Behavioural Processes 114 (2015) 14–25

Contents lists available at ScienceDirect

Behavioural Processes

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

# Against matching theory: Predictions of an evolutionary theory of behavior dynamics

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ARTICLE INFO

*Article history:*
Received 28 September 2014
Received in revised form 7 February 2015
Accepted 9 February 2015
Available online 11 February 2015

*Keywords:*
Adaptive behavior
Complexity theory
Evolutionary dynamics
Evolutionary theory of behavior dynamics
Matching theory
Selection by consequences

ABSTRACT

A selectionist theory of adaptive behavior dynamics instantiates the idea that behavior evolves in response to selection pressure from the environment in the form of resource acquisition or threat escape or avoidance. The theory is implemented by a computer program that creates an artificial organism and animates it with a population of potential behaviors. The population undergoes selection, recombination, and mutation across generations, or ticks of time, which produces a continuous stream of behavior that can be studied as if it were the behavior of a live organism. Novel predictions of the evolutionary theory can be compared to predictions of matching theory in a critical experiment that arranges concurrent schedules with reinforcer magnitudes that vary across conditions in one component of the schedules but not the other. Matching theory and the evolutionary theory make conflicting predictions about the outcome of this critical experiment, such that the results must disconfirm at least one of the theories.

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It is well known that prediction plays an important role in the development and testing of scientific theories. Some scientists and philosophers of science have identified different levels of prediction. For example, according to theoretical physicist, Richard Feynman (1997),

> When you have put a lot of ideas together to make an elaborate theory, you want to make sure, when explaining what it fits, that those things it fits are not just the things that gave you the idea for the theory; but that the finished theory makes something else come out right, in addition (p. 341).

This may be referred to as first-stage prediction. A good theory must be able to explain or account for phenomena beyond those for which it was designed to account. It follows as a corollary that the greater the range of known phenomena for which the theory can account, the better the theory.

Theoretical physicist and mathematician, John von Neumann, and economist, Oskar Morgenstern, expanded on this view:

> What is important is the gradual development of a theory, based on a careful analysis of the . . . facts. . . . Its first applications are necessarily to elementary problems where the result has never been in doubt and no theory is actually required. At this early stage the application serves to corroborate the theory. The next stage develops when the theory is applied to somewhat more complicated situations in which it may already lead to a certain extent beyond the obvious and familiar. Here theory and application corroborate each other mutually. Beyond lies the field of real success: genuine prediction by theory. It is well known that all mathematized sciences have gone through these successive stages of evolution (von Neumann and Morgenstern, 2007, pp. 7–8).

At von Neumann and Morgenstern's first stage of prediction, in agreement with Feynman, "predictions" are to facts or phenomena that are already known, but that were not used to develop the theory. This is sometimes also referred to as postdiction or retrodiction, and is an important step in theory testing; it makes sense to ask whether a theory can account for known facts before attempting to extend it to new phenomena. Von Neumann and Morgenstern's second stage of prediction includes at least some predictions for which experimental measurements have not yet been made. This is an initial step beyond what is already known. This stage of prediction may entail an experimentum crucis, or critical experiment, where two theories make incompatible predictions about an experiment's outcome. In von Neumann and Morgenstern's third stage, a theory predicts completely novel facts or phenomena, and thus entails true discovery. An example of this stage of prediction is the discovery of the planet Neptune, which was occasioned by observations of irregularities in the orbit of Uranus (Littmann, 2004). According to Newton's laws of motion and gravitation (the theory), these irregularities could only be caused by the gravitational force of a planetary body nearby. The theoretically required planet was observed in 1846, causing a sensation in 19th century astronomy

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http://dx.doi.org/10.1016/j.beproc.2015.02.007
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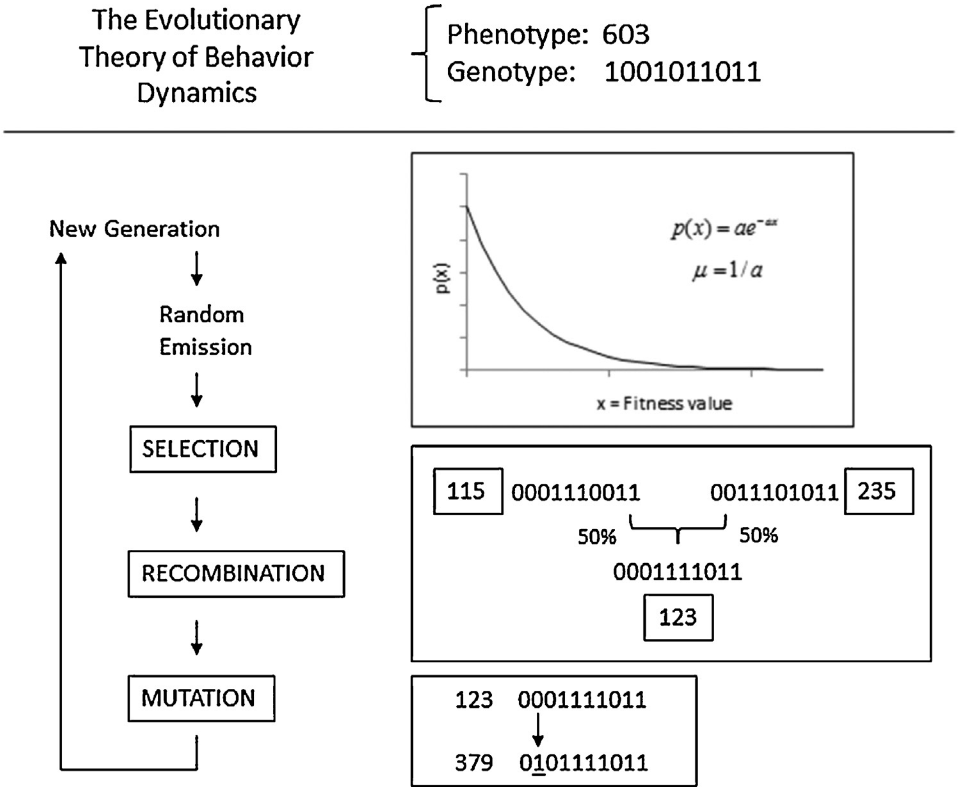

**Fig. 1.** The evolutionary theory of behavior dynamics. The flowchart on the left summarizes the algorithmic operation of the theory; "Random Emission" refers to the emission of a random behavior from an artificial organism's population of potential behaviors. Darwinian processes of selection, recombination, and mutation are illustrated in the top, center, and bottom boxes on the right. After a drawing by A. Popa.

and mathematical science (Littmann, 2004; Pannekoek, 1953). An important and desirable feature of the second and third stages of prediction is that they put a theory at significant risk of disconfirmation (Popper, 1965). Obviously, success at each of von Neumann and Morgenstern's stages of prediction increases one's confidence that the theory is a true account of nature.

The purpose of this article is to develop a second-stage prediction of an evolutionary theory of behavior dynamics (McDowell, 2004, 2013b). As explained in Section 3 below, this includes a critical experiment that compares contradictory predictions of matching theory and the evolutionary theory. In Section 1, the evolutionary theory is summarized and first-stage predictions of the theory are reviewed. In Section 2, the current empirical and theoretical status of the matching law and matching theory are reviewed in order to establish its predictions. In Sections 3 and 4, the critical experiment is described, and the evolutionary theory's predictions regarding its outcome are developed.

## 1. The evolutionary theory of adaptive behavior dynamics

The evolutionary theory is a computational instantiation of the idea that behavior evolves during the lifetime of an individual organism under the selection pressure of consequences from the environment. To implement the theory and obtain its predictions, artificial organisms and environments with which they might interact are created in computer code. Each artificial organism is animated by a population of potential behaviors that evolves over generations, or ticks of time, by the Darwinian processes of selection, recombination, and mutation. At each moment of time, the artificial organism emits a random behavior from its population, which produces a continuous stream of behavior that can be recorded and analyzed as if it were the behavior of a live organism.

### 1.1. Algorithmic operation of the theory

The algorithmic operation of the theory is simple enough to illustrate with a few diagrams that might be drawn on the back of an envelope (cf. Cox and Forshaw, 2012), as shown in Fig. 1. Behaviors in the population of potential behaviors are represented by integer phenotypes (e.g., 603, shown on the top right of the figure) and their binary genotypes (1001011011 is the binary representation of 603). The flow chart on the left side of the figure shows the overall operation of the algorithm. A behavior (phenotype) is emitted at random from the population of potential behaviors ("Random Emission" in the diagram), after which the population may undergo selection, and then recombination and mutation, as indicated by the boxes in the flow chart. The result is a new population, or generation, of behaviors from which one behavior is emitted at random, and then the cycle repeats.

The top, center, and bottom boxes on the right side of Fig. 1 illustrate how selection, recombination, and mutation are implemented. Selection entails choosing parent behaviors from the population. If the emitted behavior resulted in a benefit to the artificial organism, such as reinforcer delivery in a laboratory experiment, then fitness values are assigned to each behavior in the population. Fitness is defined as the absolute value of the difference between a behavior's phenotype and the phenotype of the just-emitted behavior. Smaller fitness values represent fitter behaviors because they correspond to behaviors that are more like the behavior that just produced a benefit. Once fitness values are assigned, a fitness density function (FDF) is used to choose parents for mating such that fitter parents are more likely to be chosen than less fit parents. The top box on the right side of the figure shows an exponential FDF. The essential property of any FDF is that the probability a behavior will become a parent ($y$-axis) decreases as its phenotypic distance from the behavior that just produced a benefit increases

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