Philosophy of Biology for Neuroscientists

Neuroscience is life science, a compartment of biology. It inevitably raises problems in the philosophy of science, in particular the phil of biology that neuroscientists take sides on—whether they notice or not.

Better to take sides on issues in the phil of bio, and phil of sci, explicitly.

Biology begins with Darwin

Historically:

Before Darwin published *On the Origin of species* in 1859, there was little more to bio than "stamp collecting" [From the epithet attributed to Rutherford, discoverer of the electron: "There is physics, and everything else is stamp collecting."]

Substantively:

Darwin's theory is the fundamental theory for all of biology, including molecular biology and certainly neuroscience

Darwin's theory organizes the life sciences the way Newtonian mechanics (still) organizes physics

Dobzhansky's dictum: "Nothing in biology makes sense except in the light of evolution."

The task of biology

to explain three features of the biological domain:

       adaptation—two kinds

          traits/parts to other part in a whole

          whole organism to setting/environment

      complexity of living systems

      diversity of living systems

Adaptation is most striking and distinctive trait of items in bio domain.

It requires explanation most urgently.

Kant, Bishop Paley and the blade of grass

By late 18th century, Newtonian mechanics—the clockwork, mechanistic model of the physical universe was established. Kant's *Critique of Pure Reason* "showed" Newton's 4 *laws* had to be necessary truths. Universe couldn't be organized any other way.

But, Kant held, "There will never be a Newton for the blade of grass"--meaning the traits and behavior of living things (blades of grass) can't be explained, causally, mechanically, physically.

Biological traits are adapted—*appear* to show design, purpose.

Bishop Paley, cataloguer of adaptations in 7 volumes of *Natural Theology*

The *appearance* of design can be explained only by positing the *reality* of design, and of an omnipotent, omniscient designer—God.

Darwin: The Newton of the Blade of Grass

On The Origin of Species, 1859 (but formulated secretly much earlier)

A purely mechanistic, causal, clockwork, physical explanation of adaptation, that also explains complexity and diversity and so delivers all of the explanatory obligations of biology.

A beautifully simple theory—Darwin's bulldog, T. Huxley, said, on finishing his first reading, "How stupid of me not to have thought of it!"

The data that support the theory didn't require a round the world trip in the RMS *Beagle.*

The theory, as Darwin presents it in *Origin*, requires 3 garden variety observations and 2 obvious inductive inferences.

How natural selection produces adaptation

Observation   1. All biological systems reproduce exponentially.

Observation   2. The carrying capacity of any region is finite.
      `   [from Darwin's reading of Malthus, *On Principle of Population*, 1798]

Inference   3. There is always an [intra- & inter-species] struggle for survival

Observation   4. There is always variation in all hereditary traits
                              Darwin's key insight: variation isn't defect, deformation, imperfection, it's the rule in bio domain

Inference   5. The fittest hereditary variant more probably survive/increase in % from generation to generation

Resulting by iteration in

                              6. Descent with modification—aka evolution by NS

Notes on adaptation by the process of cycles of reproduction and variation with fitness differences

1. Progress is always local, never global. No 'higher' and 'lower'. Today's adaptation can become tomorrow's maladaptation when environment changes. Eg. White coats on polar bears in global warming
2. Variation in traits is blind to need, advantage, benefit. It's blind/random. A second key insight of Darwin's-rejection of Lamarck
3. Natural selection is entirely passive. It's filtration. "Selection" is a poor metaphor for environmental sieving among traits.
4. Mother nature's "solutions" to "design problems" are "quick and dirty." Variations are imperfect and then wired in because hereditary, and therefore hard to remove.
5. Evolution by natural selection is probabilistic, 2d law of thermo at work. Asymmetrical, energetically wasteful, most variants maladaptive.

More notes on the process of evolution by natural selection

6. Darwinian process is neutral on the mechanism of heredity and variation. Darwin knew nothing of Mendel, mutation, genetics.
7. Darwinian process can operate at many different levels simultaneously: at the nucleotide sequence in a gene, at the level of the gene, genotype, individual, family, population, even species.
8. Darwinian processes produce adaptations wherever there is reproduction, variation, fitness differences—doesn't have to be genetic
Can be somatic neural selection: neural development, reinforcement of Hebbian learning in wiring neurons-Edelman, *Neural Darwinism*
Can be cultural evolution: If there is non-genetic reproduction—eg. Intergenerational learning, and imperfect copying. *Memetics*

How Darwinism sets the agenda of life science

Q: Why does DNA contain thymine while RNA contains uracil?

Two interpretations of the Q:

1. Proximal: What is the difference in the biosynthetic pathways to DNA and RNA? A question in organic chemistry.

2. Ultimate: What is the function, role, purpose of thymine in DNA and/or the function of uracil in RNA. A question in molecular biology.

Proximal questions are about mechanisms.

Ultimate questions are about adaptations.

Why does the DNA sequence contain thymine (uracil+methyl) when its RNA copy contains uracil?

Answer:
The *function* of DNA is high fidelity information storage, copying and transcription.

The *function* of RNA is low cost transmission of large numbers of copies of nucleotide sequence information from 1 gene to many ribosomes.
Uracil molecules spontaneously deaminate to cytosine, producing point-mutation.

In DNA this would be catastrophic to its high fidelity storage *function*. The function of thymine in DNA is to prevent point mutations.
Thymine production is more energetically costly than uracil production.
A small number of deamination errors among the large number of transfer RNAs wont degrade uracil's *copy-function.* High cost synthesis would reduce production

The functional explanation of the DNA/RNA difference is implicitly evolutionary. Why?

What is a function? Why do thing have functions? where do functions *come from*?

One possible answer : The *artifact/designer* response.

> The saw's function to cut = the metal was fabricated to meet   some intelligent agent's purpose and does so (well enough).

> Natural functions reflect operation of divine designer/craftsman

Why is this meaning/explanation of functions ruled out in biology? No evidence of designer? Evidence of no designer? No way to test claim experimentally? A better theory than divine creation.

Darwinian answers to Qs 'what is a function?' 'Why do traits have functions?'

A trait has a function = the trait has an adaptational pedigree, the trait has a Darwinian etiology of variation and selection in the past.

Functions, adaptations, taxonomies in ordinary language and life science

Nouns can be 'structural' or 'functional':

Consider the short elastic cylinder on the top of a pencil:

> British English: a rubber--structural characterization

> American English: an eraser—functional characterization

Most nouns in most languages are functionally defined.

Most of the proprietary taxonomy—descriptive vocabulary--of chemistry and physics is structural.

Most of the proprietary taxonomy of biology and life science is functional. So, the vocabulary of biology is implicitly Darwinian.

The Panglossian Paradigm: the problem, temptation, risk, necessity of adaptationalism?

The descriptive vocabulary of life science presupposes a contingent theory--Darwin's.

Every functional name we give a trait is a *h*ypothesis about that trait's evolutionary pedigree.

But our vocabulary may not "carve nature at the joints"—Aristotle's words.

Some traits we label may not have the functions we suppose, they may have different functions, they may have no functions, they may have no Darwinian pedigree**,** they may be the nonfunctional biproducts of functions

Examples: bilateral symmetry, the chin, human language and music(?)

How can we tell without a time-machine? This is the challenge biology faces.

Adaptation or Drift? The elephants' ears. Darwinian processes are probabilistic

Recall, the 5th step in Darwin's theory:
5. The fittest hereditary variant *more probably* survive/increase in % from generation to generation
Natural selection is a probabilistic process: the fittest don't always, invariably, unavoidably survive. There are environmental vicissitudes-earth quakes, forest fires, floods, that intervene non-selectively to wipe out parts of populations without regard to greater/lower fitness.
The larger the population, the smaller the chances of statistical departure from selection for fitness.
But there is always a chance—That is statistical (genetic) drift.

Is drift a biological force, like selection, or just a label for our ignorance?
Is drift a non-biological interference with selection? In a deterministic world where does it come from?

Adaptationalism: Kiplingesque "just-so" stories or indispensable tool of biological inquiry?

Hypothesizing functions and then testing such hypothesis is the method of biology. To nail down functional claim answer all of

Tinbergen's 4 questions about a trait:

1. What benefit, advantage, need of the system does the trait confer?

2. What is the evolutionary history of the trait?

3. What is the mechanism by which benefit, need, advantage is accomplished

4. How does the trait develop in the individual organism?

Individuating the trait *already* assume the hypothesis that has a function. Answers to the 4 q's could show it's not a functional, biological trait.

Why is all this relevant to neuroscience? Neuroscience addresses Tinbergen's 4 Qs

"The function of the grid-cells in the entorhinal cortex is to register the shape/size of spatial regions"—Nobel prize winning hypothesis.
[grid-cell is functional description, entorhinal cortex is structural]

What makes this claim about grid-cells true?
Systematic correlation of individual grid cell firing with shape/size of cage? No. We need the rest of Tinbergen's Qs answered, because they address its truth-maker.

What makes the function-attribution correct is some fact about the evolutionary etiology of those cells—their current behavior is the result of a process of blind variation and environmental filtration for the systematic correlation between their firing and cage-shape.

The Darwinian etiology is not available experimentally or otherwise, it's a guess, a hypothesis, one that can be undermined or refuted by evidence.

Why neuroscience looks so different from physics and chemistry

Physical science characterized by

1. Strict laws of nature which our best hypotheses and theories successively approximate to.

Eg, Newton's 4th law of gravitation: $F = g \, m_1 \times m_2/d^2$, Chemical equation balancing: $2H_2 + O_2 \dashrightarrow 2H_2O$

2. Explanatory reduction by derivation

Periodic table: Chemical composition laws explained by laws of co-valent bonding derived from theory of electron, derived in turn from QM, grounded mathematically in quantum field theory.

Neither strict laws nor reductive derivation are possible in the life sciences.

All biological generalizations are temporary, local regularities, generated by natural selection

There are no laws to discover in neuroscience, only local regularities described by narrowly restricted *models*.

Direct consequence of neuroscience's Darwinian framework:

In physics, chemistry, there are universal laws, generalizations that hold everywhere and always and would continue to be true even if the distribution of mass and charge in the universe was completely different.

Biological generalizations only hold true in virtue of the operation of natural selection on the boundary conditions. So, every regularity in biology begin to hold at a time and to cease to hold at a later time.

Beyond Natural Selection there are no laws in biology: only spatiotemporally limited regs

All metazoans are aerobic is true but not a law. Why? It became true after the great oxygenation event 2.5 billion years ago that killed off almost all anerobic bacteria. It will cease to be true if the planet is deprived of oxygen slowly enough that some random variation in metazoans' respiration enables them to use something other than O_2.

The Central Dogma: DNA codes for RNA, RNA codes for proteins was thought to be a universal law until the discovery of RNA viruses.

The Genetic Code of nucleotide triplets coding for amino acids was a "frozen accident" and turns out to have exceptions.

Natural selection always produces *arms races*--every organism's adaptation is an invitation to competitors to exploit it, unraveling regs.

Natural selection makes explanation by reduction difficult and different than in physics.

Compare the explanation of the Ideal Gas Law: PV =nrT by the kinetic theory of gases.

Assume
1. Gases are composed of point masses—molecules
2. Molecules obey Newton's laws
3. Temperature = ½ mv^2 of molecules, Pressure = average force of molecules/unit area

Derive

PV = nrT, Kelvin's great reduction: heat is identical to molecular motion

This neat derivation is not possible in life science. Why? Natural selection of course≥

Exactly why are thre no general reductive explanations in life science?

Darwinian processes select for effects and are blind to different causes of the same or closely similar effects on fitness

There are almost always more than one way to produce the same fitness-conferring effect, and random variation will result in a proliferation of different mechanisms with the same result. So there is almost never just one mechanism for any function. So often you can't reduce functions to short list of the mechanisms that explain them.

The wing evolved 40 different times, and its structure is different in each iteration. So, no general theory about the mechanism that explains the function of flight (never mind flightless penguins).

Functions are multiply realized at every level

Irreducibility at the macromolecular level
One function   many different structures
The gene for hemoglobin   =   [nucleotide sequence 1] or [nucleotide sequence 2] or….and so on indefinitely.
How many sequences? Indefinitely many actual and possible.
No bio equivalent to the reduction of heat to molec motion: T = ½ mv^2
No reductive explanation of Mendel's laws of genetics by Watson-Crick DNA mechanism.
Genes are "nothing but" DNA, but Gene's behavior—assortment, segregation, dominance, recessivity, can't be systematically explained by DNA. Problem of multiple realization even greater at higher levels

The problem is even more serious at higher levels of function—"many ways to skin a cat"

Broad function of *prey-detection*

discharged by different narrower functions:

        vision   discharged by different mechanisms in

                                      bird-–two color, non-stereoscopic mechanism

                                      human—three color, stereoscopic mechanism

                                      frog--?

        echolocation   discharged by different mechanisms in

                                      bat

                                      owl

      odor detection   dog, bear, seal—different mechanisms

      thermal gradient   *detection* snake, lizard—different mechanisms

Sources of multiple realizability in the brain

Neural plasticity

Differences in developmental pathways

Local learning schedules

Can result in differences in the brain mechanisms delivering same cognitive functions and afferent behavior, even in same species, even in sibling brains.

Genetic natural selection, developmental selection, ontogenic selection (aka reinforcement learning) can't discriminate among and select between structures that deliver (roughly) the same functions.

Multiple realizability versus reduction/mechanism in neuroscience

Multiple realizability (brought on by blindness of selection to structure) is everywhere in life sciences.

In cognitive science it results in irreducibility of mind to brain, and of cognitive models to neural models.

Methodological dispute in phil of cognitive neuroscience:

Are dynamic models in cognitive science that are not reducible, not mechanistic, nevertheless still explanatory?

Mechanist/Reductionist: No

Antireductionist: Yes

The HKB model of bimanual control: φ˙=−sinφ−2ksin2φ, predicts index finger behavior where φ˙ is phase relation between moving index fingers, k is coupling parameter.
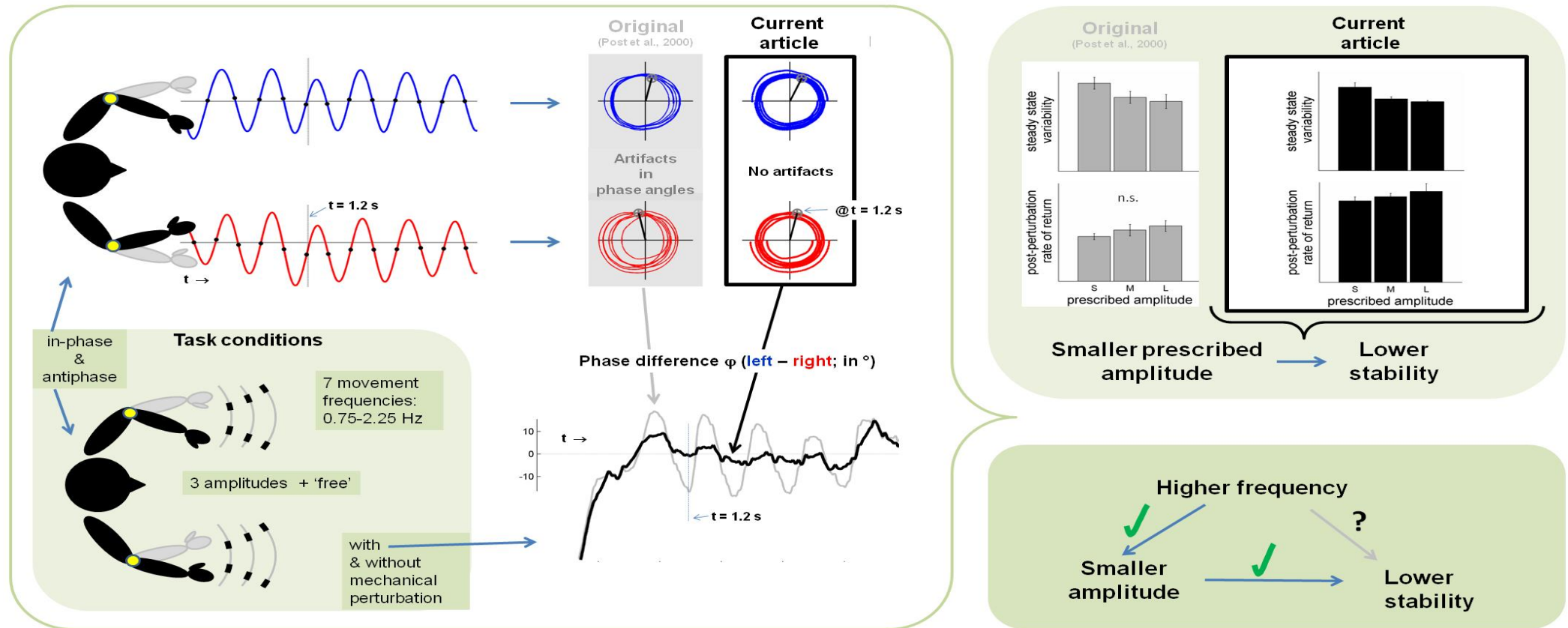
Does the HKB model explain behavior?

Antireductionists, antimechanists, dynamic systems theorists: Yes

HKB is a "law of coordination" independent of system structure (details of the possible multiple neural mechanisms) that brings it about.

The model's equation, $\dot{\varphi}=-\sin\varphi-2k\sin2\varphi$, predicts behavior in various tasks in learning, memory, other cognitive demands.

Uncovering the mechanisms that result in HKB is

Difficult—owing to multiple realizability

Doesn't add to systematic predictive power of HKB model

Therefore, doesn't increase (may decrease) explanatory power of the model

Does the HKB model explain behavior?

Reductionists, mechanists, opponents of dynamic systems theory: No

HKB model is a mere summary of the data to be explained

Explanation is causal. To explain one must cite causes.

$\dot{\phi}=-\sin\phi-2k\sin2\phi$, only describes index finger behavior. $\dot{\phi}$ is phase relation between moving index fingers, k is coupling parameter.

Neither $\dot{\phi}$ nor k is a cause of the behavior—a "difference maker" in determining whether index fingers move into phase or not.

The Philosophical problems cognitive neuroscientists must take sides on

The nature of explanation– mechanistic versus "dynamical"

The implications of irreducibility of cognitive processes to neural processes:

Either

Autonomy of the persona level, intentional states, consciousness from the brain processes that "realize," "implement," "instantiate," deliver them?

Or

Explaining the descriptions at higher levels as *useful approximations*, way-stations, *instrumental* devices on the way to a real science of the brain

Or

Eliminativism, explaining the personal level and intentionality away as illusory.