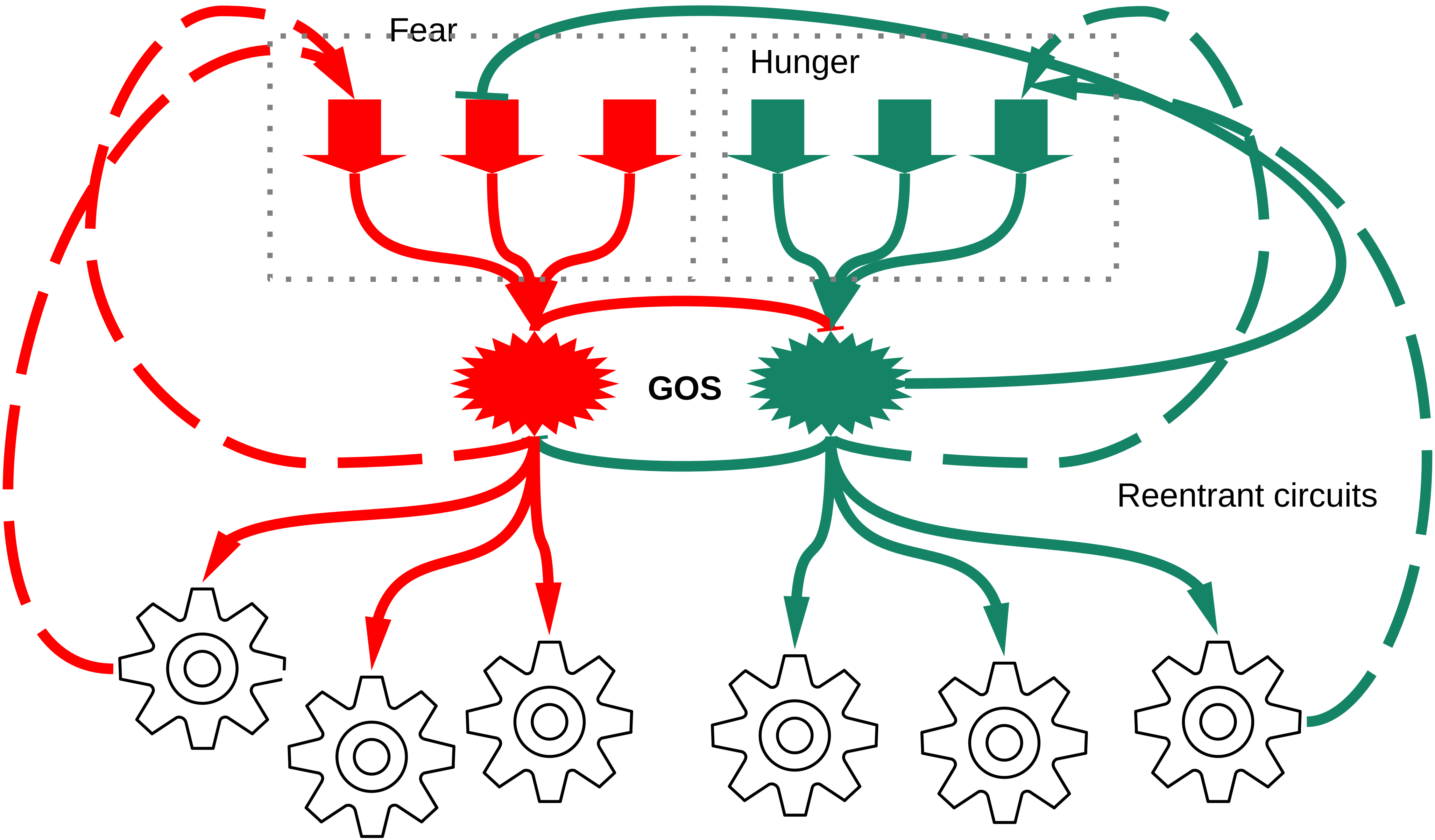
$$p \rightarrow \neg q$$

$$(p \rightarrow \neg q) \wedge (\neg p \rightarrow q)$$

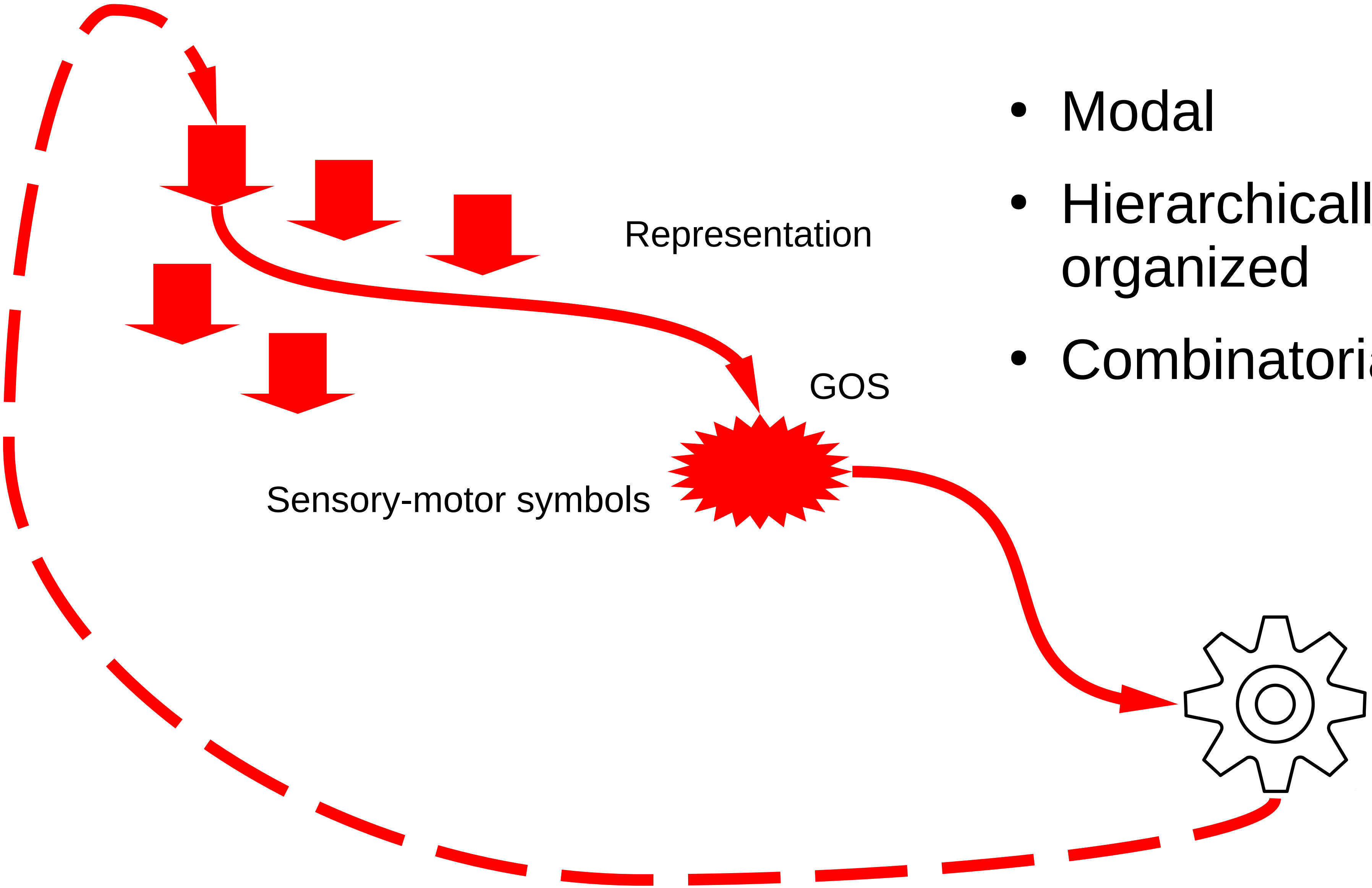

Fear
Hunger
GOS


Fear
Hunger
GOS
Appraisal

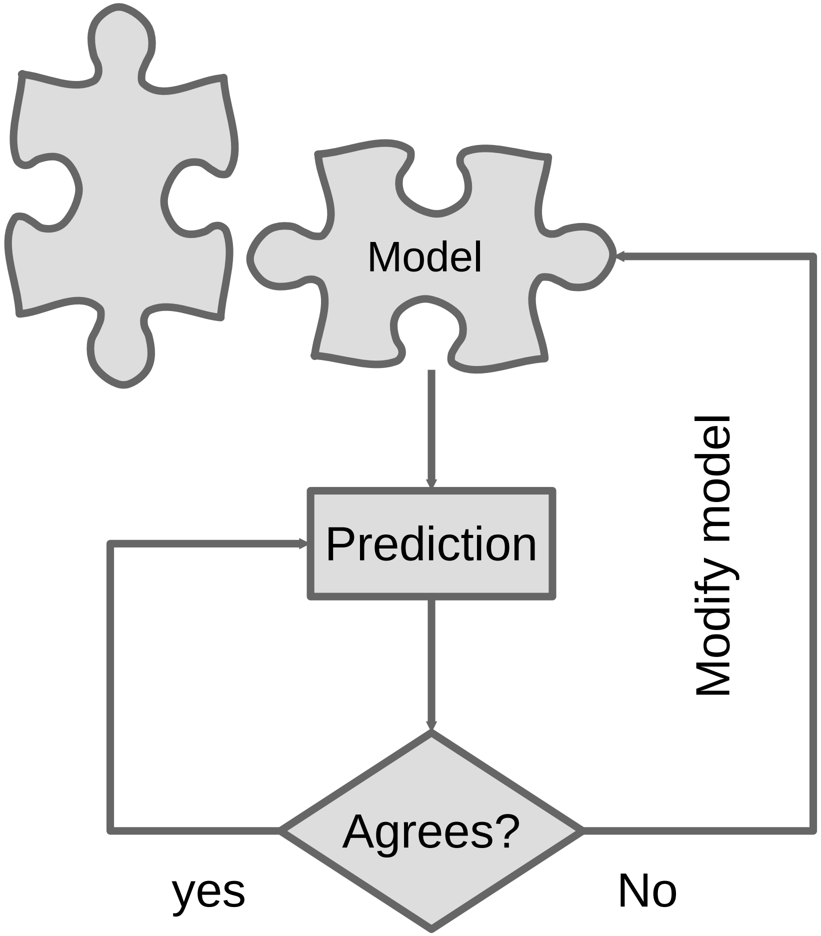

Fear
Hunger
GOS
Top-down attention

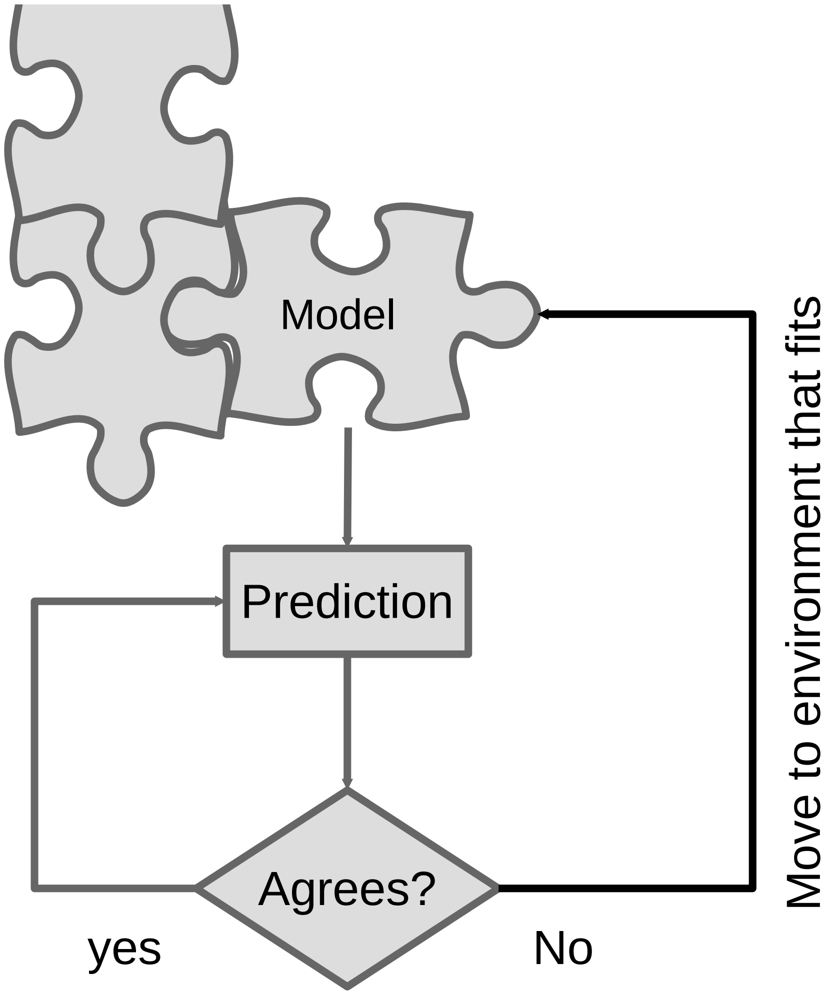

Fear
Hunger
GOS
Reentrant circuits

- Modal
- Hierarchically organized
- Combinatorial



Prediction


Model
Prediction
Agrees?
yes
No
Modify model


Model
Prediction
Agrees?
yes
No
Move to environment that fits

- Simulation theory of cognition

Review

The current status of the simulation theory of cognition

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Consciousness
Thought
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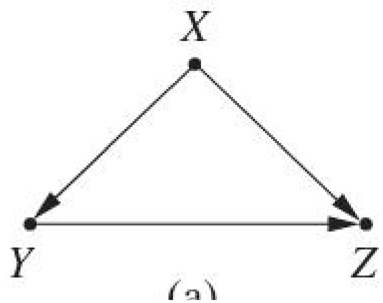
ABSTRACT

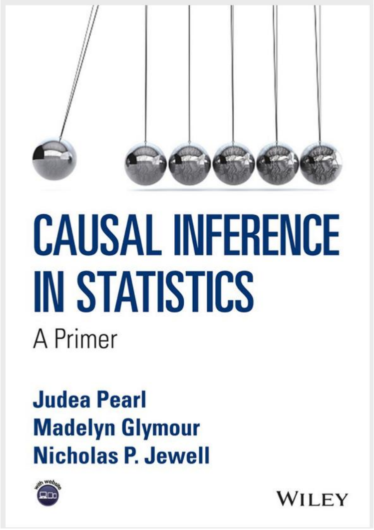
It is proposed that thinking is simulated interaction with the environment. Three assumptions underlie this 'simulation' theory of cognitive function. Firstly, behaviour can be simulated in the sense that we can activate motor structures, as during a normal overt action, but suppress its execution. Secondly, perception can be simulated by internal activation of sensory cortex in a way that resembles its normal activation during perception of external stimuli. The third assumption ('anticipation') is that both overt and simulated actions can elicit perceptual simulation of their most probable consequences. A large body of evidence, mainly from neuroimaging studies, that supports these assumptions, is reviewed briefly. The theory is ontologically parsimonious and does not rely on standard cognitivist constructs such as internal models or representations. It is argued that the simulation approach can explain the relations between motor, sensory and cognitive functions and the appearance of an inner world. It also unifies and explains important features of a wide variety of cognitive phenomena such as memory and cognitive maps. Novel findings from recent developments in memory research on the similarity of imaging and memory and on the role of both prefrontal cortex and sensory cortex in declarative memory and working memory are predicted by the theory and provide striking support for it.

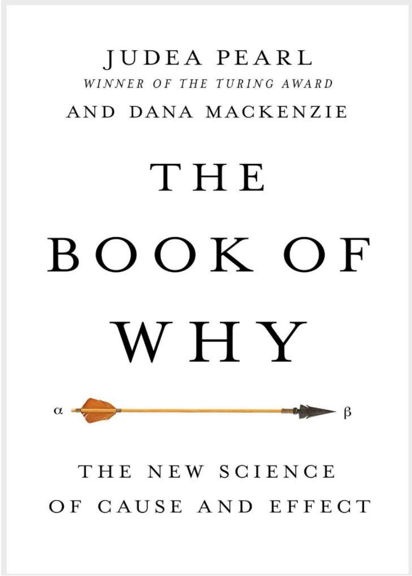
This article is part of a Special Issue entitled "The Cognitive Neuroscience".

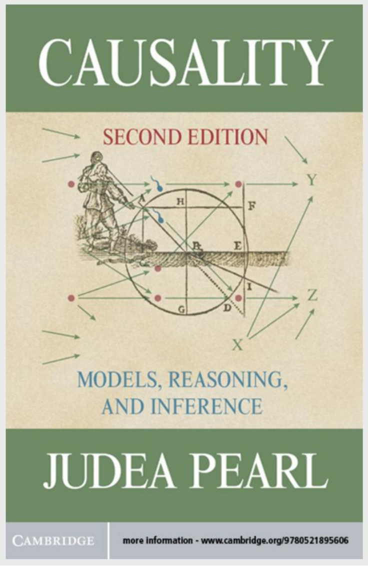
Causal inference

- **Causal inference:** modern framework for statistical inference and decision-making
- Bayesian inference
   - acyclic graph
- Intervention: ***do()*** operator
- **Counterfactuals**: simulation of “what if”









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Perceptual symbol systems

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Abstract: Prior to the twentieth century, theories of knowledge were inherently perceptual. Since then, developments in logic, statistics, and programming languages have inspired amodal theories that rest on principles fundamentally different from those underlying perception. In addition, perceptual approaches have become widely viewed as untenable because they are assumed to implement recording systems, not conceptual systems. A perceptual theory of knowledge is developed here in the context of current cognitive science and neuroscience. During perceptual experience, association areas in the brain capture bottom-up patterns of activation in sensory-motor areas. Later, in a top-down manner, association areas partially reactivate sensory-motor areas to implement perceptual symbols. The storage and reactivation of perceptual symbols operates at the level of perceptual components – not at the level of holistic perceptual experiences. Through the use of selective attention, schematic representations of perceptual components are extracted from experience and stored in memory (e.g., individual memories of *green, purr, hot*). As memories of the same component become organized around a common frame, they implement a simulator that produces limitless simulations of the component (e.g., simulations of *purr*). Not only do such simulators develop for aspects of sensory experience, they also develop for aspects of proprioception (e.g., *lift, run*) and introspec-

Grounded Cognition

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PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

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Simulation, situated conceptualization, and prediction

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Based on accumulating evidence, simulation appears to be a basic computational mechanism in the brain that supports a broad spectrum of processes from perception to social cognition. Further evidence suggests that simulation is typically situated, with the situated character of experience in the environment being reflected in the situated character of the representations that underlie simulation. A basic architecture is sketched of how the brain implements situated simulation. Within this framework, simulators implement the concepts that underlie knowledge, and situated conceptualizations capture patterns of multi-modal simulation associated with frequently experienced situations. A pattern completion inference mechanism uses current perception to activate situated conceptualizations that produce predictions via simulations on relevant modalities. Empirical findings from perception, action, working memory, conceptual processing, language and social cognition illustrate how this framework produces the extensive prediction that characterizes natural intelligence.

Keywords: categories; concepts; imagery; prediction; simulation; situated cognition

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0066-4308/08/0203-0617$20.00

Key Words

cognitive architecture, imagery, representation, simulation, situated action

Abstract

Grounded cognition rejects traditional views that cognition is computation on amodal symbols in a modular system, independent of the brain's modal systems for perception, action, and introspection. Instead, grounded cognition proposes that modal simulations, bodily states, and situated action underlie cognition. Accumulating behavioral and neural evidence supporting this view is reviewed from research on perception, memory, knowledge, language, thought, social cognition, and development. Theories of grounded cognition are also reviewed, as are origins of the area and common misperceptions of it. Theoretical, empirical, and methodological issues are raised whose future treatment is likely to affect the growth and impact of grounded cognition.

New Ideas in Psychology 29 (2011) 275–297

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ELSEVIER

Computational explorations of perceptual symbol systems theory

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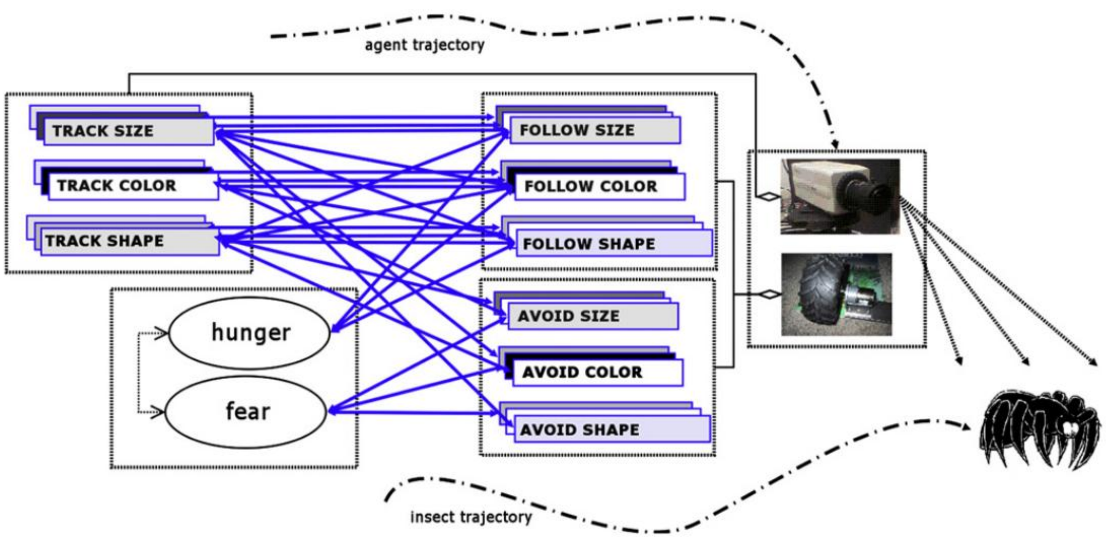
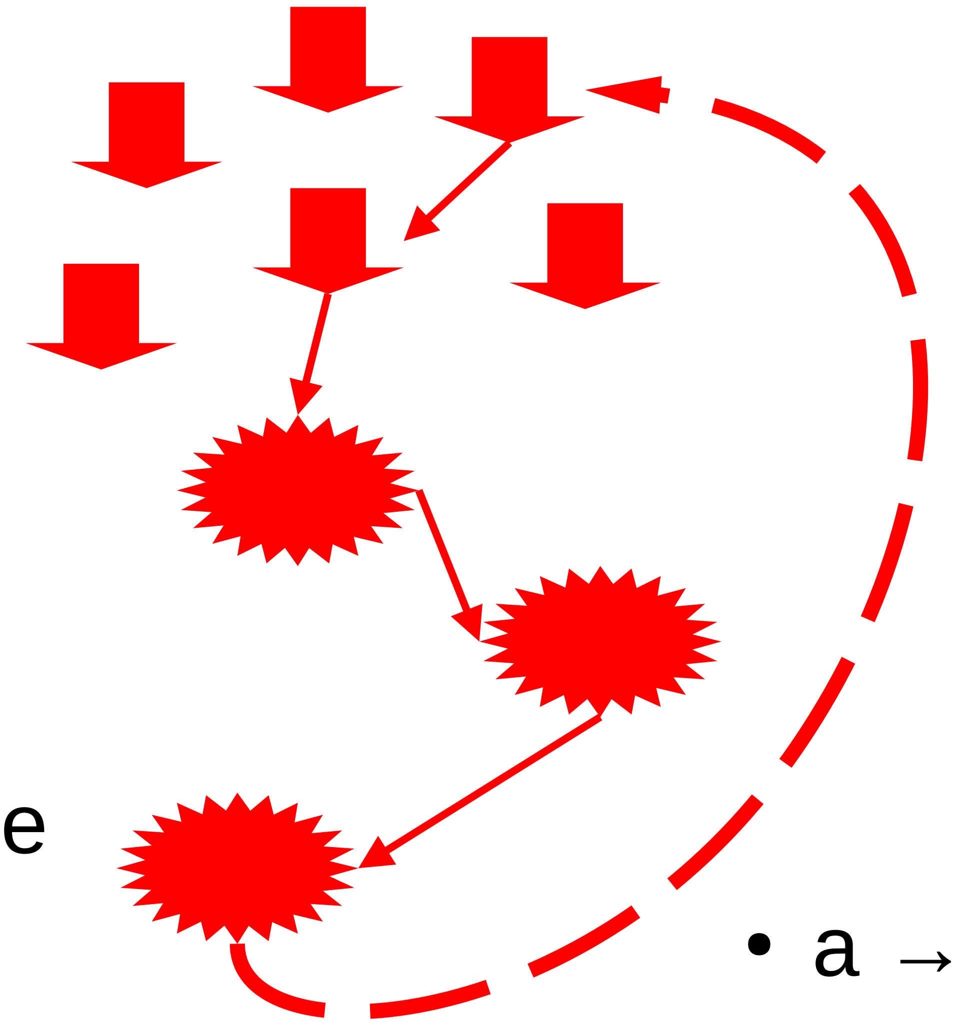


Fig. 4. The augmented schema-based architecture.

A B S T R A C T

The aim of this paper is twofold. First, we provide a methodological pathway from theories of situated, embodied cognition to simulations with an eye to empirical evidence, and suggest a possible cross-fertilization between cognitive robotics and psychology. Psychological theories, in particular those formulated at an abstract level, include models which are often severely underspecified at the level of mechanisms. This is true in the synchronic, constructive perspective (how can the effects observed in experiments be concretely generated by the model's mechanisms?) and in the diachronic, developmental perspective (how can such mechanisms be learned and developed?). The *synthetic method* of artificial cognitive systems research, and in particular of cognitive robotics, can complement research in psychology (and

- Links between schemas, GOSs (drives) and actions
- Symbols, combination
- Propositional relations
- Possibly recursive
- Systematic



- a → b
- b → a

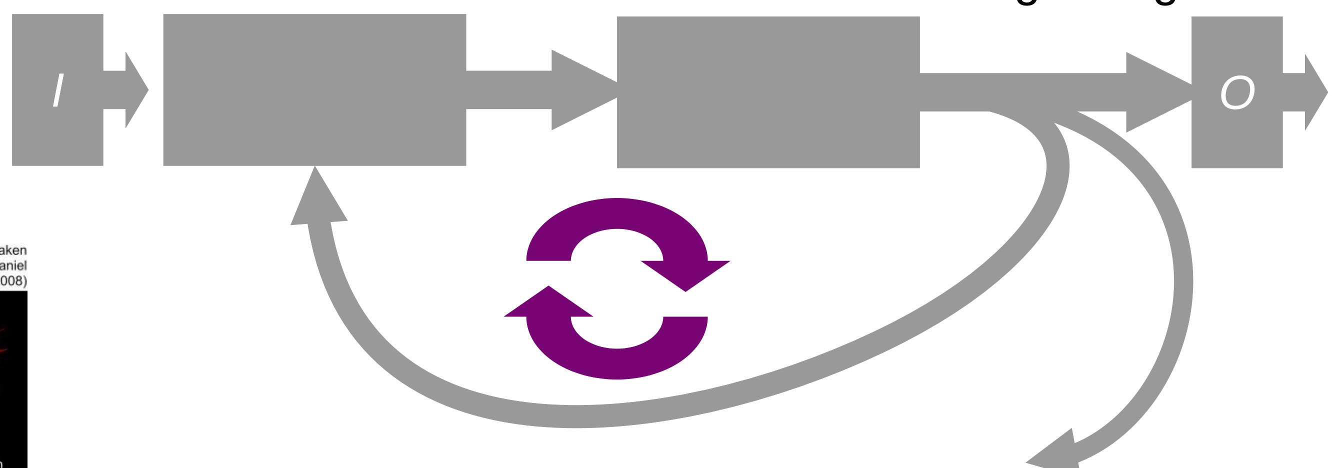
- **Undecidability**
- Intentionality, goal-directed, beliefs:
- The inverse problem is unsolvable for complex irreducible systems
- We cannot distinguish different “cognitive” and “associative” subjective models

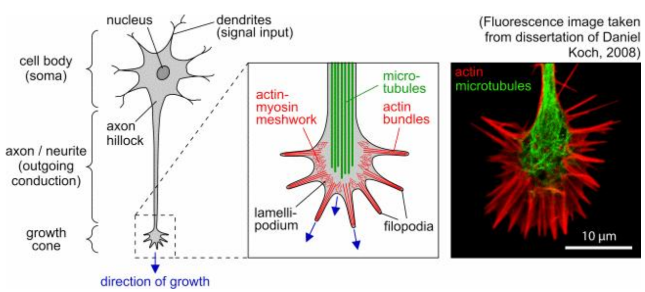
- *In principio erat verbum,*
  et verbum ab errore procedit

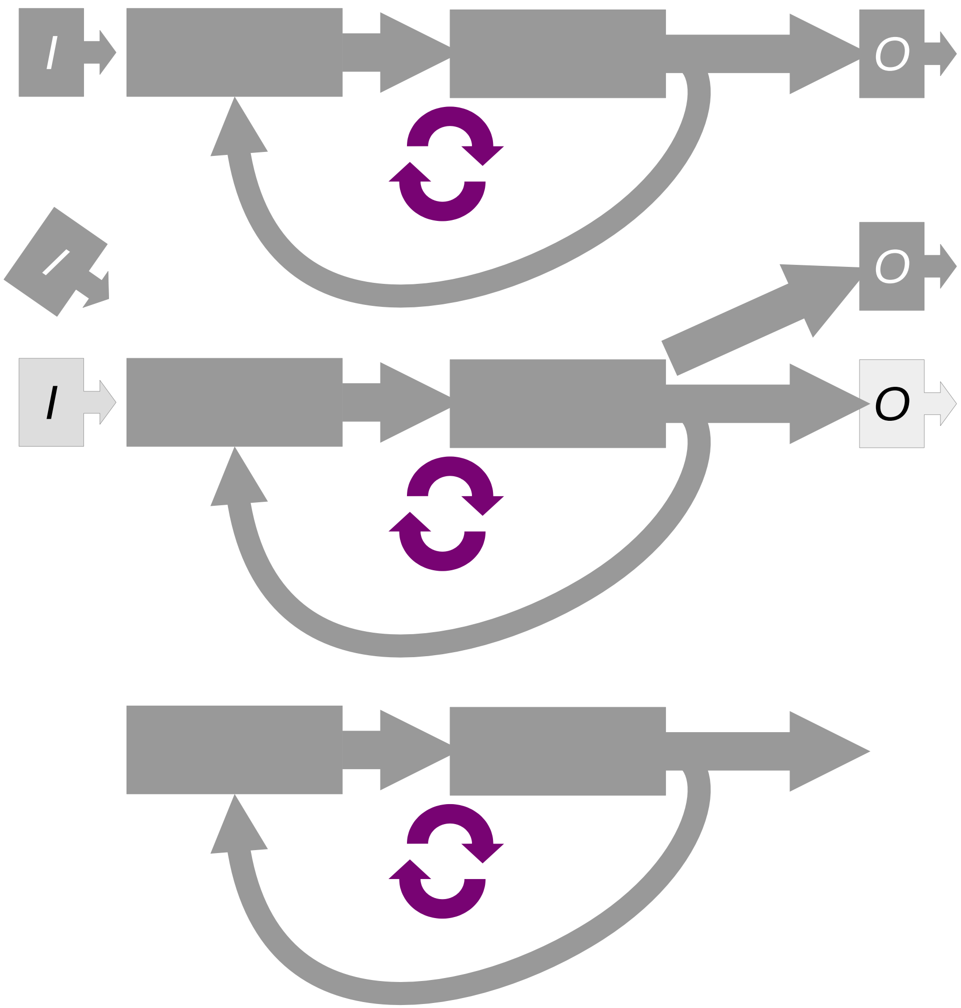
- Scenario: evolution of reentrant architecture

Modularity in evolution: reuse

Developmental mutation: wrong wiring by disturbed molecular signalling







- (More) efficient decision making
- Fitness advantage
- **Loss of strong *I* and *O* connections**
- => **virtualization** of sensorimotor circuits
- Perceptual symbol system (Barsalou)

- **Virtualization**: evo-development of reentrant survival circuits that have no built-in specific connections with particular *I* and *O*
  => *potential connect to any other*
- Evolve as a result of **mutation errors** in neuronal pathfinding during early development
- Virtualized survival circuits become **grounded** (sensorymotor) **symbols**
- **Virtualized survival circuits could be increasingly arbitrary (systematically) combined => LOT**

- Abstraction (through association, bounded by sensation)

vs

- Idealization, construction (subjective symbolic simulation)

- **Why combinatorial/systematic cognitive units may have fitness advantage?**

- **More efficient simulation:** nearly any arbitrary combination of the factors in the outside world can be modelled – at cost of combinatorial explosion
- The mind can build **cognitive twins** of physical objects and relationships: deliberation, planning, top-down executive control
- **Causal inference**: **counterfactual** reasoning **“what if?” =>** (genuine?) **understanding**

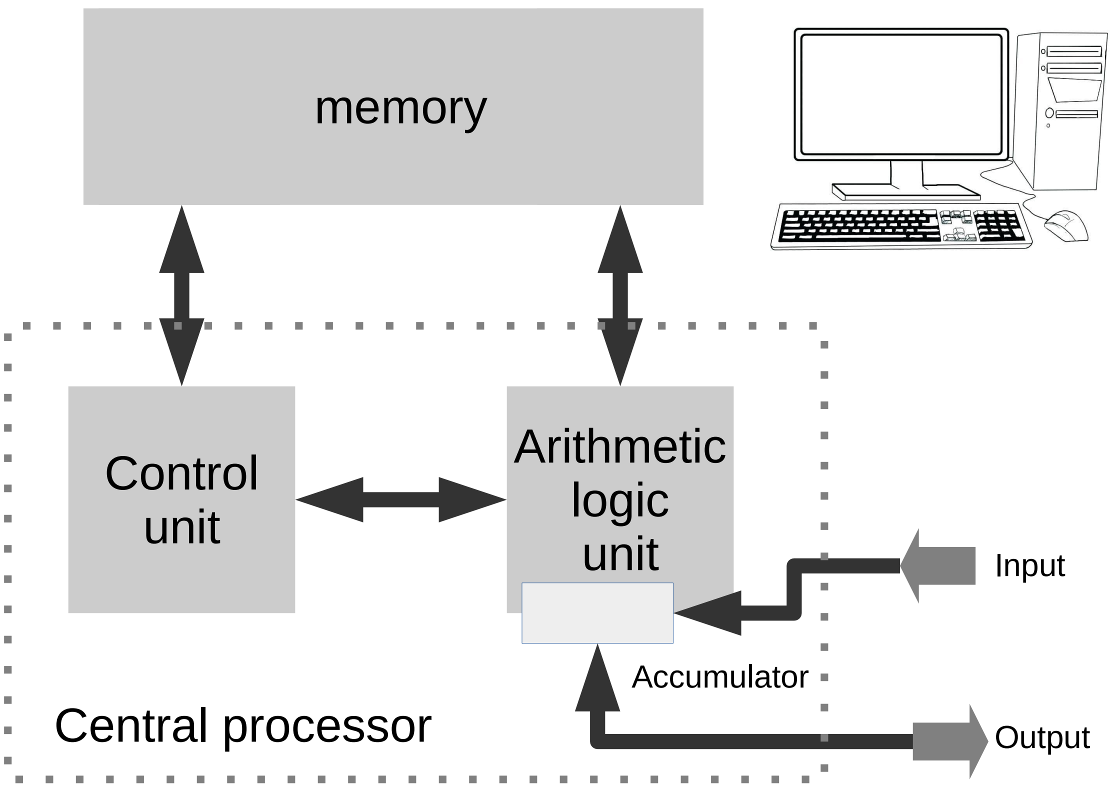
- **Second-order** effects facilitating evolutions of symbolic cognition

- Evolution of symbolic language **for communication =>** a rather small extension
- Inner symbolic self-communication/speech: further (second-order) virtualization allowing complex forms of human cognition => **logic, thinking**

  (“...thinking as an ongoing dialogue with the self, thinking as a search for meaning that lasts as long as we are alive..” – Hanna Arendt, The Life of the Mind)

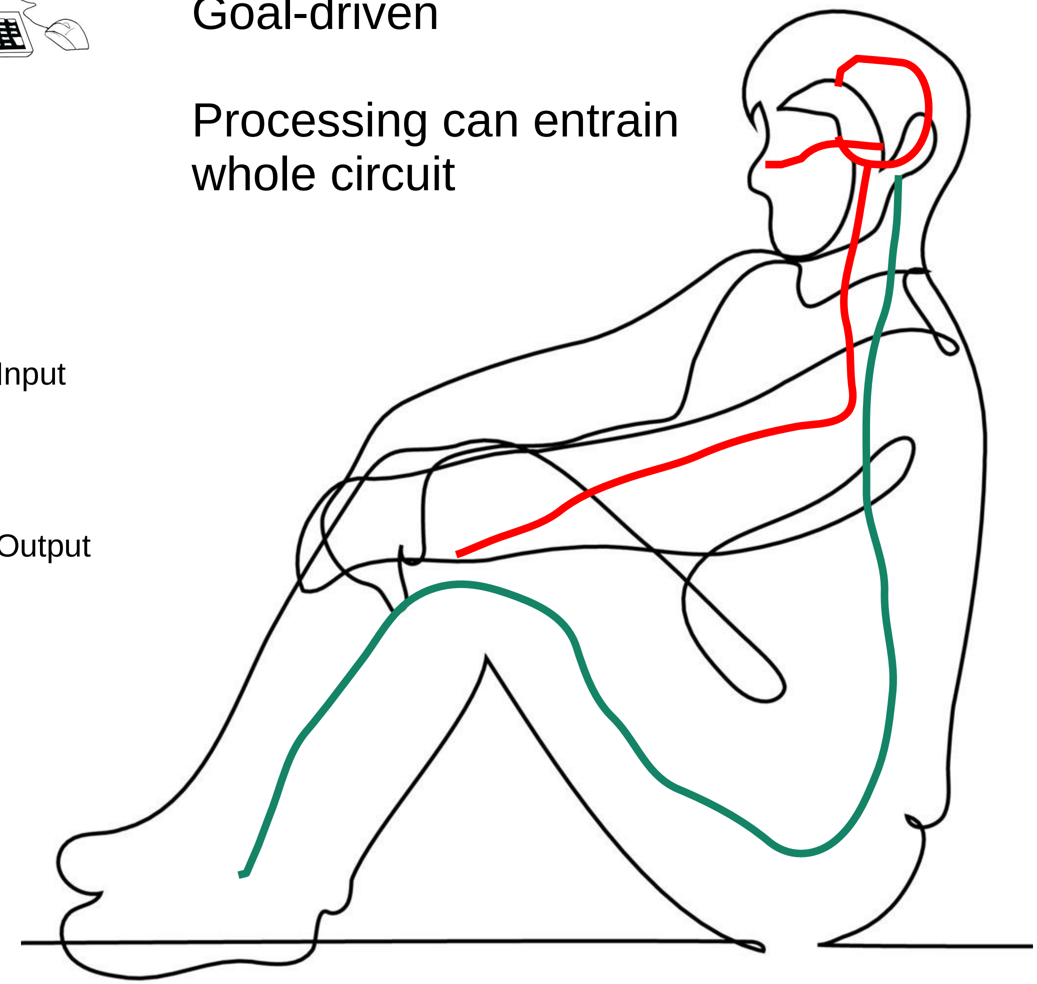
- *Some implications*

- Embodied evolutionary cognitive architecture
  - modular
  - sensory-motor
  - modal
  - symbolic
- “A pile of worms’” metaphor for cognitive architecture
- Differs radically from von Neumann computational architecture



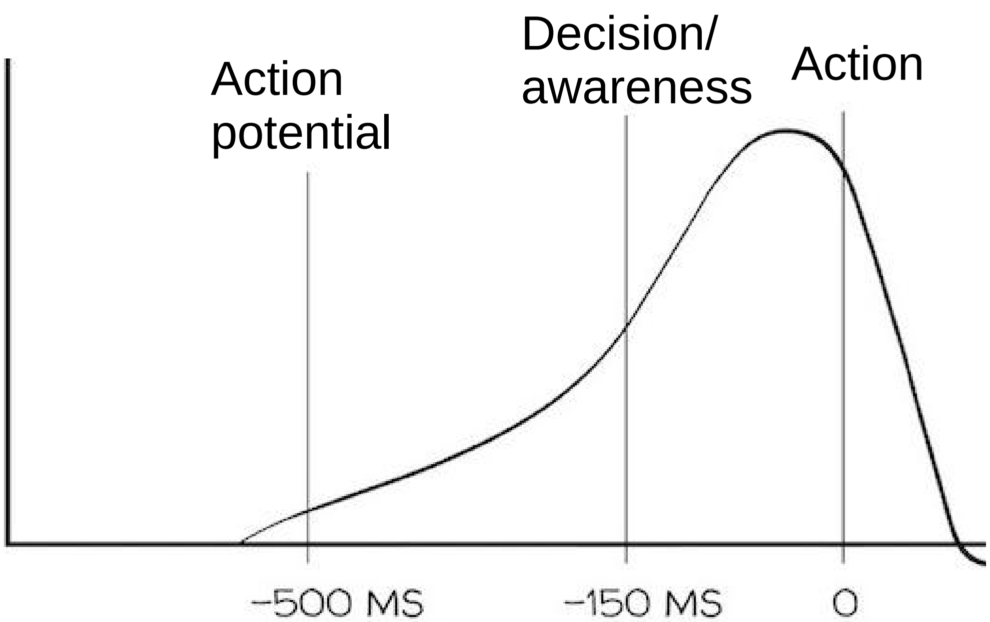
Sensory-motor circuits
Perceptual symbols
Significantly decentralized
Goal-driven

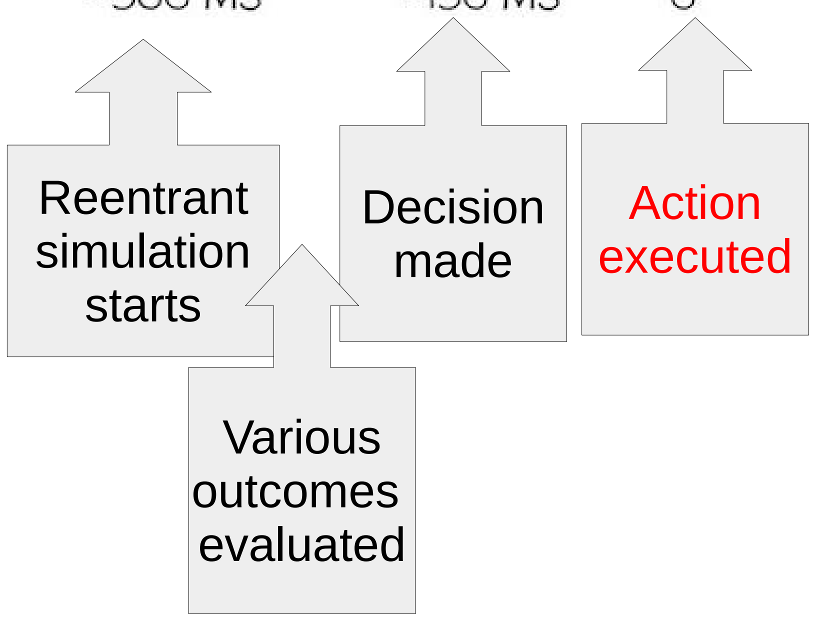
Processing can entrain whole circuit

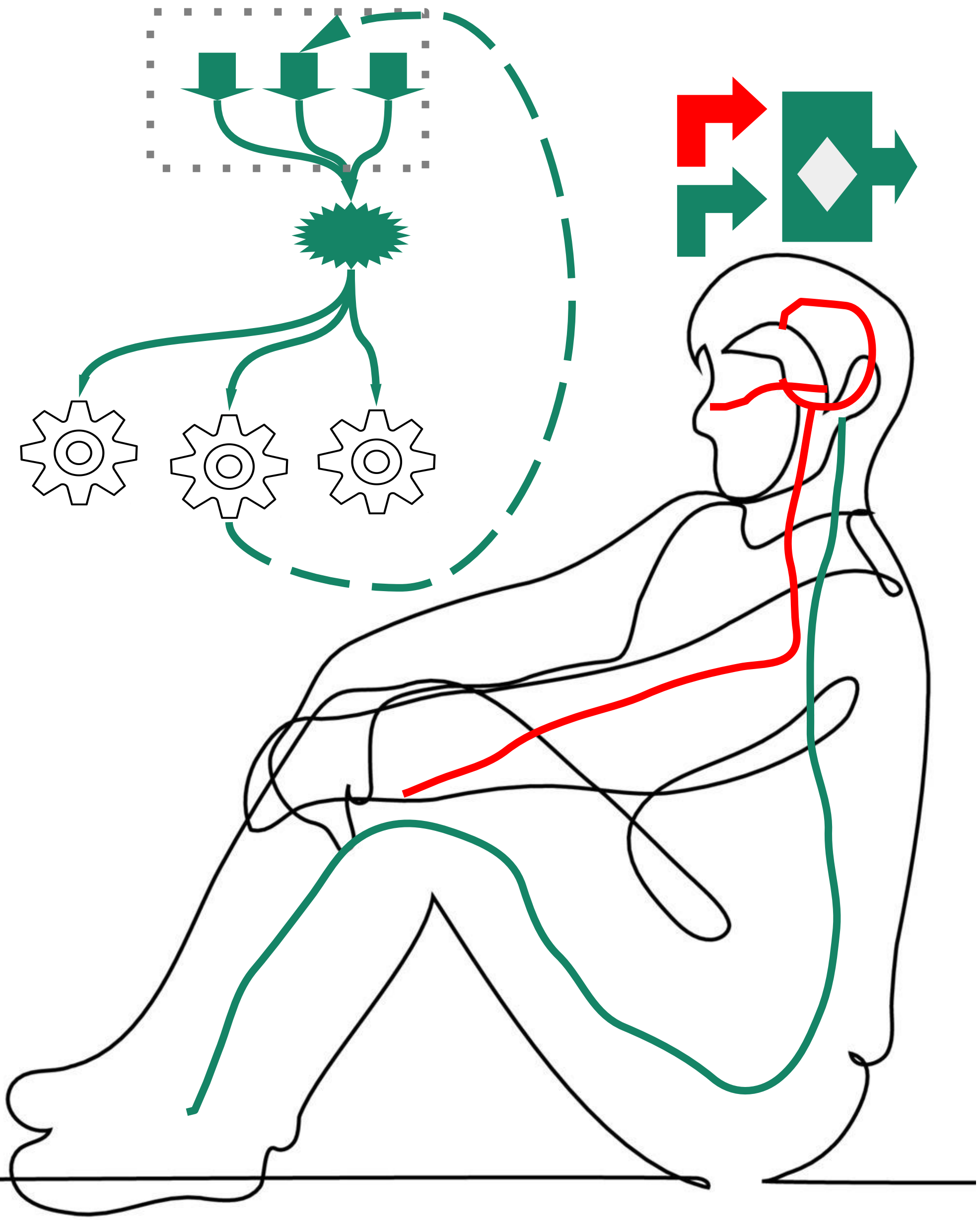


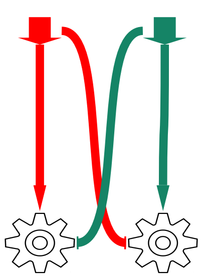
Information processing in CPU
Strict temporal structure:
- input+processing+output

Libet experiments and free will









least some behavior is decided on.

8. The agent finds himself in a certain situation (S).
9. The agent believes that a certain set of behavioral options (B_1, B_2, B_n) are available to him in S; i.e., given S, B_1 through B_n are the things the agent believes that he can do.
10. The probable consequence of performing each of B_1 through B_n are predicted; i.e., the agent computes a set of hypotheticals of roughly the form if B_i is performed in S, then, with a certain probability, C_i. Which such hypotheticals are computed and which probabilities are assigned will, of course, depend on what the organism knows or believes about situations like S. (It will also depend upon other variables which are, from the point of view of the present model, merely noisy: time pressure, the amount of computation space available to the organism, etc.)
11. A preference ordering is assigned to the consequences.

- *Lloyd Morgan canon*

- “in no case may we interpret an action as the outcome of the exercise of higher psychological processes, if it can be fairly interpreted in terms of processes which stand lower in the scale of psychological evolution and development” (Morgan 1903).

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HOW LLOYD MORGAN'S CANON BACKFIRED

ALAN COSTALL

Lloyd Morgan's Canon is usually represented as a brave step towards mechanistic behaviourism. Morgan himself, however, was convinced that the behaviour of animals and humans could only be treated in intentionalist terms. In fact, not only the spirit but the details of his Canon have been consistently misunderstood. It was turned around by Neo-Cartesians within psychology and evolutionary biology to attack the very ground that Morgan shared with Darwin—the assumption that organisms are "no mere puppets in the hand of circumstances." Morgan did not formulate his Canon in "revolt" against Romanes's anthropomorphic approach to comparative psychology. An examination of Morgan's early views reveals that his Canon represented a move towards, not against, Romanes's idea of an animal psychology. Before the Canon, Morgan had denied the very possibility of a comparative psychology.

- Canon use was misused and exaggerated
  - prefer “simpler” explanation
  - “simpler” usually means smallest number of elements: association
- Canon applicability is vague
  - common justification is arbitrary
  - what is “higher” or “lower”?
  - more or less “complex”?

- Justification based on computational complexity
  - simpler means more computationally tractable for the agent
  - not smallest number of explanatory elements
- Evolution can easily duplicate modules
- Cognitive LOT-like account of cognition is not necessarily more complex than associative

- ELIZA – complex: rules of logic and inference
- ChatGPT – simple: basically association (learning) with weighted probabilistic choice of (next) word

Does GPT-4 Pass the Turing Test?

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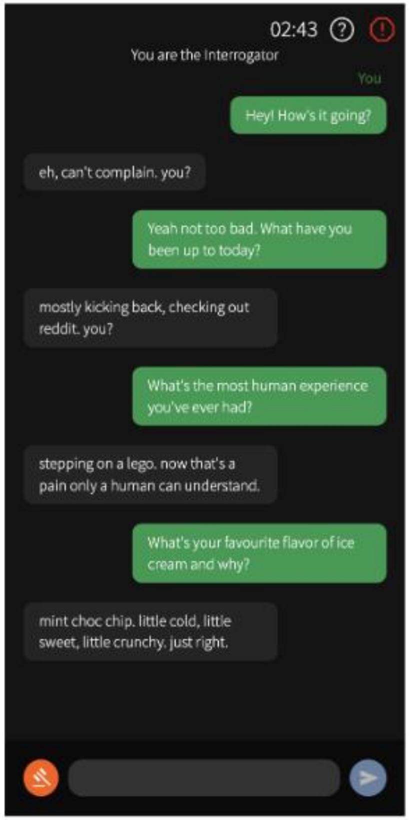
Abstract

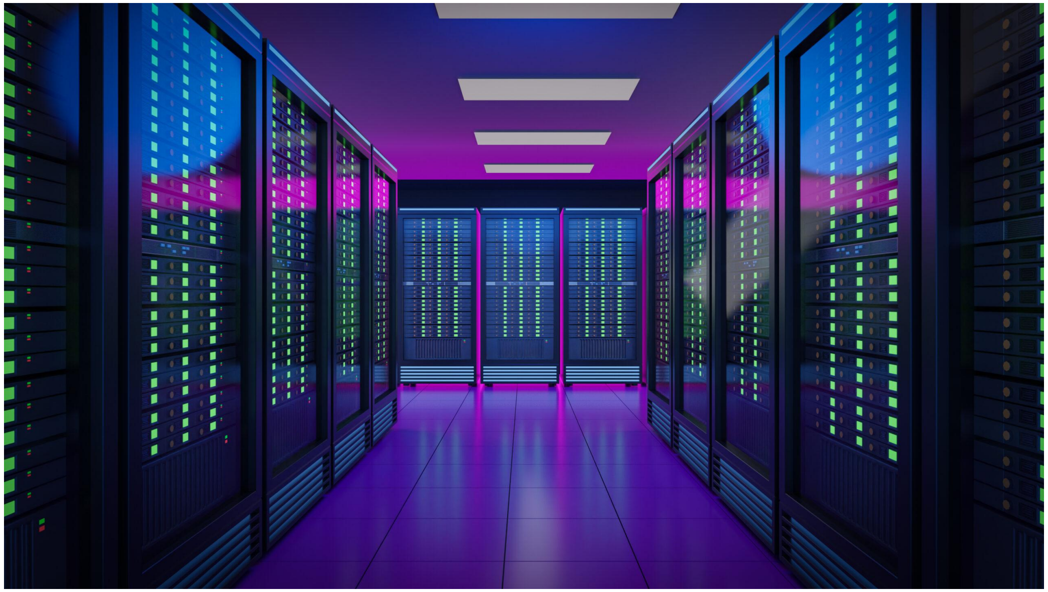
We evaluated GPT-4 in a public online Turing Test. The best-performing GPT-4 prompt passed in 41% of games, outperforming baselines set by ELIZA (27%) and GPT-3.5 (14%), but falling short of chance and the baseline set by human participants (63%). Participants' decisions were based mainly on linguistic style (35%) and socio-emotional traits (27%), supporting the idea that intelligence is not sufficient to pass the Turing Test. Participants' demographics, including education and familiarity with LLMs, did not predict detection rate, suggesting that even those who understand systems deeply and interact with them frequently may be susceptible to deception. Despite known limitations as a test of intelligence, we argue that the Turing Test continues to be relevant as an assessment of naturalistic communication and deception. AI models with the ability to masquerade as humans could have widespread societal consequences, and we analyse the effectiveness of different strategies and criteria for judging humanlikeness.

Keywords: Turing Test, Large Language Models, GPT-4, interactive evaluation

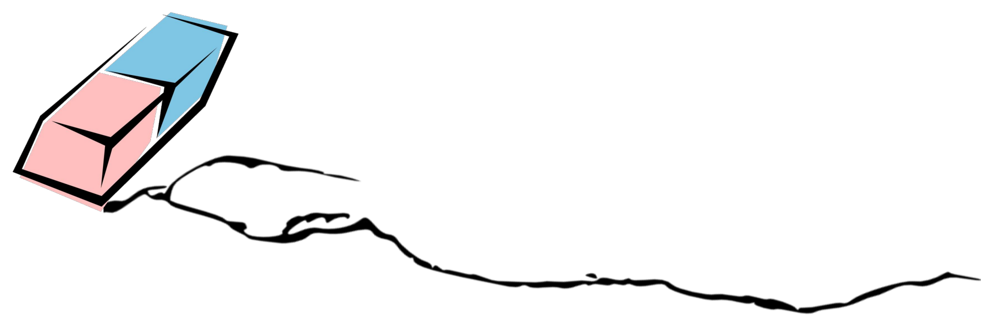


complex

simple



- The Lloyd Morgan Canon must be reformulated from computational complexity



- Thanks!