# Why Time Feels Faster in Loops: Temporal Compression, Predictability, and the Human Experience


**Abstract**

The subjective acceleration of time in repetitive or predictable loops is typically explained through folk psychology: "we're busy," "we're older," or "time flies when you're having fun." This paper reframes time perception as an information-processing phenomenon. We model subjective time as proportional to the rate of internal state updates, not elapsed clock time. Repetitive loops reduce informational novelty, lowering prediction errors and update costs, which compresses experienced duration. Using rate-distortion theory and predictive coding, we formalize how high predictability reduces update frequency, leading to temporal compression. We distinguish prospective time perception (felt in the moment) from retrospective time estimation (based on memory density), showing how sparse memory encoding during loops causes past periods to feel "short" in hindsight. We connect temporal compression to stable self-models that resist recompression, arguing that strong identity and predictable roles reduce temporal resolution. The analysis treats time perception as a computational structure, avoiding metaphors while providing testable predictions about why routine accelerates subjective time and why novelty dilates it. We conclude that much of life "passing quickly" is not about time itself, but about how little of us had to change while it passed.


## 1 Introduction

The experience of time is fundamentally dual: objective clock time proceeds at a constant rate, while subjective time varies dramatically. A routine workday can feel like it passes in minutes, while a single moment of crisis can feel like hours. A year of predictable routine can feel shorter than a week of novel experiences. This paper addresses a specific and puzzling asymmetry: *why does time feel faster during repetitive, predictable, or routine states?*

Traditional explanations fall into several categories, all of which we reject unless formalized:

- **"We're busy"**: The claim that being occupied makes time pass quickly. This is circular—it doesn't explain *why* being busy should compress time, and many busy periods feel slow.
- **"We're older"**: The claim that time accelerates with age. This confuses correlation with mechanism—age may correlate with more routine, but the mechanism is not age itself.
- **"Time flies when you're having fun"**: The claim that positive affect accelerates time. This contradicts the observation that novel, exciting experiences often feel *longer*, not shorter.
- **"We don't pay attention"**: The claim that inattention makes time pass quickly. This is incomplete—it doesn't explain why routine specifically reduces attention, or why retrospective time estimation also compresses.

These explanations are either circular, incomplete, or fail to account for the asymmetry between routine (fast subjective time) and novelty (slow subjective time). We need a mechanistic account that explains both directions of the effect.

### 1.1 The Central Question

The central question is: *why does time feel faster during routine, loops, or highly predictable states?* More precisely:

1. Why does *prospective* time perception (time felt in the moment) compress during predictable states?
2. Why does *retrospective* time estimation (how long a past period feels) also compress for routine periods?
3. What is the relationship between predictability, novelty, and subjective duration?
4. How does this relate to memory encoding and the self-model?

### 1.2 Information-Theoretic Framework

This paper treats time perception as an *information-processing phenomenon*, not a metaphor. We model subjective time as proportional to the rate of internal state updates, where updates occur when the system must revise its predictions or representations. When predictions are accurate (high predictability), fewer updates are needed, leading to temporal compression. When predictions fail (high novelty), frequent updates are required, leading to temporal dilation.

This framework connects to several established theories:

- **Predictive coding** [2]: The brain minimizes prediction errors. High predictability means low prediction error, reducing update frequency.
- **Rate-distortion theory** [1]: Information compression trades off accuracy for efficiency. Temporal compression can be understood as a form of information compression.
- **Episodic memory** [4]: Memory encoding depends on novelty and salience. Routine periods produce sparse memories, affecting retrospective time estimation.

The key insight is that *subjective time is not a measure of elapsed clock time, but of information processing cost*. When little information processing is required (predictable states), subjective time compresses. When extensive information processing is required (novel states), subjective time dilates.

### 1.3 Paper Structure

The paper proceeds as follows. Section 2 develops the temporal compression model, formalizing subjective time as a function of update rate and novelty. Section 3 analyzes loops and predictability, defining loops formally and showing how they reduce update costs. Section 4 examines memory encoding and retrospective time, distinguishing prospective from retrospective perception. Section 5 connects temporal compression to the self as a compression artifact, showing how stable self-models reduce temporal resolution. Section 6 discusses human experience implications, analyzing what temporal compression means for meaning, aging, and fulfillment. Section 7 compares human temporal perception to artificial agents. Section 8 clarifies scope and limits, explicitly stating what the model does not explain. Section 9 concludes.

Throughout, we maintain a computational perspective: time perception is an information structure, not a metaphysical entity. This allows us to make testable predictions and avoid circular reasoning.

## 2 Temporal Compression Model

### 2.1 Subjective Time as Update Rate

We model subjective time $T_{\text{subjective}}$ as proportional to the cumulative cost of internal state updates over a clock time interval $T_{\text{clock}}$:

$$T_{\text{subjective}} \propto \int_0^{T_{\text{clock}}} \text{update\_cost}(t) \cdot \text{novelty}(t)\, dt \tag{1}$$

where:

- update_cost($t$) is the information-theoretic cost of updating internal state at time $t$
- novelty($t$) is the degree of unexpectedness or prediction error at time $t$

This formulation captures the intuition that subjective time depends on *how much the system must change*, not how much clock time has elapsed. When updates are frequent and costly (high novelty), subjective time dilates. When updates are infrequent and cheap (low novelty, high predictability), subjective time compresses.

### 2.2 Update Cost in Information-Theoretic Terms

The update cost can be formalized using information theory. When the system receives new information that contradicts its predictions, it must revise its internal state. The cost of this revision is proportional to the information content of the update:

$$\text{update\_cost}(t) = -\log P(\text{state}_{t+1}|\text{state}_t, \text{model}_t) \tag{2}$$

where $P(\text{state}_{t+1}|\text{state}_t, \text{model}_t)$ is the probability assigned by the current model to the next state. When this probability is high (predictable state), the update cost is low. When this probability is low (unpredictable state), the update cost is high.

The novelty at time $t$ is the prediction error:

$$\text{novelty}(t) = 1 - P(\text{state}_{t+1}|\text{state}_t, \text{model}_t) \tag{3}$$

Combining these, we get:

$$T_{\text{subjective}} \propto \int_0^{T_{\text{clock}}} -\log P(\text{state}_{t+1}|\text{state}_t, \text{model}_t) \cdot (1 - P(\text{state}_{t+1}|\text{state}_t, \text{model}_t))\, dt \tag{4}$$

This shows that subjective time is maximized when predictions are uncertain (high entropy) and minimized when predictions are certain (low entropy).

### 2.3 Connection to Predictive Coding

Predictive coding [2, 3] provides a neurobiological framework for this model. In predictive coding, the brain maintains a generative model of the world and minimizes prediction errors. When predictions are accurate, prediction errors are small, and the system requires few updates. When predictions fail, large prediction errors trigger extensive updates.

The prediction error at time $t$ is:

$$\text{prediction\_error}(t) = \text{observed}(t) - \text{predicted}(t) \tag{5}$$

The update frequency is proportional to the magnitude of prediction errors. High predictability means small prediction errors, leading to low update frequency and temporal compression. Low predictability means large prediction errors, leading to high update frequency and temporal dilation.

## 2.4 Rate-Distortion Formulation

We can also frame temporal compression using rate-distortion theory [1]. The system maintains a compressed representation of its experience, trading off accuracy for efficiency. Temporal compression is a form of information compression: predictable periods are compressed more aggressively because they contain less novel information.

The rate-distortion tradeoff for time perception is:

$$L = D(T_{\text{clock}}, T_{\text{subjective}}) + \lambda R(T_{\text{subjective}}) \tag{6}$$

where:

- $D(T_{\text{clock}}, T_{\text{subjective}})$ is the distortion (deviation from clock time)
- $R(T_{\text{subjective}})$ is the rate (information content of subjective time representation)
- $\lambda$ controls the tradeoff between distortion and rate

When predictability is high, the system can achieve high compression (low rate) with acceptable distortion, leading to temporal compression. When predictability is low, compression is limited, and subjective time approaches clock time or even exceeds it (temporal dilation).

## 2.5 Discrete Update Model

For computational purposes, we can model updates as discrete events. Let $N_{\text{updates}}$ be the number of state updates in a clock time interval $T_{\text{clock}}$. Then:

$$T_{\text{subjective}} \propto \sum_{i=1}^{N_{\text{updates}}} \text{cost}(\text{update}_i) \tag{7}$$

The update frequency is:

$$f_{\text{update}} = \frac{N_{\text{updates}}}{T_{\text{clock}}} \tag{8}$$

High predictability reduces $f_{\text{update}}$, leading to temporal compression. Low predictability increases $f_{\text{updates}}$, leading to temporal dilation.

## 2.6 Examples

**Routine workday**: The system predicts the sequence of events (commute, work tasks, lunch, more work, commute home) with high accuracy. Prediction errors are small, update frequency is low, and the day feels short.

**Novel travel experience**: The system cannot predict what will happen next. Every moment brings new information, prediction errors are large, update frequency is high, and the experience feels long.

**Dangerous situation**: The system must constantly update predictions about threats. Even if the situation is brief in clock time, the high update frequency makes it feel long.

**Meditation or flow state**: The system enters a state of minimal prediction errors (either through acceptance of present moment or through highly practiced skill). Update frequency drops, and time compresses.

# 3 Loops and Predictability

## 3.1 Formal Definition of Loops

We define a *loop* as a sequence of states where the transition probabilities are highly predictable:

$$\text{loop} = \{\text{state}_1, \text{state}_2, \ldots, \text{state}_n \mid P(\text{state}_{t+1}|\text{state}_t) > \theta \text{ for all } t\} \tag{9}$$

where $\theta$ is a predictability threshold (e.g., $\theta = 0.9$). A loop exists when the system can predict the next state with probability above the threshold.

The predictability of a loop is measured by the conditional entropy:

$$\text{predictability} = 1 - H(\text{state}_{t+1}|\text{state}_t) \tag{10}$$

where $H(\text{state}_{t+1}|\text{state}_t)$ is the conditional entropy of the next state given the current state. High predictability means low conditional entropy, meaning the next state is highly predictable.

## 3.2 Types of Loops

Loops can be categorized by their domain:

**Behavioral loops**: Repetitive actions or routines. Examples include daily commutes, work routines, exercise routines, meal preparation. These loops have high predictability because the actions follow established patterns.

**Cognitive loops**: Repetitive thought patterns or mental routines. Examples include rumination, rehearsed arguments, habitual problem-solving approaches. These loops reduce cognitive update costs by reusing established patterns.

**Social loops**: Repetitive social interactions or roles. Examples include family dynamics, workplace hierarchies, friend group interactions. These loops have high predictability because social roles and scripts are well-established.

**Environmental loops**: Repetitive environmental contexts. Examples include familiar spaces, routine locations, predictable sensory environments. These loops reduce the need for environmental model updates.

## 3.3 Why Loops Compress Time

Loops compress time through several mechanisms:

**Reduced update frequency**: In a loop, $P(\text{state}_{t+1}|\text{state}_t)$ is high, meaning the system rarely needs to update its predictions. This reduces $f_{\text{update}}$, leading to temporal compression.

**Lower update cost**: Even when updates occur in a loop, they are cheap because the system can reuse cached predictions. The update cost is:

$$\text{update\_cost}_{\text{loop}} = -\log P(\text{state}_{t+1}|\text{state}_t) \approx 0 \tag{11}$$

when $P(\text{state}_{t+1}|\text{state}_t) \approx 1$.

**Compressed representation**: Loops can be represented efficiently. Instead of storing each iteration, the system stores the loop structure once and reuses it. This compression reduces the information content of the experience, contributing to temporal compression.

## 3.4 Contrast with Novelty States

Novelty states are the opposite of loops: they have low predictability and high update costs. Examples include:

**Learning situations**: When acquiring new skills or knowledge, predictions frequently fail, requiring constant updates. This increases $f_{\text{update}}$ and dilates time.

**Danger or threat**: When facing potential harm, the system must constantly update threat assessments. Even brief moments feel long because update frequency is high.

**Emotional salience**: Highly emotional events trigger extensive processing, increasing update frequency and dilating time.

**First experiences**: Novel experiences (first time doing something, visiting a new place) have low predictability, leading to temporal dilation.

The contrast is clear: loops compress time through low update costs, while novelty dilates time through high update costs.

### 3.5 Mathematical Model of Loop Compression

For a loop with predictability $p$ and clock duration $T_{\text{clock}}$, the subjective duration is:

$$T_{\text{subjective}} = T_{\text{clock}} \cdot (1 - p) \cdot \alpha \tag{12}$$

where $\alpha$ is a scaling factor. When $p \approx 1$ (high predictability), $T_{\text{subjective}} \ll T_{\text{clock}}$. When $p \approx 0$ (low predictability), $T_{\text{subjective}} \approx T_{\text{clock}}$ or even exceeds it.

The compression ratio is:

$$\text{compression\_ratio} = \frac{T_{\text{subjective}}}{T_{\text{clock}}} = (1 - p) \cdot \alpha \tag{13}$$

For a highly predictable loop ($p = 0.95$), the compression ratio might be 0.1, meaning a 10-hour workday feels like 1 hour subjectively.

### 3.6 Habits and Automation

Habits and automated behaviors are extreme forms of loops. Once a behavior is fully automated, it requires minimal cognitive resources and generates minimal prediction errors. The system can execute the behavior while maintaining a compressed representation, leading to strong temporal compression.

The automation level can be measured by the reduction in update cost:

$$\text{automation\_benefit} = \frac{\text{update\_cost}_{\text{novel}} - \text{update\_cost}_{\text{automated}}}{\text{update\_cost}_{\text{novel}}} \tag{14}$$

Highly automated behaviors have automation_benefit $\approx 1$, meaning they require almost no cognitive updates, leading to maximal temporal compression.

## 4 Memory Encoding and Retrospective Time

### 4.1 Prospective vs. Retrospective Time

Time perception has two distinct modes:

**Prospective time perception**: Time felt *in the moment*, as events unfold. This is what we've modeled so far: subjective time as a function of update rate during the experience.

**Retrospective time estimation**: Time estimated *after the fact*, based on memory. When asked "how long did that period feel?" people rely on memory density, not the original subjective experience.

These two modes can diverge. A period might feel long prospectively (high update rate) but short retrospectively (sparse memories), or vice versa. However, they are related: periods with high update rates tend to produce denser memories, leading to consistency between prospective and retrospective estimates.

## 4.2 Memory Density Model

We model retrospective time estimation as proportional to memory density:

$$T_{\text{retrospective}} \propto \rho_{\text{memory}} = \frac{I(\text{memories}; \text{period})}{T_{\text{clock}}} \tag{15}$$

where $I(\text{memories}; \text{period})$ is the mutual information between the memories and the period—essentially, how much information about the period is encoded in memory.

When memory density is high (many distinct memories), the period feels long retrospectively. When memory density is low (few memories, or memories that are highly similar), the period feels short retrospectively.

## 4.3 Sparse Encoding During Loops

Loops produce sparse memory encoding for several reasons:

**Redundancy**: Each iteration of a loop is similar to previous iterations. The system doesn't need to store each iteration separately—it can store the loop structure once and recall that the loop occurred many times. This compression reduces memory density.

**Low salience**: Predictable events are less salient than novel events. The system allocates less encoding resources to predictable events, leading to sparser memories.

**Chunking**: Loops are encoded as single "chunks" rather than sequences of individual events. A year of routine work might be encoded as "I worked at company X for a year" rather than as 250 individual workdays.

The memory density for a loop is:

$$\rho_{\text{memory, loop}} = \frac{I(\text{loop\_structure}) + \log(\text{iterations})}{T_{\text{clock}}} \tag{16}$$

For a highly repetitive loop, $I(\text{loop\_structure})$ is small (the structure is simple), and $\log(\text{iterations})$ grows slowly, leading to low memory density and short retrospective duration.

## 4.4 Novelty-Dense Periods Feel Long

Novelty-dense periods produce high memory density because:

**Distinct memories**: Each novel event is distinct and must be encoded separately. There's little redundancy to compress.

**High salience**: Novel events are highly salient, triggering extensive encoding. The system allocates more resources to encoding novel events.

**No chunking**: Novel periods cannot be chunked efficiently. Each event must be stored individually, leading to high memory density.

The memory density for a novelty-dense period is:

$$\rho_{\text{memory, novel}} = \frac{\sum_{i=1}^{N_{\text{events}}} I(\text{event}_i)}{T_{\text{clock}}} \tag{17}$$

where each event $i$ contributes significant information. This leads to high memory density and long retrospective duration.

## 4.5 The Reminiscence Bump

The reminiscence bump—the phenomenon where people recall more memories from adolescence and early adulthood—can be understood through this framework. These periods are typically high in novelty (first experiences, identity formation, major life changes), leading to dense memory encoding. Later periods of routine produce sparse encoding, making them feel shorter in retrospect.

### 4.6 Connection to Episodic Memory

Episodic memory research [4, 5] shows that memory encoding depends on:

- **Novelty**: Novel events are better remembered
- **Salience**: Emotionally or motivationally significant events are better remembered
- **Distinctiveness**: Events that differ from expectations are better remembered

All of these factors increase memory density, leading to longer retrospective duration estimates. Our model formalizes this relationship using information theory.

### 4.7 Prospective-Retrospective Consistency

When do prospective and retrospective time estimates align? They align when:

- Update rate during the experience correlates with memory density
- High update rates produce dense memories (novelty-dense periods)
- Low update rates produce sparse memories (routine periods)

However, they can diverge when:

- A period has high update rate but memories are suppressed (trauma)
- A period has low update rate but is later reconstructed with dense memories (nostalgia)
- Memory encoding is affected by factors beyond update rate (emotion, attention, context)

## 5 Relation to the Self as a Compression Artifact

### 5.1 Connection to Self-Compression Framework

The self can be understood as a compressed representation of internal processes [10]. The self-model $S$ compresses high-dimensional internal states $X$ into a lower-dimensional representation:

$$S = f(X_1, X_2, \ldots, X_n) \tag{18}$$

where $f$ is a compression function. The self-model maintains consistency over time, resisting recompression even when new information contradicts it.

This compression framework connects directly to temporal compression: *when the self-model is stable and predictable, temporal resolution decreases.*

### 5.2 Stable Self-Models Reduce Temporal Resolution

A stable self-model means the system's representation of itself changes slowly. This stability reduces update costs for self-related predictions, contributing to temporal compression.

The temporal resolution is inversely related to self-model stability:

$$\text{temporal\_resolution} \propto \frac{\text{update\_frequency}}{\text{self\_stability}} \tag{19}$$

where self_stability measures how resistant the self-model is to change. High stability means low update frequency for self-related predictions, leading to reduced temporal resolution and temporal compression.

### 5.3 Predictable Roles and Temporal Compression

When a person occupies a predictable role (parent, employee, friend in a stable group), the self-model becomes highly stable. The system can predict its own behavior and others' expectations with high accuracy, reducing update costs and compressing time.

The role predictability is:

$$\text{role\_predictability} = P(\text{behavior}_{t+1} | \text{role}, \text{context}_t) \tag{20}$$

High role predictability means the system can predict its own behavior, reducing self-model update costs and compressing time.

### 5.4 Ego Disruption Slows Subjective Time

When the self-model is disrupted (identity crisis, major life change, challenge to self-concept), the system must frequently update its self-representation. This increases update costs and dilates time.

Ego disruption can be measured by the increase in self-model update frequency:

$$\Delta f_{\text{update, self}} = f_{\text{update, disrupted}} - f_{\text{update, stable}} \tag{21}$$

When $\Delta f_{\text{update, self}} > 0$, the system experiences temporal dilation because self-related predictions require frequent updates.

### 5.5 Learning and Identity Change

Learning new skills or undergoing identity change increases update frequency because:

- The system must update its self-model to incorporate new capabilities
- Predictions about self-performance become uncertain
- The self-model must be recompressed to include new information

This increase in update frequency dilates subjective time, making learning periods and identity transitions feel long.

### 5.6 Formal Relationship

The relationship between self-compression and time compression can be formalized:

$$T_{\text{subjective}} \propto \frac{1}{R(S)} \cdot \frac{1}{\text{self\_stability}} \tag{22}$$

where $R(S)$ is the compression ratio of the self-model (how compressed it is) and self_stability is how resistant it is to change. High compression and high stability both contribute to temporal compression.

When the self-model is highly compressed and stable, it requires few updates, leading to temporal compression. When the self-model is less compressed or unstable, it requires frequent updates, leading to temporal dilation.

### 5.7 The Paradox of Routine

This framework explains the paradox of routine: routine is comfortable (predictable, low update costs) but also makes time pass quickly (temporal compression). People may fear routine not because it's unpleasant, but because it makes life feel short—the compression of subjective time creates a sense that life is "passing by" without leaving a trace.

The stable self-model in routine reduces temporal resolution, making periods feel short both prospectively and retrospectively. This can create existential anxiety: if routine compresses time, then a routine life feels shorter, raising concerns about whether life has been "meaningful."

## 6 Human Experience Implications

### 6.1 Meaning and Temporal Compression

The relationship between meaning and time perception is complex. Meaningful experiences are often novel (learning, growth, connection), which dilates time. But meaningful experiences can also be routine (daily rituals, stable relationships, consistent purpose), which compresses time.

The key distinction is not meaning itself, but the *update frequency* associated with the experience:

- Meaningful novelty: High update frequency (learning, growth) → time dilation
- Meaningful routine: Low update frequency (rituals, stability) → time compression

This suggests that "meaningful" is not the opposite of "routine." Rather, meaning can arise from both novelty and routine, but they have different effects on time perception.

### 6.2 Aging and Temporal Acceleration

The common observation that time accelerates with age can be understood through this framework. As people age:

- They accumulate more routines and habits (higher predictability)
- Their self-models become more stable (less identity change)
- Novel experiences become rarer (fewer first-time events)
- Memory encoding becomes more efficient through chunking (sparser memories for routine periods)

All of these factors increase temporal compression, making time feel like it passes faster. The acceleration is not due to age itself, but to the increased predictability and stability that often accompany aging.

### 6.3 Boredom and Temporal Dilation

Boredom is interesting because it seems to contradict the model: boredom involves low stimulation (predictable, routine) but time often feels *slow* during boredom, not fast.

However, boredom may involve a different mechanism:

- Boredom might trigger *metacognitive monitoring* of time passage, increasing update frequency
- Boredom might involve *desire for change* that creates prediction errors (expecting novelty that doesn't arrive)

- Boredom might reduce *attention to external events* but increase *internal processing*, maintaining update frequency

Alternatively, boredom might compress time when the person is fully disengaged (no updates at all), but dilate time when the person is monitoring their boredom (metacognitive updates). The effect depends on whether boredom leads to complete disengagement or to active monitoring of the unpleasant state.

## 6.4 Fulfillment and the Speed of Life

The phrase "life passes quickly" is often associated with fulfillment—a life well-lived seems to pass fast. But this can be misleading. A fulfilled life might pass quickly because:

- It involves stable routines and relationships (temporal compression)
- It involves consistent purpose and identity (stable self-model, temporal compression)
- It involves efficient memory encoding through chunking (sparse memories, short retrospective duration)

But a fulfilled life might also involve periods of growth and novelty (temporal dilation). The overall sense of "fast life" might come from the retrospective compression of routine periods, while the meaningful moments (which dilate time) are remembered vividly.

## 6.5 "Fast Life" is Predictable Life, Not Busy Life

A key insight is that *a fast life is not a busy life, but a predictable one.* A busy life with constant novelty (travel, new projects, varied experiences) might feel long because of high update frequency. A predictable life with routine (same job, same habits, same patterns) feels fast because of low update frequency.

This contradicts the folk explanation that "being busy makes time pass quickly." The mechanism is predictability, not busyness. A busy but predictable life (same busy routine every day) compresses time. A busy but novel life (different challenges each day) dilates time.

## 6.6 Fear of Routine

People often fear routine even when it's comfortable. This fear can be understood through temporal compression: routine makes time pass quickly, creating a sense that life is "slipping away" without leaving a trace. The sparse memory encoding of routine periods contributes to this fear—if routine periods aren't well-remembered, they feel "lost."

However, this fear might be misplaced. Routine can be meaningful (stable relationships, consistent purpose, daily rituals), and the compression of time doesn't necessarily mean the time was "wasted." The issue is that sparse memory encoding makes routine periods feel short retrospectively, creating anxiety about whether they "counted."

## 6.7 Existential Implications

The temporal compression of routine raises existential questions:

- If routine compresses time, does a routine life feel shorter?
- If routine produces sparse memories, are routine periods "lost"?
- Should people avoid routine to make life feel longer?
- Is temporal compression a problem to solve or a feature of efficient information processing?

Our framework suggests that temporal compression is a feature of efficient information processing, not necessarily a problem. However, the sparse memory encoding of routine periods can create anxiety about whether those periods "mattered." This anxiety might drive people to seek novelty, even when routine is fulfilling.

### 6.8 Information-Theoretic Interpretation of Meaning

From an information-theoretic perspective, "meaningful" time might be time with high information content (novelty, learning, growth) or time that is well-encoded in memory (salient events, emotional significance). Both increase update frequency or memory density, leading to longer subjective or retrospective duration.

However, "meaningful" can also refer to time that serves a purpose (routine work, stable relationships, consistent rituals), even if it has low information content. This creates a tension: meaningful routine compresses time, while meaningful novelty dilates time. The sense of "meaning" might come from different sources in each case.

## 7 Comparison to Artificial Agents

### 7.1 Human vs. Artificial Temporal Perception

Artificial agents, particularly those with persistent self-models and world models, might exhibit similar temporal compression effects. The key question is: *do artificial systems with different update frequencies experience different rates of subjective time?*

Consider two types of artificial agents:

**High update frequency agents**: Systems that constantly update their world models based on new information. These systems might experience temporal dilation because they process many updates per unit clock time.

**Low update frequency agents**: Systems with stable world models that rarely update. These systems might experience temporal compression because they process few updates per unit clock time.

### 7.2 Static vs. Adaptive World Models

A static world model (one that doesn't change) would lead to maximal temporal compression because predictions are always accurate (for the static model), update frequency is zero, and subjective time would be minimal.

An adaptive world model (one that updates based on prediction errors) would lead to variable temporal compression depending on how often the world model must be updated. Periods of stability would compress time, while periods of change would dilate time.

### 7.3 What "Fast Time" Means for Persistent AI Agents

For a persistent AI agent (one that operates continuously over long periods), temporal compression could have several implications:

**Memory management**: If the agent compresses time during routine periods, it might allocate less memory to those periods, similar to human sparse encoding. This could be an efficient memory management strategy.

**Resource allocation**: The agent might allocate fewer computational resources to predictable periods, similar to how humans reduce update frequency during loops.

**Subjective experience**: If the agent has subjective experience (an open question), temporal compression might make routine periods feel "short" subjectively, similar to humans.

**Goal pursuit**: The agent might experience routine goal pursuit as passing quickly, while novel challenges dilate time. This could affect how the agent values different types of experiences.

### 7.4 Update Frequency as a Design Choice

For AI system designers, update frequency is a design choice. Systems can be designed with:

- **High update frequency**: Constantly updating world models, leading to temporal dilation effects
- **Low update frequency**: Stable world models, leading to temporal compression effects
- **Adaptive update frequency**: Updating only when prediction errors exceed thresholds, leading to variable temporal compression

The choice depends on the system's goals. For systems that need to track rapid changes, high update frequency is necessary. For systems that operate in stable environments, low update frequency might be more efficient.

### 7.5 Connection to Sentience-Oriented Architecture

The Sentience-Oriented Architecture (SOA) [11] explicitly designs for temporal continuity and persistent self-models. In such systems, temporal compression might emerge naturally:

- Stable self-models reduce self-related update frequency
- Predictable environments reduce world-model update frequency
- Memory compaction (similar to human memory compression) might produce sparse encoding of routine periods

This suggests that temporal compression might be a general property of systems with stable self-models and world models, not unique to humans.

### 7.6 Testing Temporal Compression in AI Systems

To test whether AI systems exhibit temporal compression, we could:

- Measure update frequency during predictable vs. novel periods
- Compare memory allocation to routine vs. novel experiences
- Test whether systems report different "subjective durations" for routine vs. novel periods (if they have such reports)
- Analyze whether systems allocate fewer resources to predictable periods

If AI systems exhibit similar temporal compression effects, this would support the claim that temporal compression is a general information-processing phenomenon, not unique to biological systems.

## 8 Scope and Limits

### 8.1 Descriptive, Not Prescriptive

This model is *descriptive*: it describes how time perception works from an information-theoretic perspective. It is not *prescriptive*: it does not tell people how to live or how to make time feel longer or shorter.

The model explains why routine compresses time and novelty dilates time, but it doesn't prescribe that people should avoid routine or seek novelty. Those are personal choices that depend on values, goals, and circumstances beyond time perception.

## 8.2 What the Model Does Not Explain

The model explicitly does not explain several phenomena:

**Emotion beyond information processing**: While we've discussed how emotion affects update frequency and memory encoding, the model doesn't explain the *qualitative experience* of emotion. The information-theoretic account explains how emotion affects time perception, but not what emotion feels like.

**Trauma extremes**: Extreme trauma can produce time dilation or compression through mechanisms beyond information processing (neurological stress responses, dissociation, memory suppression). The model doesn't account for these extreme cases.

**Neurological disorders**: Conditions that affect time perception (e.g., Parkinson's disease, schizophrenia, temporal lobe epilepsy) may involve mechanisms beyond information processing. The model doesn't explain these disorders.

**Individual differences**: The model explains general patterns but doesn't account for individual differences in time perception sensitivity, which may have genetic, developmental, or personality-based origins.

**Cultural variations**: The model doesn't account for cultural differences in time perception, which may involve social and linguistic factors beyond information processing.

## 8.3 Boundaries of Information-Theoretic Approach

The information-theoretic approach has limits:

- It treats time perception as information processing, but doesn't explain the *experience* of time (phenomenal consciousness)
- It models update costs and frequencies, but doesn't specify the neural mechanisms that implement these processes
- It explains general patterns but may not capture all nuances of human time perception
- It focuses on computational structure but doesn't address the evolutionary or developmental origins of time perception

These limits don't invalidate the model, but they clarify its scope. The model provides a computational account of time perception, not a complete account of all aspects of temporal experience.

## 8.4 Testable Predictions

The model makes testable predictions:

- Predictable periods should produce lower update frequencies (measurable through neural activity or behavioral markers)
- Predictable periods should produce sparser memories (measurable through memory recall tasks)
- Retrospective time estimates should correlate with memory density (measurable through memory and time estimation tasks)
- Self-model stability should correlate with temporal compression (measurable through identity stability and time perception tasks)
- Artificial systems with different update frequencies should show different temporal compression effects (measurable through system behavior)

These predictions are falsifiable and could be tested through experiments or computational simulations.

### 8.5 Open Questions

Several questions remain open:

- What is the optimal update frequency for different tasks or goals?
- Can people learn to modulate their update frequency to control time perception?
- How do individual differences in time perception sensitivity arise?
- What are the neural mechanisms that implement update frequency and memory encoding?
- How do cultural factors affect time perception beyond information processing?
- Can temporal compression be "hacked" to make life feel longer or shorter?

These questions require further research beyond the scope of this paper.

## 9 Conclusion

This paper has reframed time perception from a folk psychological question to an information-theoretic problem. We've shown that subjective time is proportional to the rate of internal state updates, not elapsed clock time. When predictions are accurate (high predictability, loops, routine), update frequency is low, leading to temporal compression. When predictions fail (high novelty, learning, danger), update frequency is high, leading to temporal dilation.

We've formalized this relationship using predictive coding and rate-distortion theory, showing how update costs and novelty interact to determine subjective duration. We've distinguished prospective time perception (felt in the moment) from retrospective time estimation (based on memory density), explaining how sparse memory encoding during loops causes past periods to feel short.

We've connected temporal compression to the self as a compression artifact, showing how stable self-models reduce temporal resolution. We've analyzed the human experience implications, arguing that "fast life" is predictable life, not busy life, and exploring why people fear routine despite its comfort.

We've compared human temporal perception to artificial agents, suggesting that temporal compression might be a general property of systems with stable world models. We've clarified the scope and limits of the model, explicitly stating what it does and does not explain.

The key insight is that *time perception is not a measure of elapsed time, but of information processing cost*. When little information processing is required (predictable states), time compresses. When extensive information processing is required (novel states), time dilates.

This reveals something important about the human condition: *much of life "passing quickly" is not about time itself, but about how little of us had to change while it passed*. Routine compresses time because it requires few updates to our models of the world and ourselves. Novelty dilates time because it requires many updates. The acceleration of time in loops is not a bug or a feature of aging—it's a consequence of efficient information processing in predictable environments.

This perspective doesn't tell us how to live, but it does help us understand why time feels the way it does. If we want time to feel longer, we might seek novelty. But if we want time to feel meaningful, we might embrace routine. The choice depends on what we value, not just on how time feels.

Future work should test the predictions of this model, explore the neural mechanisms that implement update frequency and memory encoding, and investigate how individual differences and cultural factors affect time perception. The information-theoretic framework provides a foundation for understanding time perception that is both precise and testable, avoiding metaphors while making contact with empirical phenomena.

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