Cues, Tendencies and Actions: The Dynamics of Action revisited

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Abstract

The theory of the Dynamics of Action Atkinson & Birch (1970) was a theory before its time. Few psychologists of the 1970s were prepared to understand differential equations or to do computer modeling of difference equations. With modern software and computational power, the model is much easier to simulate and examine. This article describes a reparameterization of the original theory and and applies the power of simple modeling to the study of action, emotions, and social behavior.

John W. Atkinson was most known for his formalization of a theory of task preference and achievement motivation Atkinson (1957, 1974, 1981). Less well known, but perhaps more important, was his work with David Birch on the Dynamics of Action (DOA) Atkinson & Birch (1970). The DOA introduced the dimension of time to the analysis of motivational strength and direction. The fundamental idea was that analysis of choice, persistence, latency, frequency and time spent can be done in a common framework: the analysis of actions over time. E.g., the initiation of an activity should be analyzed in the same manner as the persistence of an activity, for the latency of onset of an activity is equivalent to the the persistence of not doing that activity.

In addition to introducing time as a variable, motivations and actions were thought to have *inertial* properties. This was an outgrowth of earlier work by Gestalt psychologists influenced by Kurt Lewin (e.g. Zeigarnik (1927/1967)) as well as Feather (1961) and Atkinson & Cartwright (1964). In simple terms, a wish persists until satisfied and a wish does not increase unless instigated. (This is, of course, a restatement of Newton's 1st law of motion that a body at rest will remain at rest, a body in motion will remain in motion.) By considering motivations and actions to have inertial properties it became possible to

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model the onset, duration, and offset of activities in terms of a simple set of differential equations.

Unfortunately, the theory of the Dynamics of Action was a theory before its time. Few psychologists of the 1970s were prepared to understand differential equations or to do computer modeling of difference equations. However, with a simple reparameterization (Revelle, 1986) and modern software and computational power, the model is much easier to simulate and examine. This article describes a reparameterization of the original theory and and explores the power of including temporal dyanamics in a theory of action. Applications of the revised model are extended to the dynamics of emotion (e.g., Frijda) and to social behavior. To allow the reader to explore the applications of this model, computer code simulating the revised model is written in the open source language R, (R Development Core Team, 2008) and is included in the appendix as well as on line at `http://personality-project.org/r/cta.R`[1]

The original dynamics of action

The dynamics of action was a model of how *instigating forces* elicited *action tendencies* which in turn elicited *actions*. The basic concept was that action tendencies had *inertia*. That is, a wish (action tendency) would persist until satisfied and would not change without an instigating force. The consummatory strength of doing an action was thought in turn to reduce the action tendency. Forces could either be instigating or inhibitory (leading to *negaction*).

Table 1: The basic elements of the dynamics of action

Instigating Forces	F
Action Tendencies	T
Consumatory Value	c
Consumatory Forces	C
Inhibitory Forces	I
Negaction Tendencies	N
resistance Value	r
Force of Resistance	R

The relationship between instigating forces, changes in action tendencies over time, and actions was described by a simple differential equation (reminiscent of Newton's second law)

$$dT = F - CT \tag{1}$$

[1] R users may `source("http://personality-project.org/r/cta.R")`

where

$$C = cT \tag{2}$$

and c = 0 if an action is not being done, otherwise c is a function of the type of action (eating peanuts has a smaller c than eating chocolate cake).

That is for a set of action tendencies, T, with instigating forces, F,

$$\begin{cases} dT_i = F_i - c_i T_i & \text{if } T_i \text{ is ongoing} \\ dT_A = F_A & \text{if } T_i \text{ is not ongoing} \end{cases} \tag{3}$$

It is clear from equation 3 that an unexpressed but instigated action tendency will grow linearly, but once initiated will achieve an asymptotic value when the rate of growth is zero. This occurs when $F_i = c_i T_i$ and thus

$$T_\infty = F/c \tag{4}$$

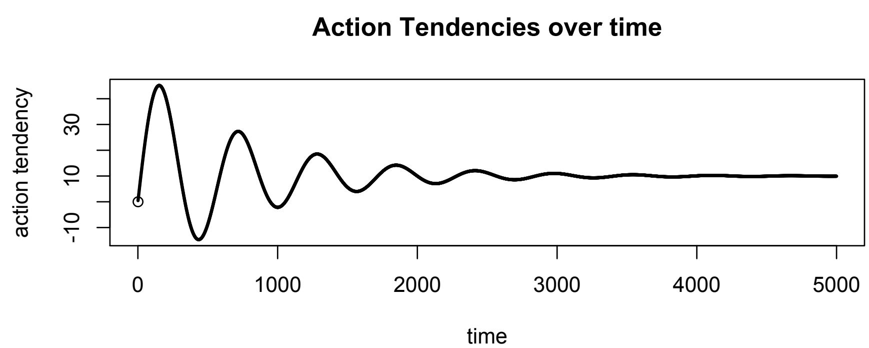

Figure 1. A single action tendency will achieve an asymptotic value of the ratio of instigating force to consumatory value as corresponding action is expressed and leads to consummation.

In parallel with action tendencies are *negaction tendencies*–tendencies to not want to do something. These grow in response to *inhibitory forces*, I, and are diminished by the force of *resistance*, R, which is, in turn, a function of the cost of resistance, r, and the strength of the negaction, N.

$$dN = I - R = I - rN. \tag{5}$$

In contrast to Equation 3 where action tendencies are reduced only if the action is happening, Equation 5 suggested the negaction would always achieve an aymptote, even if the action were not occurring. Because it requires effort to resist even if not doing a task, the force of resistance is always present and negaction will achieve an asymptotic level of

$$N_\infty = I/r \tag{6}$$

The resultant action tendencies are the difference between Action and Negaction $T_r = T - N$. Atkinson & Birch (1970) assumed that action choice between competing action tendencies simply followed the maximum action tendency.

Although a general theory of action, the dynamics of action was typically considered in an achievement setting. Based upon the theory of achievement motivation (Atkinson, 1957; Atkinson & Raynor, 1974), the instigating force was thought to be a quadratic function of task difficulty and the need for achievement:

$$F = (p_s)(1 - p_s) * N_{ach}. \tag{7}$$

But an achievement setting is also an opportunity for failure and the change in negaction induced by the task was a function of the inhibitory forces which were in turn a quadratic function of task difficulty and the need to avoid failure.

$$I = (p_s)(1 - p_s) * N_{avoidfailure} \tag{8}$$

Early suggestions for inertial properties of motivations were found in the studies by Zeigarnik (1927/1967) as well as by Feather (1961). An application of the inertial properties of motivation in an achievement setting was found in an analysis of the effect of task difficulty on performance as a function of the number of repeated trials (Revelle & Michaels, 1976). This application demonstrated how two seemingly contradictory models (Atkinson, 1957; Locke, 1968) could be reconciled with the addition of inertial properties. Assuming that success quenches action tendencies but that failure does not, resultant motivation should grow over successive failures. As task difficulty increases, the likelihood of failure increases and thus there should be more carry over and growth of motivation as tasks become harder.

By separating action tendencies from negaction tendencies, the dynamic theory had the advantage over earlier work that the measurement of approach and avoidance motivation did not have to be on the same ratio scale of measurement (Kuhl & Blankenship, 1979). That is, what determined the growth of action tendencies could be measured on a different scale from what determined negaction. This was a marked improvement over the prior work Atkinson (1957) that suggested that resultant action tendencies were a function of the difference beween acheivement strivings and fear of failure

$$T_r = T_{approach} - T_{avoid} = (N_{ach} - N_{avoid})p_s(1 - p_s). \tag{9}$$

Unfortunately, although easy to specify, the DOA model needed a number of extra parameters to work: it was necessary to include a decision mechanism that would automatically express the greatest action tendency in action. Unfortunately, the rule of always doing the action with the greatest action tendency led to "chatter" in that an action would start and then immediately stop as the action it had supplanted had a rapidly growing action tendency. To avoid this problem it was necessary to introduce instigating and consummatory *lags*, where switching to a new activity would not immediately lead to consummation of that need (eating a pizza does not immediately reduce the need to eat a pizza).

A simple reparameterization: the CTA model

To avoid the problem of instigating and consummatory lags and a decision mechanism it is possible to reparameterize the original model in terms of action tendencies and actions (Revelle, 1986). Rather than specifying inertia for action tendencies and a choice rule of always expressing the dominant action tendency, it is possible to think of actions themselves as having inertial properties. In an environment which cues for action (**C**), cues enhance action tendencies (**T**) which in turn strengthen actions (**A**). This leads to two differential equations, one describing the growth and decay of action tendencies (**T**), the other of the actions themselves (**A**).

$$d\mathbf{T} = \mathbf{sC} - \mathbf{cA} \tag{10}$$

$$d\mathbf{A} = \mathbf{eT} - \mathbf{iA} \tag{11}$$

C, **T** and **A** are vectors (perhaps of different dimensionality), one of which (**C**) is a function of the environment, and two of which (**T** and **A**) change dynamically. The parameters **s**, **c**, **e**, and **i** are matrices representing the connection strengths between cues and action tendencies (**s**), action tendencies and actions (**e**), the consummatory strength of actions upon action tendencies (**c**), and the inhibition of one action over another (**i**). They are specified as initial inputs but could themselves change with learning and reinforcement (Corr, 2008; Revelle, 2008). This model is similar to a basic connectionist architecture where the action tendencies are hidden units relating environmental cues to behavioral responses. The model, although expressed in equations 10 and 11 may also be represented as box diagram of the flow of control (Figure 2).

If just a single action tendency and the resulting action are cued, the result is an action tendency and resulting action similar to that predicted by the dynamics of action and shown in Figure 1. Actions that are not mutually inhibitory both rise and fall independently of each other (Figure 3). Cue strength (**C**) is reflected in the initial growth rate of action tendencies and of actions as well as the asymptotic level. The consummation parameter, **c**, affects the asymptotic level as well as the frequency and speed of dampening of the action tendencies and thus of the actions, the self inhibition parameter, **i**, affects the asymptotic level of action tendencies as well as the dampening of the actions themselves and indirectly, of the action tendencies (Figure 3)

$$\mathbf{T}_{\infty} = \mathbf{sCi}/\mathbf{c} \tag{12}$$

$$\mathbf{A}_{\infty} = \mathbf{eC}/\mathbf{c}. \tag{13}$$

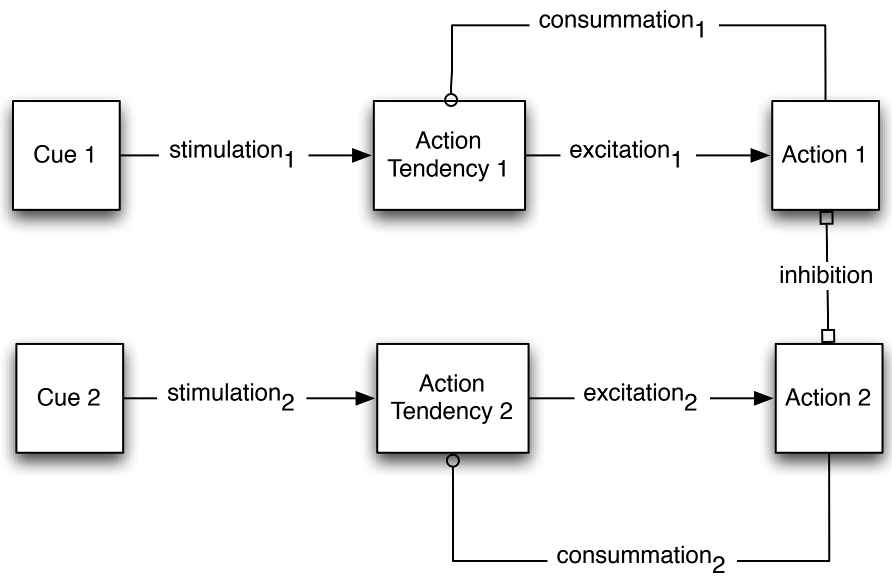

Figure 2. A simplified model of the Cues, Tendency, Action model. Cues stimulate action tendencies which in turn excite actions. Actions may be mutually inhibitory and also reduce action tendencies. Extensions of this model allow for learning by changing the stimulation, excitation, and inhibition weights.

Dynamic models of motivation and behavior

The emphasis of the DOA/CTA is that behaviors need to be considered over time, and that the analysis should include a consideration not just of one action, but of the competition between multiple activities. The need to study more than one activity when modeling motivation and behavior has been discussed by others (Anselme, 2007) who emphasized the motivational process of transitions from one activity to another. Dynamic models of behavior with specific applications to animal models have been discussed by Holland & McFarland (2001), Toates (1975, 2004, 2006) and Toates & Halliday (1980).

The application of dynamic control theory models as applied to human behavior has been reviewed by Carver & Scheier (1982, 2000) and extended to the study of affect Carver (2001, 2003, 2004).

Mutually incompatible activities

An unfortunate characteristic of life is one can not do everything. In particular, many activities are incompatible. Given a modicum of evolutionary complexity, organisms can have multiple drives which are sometimes incompatible. Within psychology, this is seen as a problem of resource limitations. In popular parlance, perhaps Lyndon Johnson's

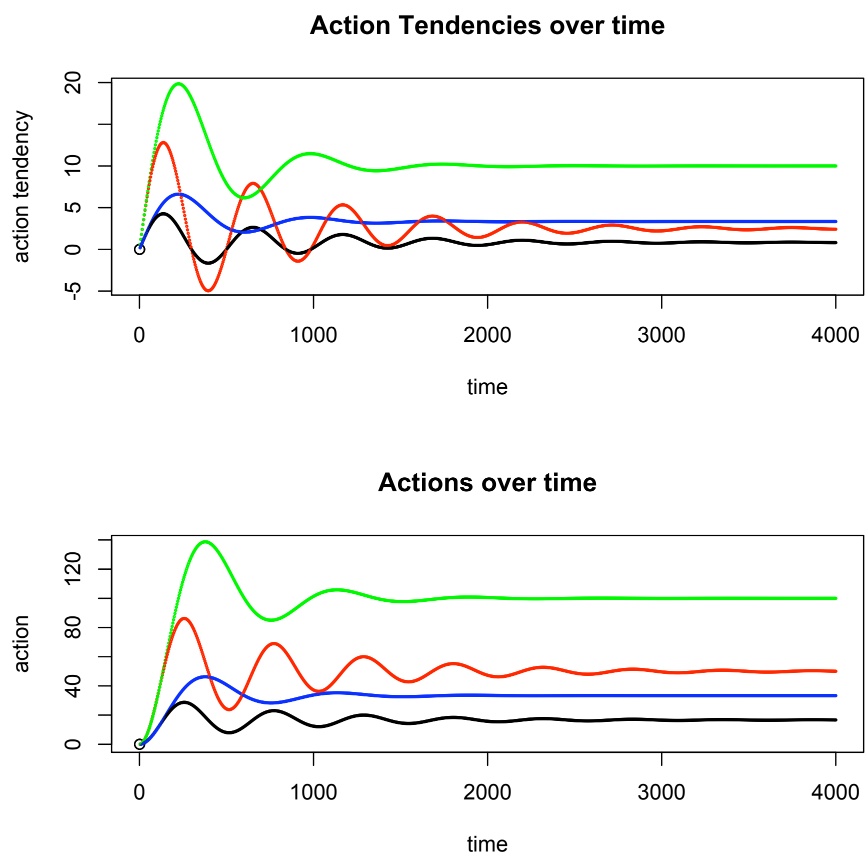

Figure 3. If actions are not incompatible and do not inhibit each other, each one will achieve an asymptotic level as a function of its cue and self inhibition strength. Note how the temporal parameters can vary, so that that the action tendencies and actions can have different damping characteristics. Using the `cta` function in R (see Appendix), cue strengths were set to 1 (black and blue lines), or 3 (red and green lines), consummation to .06 (black and red) or .03 (blue and green), inhibition to .05 (black and red) or .1 (blue and green). Note that with these settings, although the red line has stronger action tendency than does blue, this order reverses in terms of the strength of the actions.

description of Gerald Ford as unable to walk and chew gum at the same time best captures the idea of incompatible actions. A compelling biological example is that of the newt, an air breathing amphibian which mates underwater. The male newt, motivated to deposit his sperm (below the water), is also motivated to breathe (above the water); sometimes the behavior can be modified to accommodate both drives, otherwise, the more critical will dominate and temporarily inhibit the other (Halliday, 1980).

Mutual incompatibility is modeled in the CTA by mutual inhibition. The doing of $action_i$ inhibits the doing of $action_j$ and vice versa. This is implemented by the **i** matrix which allows for symmetric or asymmetric inhibition (some actions can inhibit others, but not be inhibited by them).

Change in a constant environment

The power of a dynamic model is that it predicts change of behavior even in a constant environment where the instigating cues are not changing. With mutually incompatible actions, action tendencies can all be instigated by the environment but only one action will occur at a time. Action tendencies resulting in actions will then be reduced while other action tendencies rise. This leads to a sequence of actions occurring in series, even though the action tendencies are in parallel (Figure 4).

What is particularly obvious from Figure 4 is that the rate of increase in action tendencies that are unexpressed as actions is a direct function of cue strength. More importantly, the latency of onset of an action reflects differences in cue strength. The saw-tooth patterning of action tendencies is much more clearly a function of cue strength that the seemingly chaotic patterning of actions.

The persistence of an act, once initiated is a function of its cue strength, the consummation of the action tendency, as well as the strength of other action tendencies. The blue action in Figure 4 has a smaller cue strength (2) than the black action (4), but the much smaller consummatory coefficient (.01 versus .04) leads to greater persistence once initiated.

Inhibitory cues delay but do not stop activity

Some environmental cues are inhibitory rather than excitatory. In the theory of achievement motivation, the need to avoid failure reduced resultant actions (Atkinson, 1957). In the dynamic theory, the need to avoid failure delayed the onset of actions, but did not prevent it (Atkinson & Birch, 1970; Atkinson & Raynor, 1974). This led to the prediction that the inhibitory effects of anxiety on performance were transitory and would be observable at the start of a task, but not later in the task (Humphreys & Revelle, 1984). The delaying effect of an inhibitory cue may be seen in Figure 5. The top panel shows two action tendencies and the resulting actions over time. The lower panel adds an inhibitory cue, leading to an inhibitory action tendency, inhibiting the onset of the second action. Note how the second task is delayed rather than prevented.

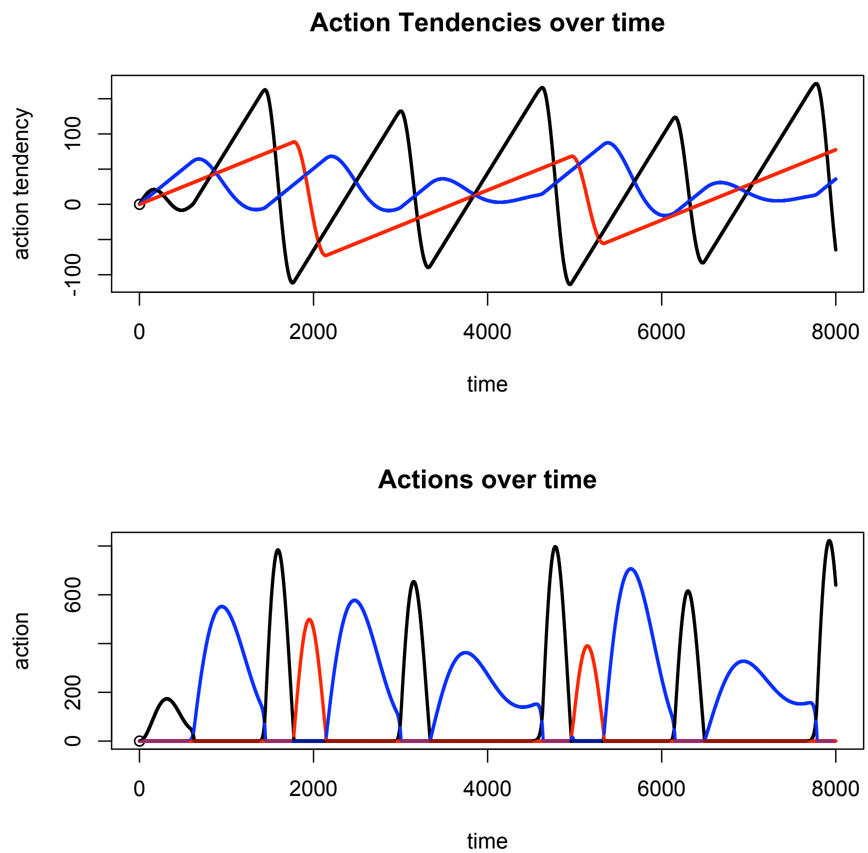

Figure 4. If actions are incompatible (mutually inhibitory), action tendencies will run in parallel but actions will be serial (only one action will occur at a time). Using the `cta` function in R, cue strengths were set to 4 (black line), 2 (blue), and 1 (red), consummation to .04, .01 and .03, and the diagonal of the inhibition matrix was /04, .06 and .02., with the off diagonal elements set to 1.0. Note how cue strength affects the latency and frequency of actions.

An example of this effect could be the self worry statements that anxious individuals make when starting a test that inhibit doing well on the test. Once performance is initiated, however, anxiety no longer has its effect upon performance.

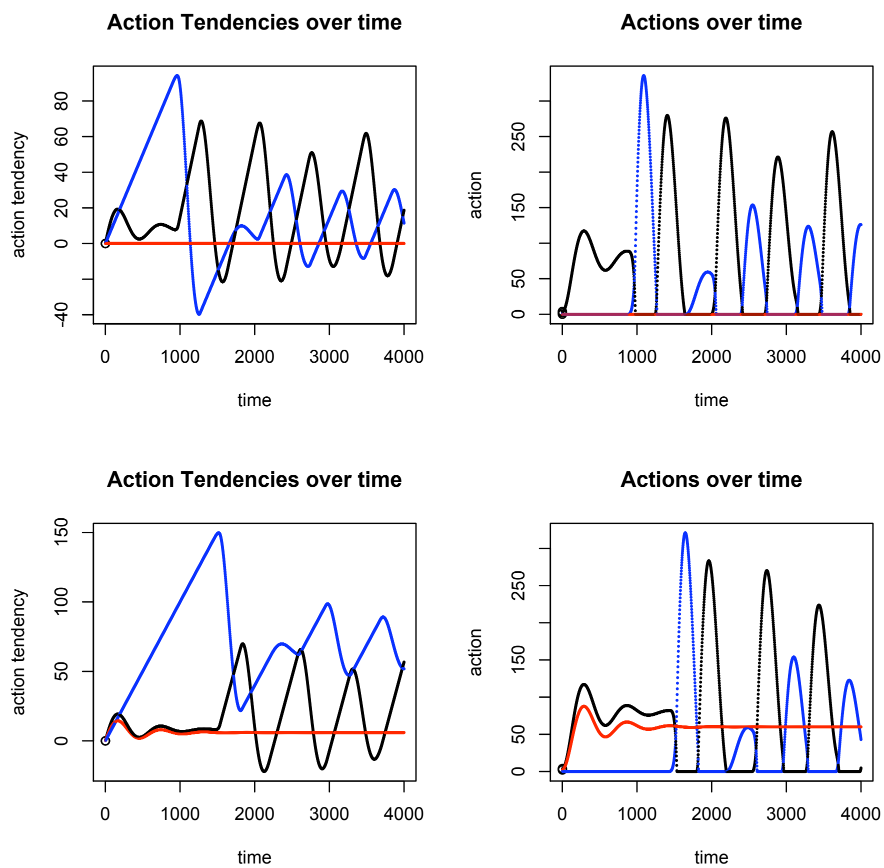

Figure 5. An inhibitory cue leads to an inhibitory action tendency which inhibits a specific action. The effect is transitory and just delays the eventual onset of the other action. The top panels show two behaviors without inhibition, the bottom two show an inhibitory tendency that delays the onset of an action (blue line).

State space diagrams

The previous figures have shown actions and action tendencies over time. An alternative representation is to plot two action tendencies against each other in a *state space* diagram (Figure 6). Although somewhat confusing, the message is that action tendencies are in constant turmoil, never achieving a steady state. For as one action is released, the strengths of the other action tendencies grow.

CTA and RST: Modification of cue stimulation

Reinforcement sensitivity theory (RST) as developed by Gray & McNaughton (2000) (see also Corr (2008)) is a biological model of how individual differences in sensitivity to cues for rewards and for punishments lead to learning. To incorporate this within a dynamic framework it is necessary to modify the basic CTA to include feedback of the outcome of responses to the strength of the connections between cues and action tendencies (the stimulation parameter).

Application to emotions

The application of the CTA model to the study of emotions is particularly compatible with the emotional theory of Nico Frijda (2007). To Frijda, "Emotions are passions" that "clamor for action or that impose inaction", indeed, they are "action tendencies" Frijda (2008). Within this framework of emotions as action tendencies, we have examined the rates of growth and decay of emotional states (Gilboa & Revelle, 1994; Gilboa-Schechtman et al., 2000) as they affect cognitive processing.

Although not yet explored, it seems very likely that Frijda's approach to emotion can be extended through the use of the CTA. The obvious questions to ask include what determines the rate of growth and the rates of decay of various emotions. Preliminary evidence (Gilboa & Revelle, 1994) suggests that the dimension of neuroticism is related to the decay rate of negative emotions rather than to the rise time.

Application to social interactions

Although originally thought of as a model for the sequential interplay of behaviors within a person, the model would seem to be easily generalized to interpersonal interaction. Consider the case of four people interacting in discussion. The topic differs in the excitatory strength for different people, and the satisfaction (consummation) of talking can also differ across people. When one person talks, this talking inhibits the talking of the others. A simple model of such an interaction is seen in Figure 7.

However, it is not clear if the pattern of behavior as a function of group size matches actual data. In an examination of the interactive effect of group size and extraversion on talking behavior, Antill (1974) reported that as group size increased, the relative proportion of time spent talking increased for extraverts and decreased for introverts. Simple variations of group size keeping the range of cue strength constant do not reproduce this effect.

Summary and Conclusion

The *Dynamics of Action* was a premature theory of action that with modern simulation techniques and a minor reparameterization is now more readily studied. The funda-

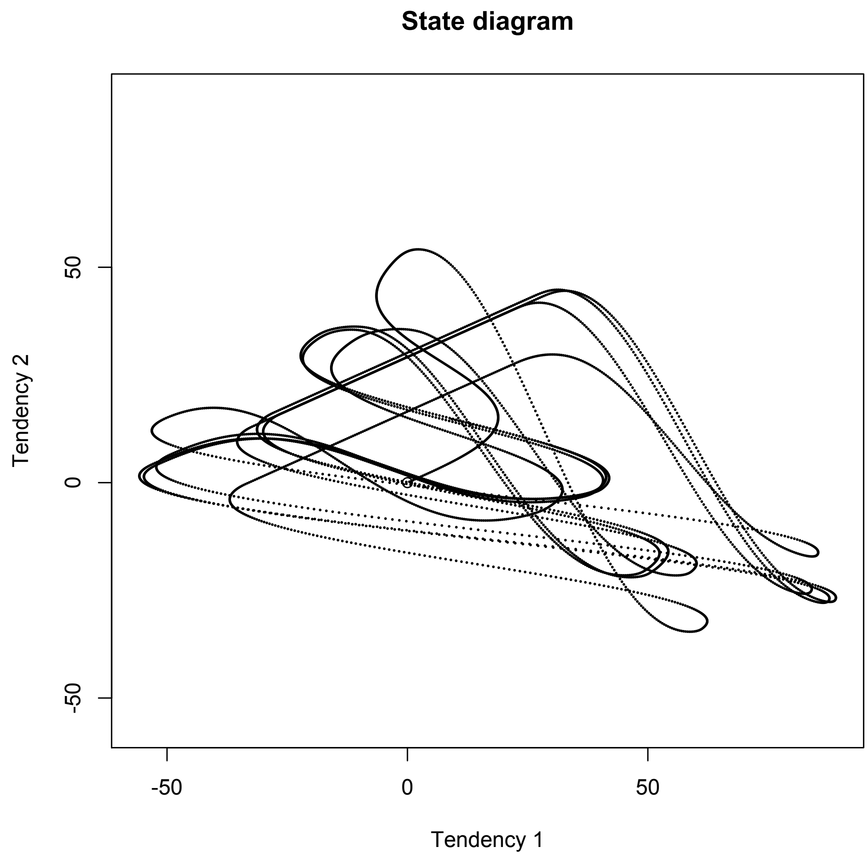

Figure 6. A state diagram plots two action tendencies against each other rather than plotting against time. With six mutually incompatible activities, the action tendencies never achieve asymptotic values but rather grow and decay in particular regions of the state space. Some regions of the state space are over represented, some are underrepresented. Simultaneous increases in T1 and T2 imply that another action is taking place. Increases in T1 while decreasing T2 implies that Action 2 is taking place.

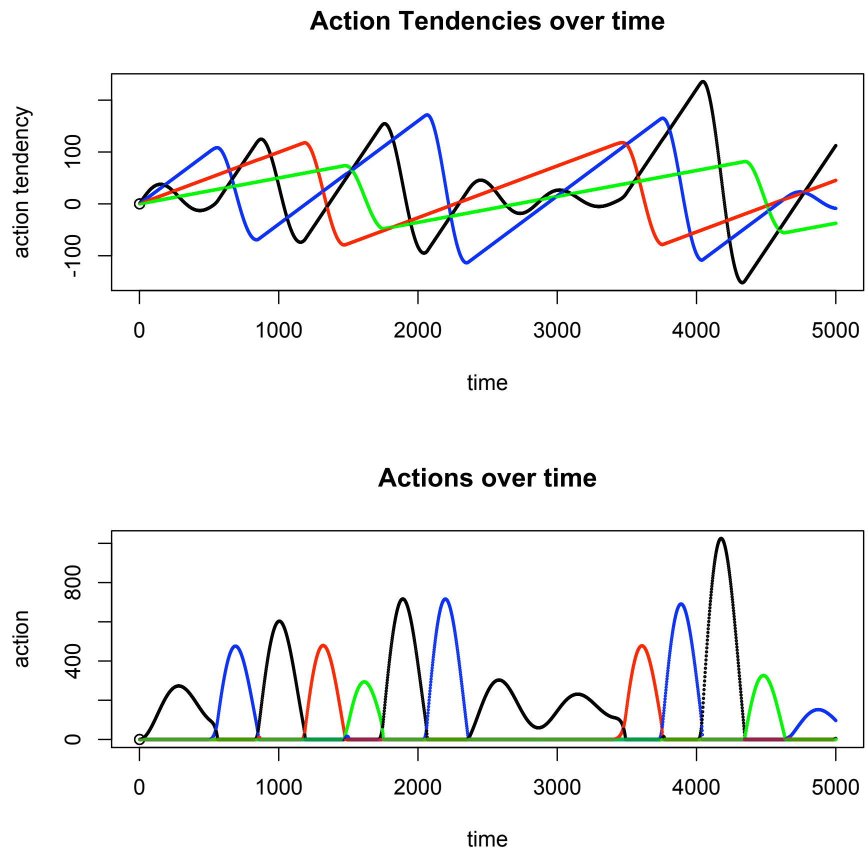

Figure 7. Social interaction can be modeled using the CTA model. The desire (action tendency) of four people reflects their interest in talking and when one person is talking, that inhibits the others. Note that one person talks frequently while another is much less involved.

mental assumption, that motivation and behavior are dynamic and have inertial properties has far reaching implications for an adequate theory of behavior. Action tendencies may be seen as the "hidden units" that link environmental cues to actual behavioral acts. Further explorations of the DOA/CTA model should incorporate the levels of analysis concepts of Ortony et al. (2005) who argued for the distinction between reactive, routine, and reflective levels of processing. Reactive processing presumably links cues directly to actions. Routine processing requires motivational (action tendency) states. Reflective processing probably reflects internal "actions" that feedback upon subsequent actions and action tendencies.

Examples of the power of dynamic analysis are applications to the study of emotions, interpersonal behavior, and achievement motivation. Within the dynamic framework, stable (trait) differences between individuals are seen as rates of change in action tendencies (both in terms of excitatory and inhibitory strengths). It is not the actions themselves that provide the temporal signature of an individual, but it is the rate at which affects, behavior, cognitions, and desires change over time.

References

Anselme, P. (2007). Some conceptual problems with the classical theory of behaviour. *Behavioural Processes*, *75*(3), 259–275.

Antill, J. K. (1974). The validity and predictive power of introversion-extraversion for quantitative aspects of conversational patterns. *Dissertation Abstracts International*, *35*(1-B), pp.

Atkinson, J. W. (1957). Motivational determinants of risk-taking behavior. *Psychological Review*, *64*, 359-372.

Atkinson, J. W. (1974). Strength of motivation and efficiency of performance. In J. W. Atkinson & J. O. Raynor (Eds.), *Motivation and achievement* (p. 117-142). New York: Winston (Halsted Press/Wiley).

Atkinson, J. W. (1981). Studying personality in the context of an advanced motivational psychology. *American Psychologist*, *36*(2), 117-128.

Atkinson, J. W., & Birch, D. (1970). *The dynamics of action.* New York, N.Y.: John Wiley.

Atkinson, J. W., & Cartwright, D. (1964). Some neglected variables in contemporary conceptions of decision and performance. *Psychological Reports*, *14*, 575-590.

Atkinson, J. W., & Raynor, J. O. (Eds.). (1974). *Motivation and achievement.* New York: Winston (Halsted Press/Wiley).

Carver, C. S. (2001). *Affect and the functional bases of behavior: On the dimensional structure of affective experience.* Personality and Social Psychology Review Vol 5(4) Nov 2001, 345-356.

Carver, C. S. (2003, March). Pleasure as a sign you can attend to something else: Placing positive feelings within a general model of affect. *17*(2), 241-261.

Carver, C. S. (2004). *Negative affects deriving from the behavioral approach system.* Emotion Vol 4(1) Mar 2004, 3-22.

Carver, C. S., & Scheier, M. F. (1982). *Control theory: A useful conceptual framework for personality-social, clinical, and health psychology.* Psychological Bulletin Vol 92(1) Jul 1982, 111-135.

Carver, C. S., & Scheier, M. F. (2000). *Origins and functions of positive and negative affect: A control-process view.* New York, NY: Psychology Press.

Corr, P. J. (2008). Reinforcement Sensitivity Theory (RST): Introduction. In P. J. Corr (Ed.), *The reinforcement sensitivity theory of personality.* Cambridge: Cambridge University Press.

Feather, N. T. (1961). The relationship of persistence at a task to expectation of success and achievement related motives. *Journal of Abnormal and Social Psychology*, *63*, 552-561.

Frijda, N. H. (2007). *The laws of emotion.* Erlbaum.

Frijda, N. H. (2008, September). *How emotions work.* (Presented at the second bienniel symposium on Personality and Social Psychology, Warsaw, Poland)

Gilboa, E., & Revelle, W. (1994). Personality and the structure of affective responses. In S. H. M. van Goozen, N. E. Van de Poll, & J. A. Sergeant (Eds.), *Emotions: Essays on emotion theory* (p. 135-159). Hillsdale, NJ, England: Lawrence Erlbaum Associates, Inc.

Gilboa-Schechtman, E., Revelle, W., & Gotlib, I. H. (2000). Stroop interference following mood induction: Emotionality, mood congruence and concern relevance. *Cognitive Therapy and Research*, *24* (5), 491-502.

Gray, J. A., & McNaughton, N. (2000). *The neuropsychology of anxiety: An enquiry into the functions of the septo-hippocampal system* (2nd ed.). Oxford: Oxford University Press.

Halliday, T. R. (1980). Motivational systems and interactions between activities. In F. M. Toates & T. R. Halliday (Eds.), *Analysis of motivational processes* (p. 205-220). London: Academic Press.

Holland, O., & McFarland, D. (2001). *Artificial ethology.* Oxford, England: Oxford University Press.

Humphreys, M. S., & Revelle, W. (1984). Personality, motivation, and performance: A theory of the relationship between individual differences and information processing. *Psychological Review*, *91* (2), 153-184.

Kuhl, J., & Blankenship, V. (1979). The dynamic theory of achievement motivation: From episodic to dynamic thinking. *Psychological Review*, *85*, 239-248.

Locke, E. A. (1968). Toward a theory of task motivation and incentives. *Organizational Behavior and Human Performance*, *3*, 157-189.

Ortony, A., Norman, D. A., & Revelle, W. (2005). Effective functioning: A three level model of affect, motivation, cognition, and behavior. In J. Fellous & M. Arbib (Eds.), *Who needs emotions? The brain meets the machine.* (p. 173-202). New York: Oxford Univeristy Press.

R Development Core Team. (2008). *R: A language and environment for statistical computing.* Vienna, Austria. (ISBN 3-900051-07-0)

Revelle, W. (1986). Motivation and efficiency of cognitive performance. In D. R. Brown & J. Veroff (Eds.), *Frontiers of motivational psychology: Essays in honor of J. W. Atkinson* (p. 105-131). New York: Springer.

Revelle, W. (2008). The contribution of reinforcement sensitivity theory to personality theory. In P. J. Corr (Ed.), *The reinforcement sensitivity theory* (p. 508-527). Cambridge: Cambridge University Press.

Revelle, W., & Michaels, E. J. (1976). Theory of achievement-motivation revisited - implications of inertial tendencies. *Psychological Review*, *83*(5), 394-404.

Toates, F. M. (1975). *Control theory in biology and experimental psychology.* London: Hutchinson Educational Ltd.

Toates, F. M. (2004). Cognition, motivation, emotion and action: a dynamic and vulnerable interdependence. *Applied Animal Behaviour Science*, *86*(3-4), 173–204.

Toates, F. M. (2006). A model of the hierarchy of behaviour, cognition, and consciousness. *Consciousness and Cognition*, *15*(1), 75–118.

Toates, F. M., & Halliday, T. (Eds.). (1980). *Analysis of motivational processes.* London: Academic Press.

Zeigarnik, B. (1927/1967). On finished and unfinished tasks. In W. D. Ellis (Ed.), *A source book of Gestalt psychology (reprinted and translated from Psychological Forschung, 1927, 9, 1-85).* New York: Harcourt Brace.

Appendix
Simulation code

The R code for simulation of the CTA model is included in the **psych** package as well as in this appendix.

```
"cta" <- function(n=3,t=5000, cues = NULL, act=NULL, inhibit=NULL,
 consume = NULL,ten = NULL, type="both",fast=2 ,compare=FALSE) {
#simulation of the CTA reparamaterization of the dynamics of action

if(n > 4){ colours <- rainbow(n)} else {colours <- c("black","blue", "red", "green") }

step <- .05
ten.start <- ten
act.start <- act

if(is.null(cues)) {cues <- 2^(n-1:n)}
if(is.null(inhibit)) {inhibit <-  matrix(1,ncol=n,nrow=n)
                     diag(inhibit) <- .05}
if(n>1) {colnames(inhibit) <- rownames(inhibit) <- paste("A",1:n,sep="")}
if(is.null(consume) ) {consume <- diag(.05,ncol=n,nrow=n) }
excite <- diag(step,n)

#first run for time= t  to find the maximum values to make nice plots
#as well as to get the summary stats
if (is.null(ten.start)) {ten <- rep(0,n)} else {ten <- ten.start}
if(is.null(act.start) ) {act <- cues} else {act <- act.start}
maxact <- minact <-  minten <-  maxten <- 0
counts <- rep(0,n)
transitions <- matrix(0,ncol=n,nrow=n)
frequency <- matrix(0,ncol=n,nrow=n)
colnames(frequency) <- paste("T",1:n,sep="")
rownames(frequency) <- paste("F",1:n,sep="")
old.act <- which.max(act)
for (i in 1:t) {
        ten <- cues %*%  excite  + ten - act %*% excite %*% consume
        act <- ten %*% excite + act - act %*% excite %*% inhibit

        act[act<0] <- 0
        maxact <- max(maxact,act)
        minact <- min(minact,act)
        maxten <- max(maxten,ten)
```

```
        minten <- min(minten,ten)

        which.act <- which.max(act)
        counts[which.act] <- counts[which.act]+1
        transitions[old.act,which.act] <- transitions[old.act,which.act] + 1
        if(old.act!=which.act) { frequency[old.act,which.act] <-
                                      frequency[old.act,which.act] + 1
                                 frequency[which.act,which.act] <-
                                 frequency[which.act,which.act] +1}
        old.act <- which.act
}

#now do various types of plots, depending upon the type of plot desired

plots <- 1
action <- FALSE
#state diagrams plot two tendencies agaist each other over time
if (type!="none") {if (type=="state") {
        op <- par(mfrow=c(1,1))
        if (is.null(ten.start)) {ten <- rep(0,n)} else {ten <- ten.start}
        if(is.null(act.start) ) {act <- cues} else {act <- act.start}
        plot(ten[1],ten[2],xlim=c(minten,maxten),ylim=c(minten,maxten),col="black",
        main="State diagram",xlab="Tendency 1", ylab="Tendency 2")

        for (i in 1:t) {
                        ten <- cues %*%  excite  + ten - act %*% excite %*% consume
                        act <- ten %*% excite + act - act %*% excite %*% inhibit
                        act[act<0] <- 0
                        if(!(i %% fast)) points(ten[1],ten[2],col="black",pch=20,cex=.2)
                        }
        }  else {

#the basic default is to plot action tendencies and actions in a two up graph
if(type=="both") {if(compare) {op <- par(mfrow=c(2,2))} else {op <- par(mfrow=c(2,1))}
                plots <- 2 } else {op <- par(mfrow=c(1,1))}



if (type=="action") {action <- TRUE} else {if(type=="tend" ) action <- FALSE}

for (k in 1:plots) {
```

```
        if (is.null(ten.start)) {ten <- rep(0,n)} else {ten <- ten.start}
        if(is.null(act.start) ) {act <- cues} else {act <- act.start}
        if(action )   plot(rep(1,n),act,xlim=c(0,t),ylim=c(minact,maxact),
        xlab="time",ylab="action", main="Actions over time") else     plot(
        rep(1,n),ten,xlim=c(0,t),ylim=c(minten,maxten),
        xlab="time",ylab="action tendency",main="Action Tendencies over time")
                for (i in 1:t) {
                        ten <- cues %*%  excite  + ten - act %*% excite %*% consume
                        act <- ten %*% excite + act - act %*% excite %*% inhibit
                        act[act<0] <- 0
                        if(!(i %% fast) ) {if( action) points(rep(i,n),act,
                        col=colours,cex=.2
                            ) else points(rep(i,n),ten,col=colours,cex=.2) }}
action <- TRUE}
} }
results <- list(cues=cues,inihibition=inhibit,time = counts,
frequency=frequency, ten=ten, act=act)
return(results)
}
```