

Time-Behavior Models: A Conceptual Tool for Analyzing Decision-Making Options When Multiple Timescales and Network Effects Come into Play

Neil H. Wasserman

Adaptive Service Engineering

28 Coolidge Rd.

Belmont, MA 02478

nwasserman@adaptiveservices.com

Numerous studies in behavioral economics show that human decision-making tends to overweight short-term benefit over longer-term opportunity. The inability to pay proper attention to effects that emerge slowly over extended periods of time poses challenges to addressing problems in widely varying domains, including savings behavior, climate change, and health behaviors. The paper presents an approach to modeling individual human and organizational behaviors which are periodic and which extend over a range of timescales. Within this "time-behavior" framework, the determinants for shifting from short-response to longer-term regularized behaviors are examined from a cognitive and information theoretic perspective. A model is developed which differentiates short-term behaviors (called t_0) from behaviors which are characterized by repeated events with cumulative impact over time. These "t1-behaviors" reflect a type of Fourier decomposition of behaviors with multiple periodicities. T2 and t3-behaviors are introduced which account different network effects as t1-behaviors are replicated across populations. The model can be used as both a descriptive tool which accounts for powerful growth effects and a decision making tool to identify critical behaviors that act as control points for influencing change in a particular environmental domain. The paper suggests ways to understand the infrastructure that supports the transition from short-term t_0 time-behaviors to regularized t1 and higher-order behaviors. The model is structurally stable when applied to varying domains in financial services, healthcare, environment, and organizational change. Examples are provided.

1 Introduction

The most prominent metaphor for economics in the last century is that of physics. Economic observables like prices emerge from a kind of interacting gas of utility maximizers, each of whom carries out transactions based on rational calculations of self-interest. That tradition dates back to Daniel Bernoulli in his 1738 analysis of gambles in 1738 and has continued with increasing mathematical sophistication to this day. Such calculations, extended to multiple actors and multiple transactions over time, can become extremely complex and, therefore, costly to the decision-maker. Out of this conundrum arises another tradition dating at least to Alfred Marshall, which attempts to understand the observed psychology of human economic behavior and its effect on economic decision-making. In reality, human beings short-circuit these decision-making processes using what Gerd Gigerenzer and others call the heuristics of bounded rationality [Gigerenzer 2000, 2001]. A preference for short-term reward is one example of many biases or heuristics that imperfect human brains exhibit to deal with a world of limitless information and finite time and neural resources. No one brain is equivalent to the analytical power of a Commerce Department and so we get by with shortcuts.

These intuitive methods come at the price of introducing what may appear to be suboptimal preferences into the decision-making process, one of the most important of which is the bias in favor of short-term benefit, commonly called hyperdiscounting. The burgeoning field of behavioral economics has explored the consequences of short-term time preferences in great detail. Underweighting future effects has a large and often deleterious impact in relation to many areas of endeavor, including investment behaviors, healthcare, and the environment. In fact, in a useful collaboration of behavioral economics and neuroscience, it has been shown that short-term and long-term decisions employ distinctly different parts of the human brain [McClure, et al. 2004]. The ways that human beings account for future effects and adopt behaviors in relation to differing timescales is one focus of the “Time-Behavior Framework” explored in this paper.

Another approach to the problem of costly decision-making processes is based on the imposition of habit on economic behavior. If an activity is repeated over time in an automatic fashion, decision costs are minimized over the lifetime of the habit. The value of routines in organizations as a mechanism for reducing the costs and uncertainty involved in information transmission has been explored by many investigators beginning with Herbert Simon’s work in the 1950s [Simon 1957, Cyert and March 1963]. Gary Becker has also elaborated models of habitual behavior within a rational decision framework [Becker & Murphy 1988], which account for the influence of prior events on current behaviors. The relationship of routine to short-term time bias has also been developed in the many works on “self-command,” which address issues of self-discipline and procrastination. As in many other areas of behavioral analysis Thomas Schelling’s work has played a foundational role [Schelling 1978, 1984]. In this view, a major value of organizations and supervisory processes is countering the common disease of procrastination. Organizational rules and incentives exist to control short-term impulsive behavior.

In this paper, we propose a generalization of the idea of habit or ritual that takes specific account of the periodicity of such behaviors. As important, these periodic behaviors exhibit a coherence in relation to time, not only within individuals, but also across populations. We call these behaviors, regularized time-behaviors, or t-behaviors. They fall into four classes. t \emptyset behaviors are isolated single events. T1-behaviors are periodic events that have an incremental impact over time. T1-behaviors represent a kind of atomic grouping of events, zero-cost decisions that are either adopted or rejected as a whole. T2 and t3-behaviors reflect processes of networked replication of t1-behaviors.

The replicability of these behaviors over time and across populations creates powerful effects. Recent research on social cognition suggests that many features of our neural make-up are designed to reproduce social behavior and that humans have evolved large brains to accomplish the tasks required for navigating ever larger social groups [Hermann 2007 and Dunbar]. The adoption of t1, t2 and t3-behaviors permits the individual social group to have a powerful impact on the future in an environment of virtually costless decision-making. We suggest that such periodic networked behaviors are an important basis for how human cultures have used social behaviors to impact their futures. Reciprocally, cultures have evolved a set of capabilities support the propagation the ritualized, periodic behaviors we call t-behaviors. These abilities include the uniquely human capability to imitate behaviors, to vet behaviors through internalized norms, and to store and transmit the supporting knowledge from one individual to another and from one generation to the next. We call these capabilities the t-behavior infrastructure, a topic for later discussion. Understanding the factors that enable the persistence and propagation of t-behaviors may enable better strategies for controlling and changing behaviors critical to health, the environment and other applications.

2 Structure of Time-Behaviors

The t-behavior view involves a change in perspective not unlike a change that has occurred in our understanding the behavior of visual systems in people, cats, and other animal subjects. While our experience of sight is experienced as a spatial grid, with an image formed like pixels on a flat screen TV, the brain also processes images in relation to spatial frequencies, decomposing visual space in terms of multiple periodic functions. A similar perspective can be applied to time-behaviors. While our conscious experience of time is linear and continuous, it is also possible to view our relation to time in terms of sets of periodic events. As noted in the introduction, this representation is informationally much more compact and reflects the structure of many common behaviors that we associate with habits, rituals, routines, as well as biological and physical time cycles.

Time-behaviors can be usefully be divided into four classes, each of which reflects a distinct set of properties in relation to the effects of replication across a network and the effects of incremental impact over time.

2.1 tØ Behaviors

Behaviors that that respond to short-term exigencies and have a short-term time horizon for expected reward are designated tØ. A tØ time behavior represents the normally short-term behavior that is characteristic the response of most species response to an environmental opportunity or threat. For individuals and organizations, tØ behaviors or events include the everyday (and sometimes, every-second) interruptions that have become the normal course of life in our communications-driven environment. tØ events include urgent reactions to emergencies and responses to the small, but frequent demands of email, cell phones, news and entertainment media, ordinary conversation as well as the continuing, semiconscious input of our senses as we navigate our most immediate world.

2.2 t1-Behaviors

A t1-behavior is the first of three classes of extended time behaviors. We call these time behaviors “persistent time-behaviors.” The t1 class of behavior is the atomic unit for analyzing persistent time behaviors. Other persistent time-behaviors are distinguished by the way in which the t1-behavior is propagated across populations.

A t1-behavior consists of a series of linked, similar events or activities, which produce a cumulative impact on an individual or organization. Think of the process of a child learning to play a musical instrument, say, acquiring the skills to perform on a violin. That learning process may actually consist of several linked t1-behaviors. In this example, the child takes lessons once per week, practices five times per week, participates in orchestra rehearsals two times per week leading to a concert and perhaps a recital two times per year. In the case of t1 practice behavior, each practice session adds incrementally to the child’s skill. That incremental progress reflects a complex rewiring of neural connections in the young violinist’s malleable brain, changes her musculature, and acquisition of explicit knowledge of music and technique. The experience of repetitive events results in a set of conscious and non-conscious capabilities that we associate with musicianship. This t1-behavior has a structure which, over several years, sometimes results in a child for whom violin playing becomes a part of the way her mind and body operates. That structure, characteristic of all t1-behaviors, includes an activity that is learned and repeated, the practice session, a goal or vision of a future state, a scenario for getting there, and a set of norms that support the behavior. There are also measurable parameters that are associated with the t1-behavior such as frequency or repetition, incremental impact (growth factor), and probability of replication. The latter measure reflects the chance that the behavior will persist from one regular event to the next.

The violin example illustrates a t1 learning behavior. Most permanent learning can be viewed as a product of t1-behaviors. Cognitive changes in the brain occur slowly in response to repetition over time, whether the goal is learning multiplication tables or how to hit a baseball. T1-behaviors apply to many activities including social interactions and nurturing, discovery and exploration, product innovation, and the management of behaviors within a social group.

T1-behaviors have manifestations that are present in all human cultures, including those of business organizations. We sometimes call them habits, traditions, or rituals. Indeed, a promising subject for further study is the bi-directional relationship between t1-behaviors and the cultural environment. One may ask why we do not simply use the term, habit, rather than t1-behavior. The reason is that t1-behaviors have certain attributes that permit a more precise understanding of familiar behaviors like habits, rituals and manners. Habits, as they are commonly understood, are a special case. The more general view of the t1-behavior involves understanding a number of modeling characteristics. These include:

- Core attributes – The measures of change or impact associated with the behavior.
- Trigger – An event or condition that initiates an instance of the behavior.
- Initiation cost – The cost of establishing the t1-behavior.
- Set point or reference point – The starting point for the measured t1 attribute.
- Period – The time-interval between repeated events.
- Growth factor – The incremental growth as a result of each cycle.
- Decay envelope – Described by an exponential decay from the initiation point, this factor captures the tendency of persistent behaviors to dissipate in time.
- t1 – t1 linkage – This describes the coupling between atomic t1-behaviors. Complex t1-behaviors are those behaviors (the typical case) in which multiple behaviors are linked.
- T1 infrastructure – The t1 infrastructure consists of a those elements that sustain the identified behavior. This may include a knowledge base, norms, policies, and material resources.

T1-behaviors are closely connected with the cultural infrastructure in which they reside. For example, t1-behaviors act to form the norms in the culture and the shared set of information in the community or organization. Explicit guidance in the form of governance policies and procedures and regular behaviors involving training and mentoring act to establish an accepted set of t1-behaviors the organization. The infrastructure and normative framework of the community is one factor that supports the persistence of t1-behaviors across generations. Another source of persistence is the inertial effect of linkage among t1-behaviors. A particular t1-behavior becomes stable in part due to its dependence on other t1-behaviors.

2.3 Networked t2 and t3-behaviors

T2-behaviors are a generalization of the t1 class. If t1-behaviors can be thought of as a series of regularly spaced, cumulative events on a time line, t2 can be thought of as multiple t1s emerging from a central point of origin. The effect of the t1 impacts are then multiplied by means of replication of individual behaviors throughout a population.

For t1-behaviors the probability of repetition from event n to n+1 is an important measure of the impact of the behavior. For t2-behaviors, the important measure is the linkage among similar behaviors within a population. T2-behaviors emerge in

many different environments from savings and investment decisions to healthcare practices to climate change. To establish changes in business policy, t2 mechanisms are often carried out through a formal establishment and monitoring of procedures in the distributed business units of the organization.

T2-behaviors derive their effect from replication from a single point of control. This hub and spoke model of replication is visible, for example, in an organization that implements a policy change via a centrally administered training program. In contrast, t3-behaviors comprise mechanisms of replication in which nodes in the network are multiply connected. Each node generates t1-behaviors in related nodes. Rather than having a single distribution point, each member of the population carrying out the t1-behavior becomes a distribution node. The t3-behaviors are self-replicating. This model is similar to the spread of word-of-mouth information, with the significant difference that we are speaking of behavioral changes that persist in time. Consider the spread of a figure of speech such as the use of the word “bad” to mean “good.” A teenager may hear the word used in her social group, deem it to be cool, and begin to use the word. It is repeatedly used, supported by the norms of the group, and eventually becomes a persistent part of the linguistic behaviors of an individual and the individual’s local community. That behavior may be replicated in a t2 mode via incorporation in a television show or advertisement. But the dominant mode of propagation is the t3 mode of self-replication, in which each adopter of the behavior becomes a replicator.

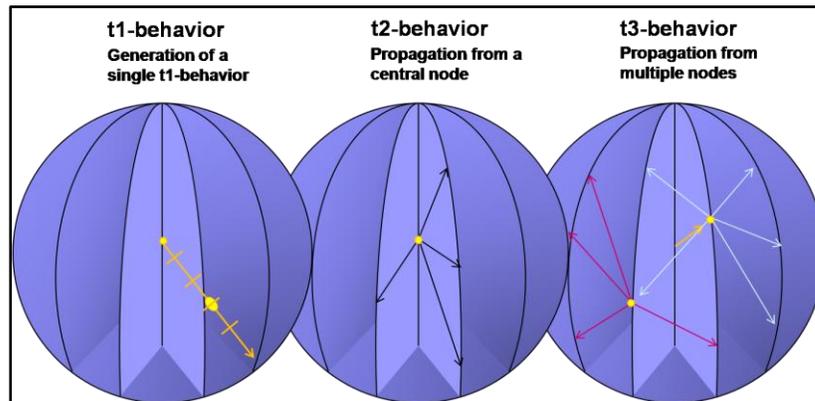


Figure 1- Time-behavior classes.

In Figure 1, the persistent t-behaviors are pictured geometrically. Here a t_0 behavior, or event at $t=0$, can be thought of as a single point at the center of a sphere. The sphere can be viewed as an object growing in time with a radius, t . A t1-behavior can then be pictured as a series of evenly spaced points on a line extending outward from the center. A t2-behavior is given by lines emanating from the central node at the center of the sphere. T3-behaviors propagate from each node, and multiply as new generations of t1-behaviors emerge.

2.4 Time-Behavior Impact

The categorization of t-behaviors serves a number of purposes. The different classes are far different in their capacities to effect change. In general, t \emptyset effects, such a single gain or loss in a stock trade, get washed out in the longer-term effects of persistent (t1, t2 and t3) time-behaviors. There are of course instantaneous t \emptyset events that can be catastrophic. Consider the effect of a large-scale terrorist incident or a destructive cyclone. Such events are, thankfully, rare. In reality, the randomness may be illusory. Many such dramatic events may be more accurately viewed as a direct or indirect product of longer-term t1, t2, and t3 effects. Consider the relationship between large-scale “random” weather events and more predictable behaviors that induce climate change.

t \emptyset events also generate persistent effects via consequential t1-behaviors. Take the investor who experiences a big one-time loss and as a result fearfully puts his money in a low-interest “safe” savings account for the long-term. The one-time loss quickly is overshadowed by the lost-opportunity to maintain an “efficient frontier” investment strategy. More common, however, are the t \emptyset events that merely draw our attention without much effect. The barrage of short-term events – email, “news”, television – often simply reflects the noise of life. They leave little trace in terms of memory or consequence.

The t1-behavior category is next in the order of increasing impact. Because of extension of t1-behaviors in time, repetitive events with even small individual effects can accumulate significantly over an extended interval. In the case of personal health, having the extra scoop of ice cream at the birthday party may add a fraction of an ounce to one’s weight and cause a temporary spike in glucose level, but in the long-run, the indulgence won’t matter. If that same scoop becomes part of a regular routine, however, the result will be significant in its effect on weight and health. T1 impacts overwhelm t \emptyset effects because the magnitude of the t1 impact grows cumulatively and often exponentially with time. What matters is the persistence of the behavior more than the magnitude of each event in the t1 series. The impact of t1-behavior is, therefore, sensitive to the impact of each event, but more sensitive to the persistence of the behavior in time. Getting the heart bypass may be important (a t \emptyset event). But the one-time arterial fix will have little impact on longevity without persistence in the recommended life style change (a t1 effect).

Linkage among time-behaviors increases the impact of the t2 and t3 categories. In the case of t2, behaviors are replicated from a central point of control. This hub and spoke model would occur in the case change in a security protocol, which is carried out by multiple departments. If the change is implemented, the effect grows linearly with the number of nodes connected to the hub. T3-behaviors have a very different growth pattern. With each node generating replicated t-behaviors across a population, the impact of the t3 model grows exponentially in time.

In summary, persistent time-behaviors are powerful for two reasons. First, the effects of persistent behaviors accumulate over time. The growth is sometimes exponential as in the case of the result of ongoing savings behavior. Second, the propagation of t1-behaviors through a network rapidly escalates the impact of each t1-behavior. The persistent action of t-behaviors creates resonant effects that are

sensitive to medium – in particular, the culture – in which the time-behavior resides. We can think of time-behaviors as waves in time that have resonant effects on the future state of the individual, organization, or culture.

2.5 Microstructure of Time Behaviors

The impact of time-behaviors can be modeled using traditional techniques. To sketch such a view of t1-behaviors, we can consider a t1-behavior that is a series of events with a period λ and an impact measure for each event, m , given by $c(t_m)$. Then the cumulative impact over n events is given by:

$$U_\lambda(n) = \sum_{m=1}^n \delta_T(P_m) c(t_m) \beta^{-t_m}$$

where $t_m = t_0 + \lambda m$, the time after m events. $P_m =$ the persistence measure of the t1-behavior at the time of the activity, m . $\delta_T(P_m) = 1$ for $P_m \geq T$ and $\delta_T(P_m) = 0$ for $P_m < T$, where T is a threshold of continued repetition of the event or activity. β^{-t_m} is the discount factor at the time of event, m . Alternatively, it may also be desirable to introduce a probability distribution in place of the $\delta_T(P_m)$ step function.

The cumulative impact of the t1-behavior is sensitive to the persistence of the behavior over time. The persistence is captured by a parameter P_m which must remain over the threshold, T , for the behavior to continue. One approach to valuing the persistence parameter is given in the following expression.

$$P_m = P_\lambda + P_{m0} + \sum_{r=1}^{m-1} S_0 P_r e^{-\alpha(m-r)}$$

where P_{m0} is the baseline persistence value at event, m , P_λ is the period-dependent infrastructure that supports the t1-behavior, and S_0 is the “social” factor that measures the influence of previous events on the current event, and α is a measure of the decay of influence of previous instances on the current event. For different conditions placed on P_m , we can derive an expected value of $\sum U(n)$ across a population. The persistence factor will depend on the social or networked environment of the particular t1-behavior.

This calculation is intended to capture the fact that persistence is enhanced through entrainment by means of previous events. In the case of a single interruption, the behavior may continue. But multiple interruptions will end the behavior since events several periods in the past will have little impact on the current event.

The t-behavior infrastructure that supports persistence is often dependent on the period of the behavior. Behaviors that are carried out on a daily basis, for example, require different support mechanisms from those that are carried out over longer intervals.

3 T-Behaviors, Informational Efficiency, and The Generation of Culture

A key advantage of time-behaviors, and an important reason why such behaviors are prominent in human societies and organizations, is informational efficiency. T0-behaviors consume significant informational and decision-making resources because they occur as single instances. The higher time-behavior categories replicate behavioral events and reuse information from one instance to another. Like reusable software components, the behaviors conserve previously generated information and experience. Such replication occurs longitudinally over time in the case of t1-behaviors and horizontally across population networks in the case of t2 and t3-behaviors.

Sometimes t-behaviors become part of consciously held strategies to change an environment. A campaign to increase the visibility and context of a brand, whether intended for a product or politician, depends on continuous repetition of an easily assimilable message. Yet most persistent t-behaviors are not understood as regularized periodic events. The behaviors recur independent of repeated decision-making. Commuting, grooming, comforting a child at bedtime, all happen without the thought of executing a regularized t-behavior. That is a good thing for both the efficient use of time and efficient use of brain resources. T1-behaviors are reusable. They can be called upon when needed. Like a software component, when the behavior is carried out, no new code needs to be written. The required module is on the shelf, ready to reuse. Moreover, the trigger for the regularized behavior is predetermined, written into the rules (and norms) governing the t1-behavior. Decision resources are in this way minimized at the cost of flexibility. It is a good bargain. T1-behaviors are often highly rigid, and that has significant value in a social environment that depends the stability and predictability of such behaviors. Because of that value, our brains have evolved to support the acquisition and stability of t1-behaviors. The downside is that such behaviors become difficult to change, even when change is consciously desirable. One useful perspective on the difficulty of behavioral change is understanding the context for the stability and social vetting of persistent time-behaviors. The Time-Behavior Framework, building on work in cognitive science, behavioral economics and evolutionary psychology, aims to provide such a context.

T1-behaviors are themselves an instrument for the capture of information required for the execution and communication of t1-behaviors. The cumulative knowledge that allows a machine shop to operate with predictable precision is the result of t1-behaviors within the production organization. T1 training behaviors enable t1 production behaviors. Because of information reuse, t1-behaviors are efficient in terms of information requirements and cost. This informational efficiency, what we would call a principle of information economy, is one factor that enables t1-behaviors to operate effectively in a social context. Because t1-behaviors encapsulate compact definitions of acceptable behaviors and other supporting information, they can be more easily transmitted to other individuals and groups. As t1-behaviors become t2-behaviors, replicated across the group, the information that

supports the behavior becomes social knowledge, a component of the t-behavior infrastructure.

T1-behaviors serve multiple functions within a culture. Behaviors define the boundaries of the culture – what is acceptable practice, who belongs, who doesn't. Violations of the behavioral norms often incur a cost or threat of a cost, the most extreme being exclusion from the social group. Anthropologists have documented the many ways in which adherence to rituals and other behaviors define requirements for group membership. In early hominid evolutionary history, exclusion often corresponded to a death sentence or, at least elimination of reproductive opportunities. There was, therefore, considerable adaptive pressure to acquire abilities needed to retain social group membership. Because of the relationship between certain t1 social behaviors and group membership, group members benefit from capabilities that support acquisition and retention of t1-behaviors within the reproductive unit.

In addition to defining membership, persistent time-behaviors generate other cultural capabilities. Language and dialect (identifiers of social membership), are themselves a product of the persistent nurturing behaviors of the child's social environment. Skill building, whether the product of formal education, informal social interactions, or competitive games, result from t1-behaviors carried out by both learner and mentor. This is one example of the many cultural features that are both products of t-behaviors and part of the cultural capabilities designed to support t-behaviors in terms of acquisition, propagation and enforcement. t-behaviors create conditions of knowledge generation, accumulation, and distribution and are both the means and products of the nurturing cycle. T-behaviors create and store the products of cultural innovation, whether they are physical products or culturally distributed practices.

There is an intricate relationship between t-behaviors and the evolution of culture. Genetic cognitive capabilities and cultural capabilities needed to manage persistent t-behaviors have coevolved. Understanding how those capabilities have developed in human history informs our understanding how our existing behaviors and organizational cultures can change in time.

One final point. The adoption of a t-behavior, such as the sanitation practices that reduce the chance of disease transmission, is of greater value when adopted across a population. But that universality comes at a cost. It requires a social investment of time, cognitive attention, and often material resources. This means that t2-behaviors involving the entire social unit cannot be adopted willy-nilly. Consequently, there is high value in a vetting process, which determines which t-behaviors are acceptable or required. This in turn depends on some structure of authority. That authority may take multiple forms, a religious text, or a leader with authority, sometimes divine, so recognized by the community. That authority may be communicated by means of symbolic objects, places or rituals. A rite of passage, whether through circumcision or through doctoral research, commends membership in a defined community, with attendant expectations of behavioral conformance. In this way, the rituals of preparation required for admission to the community helps train the entrant in the t-behaviors that define the community.

Anthropologists have devoted a great deal of useful research to understanding the interplay between rituals and belief systems in traditional societies. Here will simply note that the selection and enforcement of recognized t-behaviors is often accomplished through internalized value-based criteria, otherwise known as norms, preferences and beliefs. This is a low-cost means for enforcement, reducing the need for decision-making on the part of individuals within the group. It is the behavioral analog of Thomas Kuhn's normal science. Imitation and coherent t-behaviors within the social group cost less than innovation and uncertainty in a world of behavioral options. (For a detailed discussion of the balance between imitation and innovation see [Richerson 2005].) In this context, belief systems are valuable as an instrument for transforming t1-behaviors into coherent t2-behaviors across the social group.

Because the power and efficiency of t-behaviors grows with the size of the social group, it is not surprising that hominid intelligence evolved to handle the complexities of social interactions in ever larger social units. [see Dunbar and Shultz 2007]. These capabilities for managing social relationships are a subset of the larger set of individual and social cognitive capabilities, which support the regulation and transmission of t-behaviors in two dimensions, across social groups and across generations. How have we as a species managed to stabilize important t-behaviors across generational time? The question addresses nothing less than why we care about the future. How have we as a species developed the capacity to imagine possible futures and then act on that knowledge? That capacity is no accident of nature, but rather a key to our survival both in both our evolutionary past and in our uncertain future.

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