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CYBERRAT, INTERBEHAVIORAL SYSTEMS ANALYSIS, AND A "TURING TEST" TRILOGY

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ABSTRACT: This monograph introduces the functional characteristics and conceptual significance of a simulation software system called *CyberRat* (Ray, 1996a, 2003a, 2012a, 2012b). *CyberRat* expands upon prior illustrations (Ray & Delprato, 1989; Ray, 1992) of how such computer-based simulations can serve to formatively enhance, and eventually validate, the descriptive research methodology upon which their development relies. To illustrate this process I also review highlights of previous publications (cf. Ray & Brown, 1975, 1976; Ray & Delprato, 1989), detailing the unique research methodology used to collect data that guided *CyberRat's* development. This methodology integrates interbehavioral psychology (Kantor, 1959) and general systems analysis (von Bertalanffy, 1968), and thus is referred to as *interbehavioral systems analysis* (IBSA). *CyberRat's* validation of IBSA methods involves a process analogous to Turing's (1950) famous test for simulation authenticity, in that it relies upon "phenomenological equivalence" criteria for observers to compare experiences of real vs. simulated events. And because IBSA stresses three convergent strategies for research, including *structural analysis*, *functional analysis*, and *operations analysis*, my organizing theme addresses how closely *CyberRat* comes to passing a trilogy of hypothetical Turing tests—one for each of these three analytic strategies.
Key words: Interbehavioral Systems Analysis, *CyberRat*, Turing test, behavior analysis, structural analysis, functional analysis, operations analysis

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AUTHOR'S NOTE: In addition to being the inventor, producer, and director, but not the computer programmer, for *CyberRat*, the author is also the President/CEO and a stockholder in the company, (AI)^2, Inc., that funded, publishes, and distributes *CyberRat* as a commercial product. All computer programming for *CyberRat* was authored by Victor Begiashvili as either an employee of, or independent contractor to, (AI)^2, Inc. and his contributions were absolutely critical for the realization of the modeling projects that *CyberRat* represents. All *CyberRat* videos and screenshots are copyrighted by (AI)^2, Inc. and are used here by permission. Finally, this monograph owes far more than I can express to my friend and colleague, Dr. David A. Eckerman, for his persistent encouragement while I was writing it, as well as his major editorial advice and contributions through the multiple drafts I produced while struggling with it. He persevered through virtually all of the seven years I spent on the many false starts and failed productions that preceded this final version. I am very grateful for his efforts and support, but can lay no responsibility at his feet for its remaining shortcomings. Please address correspondence to Roger D. Ray, Department of Psychology, Rollins College, Winter Park, FL 32789; Email: rdray@rollins.edu

I have multiple and overlapping goals guiding this monograph. My ultimate goal is to articulate the conceptual and methodological validation value of a computer-based simulation called *CyberRat* (Ray, 1996a, 2003a, 2012a, http://www.cyberrat.net), which is kinetically illustrated in Video Illustration 1 (click linked text to view) and statically illustrated by the CyberRat V3.x User's Guide (Ray, 2012b).

Please Enter your Login ID (User ID): Visitor

Video Illustration 1. After viewing how one may access and experiment with the many features of *CyberRat* offered via the default Visitor login illustrated in the video linked above, readers may wish to download a free evaluation copy of the *CyberRat* computer application to try it themselves. An Apple Mac dmg installer is available for free using this link. Alternatively, the free Windows Installer for CyberRat may be download using this link. After downloading, install the application, launch it, and follow instructions illustrated in this video.

CyberRat is a successful and effective operant laboratory replacement for many live-animal demonstrations of behavioral principles (e.g., Ray & Miraglia, 2011). Most psychologists experiencing *CyberRat* for the first time are quick to see potential educational value in the system, but few consider its conceptual value. Likewise, few who know of *CyberRat* realize just how much original data were collected to give formative guidance to the realism and capabilities of the model. Sharing those original empirical data in the present context is another of my overlapping goals, for those data also play an important conceptual role in evaluating the model itself.

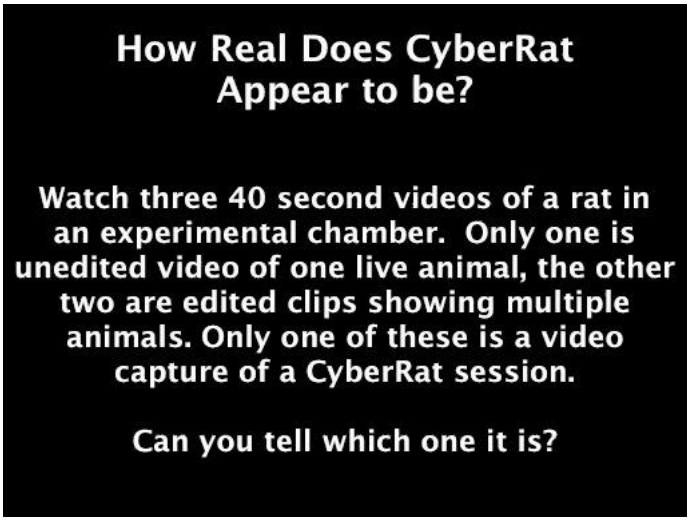
The conceptual value of *CyberRat* is based, in part, upon how well the model reconstructs behavior from the descriptive data that guided its development. The fact that those data were themselves both necessary and sufficiently complete to allow the creation of such a valid model also serves, in turn, to validate the relatively obscure research approach that guided that data collection—an approach founded largely upon J. R. Kantor's (1953, 1959) interbehavioral psychology and von Bertalanffy's (1968) General Systems Theory (GST) and its early predecessors, such as Ashby's (1956/1999) contributions on cybernetics. Because Kantor's approach stresses description, as opposed to experimentation, it shares a problem inherent in all descriptive research: determining what descriptions are both necessary and sufficient for a complete scientific understanding of events/fields being described. I have previously argued (e.g., Ray, 1992; Ray & Delprato, 1989) that simulations are an important means for addressing this adequacy issue, and I will use *CyberRat's* presently asserted success in simulating the original conditions that generated its founding data as a new and extended case in point. But this assertion raises an additional issue that also must be considered. If a simulation is used to validate the adequacy of descriptive methods, what validates the adequacy of the simulation?

This last question was addressed by Turing's (1950) famous paper proposing his "imitation game" as a test for simulation authenticity in artificial intelligence. Turing proposed a set of criteria for authenticating a model of machine-based "thinking." He argued that if outputs from a computer-based simulation of human activity could not be discriminated from outputs generated by parallel real human activities, the simulation would be deemed authentic.

The analogy I will presently offer is based upon an observer's ability to discriminate whether he or she is observing, and collecting data from, a live animal viewed through closed-circuit television with data presented through a cumulative response recorder or if the observations and data derive from a computer-based simulation of such an animal. Observers will have this challenge of determining real vs. simulated animal behavior whether they are only passively viewing, actively collecting systematic observational data, interactively training, or otherwise producing graphically-depicted experimental data. As such, the substantive theoretical value in *CyberRat*'s production is predicated upon the authenticity of a researcher's experiences of the animal and the data produced.

Thus, after introducing *CyberRat's* many attributes and the methodology upon which they were established, I will consider the degree to which *CyberRat* generates authentic outcomes through consideration of a specific series of proposed hypothetical Turing tests by which the model might be evaluated. I will not claim in this presentation that *CyberRat*, in its present form, will *absolutely* pass the Turing tests being proposed; I will also point out several reasons it is not likely to do so in each case. But I will suggest that it comes *sufficiently close* to meeting such criteria as to validate the underlying IBSA descriptive methodology that made the model possible. I will address each of the three strategies of analysis to be described with a separate set of hypothetical Turing tests. In the end I will assert that *CyberRat's* unique *visual* reconstruction of highly variable and continuous behavioral streams represent sequential behaviors-in-environmental-context that approximate all of the *structural* aspects associated with real animals interacting within this environment for extended periods of time. As such, I will also assert that *CyberRat* represents a primary and unique contribution to behavioral science. Further, I will suggest that *CyberRat's* simulations of *functional* interbehavioral adaptations as well as its *operational* time-series reproductions of data are nontrivial accomplishments and will meet most phenomenological and/or statistical criteria for authenticity as well.

My assertion that this represents a process of descriptive methodological validation is based on the following logic: The degree to which these tests meet Turing's criteria of phenomenological non-distinguishability is the degree to which the methods used to generate the simulation must also be adequate for producing a complete description of original events (experience one such test—a test of "structural/behavioral" reproduction accuracy—offered in Video Illustration 2).



How Real Does CyberRat Appear to be?

Watch three 40 second videos of a rat in an experimental chamber. Only one is unedited video of one live animal, the other two are edited clips showing multiple animals. Only one of these is a video capture of a CyberRat session.

Can you tell which one it is?

Video Illustration 2. This video illustrates a "structural analysis" Turing test for behavioral reconstructions by *CyberRat*. Aspects that may cause *CyberRat* to fail this test, thus enabling your accurate detection of the real *CyberRat*, will be discussed in a subsequent section along with arguments for why this is a "trivial failure" for the validation case being made.

I begin my presentation with a brief functional, as opposed to algorithmic, documentation of what *CyberRat is*, leaving many specific details of what it *does* for subsequent discussions, where *CyberRat's* outputs will be compared to empirical data as a series of Turing tests. Each Turing test considered will begin with a summary of the related *interbehavioral systems analysis* (IBSA) research strategy upon which *CyberRat* is based. Both the IBSA approach and its ties to Kantor's

(1953, 1959) interbehavioral psychology have been extensively detailed in various publications (cf. Ray & Brown, 1975, 1976; Ray & Delprato, 1989; Ray & Ray, 1976; Ray, Upson, & Henderson, 1977; Upson & Ray, 1984). Readers are thus assumed to have sufficient familiarity with this approach to allow me to present only a relatively brief summary. Likewise, readers are assumed to be familiar with prior literature comparing and contrasting *the experimental analysis of behavior* (TEAB), as championed especially by B. F. Skinner (1938), with Kantor's *interbehavioral* approach (e.g., Kidd & Natalicio, 1982; Morris, 1982). Morris's review is an especially comprehensive integration of previously published commentaries regarding the compatibility of the two systems up to the time of his own 1982 publication (e.g., Mountjoy, 1976; Stephenson, 1953; Verplanck, 1954). Morris also cites extant commentaries on the value of integrating the two approaches for research and theoretical consolidation (e.g., Grossberg, 1981; Kidd & Natalicio, 1982; Krasner, 1977, Pronko, 1980; Wahler & Fox, 1981).

It should be clear to readers familiar with this literature that the IBSA approach represented by *CyberRat* incorporates aspects of TEAB but also includes critical extensions and modifications that go well beyond the traditions of that approach to research. Formative research data used to develop *CyberRat* were collected using a hybrid IBSA/TEAB approach while investigating live rats in traditional operant experiments, as will be made apparent in latter portions of my presentation. But, as I also hope to illustrate, *TEAB methods by themselves would not provide a sufficient basis for developing CyberRat*.

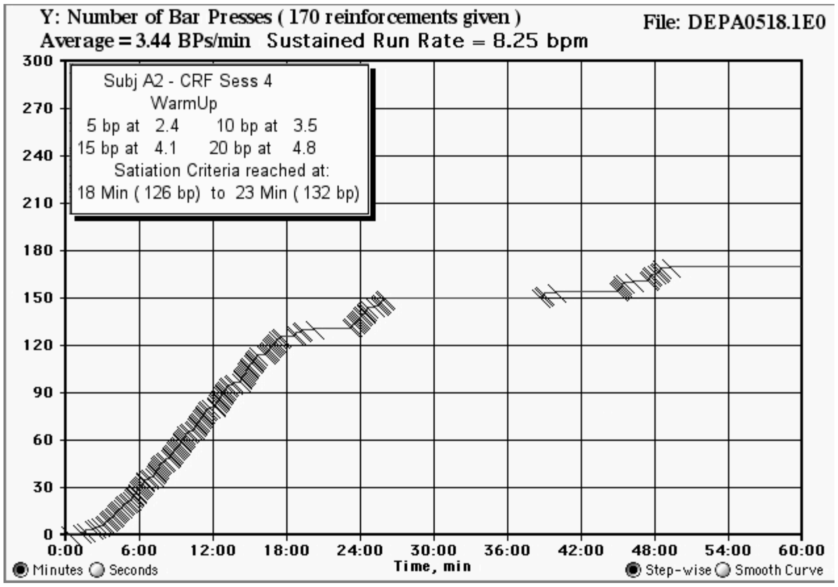
From its outset, *CyberRat* (Ray, 1996a, 2003a) intended to dynamically generate highly realistic digital video reproductions of the continuous stream (cf. Schoenfeld, 1976; Schoenfeld & Farmer, 1970) of an animal's many forms of behavior as well as authentic cumulative response records of bar-pressing rates in response to various operant experimental operations. In the latter portion of this monograph I will provide evidence that those aspirations for *CyberRat* have been realized, and I will reflect upon what that accomplishment implies for the methods used to guide and evaluate *CyberRat*'s development.

CyberRat: A Virtual Operant Laboratory

All *CyberRat* (Ray, 1996a, 2003a, 2012a) simulations first and foremost intended to generate a highly realistic and continuous visual representation of a rat in an operant chamber. The goal was to achieve a viewing experience equivalent to watching a live closed-circuit video of an albino rat in an operant chamber environment for rather extended periods of time (i.e., sessions that can extend to one or more hours in duration). These *CyberRat* modeling projects also provided for the emergence of new sequential behavioral patterns and/or emergent forms and functions of behavior (e.g., turning in tight circles or lever/bar-pressing) resulting from reinforcement contingencies established by a human interacting with the model. To accomplish a convincing and novel visual reproduction of such continuous behavioral streams across lengthy experimental sessions, *CyberRat* incorporates a dynamically changing sequence of behaviors using more than 1800 brief and probabilistically accessed digital video "clips" depicting rat behaviors selected from many hours of original video recordings of live animals in an operant chamber (see Video Illustration 3).

Video Illustration 3. Many hours of videos were made of three different live animals trained to perform various behaviors to compile a video source corpus for the final videos incorporated into *CyberRat*. The video linked here is a 2-minute sample from that original source video and reflects both the video compressions then-available for minimizing digital file sizes as well as modern web compressions. This sample will also be used in a subsequent illustration (Video Illustration 4) of IBSA's structural analyses used to analyze such events.

CyberRat incorporates variations in organismic "field" factors, such as current body weights and learning histories, and reflects the behavioral *changes* occurring during habituation, deprivation, and other dynamically changing "establishing" operations (cf. Keller & Schoenfeld, 1950/1995; Michael, 1993) or "setting" conditions (cf. Ray & Brener, 1973; Verplanck, 1957). These changes provide a context that alters the impact of "consequential operations" (cf. Catania, 2007) that change the probability of behavior, whether these behavioral changes are under the control of human interactions (as reflected, for example, in response shaping via manual deliveries of reinforcement) or through automated reinforcement schedules and superimposed stimulus discrimination schedules. The model generates authentic cumulative response records of bar-pressing across extended training sessions under a variety of commonly cited operant experimental conditions (see Figure 1).


Y: Number of Bar Presses (170 reinforcements given)
Average = 3.44 BPs/min Sustained Run Rate = 8.25 bpm
File: DEPA0518.1E0
Subj A2 - CRF Sess 4
WarmUp
5 bp at 2.4 10 bp at 3.5
15 bp at 4.1 20 bp at 4.8
Satiation Criteria reached at:
18 Min (126 bp) to 23 Min (132 bp)
300
270
240
210
180
150
120
90
60
30
0
0:00
6:00
12:00
18:00
24:00
30:00
36:00
42:00
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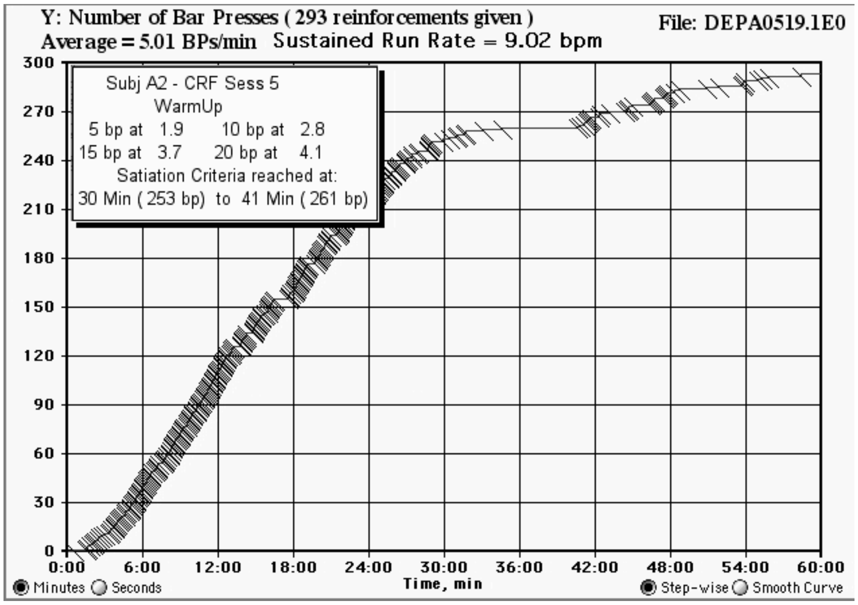
Time, min
● Minutes ○ Seconds
● Step-wise ○ Smooth Curve

a)


Y: Number of Bar Presses (293 reinforcements given)
Average = 5.01 BPs/min Sustained Run Rate = 9.02 bpm
File: DEPA0519.1E0
Subj A2 - CRF Sess 5
WarmUp
5 bp at 1.9 10 bp at 2.8
15 bp at 3.7 20 bp at 4.1
Satiation Criteria reached at:
30 Min (253 bp) to 41 Min (261 bp)
300
270
240
210
180
150
120
90
60
30
0
0:00
6:00
12:00
18:00
24:00
30:00
36:00
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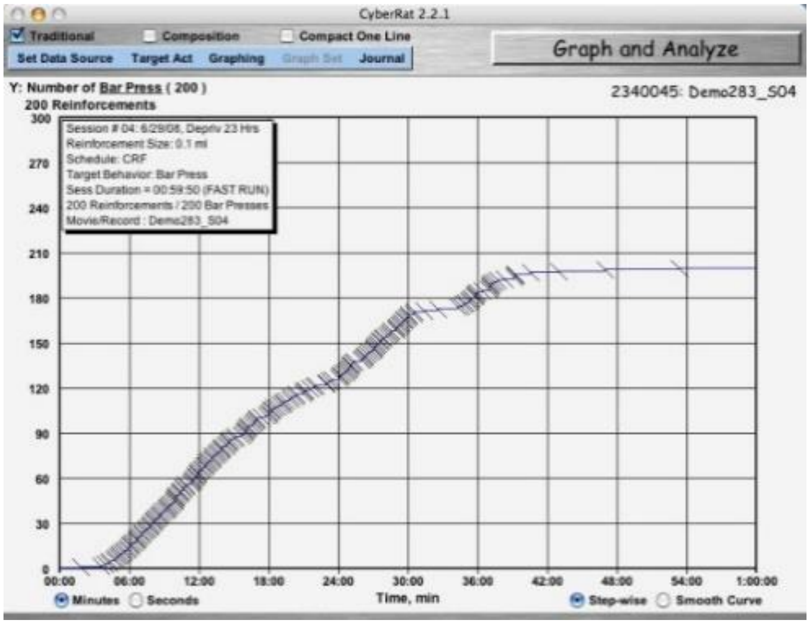
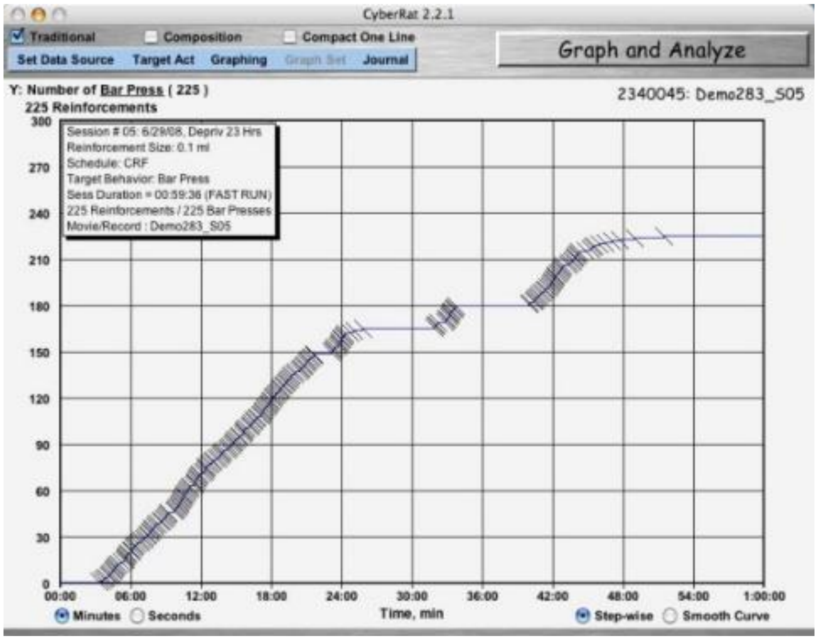
48:00
54:00
60:00
Time, min
● Minutes ○ Seconds
● Step-wise ○ Smooth Curve

b)



Session # 04: 6/29/08, Depriv 23 Hrs
Reinforcement Size: 0.1 ml
Schedule: CRF
Target Behavior: Bar Press
Sess Duration = 00:59:50 (FAST RUN)
200 Reinforcements / 200 Bar Presses
Movie/Record : Demo283_S04

c)



Session # 05: 6/29/08, Depriv 23 Hrs
Reinforcement Size: 0.1 ml
Schedule: CRF
Target Behavior: Bar Press
Sess Duration = 00:59:36 (FAST RUN)
225 Reinforcements / 225 Bar Presses
Movie/Record : Demo283_S05

d)

Figure 1. Cumulative response records both of a single randomly selected live animal under continuous reinforcement (CRF) for bar-pressing across a 60-minute session on two successive days (Figure 1a = 4th live animal [A2] session; Figure 1b = 5th live animal [A2] session under CRF conditions) and a

randomly selected single *CyberRat* animal (Figures 1c and 1d) under conditions simulating those for the live animal (Figure 1c = 4th simulation animal “Demo” session; Figure 1d = 5th simulation session for animal “Demo”) following first stable bar-pressing training sessions. Note the slow (warm-up) start to bar-pressing at approximately 1–4 min and the satiety-induced drop in rates at between approximately 10 and 30 minutes in the sessions).

Evidence of a serious scientific purpose for developing *CyberRat* from its inception includes invited addresses and presentations at the Association for Behavior Analysis meetings (Ray, 1996b, 2003a, 2003b; Miraglia & Ray, 2003) and elsewhere (Ray & Miraglia, 2008). Those various presentations of *CyberRat* serve as foundations for the present article.

What *CyberRat* Simulates

CyberRat currently simulates 1) processes described as habituation, 2) satiation to water reinforcement that varies based on lengths of deprivation, 3) development of shorter-latency responding and secondary reinforcement functions through stimulus signaling of water presentations (i.e., respondent conditioning), 4) emergence of various new response classes (e.g., turning in tight circles or bar-pressing) via the method of successive approximations (shaping), and 5) the formation of realistic operant response rate characteristics for a wide array of simple reinforcement schedules. It also generates convincing transition dynamics when shifting from one reinforcement schedule to another. Among the modeled transition dynamics are processes such as extinction, ratio-strain, discriminative stimulus control, and behavioral contrast (cf. Catania, 2007). Various *CyberRat* simulation results based on Catania’s (2007) classification of alternative experimental operations typically used by behavior analysts are illustrated graphically in Ray and Miraglia (2011).

Empirical IBSA Data Needed for Modeling: The *CyberRat* Research Project

Throughout *CyberRat’s* V2.0 development cycle we attempted to locate and model research-based parametrics associated with *each* of the processes simulated, including those described above. As a result, most processes in *CyberRat* are simulated with highly accurate data-reproduction fidelity. To accomplish this fidelity, each time we could not find published parametric data on the process being simulated we conducted our own systematic investigations using live rats and the empirical water deprivation/presentation dynamics that are equivalent to those metaphorically incorporated into version 2.0 of *CyberRat*. This research was carried out, in part, by Dr. Paul K. Brandon at Mankato State University, but in the main through a collaborative series of experiments conducted by Kevin Miraglia (through the auspices of a summer student/faculty collaborative undergraduate research program and Kevin's subsequent senior undergraduate research project that I supervised) within my own laboratories at Rollins College.

After graduation, Kevin continued to serve as a laboratory teaching associate in my academic department at Rollins College. In that role he supervised most live-animal laboratory exercises as well as *CyberRat* assignments conducted by students within the Learning course I teach each year. Selected illustrative results from this original empirical research, hereafter referred to as the CyberRat Research Project (CRRP), were first reported at the meetings of the Association for Behavior Analysis (Miraglia & Ray, 2003), and all subsequent references to the CRRP or its results reflect these original collaborative research efforts. Throughout subsequent sections of this monograph I present salient examples from the CRRP both to illuminate the scope and accuracy of the current *CyberRat* algorithmic and video modeling project and also to present some specific comparisons of empirical vs. simulated data.

The CRRP was focused exclusively on rats because, even if prior research had been published on the relevant operant procedures being simulated, most available data were produced using pigeons pecking keys for grain. Such data are not parametrically informative for modeling data generated by rats due to the timing differences for bar-pressing vs. key-pecking and differences between drinking water vs. pecking at grain. We were especially in need of empirical data from the following experimental conditions with rats: 1) habituation during first-exposure to operant chambers, including both specific-behavior and multi-behavior structural–organizational (kinematic) dynamics and associated operating characteristics (terms which will be defined in subsequent sections); 2) magazine training as an example of classical/respondent conditioning processes; 3) functional response shaping as a successive-approximation process involving differential reinforcement of alternative response topographies; 4) bar-press warm-up dynamics as yet another kind of habituation process; 5) water deprivation and reinforcement–satiation dynamics; 6) extinction dynamics; and finally, 7) intermittent reinforcement schedules and associated response rate patterning (response operating characteristics) as reflected in cumulative records.

Conceptual Reflections on What Gets Modeled and What is Required to Accomplish It

Even with such a cursory description of *CyberRat's* functional characteristics as given above, it seems appropriate to consider the challenges to data collection methods that such a simulation poses. I will emphasize throughout this monograph that simulations play a significant "feedback" role in guiding researchers toward more and more complete descriptions of the original events being simulated. This feedback role stems from the fact that two of the most significant reasons that simulations fail to meet their aspirations of being highly realistic are: 1) the simulation itself is poorly designed and executed—either from faulty engineering of the model *per se*, from inadequate technologies (e.g., lack of raw computing power, etc.), or both; or 2) the data being used to guide development of the model are insufficient for producing an *accurate* model. However, if model-produced events in the simulation cannot be distinguished from the original events being modeled, both of these potential faults have been eliminated—and as I have noted, this was Turing's (1950) argument for testing the adequacy of a simulation.

Thus, one might ask whether a cumulative record of bar-pressing activities of a rat in an operant chamber is sufficient to realistically model an operant experiment via computer simulation. The answer depends on the desired simulation experience. Are we asking to see a reconstruction of only the cumulative record, or to see the animal as it produces such a record, or both? One might easily model a "black box" experiment involving an assumed animal pressing a bar under unseen circumstances (e.g., Shimoff & Catania, 1995). It is not all that difficult to write a computer algorithm that produces a cumulative graph reflecting "pen steps" with the same general rate and with a similar temporal distribution as those seen in an original sample of many cumulative records (although constructing even these types of algorithms is more difficult than many might anticipate when time-series complexities such as variable instances of response-rate "scalloping" under fixed interval reinforcement scheduling are involved). As such, cumulative records generated by a computer programmed with a mathematical algorithm that reflects the original statistical properties of an animal's production of switch closures can be convincingly similar to a record generated by a real animal.

But asking this same model to also show a corresponding video of a realistic but purely simulated animal that is performing the corresponding bar-pressing activity that produces our cumulative record while also showing all the behaviors that intercede between these presses would be virtually impossible if one begins only with the cumulative response record and/or the equations that model it. The cumulative record simply does not afford a sufficiently complete description to statistically recreate a continuous video display of an animal, even if one has a sufficient corpus of original rat-in-chamber video records that are suited to the task. Thus, the fact that a highly realistic simulation like *CyberRat* can be created serves as an important confirmation of both the *necessity* and *sufficiency* of the original descriptive methods that guided its development. To elaborate on this assertion, let me highlight in a bit more detail the actual method that was used in this process before going on to detail *CyberRat* as a case in point.

Interbehavioral Systems Analysis: A Descriptive Research Methodology

Prior to offering a brief summary of the IBSA approach, it will be useful to note its historical context and to provide some citations for an interested reader to explore. As already noted, the methodology evolved from a rich history of philosophical and practical arguments in support of a descriptive interbehavioral view of environmental–organismic interactions (cf. Delprato, 1987; Kantor, 1953, 1959, 1970; Moore, 1984; Morris, 1982; Smith, Mountjoy, & Ruben, 1983; Verplanck, 1983a). But the approach is also steeped in traditions of a process-focused philosophy that emphasizes *event*/*process* rather than *substance* ontology (i.e., that what we consider to be *things*, including rocks, planets, and stars, are really dynamically changing *processes* that evolve over time—cf. Browning & Myers, 1998; Hartshorne, 1971; Whitehead, 1925, 1948) and an incorporation of general systems analysis concepts and methods (cf. Ackoff & Emery, 1972; Checkland, 1997; Klir, 1969; Kuhn, 1974; Laszlo, 1996; von Bertalanffy, 1968). Interested readers wanting to know more details than can be offered here are encouraged to begin with Ray and Delprato's (1989) overview of a) IBSA's compatibility with modern trends in the philosophy of science, b) its strategic and tactical requirements and unique empirical contributions, and c) its reliance on alternative modalities of descriptive representation and what each of these modalities contributes that is unique. In the present review I will briefly focus on just a few interbehavioral and general systems contributions to IBSA. I will also review a sample of description modalities (i.e., alternative forms of representation, including symbolic, graphic, and models as well as linguistic representations) used in IBSA to show how *CyberRat* embodies each.

As I have already suggested, while *CyberRat* incorporates accurate simulations of many of Skinner's (1938) traditional functional analyses of operant response classes, developing *CyberRat* quickly convinced me that it could not have been realized from Skinner's preferred analyses alone. I had to supplement TEAB with the methods inherent in IBSA's requirement of a much more naturalistic, descriptive, and comprehensive approach to research. Just as importantly, the work on *CyberRat* demonstrated not just the inherent relevance of IBSA, but also some practical shortcomings of the IBSA approach as we initially applied it—mostly by exposing inadequacies in the original descriptive categories, as I will illustrate shortly. As already noted, IBSA is a methodology for understanding behavior that was derived from J. R. Kantor's (1959) interbehavioral approach to psychology. Yet the work of B. F. Skinner (1938) was also critical for certain aspects of the project.

Kantor (1970) once criticized TEAB for being so devoted to a singular and highly specialized pattern of research. This pattern was characterized as overly stressing conditioning as the prototypical model for understanding behavior and as seeing the environment as independent variables that fall into only two highly generic classes: stimulus *antecedents* that are functionally described as discriminative stimuli, or S^Ds, and *consequential* stimuli, typically defined functionally as *reinforcers* (S_rs). This conceptualization is, of course, the basic construction of Skinner's "three-term contingency" of antecedent, behavior, and consequence analysis of behavioral dynamics as illustrated in Figure 2.

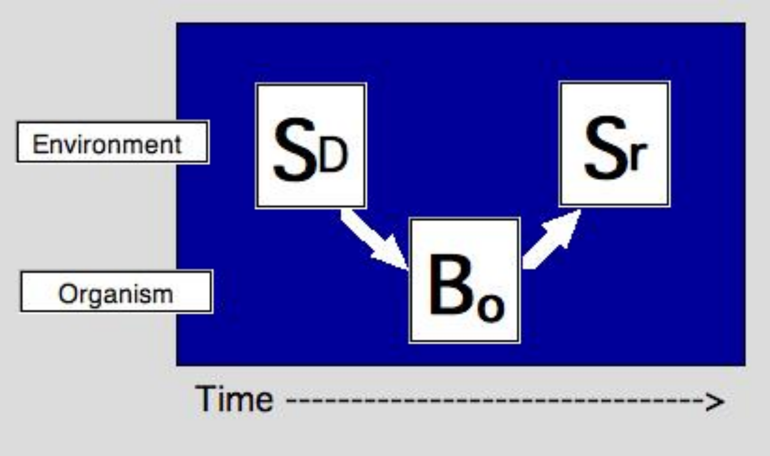


Figure 2. A schematic diagram illustrating primary functional elements in Skinner’s conception of the three participating factors (or three-term contingency) used for the experimental analysis of behavior. The top segment represents the antecedent (S^D) and consequential-reinforcing (Sr) environmental stimuli that serve as independent variables arranged to be a discriminative setting (S^D) of a contingent consequential (Sr) stimulus occurring when a representative operant behavior class event (Bo) is emitted.

Skinner’s experimental approach and his focus on operant and respondent response classes was antithetical to Kantor’s more naturalistic and all-inclusive *field* approach (e.g., Kantor, 1959, 1970). Kantor (1970) also characterized Skinner as focusing on independent–dependent variable specifications with their implied cause–effect functionality, while Kantor himself championed a more statistical and non-causative view that stressed the description of integrated event fields (see also Moore, 1984; Ray & Delprato, 1989). Rather than stressing *behavior*, Kantor stressed what he called *the psychological field*. These psychological events/fields might be considered as momentary events within a continuous stream of evolving fields across time, and they define a temporal sequence of reciprocal interactions, or *interbehaviors*, between the organism and its environment. For Kantor, functional relations were a two-way process of reciprocated influence, or *mutual implications*, that logically rule out a distinction between independent and dependent variables. Instead, all contributing components in the psychological field were seen as being *interdependent*.

Kantor also stressed that an organism’s *interbehavioral history* of preceding event/fields are among the many contributing *contextual setting factors*. While Skinner stressed an organism’s *reinforcement history*, Kantor’s *interbehavioral biography* included far more than simply conditioning concepts, especially for humans. Kantor included circumstances that included rivalry, compliances, and competition as well as emotional histories. His approach easily accommodates research of ethologists, for example, that illustrates the role of past perceptions of such “sign-stimuli” as body color or response pattern configurations on subsequent hormonal states as preparatory field factors for relatively stereotypical, but nevertheless complex, reciprocal patterns of sexual mating interactions with a member of the opposite sex in most species.

Likewise, any psychological field being described by an investigator using the Kantorian approach must include a *systematic* account of that investigator as a participating field factor. An abstraction of the participating factors defining Kantor’s momentary psychological event/field is illustrated in Figure 3. For Kantor, psychology has only the task of describing all forms of psychological interactions contextually within both these historical and current field/setting conditions.

But Kantor had serious limitations as a champion of his descriptive approach to research. While Kantor published at least 14 books,[1] according to Moore (1984) Kantor published only one empirical experimental study in his lifetime. The most commonly heard criticism of Kantor’s work focuses on his failure to articulate a methodology suited to his emphasis on descriptive research. Thus, a year prior to Kantor’s death, Verplanck (1983a) noted that despite the highly significant conceptual power of Kantor’s interbehavioral approach to psychology (Kantor, 1959), his nearly total disregard for laboratory experimentation resulted in Kantor having little to no eventual influence on the modern science of behavior. Schoenfeld (1969) had offered a similar argument much earlier and suggested that Kantor’s disinclination to conduct *research* led to a broad disregard of Kantor’s significant *conceptual* contributions. Perhaps Kantor shunned laboratories largely because he always rejected the experimentalists’ mantra of searching for cause–effect relations among the various participating factors defining interbehavioral events. If so, it was unfortunate because Kantor gave little corrective guidance to those who were more inclined to conduct actual research from his interbehavioral perspective.

Of course, Kantor was not the only voice arguing for more descriptive approaches. Reflecting Kantor’s earlier professional influence, Verplanck (1970) also stressed the usefulness of an interbehavioral approach and offered several illustrations of the types of research he considered to be worthy endeavors. I personally agree with Kantor’s and Verplanck’s championing of purely descriptive approaches to psychological inquiry that emphasize the inclusion of complex interactive field-defined events. But I have also consistently accepted the challenge of creating new ways to translate the systematic propositions of interbehavioral psychology into a more robust and validated research methodology—including a methodology that is as well suited for experimental laboratories as it is for naturalistic settings. Those interested in a brief tutorial on IBSA methodology as it was applied in the CRRP may view a slide presentation of data collection, analysis, and presentation of a small sample of rat observations in Video Illustration 4.

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[1] Kantor’s website has a full bibliography of titles still in print as well as online papers: https://web.archive.org/web/20130813061915/http://web.utk.edu/~wverplan/kantor/kantor.html

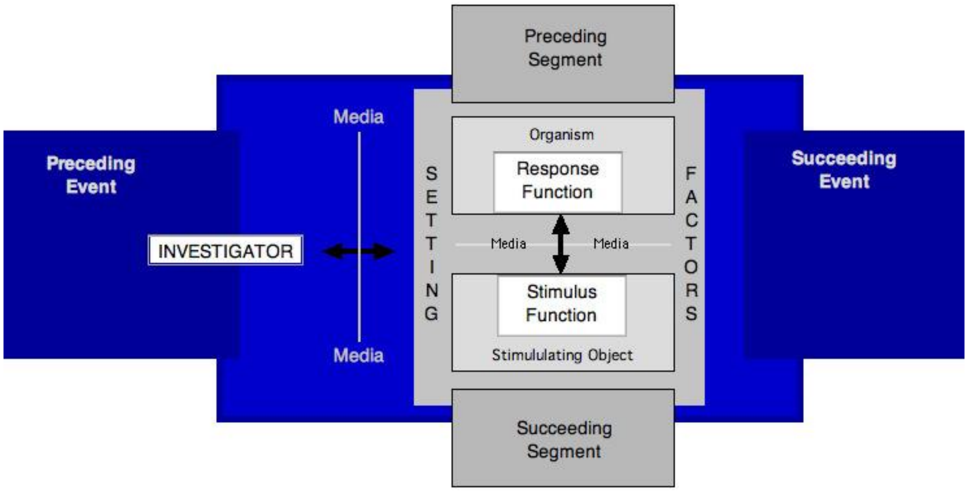

Figure 3. A schematic diagram illustrating primary functional elements and contextual field and setting elements in Kantor's conception of the psychological event. The vertical (lighter) components in the diagram represent the organism–environment interactive elements, while the horizontal (darker) elements represent the momentary intersection of an investigator observing the interactions.

Given my attempts to detail a method suited to IBSA concepts, I have also asserted that properly controlled and described analog comparisons between laboratory research and descriptions of behavioral dynamics in more naturalistic settings can serve as one, albeit limited, means for validating (empirically and ecologically) both activities (cf. Ray & Ray, 1976). I have already mentioned how I see simulations also playing a validating role, and I will pause to elaborate further on how such simulations fit within the broader descriptive process before I subsequently offer highlights of general systems theory and how that approach is relevant to extending IBSA as a true research methodology.

Reflections on Alternative Modes of Description and their Role in Simulations

Ray and Delprato's (1989) article not only defined a methodology based on interbehavioral and systems philosophy, it also offered a relatively comprehensive summary of the various modalities of phenomenological description beyond linguistics and the roles each can play in the IBSA approach to behavioral science. Just over a decade later, I (Ray, 2000) refined that taxonomy by classifying descriptions through the use of significantly different types of *products* that result from the descriptive process. These types of products or artifacts represent different *production domains* that include: 1) *textual/verbal representational productions* and their direct artifacts—such as this manuscript—that rely upon either natural or contrived language, including more formalized and limited computer programming languages; 2) *graphical representation* such as single-frame or even kinetic sequences of drawings or pictures (including film and video), Cartesian coordinates and other varieties of quantitative or qualitative graphing, and any other "pictorial/graphic" representation—such as the various Figures and Videos used as illustrations in this monograph; 3) *symbolic representation* systems such as logic notation, musical notation, or mathematical variables and/or equations that describe fundamental variable states and relationships; and 4) *constructional model* building, as in architectural or other constructed models, including digital models and visualized dynamic simulations that intend to represent proposed and/or observed processes or entities (including *CyberRat* itself).

Notably, these linguistic, graphic, symbolic, and constructional model domains do not always exist as distinct and mutually exclusive sets. Rather, the domains are better represented by fuzzy set theory, where boundaries are not always distinct and overlaps are rather common. Thus, computerized three-dimensional representational "virtual reality" or "walk-through" models actually incorporate multiple descriptive modalities. First are the mathematical algorithms that represent the dynamics of light source and reflective surface dynamics that are used to generate the apparent surfaces within a given conceptual/visual space. Computer programming and its inherent logic is used not only to generate the images, but also the dynamics of the interactive user interface that allows the model to be movement-responsive and visually accurate. Importantly, these graphical representations of spatiotemporal constructions may only exist in digital form and not in the real world, as when an architect's virtual model of a proposed building is created to convince a potential client to actually fund the future construction of the conceptualized design.

Today's representational technologies allow us not only to "describe" spatiotemporal events and aggregations that do not even exist in the real world, but they allow us to do so using convergent multiple modalities that result in highly realistic, though thoroughly artificial, viewer experiences—a use of art to create fictionalized science based on the use of genuine science to produce that art! While the modern digital gaming and motion picture industries have been both quick and highly sophisticated in their adoption of such convergent multimedia constructive modeling projects for purposes of human entertainment, those same technologies are only slowly being brought to bear for the advancement of science—especially behavioral science.

Perhaps the most notable advances in utilizing multimodality descriptive representation in science are the use of various imaging technologies in weather forecasting, astronomy, or modern brain and neurosciences. Models forecasting how weather fronts will emerge and develop across time, or how intersecting galaxies might influence one another, or how star systems evolve all abound in modern weather simulations, astronomy, and studies of the cosmos. Likewise, functional brain imaging is being used prolifically to describe the functional and architectural similarities and differences in brain dynamics across a very wide variety of human individuals and situations. But behavioral sciences have lagged significantly in taking advantage of the descriptive power of convergent multimodality descriptive methods. *CyberRat* is being presented here as a notable pioneering exception, even though it represents a highly restricted and limited first step. Further, my reliance upon multimedia forms of description of *CyberRat* and its theoretical implications in this very monograph is, itself, a demonstration of the relevance of using a convergence of these alternative modes of description. To fully understand this interpretation of *CyberRat*, and even of this monograph, let me continue with my overview of the final convergent contribution to IBSA: *General Systems Theory* (GST).

General Systems Theory and its Contributions to IBSA

General Systems Theory specifies three different analysis strategies. The first strategy, called *structural analysis,* begins with a system’s definition. Once a system is defined through this *structural analysis* the dynamics of that system are further investigated using strategies called *functional analysis* and *operations analysis* (cf. Checkland, 1997; Laszlo, 1996; Ray & Delprato, 1989). The defining process involves a specification of the temporal and spatial organizational rules that describe the interrelationships among constituent events that make up the system. Such events are, themselves, considered elemental subsystems of the parent system, thus establishing a fundamental principle of hierarchical perspective (cf. Ackoff & Emery, 1972; Checkland, 1997; Klir, 1969; Kuhn, 1974; Laszlo, 1996; von Bertalanffy, 1968). Ray and Delprato (1989) illustrated the system’s concept of an organization of elements using a simple geometric example that has been reproduced in Figure 4.

The system in this example is defined by a two-dimensional geometric “boundary” (i.e., the enclosing rectangle) that encapsulates a dynamic array of 20 geometric “points.” Two alternative organizational “states” of this system are depicted. In the first state (Figure 4a) the 20 points are mutually exclusive (i.e., independent) of one another, and thus represent only a random organization that is frequently described as a systemic state of chaos or entropy (cf. Bowler, 1981). Ray and Delprato posed the hypothetical case of one of these points being removed from the illustrated chaotic system and asking an observer of the resulting array to predict where the missing point should be inserted from knowledge only of the 19 remaining points. In Figure 4a the answer of “anywhere” would not be correct, as that would not reproduce the specific randomized 20-point system illustrated. But because there is no descriptive or relational *organizational rule* defining any mutual implications among the particular points in this example, no accurate specification would be possible.

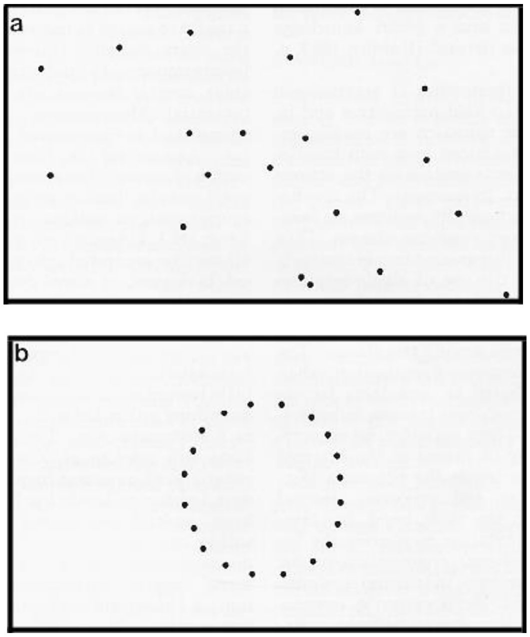

Figure 4. Illustration of two extremes of systematization between elements of a simple geometric system made of points and a rectangular boundary. The top (a) illustrates a random array of points that define a state of entropy or complete randomness, while the bottom (b) illustrates a relatively coherent and organized array where each point shares a mutual implication for the approximate location of other points. (Adapted from Ray & Delprato, 1989)

Now consider the same question posed for the alternative array of 20 points illustrated in Figure 4b. The high degree of organization (i.e., spatially-defined mutual implications) in this illustration helps one to grasp quickly the fact that, while no single point *causes* any other point to appear in its respective location, seeing the location of only a relatively few points in this system would allow a fairly accurate prediction for locating any missing point. In addition to the *mutual implications* that replace traditional concepts of linear cause and effect, two additional and important concepts are illustrated in this second example: 1) *statistical determinism* vs. absolute determinism, and 2) *emergent properties*. Thus, the illustration deliberately allows only a statistical, or probabilistic, near-accuracy in one's ability to specify any given location, in that the points are only approximately equal in distance from one another with respect to a theoretical radius and circumference as references for what appears to define a circle. Likewise, the apparent circularity in this example is an *emergent phenomenological property* of this specific geometric array—a phenomenon that is frequently described as "the whole being more than the sum of its parts."

One might animate this example by adding temporally-paced systematic (i.e., rule-governed) changes with respect to which dot is missing and thereby generate another very well-known emergent property known as the Phi phenomenon. Thus, we could put one of these points into apparent motion simply by removing one point and then replacing it as we remove an adjacent point in a repeating, clockwise, temporally-paced animated exchange. With sufficiently rapid successive replacements, apparent movement becomes an emergent property, just as cartooned animations at proper frame-change rates convince us that line-drawn animals can move about on a screen.[2]

Traditional psychology describes such phenomena as these as being visual *illusions*, but of course systems theorists do not treat emergent properties as illusions because all emergent properties are a matter of relative observational and descriptive perspective. This is a characteristic of hierarchical perspectives on organization that allows many dynamic processes to have an apparent and relative persistence or consistency that results in our describing them as substantive *things* even though they emerge from what are actually *processes of change* based on a different temporal scale than the observer's experiences—as when a table appears to be a solid when, in fact, it is mostly empty space between highly dynamic atoms when viewed from an atomistic perspective.

Emergent properties typically derive from systems taking on a temporally and spatially localized state of organizational *coherence*, or *negentropy* (cf. Bowler, 1981). As such, all systems are *hierarchically composed* from multiples of subsystems, or unitized organizations of constituent elements that appear to be stable from other levels of analysis, or relative perspectives. Thus, for example, an automobile is composed of subsystems that offer fuel distribution, power creation, power distribution, steering systems, lighting systems, transmissions with alternatively sized gears to shift power distribution levels, etc. Replacement of any subsystem that loses its functional integrity with a fully functioning alternative allows the larger automotive system (i.e., the car itself) to long outlive its subsystems. Likewise, engineers often work to design and create alternative structural subsystems to impact the functional and operational characteristics of the larger "automotive" system, as when alternative fuel systems are created to improve the operating characteristic called *fuel efficiency* (i.e., miles transported per unit of expense for fuel consumed) of automobiles.

As this automobile example suggests, systems analysis itself is a multi-dimensional process. In this process, alternative strategies or perspectives exist regarding not only the level of resolution one might take in describing systems vs. subsystems, but also strategies regarding how other characteristics of a system besides *structure* are presented, as I will now highlight. The *structural analysis* I have been describing stresses the description of what the *elements* are, how these elements are *spatially–temporally arranged* (i.e., their *organization*), and what their statistically-defined *mutual implications* are for one another. From another perspective, observers might focus on the purpose, goals, or accomplishments/

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[2] A brief history of the discovery of the Phi phenomenon and its related and similar Beta phenomenon, as well as animated illustrations of each, are available for nearly universal access at: http://en.wikipedia.org/wiki/Phi_phenomenon

outcomes of a dynamic and constantly changing system, and this strategic focus is described as *functional analysis*. Thus, in the automobile example the primary function of a car is transportation. But other functions might also be explored, such as environmental impact or social status gained by having one brand of automobile over another. A third perspective involves how a system changes states, or “operates,” across time (i.e., a strategic focus on *operations research* or *operations analysis*). This was the perspective taken in my fuel efficiency example described above. Other operating characteristics might include the accelerative capabilities (i.e., how quickly one can go from zero to 60 mph, for example) or wind resistance (i.e., *drag coefficient*) when in motion. Combined, these alternative strategies for analysis generate a balanced and comprehensive account of any system.

To illustrate how each of these three analytic strategies is translated into tactical procedures, and what the implications are for understanding interbehavioral systems, the remainder of this monograph will elaborate on each analytic strategy and its associated procedural tactics. Each analysis strategy, in turn, will be used to describe a rat’s behavior within Skinner’s traditional operant chamber. Those descriptions will then be used to illustrate how *CyberRat* serves to validate the adequacy of the analysis by applying Turing’s phenomenological “testing” criteria. However, I wish to emphasize once more that I will not claim that *CyberRat* will *fully* satisfy the most stringent Turing criteria—only that it comes sufficiently close to passing such tests as to trivialize the faults that may be used to tell the difference between *CyberRat* and live animals or associated experimental data. The main point thus remains that the various simulations to be presented are sufficiently realistic as to affirm that both necessary and sufficient descriptions have been accomplished in the application of IBSA to validate the method. So let me presently turn to consider the first of the three forms of IBSA—Structural Analysis—and how *CyberRat* serves to validate this approach.

Structural Analysis of Interbehavioral Systems

Skinner classified behavior largely by whether or not a singular class of antecedents (elicitors) reliably *elicited* behaviors (i.e., respondents) or whether behavior functionally evolved under less specific or predetermined antecedent stimulus control (i.e., *emitted* operants). In his early definitions of the class, the rate or probability of respondents could not be modified by consequential environmental outcomes of the behavior, and thus were more structurally defined by antecedent elicitors and relatively fixed response topologies. As a result, it was the rate of environmental *elicitors* that was reflected in the rate of respondents, so the rate of the behaviors was a mere reflection of the rate of stimulus presentation. On the other hand, operant behaviors were defined as being emitted by the organism, and the rate of this emission was dynamic because of functional consequences produced by such behaviors. Catania (2007) has distinguished between two uses of the term “operant.” The first is the *descriptive* or *nominal* use that defines a single operant class as one that includes all behavioral topographies that result in a common environmental effect. Thus, lever-pressing is a nominal operant class defined by the fact that the animal's behavior results in a mechanical switch closure, not by the specific form of the animal's behavioral movements that closed the switch.

Catania also points out that operant response classes have alternatively been defined *functionally* as behaviors that are changed by common consequences. In either case, switch closures are merely intermediary events from the point of Skinner's analysis of behavioral ontology, as it was the fact that such closures defined the criterion for delivery of reinforcing stimulus events that is critical. Regardless of whether one takes a nominal or functional perspective on operant behavior, Skinner assigned a crucial role to the reinforcing consequences of such behavior as depicted in Figure 2. This figure also illustrates that any antecedents that reliably signal the availability of these consequential outcomes for behavior come to have discriminative functions for the emission of operant behaviors. As such, Skinner's "elements" are either eliciting–stimulus and respondent or antecedent–operant–consequence. He focused almost exclusively on investigations of operants, giving Pavlov and others credit for elucidating respondent principles. But critical to the present problem, Skinner made no attempt to build any taxonomy of alternative operant classes, thus treating any given operant response class as being representative of any other operant response class when it came to understanding behavioral principles.

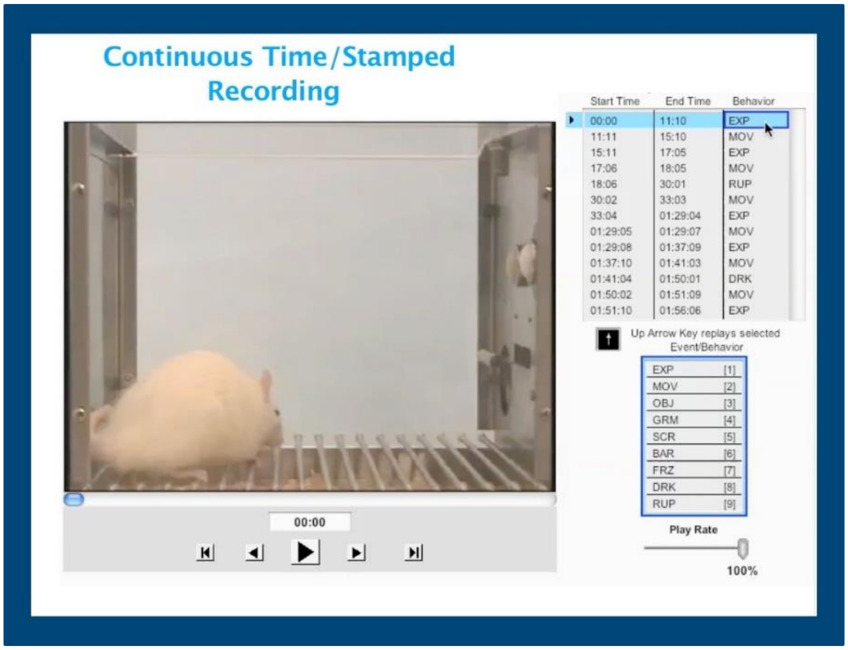
In Kantor's view, the interbehavioral event/field was psychology's "element," or fundamental construction to represent the "psychological event." And such event/fields are an emergent property of the constituent structural and functional components extant within attendant field and setting conditions, as depicted in Figure 3. As such, Kantor's interbehavioral events were described by reciprocating functions and were not treated as necessarily representative of other forms of functional interaction. But as I noted earlier, the challenge that Kantor left for researchers was how to incorporate such interbehavioral elements and their functional differences into a coherent research methodology. Thus, the research reported in Ray and Brown (1975, 1976) and Ray and Ray (1976) was among the first to explore the significance of using Skinner's vs. Kantor's elemental event conceptions both in the laboratory and in human "field" research settings. These reports translated Kantor's interbehavioral concepts into practical and empirical methods by emphasizing the inherent compatibility between 1) then-emerging human applications of TEAB to modifying problematic human behaviors in real-world settings (cf. Kazdin, 1975, 1978), 2) Skinner's emphasis on control and prediction vs. Kantor's emphasis on description as the ultimate goal of psychology as a science, and 3) conceptual developments in GST research strategies.

Those projects also reflected Verplanck's (1958) early endorsements of comparative ethology as being highly compatible with the interbehavioral viewpoint and his subsequent emphasis on the need for psychology to search for a more descriptive foundation for all of its research (Verplanck, 1970). Thus, both the human (Ray & Ray, 1976) and animal (Ray & Brown, 1975, 1976; Ray, 1977) research that was conducted relied substantially on the naturalistic methods of comparative ethology (cf. Lehner, 1996). The approach was driven by GST's emphasis on structural analysis as the beginning point for systems analysis, with its emphasis on first defining the *elements* and subsequently defining their *mutual implications* that gave rise to organization.

As Verplanck (1958) had noted earlier, ethologists also follow this strategy early in their research on any new species. Ethologists begin research by developing descriptive taxonomies, called *ethograms*, to classify the reoccurring and relatively fixed patterns of sequential actions that define *behavioral elements* for each species they study. Many examples of ethograms are found throughout both early and current ethological research, and an engaging illustration is McDonnell and Poulin's (2002) article that defines an ethogram to describe play behavior in *Equids* (semi-feral Shetland-type ponies). Through the use of a taxonomic strategy, ethologists can then compare species for behavioral patterns that are unique to the species (i.e., are *species-specific*) vs. those that are more generalized in their occurrence across species. It is the observed *sequential* pattern across time/space from one taxonomic category to the next that defines *element and organization* in behavior for ethologists (e.g., ethology's well-known *fixed action patterns*).

Ray and Brown (1975, 1976) thus explored a unique convergence of ethological and systems methods for observational research while stressing a strong compatibility with Kantor's interbehavioral fundamentals. We especially stressed Kantor's concept of an ongoing temporal/sequential "stream" of interbehavioral events by continuously observing and recording observer-based descriptions of such events using mutually exclusive and exhaustive descriptive categories, much as ethologists typically do. The development of a suitable taxonomy of interbehavioral event categories makes explicit the constructive and *radical–phenomenological* character of recurring, relatively stable, interbehavioral elements as described from an observer's perspective (cf. Kvale & Grenness, 1967; Verplanck, 1971; Palmer, 2003). In our initial demonstration projects, Ray and Brown (1975, 1976) adopted recurrent but unique *interbehavioral categories* for describing rat behaviors and approached the experimental setting of the operant chamber from a naturalistic and descriptive perspective as well as a manipulated/experimental perspective. Our taxonomy included, in abbreviated terms, "explore," "move," "object manipulation," "groom," "scratch," "eat," "lick/drink," "bar press," and "freeze." Such categories refer simultaneously to both the organism and the environment (which may include the animal itself as an "object" or "stimulus"—as in "grooming" and "scratching" one's self). Thus, a specification of the elements to be systematically observed and recorded was our first achievement in this research.

Once again, let me stress that systems theorists also emphasize that a structural analysis should include not simply a cataloging of elements, but also a specification of the organizational rules, or probabilistically-defined mutual implications, that describe a system's spatiotemporal organization. That is, the very definition of a system typically stresses that a system is a set of elements that are organized, and this organization reflects interdependencies or mutual implications that elements have for one another (cf. Ackoff & Emery, 1972; von Bertalanffy, 1968). Ray and Brown's (1975, 1976) approach used *interbehavioral categories* as the elements, and *sequential organization* across time/space defined the interdependencies among these elements. These interdependencies were described by calculating the conditional probabilities of transitioning from one observed interbehavioral element to another. Such transitions define the continuous stream of events as a probabilistic sequential pattern of interbehavioral elements that change across time, space, and other various setting/field conditions. Probabilistic patterns of change in interbehavioral events are referred to as *behavioral kinematics* and their associated sequential paths are typically summarized visually via flowcharts that depict both the elements and their sequential probabilities within various setting conditions. A brief illustration of how continuous coding, time-stamped data summaries, subsequent kinematic analysis, and flowchart kinematic graphing procedures may be applied to the behavior of a rat is illustrated in Video Illustration 4. Examples of two kinematic flowcharts depicting element organization, or interbehavioral systems, defined by two alternative contextual discriminative setting/field conditions are illustrated in Figure 5 (adapted from Ray & Brown, 1975).



Continuous Time/Stamped Recording

Start Time	End Time	Behavior
00:00	11:10	EXP
11:11	15:10	MOV
15:11	17:05	EXP
17:06	18:05	MOV
18:06	30:01	RUP
30:02	33:03	MOV
33:04	01:29:04	EXP
01:29:05	01:29:07	MOV
01:29:08	01:37:09	EXP
01:37:10	01:41:03	MOV
01:41:04	01:50:01	DRK
01:50:02	01:51:09	MOV
01:51:10	01:56:06	EXP

Up Arrow Key replays selected Event/Behavior

EXP	[1]
MOV	[2]
OBJ	[3]
GRM	[4]
SCR	[5]
BAR	[6]
FRZ	[7]
DRK	[8]
RUP	[9]

Video Illustration 4. This video presents a brief introduction to the entire observation, recording, analysis, and graphic representation process used in IBSA's structural analysis research. The video begins with a repeated presentation of the brief sample video of original rat recordings seen in Video Illustration 3. The remainder of the video slideshow illustrates how a behavioral taxonomy similar to that used by Ray and Brown (1975, 1976) may be used for continuous coding of observations and how that results in time-stamped recording to allow subsequent kinematic analysis similar to that illustrated in Figure 5 from Ray and Brown (1975).

In both Video Illustration 4 and in Figure 5 the width of each arrow connecting interbehavioral elements is proportional to the measured conditional probability of that specific sequence of change from one elemental event to the next.

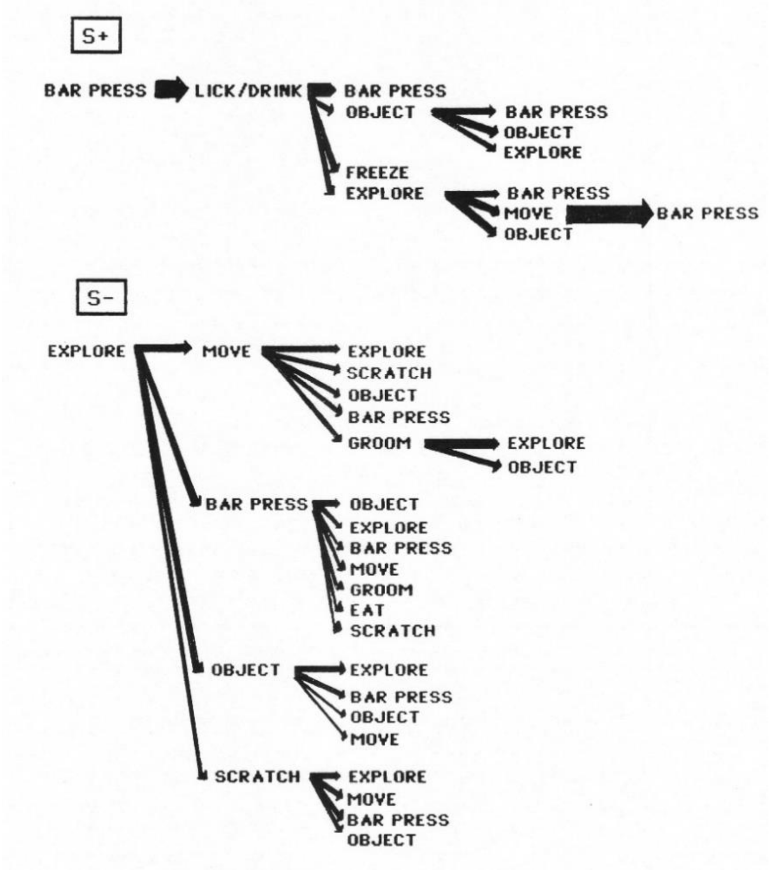


Figure 5. Behavioral kinematic flow diagrams from Ray & Brown (1975) illustrating the conditional probability of continuous behavioral changes in rats under two different experimental/contextual settings. In the S+ setting rats were reinforced with water for each bar-press (CRF schedule), while in S- no bar-presses generated reinforcement (extinction).

Since all paths end in an interbehavioral element that has prior specification (kinematic representation) of its implied "next elemental occurrence" and the specific probability of each, such kinematic flowcharts/diagrams reflect a closed-loop description of *all possible* transitional interbehavioral elemental states and their associated probabilities for any given contextual field condition. As such, behavioral kinematic analyses allow a reliable set of *descriptive statistics* to specify the probability of any *future* interactional category from one's knowledge of any *current* interactional category. Thus, it is a sequential organization or pattern that is described for spatiotemporally-defined interbehavioral elements, not a geometric/ architectural organization. Unique attendant setting conditions are incorporated in the descriptive summaries by isolating separate kinematic analyses to discern the significance of each setting/field context with respect to associated interbehavioral element probabilities and/or their sequential organizational dynamics.

What is missing from Video Illustration 4 as well as Figure 5 is the incorporation of any descriptive statistic summarizing durations of the categories or even the relative amount of total time spent in each behavior across some reference period. Time is an important dimension that was missing in the earliest reports by Ray and Brown (1975, 1976) because of the limited technology available to those research projects—we relied upon time-limited (5 sec) direct observation periods followed by longer (15 sec) periods that allowed for recording those observations (for a complete taxonomy of the many alternative procedures for collecting systematic observational data see Ray, Ray, Eckerman, Milkosky & Gillens, 2011). Thus, only frequency and sequence accounts were recorded. Fortunately, modern recording technologies such as video lowered the relative cost of recordings that allow for rather accurate time-measures for each categorical event, so later studies incorporated specific investigation of this dimension as well (e.g., Ray, Upson, & Henderson, 1977). This later research illustrated both time and conditional probability measures, but never in a single graphic—instead we relied upon separate bar graphs to represent the time dimensions for each behavioral category. But it is quite feasible to incorporate time into kinematic diagrams by making the "nodes" that represent the categories into circles that are proportional to each respective category's mean duration or total-time allocation.

As noted, Ray and Brown (1975, 1976) investigated only kinematic probability dynamics and organization, but we did so under several alternative setting/field conditions that were manipulated for such separate analyses. These settings included alternating discriminative ambient lighting conditions, alternative but constant ambient temperature conditions, and even organismic setting conditions induced by various drug conditions. Figure 5 presents one very simple illustrative set of results from live-animal experiments using two alternating ambient lighting conditions as discriminative settings. These two alternative setting conditions relied upon a relatively standard operant conditioning procedure involving presentations of two alternating but persistent lighting conditions for the experimental chamber. A persistent and brighter lighting of the chamber, symbolized by "S+" in Figure 5, signals that each bar-press under this lighting condition has a 100% probability of delivering water reinforcement. Likewise, a persistently dimmed lighting of the chamber, symbolized by "S-" in Figure 5, signals that there is a zero probability of water reinforcement for bar-pressing or any other type of interaction. Each discriminative setting alternated every few minutes across experimental sessions lasting a quarter-hour or more, and the kinematic analyses depicted in Figure 5 represent an averaged set of conditional probabilities across all repetitions of each respective setting condition and across three different animals.

But it remained for future technological advances in subsequent decades before temporal continuity, and its implications for enabling real-time simulations, became an integral part of IBSA research methods (cf. Ray, Upson & Henderson, 1977; Ray & Delprato, 1989; Ray, 1992, 1996a, 2003a). These later articles describe how IBSA can be applied to operant-chamber experimental arrangements using continuous behavioral descriptions that focus on temporal as well as sequential assessments, and how IBSA, in turn, can not only be reciprocally informed by such simulations, but also how simulations can become virtual *sine qua non* tests for reconstructing behavioral stream dynamics based only on original descriptive summaries. For present purposes, let me first address the broader concepts of modeling kinematics of animal behavior, then I will consider the most current version of *CyberRat* as a specific case in point of how simulation informs and improves descriptive research. (Readers may also find of interest Verplanck's (1983b) account of alternative means for, and roles of, verbal reconstructions—as opposed to the present video and data reconstructions—as this process relates both to description and to how memory might be redefined.)

Conceptual Foundations for Modeling Interbehavioral Systems

The original Ray and Brown (1975, 1976) experiments made it seem likely to myself, if not others, that if one could ever create a visually accurate set of kinetic graphic depictions, such as a series of animation "cels" (so-called because of the transparent celluloid, and later cellulose acetate, upon which each frame of an animation sequence was drawn using the early technology of hand-drawn animations), then kinematic flow diagrams such as those depicted in Figure 5 might become the source of animated reconstructions of animal behavior. As such, kinematics would also serve as the foundation for *visual* simulations, based on probabilistic reconstructions, of the original events the kinematics intended to describe. One might easily believe that such an animation would generate a kinetic visual reconstruction and even a more generalized and probabilistically-determined modeling of the animal behaviors that such diagrams depict. That is, if animations were created to represent each of the interbehavioral categories incorporated into the kinematic summaries, then a visually-enhanced model that used conditional probabilities as its editing-selection script would become a generalized model of that system (i.e., an animal within the experimental conditions that gave rise to the summarized data).

Such an animation process is, in part at least, inspired by what Walt Disney and his colleagues accomplished through their "artistic perspective" in Disney's production of the film *Bambi*. As Finch (1983) points out:

> Great emphasis was placed on naturalism in the making of Bambi. Special art classes—an extension of the existing training program—were instituted so that Rico LeBrun could instruct the animators in the finer points of drawing animals. Real deer were kept on the lot as models for the artists. Books of photographic studies and innumerable model sheets were compiled, along with analyses of animal action and thousands of feet of live-action material to be used for reference. (p. 257)

Finch includes several illustrative figures showing successive sketch studies (i.e., *graphic descriptions*) of deer executing a "Gallop," a "Bound," and even a "Banking at Bound" (p. 265). These descriptive behavioral categories are actually used as verbal labels for the succession of (single-frame/cel) drawings that are suited for making an animated sequence of each categorical event using multiples of cels. From the very beginning of interbehavioral systems research I saw no reason why such data as the Ray and Brown kinematic flow diagrams couldn't be used to reconstruct, setting by setting, similarly animated behavioral sequences. What seemed to be missing was only a technology for dynamically and seamlessly "splicing" such animations together following the probabilistic patterns depicted in the kinematic diagrams.

I was eventually to discover that I was only partly correct in my assumptions that such visual reconstructions would be relatively easy and straightforward to accomplish. As digital technologies—first for digital cartoon animations and subsequently for live-animal digital video recordings and playbacks—began to emerge based on rapid advances in computing power in the 1980s and 1990s, I began to actually experiment with such concepts. Following the sequence of digital technology advances, I first focused on the highly simplified animations of a cartooned animal (Ray, 1992) and eventually on the use of random-access digital video clips that establish the core of all versions of *CyberRat* (Ray, 1996a, 2003a). It was during these explorations that I began to appreciate more fully the theoretical value of the feedback these simulations offered regarding the sufficiency both of the technology being used and of the data that were guiding the modeling process.

This point about feedback regarding data sufficiency is worth illustrating with a concrete example, as it is the foundation for my validation assertion that a simulation that passes a Turing test is a simulation that also confirms the adequacy of methods and data upon which the simulation was established. *CyberRat* simulates structural, functional, and operational dynamics involved in the traditional operant prototypical experiment using an animal in an operant chamber. The role of feedback offered by simulations will be illustrated by examples from all three of these GST strategic methodological perspectives in the remainder of this monograph. But I will begin by elaborating first the structural models that rely upon the types of video reconstructions just described as my primary illustration of the role of feedback from simulations.

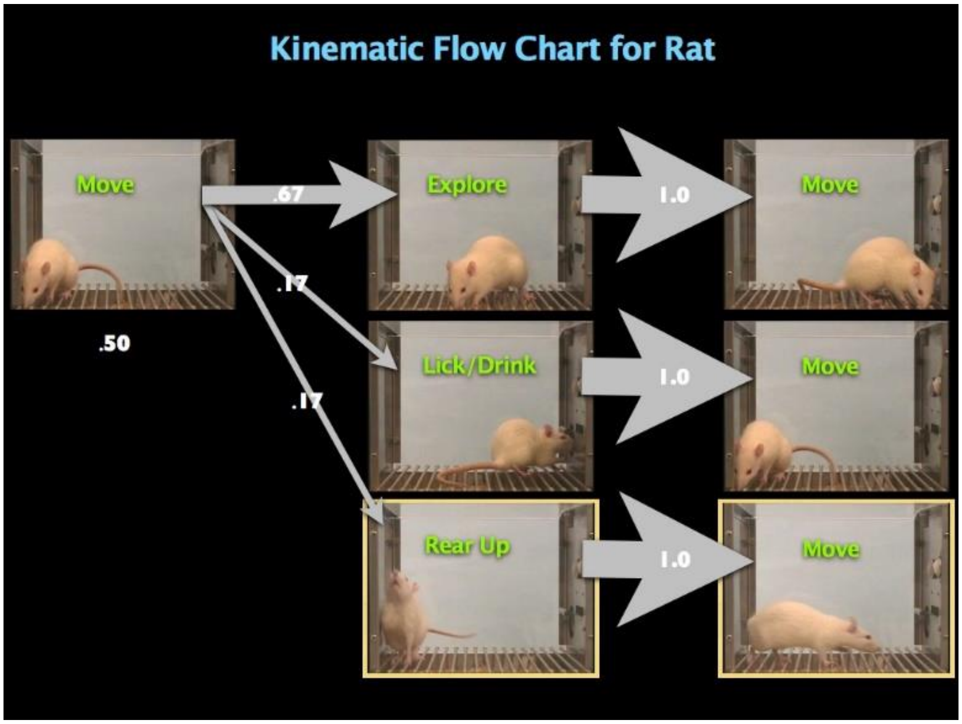
Fidelity of Real-Time Video Reconstructions: How Visual Simulations Can Reveal Deficiencies in Structural Descriptions

I quickly discovered from my very earliest visual reconstruction efforts (Ray, 1992) that behaviorally descriptive categories such as those used in the early Ray and Brown (1975, 1976) kinematic studies were woefully inadequate for accomplishing graphic reconstructions if one intended for the reconstructions to illustrate appropriately how an animal interacts with its general environment. Such discoveries have much more conceptual significance than their associated practical implications, as they get to the heart of "adequacy of description" issues.

Broad descriptions such as "move," "explore," "object manipulation," etc. had been used in prior literature (cf. Baenninger, 1967; Bindra & Blond, 1958; Bolles & Woods, 1964; Grant, 1963) and were inspired by highly successful developments of species-specific behavioral *ethograms* by ethologists (see also Immelmann & Beer, 1989). Thus, the Ray and Brown series, as well as various publications that followed (e.g., Ray, 1977; Ray & Delprato, 1989; Ray & Ray, 1976; Ray, Upson & Henderson, 1977; Upson & Ray, 1984) continued to use similarly broad descriptive categories. Nevertheless, a close reading will reveal that several studies in the series of publications just cited did incorporate systematically coded descriptions of attendant antecedent, concurrent, and even consequential stimulus events and setting conditions. Two highly detailed examples may be found in Ray and Ray (1976) and Ray (1977).

Originally I viewed these behavioral categories as being adequate for classifying or indexing multiple graphic exemplars of the behavioral events they described. The idea was to use such nominal classification indices for selecting, from a sample of common-category representations, random graphic exemplars for supporting a dynamic editing/composition process focused on reproducing a probabilistically-constructed visual playback of kinematic flow sequences. But when technological advances made the actual use of such exemplars possible, it quickly became apparent that my categories of behavior were totally inadequate for such a process to succeed. I found these categories to be incomplete for describing the specifics of an animal's interactions with even a highly restricted environment, such as an operant chamber. I had to begin adding concomitant descriptors of environmental elements, organismic spatial orientations, and several other setting factors. Here's why.

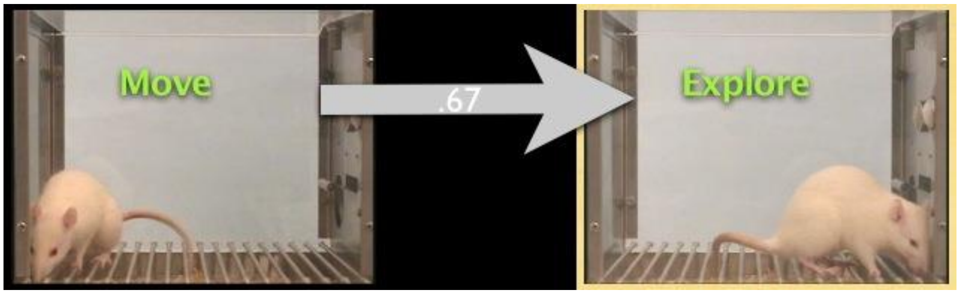
When one relies upon random selections from a collection of multiple video clips representing each of the categories of behavior I had used in describing kinematic sequences from category to category, a smooth and convincing visual reconstruction of behavioral kinematics is simply not possible. To illustrate the limitations inherent in this simplified approach to reconstructing kinematic flow diagrams, such as those represented previously in Video Illustration 4, imagine that we begin by observing a randomly selected representative video clip showing a rat engaged in the most probable behavior of moving around the chamber using at least one of its hind legs (i.e., the formal definition of **Move)**, as is illustrated in the second slide of Video Illustration 5 on the following page.



Video Illustration 5. While the Move→Explore described in the main text is a perfectly acceptable kinematic representation in a simple kinematic flow diagram summary, the visual experience of the described video sequence will almost certainly include impossible "jumps," not just from one behavior to the other, but also from one location to another. Such a discordant sequence is graphically depicted in this slide sequence video that corresponds to the kinematic diagram established by the analysis described earlier in Video Illustration 4.

As illustrated by the image on the left on the following page, the first video-illustrated kinematic representation of **Move** in Video Illustration 5 has, by chance, the rat beginning its spatial movement from the rear-left corner of the operant chamber while facing away from the video camera. The rat continues moving locations until the animal is in the front-left corner of the chamber, now facing toward the camera, as illustrated in the image on the right. When the hind-limb movements stop, if at least one fore-paw is on the horizontal surface the animal automatically shifts into the category **Explore**. That is, according to the operational definition for **Explore**, the animal has the two hind-paws and at least one forepaw in a fixed location, and thus the category allows for an animal to move its head about, possibly rearing up slightly, but with only one forepaw, if any, off the floor. The animal may even crawl forward a bit by stretching out the body with only the forepaws in movement, thus keeping the hind paws in a fixed location.

The first behavioral *sequence* illustrated by Video Illustration 5 results from randomly selecting a clip from a pool of video exemplars of **Explore** to depict this behavior as the subsequent event to follow the initial **Move** example cited in the previous paragraph. The graphic below immediately illustrates the problem under consideration. As illustrated, the selected clip for **Move** ends with a depiction of the animal on the left forward corner of the chamber. But the randomly selected clip representing **Explore** depicts the animal *beginning* its **Explore** with all four paws on the floor and positioned at the front right-corner of the chamber! Even a quick *reading* of these two descriptions would have illustrated the problem, but it becomes even more obvious when one sees the described clips in animation, as is the experience of viewing all of Video Illustration 5. Thus, while the kinematic analysis of the sample of behaviors presented earlier in Video Illustration 4 may first appear to be an adequate descriptive analysis, graphic illustrations of that same kinematic now make it abundantly clear that robust descriptive categories of behavior that are not reduced to being one-of-a-kind must include quite a variety of structural details beyond those provided by the original Ray and Brown (1975, 1976) definitions.



As noted, a perceptive reader might have grasped this disparity without having to actually view the examples illustrated by the graphic forms of representation, but the more subtle such disparities become the more difficult they are to discriminate from a mere linguistic narrative or by logical reasoning alone. But such disparities are often easily and quickly detected visually. A similar illustration based on referential inconsistencies during textual reconstructions of *verbal* content analyses that relied upon categorical codings was described in Ray and Delprato (1989), so linguistic/grammatical reconstructive simulations may also serve a similar function of detecting inconsistent, illogical, or incomplete descriptions, just as Turing (1950) proposed in his original "thinking" test of the authenticity of artificial intelligence.

In the video examples above, as the clips are dynamically spliced together to depict the described behavior changes, it immediately becomes apparent to observers that a rather drastic video edit has occurred because the behavioral transition depicted is far from including behavioral continuity. Thus, the difference between any two spliced clips being used as a behavioral reconstruction would easily be discriminated from a closed-circuit video display of a live animal making a similar transition to that described by the kinematics. As such, the described video reconstruction will miserably fail a visual Turing test as a believable simulation, as was likely the case in the first example asking the reader to detect non-edited from composited video in Video Illustration 2 and as constructed in Video Illustration 5 in the ending composited video. So the question becomes, is the whole simulation concept wrong-headed? Or is the original description simply insufficient in its details? Might a more comprehensive classification of interbehavioral events allow a phenomenologically realistic reconstruction without resorting to a full video replay of the entire original event sequence?

As an aside, an astute reader may note that the above narrative account was generally sufficient to establish an understanding of the spatial and topological discrepancies in the faulty video sequence that was described. Even though the graphics may have helped significantly in visualizing the narrative, they may have been a bit redundant. So why are most readers able to follow that verbal account and fully understand the resulting failure to model a realistic video reconstruction sequence? Obviously, the added narrative offers significant elaborations of the simple categories (which is also the role of operational definitions) that helped readers understand the spatial-topographical discrepancies between the example clips being described. So more descriptive wording (i.e., more concise and inclusive operational definitions) can solve much of the problem of insufficient description. But how much description is enough? The answer to that question can be determined by further refinements of descriptively guided simulations, for, as I have already suggested, the eye is an even better discriminator of such discrepancies than language—as visual comparisons of videos "a" (a sample from *CyberRat*'s compositing) vs. "b" (a non-edited original video from which *CyberRat* was created) vs. "c" (the video created based on the kinematic analysis illustrated in Video Illustration 4 and composited using randomly selected exemplars of categories in Video Illustration 5) in the detection tests of Video Illustration 2 should attest.

Clearly, the above examples suggest that as many contextual/field elements as possible, as well as movement and orientation qualifiers, *must* be included as an integral part of the original descriptive categories if the obvious faults illustrated are going to be eliminated. Without such qualifiers virtually all reconstructed transitions will result in visual reproductions of an animal that randomly appears in any location, with any directional orientation, and with drastically changing topographical body configurations—somewhat analogous to Disney's (1951) depictions of Alice's experiences with the Cheshire cat while in Wonderland (cf. Carroll, 1865/2009)! It is worth noting at this juncture how closely this generic specification comes to having Kantor's interbehavioral element depicted in Figure 3 as its guide for adequate description. It is also clear that the contextual and organismic field configurations must also be an integral part of what is descriptively categorizing each clip, not simply categories reflecting the animal's behavior with environmental references at the level on which my early research had focused, *and most certainly not the pen movements typically recorded as operant performance measures in cumulative records, as TEAB would typically guide us to collect*.

To make this latter assertion even more evident, let me consider the use of a cumulative response record to guide a sequential assemblage of video clips of rats pressing a bar. Assume that several bar-presses follow one another in rapid succession, as typically occurs in most variable intermittent schedules. Now assume that each bar-press is depicted by a randomly selected video clip of the same animal bar-pressing at different times. In one clip the animal may be pressing while standing with three paws on the floor and its head nearly inside the water dispenser. This **press** is more like **pulling** the lever down toward the animal by using the free paw—very much a "least effort" way of getting water reinforcements as is seen frequently in highly trained animals. Now assume a second (and immediately subsequent) **press** is illustrated with a sampled clip that shows the animal standing upright over the bar and pressing downward with both paws. How did the animal get from one position to the other? Body orientations and topographies make a difference in such visual reconstructions, even though they play no role whatsoever in creating successive pen-steps across a cumulative recorder. And, of course, we would have no way of even attempting a visual reconstruction of the zero-slope (no bar-pressing) portions of the cumulative record. Such "not-bar-pressing" behaviors would clearly return us to our starting examples of **Move→Explore**, etc., even if we had observed and recorded during those periods—which, of course, TEAB does not typically do.

The above discussion is focused mostly on a *single kind of inadequacy* in commonly used direct observation research strategies—that is, their likelihood of passing a visual reconstruction test for how complete the respective categories are for describing and thus representing the original observed events. It is mainly because of its visually enhanced simulated reconstructions that *CyberRat* reveals such descriptive research shortcomings. However, *CyberRat* also actually *affirms several* of the underlying methodological strategies and tactics reviewed by Ray and Delprato (1989), if not their specific choice of categories. Thus, the next step is to consider what aspects of IBSA *CyberRat* currently incorporates to make it finally *succeed* as well as it does as a visual reconstruction of *structural interbehavioral analyses*.

So let me turn to what else I learned from the new research that had to be conducted in the CRRP that was critical to the successful development of *CyberRat*. And, of course, I must also consider along the way how closely *CyberRat* comes to passing at least the hypothetical Turing-type tests I will propose for it, as passing these tests has now been established as the *sine qua non* for demonstrating that the methods used were necessary and sufficient for the simulation task, and thus for fully representing the original events as well—a representation that was Kantor’s goal. So let me detail how we achieved *CyberRat’s* qualitative (i.e., phenomenological) and quantitative (i.e., descriptive statistical data) reproductions as they relate to the GST strategy of conducting a *structural analysis* of this particular interbehavioral system as a case study.

The First Series of Turing Tests: Interbehavioral Setting and Field Elements Simulated in *CyberRat*

Let me stress once more that simulations of interbehavioral system dynamics must model all aspects of those interbehavioral events illustrated in Figure 3. This includes modeling the realism of organismic and environmental setting conditions and field factors as well as an animal’s movements and functional interactions in specific spaces across time. Thus, as Video Illustration 1 has already shown, *CyberRat* simulations begin with animal selection from the “colony room,” where *CyberRat’s* animals “live,” and with experimenters being required to set parameters for the experimental conditions. *CyberRat* offers various selection options involving animals with various pre-established experimental histories, including naïve animals as well as those with only prior magazine training or even prior bar-press shaping history. But the typical selection is of a naïve animal (i.e., with no individual experience of the operant chamber or any similar apparatus).

Next, experimenters must make choices regarding almost all the variables and options they would set in a real operant laboratory. Further, the animal(s) an experimenter selects and retains will actually vary within a normal but restricted range of randomized weight and age, with each being 90–120 days of age. In addition to age and weight, another random variation is the level of “intelligence” of individual animals, which operationally translates into an individual animal’s rate of change in behavior probabilities when reinforced, and therefore its rate of learning new behaviors. Experimenters may obtain and keep as many animals as desired and each new subject will reflect individual differences in these *organismic* setting factors.

I will describe in subsequent sections various Turing tests for evaluating outcomes of experimental manipulations, thus keeping the present discussion focused primarily on observation-based descriptive research with minimal experimental manipulation involved. But I should point out that, as the screenshot from Video Illustration 1 on the following page illustrates, experimenters may set many experimental parameters, including various reinforcement rules and schedules, the temporal duration of water deprivation (thus adjusting the effectiveness of the metaphorical "reinforcing stimulus" in *CyberRat*), and the size of water drops to be used as reinforcers. Selection of a naïve animal may be followed by choosing to conduct pre-conditioning "habituation" sessions (the last item in the "Reinforcement Rules" panel) that expose an animal to the operant chamber with no water available under any conditions. This also establishes an opportunity to conduct simple "naturalistic" observation of the animal under minimally manipulated conditions.

CyberRat 3.1.0 (06/09/12)

Experimental Subject: Homer312
Reinf Rule: Manual Reinf / Bar On
Objective: Bar Press

Deprivation and Reinforcement Settings:

Hours of Water Deprivation = 23

Amount of Reinforcement = 0.1 ml per drop

Fixed Ratio (number of Responses required per Reinforcement) = 1

Fixed Interval (number of seconds between available Reinforcements) = 1

There are two "Manual Reinforcement" settings, one that includes the bar as an additional means for the animal to obtain reinforcement and one that excludes the bar. Through the use of manual (i.e., experimenter-administered) reinforcement, experimenters may demonstrate their own skills both in magazine training and in conditioning an animal to bar-press (or to increase the frequency of any other behavior). Perhaps the most artificial aspect of *CyberRat* lies with the fact that naïve animals will never press the lever, as real naïve animals will actually do occasionally in their random explorations and manipulations. This artificiality is included by design, thus assuring instructors that any animal that bar-presses has been shaped to do so through student shaping skills, not by random processes. But because real animals have such a low probability of bar-pressing, the impact of this artificial setting on other behavior probabilities is really quite minimal.

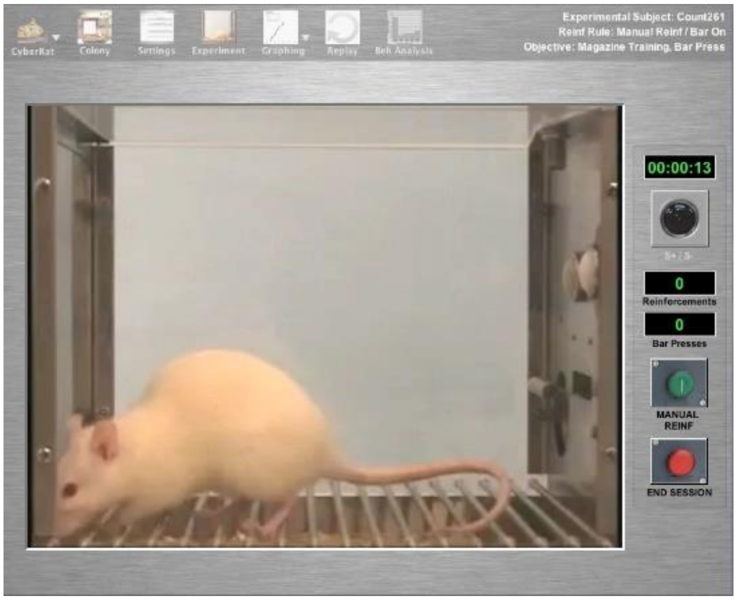
Following successful bar-press shaping, experimenters may further investigate the development of stimulus discrimination by using simulated alternating discriminative illumination conditions. They may also investigate a wide variety of intermittent reinforcement schedules based on temporal, interval, or ratio contingency rules. As noted earlier, I will detail such experimental simulations in subsequent sections where they are contextually appropriate and where applicable Turing tests will be considered. But prior to those discussions let me offer details regarding the use of *CyberRat* for simple observational research simulations.

As already discussed, observational research relies upon systematically observing and recording what animals do in contexts where the experimenter is not changing the environment, which is represented in *CyberRat* by selecting Habituation as the desired "Reinforcement Rule." Students will find it useful to use behavioral categories to describe the rat's behavior—categories that derive from prior reports like those of Ray and Brown (1975, 1976). However, my previous discussion of problems inherent in using such macro-level descriptions for video reconstruction should make it clear that the actual simulations in *CyberRat* rely upon a more complex array of descriptive categories. Those categories meet criteria for an adequate incorporation of the many contextual spatiotemporal elements involved in interbehavioral events. So let me now present a case for an assertion that the current version of *CyberRat* sufficiently meets all relevant criteria as to readily qualify as an authentic and believable simulation of an animal experiencing the operant environment for the first time. In other words, *CyberRat* will pass a Turing test for its authenticity in modeling *structural elements and their kinematics* during a habituation session.

Turing Test 1.1: Visual Fidelity and Structural Modeling in CyberRat

Given the difficulties in achieving a phenomenological fidelity from multi-clipped video reconstructions, any reader who has not seen *CyberRat* first-hand will likely question the success of its dynamic "on-the-fly" compositions while using only its clip library. This disbelief is perhaps the first and most critical hurdle to overcome in claiming that such a visually-based model might meet criteria for a Turing-type test of its authenticity. On this point I must elaborate on my earlier comment that *CyberRat* doesn't meet *all* standards a human visual detection-of-reality test is likely to require. But it is important also to note that I feel it certainly *could* meet or exceed the demands of such a test, and could do so fairly easily. It is true that *CyberRat* in its present form does not create *absolutely* "seamless" video action as one video clip transitions into another. However, most video clips are "close enough" to providing smooth body topography transitions at the point of clip sequencing as to allow the human eye to "bridge the gaps"—especially given the fact that rats often change positions naturally with very rapid shifts. And with modern digital techniques of "morphing," *CyberRat* could achieve a virtually flawless set of transitions. Let me elaborate on these points with concrete illustrations.

Figure 6 and Figure 7 illustrate two examples of a “last-frame-to-first-frame” visual comparison using selected behavioral clips spliced “on-the-fly” in real-time to create *transitions* that *CyberRat*’s constructed-editing algorithms created during a single simulation session. Close inspection of these two Figures reveals a much closer match between the *a)* and *b)* components in Figure 6 than between alternative pre/post components illustrated in Figure 7. Thus, Figure 6 is a “preferred match” transition, while Figure 7 is only an “acceptable match” transition. But all frames in *CyberRat* change at the rate of 15 frames per second, which is sufficiently close to the commonly accepted rate of human flicker-fusion that even the relatively large discrepancy between the end→start positions illustrated in Figure 7 are hardly noticeable when actually viewed in real-time video play.



Experimental Subject: Count261
Reinf Rule: Manual Reinf / Bar On
Objective: Magazine Training, Bar Press

00:00:13

0 Reinforcements

0 Bar Presses

a)

Experimental Subject: Count261
Reinf Rule: Manual Reinf / Bar On
Objective: Magazine Training, Bar Press

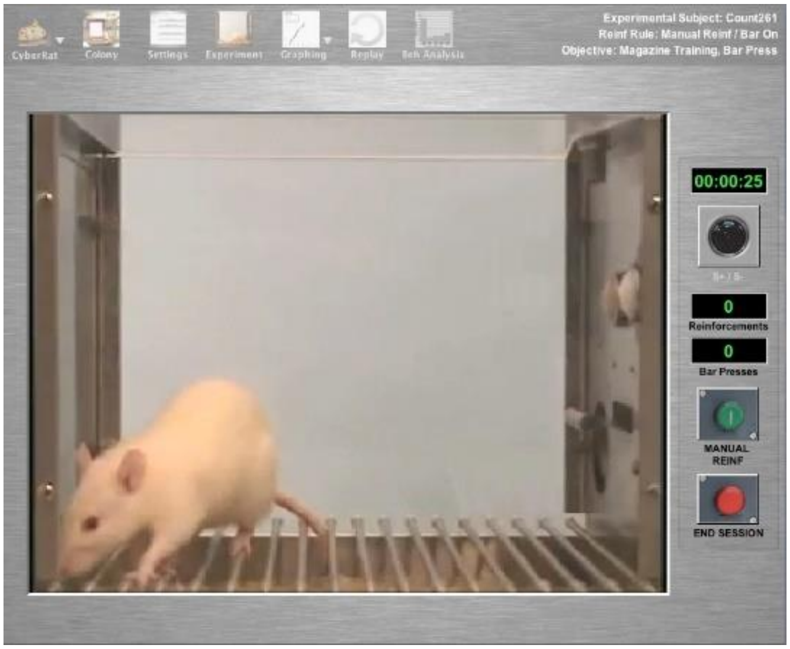
b)

Figure 6. Illustration of a clip-sequence recorded during a *CyberRat* experimental session. Figure 6a illustrates the last video frame of a preceding clip and 6b is the first video frame of the subsequent clip. This sequence will be much less likely to be detected by an observer than the sequence illustrated in Figure 7. The dynamic "splicing" of such clips is achieved by statistically loading and playing each subsequent clip based on current conditional probabilities of a given "set of clips" aggregated as a "field-inclusive interaction class" following the preceding "set of clips," represented by a currently playing selection from that set. Note especially the relatively small difference in the placement of both hind legs with respect to which floor-bars are contacted (a frame-to-frame difference that would easily be interpreted as a simple "step" adjustment), as well as the small differences in tail placement. The likelihood of detecting that a dynamic "editing" has occurred when these two clips are programmatically "spliced" in real time depends largely on minimizing differences in body configurations and locations/orientations within the chamber, and this clip sequence is relatively successful in recreating a realistic, non-detectable splicing of the two clips in real-time.

Nevertheless, even untrained observers will detect most of *CyberRat's* clip transitions if they attend to the animal closely, although few observers find these transitions distracting from their overall experience. In part this acceptance is due to the fact that *CyberRat*'s selection of "next behavior" clips are randomly chosen from a finite collection of clip options that were defined by criteria that more heavily favor "best matches" for pre-to-post transition "head-positions" and "fore-paw-positions" over "hind-leg-positions" or "tail-positions." These "matching" priorities were established because, under training conditions, most trainers will focus more closely on the animal's head and forepaws than on other parts of its body, thus making for smoother transitions at the visual focal point.

Experimental Subject: Count261
Reinf Rule: Manual Reinf / Bar On
Objective: Magazine Training, Bar Press

a)



Experimental Subject: Count261
Reinf Rule: Manual Reinf / Bar On
Objective: Magazine Training, Bar Press

b)

Figure 7. Illustration of another clip-sequence recorded during a *CyberRat* experimental session. Figure 7a illustrates the last video frame of a preceding clip and 7b illustrates the first video frame of a subsequent clip. This sequence will be much more likely to be detected by an observer than the sequence illustrated in Figure 6. As with Figure 6, the dynamic "splicing" of such clips is achieved by statistically loading and playing each subsequent clip based on current conditional probabilities of a given "set of clips" aggregated as a "field-inclusive interaction class" following the preceding "set of clips," represented by a currently playing selection from that set. Note especially the more substantial difference in the placement of both hind legs with respect to which floor-bars are contacted, as well as the noticeable differences in tail placement and curvature. The likelihood of detecting that a dynamic "editing" has taken place when these two clips are programmatically "spliced" in real time depends largely on minimizing the differences in body configurations and their locations/orientations within the chamber, and despite its inclusion in *CyberRat*, this clip sequence is marginally successful in recreating a realistic, non-detectable splicing of the two clips in real-time.

However, given the modern state of graphic "morphing" technologies, little of the above discussion is problematic for my proposed hypothetical Turing test. Morphing typically relies upon algorithms that 1) begin with event *a* vs. event *b* differences in target features, 2) use specified desired numbers of interpolated frames to time the transition, then 3) generate successive approximations in feature changes to result in a visual reconstruction that the human eye responds to as seamless transitions. Such morphing technologies are, themselves, based on mathematical descriptions of differences between first/last graphics and are commonly used in generating highly realistic visual effects within the movie industry. For example, morphing makes humans seem to turn into animals or robots within seconds, with no apparent missteps in transition along the way.

Importantly, every behavioral clip transition possibility within *CyberRat* is a known entity and the algorithm selects a given "subsequent behavior clip" based on the associated conditional probability determined from real behavioral kinematics research. But the algorithm could just as easily select with the same established conditional probability a pre-recorded "morphing transition" as a precursor to the subsequent clip and then follow the morphing component with the subsequent behavior clip itself. This would be a relatively straightforward process given that all of *CyberRat's* transitions involve relatively minor morphing requirements to bridge their spatial gaps. So why wasn't morphing included in *CyberRat*? Because creating a morphing library would require far too much time and labor expense for the relatively small increased quality in perceptual experience.

Fortunately, as already noted, almost all observers' perceptual processes naturally morph or ignore most of *CyberRat's* clip transitions, and thus viewers tend to overlook minor dislocations in the transitions—even those involving larger differences in transitional body configurations. In other words, I am arguing that *CyberRat* is *good enough* for most observers to become sufficiently immersed in their interactions with the simulation to believe they are interacting with a real animal without requiring further development and any use of extraordinary and costly means to make *CyberRat* perfect. *So the fact that CyberRat isn't perfect should not be considered a critical failure in its meeting a Turing test's standards of non-discriminated differences—especially with respect to CyberRat's role in affirming the completeness of original live-animal descriptions underlying the model.*

So, unlike my original discussions of how descriptive categories used in Ray and Brown's (1975, 1976) research were insufficient for visual reconstruction, in the present case we know how to address observer-detected differences without going back to the original descriptive methods for a solution. The original classification scheme for clustering clips into common interbehavioral categories seems to be both necessary and sufficient to the demands of visual constructive composition that, if morphed only a bit, the model would most likely not be discriminated from closed-circuit video feeds.

There's More to the Test than Transitions. In addition to transition jumps, two remaining foundations for discriminating between digital reconstruction vs. closed-circuit live video feeds in *CyberRat* might involve: 1) how limited the variations in the video-clip library are, and 2) whether there are any noticeable differences in clarity of the video due to digital file compression algorithms. Let me consider each point in turn.

If only one exemplar of each behavior-in-context existed, anyone watching a video reconstruction based on such a small sample would quickly detect artificial repetitions in the patterns of behavioral sequencing. It would appear as if a relatively short video was playing "in a loop" that results in obvious stereotypical behavior replays. The first version of *CyberRat* incorporated approximately 850 video clips, while the second version more than doubled the size of this sample. This assures that most viewers will have to watch a very extended length of time to note any single clip's repetition, and even then a single clip is likely to appear within a different preceding/succeeding clip sequence. Thus, the potential for stereotyped playback was addressed from the very beginning of *CyberRat* development and was only improved—especially with respect to bar-press variations—in the revised version.

Video clarity (which is degraded by file compressions) is also not really a critical dimension of the test for discriminating differences between live-feed vs. constructed video, given ever-improved compression algorithms for digital video (*CyberRat* uses circa 2002–2003 technologies, and technologies have since improved significantly). Such visual display quality is also reliant upon camera resolution and focus, and it certainly would be simple enough with today's technologies to either videotape in high definition or simply degrade a closed-circuit feed to match the resolution qualities extant in *CyberRat*. So again I assert that, while in its present state *CyberRat* doesn't completely meet the strictest requirements of my suggested Turing test for detecting simulation animals from closed-circuit viewings of live animals, it easily could without changing original descriptive methodologies. This leaves all detected differences being essentially trivial with respect to the feedback the model offers for improving original research methods used for this structural analysis.

Based on the phenomenological similarities of viewing the simulation vs. live closed-circuit video, I propose that *CyberRat* validates the descriptive methods and analyses that guided its development. To be more specific, given that our classification of interbehavioral event *elements* was found to be sufficient for believable visual reconstructions of appropriately probabilistic variations in these elemental events, I conclude that *CyberRat* validates the descriptive categorization, observation, and coding methods used for defining element classes. And from a GST perspective, defining elements of a system is the starting point for any structural analyses.

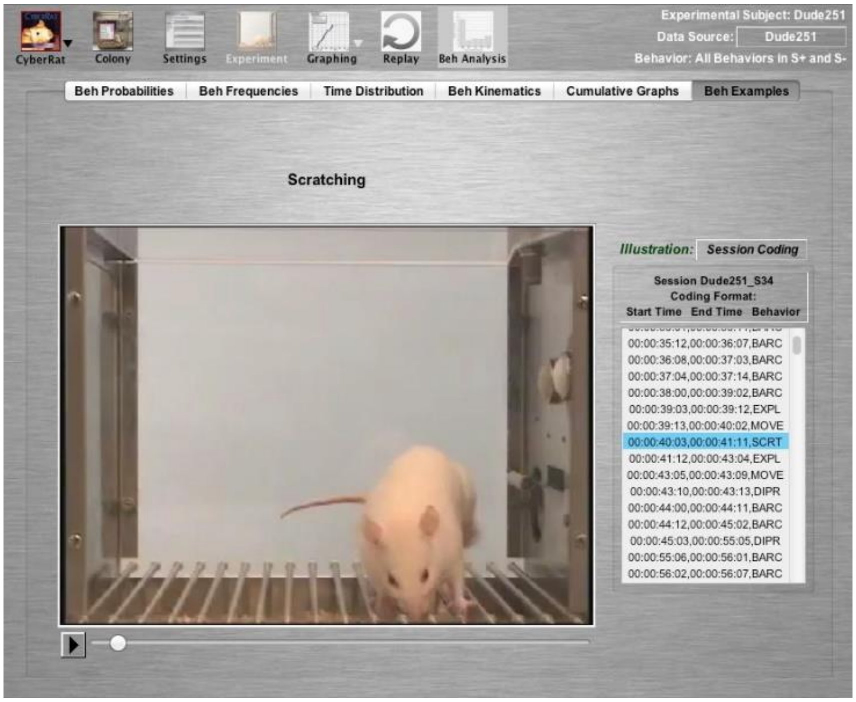
It might be easy to undervalue this fact, especially if you are a traditional operant theorist. Let me stress that, in my view, it is not a trivial contribution to account for every behavioral event that is *not* graphed on a cumulative bar-press record, and to do so in a manner that, if appropriate methods of observational data collection were applied to any *CyberRat* session, those data would match closely any data collected from live-animal experiments under equivalent conditions. But this is an assertion of a different kind of structural authenticity. It poses the question: "How realistic are the numeric data generated by *CyberRat vis-à-vis* kinematic dynamics?" I will turn to a consideration of this aspect next. But first, a reflective comment on numeric data comparisons in the broader sense.

Any test of "comparable data" could be based either upon statistical detections of difference or upon a simple phenomenological (visual) evaluation of apparent differences. Unfortunately, attempting a statistical test implies proving the null hypothesis, which is not at all consistent with the usual statistical testing for sample differences. Even if one ignores this caveat, statistical testing implies far more empirical sampling than the purpose of the present monograph warrants. As such, I will not suggest actual comparative statistical testing as a criterion for passing further proposed Turing tests that are based upon numeric data. However, that lack of comparison leaves an interesting challenge for the properly motivated and interested reader! So let me now consider a phenomenological evaluation of the kinematic patterns and conditional probabilities generated by *CyberRat* simulations. Other numeric comparisons will be considered in later sections.

Turing Test 1.2: Kinematics Fidelity and Structural Modeling in CyberRat

When placed into the operant chamber for the very first time, *CyberRat's* naïve animals begin with a kinematic "data seeding" that reflects a truly representative matrix of *conditional probabilities* for determining behavioral (clip) sequences to be composited in real-time playback. This, of course, also implies that any observer conducting systematic observations and recordings would generate a representative "behavioral hierarchy" (cf. Catania, 2007) summary of unequal *unconditional* probabilities for all response classes that have video representations within the video clip collection. But more importantly, this also implies that clip sequences will always reflect real kinematic data averages and standard errors that model those determined from our CRRP empirical research project. The CRRP generated statistical averages and standard deviations across several live animals observed in each of the various conditions simulated by *CyberRat,* including first-exposure habituation sessions in an operant chamber (Miraglia & Ray, 2003).

Unfortunately, the complex “field” categories eventually used to realize *CyberRat* itself are complex descriptions that are not well suited to simple illustrations of the kinematic fundamentals for users. Thus, to assist users of *CyberRat* in understanding kinematics, the system includes a “Multi-Behavior Analysis” feature whereby any session may be automatically translated from the video composition script generated statistically during any session into a more simplified and understandable behavioral coding representation of that session using behavior categories essentially equivalent to those originally used by Ray and Brown (1975, 1976). To make the stages of data analysis more clear to users, *CyberRat* includes a “continuous coding” file that highlights each behavior’s descriptive “coding” simultaneously with video playback as illustrated in Figure 8. Thus, any selected experimental *CyberRat* session may be used to generate not only the source-sequence file illustrated in Figure 8, but also associated summaries of each such file accessed via the various tabs, including both numeric and graphical summaries of absolute frequencies and relative frequencies (probabilities) of unconditional behavioral occurrences for each behavior, relative durations, and total-time summaries for each behavior.



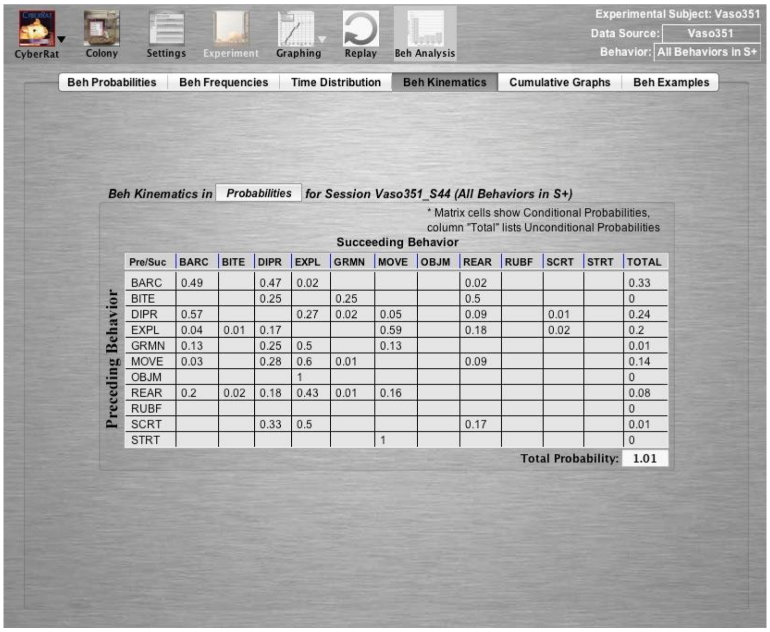
Session Dude251_S34
Coding Format:
Start Time End Time Behavior

```
00:00:35:12,00:00:36:07,BARC
00:00:36:08,00:00:37:03,BARC
00:00:37:04,00:00:37:14,BARC
00:00:38:00,00:00:39:02,BARC
00:00:39:03,00:00:39:12,EXPL
00:00:39:13,00:00:40:02,MOVE
00:00:40:03,00:00:41:11,SCRT
00:00:41:12,00:00:43:04,EXPL
00:00:43:05,00:00:43:09,MOVE
00:00:43:10,00:00:43:13,DIPR
00:00:44:00,00:00:44:11,BARC
00:00:44:12,00:00:45:02,BARC
00:00:45:03,00:00:55:05,DIPR
00:00:55:06,00:00:56:01,BARC
00:00:56:02,00:00:56:07,BARC
```

Figure 8. Illustration of the Multiple-Behavior Analysis screen in *CyberRat* showing the "continuous coding" of an experimental session that translates the interbehavioral clip categories into a taxonomy more similar to the one used by Ray and Brown (1975, 1976). This feature highlights each behavior's descriptive "coding" of start/stop frame time and behavioral category simultaneously with real-time video playback to assist users in identifying traditionally categorized behavioral events and how they are coded by investigators. Stop-frame analysis is made possible simply by using the space bar to pause/continue video play.

All summaries are separately available for each contextual/discriminative setting if discrimination training was a part of the experimental session, as is illustrated in Figure 9 where transitional probabilities between these "derived descriptions" for *CyberRat's* behavior in S+ and in S- are summarized for the illustrated session. I have already noted the logical difficulty of proving these are representative of actual experimental data, but they model the averages and standard deviations across many replications in *CyberRat* that closely match those obtained in our empirical CRRP research. This modeling fidelity means, of course, that no observer is going to see a *CyberRat* animal make unexpected or illogical transitions from one behavior to another. I am also confident that the range of possible presentations of original data summaries could not be visually discriminated from a similar range of data summaries generated by *CyberRat* simulations. As such, I am also asserting that these structural/kinematic simulations would also pass the appropriate visual and/or data-oriented Turing test.

Having thus specified the attendant interbehavioral environmental/contextual and organismic setting factors, as well as the primary interbehavioral elements and how these elements are mutually implicated through conditional probabilities in transitions across time, our structural analysis of the traditional operant experiment from the IBSA perspective is complete. Let me now address a functional analysis of this system from the IBSA perspective.



Experimental Subject: Vaso351
Data Source: Vaso351
Behavior: All Behaviors in S+

Beh Kinematics in Probabilities *for Session Vaso351_S44 (All Behaviors in S+)*

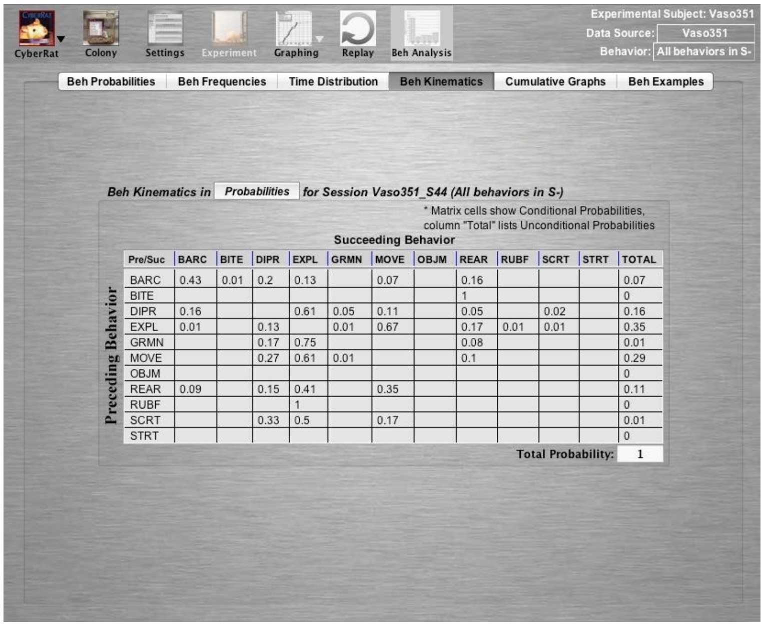
* Matrix cells show Conditional Probabilities,
column "Total" lists Unconditional Probabilities

Succeeding Behavior

Pre/Suc	BARC	BITE	DIPR	EXPL	GRMN	MOVE	OBJM	REAR	RUBF	SCRT	STRT	TOTAL
BARC	0.49		0.47	0.02				0.02				0.33
BITE			0.25		0.25			0.5				0
DIPR	0.57			0.27	0.02	0.05		0.09		0.01		0.24
EXPL	0.04	0.01	0.17			0.59		0.18		0.02		0.2
GRMN	0.13		0.25	0.5		0.13						0.01
MOVE	0.03		0.28	0.6	0.01			0.09				0.14
OBJM				1								0
REAR	0.2	0.02	0.18	0.43	0.01	0.16						0.08
RUBF												0
SCRT			0.33	0.5				0.17				0.01
STRT						1						0

Total Probability: 1.01

a)



Experimental Subject: Vaso351
Data Source: Vaso351
Behavior: All behaviors in S-

Beh Kinematics in Probabilities *for Session Vaso351_S44 (All behaviors in S-)*

* Matrix cells show Conditional Probabilities,
column "Total" lists Unconditional Probabilities

Succeeding Behavior

Preceding Behavior

Pre/Suc	BARC	BITE	DIPR	EXPL	GRMN	MOVE	OBJM	REAR	RUBF	SCRT	STRT	TOTAL
BARC	0.43	0.01	0.2	0.13		0.07		0.16				0.07
BITE								1				0
DIPR	0.16			0.61	0.05	0.11		0.05		0.02		0.16
EXPL	0.01		0.13		0.01	0.67		0.17	0.01	0.01		0.35
GRMN			0.17	0.75				0.08				0.01
MOVE			0.27	0.61	0.01			0.1				0.29
OBJM												0
REAR	0.09		0.15	0.41		0.35						0.11
RUBF				1								0
SCRT			0.33	0.5		0.17						0.01
STRT												0

Total Probability: 1

b)

Figure 9. Illustrations of screen selections in the Multiple-Behavior Analysis section of *CyberRat*. In Figure 9a the Tab and menu combination that is selected is the Kinematics (i.e., conditional probabilities) matrix for all behavioral sequences during all combined S+ setting conditions across a given simulation session involving an experimental animal with an extensive training history involving light discrimination (i.e., bar-pressing was reinforced during S+ but not during S-). Figure 9b depicts the same data during all combined S- setting conditions across the same session. Comparing data in these two matrices reveals a major contrast in behavioral kinematics, and thus related video compositions, between the two settings. For example, in Figure 9a the most prominent behaviors are BARC (.33) and DIPR (.24) with high degrees of sequential integration between the two, while in Figure 9b the most prominent behaviors are EXP (.35) and Move (.29), also with high transitional connectivity between them. These two illustrations are highly similar to the results reported by Ray and Brown (1975) and illustrated previously in Figure 5. Codes used in the Figures are as follows: BARC=bar contact, BITE=bite-groom self, DIPR=nose inserted into water dispenser, EXPL=head and/or fore-limb movement while not rearing up, GRMN=lick-groom self with paws over face/nose, MOVE=hindlimb movement resulting in animal changing locations, OBJM=object bite, lick, manipulation, REAR=both forepaws off the floor with body upright, RUBF=rubbing face against objects, including the bars making up the floor of the cage, SCRT=scratch self with hind-legs as a form of grooming, and STRT=animal being placed into the chamber for the start of a new experimental session.

Functional Analysis of Interbehavioral Systems

I have already described how some contextual setting conditions (e.g., house lights on/off) can impact kinematic organization patterns if such settings serve discriminative functions like those depicted in Figure 5. Researchers using TEAB methodology typically incorporate such contextual settings as the antecedent stimuli that serve discriminative functions, thus having different implications for behavioral events that occur in their presence vs. absence. But a typical TEAB analysis of the Ray and Brown (1975) experiment represented by Figure 5 would evaluate only the rate of bar-pressing (i.e., electrical switch closures) through the use of a cumulative response record under alternating discriminative stimulus conditions, instead of the full pattern of kinematic organization and change dynamics illustrated by this Figure. Such a cumulative record might well depict each corresponding S+/S- condition across time during the session, thus allowing one to view the specific impact of discriminative setting conditions *vis-à-vis* bar-press rates, but only bar-press rates. And while such an analysis contributes a great deal to a systemic understanding of important dynamics in this situation, Kantor surely would have asserted that it does not afford a complete description.

Focusing on one singular response class that systematically results in an outcome like the delivery of reinforcing consequences accomplishes what both traditional behavior analysts as well as systems theorists would describe as a *functional analysis.* The three-term contingency conceptualization representing TEAB includes two stimuli, each with quite different functions with respect to behavior. The antecedent has a "signaling/discriminative" function in that it sets the occasion for responding to have some probability of being followed by consequences. The consequence has either a reinforcing or a punishing function, with that function being defined by whether the subsequent rate of the behavior generating such consequential events increases (reinforcing function) or decreases (punishment function) in probabilities or rates. As noted, TEAB views these functions as primarily impacting the specific response class of bar-pressing and is silent about the effect on other supportive or competing behaviors that may interact with that response class across changes in time and space.

Functional analysis in systems theory derives mostly from engineering models and thus focuses on the goal or purpose (i.e., impact or outcome) of a system. This is an easy conceptualization, given that engineered systems typically are designed to address specific purposes from the outset. And such impacts may be assessed either with respect to the system itself, with respect to the system's environment, or, more typically, both. Self-impacting functions take quite a variety of different forms, typically described by ultimate outcomes such as self-degradation, homeostatic self-maintenance, or even adaptive functions, which include self-adjusting of goals (as when an adaptive thermostat in an air-conditioning system adjusts its settings for different temperature maintenance during daytime vs. night-time hours), functions, structures, or even operating characteristics. Systems that are studied for their external functions are typically described by some reference to what they accomplish, such as transporting, temperature exchanging, chemical extracting, etc.

(cf. Ackoff & Emery, 1972). A concrete engineered example may help to clarify these abstractions while also giving us some useful comparisons and contrasts between structural analysis and functional analysis.

Consider a common engineered system such as an automobile. From the structural analysis perspective, an automobile is a good illustration of the difference that organization makes in a system. Taking all of the necessary and sufficient elements (parts) required for building any given automobile, think of alternative ways we might arrange these parts. For example, we might arrange them alphabetically using each part's name. Placing these parts adjacent to one another on shelves in a building gives them a functional purpose that might be described as an auto-parts store. From a functional perspective, such a store serves as a one-stop depot for purchasing and/or disseminating replacement parts for the associated make/model of automobile that includes such a part in its composition. This is, of course, only one function of such a system called an auto-parts store. Another is to make money for the store's owner/operator. As a side note, my own father-in-law sent four children through universities from such a parts store located in a small southern agricultural town. So for him, the money itself was not his store's primary function, but rather that money served as a "means" to many ends (functions), including feeding and educating his family.

But what if all of those different automotive parts were organized in the manner the original automotive engineers intended when they designed the parts? That is, what if the parts came in the form of a new and fully functioning automobile? Note that we have a different name for this organization than for the previous—we have gone from parts store to auto dealership as the primary place for buying the object of interest. In part, that is because the spatial configurations of parts (i.e., organizations) are so drastically different between the parts store and a car in a dealership. It is also because we have named them from their functional perspectives rather than their structural perspective. Automobiles function primarily as transportation devices. Some automobiles also function as status symbols, collectibles, and even recyclable "junk" materials. Others accidentally function as a means for killing or maiming people. It all depends upon the criteria one applies for what the "outcome" is that has priority in a human-use-of-system context. Those "human uses" are all external functions of automobiles.

On the other hand, the internal functions of an automobile are mostly defined by separate functions of its subsystems and their role in enabling or maintaining the collective external function of transportation. Thus the *starter* or *ignition system* functions to enable an operator to change the state of the automobile's engine from an "off" state to a "running" state. Likewise, a fuel pump distributes fuel from storage (gas tank) to the engine, thus initializing and maintaining the engine's running state. The accelerator allows an operator to change the rate of revolutions in the engine, and the drive-train and transmission transfer the engine's energy production to enable the car to move. Of course, the car does not function well without a human operator, so a driver serves as the truly adaptive intelligence in this transportation system by using the steering wheel to guide the car. Staying within the assigned road lanes involves maintaining a homeostatic "balance" in the car's direction (thus avoiding head-on collisions and probable death to the driver), and sharp turns allow for dramatic changes in direction, thus giving a maximal adaptivity to the car as a "general" transportation system. It is, in part, this adaptivity that gives automobiles advantages over, say, trains or airplanes, in that automobiles as transport systems can take us to our front doors while trains and airplanes can leave us miles from our final destination.

Of course, prolonged use of the car for transportation will begin to have internal functional implications as well, and eventually various parts of the system will be degraded, depleted, or totally transformed into alternative states (called "broken"). Thus, fuel is transformed into alternative emissions as well as energy transfer and will have to be replaced relatively quickly, the tires get worn down and will have to be replaced over a much longer-term perspective, and the exterior metals will only very gradually lose paint and other protective coatings and begin to rust away.

Astute and informed readers (or aspiring engineers) will already be finding alternative "parts" to make this narrative different. Thus, changing to electricity from gasoline will cause the emissions (external functions) to change. Substitute or add new materials, such as steel radial belting, to the tires and their life is extended; and build the body with plastics instead of steel and one avoids the rust. Note how these examples include different parts or elements (i.e., structure) to address certain functional problems in the engineering or use of the automobile, but the transportation function remains. Verplanck included an interesting entry in his *Glossary and Thesaurus of Behavioral Terms* that illustrates this change in parts vs. constancy in function in very human terms. That entry concerns the term/concept "Grandfather's knife" and it illustrates psychological functions that can be quite unique, as he states:

> **Definition:** the pocket knife that belonged to grandfather, who got it from his grandfather: They both always carried it with them and used it so much, that its blade had to be replaced five times, and its handle seven times.
>
> **Commentary:** An illuminating example of the distinction between the languages of the physical scientist and of the psychologist: Is it the same knife? For the physicist, obviously no. For the psychologist, as for grandfather, and grandfather's grandfather, emphatically yes. If it gets lost and a stranger finds it, it is no longer grandfather's knife, in the present tense. In a small-town museum in Illinois (or is it in Kentucky?), "Lincoln's axe" is on display. The axe displayed no longer has the same handle or the head as used by Lincoln, both have been replaced at least once. Despite this, the museum's curators insist that the axe on display is Abraham Lincoln's axe. . . . Communities maintain their identity; so too, do individuals, in spite of what some analyses in the biological sciences tell us, when they show that every molecule will be replaced during the lifetime of the individual. Identities are maintained primarily, if not solely, by continuing interactions with a set of other individuals, whose members change with time. See identity. (Verplanck, http://www.ai2inc.com/Products/GT.html)

I will return to my car example in the next section as well, when I illustrate the concept of operations analysis. In that context I will consider, among other features, how a car handles from the perspective of the person driving it, as well as what kind of total fuel efficiencies (cost per mile) is involved in the automobile's daily operations.

Ray and Delprato (1989) described and illustrated in detail the complementarity between structure and function. Most interbehavioral systems are highly adaptive while also being fundamentally homeostatic when that process is possible. It is typically when a dynamic stability cannot be maintained that adaptivity occurs. What this means from a practical perspective is that smaller interbehavioral elements frequently combine into specific, and frequently quite probabilistic, alternative patterns of organization that may be subsequently defined by their change in functions, much as micro-patterns of actions become "bathing" or "eating" episodes involving a series of complex micro-level interactions. Thus, in behavioral systems micro-interactions become elements that organize into hierarchical behavioral patterns that become, themselves, newly defined macro-structures that are established and aggregated by commonly shared functional outcomes. Without reflection on the behavioral steps that define exactly how we bathe ourselves differently in showers vs. bathtubs filled with water, we go about the task of cleansing our bodies of the daily dirt and oils that accumulate. That variation is highly adaptive, of course. Likewise, we give little thought to appropriate uses of knife, fork, spoon, or even combinations to "eat our meal." Thus, our interbehavioral elements becomes larger and larger elements that define even higher-level functional purposes such as work, recreation, entertainment, etc.

Ray and Delprato (1989) offered many concrete data-based illustrations of this process and its implications based on research with rats, with dogs, and even with killer whales. Other TEAB-oriented researchers have recognized this phenomenon, and the term "meta-contingency" has been coined to describe the larger functional aggregates of behavioral units at the cultural level of analysis (cf. Glenn, 1988; Malott & Glenn, 2006). It should be sufficient in the present context to simply illustrate how functional analysis impacts *CyberRat* design and simulation, as various functional simulations are made available within the model.

The Second Series of Turing Tests: Some Functions Simulated in *CyberRat*

First, of course, *CyberRat* models the complex behavioral pattern changes that occur as *adaptive* processes that result in new functionalities when water access is controlled by highly specific behavioral reinforcement contingencies. That is, when water becomes available through only one selective class of behavior, *CyberRat* will adapt to those contingencies either by rearranging existing response patterns and/or through the development of new behavior(s) that include high probabilities of that response class. Stated simply, you can operantly condition *CyberRat*. And through proper shaping procedures, you can even generate a new form of *functional* behavior (e.g., tight circling or bar-pressing for water reinforcement) as one form of interbehavioral adaptation. Of course, you may also simply increase the operant rate of any pre-existing behavior by making it the contingent response for water delivery. This is how *CyberRat* models adaptive/functional processes. But other adaptive-in-function processes are also modeled. This includes, for example, respondent conditioning as a means for developing conditioned reinforcement functions attending previously neutral events. Of course, discriminative setting functions may also be established if lighting conditions signal that reinforcement contingency rules are presently in effect. So let me turn now to consider how realistic these processes might seem to someone training *CyberRat* animals through the management of reinforcement delivery. I will also reflect on how well the data produced during this process match empirical data from live animals.

Turing Test 2.1: Magazine Training and the Development of Secondary Reinforcement Functions as Respondent/Classical Conditioning

Pavlov (1927) is perhaps the best known of those researchers who systematically explored the dynamics of presenting stimuli that were reliably followed by a biologically significant stimulus, which Pavlov called an *unconditional stimulus* because there were no conditional restrictions or necessities for such stimuli to elicit behaviors. Of course, because Pavlov was a physiologist, the types of behaviors he tended to study were largely autonomic activities, and thus those that were considered to be "reflexive" reactions to such unconditional stimulation. But following Pavlov's early investigations, it became more and more clear that the unique aspect of his procedure was his presentation of some preceding stimulus as the signal for his subsequent presentation of an unconditional stimulus. This *procedure* has carried numerous labels including *Pavlovian Conditioning*, *Classical Conditioning*, and *Respondent Conditioning*. Catania (2007) has described the use of these stimulus relations in detail, and points out their unique operational characteristics as follows:

> Respondent conditioning is an instance of stimulus control applied to stimulus-presentation operations rather than to the contingencies of consequential operations. In other words, instead of signaling the consequences of responding, a stimulus simply signals the presentation of some other stimulus. Pavlov's conditioned salivary reflexes are the prototype example. (p. 198)

Ray and Brown (1976) demonstrated that the entire pattern of behavioral kinematics is reorganized as dramatically under such stimulus$_1$–signaling–stimulus$_2$ conditions as they are under consequential operations. But another important outcome of such stimulus–stimulus contingencies is the development of functional conditioned reinforcement properties for the signaling stimulus. Such conditional, or secondary, reinforcing properties have long been recognized and used in the successful shaping of operant behavior both in the laboratory and in more naturalistic settings.

In TEAB this process of generating a conditional reinforcement function is often called *magazine training*. Magazine training as a term harks back to food-delivery mechanisms that worked much like everyday bubblegum machines. In such machines, a rotating disc with holes (the "magazine") rotates underneath a container of gum-balls (or food pellets), allowing only one ball to drop into the hole, which is plugged underneath until it rotates into an open location that allows the ball to drop into a dispenser, thus completing a delivery. Guns, including those called revolvers, also use magazines to deliver bullets into place for firing.

Food magazines typically make a distinctive noise as they rotate (historically this sound was from a solenoid closing), thus making a clicking sound that immediately precedes food delivery. Of course, dippers or solenoids used to deliver drops of liquid also make similar delivery noises. This noise→food presentation, noise→water presentation, or any other $\text{stimulus}_1 \rightarrow \text{stimulus}_2$ contingency represents a respondent conditioning trial each time such a temporally-close pairing between two stimuli occurs. If presented over a sufficient number of $\text{stimulus}_1 \rightarrow \text{stimulus}_2$ presentations, no matter where an animal is in the operant chamber or what behavior is occurring there, the animal comes to have a very high probability of quickly responding to the occurrence of stimulus_1 (in our case, sound associated with water delivery) by running to the dispenser location and consuming the second stimulus—e.g., the food or water signaled by that stimulus. When this rapid response to the sound of delivery becomes a highly reliable reaction, the animal may be reinforced for a behavior occurring within hearing range of the sound because the sound has become a conditioned reinforcer.

CyberRat was designed to simulate this adaptive process whereby previously non-eliciting (typically referred to as neutral) stimuli evolve new functional implications for various behaviors, and thus *CyberRat* incorporates the full modeling of this respondent/classical conditioning process—including the development both of a more probable and shorter-latency "go to dipper" response and of the sound's secondary reinforcement functions. This is illustrated in Figure 10 adapted from Ray and Miraglia (2011) where pre-training latencies of going to the dipper following water delivery may be compared to post-training "go to dipper" latencies after magazine training.

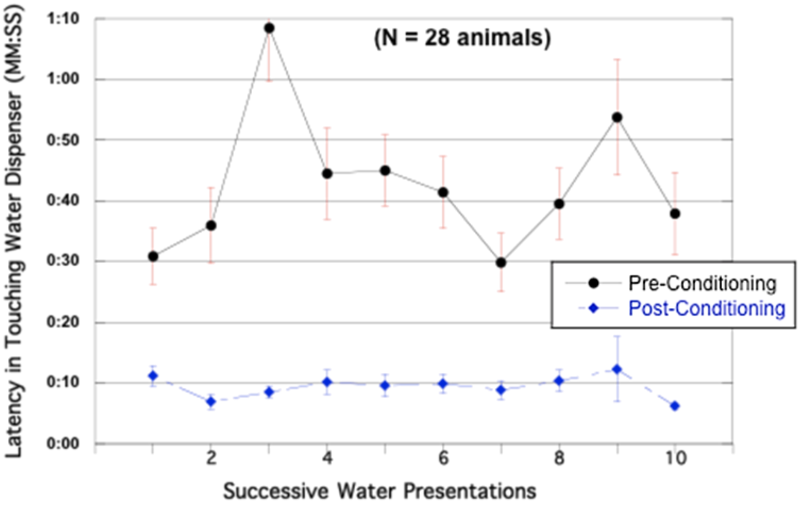


Figure 10. Illustration of experimental data from *CyberRat* simulations illustrating observed latencies of "drink" behavior following delivery of sound plus water across 10 successive presentations via use of a VT 90 sec schedule in *CyberRat* before (Pre-Conditioning) and after 30 trials of "magazine training" (Post-Conditioning). This schedule assures a relatively random interception of ongoing categories of behavior under both experimental conditions. (from Ray & Miraglia, 2011)

But the number of such stimulus–stimulus presentations required to establish reliable responsiveness and conditioned reinforcement functions is largely a product of where the animal is and what that animal is doing when the signal→water pairing is presented. If an animal begins with the sound being a "neutral" stimulus, as conditional stimuli in respondent conditioning experiments typically are, and if such a sound occurs under circumstances resulting in the animal *not* being obviously responsive to the presentation of water or food that follows, *there is no signaling taking place* from the animal's perspective. Thus, to assure that there is a reasonably close temporal relation between the two stimuli, successful magazine training is facilitated if the sound→water sequence occurs such that the animal is likely to notice (and approach) the water's delivery or presence. As such, more efficient respondent conditioning occurs if the water drop is presented when the animal is close to the dispenser and oriented to it as well. This behavioral precondition, of course, simultaneously creates a behavioral→consequential operation occurring along with the stimulus→stimulus operation.

Unfortunately, most of the dynamics attending the magazine training process are known only through laboratory lore. Both magazine training and shaping responses via Skinner's well-known process of *successive approximations* (Peterson, 2004) are typically taught as an art, via apprenticeships and imitation, rather than as prescribed and precise scientific procedures. Because magazine training is not documented through published parametric investigations, our CRRP had to evaluate the typical number of signaling presentations required for responsive reactions to appear in live animals.

CyberRat models the data from these experiments, and thus offers most users with prior experience with the magazine training process a realistic feeling that they are managing an authentic adaptive process with respect to rate of success in its development of both animal responsiveness and the development of conditional reinforcement properties. That being said, perhaps one of the most unnatural and unrealistic of *CyberRat's* characteristics is revealed in the slowness of an animal's response to "test probes" that involve delivery of sound/water combinations to assess latencies in "going to the dipper." This is true despite the observed relative declines in response latencies following magazine training, as reflected in Figure 10. Such probes are typically given in order to evaluate magazine training progress, and anyone using such a probe typically anticipates finding a very short latency between sound→go-to-drink reactions by the animal—shorter than those achieved in Figure 10, in fact. The reason for this discrepancy is relevant to consider.

CyberRat uses video clips that vary from 1–2 sec up to 10–15 sec in duration before a currently depicted behavior will sequence into a subsequent behavior. Thus, if a water-delivery signaling sound (in *CyberRat* this is a simulated "drip" sound) is presented just as a relatively long clip has begun play, it is not possible for *CyberRat* to "abort" that clip immediately and have the animal run to the water dispenser to drink, as most real animals will do. Thus, trainers in *CyberRat* must be satisfied with only a very high probability that the animal will return to the dipper after the current clip has completed play, and with the imposed 9–12 second latencies required to allow video clip completions rather than seeing the animal respond with the very quick reactions one expects of live animals. So on this feature, *CyberRat* passes a Turing test for functional adaptation based on how it models the process of *respondent/classical conditioning* and its associated implications based on response-probability changes, and with some of the expected decreases in latency (illustrated in Figure 10) as well as the acquired conditional reinforcement functions, but it admittedly falls a bit short on the criterion of nearly instantaneous response latencies following administration of a conditional stimulus (sound of delivery).

Turing Test 2.2: Successive Approximations and Response Class Generalization Dynamics

There is a very famous film segment depicting B. F. Skinner giving a demonstration of how to shape a pigeon to turn in a circle as a result of successive changes in the targeted response that is reinforced. He begins by reinforcing only those random movements that result in the animal turning its head a bit counter-clockwise. When this head movement increases sufficiently in rate, Skinner shifts from reinforcing head turns to reinforcing when he sees the animal's body turn slightly in that same direction. This soon turns into reinforcing only quarter-turns, then half-circle turns, and eventually full-circle turns. *CyberRat* offers experimenters similar opportunities for training a rat to make tight circles in either direction using much the same successive approximation, or *response shaping*, process. *CyberRat* animals will respond to the same process in much the same way, thus learning to turn either clockwise or counter-clockwise tight circles if shaped properly.

In its generalized form, Skinner's technique for response shaping (Peterson, 2004, Skinner 1951) relies upon a process of reinforcing a series of successive approximations toward the target behavior that one wishes to teach. The process is usually based upon reinforcing each of a series of steps in a response's topography by selectively reinforcing each topography in turn as it more closely approximates the desired final behavior topography. A substantial discussion of this process is given in Catania (2007) for those who may not be familiar with the process or its use of *differential reinforcement* of successive approximations to the goal response class. As another example, shaping real animals to bar-press for water reinforcement typically will begin (after successful magazine training) by reinforcing when the animal simply removes its head from the water dispenser after drinking. But it is even better if that head-removal results in the animal turning toward the manipulandum (lever or bar). Turning its nose in the direction of the bar while exploring, sniffing the bar, touching it with one paw, and then two paws—all define a succession of more stringent criteria that gradually come progressively closer to having the animal actual pressing the bar down sufficiently to close an electromechanical switch to create automatic delivery of reinforcement.

Each of these described interbehavioral event stages has multiple representations within *CyberRat*, and as one class of similar events increases in probability through reinforcement, other, and slightly different classes of events that are, themselves, closely related in form and orientation also increase, though not as much as the reinforced class. Thus, a genuine response and reinforcement "generalization process" for several different but similar response patterns is modeled in *CyberRat*, and this modeling generates a very realistic training experience for those familiar with the nuances of response shaping through successive approximations.

CyberRat is ultimately designed as a teaching tool for developing student skills in shaping behavior and in conducting various experiments. Thus, a *CyberRat* feature that is important for evaluating students is included in the simulation. Untrained animals in *CyberRat* all begin with a zero probability of pressing the bar (but not of turning a full circle—that behavior has an only a slightly greater than zero probability). This is the *one* distortion incorporated by design into *CyberRat*. A zero bar-press probability is not reflective of real animals, but it is extremely useful for determining that it is the student's shaping skill that results in successful bar training in *CyberRat*. We felt that this was a more important feature, given *CyberRat's* intended educational use, than giving the model a higher fidelity that, in real-world situations, allows for trial-and-error explorations that may result in some animals learning to bar-press by random processes alone. Of course, it would have taken but a simple change in the initial conditional probability matrix for naïve or habituated animals to incorporate a small but positive "chance" possibility of an animal pressing the lever. As such, I would argue that this variation of the proposed

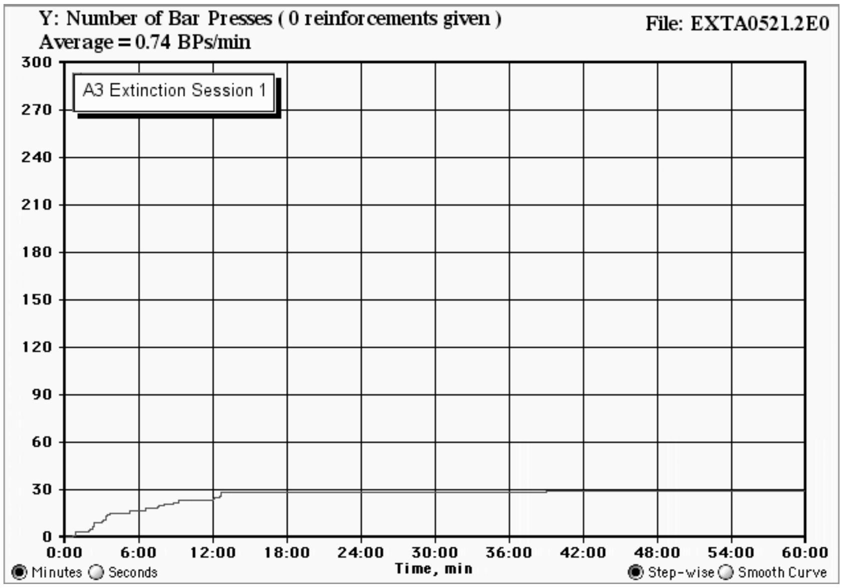
Turing test passes on most criteria, and could be corrected to pass even on this initial bar-press probability criterion as well.

Turing Test 2.3: Behavioral Extinction Dynamics

B. F. Skinner is also typically credited with having discovered the extinction process as it impacts operant responding. His relatively famous self-description of this discovery appears in his autobiography:

> My first extinction curve showed up by accident. A rat was pressing the lever in an experiment on satiation when the pellet dispenser jammed. I was not there at the time, and when I returned I found a beautiful curve. The rat had gone on pressing although no pellets were received. . . .The change was more orderly than the extinction of a salivary reflex in Pavlov's setting, and I was terribly excited. It was a Friday afternoon and there was no one in the laboratory who I could tell. All that weekend I crossed streets with particular care and avoided all unnecessary risks to protect my discovery from loss through my accidental death. (Skinner, 1979, p. 95)

Unfortunately, published research on the characteristics of such extinction curves is rarely based on the combination of using rats, water reinforcement, and continuous reinforcement (or most any other) pre-extinction reinforcement schedules. So the CRRP had to include an investigation of this unique experimental combination's parametrics in extinction. The same animals used throughout our CRRP experiments were transferred from continuous reinforcement schedules to three successive days of extinction procedures, where no water reinforcement was available throughout each session. As Figures 11, 12, and 13 illustrate, both within- and across-session declines and eventual total cessations in bar-pressing were observed for all animals. *CyberRat* was designed to simulate these same operating characteristics with very similar parametrics, including the range of variability typically observed between animals within and across successive daily sessions (see Figures 14 & 15). Also noteworthy in both the CRRP live-animal Figures (11–13) and the simulation-produced Figures (14 & 15) are the declining degrees of spontaneous recovery on each successive extinction day.


Y: Number of Bar Presses (0 reinforcements given)
Average = 0.74 BPs/min
File: EXTA0521.2E0
A3 Extinction Session 1
300
270
240
210
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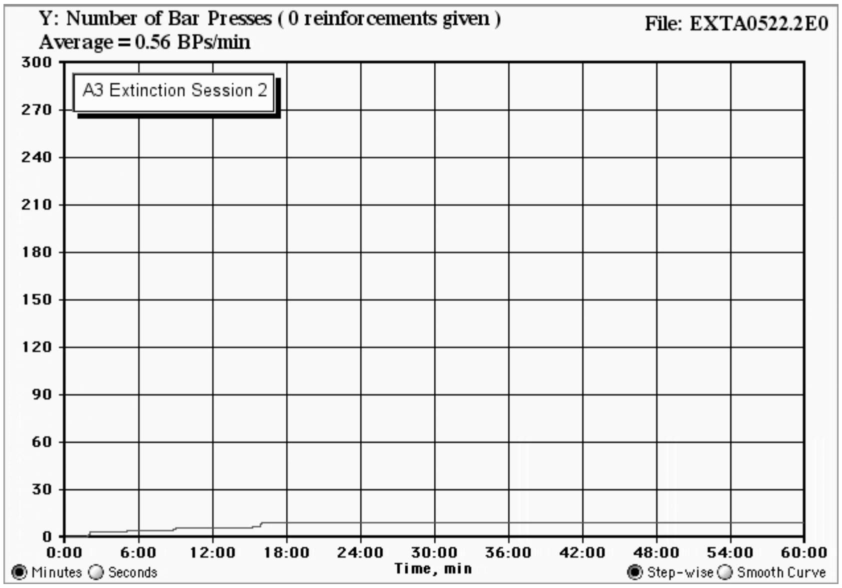
6:00
12:00
18:00
24:00
30:00
36:00
42:00
48:00
54:00
60:00
Time, min
● Minutes ○ Seconds
● Step-wise ○ Smooth Curve

11-1)


Y: Number of Bar Presses (0 reinforcements given)
Average = 0.56 BPs/min
File: EXTA0522.2E0
A3 Extinction Session 2
300
270
240
210
180
150
120
90
60
30
0
0:00
6:00
12:00
18:00
24:00
30:00
36:00
42:00
48:00
54:00
60:00
Time, min
● Minutes ○ Seconds
● Step-wise ○ Smooth Curve

11-2)

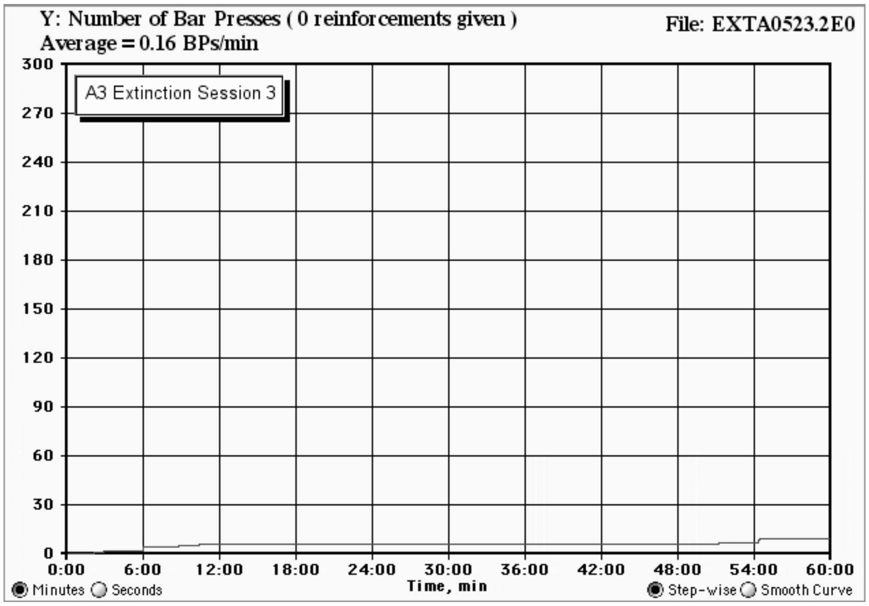
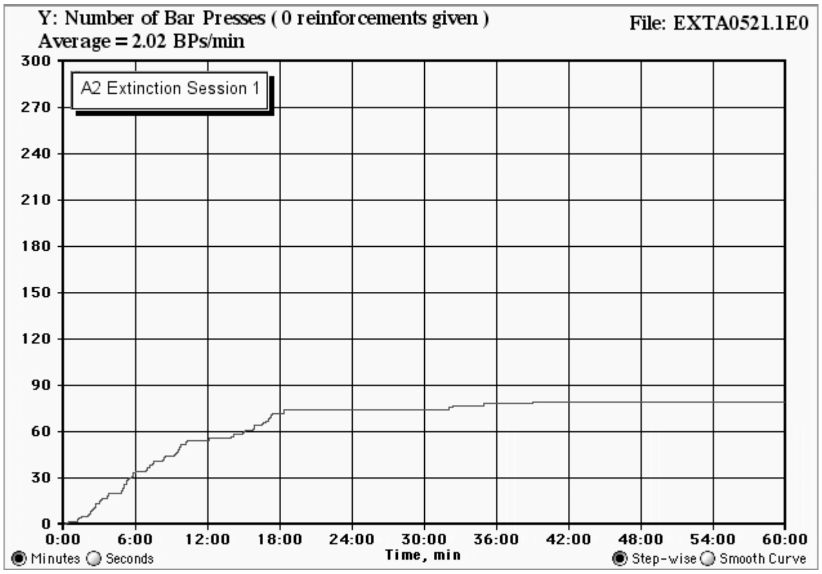
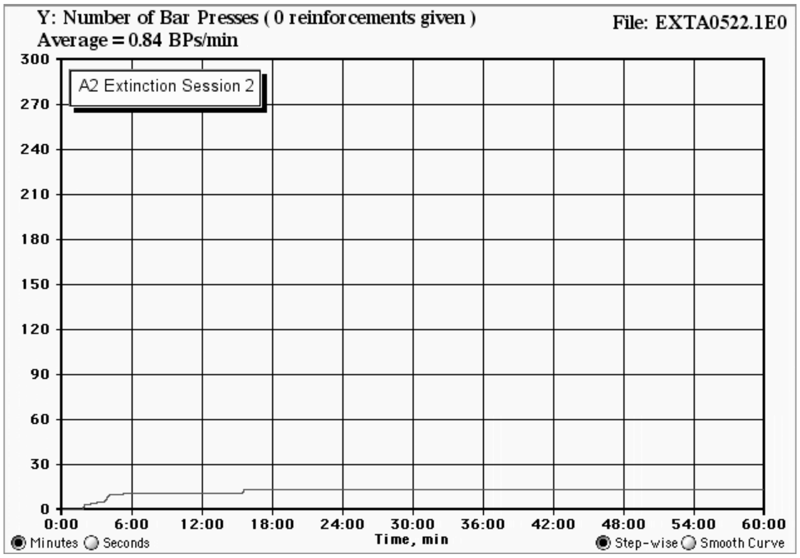
11-3) 

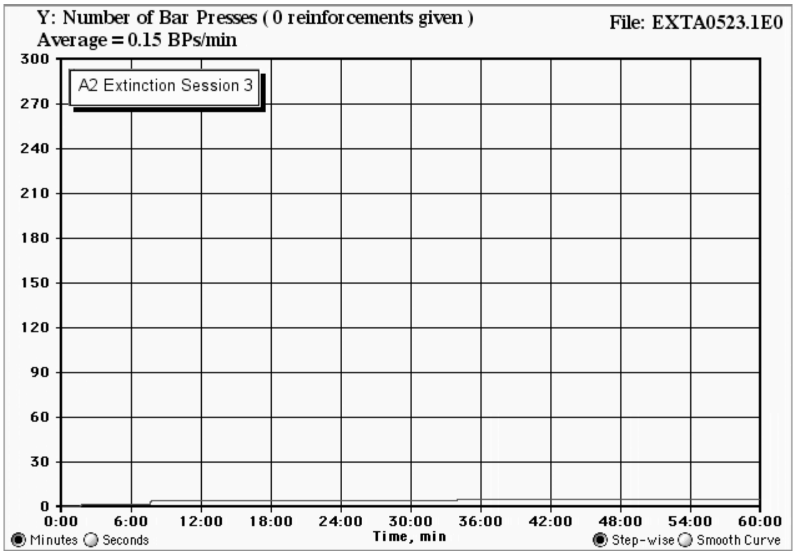
Figure 11. Animal A2's rate of bar-press responding during three successive days of CRRP exposure to 60-minute sessions of extinction conditions (no water available for bar-pressing or any other activity). Figure 11-1) illustrates the first day, 11-2) the second, and 11-3) the third successive day of extinction. Comparisons of this Figure to Figures 12 and 13 reflect live-animal between-subject variability in the parametrics of the extinction process.


Y: Number of Bar Presses (0 reinforcements given)
Average = 2.02 BPs/min
File: EXTA0521.1E0
A2 Extinction Session 1
300
270
240
210
180
150
120
90
60
30
0
0:00
6:00
12:00
18:00
24:00
30:00
36:00
42:00
48:00
54:00
60:00
Time, min
● Minutes ○ Seconds
● Step-wise ○ Smooth Curve

12-1)

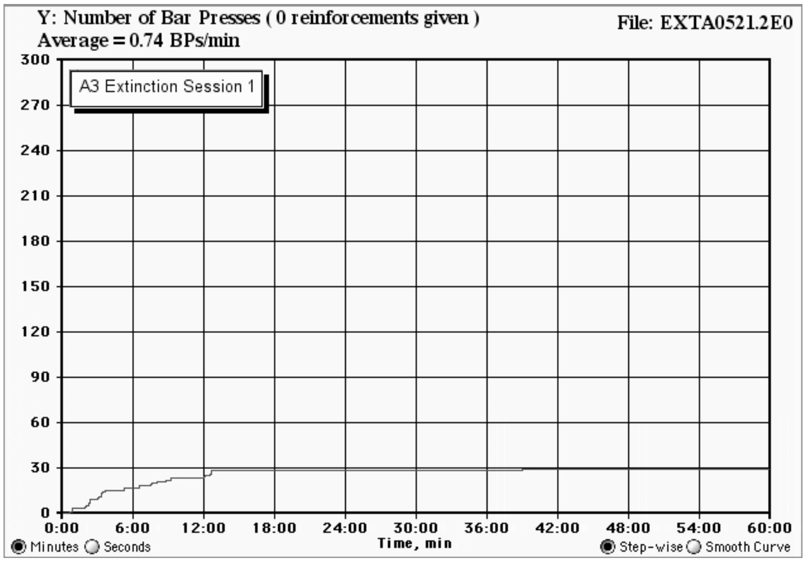

Y: Number of Bar Presses (0 reinforcements given)
Average = 0.84 BPs/min
File: EXTA0522.1E0
A2 Extinction Session 2
300
270
240
210
180
150
120
90
60
30
0
0:00
6:00
12:00
18:00
24:00
30:00
36:00
42:00
48:00
54:00
60:00
Time, min
● Minutes ○ Seconds
● Step-wise ○ Smooth Curve

12-2)

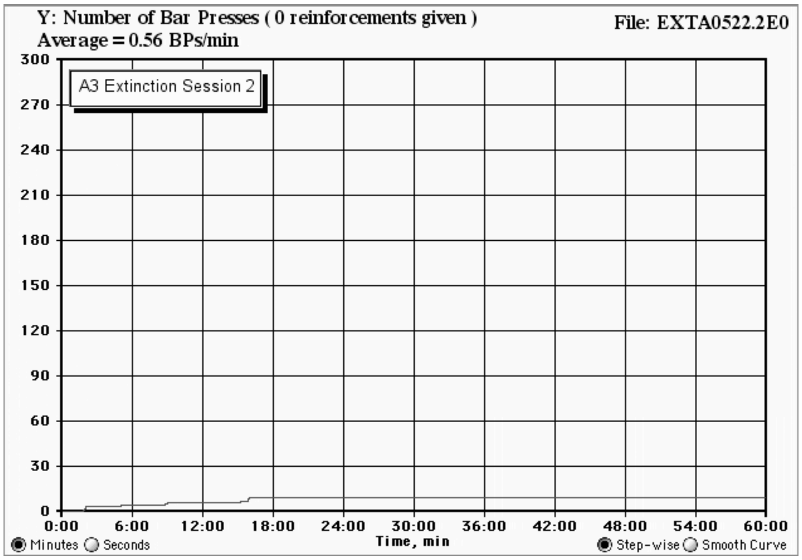


12-3)

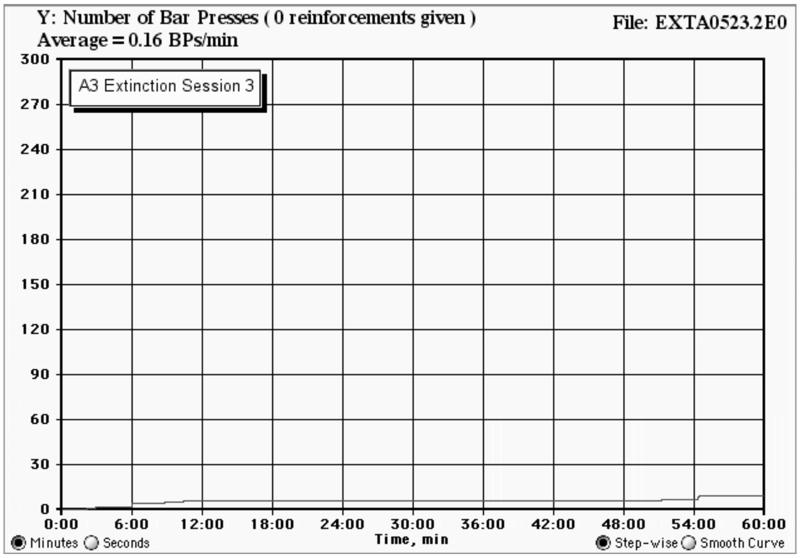
Figure 12. Animal A3's rate of bar-press responding during three successive days of CRRP exposure to 60-minute sessions of extinction conditions (no water available for bar-pressing or any other activity). Figure 12-1) illustrates the first day, 12-2) the second, and 12-3) the third successive day of extinction. Comparisons of this Figure to Figures 11 and 13 reflect live-animal between-subject variability in the parametrics of the extinction process.



13-1)

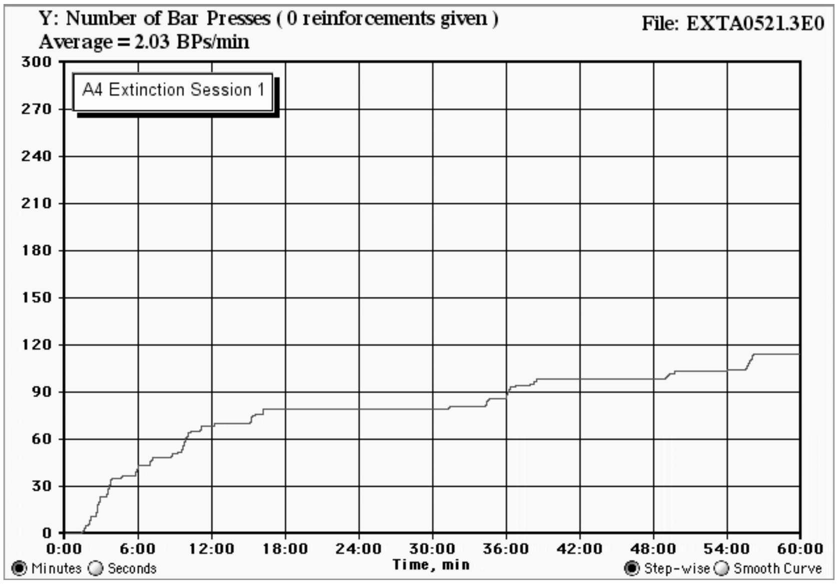


13-2)

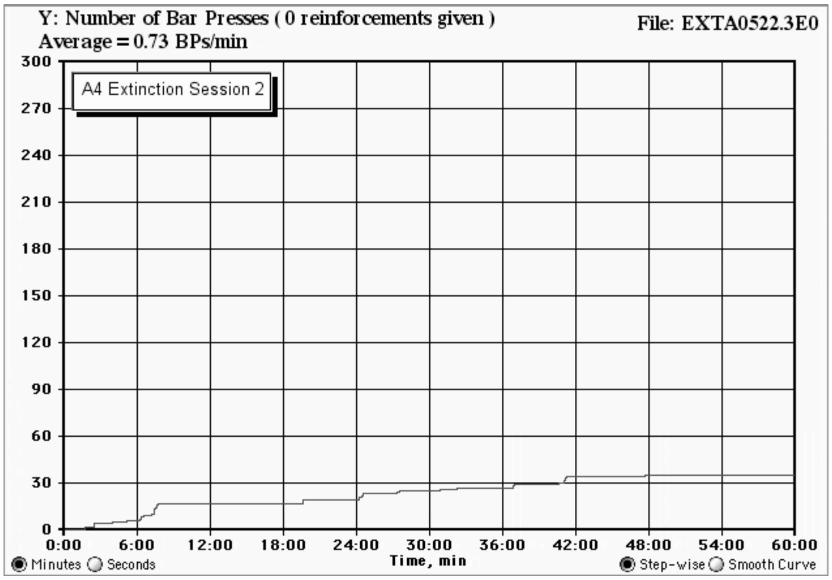


13-3)

Figure 13. Animal A4’s rate of bar-press responding during three successive days of CRRP exposure to 60 minute sessions of extinction conditions (no water available for bar-pressing or any other activity). Figure 13-1) illustrates the first day, 13-2) the second, and 13-3) the third successive day of extinction. Comparisons of this Figure to Figures 11 and 12 reflect live-animal between-subject variability in the parametrics of the extinction process.


Y: Number of Bar Presses (0 reinforcements given)
Average = 2.03 BPs/min
File: EXTA0521.3E0
A4 Extinction Session 1
300
270
240
210
180
150
120
90
60
30
0
0:00
6:00
12:00
18:00
24:00
30:00
36:00
42:00
48:00
54:00
60:00
Time, min
● Minutes ○ Seconds
● Step-wise ○ Smooth Curve

14-1)


Y: Number of Bar Presses (0 reinforcements given)
Average = 0.73 BPs/min
File: EXTA0522.3E0
A4 Extinction Session 2
300
270
240
210
180
150
120
90
60
30
0
0:00
6:00
12:00
18:00
24:00
30:00
36:00
42:00
48:00
54:00
60:00
Time, min
● Minutes ○ Seconds
● Step-wise ○ Smooth Curve

14-2)

14-3)

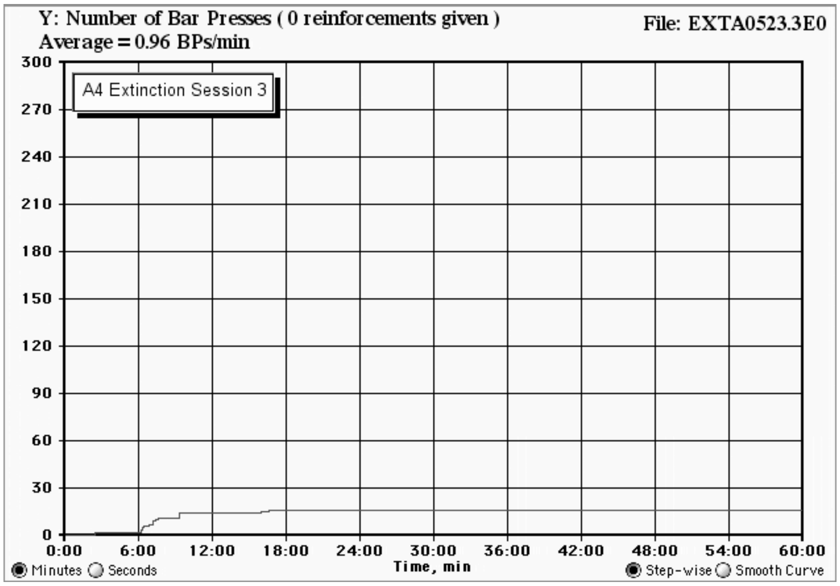
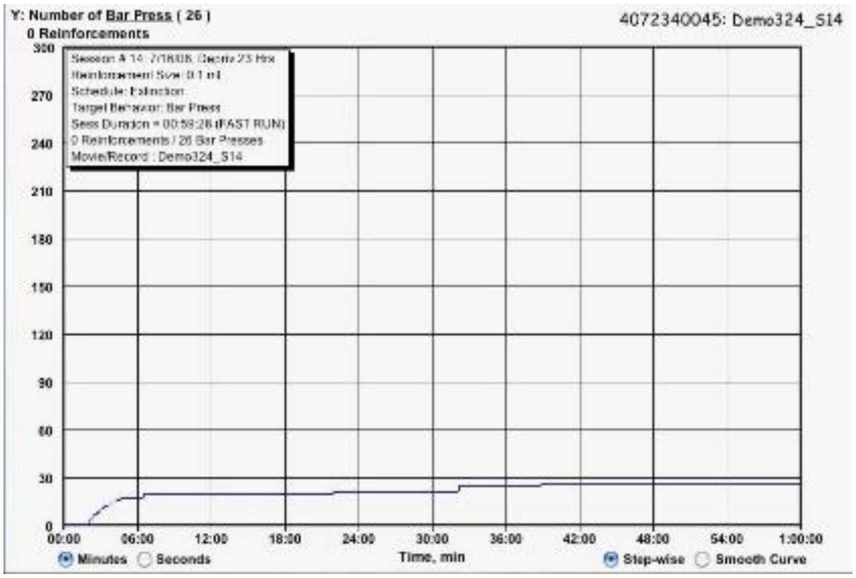


Figure 14. Illustration of first *CyberRat* animal Demo324's rate of bar-press responding during three successive 60-minute sessions (equivalents of days) of extinction Reinforcement-Rule settings (no water available for bar-pressing or any other activity). Figure 14-1) illustrates the first day, 14-2) the second, and 14-3) the third successive day of simulated extinction. Comparisons to Figures 11, 12, and 13 reflect how *CyberRat* simulations compare to live-animal data, while comparison to Figure 15 reflects a sample of between-subject variability in *CyberRat* simulations.

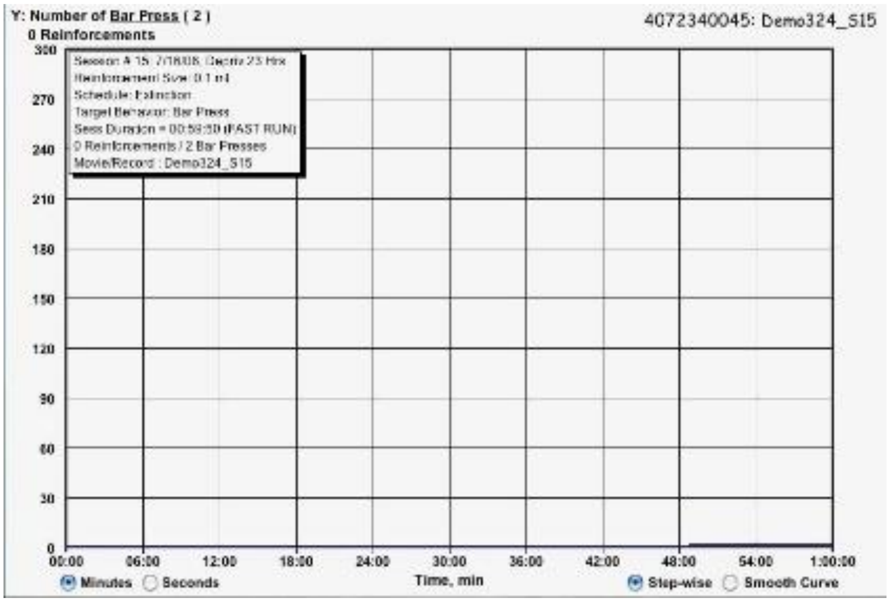
Session # 13: 7/18/08, Deprv 23 Hrs
Reinforcement Size: 0.1 ml
Schedule: Extinction
Target Behavior: Bar Press
Sess Duration = 00:58:34 (FAST RUN)
0 Reinforcements / 123 Bar Presses
Movie/Record : Demo324_S13

15-1)



Session # 14: 7/18/08, Deprv 23 Hrs
Reinforcement Size: 0.1 ml
Schedule: Extinction
Target Behavior: Bar Press
Sess Duration = 00:59:26 (FAST RUN)
0 Reinforcements / 26 Bar Presses
Movie/Record : Demo324_S14

15-2)



15-3)

Figure 15. Illustration of second *CyberRat* animal Demo284's rate of bar-press responding during three successive 60-minute sessions (equivalents of days) of extinction Reinforcement-Rule settings (no water available for bar-pressing or any other activity). Figure 15-1) illustrates the first day, 15-2) the second, and 15-3) the third successive day of simulated extinction. Comparisons to Figures 11, 12, and 13 reflect how *CyberRat* simulations compare to live-animal data, while comparison to Figure 14 reflects a sample of between-subject variability in *CyberRat* simulations.

Turing Test 2.4: Development of Discriminative Stimulus Functions

I have already described in detail how TEAB researchers long ago established that antecedent stimuli that signal consequential contingencies are in effect for specific behaviors will develop a contextual setting function called *stimulus discrimination*. This functional impact isolates high probabilities of the contingent behavior to that discriminative stimulus context or setting.

To study this phenomenon with *CyberRat* animals, one can set experiments to be conducted either with real-time video or in fast simulation mode while *CyberRat's* stimulus control (discrimination) schedules are set to various durations, for example to alternations of 60 sec S+ and 60 sec S-. This can be done under CRF or any intermittent reinforcement schedule that is well stabilized, such as a VR 10 reinforcement schedule. Experimenters need only to conduct approximately 20–25 sessions of 60 minutes duration each to develop a stable discrimination index across, say, five successive sessions. Stability criteria can be made a point of class discussion, but might, for example, be defined as +/- 5 percentage points around a

90% discrimination index value. Assigning such an experimental series was reported in Ray and Miraglia (2011), where students were requested to plot each successive session's discrimination index (a ratio of total bar-presses during S+ vs. total bar-presses for the entire session, which includes all S+ and S- periods) in a spreadsheet and then to graph the process's development curve. A typical outcome is illustrated in a figure reproduced from Ray and Miraglia's report (see Figure 16).

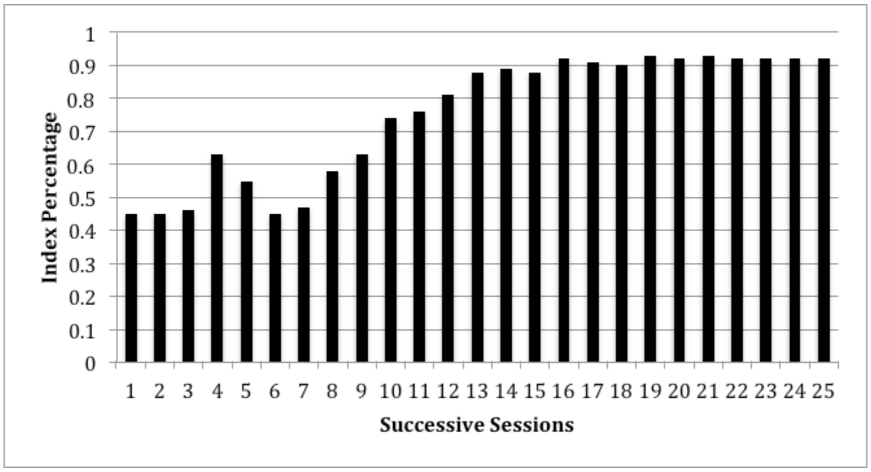


Figure 16. Discrimination Index plotted across a series of 25 successive sessions under an alternative 60 sec S+/S- stimulus discrimination schedule setting in *CyberRat*. (from Ray & Miraglia, 2011)

The development of this discriminative control function illustrated in Figure 16 will vary depending upon reinforcement schedules and individual animals. However, I have found that a graph of this index from *CyberRat* vs. a similar graph from live animals given this experience are likely to be quite difficult to distinguish from one another. As such, I propose that another Turing test is reasonably satisfied either on the phenomenological basis of directly observing the animal's full range of behaviors during a late discrimination session or on the basis of quantitative data plot comparisons. And this latter point holds regardless of whether the quantitative data are traditional session-based cumulative response records or graphs of derived measures, such as successive plots of discrimination indices. Likewise, a comparison of kinematic behavioral organizations within the S+ vs. S- will closely align with those depicted in Figure 5 if respective reinforcement conditions match those used by Ray and Brown (1975) to generate these results.

Operations Analysis of Interbehavioral Systems

In the previous section I used the automobile as an example to illustrate the marked difference between structural and functional analysis from the systems perspective. I also mentioned briefly that operational characteristics, such as how a car handles or what kind of total fuel efficiencies it accomplishes, would be further detailed in my subsequent section. This is that subsequent section. Operating characteristics of a system are best described as patterns of change or consistencies in a system's state across time. Thus, an automobile has quite different fuel efficiencies that can change from moment to moment depending upon how and where it is driven (e.g., city-based stop-and-go driving with many accelerations/ decelerations and associated frequent changes in gear ratios vs. highway driving at relative constant speed and in an "overdrive" transmission state).

If you add a relatively small amount of water to your car's gas tank you are likely to experience a lot of lurching or misfiring in the engine, which may also result in momentary "stalls." The normally smooth sequencing of piston-cylinder firing as an operating characteristic is being changed by these intermittent misfires on various cylinders, and you phenomenologically detect this change in operating characteristics. Of course, your mechanic has a machine that can monitor and diagnose such misfires by identifying both specific location and timing of each misfiring cylinder.

Add even a relatively small weight to a single wheel of your automobile to put that wheel somewhat out of balance and the normally smooth driving characteristics associated with well-balanced wheels will quickly change to a shaky or vibrating driving experience (plus a quick and uneven wearing of the tread on the tire that is out of balance). The high-speed rotational balancing machine often used for adjusting the balance of a wheel is actually a special-purpose monitor of a wheel's rotational operating characteristics. All of these examples illustrate a phenomenon that GST refers to as specific *operating characteristics* of your car. The phenomenological detections of these irregular or abnormal operating characteristics serve as important prompts for you to take your car to a garage for more formal diagnosis and repair before is stops operating altogether.

"Operations analysis" is a broad term in GST that encompasses several related, formalized disciplines that coalesced in the mid-twentieth century, including operations research (cf. Churchman, Ackoff, & Arnoff, 1957; Taha, 2011) and dynamical systems analysis (cf. Abraham & Shaw, 1992; Alligood, Sauer, & Yorke, 2000; Katok & Hasselblatt, 1996). Both of these fields use applications of time-sensitive mathematics. What distinguishes them is whether their time-series analyses are applied primarily (although not exclusively) to complex human decision making and management science (operations research) or trajectory predictions and chaos theory (dynamical systems). The one common element of all operations analysis is an emphasis on momentary states of a "controlled system" that subsequently change (or not) across time in somewhat predictable ways. Frequently, such changes occur because of built-in feedback or other self-influencing mechanisms (hence the description as a "controlled" system) incorporated into the system itself. Feedback and other internal control mechanisms typically generate some relatively coherent pattern in a time-series of successive measurements of that system's state. Several mathematical techniques for describing such patterns or their components are used by systems analysts, including power-spectral analysis and dynamical equation modeling (cf. Jagacinski & Flach, 2003; Powers, 1973).

At a very rudimentary level, Skinner was unwittingly one of the pioneers in the use of time-series measurement in the study of animal behavioral dynamics. Thus, one of Skinner's primary contributions to behavioral science was his strong reliance on a visual form of time-series measurement—the cumulative record (cf. Lejeune, Richelle, & Wearden, 2006). This contribution supported Skinner's emphasis on measuring response rates rather than accuracies (e.g., Skinner, 1950). Cumulative records track how a functional class of operant behavior (e.g., bar-pressing transformed into electrical switch closures) changes in rate of occurrence under various establishing and experimental circumstances such as intermittent schedules of reinforcement (e.g., Ferster & Skinner, 1957) or the discriminative settings already described. Of course, Skinner was not the first, nor the only, person to emphasize the use of rate measures of behavior (cf. Morris & Smith, 2004). Nevertheless, his insistence on the functionality of cumulative records and the emphasis they placed on rate of response is one of his major contributions to early psychological research (cf. Skinner, 1950).

Unfortunately, Skinner tended to emphasize only visual inspection of cumulative response records (cf. Ferster & Skinner, 1957). Thus, rate-change characteristics associated with various intermittent schedules of reinforcement, such as scalloping under fixed-interval schedules and break-run patterns observed under fixed ratio schedules, are widely cited time-series characteristics associated with Skinner's research. Skinner never formalized the mathematical analysis of changes in the rates depicted in his cumulative records (i.e., equations describing patterns of accelerations/decelerations), but more specialized areas of research on the time-series characteristics of responding using the TEAB methodology have been developed in research subsequent to Skinner's work. Notable examples exist mainly in the sub-field of TEAB called the *Quantitative Analysis of Behavior* (QAB), with some examples being Schneider's analysis of fixed-interval response characteristics (cf. Schneider, 1969), Strand's (2001) analysis of momentum and matching, as well as Nevins's work on behavioral momentum (cf. Nevin & Grace, 2000; Nevin, Mandell, & Atak, 1983). Historically, textbooks on TEAB rarely included such research in any significant detail, but recent publications suggest that this may eventually change (cf. Fisher, Piazza, & Roane, 2011).

As noted, from the GST point of view both TEAB's and QAB's emphases on cumulative records and single response classes to describe bar-pressing *rate changes* illustrate interests in the *operating characteristics* of an animal's bar-pressing. To investigate the consistency or changes of response rates under alternative experimental conditions (e.g., intermittent reinforcement schedules or the discriminative S+ and S- conditions cited earlier) is clearly an example of an experimenter's interest in operating characteristics as a function of external variations in attendant experimental conditions. Unfortunately, the history of TEAB has typically limited its focus on only a *single* functional response class—especially one defined by mechanically punctate events such as electro-mechanical switch closures. This focus fails to capture the broader organizational dynamics between various functional response classes and other behaviors attendant to those functional events, thus typically ignoring the operating characteristics of the larger organismic–environmental system as defined by the IBSA perspective.

An analysis of any system's operating characteristics emphasizes dynamic processes and state changes. As noted earlier, such an emphasis is grounded in a fundamental break from entity/substance philosophy in favor of process-focused philosophy (c.f., Browning & Myers, 1998; Hartshorne, 1971; Whitehead, 1925, 1948). Ray & Delprato (1989) offer some details of how this change from substance theory to process theory relates to Kantor's interbehavioral view of organism–environment interaction. Through many concrete and empirical examples, Ray and Delprato illustrate unique operations-oriented concepts such as behavioral velocity, pattern complexity/coherence, and circadian and ultradian rhythms in behavior. It is not my purpose to review these examples in the present context, but a few highlights relevant to *CyberRat* modeling need to be described to better understand what has been included in that model specifically.

Some Operations Analysis Experiments and *CyberRat's* Modeling

As I have noted previously, the Ray and Brown (1975, 1976) publications were among the first of which I am aware that investigated behavioral patterning and organization associated with rats habituating to their first exposure to an operant chamber. Unfortunately, the limited technologies available in the early 1970s required the use of behavioral sampling techniques that allowed only approximate calculations for behavioral sequences and associated unconditional/conditional behavioral probabilities. Durations for each successive behavior were not possible to calculate because behavioral occurrence and sequence within the "5-second observation/15-second recording" sampling windows that were used were the only parameters recorded. However, decreasing prices of video recording equipment in the latter part of the 1970s began to make continuous recording more accessible and affordable for researchers. Thus, Ray, Upson, and Henderson (1977) were able to study the temporal dynamics inherent in behavioral systemics with much higher degrees of temporal precision than earlier studies. The continuous recording techniques in this later study allowed us to focus on temporal operating characteristics in general behavioral kinematics. Thus, a new dimension was added to our research tactics that relied upon time-series data collection and analysis. Using this tactic revealed highly reliable and interdependent temporal patterns in various behavioral dynamics within various alternative setting conditions and across multiple 24-hour periods. Unfortunately, that series investigated highly trained rats under different schedules of discriminative stimulus control, but it did not investigate simple chamber habituation at all. Other data that Ray, Upson, and Henderson report were largely derived from observations of killer whales (*Orcinus orca*) living and working in captive oceanaria. As such, this publication provided no parametrics on time-series measures relevant to *CyberRat's* modeling of habituation behavior in operant chambers.

Thus, one of the first systematic observations we made during the CRRP focused on describing *operating* characteristics of changes in *interbehavioral structure* during pre-conditioning exposure of rats to an operant chamber—a process typically referred to as contextual habituation (cf. Churchill, Remington, & Siddle, 1987; Mitchell, Yin, & Nakamatsu, 1980). This portion of the CRRP research allowed us not only to establish parametric variations applicable to modeling *CyberRat's* general kinematics during habituation, it also allowed us to incorporate other important operating characteristics that were unique to any specific behavioral category as well, as will be illustrated below. In this stage of the CRRP we recorded behavioral observations using a relatively mid-grained behavioral category system similar to my previous studies (see Table 1).

Table 1. Behavioral coding taxonomy used in the CyberRat Research Project (CRRP) conducted to establish parametrics of behavioral kinematics during pre-experimental habituation sessions.

Behavior	Definition
bar press	Subject depresses the lever operandum sufficiently to trigger a monitoring light diode.
bar touch	Subject touches the lever operandum with nose or paw(s).
dipper entry	Subject breaks the plain of the dipper/wall barrier with nose.
object touch	Subject touches lights, top latch, or wall screws with nose or paw(s).
rest	Subject shows no movement, other than fibrissa, for sustained period (>3 seconds).
freeze	Subject shows no movement, including fibrissa, for sustained period (>3 seconds).
groom self	Subject licks self or paws, including movement of paws over nose.
bite self	Subject divides fur and bites at self during grooming.
scratch self	Subject uses hind foot to scratch self during grooming.
move	Subject moves at least one hind paw, thus changing locations and/or orientations in the chamber.
explore	Subject moves upper body, but not hind feet, thus changing orientations and/or levels in the chamber. One forepaw may be raised from the floor in this activity, but not both at the same time.
rear	Subject raises both forepaws off the floor in upright exploration, but remains fixed in the placement of both hindfeet.

The more *dynamic* tracking using time-series *operations analyses* tactics focused on more subtle kinematic changes across the session in this same habituation context. This analysis relied upon measurements of various behavioral kinematic parameters within each successive 5-minute window across each session for individual animals. Structural/organizational (i.e., kinematic) analysis of the last 5 minutes of behaving in the chamber was used to reflect the final adaptation that occurs when referenced against a similar analysis of the first 5 minutes of behaving in the chamber, while the interceding kinematics reflect the transitional dynamics of this adaptive process. This implies, of course, an assertion that habituation is one form of *functional* adaptation as systems theorists view the adaptive process. And the first *operating characteristics* modeled by *CyberRat* that will be detailed are those time-series dynamics we found to be associated with this adaptive habituation process.

The Third Series of Turing Tests: Operating Characteristics and Time Series Dynamics Simulated in *CyberRat*

The kinematic flowchart resulting from a structural/kinematic analysis determined from behaviors occurring across the entire habituation period (i.e., each of the complete 30-min sessions combined with one another) assessed during the CRRP is depicted in Figure 17. For simplification, this Figure includes only the higher probability paths of behavioral organization and thus leaves out all conditional probabilities with less than .05 values.

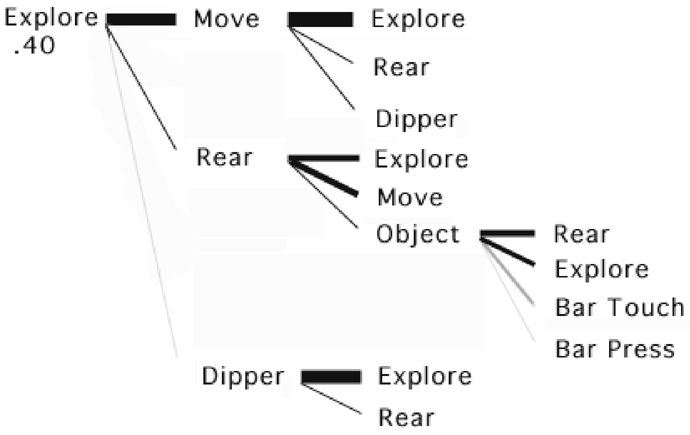


Figure 17. Kinematic flow diagram depicting a composite average of three separate live animals from the *CyberRat* Research Project (CRRP) across their first "habituation" session in an operant chamber. Habituation involves no external stimulus manipulations by the experimenter other than the setting change. No water is available to the animal during such sessions. In this flow diagram, arrow widths are proportional to the conditional probabilities for each type of

> sequence. To make the diagram simpler, all types of behavior sequences with less than .05 probability have been removed. These data were used to determine approximate "seed" values for *CyberRat's* original kinematic matrix, but each first had to be adapted to the more complex coding categories used to classify clips comprising the simulation.

The most frequently occurring behavior illustrated in this Figure is **Exploring**, which accounts for 40% of all initiated behaviors for the entire 30-minute session. From **Exploring** behaviors, subjects subsequently engage in **Move** with a .43 probability, followed by **Rearing** and **Dipper Entry** each at approximately .10 probability. From **Move** and **Rear**, the animals are most likely to return to **Exploring**, with a .94 probability of ***Move→Explore*** and approximately .40 probability of **Rear→Explore**. Approximately 90% of all sequences involve these three behaviors. As noted previously, these data were used to seed the initial behavioral kinematics in our modeling of habituation and all pre-training video reconstructions in *CyberRat V2.0*. But we also incorporated dynamic characteristics not yet described—dynamics reflected in specific behavioral *unconditional* probabilities as those probabilities change across habituation sessions for each category of behavior. So let me now consider how realistically *CyberRat* models the dynamics of those category-specific behavioral operating characteristics we found from the CRRP project.

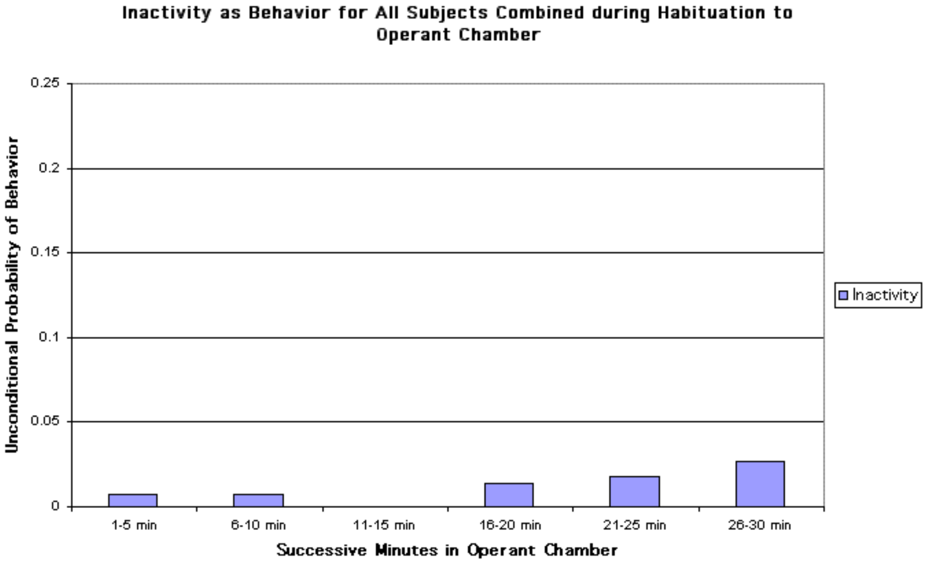
Turing Test 3.1: Kinematic Dynamics Across the Process of Habituation

To explore the operating characteristics of specific categories of behavior and how each of their associated probabilities may change across the habituation session in the CRRP, we combined selected behavior categories to create a more "macro-level" of description (cf. Ray, Upson, & Henderson, 1977). We collapsed the initial coding categories described in Table 1 into new macro-behavioral categories comprised of *functionally* related groupings as follows:

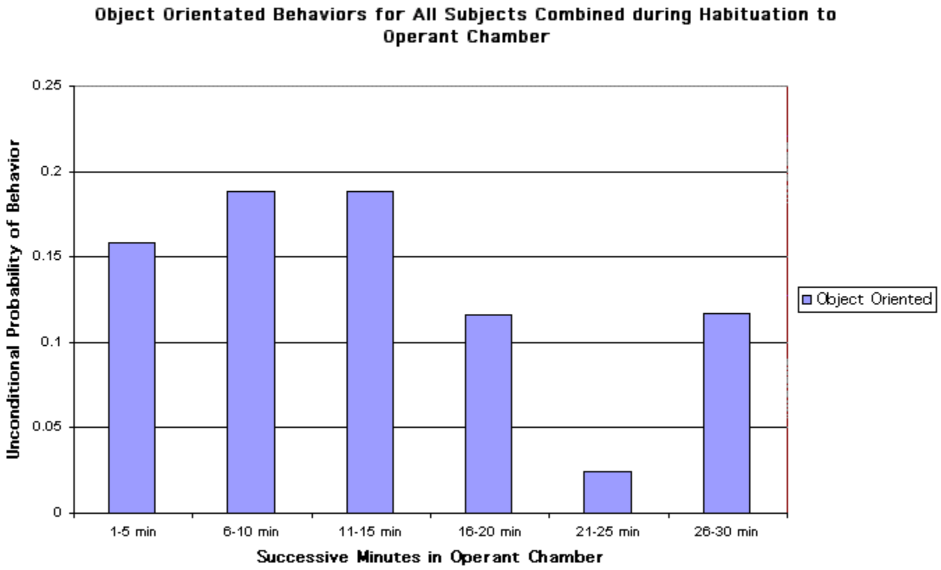
Inactive Behavior (rest and freeze)
Object-Oriented Behaviors (bar press, bar touch, dipper entry, and object touch)
Self-Oriented Behaviors (groom self, bite self, scratch self)
Spatially-Oriented Behaviors (move, explore, and rear)

Figure 18 illustrates temporal changes in the *unconditional probability* for each of these four macro-categories across each successive 5-minute window of a 30-minute habituation session for three subjects combined. These unconditional probability graphs illustrate that subtle but systematic temporal changes occur in some behavioral probabilities across the duration of a single habituation session. For example, the graphs reveal relatively high probabilities of object-directed behavior early in the habituation session, and these probabilities increase up to approximately mid-session. At this time self-directed behaviors, having gradually increased until minutes 16–20, become more probable, then afterwards decline. At the same time, spatially-directed behavior is maintained at a high probability throughout most of the session, but with a noted increase at the end of the session. Inactive behavior increases in probability gradually during only the latter half of the habituation session.

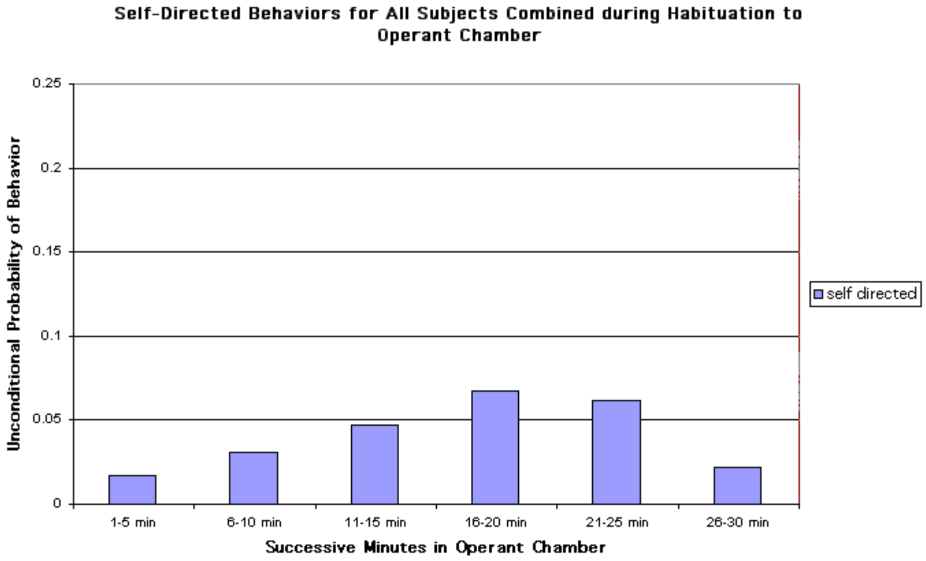
a)



b)


Object Orientated Behaviors for All Subjects Combined during Habituation to Operant Chamber
Unconditional Probability of Behavior
0.25
0.2
0.15
0.1
0.05
0
1-5 min
6-10 min
11-15 min
16-20 min
21-25 min
26-30 min
Successive Minutes in Operant Chamber
Object Oriented

c)


Self-Directed Behaviors for All Subjects Combined during Habituation to Operant Chamber
Unconditional Probability of Behavior
0.25
0.2
0.15
0.1
0.05
0
1-5 min
6-10 min
11-15 min
16-20 min
21-25 min
26-30 min
Successive Minutes in Operant Chamber
self directed

d)

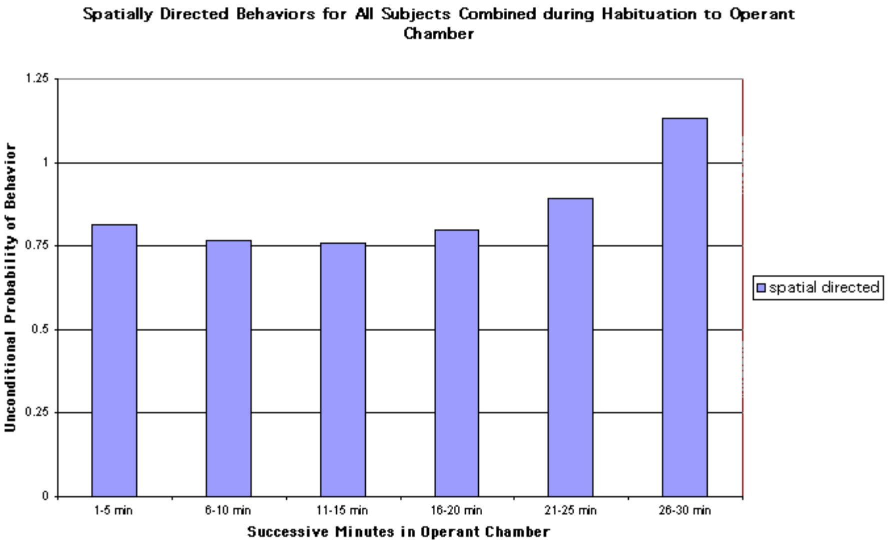
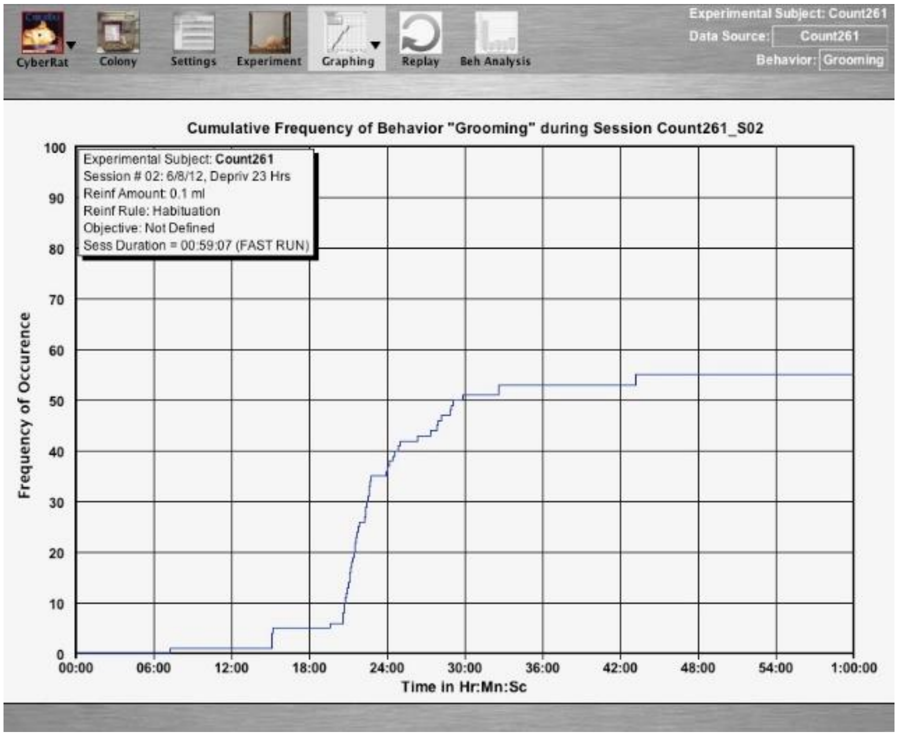


Figure 18. Time-series plots from the *CyberRat* Research Project (CRRP) across successive 5-minute windows depicting unconditional probabilities for 18-a) Inactive Behaviors, 18-b) Object-Oriented Behaviors, 18-c) Self-Directed Behaviors, and 18-d) Spatial-Orientation Behaviors for all three live animals combined during pre-training Habituation exposure to the operant chamber.

If an experimenter conducts a single 60-minute habituation session in *CyberRat* and uses a coding scheme comparable to the macro codings that were applied in the CRRP, a very similar graph will be obtained. But *CyberRat* allows one to generate graphs even without direct observational coding for a few micro-level categories of behavior. The behaviors that are auto-tracked in *CyberRat* are based upon their special focal interest (e.g., visits to the water dipper or self-grooming) or their potential as shaping objectives (e.g., turning in tight circles). As noted, these categories may be graphed as cumulative records without requiring the labor and time associated with systematic observation-based coding of each category.

One example of the realistic modeling of a single category's operating characteristics is *CyberRat's* reliable reproduction of the mid-session concentration of grooming as documented in the CRRP and illustrated in Figure 19, which is a different animal but a near-perfect reproduction of an equivalent *CyberRat* experiment reported in Ray and Miraglia (2011). *CyberRat* reproduces the systematic time-series variations in this behavior category's dynamics with sufficient fidelity to warrant the assertion that *CyberRat* would likely pass a Turing test for this particular operating characteristic, as it is likely to do for other specific behaviors as well. However, there is one associated interbehavioral dynamic associated with habituation that is not reproduced by *CyberRat* and thus deserves explanatory comment. That dynamic is the general rate of change from behavior-to-behavior throughout entire sessions—a time-series measure best described as *behavioral velocity*.



Experimental Subject: Count261
Data Source: Count261
Behavior: Grooming

Experimental Subject: **Count261**
Session # 02: 6/8/12, Depriv 23 Hrs
Reinf Amount: 0.1 ml
Reinf Rule: Habituation
Objective: Not Defined
Sess Duration = 00:59:07 (FAST RUN)

Figure 19. Sample of *CyberRat* data illustrating typical second-quarter-of-session concentrations of occurrences for Grooming events across a 60-minute Habituation session graphed as a traditional cumulative record but with the Y axis set to 100 events maximum to amplify lower-frequency events.

Behavioral Velocity during Habituation. Ray and Brown (1975) first introduced the idea of measuring the rate at which all behaviors change from category to category throughout the kinematic flow and regardless of which specific behaviors are involved in each successive change in behavior. Over the years I have referred to this measure as either "behavioral flow rate" (Ray & Brown, 1975) or "behavioral velocity" (Ray & Delprato, 1989). In essence, the measure is an inverse reflection of the *generalized* durations of all behaviors considered collectively. When behavioral velocity is high, most behaviors are relatively short in duration. When behavioral velocity is low, many, if not most, behaviors tend to be longer in duration. Selective behaviors can impact this general measure, of course. For example, grooming tends to be much longer in duration than movements from place to place. As each category of behavior changes in relative frequency and duration, general behavioral velocity will reflect such changes as a more global and integrated measure than will each specific behavior category's measures (Ray, Upson, & Henderson, 1977).

The general behavioral velocity averaged across all three subjects in the CRRP was calculated for each successive 5-minute window across the entire habituation session. Results of this analysis are depicted in Figure 20, where one can see a gradual and systematic decline of nearly 50% in the rate of change from behavior to behavior up until the last 5-minute period, at which time behavioral velocity begins to increase again. As noted in the previous section, this is due largely to the fact that the animals are increasing spatial exploration during this last windowed period, and such behaviors are typically of shorter duration than self-directed behaviors such as grooming and resting.

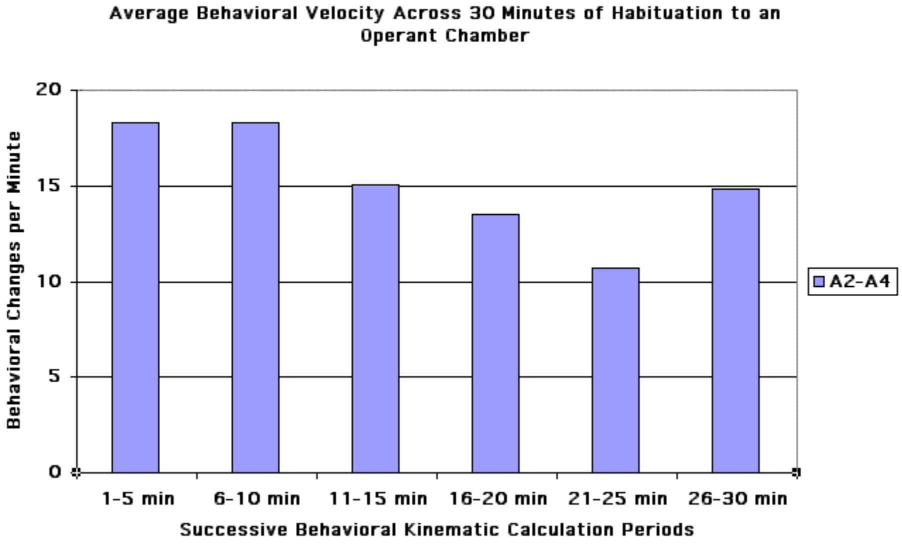


Figure 20. Data from the *CyberRat* Research Project (CRRP) plotted as a time-series across successive 5-minute windows depicting average behavioral velocity across three live animals during 30 minutes of a pre-training Habituation exposure to the operant chamber.

Unfortunately, the generalized behavioral velocity just described is one parameter that could *not* be incorporated into *CyberRat*. This is largely because *CyberRat* uses a random selection from any given sample of video clips representing each behavioral category in the *CyberRat* corpus. *CyberRat* includes various numbers of video illustrations for its different categorical events, even though such behaviors must include similar context and orientation. For example, there is a very large variety of bar-pressing clips to allow the topography of bar-pressing to vary and/or to become stereotyped across reinforcement patterns. This gives the constructed video play a sufficient variety of selections to make repeated clips hardly noticeable even when kinematic patterns are, themselves, relatively stereotyped. But most clips representing any given category, whether bar-pressing or any other behavior, are of relatively similar durations. But even if such clips were dramatically different in duration, random selection from each categorical sample means that rhythmic variations in duration *within a given category* or in general velocity *across windows of time* are not likely to occur in *CyberRat* simulation-generated data. As such, behavioral patterns in *CyberRat* do not typically reflect systematic changes in generalized behavioral velocity.

Nevertheless, where possible *CyberRat* does use some event self-repetitions to artificially extend durations of some behavior categories at appropriate times during a session, especially for creating multiple and/or rapid-rate bar-press "bouts" and for extending "resting" periods involving little to no movement. It is from this latter case that late-session increases in probabilities of *inactivity* (see Figure 18a) are possible in *CyberRat*. But resting does not occur as reliably and systematically as in many real-animal observations.

From research on real animals (Ray, Upson, & Henderson, 1977) we know that, especially in settings that do not incorporate reinforcement dynamics (such as S- conditions, where no reinforcement contingencies exist in discrimination experiments), general behavioral velocity is largely a function of the rate of alternating setting conditions (i.e., rates of changing from one contextual stimulus state to another, e.g., S+ / S- changes). Rapid changes in environment can result in dramatic perturbations in moment-to-moment behavioral velocity when S- first begins, but these perturbations are typically followed by damped oscillations in that velocity (see Figure 21). As with my previous example of limitations in simulating behavioral velocity, both the random sampling and the homogeneity of durations of clips that represent the same behaviors make it nearly impossible to accurately model transitional perturbation/decay dynamics of behavioral velocity resulting from changes in the durations of alternating discriminative settings. Thus, no effort was made to incorporate such dynamics into *CyberRat's* simulations.

This is an instance where the interbehavioral systems descriptive methodology clearly outpaces *CyberRat's* ability to incorporate real data into its video-driven modeling of complex behavioral dynamics. But one could, with sufficient investments of time and effort, overcome this shortcoming by using a much larger sample of clips depicting each behavioral category and by sorting clips into sub-classifications based on varying durations. This would allow algorithms to then specify whether long, medium, or shorter durations for a given category is to be selected dependent upon the current algorithm-driven velocity requirements. So this issue is more of a practical limitation rather than a shortcoming of IBSA methodology *per se*.

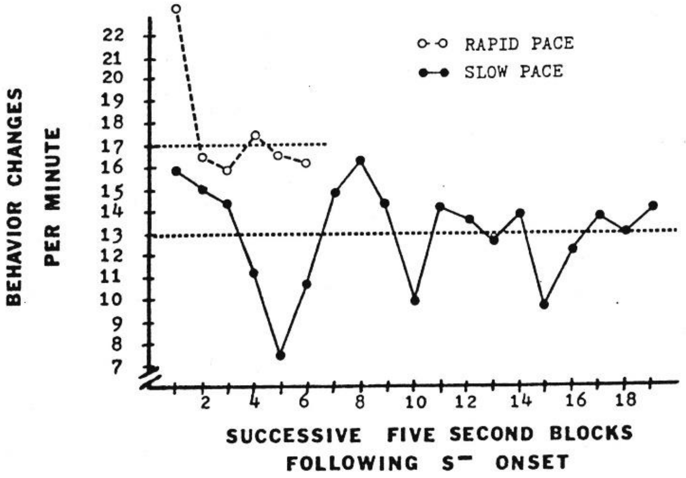


Figure 21. Figure from Ray, Upson, and Henderson (1977) depicting mean changes in behavioral velocity during each successive 5-second window following S- (house-light "off") onsets and continuing until the mean S+ (house-lights "on") onset. Data are from a response-contingent group of animals highly trained for stimulus discrimination and depicted changes are for the combined final two sessions of rapid S+/S- alternation pacing vs. slow S+/S- alternation pacing.

Other Operating Characteristics Modeled in CyberRat. The coding system used in the CRRP was also used for our initial identification of *CyberRat*'s potential video clips. As noted previously, in *CyberRat* the animal's directional orientation and physical location within the chamber were also taken into account for eventual clip edit-selection and sequential integration. Thus, after our initial identification of potential clips, a more micro-level coding system using relatively fine-grained, field-specific criteria was used to select clips in the new and improved digital video corpus for *CyberRat V2.0*. Of course, such micro-level accounts must coincide with reconstructions of macro-categories with respect to the previously described operating characteristics in macro-behavioral parametrics *and* patterns. This is made possible by the fact that within *CyberRat* micro-level categories are all related by higher-order macro-level categories like those used in the CRRP.

This ability to translate from lower-level categories to more globally-focused higher-level categories is one of the explicit properties of hierarchically-defined subsystems within systems theory, and the phenomenon was illustrated in detail by

Ray and Delprato (1989). As such, *CyberRat*'s Multi-Behavior Analysis component introduced earlier (see p. 245) incorporates algorithms that can, with *reasonable approximations*, translate any video transcript archive of any session into relatively accurate macro-codings similar to the macro system used in our CRRP project. This is also the mechanism for a feature in *CyberRat* that allows users to graph cumulative records for several specific macro categories of behavior across the duration of any session—as was illustrated for grooming in Figure 19. This allows users to explore each incorporated macro-category's operating characteristics across any given session.

But in addition to the "structural" hierarchical translations described above, unique to *CyberRat*'s modeling is its incorporation of macro-category-specific "rhythms" in the changing probabilities of individual macro categories of behaviors (thereby impacting the probability of use for each associated micro-level clip within the corpus). These rhythms were generally designed to model temporal patterns of specific temporal behavior probability dynamics depicted in Figure 18. Thus, early in a session each animal in *CyberRat* is more likely to consistently explore and move about the chamber than it is to self-groom/scratch. And as I reported in a previous section, grooming categories are much more likely to occur during the mid to latter portions of a typical 30-minute session than in early or the very last portions of such a session (Figure 18c). Of course, the interplay between such independent rhythms results in a complex and varying reproduction, which reflects normal variances in mean *probability* values of any given macro-behavior family. Thus, the temporal dynamics revealed in such behaviorally-specific cumulative response records as the one discussed earlier depicting how grooming occurrences were distributed throughout a session of habituation are also reproduced in *CyberRat's* modeling. But *CyberRat* was also designed especially for student learning where live-animal laboratories are no longer available (cf. Ray & Miraglia, 2011). Because most of the courses that would rely upon such laboratories are teaching TEAB principles, the primary behavior *CyberRat* uses to reflect such temporal behavioral operating dynamics as they are impacted by intermittent reinforcement dynamics is the category of bar-pressing.

Thus, in *CyberRat's* modeling we focused especially, but certainly not exclusively, on the singular-response class of bar-pressing and its associated cumulative response dynamics. In sections that follow I will review parametric data produced especially during the CRRP and its focus on bar-press operating characteristics under various intermittent schedules of bar-press reinforcement. In addition to our own CRRP research, Dr. Paul K. Brandon at Mankato State University in Minnesota also graciously conducted many experimental sessions with rats to generate cumulative response data comparisons and guidance in our development of simulations that matched real-animal data. These data were crucial in achieving *CyberRat's* realistic modeling of associated temporal operating characteristics in bar-press rates. As such, traditionally defined operant/respondent conditioning dynamics will be the main focus of the remainder of my presentation. Most of these dynamics required new parametric investigations via the CRRP and Dr. Brandon's efforts to allow detailed modeling, as many phenomena described in typical behavioral analytic publications rely upon pigeons and rats under food deprivation.

As noted earlier, few extant publications used the specific combination of rats bar-pressing and the use of water deprivation and water reinforcement. Further, many well-known phenomena we included in our model are only described as a sort of laboratory folklore or art, such as magazine training and response-shaping dynamics. Some of our required investigations were simple to carry out, while others required many sessions and complex manipulations. But readers should not lose sight of the fact that when *CyberRat* models bar-pressing, the video reconstructions in *CyberRat* also require a faithful reproduction of *all non-bar-pressing behaviors* that fill the temporal and spatial gaps between each bar-press. I will begin reviewing some challenges of this reproduction process by detailing our research on a singular dynamic involving short-term operating characteristics of behaviors that precede bar-pressing at the very beginning of any new experimental session—a specific habituation-to-setting-change phenomenon we refer to as "warm-up" dynamics.

Turing Test 3.2: Setting Changes and Bar-Press "Warm-up" Dynamics

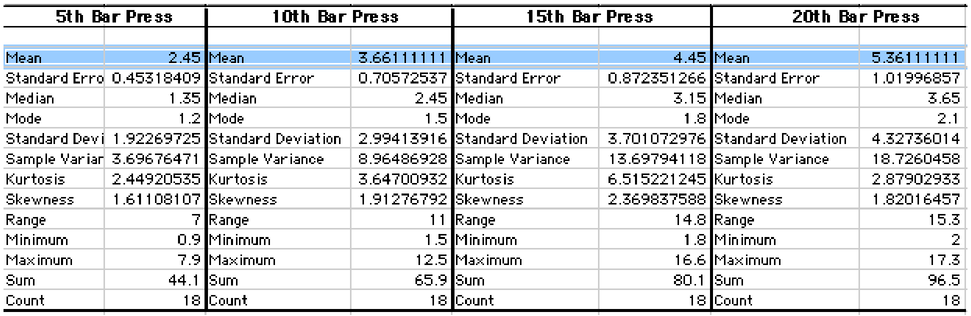
With perhaps the exception of studies reported by Ray, Upson, and Henderson (1977), there appears to be little systematic research available on complex behavioral dynamics associated with individuals—whether human or non-human—habituating to a change in contextual settings. As our 1977 paper reported, when organisms experience a change from one setting to another there is a "perturbation and settling" period typically involved that precedes the organism's engaging directly in behavior patterns more common or appropriate for the new setting. Even without prior study of the process, readers will likely recognize the phenomenon. Think back to the last time you entered a room where people were in the process of being seated in anticipation of the start of a class, a presentation/lecture, or a meeting. How quickly and with what difficulty is everyone's attention focused on starting the meeting? A relative few appear to be ready at once, while others continue conversations and/or are taking out notepads, laptop computers, etc. This process persists for quite some time, even after the teacher, speaker, or moderator has begun to start "calling the class/meeting to order."

It is much the same with rats—including individual rats being moved from home cages to previously-experienced operant chambers for new experimental sessions. Thus, well after a rat has been trained to bar-press reliably and consistently, any new session that involves moving that rat or changing the discriminative ambient lighting conditions imposes a contextual setting change on the animal. As with most such setting changes, the act of moving even a deprived animal from home cage to the operant chamber will result in an immediate period of exploration, movement, rearing, and other "settling" behaviors—including an isolated press/drink now and then, that precedes the animal becoming focused more exclusively on bar-pressing at a relatively steady rate. To differentiate this form of habituation from the pre-training or full-session habituation, I will refer to this much more brief habituation period as a pre-bar-press "warm-up" period and, as with most real-world parametrics modeled in *CyberRat*, no publications on the phenomenon were found that were suitable for informing our simulations of the process.

So in the CRRP we subsequently trained the same three animals we had used for the pre-training habituation research reported earlier to press a lever for continuous reinforcement. After they were trained, we especially focused on the dynamics leading up to reliable and consistent rates of bar-pressing within and across successive sessions for each animal. Descriptive statistics for these data are depicted in Table 2.

This table reveals a collective across-animal mean of 2.5 minutes for the animals to press the bar 5 times, a mean of 3.7 minutes to press 10 times, a mean of 4.5 minutes to press 15 times, and finally a mean of 5.3 minutes (standard deviation of 4.3 minutes) to reach their 20th press. Inspection of individual plots revealed two or three “outliers” at the 20th press that tend to inflate the “average time to reach 20 presses.” Thus, we deemed the median to be a better representative of the true 20-press warm-up time (3.65 minutes), and *CyberRat* animals reflect similar warm-up habituation dynamics that realistically vary from session to session.

Table 2. Descriptive statistics for the number of minutes elapsed after animals were placed into the operant chamber and prior to 5th, 10th, 15th, and 20th bar-press. Values are composited across three animals investigated in the CyberRat Research Project (CRRP) and establish the mean and median values for typical “warm-up” habituation prior to sustained bar-pressing.



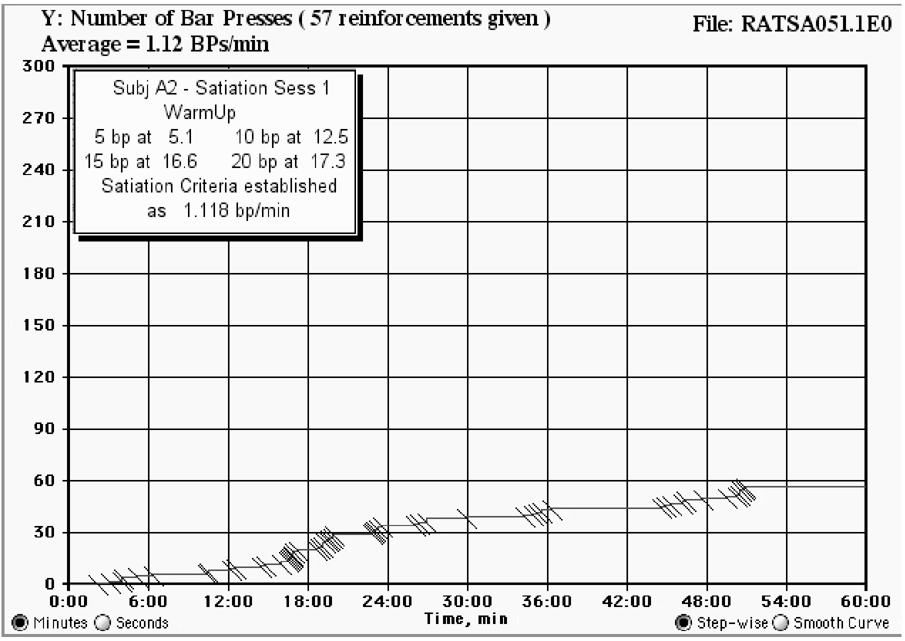
5th Bar Press		10th Bar Press		15th Bar Press		20th Bar Press	
Mean	2.45	Mean	3.66111111	Mean	4.45	Mean	5.36111111
Standard Erro	0.45318409	Standard Error	0.70572537	Standard Error	0.872351266	Standard Error	1.01996857
Median	1.35	Median	2.45	Median	3.15	Median	3.65
Mode	1.2	Mode	1.5	Mode	1.8	Mode	2.1
Standard Devi	1.92269725	Standard Deviation	2.99413916	Standard Deviation	3.701072976	Standard Deviation	4.32736014
Sample Variar	3.69676471	Sample Variance	8.96486928	Sample Variance	13.69794118	Sample Variance	18.7260458
Kurtosis	2.44920535	Kurtosis	3.64700932	Kurtosis	6.515221245	Kurtosis	2.87902933
Skewness	1.61108107	Skewness	1.91276792	Skewness	2.369837588	Skewness	1.82016457
Range	7	Range	11	Range	14.8	Range	15.3
Minimum	0.9	Minimum	1.5	Minimum	1.8	Minimum	2
Maximum	7.9	Maximum	12.5	Maximum	16.6	Maximum	17.3
Sum	44.1	Sum	65.9	Sum	80.1	Sum	96.5
Count	18	Count	18	Count	18	Count	18

Turing Test 3.3: Water Deprivation, Satiation, and Bar-Pressing Dynamics

Skinner (1938) was one of the first to report that animals repeatedly exposed to the pairing of primary reinforcement such as food or water (in Skinner's case food), with the sound of a mechanical delivery device (the delivery *magazine* described earlier) was sufficient to train rats to press levers under conditions of only the magazine sound as reinforcement. Whether this was a demonstration of conditioned reinforcement or something else, it raises the question as to whether some amount of bar-pressing in trained animals might persist even though the animals were not deprived of the primary reinforcement stimulus (e.g., water) used in their training or testing. We found no published parametric data regarding the rate at which rats would press levers if they had not been deprived of water prior to the experimental session where water continued to be available as a consequential stimulus. Likewise, there were no studies we discovered on how quickly rats might reach any reasonably-defined satiety level when pressing under continuous or intermittent water reinforcement after they had been fully deprived of water prior to the experimental session.

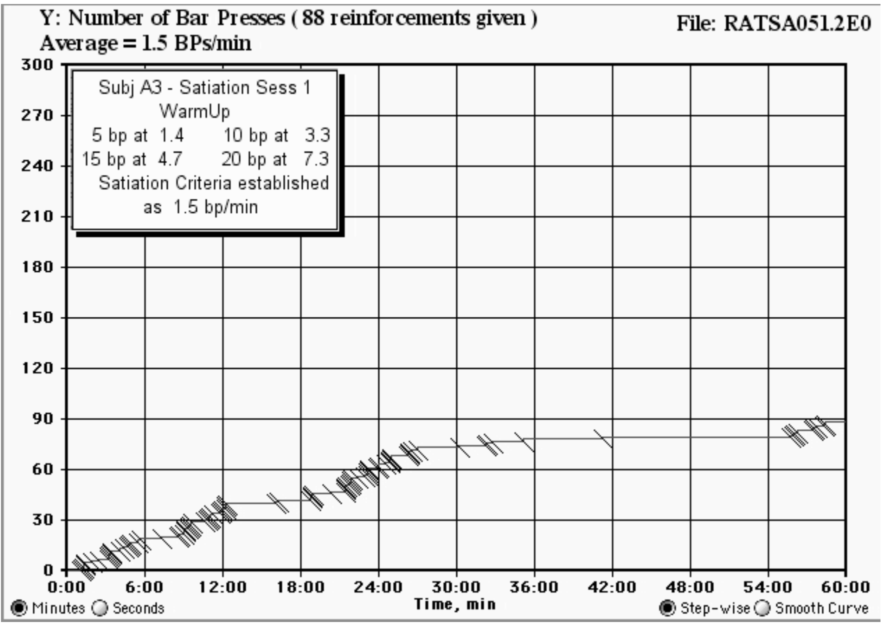
The CRRP project thus set out to determine parametrics both for pressing rates during sessions involving pre-session *ad-libitum* water availability (no deprivation) and dynamics for the development of satiation under continuous reinforcement (CRF) when animals were pre-session deprived for 22.5 hours. One post-training test session of 60 minutes' duration established a benchmark post-satiety bar-press rate for comparing same-animal press rates in sessions where no pre-session water deprivation had been imposed. For this evaluation series, the same three animals that by now had experienced prior sessions involving CRF and variable ratio (VR) schedules were removed from their normal deprivation schedules for several weeks before conducting a pre-session satiation bar-pressing test session. For one entire test day each subject remained on *ad-libitum* water availability in the home cage but was subsequently placed in an operant chamber with continuous water reinforcement (CRF) available for bar-pressing across a 1-hour evaluation session.

As illustrated in Figure 22, despite being maintained on an *ad-libitum* schedule of water access, all three animals pressed the bar approximately 60 to 90 times across their respective 1-hour session. They also typically consumed the water that was delivered for each press. Each of the three subjects' average bar-press rates, plus the time elapsed until the 5th, 10th, 15th, and 20th bar-press (warm-up period) are also reflected in the insert-notes included in each graph. These graphs were generated by specially-written software that analyzed and reported these parameters as we continued to probe various unknown factors in the CRRP.



Subj A2 - Satiation Sess 1
WarmUp
5 bp at 5.1 10 bp at 12.5
15 bp at 16.6 20 bp at 17.3
Satiation Criteria established
as 1.118 bp/min

a)



Subj A3 - Satiation Sess 1
WarmUp
5 bp at 1.4 10 bp at 3.3
15 bp at 4.7 20 bp at 7.3
Satiation Criteria established
as 1.5 bp/min

b)

c)

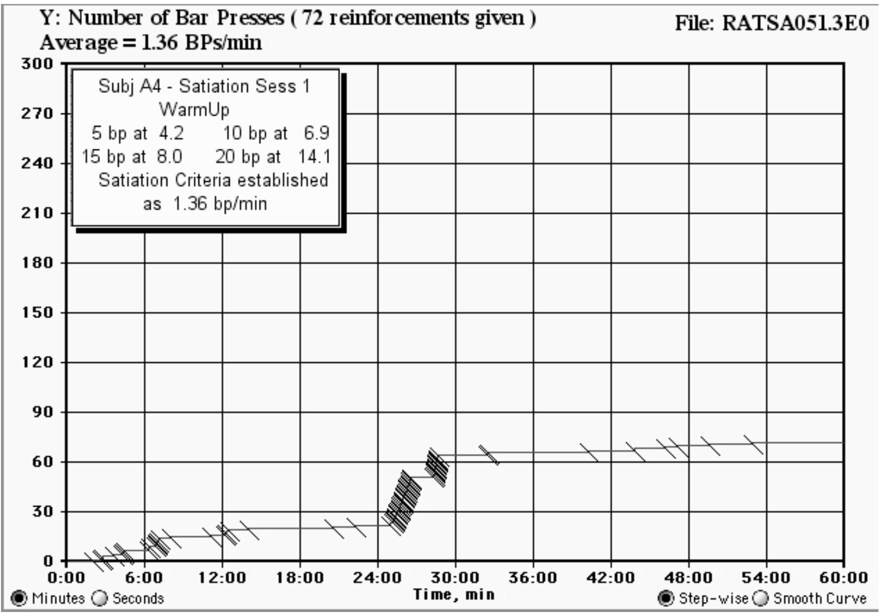


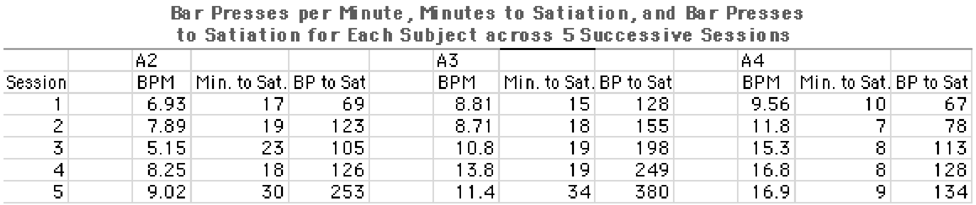
Figure 22. Number of bar-presses for a) Subject A2, b) Subject A3, and c) Subject A4 during their first experimental session following removal from deprivation schedules in the *CyberRat* Research Project (CRRP). Water was available *ad-libitum* in home cages across multiple days prior to these first sessions, thus representing typical bar-press rates under pre-experimental satiety conditions. Reinforcement was water delivered on a continuous schedule (CRF) throughout each session.

Following the session under no deprivation conditions we re-established a standard 22.5-hour deprivation schedule as an establishing operation and subsequently conducted another series of CRF evaluation sessions to assess the overall rates and rate stability for these same animals. Individual bar-press rates during the no-deprivation evaluation session were subsequently used to establish a satiety condition criterion bar-press rate for each well-trained animal bar-pressing under pre-session deprivation conditions. Thus, we applied the following criterion: *satiation was defined as the first running 5-minute period wherein the average bar-press rate for that 5-minute window was at or below the average bar-press rate for that same subject during the no-deprivation test session*. The time of onset for this 5-minute period was then used as the time at which satiety had been reached for that animal, regardless of subsequently observed bar-press rates.

Detailed analyses of the results from these sessions are summarized in Table 3. In the first “bar-pressing for continuous reinforcement” session under deprivation conditions (i.e., after the 22.5-hour deprivation schedule was first initiated), response rates were considerably elevated above the previous day’s no-deprivation test session, where average bar-press rates for the entire session ranged from 1.1 to

1.5 bar-presses per minute (bpm). In contrast, during the first sessions under the re-imposed deprivation conditions, bar-press rates range from 6.9 (A2) to 9.6 (A4) bpm. By the fifth day of CRF testing, rates were even higher. As Table 3 illustrates, rates of bar-pressing for animal A2 went from approximately 7 bpm to 9 bpm between sessions 1 and 5; animal A3 went from 8.8 to 11.4 bpm; and animal A4 went from 9.56 to nearly 17 bpm. This suggests an accumulating effect of deprivation scheduling even though all animals were given *ad-libitum* access to water for 30 minutes following experimental sessions in which they pressed to satiety.

Table 3. Bar-presses per minute (BPM), minutes to satiation criterion (Min to Sat), and bar-presses to satiation criterion (BP to Sat) for each rat (A2, A3, A4) across five successive sessions conducted during the *CyberRat* Research Project (CRRP). Each session was conducted on consecutive days following the first reinstatement of a 22.5-hour water deprivation establishing operation.



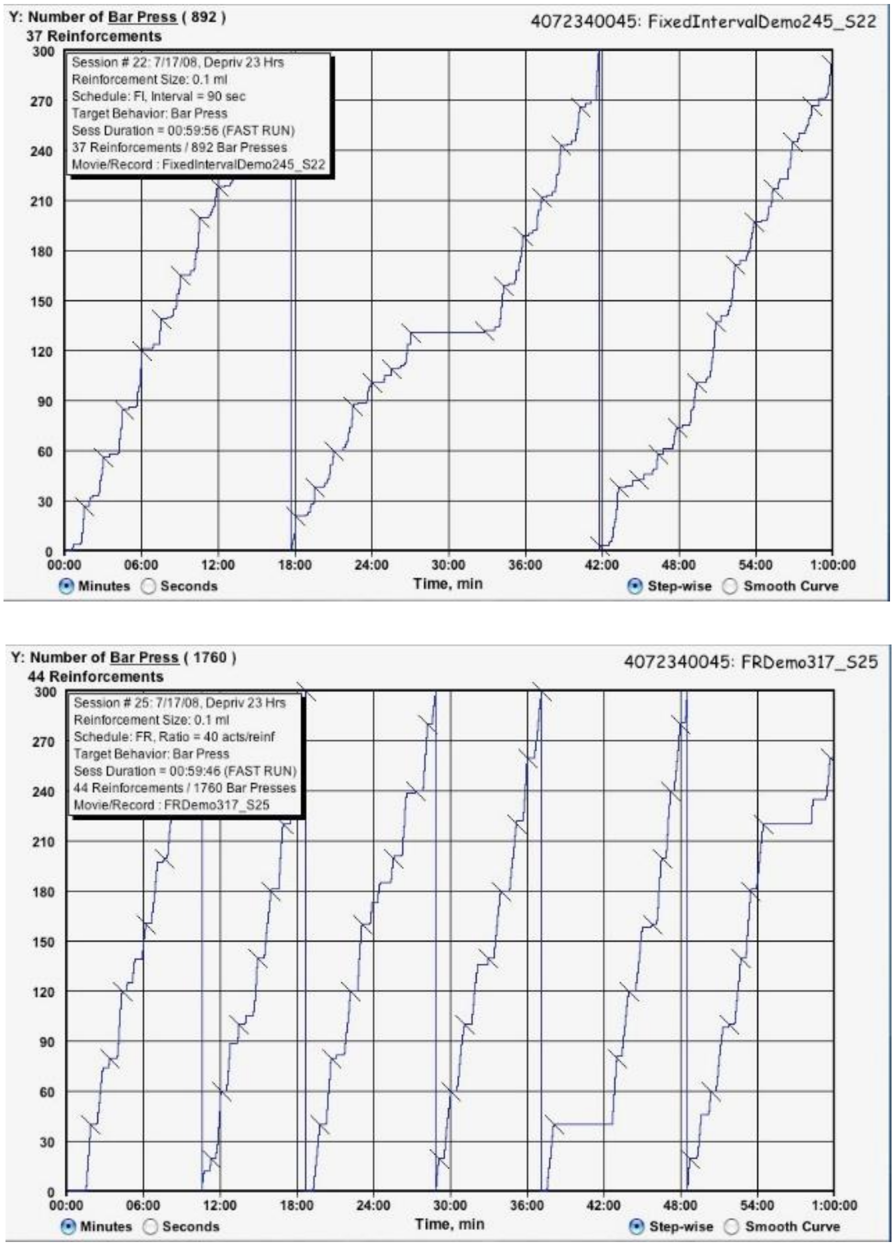
Bar Presses per Minute, Minutes to Satiation, and Bar Presses to Satiation for Each Subject across 5 Successive Sessions

	A2			A3			A4		
Session	BPM	Min. to Sat.	BP to Sat	BPM	Min. to Sat.	BP to Sat	BPM	Min. to Sat.	BP to Sat
1	6.93	17	69	8.81	15	128	9.56	10	67
2	7.89	19	123	8.71	18	155	11.8	7	78
3	5.15	23	105	10.8	19	198	15.3	8	113
4	8.25	18	126	13.8	19	249	16.8	8	128
5	9.02	30	253	11.4	34	380	16.9	9	134

Likewise, the total minutes of bar-pressing until the animal met criteria for within-session satiety increased for two of the three subjects: A2 went from 17 minutes (session 1) to 30 minutes of bar-pressing (session 5), A3 went from 15 to 34, but A4 remained about the same (10 and 9). However, the actual *number of bar-presses* accumulated during these periods seems to reflect an increasing effect of the newly-imposed deprivation schedule. Thus A2 went from 69 bar-presses to satiation criteria in session 1 to 253 bar-presses to reach the same criteria in session 5; A3 went from 128 (session 1) to 380 (session 5); and A4 went from 67 to 134 bar-presses between session 1 and 5 before reaching satiation criteria. *CyberRat's* modeling does not account for such a successive increase in deprivation setting effects. Rather, the model assumes a stabilized deprivation process that, nevertheless, varies in its associated range of presses and time to reach satiety within sessions—at least if sessions are conducted with sufficient duration to allow the process to manifest itself. Thus, if one compares *CyberRat* animal satiation dynamics to the parametrics associated with the fifth sessions of the CRRP, a very similar pattern of number of bar-presses to satiation, as well as time of reaching satiation, are observed.

Turing Test 3.4: Reinforcement Schedules and Temporal Response Rate Patterns

Ferster and Skinner (1957) dedicated an entire book to the topic of response rate patterning under different intermittent schedules of reinforcement. As such, there is a rich history in TEAB concerning specific operant class (bar-pressing or key-pecking) operating characteristics and how these rate characteristics are impacted by various rules for contingent but intermittent delivery of reinforcement. Certainly, the topic is far too broad and complex to elaborate here. Suffice to say that the CRRP also explored various selected intermittent schedule effects to determine typical variability between rats where water is the reinforcer, as well as the temporal transition dynamics involved in stabilizing a response rate pattern after shifting from one intermittent schedule to another—a phenomenon known as *schedule transitioning*. That work served to guide our simulations of similar dynamics to generate as realistic a transitional and terminal pattern stabilization as possible by *CyberRat* animals. Thus, once transitions are complete, relatively stable *patterns* of responding appropriate to the schedule are produced, as illustrated in Figure 23a, which illustrates *CyberRat's* production of the well-known *scalloping* effects of fixed interval schedules, and Figure 23b, which illustrates *break-run* patterns associated with fixed ratio schedules in *CyberRat* animals.



a)

Y: Number of Bar Press (892)
37 Reinforcements

4072340045: FixedIntervalDemo245_S22

Session # 22: 7/17/08, Depriv 23 Hrs
Reinforcement Size: 0.1 ml
Schedule: FI, Interval = 90 sec
Target Behavior: Bar Press
Sess Duration = 00:59:56 (FAST RUN)
37 Reinforcements / 892 Bar Presses
Movie/Record : FixedIntervalDemo245_S22

● Minutes ○ Seconds
● Step-wise ○ Smooth Curve

b)

Y: Number of Bar Press (1760)
44 Reinforcements

4072340045: FRDemo317_S25

Session # 25: 7/17/08, Depriv 23 Hrs
Reinforcement Size: 0.1 ml
Schedule: FR, Ratio = 40 acts/reinf
Target Behavior: Bar Press
Sess Duration = 00:59:46 (FAST RUN)
44 Reinforcements / 1760 Bar Presses
Movie/Record : FRDemo317_S25

● Minutes ○ Seconds
● Step-wise ○ Smooth Curve

Figure 23. a) Example of a stabilized "scalloped" pattern of *CyberRat* simulated bar-press rates under a 90-second Fixed-Interval schedule of reinforcement. b) Example of a stabilized "break-run" pattern of *CyberRat* simulated bar-press rates under a 40:1 Fixed-Ratio schedule of reinforcement. The primary difference is in the more gradual start of the eventual "run" made in the FI schedule compared to the sharper and more definite start of the run under FR conditions.

Efforts to simulate transitional effects when shifting schedules also include what I assert to be relatively high-fidelity replications of the well-known phenomenon of *ratio strain*. Ratio strain results when experimenters shift too quickly from rich (high-density) response-to-reinforcement ratio schedules to very lean (low-density) reinforcement ratio schedules. In such cases the now-lean schedules may deliver reinforcement so rarely as to result in extinction before a successful schedule transition is fully accomplished. In many such circumstances it may first appear that an animal is making a perfectly acceptable, if slow, transition from the more-rich to the more-lean schedule, but quite suddenly responding rates may drop and eventually responding stops altogether. *CyberRat* animals, like real rats, need to have schedules leaned gradually to avoid such ratio strains. Such *leaning* is another type of *successive approximation,* with this type focused on staged manipulations of consequences rather than stages of operant response class formation.

Finally, after *CyberRat* had circulated for several years, interested researchers began to probe whether other schedule-related phenomena might be replicated by *CyberRat* simulations, even though the application had not consciously attempted to model these phenomena. One such experiment was described in Ray and Miraglia (2011). The experiment was initially suggested by Professor David Eckerman at the University of North Carolina–Chapel Hill, and it tests for an expected interaction effect from using a common density of reinforcement but using different schedule rules (interval vs. ratio) for reinforcement delivery. For example, one known effect of fixed ratio schedules is the production of higher rates of responding, and thus a larger total number of responses in equal duration sessions, in relation to rates and totals produced by fixed interval schedules. So Eckerman had students conduct experiments where highly stable patterns of responding in *CyberRat* animals were achieved using a fixed ratio of 30:1 (FR30) schedule using proper schedule transitions. A series of six 1-hour sessions (using the Fast-Simulation mode) under these conditions was used to determine the average time that resulted between successive reinforcements. This was determined to be a rounded value of 73 seconds across all six sessions combined.

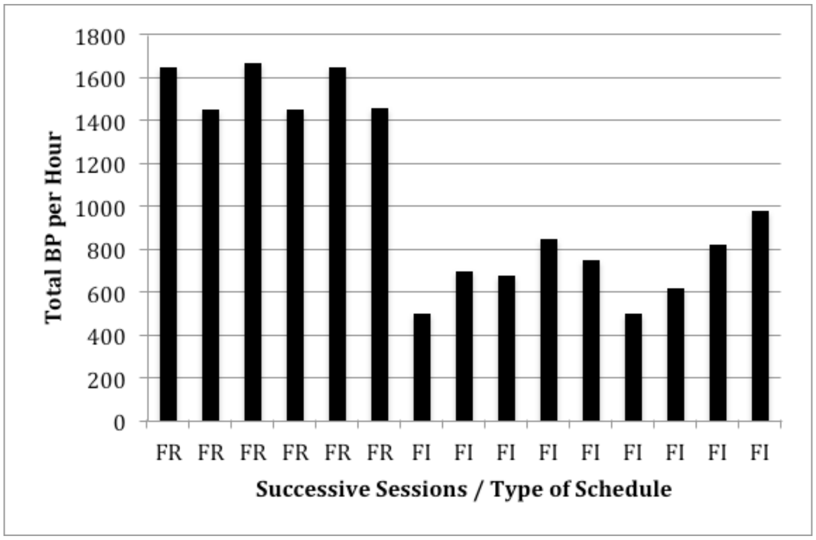


Figure 24. A series of successive sessions applying two equal-density reinforcement schedules is illustrated in this figure adapted from Ray & Miraglia (2011). A series of stable FR30 sessions were conducted for 60 min each to determine the average time between reinforcements. This time of 73 sec was used as the defining criteria for a shift to a subsequent series of FI73 sec scheduled sessions. This illustrates different response rates under alternative conditions of equal densities of intermittent reinforcement.

Subsequently, the *CyberRat* animals were shifted to fixed interval schedules where the animal would receive reinforcement for the first bar-press made after the 73-second interval had elapsed following a previous reinforcement delivery. Given that animals press at very high rates when such intervals are about to end, this results in reinforcements being separated by 73 seconds, just as they had been in the FR30 sessions. Figure 24, adapted from Ray and Miraglia (2011), illustrates that the number of bar-presses under these two comparative conditions of equal reinforcement density are a bit less than half the total during FI73 compared to the number of bar-presses during FR30, just as one would expect. While *CyberRat* is only intended to be a *descriptive model* rather than a *predictive model*, it seems nonetheless capable of passing at least some tests for simulation fidelity that were never even anticipated for it!

Operant Processes Modeled and Not Modeled by *CyberRat*

Thus far I have presented a case for *CyberRat*'s faithful reproduction of a very large number of structural and functional processes as well as numerous operating characteristics historically defined both by IBSA and by the more traditional TEAB approach. I feel compelled to emphasize one more time that it is the *convergence* of the IBSA and TEAB approaches that is being validated by the model that is *CyberRat*. To meet demands of being both *sufficient and necessary* one must conduct and simulate *structural*, *functional*, and *operations* analyses. Nothing else is likely to accomplish the feat of showing, at all times and under all incorporated conditions, a realistic video portrayal of what an animal will do in this array of circumstances.

I have already stressed the emphasis that was placed on accurate *structural* reproductions of multi-behavioral hierarchies based on unconditional probabilities, as well as response interdependencies as reflected in kinematics and their associated conditional probabilities. Thus, a close inspection of a kinematic matrix associated with any continuous reinforcement session in *CyberRat* is very likely to reveal the relatively fixated *bar-press*→*drink*→*bar-press* probability pattern. But that same close inspection, when focused on the difference between the conditional probability of *bar-press*→*drink* vs. the conditional probability of *drink*→*bar-press* will reveal the fact that movement, exploration, or grooming is much more likely to occur following drinking than it is to occur following bar-pressing. That is a replication of consistent empirical data from live animals as well.

Thus, there are numerous conditions under which *CyberRat* is likely to pass the hypothetical Turing tests proposed. Besides the fully-described tests for structural analysis replication, both in terms of data and visual phenomenological reproductions, other tests for realism that are likely to generate convincing results include tests for functional interbehavioral adaptation processes including respondent conditioning, conditional reinforcement, operant response shaping, extinction, and discriminative antecedent stimulus control, as well as tests for realistic transitional or sustained operating characteristics including rhythmic fluctuations in various behavioral parameters during habituation, warm-up prior to bar-pressing, dynamic response patterns under deprivation/satiation, intermittent schedule transitions and ratio strains, and the dynamic stabilities under CRF as well as various other intermittent schedules of water reinforcement.

But I would be remiss if I did not acknowledge that *CyberRat's* portrayed circumstances *are* limited. Thus, there are numerous processes one *might* investigate using rats in operant chambers that are not included in *CyberRat*. For example, one quite well-known interdependency phenomenon, known as *adjunctive behavior*, is not simulated in *CyberRat*. This is because most studies of adjunctive behavior have included *food* in the chamber when water is the reinforcer, or vice versa (cf. Falk, 1977). Alternatively, *running wheels* have also been used to demonstrate that running can follow eating as much as drinking does (Levitsky & Collier, 1968). Because the filming of *CyberRat* was conducted with no other manipulanda, objects, or consumables, there is no opportunity, nor any effort, to model the typical adjunctive behaviors known to be schedule-induced by reinforcement consumption.

Likewise, for the same reason (no other manipulanda or complex stimuli available) *CyberRat* does not simulate choice behaviors and associated response distributions across multiple manipulanda. The model also does not attempt to simulate tandem, mixed, chained, or other complex schedules or schedule combinations. Neither does the model attempt to simulate differential reinforcement of response rates (i.e., DRH or DRL schedules attempting to generate higher or lower rates of responding, respectively). This, of course, also implies that no effort was made to simulate behavioral contrast effects, which is typically based on complex scheduling. However, once again David Eckerman (personal communication, December, 2008) has reported generating convincing evidence of behavioral contrast effects using discriminative stimulus control training while making shifts from a VI schedule of reinforcement with no discriminative stimulus conditions to discrimination training using the same VI schedule (i.e., multiple S^+ = VI / S^- = extinction exposures). This finding is especially interesting given that, in our development of *CyberRat* as a *descriptive model,* we did not attempt to model such contrast phenomena. Further, Eckerman (personal communication, January, 2012) has shown the greater persistence of responding for richer reinforcement schedules expected by behavioral momentum theory (cf. Nevin & Grace, 2000; Nevin, Mandell, & Atak, 1983) following transition from VI schedules of reinforcement (which are response-dependent for delivery of reinforcers) to Variable Temporal schedules (which involve only response-independent reinforcer delivery). Again, there was no effort made to actually design such simulated results into *CyberRat*—they, like other non-intended reproductions I have described, seem to be an emergent property of descriptive algorithms designed to reproduce other effects!

CyberRat does not allow for exporting inter-response time (IRT) data, and thus no IRT distribution analyses or other temporally-focused analyses are supported. Of course, this does not prevent those using *CyberRat* from doing their own timing and plotting to evaluate temporal parametrics. I have already illustrated, however, that pressing in *CyberRat* comes under discriminative stimulus control gradually across sessions, and successive session results such as the discrimination ratio may be externally accumulated and plotted across sessions to reveal an emerging discriminative control of bar-pressing as a functional development curve. But it is not possible in *CyberRat*—at least not in any automated way—to auto-generate a within-session analysis that isolates behavioral patterning during S^+ vs. patterning during S^-, as reflected in Figure 5 from the Ray and Brown (1975) study discussed earlier. But again, anyone desiring to test such data could observe and record multi-behavioral dynamics using *CyberRat's* "Replay Session" feature to review the video record from such sessions, and thus could replicate the original methods of the Ray, Upson, and Henderson (1977) study from which Figure 21 is reproduced. Yet, as detailed earlier, the use of relatively consistent clip lengths and random selections make perturbations like those reflected in Figure 21 highly unlikely to be generated by simulations using video-enhanced (or better, perhaps, to say in this context, *video-restricted*) modeling.

None of the above limitations are critical, of course, to the major point of my argument for reasonable Turing test results across a wide variety of functional and operational characteristics that were intended in *CyberRat's* simulations. Nor do any seem impossible to incorporate into a model like *CyberRat*—only highly impractical. As such, I assert that there is little to be gained from such exercises for testing non-intended authenticities. Focusing on what *CyberRat* does *not* simulate is clearly a neverending and pointless endeavor. I point out the ignored elements above only to address some of the many obviously related, and research-documented, events typically studied with organisms in operant chambers.

What are *CyberRat's* Contributions?

As I conclude this monograph, it is crucial that I attempt to assure that readers understand my primary intents in writing it. Thus, I reiterate my aspirations for this endeavor—and, in fact, for *CyberRat* itself. As I stated in my opening paragraph, my ultimate goal was to articulate the conceptual and methodological *validation value* of *CyberRat* as a computer-based simulation. While I also wanted to share the CRRP's original empirical data in the context of *CyberRat's* development, I primarily set out to demonstrate how the conceptual value of *CyberRat* is based, in part, upon how well the model *reconstructs* those descriptive CRRP data that guided its development—that is, how well it holds up to the various Turing-type tests I present. The fact that those CRRP data were, themselves, both necessary and sufficiently complete to allow the creation of such a realistic model *also serves, in turn, to validate the IBSA research approach*.

But some readers may question whether *CyberRat* has generated any new research beyond those unintended reconstructions I have already reported—reconstructions such as behavioral contrast and behavioral momentum. From the perspective I have asserted in this manuscript, that is the wrong question to ask. To raise the question of new research shifts the focal intent of *CyberRat's* development from that of generating a *descriptive* model that validates methodology to that of generating a *predictive* model that intends to function much like a theory. Let me reiterate that my ultimate goal in *CyberRat's* development was its formative guidance and feedback regarding whether the descriptive methods I had used to analyze animal behavior in operant situations were sufficiently complete to allow statistical (vs. literal event-by-event) reconstructions of all of the structural, functional, and operating dynamics I had described in prior research. I have attempted to illustrate how informative *CyberRat's* development processes were, especially those relating to the Ray and Brown (1975, 1976) behavioral taxonomy probes, and how that taxonomy itself relates to the ultimate discoveries offered by *CyberRat*. While structural/visual reconstruction of all behaviors-in-context required significant expansion of descriptive contextual elements and definitions required to fully reconstruct interbehavioral events, nevertheless those expansions may "contract" into the original, simpler Ray and Brown taxonomy with relative ease—as the Multi-Behavior feature in *CyberRat* reveals. The Ray and Brown taxonomy cannot generate *CyberRat*, but *CyberRat* can generate data that are meaningful from the perspective of that taxonomy. As such, *CyberRat* serves to affirm many of those dynamics described by Ray and Delprato (1989)—dynamics that, for almost a century now, have been ignored by researchers relying exclusively upon TEAB methodology. From my perspective, *CyberRat* affirms a sufficiently complete description of behavior as to validate prior descriptions of hierarchy change dynamics and kinematic dynamics. On the other hand, while *CyberRat* has been shown to reconstruct most of the operating characteristics of interest to Skinner, existing video sample limitations leave *CyberRat* less confirming of behavioral velocity as a function of setting change velocity, natural biological rhythms in behavioral organization dynamics, and a variety of other phenomena summarized by Ray and Delprato (1989). But I have attempted to demonstrate that I believe that my primary goal has been realized, and that is the ultimate contribution of *CyberRat* as a descriptive model.

But the fact that *CyberRat* also offers potential value for students represents a wonderful heuristic of the end product. Students around the world have progressively lost access to live-animal research training. That student users may test their skills at shaping new behaviors and may investigate a wide variety of experimental manipulations of attendant variables critical in behavioral organization dynamics, adaptation, and operating characteristics is a definite added value in the development of *CyberRat*. I would thus conclude by pointing out that *CyberRat* demonstrates yet another dimension of a comprehensive descriptive accounting of behavioral interactions, both within and between organisms. Beyond that, I am asserting that multimedia simulations such as *CyberRat* serve as confirmations of a researcher's adequacy in describing his or her interactions with their subject matter to the fullest extent possible. Kantor (1953) and Verplanck (1970, 1995) alike always championed the importance of describing actions of the researcher as clearly as one should describe the events being directly observed and described for intended research by that researcher. That, after all, was the foundation of Verplanck's (1957) glossary of behavioral terminology—he attempted to match the operations performed by experimenters to the language they used to communicate those operations. I like to think that both scientists, each a staunch and vocal interbehaviorist, would likely approve of the achievements, and even the yet-unrealized potentials, of the visual and data reconstructive models of interbehavioral systems dynamics reflected in *CyberRat*.

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