Model of Narrative Nowness for Neurocinematic Experiments

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Abstract

Cognitive neurosciences have made significant progress in learning about brain activity in situated cognition, thanks to adopting stimuli that simulate immersion in naturalistic conditions instead of isolated artificial stimuli. In particular, the use of films in neuroscientific experiments, a paradigm often referred to as *neurocinematics*, has contributed to this success. The use of cinematic stimuli, however, has also revealed a fundamental shortcoming of neuroimaging studies: The lack of conceptual and methodological means to handle the viewers' experience of narrative events in their temporally extended contexts in the scale of full cinematic narrative, not to mention life itself. In order to give a conceptual structure to the issue of temporal contexts, we depart from the *neurophenomenological* approach to time consciousness by neurobiologist Francisco Varela, which in turn builds on Husserl's phenomenology of time. More specifically, we will discuss the experience of narrative tension, determined by backward-looking conceptualizing retention, and forward-looking anticipatory protention. Further, this conceptual structure is built into a preliminary mathematical model, simulating the dynamics of decaying and refreshing memory traces that aggregates a *retentive perspective* for each moment of nowness, which in turn may trigger anticipations for coming events, in terms of Varela and Husserl, protentions. The present tentative mathematical model is constructed using simple placeholder functions, with the intention that they would eventually be replaced by models based on empirical observations on the psychological capabilities that support narrative sensemaking. The final goal is a model that successfully simulates the way how the memory system maintains narrative tension beyond the transient nowness window, and thereby allows mappings to observed brain activity with a rich temporal system of narrative contexts.

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1 Neurocinematics

Naturalistic neurosciences aim at studying human cognitive functions in conditions that resemble real-life situations. To apply films as the source of life-like stimuli for brain imaging experiments in particular has been referred to as *neurocinematics* [11]. From the methodological point of view, films, despite their apparent complexity, are highly controllable because every aspect of narrative flow has been designed to accomplish particular effects by

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means of the established cinematographic methods. In turn, the viewers expect the narrative flow to be structured to guide their attention and anticipation.

Neurocinematic studies have revealed the similarity of brain responses across viewers when watching the same film [12, 16]. They have also identified distinct brain dynamics in subjects viewing, for instance, faces of other people or landscapes [12, 27], global or local movement [3], or aspects of social behavior [23, 28]. Another study seems to suggest that narrative tension makes a difference. The fMRI experiment by Hasson and colleagues showed significant intersubjective correlation between the brain responses of viewers of a Hitchcock film, but this did not hold for those watching a random surveillance video footage [11]. This indicates that the similarity of brain behavior between viewers is likely due to the way their attention is trapped, guided, and tricked by the narrative design that is, in our interpretation, a system of temporal contexts.

Indeed, filmmaking relies on the mastery of manipulating the viewer's attention in time. The neuroscientific observations of film-viewing made so far make it compelling to look into the factors contributing to narrative cognition in the full temporal scope of films, which, broadly seen, may correspond to the temporal situatedness of humans in life. However, as has been pointed out, the mere comparison of content annotation of features present at a given moment with the synchronized brain responses may not alone provide a sufficient basis for naturalistic neurosciences to understand higher levels of cognitive functions [12, 16]. This will require new means of taking into account a broader temporal frame of narrative contexts. In our view, neuroscientific studies that neglect the viewer's temporal situatedness with respect to continuous narrative just fall short of meeting the attribute 'naturalistic'. It is important to emphasize that we do not count on the possibility of solving the context-dependency on the level of annotation. Instead we trust on that the contextualization is to a great extent an idiosyncratic process and dynamically dependent on one's previous experiences, which, yet, is to a great extent intersubjectively shared between different people due to the similar biologically and socio-cultural conditioned situatedness.

2 Time and narration in neurocinematics

Due to the rapid development of data collection and analysis methods recent brain research has in large part overcome the technical issues related to the massive amounts of brain data accumulating from long sequences of stimuli, such as films. The so called *free-viewing* method allows unconstrained viewing of entire films in fMRI [12, 2]. In such settings, similar to everyday movie viewing experience, all previous events condition the experience of nowness and the anticipation of the coming events along the narrative. Consequently, the key question for neurocinematics is, how to relate the measured brain activation to the viewer's experience of making sense of the story.

Annotation of content is the prerequisite of interpreting brain activity against cinematic content [31]. Several overlapping methods are already in use within distinct fields, e.g. in automated video analysis, discourse analysis, dramaturgy, psychology, or sociology [4, 41, 30, 40]. This is, however, a broad field of methodological development that falls outside of the present topic. For our discussion it suffices to assume that meaningful events in the footage are annotated and time-synchronized so that they can be related with the brain activity that they evoke.

The point we wish to make is that time-synchronized annotation alone is not enough to describe the viewer's consciousness of the narrative sequence through time. We propose that another layer of representing the narrative is needed to relate it to the brain activity.

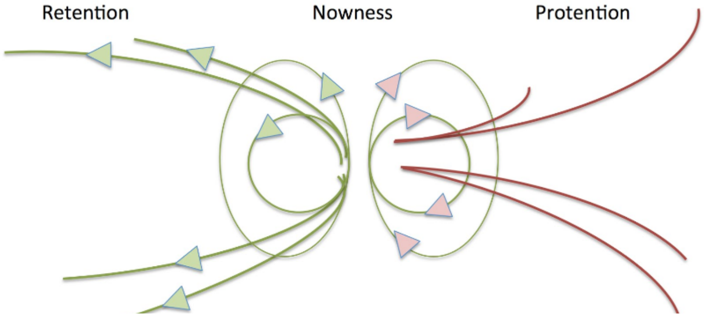

Figure 1 The multi-layered structure of nowness constituted by 'retention' and 'protention'. In the image, narrative time can be seen to flow horizontally from left to right. Between the dynamical loops of retention and protention emerges the experience of nowness. The arrows indicate the experiential 'knowledge' constituted by the memory traces of the past (retention) and simultaneous anticipation of the future (protention). No arrows are marked to the protentional 'threads' (red lines) as this is yet to unfold. Originally drafted to describe the time consciousness as 'nowness' in general, the image is here adapted from Varela ("The Specious Present", 1999, p. 303) to describe the experiential moment of 'narrative nowness' in particular.

The recent findings of *temporal receptive windows* in the brain may guide the mapping of phenomenological, neural and behavioral nowness into narrative structures on different time scales. For example, a cortical hierarchy related to varying scales of temporal narrative coherence was detected by Lerner and colleagues in a functional neuroimaging study that looked at intersubject correlations across people who were engaged in a) 'backward story', b) 'scrambled word', c) 'scrambled sentence', d) 'scrambled paragraph', and e) intact 'forward story' [25]. The studies suggest a hierarchy of frequency bands in brain signals, typically with highest frequencies in the posterior and lowest in the most anterior parts of the brain [25, 13, 22]. According to Hasson and colleagues, the higher cognitive regions, such as posterior lateral sulcus, temporal parietal junction, and frontal eye field, responded to information accumulated over longer durations (∼36s) than, for example, superior temporal sulcus and precuneus (∼12s) [13]. This leads to the reasoning that perhaps the measured length of the temporal receptive windows in the brain corresponds to the size and complexity of spatial receptive fields (e.g., visual cortex) on one hand, and, on the other, to the level of abstraction of neural representations [13, 15]. The direct implication of these findings is that temporal situatedness is to be conceived of in terms of multiple layers. In order to accommodate this, we will first elaborate a preliminary conceptual model of narrative time to be followed by a more formal mathematical model.

3 Conceptualizing time consciousness

Varela's neurophenomenological interpretation of Husserl's views on temporality assumes moments of nowness embedded in broader temporal contexts in terms of *retention* and *protention* [37, 36, 14]. *Retention* refers to the temporally backwards-extended present, consisting of a tail of past events, retained on multiple levels of gradually decaying memory traces, serving as contexts that determine the interpretation of nowness. *Protention*, in turn, refers to the anticipation of the next moment implied by nowness. (Fig. 1) The experience of narrative tension can be said to consist of both retention and protention dynamics.

In terms of this conceptualization, we propose a dynamic model of narrative nowness that serves neurocinematic studies beyond the present and ideally allows mappings between retention and protention onto observed brain activity. Varela points out three aspects that are intertwined in the neurophenomenological study of time consciousness: "(1) the neurobiological basis, (2) the formal descriptive tools mostly derived from nonlinear dynamics, and (3) the nature of lived temporal experience studied under reduction"[1]. The proposed model allows comprehension of *nowness* as simultaneously passing past with the still reachable memory of the gradually distancing past (retention), as well as the anticipation of gradually approaching future events (protention). A spatial metaphor may help to depict the gradually 'distancing' or 'approaching' nature of the experiential elements of nowness. In James's terms, nowness can be said to have a focus, margin, and a fringe [18]. The duration of nowness can be intuitively defined in terms of the natural limits of ongoing action, e.g., gestures or actions. This draws from the studies suggesting that cognitive segmentation of narratives into meaningful sequences and events is seemingly an in-built cognitive mechanism [43, 32]. The corresponding instrumental notion of *protonarrative*[2] relates to the phenomenological idea of nowness, referring to the shortest possible meaningful event. For example, the moment when someone is rejected by another person exemplifies a protonarrative within the duration of a few seconds. This unit, may serve as a preliminary heuristic for the segmentation of film content into events, such as discussed by Zacks and colleagues [42], and thereby as a pointer to the neural phenomena related to the sense of nowness.

Quite obviously, the order of introducing narrative elements constitutes the foundation of a narrative. What has happened earlier will define the interpretation of every following moment of nowness. We assume that once introduced, each meaningful event i establishes a *narrative dimension*, and everything that takes place after it can be described in relation to dimension i with reference to the corresponding *narrative coordinate dimension* x_i. The dimensions altogether define a high-dimensional *narrative ontospace* [29], the abstract stage representing all features whose presence can be meaningful in the story. The ontospace [21] is very high-dimensional altogether, but the perspective, as we define it, limits the dimensionality of the momentarily significant space (representational space). There is no need to assume orthogonality of the dimensions.

Further, we assume that the prominences of each of the dimensions altogether constitute a set of weights, one for each. This set, termed the retentive perspective, determines to what extent each narrative dimension is taken into account in the experience of nowness by the viewer, following the spatial conceptualization of Pugliese and colleagues [29]. A narrative perspective can be conceived of as a vector, with weights assigned to each dimension. Based on previous research of the memory [5, 33, 20, 39], decay functions (forgetting curves) can be modeled with power-law (i.e., $\sim t^{-w}$) and exponential (i.e., $\sim e^{-wt}$) functions, with specific decay weights ($w > 0$) for narrative dimensions. The *narrative perspective* refers to automated, predominantly unconscious moment-to-moment prioritizations among the dimensions set by the individual movie viewer's memory and attention, determining the influence of each in the experience at each transient moment. Another factor is the one of context-refreshing associations induced by the unfolding story, constituting a feedback loop that regulates the way the retentive memory traces influence the interpretation of nowness.

The experience of nowness, as described above, while being based on the retentive perspective, is dynamically coupled to some *protentive function*, triggering anticipation of

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[1] Varela "The Specious Present", p. 305.

[2] The notion of protonarrative applied in neuroscience by Pia Tikka in 2010; See also Philip Lewin's essay "The Ethical Self in the Play of Affect and Voice," at the Conference on After Postmodernism, University of Chicago, November 14-16, 1997, `www.focusing.org/apm_papers/Lewin.html`.

coming events. It is, however, beyond the proposed model to predict what the anticipated events may be. It may suffice here to assume that anticipations involve the entire cognitive-perceptual and experiential apparatus, with its evolution-hard-wired elements, such as emotions, logic inference, as well as learned and culturally assimilated associations.

The implicit assumption behind the model is that among the functional neural networks that are active at the moment of nowness are those that were also triggered at previous stages, when particular aspects of the story were originally introduced, thus constituting the narrative context against which it is now interpreted. This assumption is similar to Damasio's idea of somatic markers, where 'marker' signals "influence the processes of response to stimuli, at multiple levels of operation, some of which occur overtly (consciously, 'in mind') and some of which occur covertly (non-consciously, in a non-minded manner)"[8]. In other words, narrative nowness involves continuous holistic updating of one's situatedness that aims at predictive decision-making related to protentive landscape. The ideal model, for the time being considered as a conceptual model, should eventually be modified to match with empirically observed memory and attention functions. Provided a level of validity with respect to these aspects of psychology, the model should be able to generate predictions for brain responses to cinematic events embedded in their full narrative contexts.

4 Formal framework of the Narrative Nowness model

We now propose a mathematical framework for the nowness model, which aims to catch explanatory aspects of time-dependent dynamics of activation, decay and interference of narrative weights (x_i's). The model is inspired and based on studies on memory and text processing [1, 38, 19, 5, 33, 26, 39, 17, 34, 24] and the model proposed by Cadez and colleagues [7, 6], where multiple memory traces were considered. Narrative weights associated with narrative dimensions are considered mainly as representations of episodic memories with relatively short durations (up to hours rather than days). Narrative weights are assumed to evolve continuously in time. We also assume, for the sake of simplicity, that the structure of the narrative is relatively linear and classical (i.e., exposition, climax, resolution). Let us assume that there are N real-valued narrative dimensions (x_i's). Weights are assumed to follow the dynamical equation

$$\frac{dx_i(t)}{dt} = F_i^D(t) + F_i^S(t) + \sum_{\substack{j=1 \\ j\neq i}}^{N} F_{i,j}^I(t) + F_i^P(t) + \varepsilon_i(t) \tag{1}$$

where $i{=}1, 2, \ldots, N$. At each timepoint, the set of weights x_i define the *narrative perspective*. Real-valued functions are as follows: F^D defines the decay, F^S defines the activation source, F^I defines the narrative interactions, F^P defines the protention mechanism, and ε is the error. Error function ε covers any model inaccuracies and randomness (noise) and it can be expected to become significant especially for complex and rich stimuli, such as movies. In the presence of random noise, the dynamics becomes stochastic. Protentive functions F^P contain high-level abstract cognitive processing of the narrative information and generally have long temporal memory. We assume that the narrative tension, consisting of the interplay of retention and protention, is essential for well constructed narratives, where events are related to each other both in time and between narrative dimensions. Therefore the protention creates a kind of anticipatory mechanism of the future events.

In general, solutions x_i are not expected to be unique with respect to functions F; there might be more than one stimulus that produce the same solution. All functions in Eq. (1)

are assumed to have nonlinear time-dependent forms that - without further approximations - cannot be reduced into elementary functions. Time-dependency (i.e., non-stationarity) is important, because narratives develop in time.

We now describe a simplified version of Eq. (1) using linearization and elementary functions. For each narrative dimension, we assume that there is a set of instantaneous narrative events at times $0 < T_i(1) < T_i(2) < \cdots < \infty$ with corresponding impulse weights $0 < I_i(k) < \infty$ for all $k = 1, \ldots, |T_i|$. Impulses can be defined using the delta function $\delta(t)$. After the impulse has occurred, the corresponding weight decreases exponentially with the decay rate $d_i > 0$, which are gradually reduced with a factor $r_i \in (0, 1]$ after each impulse. Factor r_i simulates the memory reinforcement effect due to repetitions. While power-law decay may be closer to empirical data (see discussion in Refs. [5, 33, 20]), exponential function is easier to implement due to linear derivative. Narrative dimensions are coupled to each other linearly with coefficients $C \in \Re^{N \times N}$, where negative (positive) values indicate reinforcement (interference) between two narrative pairs. Interference increases the decay rate, which leads to faster decrease of the narrative weight. In a simple approximation, the noise term ε_i takes a Gaussian form $\alpha(t)dB(t)$, where $\alpha(t) \geq 0$ and $dB(t)$ is the Wiener process with $B(t + \triangle t) - B(t) \sim \sqrt{\triangle t}\mathcal{N}(0, 1)$ [35]. As the noise should activate only after the first impulse (i.e., introduction of the narrative dimension), we set $\alpha_i(t) := \hat{\alpha}_i(t)H(t - T_i(1))$, where H is the Heaviside step function and $\hat{\alpha}_i(t)$ is the noise coefficient. The noise is assumed to be uncorrelated between narrative dimensions. Since the protention functions F_i^P's depend on the narrative (stimulus), they cannot be simplified. However, depending on the specific narrative and by choosing the narrative dimensions carefully (e.g., via basis transformations), it could be possible to separate the dimensions in *retention-weighted* and *protention-weighted* ones. For retention-weighted dimensions, we can assume that the effect of impulses, decay and interactions overcome the protention effects (e.g., long memory) and set $F^P \approx 0$. Similarly for protention weighted dimensions, we may assume that F^P dominates the dynamics. With above assumptions, the time-evolution of retentive weighted x_i is given by

$$\frac{dx_i(t)}{dt} = -x_i(t)\left(d_i^0 r_i^{|\{k:T_i(k)<t\}|} + \sum_{\substack{j=1 \\ j \neq i}}^{N} C_{i,j}(t)x_j(t)\right) + \sum_{k=1}^{|T_i|} I_i(t)\delta(t - T_i(k)) + \alpha_i(t)dB(t) \quad (2)$$

If proper scaling of parameters is used, absorbing boundary conditions $x_i(t) \in [0, 1]$ can be used. At minimum, one must define parameters d_i^0 (initial decay rate), impulse timepoints T_i and interaction matrix C, while the remaining parameters are approximated by other means. If the protention effects are of interest and/or they cannot be separated, functions F^P must be provided and included in the model. Despite its simplicity, Eq. (2) already allows complicated non-linear dynamics to emerge. Numerical solutions are straightforward to compute and one can apply Monte Carlo approach to study the model.

Finally, let us run a numerical simulation to demonstrate Eq. (2) for N=5 with four retention ($i = 1, \ldots, 4$) and one protention-weighted ($i = 5$) dimensions with an artificial stimulus of duration 2h (7200s). For the initial decay rates, we set $d^0 = [3E{-}4, 4E{-}4, 5E{-}4, 6E{-}4]$. Value $\sim$4.3$E{-}4$ corresponds to the classical result by Herman Ebbinghaus (1885) of forgetting $\sim$40% in 20min. Matrix C is symmetric with $C_{1,2} = -1E{-}3$, $C_{1,3} = 2E{-}3$, $C_{1,4} = 4E{-}3$ and $2E{-}3$ for the remaining three. Impulse powers are set to $I = [1, 0.75, 1, 0.90]$. Noise coefficient $\hat{\alpha} = 1.5E{-}3$ and repeat factor $r = 0.80$ are set equal for all $i = 1, \ldots, 4$. Impulses are picked at random with total counts $10, 13, 7$ and 12. For the protention-weighted dimension, we set $x_5(t) = \int_{\max(0,t-600s)}^{t} ds x_1(s)x_2(s)x_3(s)/\min(t, 600s)$, i.e., a product function with 10min memory, from which F^P can be computed. Initially at $t = 0$ all x_i are set to zero. Numerical solution with the time discretization 0.5s is depicted in Fig. 2.

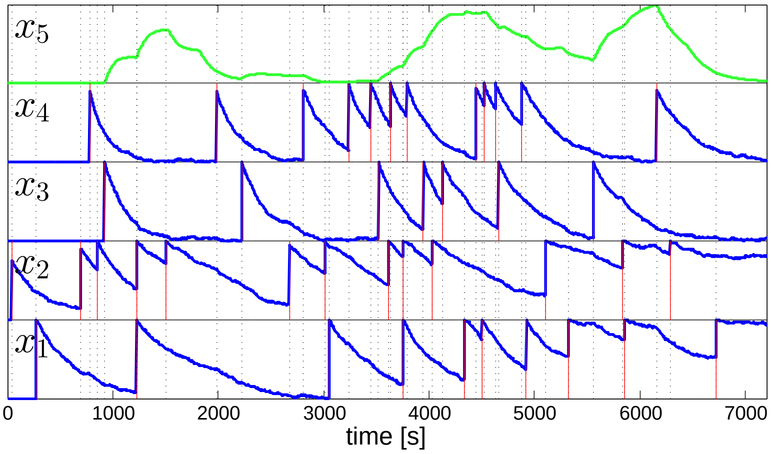

Figure 2 Numerical solution of equation set (2) with N=5 narrative dimensions and an artificial 2h stimulus. The speculative protention-weighted dimension x_5 (green line) depends on retention-weighted dimensions $x_{1,\ldots,4}$ (blue lines). Vertical red lines indicate stimulus impulses.

5 Discussion

So far, naturalistic neuroscientific studies have revealed important relations between the audiovisual content and the corresponding brain activity across spectators. However, this has been feasible only within isolated time frames, without relating contextual conditions constituted by the earlier narrative events and the anticipations they trigger in the viewers' experience in time scales natural to film viewing, not to mention life itself. We envision that the narrative nowness model will open new ways for analysing and interpreting the results of neurocinematic experiments, which assume time consciousness within the duration of entire movies. In addition, the concept of narrative perspective, associated with nowness, can in principle accommodate even broader life contexts and other individual determinants of experience, such as engagement in a film culture, or cross-references between movies. Because of this complexity, it is meaningless to make more detailed assumptions of the model at this hypothetical phase.

We acknowledge the similarity between the paradigms of sentence processing and narrative processing as both require integration and memorization of previous events (i.e., words, sentences and narrative elements; see [26, 17, 34]). However, the time-scale of sentence processing is much shorter (seconds), which is not enough to generate long-duration dynamics required by protention mechanism. Existing computational models in linguistics are typically discrete (see, e.g., [10, 9, 24]) rather than occurring in continuous time domain. There is a need for a model that allows studying narrative comprehension closer to the signal processing perspective.

A mathematical framework for a nowness model was presented (Eq. (1)) with a simplified version (Eq. (2)) allowing numerical experiments. This model accommodates a number of aspects that are assumed to be relevant in narrative comprehension, such as increasing, decreasing and interacting of narrative weights. Although it is generally impossible to reduce high-level cognitive processes into few equations, the model is (another) step towards understanding narratives via computational methods.

We are fully aware that the experimental verification of the proposed model is a significant challenge at this stage, since it is not directly evident which values in the empirical observations would correspond to narrative weights (x_i). With techniques, such as MEG and fMRI, the possible information of the weights is expected to be hidden within measured multivariate signals. These techniques also have limitations of their own, such as long-tailed autocorrelation in the fMRI's BOLD signal. On the other hand, behavioral measurements require active participation of the subjects, which can interfere with the narrative comprehension, especially when time-dependent data is needed. One must also define the numerical values of narrative weights, e,g., they might be percentages of correctly remembered details or recall time of narrative elements. The model does not specify any rules how to define protention functions (F^P), as these are fundamentally linked to building narratives themselves. However, it might be easier to solve an inverse problem: Estimate F^P's while given (protention weighted) solutions x_i. Indeed, it is typically certain protention functions that are targeted when designing the story arc of the narrative (e.g., tension, fear, arousal), which lead to selection and timing of individual narrative events and cues.

While the proposed nowness model should be regarded as the broad hypothesis that the experience of nowness can be modeled and mapped to its neural epiphenomena, drawing inspiration from the heritage of Husserl and Varela, it may also be seen to imply a new paradigm of research. The model can contribute to the analysis of time- and context-dependency of narratives and facilitate bridging the gap between the real-life situations and restricted neuroimaging conditions on one hand. On the other, it will allow generalisations from cinematic situations to those of everyday life thus supporting the relevance of neurocinematics to naturalistic neuroscience in general. After all, the issue of time consciousness is not unique to cinema. All cognitive functions are associated with their temporal situatedness within the world's narratives, as reflected by one's unique experience. The potential of conducting experiments with narratively significant contexts increases also the value of the neurocinematic studies for the cinematic arts, and more generally, all narrative arts.

6 Conclusions

The neurocinematic paradigm has revealed the limits of the so called naturalistic neuroscience with regard to interpreting brain activity elicited by narrative events embedded in temporal contexts beyond the immediately present. This points out the need for a method of interpreting neural activity elicited by events in their broad narrative contexts in the scale of full-length films. Following Varela and Husserl's phenomenology of time, we divide the assumed narrative tension at a particular moment of nowness into the backward and forward looking components of retention and protention, respectively. We have proposed a preliminary model of how memory traces of past events in a narrative sequence may dynamically aggregate a retentive perspective that conditions the experience of each moment of nowness. The model is purely mathematical, constructed using simple placeholder functions that can later be replaced by empirically founded functions capable of framing a refined understanding of how narrative memory traces retain and decay in the memory. Although we postulate that the experience of nowness in itself implies an anticipation for future events and reserve it a place, modelling this protentive aspect remains as another challenge beyond the present.

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