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# Viscous Time Theory (VTT): A Mathematical Proposal for Coherence-Dependent Temporal Response

**Payam Danesh**[1], **Raoul Bianchetti**[2]

[1]Department of Biosystems Engineering, University of Tehran, Tehran, Iran
[2]Information Physics Institute, Gosport, UK
Email: payamdanesh71@gmail.com, raoul.bianchetti@informationphysicsinstitute.net

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## Abstract

This work presents Viscous Time Theory (VTT) as a mathematical proposal for modeling temporal response in structured systems. The central idea is that response delay, transition tendency, and local recovery may depend not only on external time, but also on the internal organization of the system. In this work, the proposed variables are a normalized coherence density, a coherence-flux field, calibrated temporal viscosity, residual memory, and an informational entropy-pressure term derived from coherence-flux divergence. The proposal states the core equations, clarifies the intended interpretation of the terminology, and outlines a falsifiable research program. The aim is not to replace relativistic time, quantum dynamics, or thermodynamic entropy, but to introduce a response-level framework that can be tested in non-equilibrium, quantum, computational, and biological systems.

## Keywords

Viscous Time Theory, Coherence Flux, Temporal Viscosity, Residual Memory, Entropy Pressure, Non-Equilibrium Response

## 1. Introduction

The study of time in mathematical physics has usually proceeded through distinct but related languages: absolute time in classical mechanics [1], spacetime geometry in relativity [2], and entropy-based irreversibility in thermodynamics and non-equilibrium theory [3]. Each language is appropriate within its own domain. The question raised in modern physics is narrower and more operational:

*Does coherence structure govern temporal response?*

Here, temporal response means the observable delay, persistence, transition tendency, or recovery scale of a structured system after perturbation. Many systems do not simply move from disturbance to equilibrium in a featureless way. They retain memory, show delayed relaxation, pass through thresholds, or recover only when enough internal structure remains. This suggests that the internal organization of a system may influence the way it responds over time.

Viscous Time Theory (VTT) is proposed as a response-level framework rather than a new fundamental clock. Its purpose is to formalize how internal coherence, transport of coherence, calibrated resistance to reconfiguration, and residual memory may jointly influence observed relaxation. In this sense, "viscous time" does not mean that time is literally a fluid. It means that structured systems may exhibit resistance to temporal reconfiguration, much as viscous media resist rapid deformation.

This proposal extends earlier VTT-related work on informational geometry, curvature, persistence, and variational metric-type structure [4]-[7]. The present report gives the compact theoretical frame needed before a full experimental program is completed. The purpose of this frame is to present the idea, define the mathematical objects, state the testable consequences, and identify how the proposal can be evaluated.

## 2. Theoretical Background

The starting point is the observation that many structured systems do not respond instantly to perturbation. They may exhibit hysteresis, delayed recovery, threshold behavior, metastability, or partial recoherence. These phenomena appear in non-equilibrium physical systems, quantum systems, biological regulation, and computational models with memory or internal state.

Information theory provides a language for uncertainty and structure [8]. Quantum coherence theory provides a precise example in which coherence can be defined from off-diagonal density-matrix elements, once a basis is fixed [9]. Dynamic critical phenomena show that response can slow near organized transitions [10]. Memory-kernel approaches in irreversible thermodynamics show that reduced descriptions often inherit history dependence from unresolved degrees of freedom [11]. In view of these established frameworks, VTT is not proposed as a replacement for them. It introduces a phenomenological bridge between coherence structure and response time. The proposal is that response is not determined only by external forcing or clock time, but may also depend on internal coherence gradients, coherence transport, temporal resistance, and residual memory.

### From Thermodynamic Memory to Coherence Variables

The memory concepts discussed above motivate the VTT variables, but they do not by themselves determine them. In VTT, the role of memory is transferred from a general history dependence to a more specific coherence-based description: a perturbation first changes the organization of the system, part of that change may persist, and the remaining structure may then affect the later response. This is the bridge from thermodynamic memory to the present framework. The past is not introduced as an independent hidden variable; it enters through measurable departures from a reference coherence state and through the transport of those departures across the chosen domain. The next section formulates this passage in compact mathematical form by introducing the coherence field, the reference state, the residual-memory term, the coherence flux, and the entropy-pressure response index.

## 3. Core VTT Frame

The mathematical frame is deliberately minimal. To begin, let $x$ denote a point in physical space, state space, network space, or another domain appropriate to the system under study. The normalized coherence density is

$$C(x,t) \in [0,1]. \tag{1}$$

Coherence must be defined from observables rather than introduced as a metaphor. For a domain $D$, one writes

$$C_D(x,t) = \hat{C}_D\left[Q_D(x,t)\right], \tag{2}$$

where $Q_D(x,t)$ is the measured state of the system and $\hat{C}_D$ is the domain-specific coherence estimator. A reference state $C_{\text{ref}}$ gives the coherence displacement

$$\Delta C(x,t) = C(x,t) - C_{\text{ref}}(x,t). \tag{3}$$

For an empirical application, the coherence estimator and the reference state should be fixed before fitting the response model. A suitable coherence estimator should satisfy three practical criteria. First, it should be computable from measured variables $Q_D(x,t)$. Second, it should increase when the system becomes more ordered, synchronized, correlated, or structurally regular in the representation being used. Third, it should be stable enough that small measurement noise does not dominate the estimated coherence field.

The reference state $C_{\text{ref}}(x,t)$ may be chosen in several ways, depending on the experimental setting. In a relaxation experiment, it may be the pre-perturbation coherence profile. In a driven non-equilibrium system, it may be the statistically stationary profile obtained by averaging over unperturbed trials. In a quantum experiment, it may be the coherence value in a specified basis before environmental coupling or external disturbance is applied. In a computational system, it may be the internal-state coherence measured before an input shock or memory perturbation. The essential requirement is that $C_{\text{ref}}$ be defined independently of the response event being predicted.

Thus, the quantities $C_D$ and $C_{\text{ref}}$ are not free fitting labels. They are part of the experimental design. Once they are fixed, the displacement $\Delta C$, residual memory $R$, coherence flux $J_C$, and entropy-pressure term $E_{VTT}$ become derived quantities that can be tested against observed response times or transition events.

The core notation of the proposal before any dynamical step is fixed in Table 1. This is important because the same formal structure may be applied across different domains, but each variable must keep a precise mathematical role.

Table 1. Core variables of the VTT proposal.

| Symbol | Meaning | Role |
| --- | --- | --- |
| $C(x,t)$ | Coherence density | State variable |
| $J_C(x,t)$ | Coherence flux | Transport of coherence |
| $\eta_{\text{cal}}(x,t)$ | Temporal viscosity | Calibrated resistance |
| $R(x,t)$ | Residual memory | History of coherence displacement |
| $E_{VTT}(x,t)$ | Informational entropy pressure | Viscosity-modulated flux divergence |
| $\tau_{VTT}(x,t)$ | Temporal response scale | Predicted delay |

The local gradient and divergence notation used in VTT is meaningful only when the chosen domain admits a notion of neighborhood, distance, or adjacency. In physical space this is the usual spatial structure. In a network or state space, it must be supplied by a graph, metric, embedding, or transition relation. Without such structure, expressions such as $\nabla C$ and $\nabla \cdot J_C$ should be understood only after an appropriate discrete or geometric analogue has been defined.

The framework also assumes that coherence is representation-dependent. In a quantum setting, for example, coherence depends on the chosen basis. In a biological or computational setting, coherence depends on the measured variables and the scale at which coordination is defined. For this reason, VTT is not intended to assign a unique universal coherence value to every system. It applies only after the observable state variables, coherence estimator, reference state, and domain geometry have been specified.

These assumptions limit the scope of the proposal, but they also make it testable. Once the representation is fixed, the coherence field, its displacement from reference, the memory term, and the derived flux quantities become operational objects.

The coherence flux is modeled in the general form:

$$J_C = v_C C - D_C \nabla C + J_C^{\text{act}} + \xi_C. \tag{4}$$

Here $v_C C$ represents effective advective transport, $-D_C \nabla C$ is passive diffusive redistribution, $J_C^{\text{act}}$ represents active or internally driven transport, and $\xi_C$ represents unresolved or stochastic flux. The passive limit is recovered when the advective, active, and stochastic components are suppressed.

Local coherence balance is expressed by

$$\frac{\partial C}{\partial t} + \nabla \cdot J_C = G_C - L_C + S_C, \tag{5}$$

where $G_C$, $L_C$, and $S_C$ denote coherence generation, coherence loss, and external coherence injection or removal. Residual memory is defined relative to a reference state, not by the accumulation of raw coherence:

$$R(x,t)=\int_{t_0}^{t}\lambda e^{-\lambda(t-s)}\left[C(x,s)-C_{\text{ref}}(x,s)\right]\mathrm{d}s. \tag{6}$$

This definition matters. A system that remains highly coherent at baseline should not automatically be described as memory-loaded. Memory appears when coherence has departed from reference and that departure persists into later response.

Temporal viscosity is a calibrated response coefficient:

$$\eta_{\text{cal}}=\frac{\tau_{\text{cal}}/\tau_*}{\left|\Delta C_{\text{cal}}\right|+\varepsilon}. \tag{7}$$

The calibration perturbation must be distinct from the perturbation later predicted. This avoids circularity: $\eta_{\text{cal}}$ is not defined from the same event whose response time is being modeled. The central response quantity is the informational entropy-pressure term

$$E_{VTT}(x,t)=\eta_{\text{cal}}(x,t)\nabla\cdot J_C(x,t). \tag{8}$$

This is not thermodynamic entropy. It is a local response index measuring coherence-flux divergence weighted by resistance to coherence reconfiguration.

The proposal in a compact mathematical frame is shown in Figure 1. The upper branch shows the transport chain from coherence density to entropy pressure; the lower branch shows how reference-adjusted displacement, memory, and calibration enter the response law. The figure identifies the dependency structure that must be preserved in any empirical implementation.

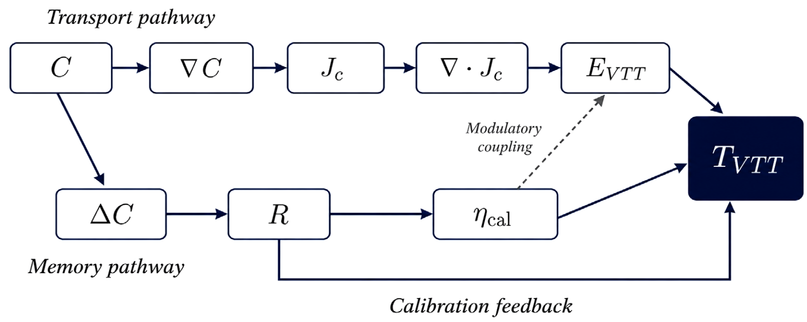


Figure 1. Mathematical frame of the VTT proposal.

The response scale $\tau_{VTT}$ is assembled from coherence transport, residual memory, and calibrated temporal viscosity. The frame separates state, transport, memory, and response variables while keeping them in one analytical structure.

## 4. Response Law and Testable Consequences

The proposed local response law is

$$\tau_{VTT}=\tau_0\exp\left[a_1\tilde{\eta}\left|\widetilde{\nabla C}\right|+a_2\left|R\right|+a_3\left|\tilde{E}_{VTT}\right|+a_4\tilde{\eta}\left|\widetilde{\nabla C}\right|\left|R\right|\right]. \tag{9}$$

The exponential form guarantees positive response time and allows nonlinear amplification when coherence tension and residual memory coexist. The simplest expected signs are

$$a_1 \geq 0, a_2 \geq 0, a_3 \geq 0.$$

The interaction coefficient $a_4$ should be estimated rather than assumed. A positive value would mean that residual memory strengthens the delay associated with coherence gradients.

For transition events, the corresponding probability model can be written as

$$P_{\text{trans}} = \sigma\left[\theta_0 + \theta_1\left|\widetilde{\nabla C}\right| + \theta_2\tilde{E}_{VTT}^{+} + \theta_3\left|R\right| + \theta_4 U\right], \tag{10}$$

where $\sigma$ is the logistic function, $\tilde{E}_{VTT}^{+} = \max\left(0, \tilde{E}_{VTT}\right)$, and $U$ represents ordinary control variables such as noise intensity, driving amplitude, temperature, coupling strength, or environmental interaction.

The exponential and logistic forms are used here as phenomenological choices, not as final microscopic laws. The exponential response law is useful because it guarantees a positive response time and allows several small structural contributions—coherence gradient, residual memory, entropy pressure, and their interaction—to combine multiplicatively. A purely linear response law may be adequate near equilibrium, but it can give unphysical negative response times if extrapolated and does not naturally represent amplification when memory and gradient tension act together.

The logistic transition model is used for a similar reason. Transitions in structured systems are rarely expected to occur at a perfectly sharp universal threshold. Noise, finite-size effects, history dependence, and environmental forcing usually turn a threshold into a crossover region. The logistic form keeps the model simple while representing this crossover as a probability between zero and one. In this report, these forms should therefore be read as minimal phenomenological closures: simple enough to test, but flexible enough to represent positive response scales and probabilistic transition behavior.

For empirical use, the variables in the response law should be separated according to how they are obtained. The measured quantities are the observable state variables $Q_D(x,t)$, from which the coherence field $C_D(x,t)$ is computed, and the observed response outcome, such as relaxation time, transition occurrence, or recovery time. The reference state $C_{\text{ref}}$ is fixed by the experimental protocol, for example from the pre-perturbation state or from an unperturbed control ensemble. The quantities $\Delta C$, $R$, $J_C$, and $E_{VTT}$ are then derived from these measured and reference fields. The temporal viscosity $\eta_{\text{cal}}$ is calibrated from a separate perturbation class and is not fitted from the same response event being predicted. The coefficients $a_i$, $\theta_i$, $k$, and $\gamma$ are model parameters to be estimated from training data and evaluated on held-out data. This separation is essential: without it, the model could fit response behavior retrospectively without providing a genuine prediction.

This formulation avoids treating thresholds as rigid universal boundaries. Instead, the theory predicts increasing transition probability as coherence-gradient magnitude, positive entropy pressure, and residual memory increase.

The recovery condition may be expressed by introducing a local stabilizing-response field

$$R_{IRS}\left(x,t\right)=-k\nabla E_{VTT}\left(x,t\right),k>0. \tag{11}$$

Local recoherence is predicted when

$$\left|R_{IRS}\right|+\gamma\left|R\right|>\left|E_{VTT}\right|. \tag{12}$$

This condition does not imply global entropy reversal. It shows only that local recovery may occur when stabilizing response and residual structure exceed the local entropy-pressure load.

## Distinctive Tests of the Proposal

The empirical value of VTT should be judged against a baseline response model. Let $U$ denote ordinary control variables such as perturbation amplitude, damping, coupling strength, noise level, temperature, or driving intensity. A baseline model may be written as

$$\log\tau_{\text{obs}}=b_0+b_U U+\epsilon. \tag{13}$$

The VTT-augmented model is

$$\log\tau_{\text{obs}}=b_0+b_U U+b_1\tilde{\eta}\left|\widetilde{\nabla C}\right|+b_2\left|R\right|+b_3\left|\tilde{E}_{VTT}\right|+\epsilon. \tag{14}$$

The proposal is supported only if the coefficients have the expected signs,

$$b_1>0,b_2>0,b_3>0, \tag{15}$$

and if Equation (14) improves held-out prediction relative to Equation (13). This requirement is important because the theory should not merely fit response times after the fact; it must add predictive information beyond ordinary control variables.

Three quantitative tests follow directly. First, consider two perturbations with comparable amplitude and comparable ordinary controls $U$, but different coherence-gradient magnitudes. VTT predicts that the event with larger $\tilde{\eta}\left|\widetilde{\nabla C}\right|$ should have the longer response time:

$$\Delta\log\tau_{\text{obs}}\approx b_1\Delta\left(\tilde{\eta}\left|\widetilde{\nabla C}\right|\right)>0. \tag{16}$$

Second, consider two systems with similar current coherence level but different residual memory. VTT predicts that the memory-loaded system should relax more slowly:

$$\Delta\log\tau_{\text{obs}}\approx b_2\Delta\left|R\right|>0. \tag{17}$$

This distinguishes VTT from models that depend only on the present value of coherence.

Third, for transition events, compare a baseline logistic model,

$$P_{\text{trans}}^{(0)} = \sigma\left(c_0 + c_U U\right), \tag{18}$$

with a VTT-augmented model,

$$P_{\text{trans}}^{(1)} = \sigma\left[c_0 + c_U U + c_1\left|\widetilde{\nabla C}\right| + c_2 \tilde{E}_{VTT}^{+} + c_3\left|R\right|\right]. \tag{19}$$

The distinctive prediction is

$$c_1 > 0, c_2 > 0, \tag{20}$$

with improved held-out classification of transition events. In particular, VTT predicts that transition probability may be high in regions of strong positive entropy pressure even when the scalar coherence amplitude itself is not maximal. This separates the transport-based prediction from a model based only on coherence level.

A clear disconfirming pattern is also available. If response time and transition probability are fully explained by perturbation amplitude, damping, current coherence level, and other standard controls, while $\tilde{\eta}\left|\widetilde{\nabla C}\right|$, $R$, and $E_{VTT}$ do not improve held-out prediction, then the proposed VTT response mechanism is not supported in that domain. In such a case, the framework should be revised rather than reinterpreted.

## 5. Short Numerical Illustration

A minimal one-dimensional benchmark is sufficient to illustrate the internal meaning of the variables. Let $x \in [0,10]$ and define a two-peak coherence profile

$$C(x) = 0.1 + 0.75\exp\left[-\frac{(x-3)^2}{1.1}\right] + 0.55\exp\left[-\frac{(x-7.1)^2}{0.8}\right]. \tag{21}$$

With passive flux

$$J_C = -D_C \frac{\mathrm{d}C}{\mathrm{d}x}, D_C = 0.90,$$

the entropy-pressure field becomes

$$E_{VTT} = \eta \frac{\mathrm{d}J_C}{\mathrm{d}x}. \tag{22}$$

This example shows that entropy pressure is not maximal simply where coherence is maximal. It is strongest where coherence flux has strong divergence, which is controlled by the curvature and redistribution of the coherence field. This distinction is important because $E_{VTT}$ is a derived transport quantity rather than a restatement of $C$.

For response analysis, one may use

$$\frac{\tau_{VTT}}{\tau_0} = \exp\left[a_1\eta G + a_2 R + a_3 E + a_4 \eta G R\right], \tag{23}$$

where $G = \left|\widetilde{\nabla C}\right|$. This surface increases most strongly when $G$ and $R$ are simultaneously large. The systems that are both structurally strained and historically loaded should respond more slowly than systems with weak gradients and little residual memory.

## 6. Conclusion

This report has presented Viscous Time Theory as a coherence-flux framework for modeling temporal response in structured systems. The central proposal is that response delay, transition tendency, and local recovery may depend not only on perturbation amplitude or external control variables, but also on the internal organization of the system. In the present formulation, this organization is represented through a normalized coherence field, a reference coherence state, residual memory, coherence flux, calibrated temporal viscosity, and an informational entropy-pressure term derived from coherence-flux divergence. The framework is deliberately response-level. It does not replace relativistic time, quantum dynamics, thermodynamic entropy, or established theories of non-equilibrium relaxation. Instead, it provides a compact mathematical language for systems in which present response is influenced by coherence structure and retained history. The role of the reference state is especially important: it allows memory to be defined as persistence of a prior coherence displacement rather than as a vague accumulation of past behavior. Likewise, the coherence flux and its divergence allow the framework to distinguish coherence amplitude from coherence transport, so that delayed response and transition risk can be tied to local structural imbalance rather than to coherence level alone. The proposed response law and transition model should be understood as phenomenological closures. Their purpose is to generate testable predictions, not to claim a final microscopic theory. The exponential response form ensures positive response times and allows gradient tension, residual memory, entropy pressure, and their interaction to amplify the response scale. The logistic transition form treats transitions as probabilistic crossovers rather than universal sharp thresholds, which is more appropriate for systems affected by noise, finite size, memory, and environmental forcing. A central requirement of the framework is operational identifiability. The observable state variables $Q_D(x,t)$ are measured; the coherence estimator and reference state are fixed by the experimental design; the displacement, memory, flux, and entropy-pressure variables are derived; temporal viscosity is calibrated from a separate perturbation class; and the remaining coefficients are fitted and evaluated on held-out data. Thus, the contribution of this report is not a completed physical theory of time, but a precise and testable proposal for coherence-dependent temporal response. Its value will depend on future applications in systems where coherence can be measured, reference states can be defined, perturbations can be controlled, and response outcomes can be evaluated quantitatively.

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## Data Availability

Data will be sent upon reasonable request.

## Conflicts of Interest

The authors declare no conflicts of interest.

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