

Evolutionary Psychological Structures and the Neural Execution of Human Centered Reasoning

A first principles account of group coordination and adaptive social behavior

Mvuselelo Houston Khanyile
CVEST, South Africa

Version 0.2 | 2 October 2026 | Computational experiments integrated

Abstract

Human social behavior depends on how people interpret situations, assign significance, organize competing motives, and revise responses after consequences. Evolutionary Psychological Structures (EPS) connects these operations across sociology, psychology, and neuroscience. We construct the framework from continued existence and the conditional benefits of collective action under constraints of limited resources, incomplete information, and coordination. Belonging, Identity, and Power (BIP) organize participation, meaningful roles, and consequential influence through five interacting stages: contextual filtering, value mapping, motivational allocation, emotional modulation, and existential state confirmation. We reason from neuronal properties to candidate execution mechanisms and operationalize selected functions in a recurrent population model with differentiated outcome learning. Ten matched seeds, eight model and control conditions, and 600 episodes per condition and seed produced 48,000 synthetic interactions. When the successful response contingency changed, full EPS success decreased from 92.0% before reversal to 39.3% in the first post-reversal block and recovered to 91.5% in the final block. Frozen weights and equal-row learning reached 30.8%, unrelated feedback 26.3%, and a simpler linear learner 90.8% in the final block. Filtering improved early learning and the initial response to reversal, while other component removals produced similar final performance. The results establish differentiated associations and contingent adaptation in the implemented task. They do not establish the necessity of the complete EPS organization or its proposed anatomical correspondence. The neural execution account remains a biologically motivated hypothesis requiring psychological, ecological, and circuit validation.

Keywords: Evolutionary Psychological Structures; first principles; social motivation; neuronal integration; recurrent models; reversal learning

1 Introduction

A social event acquires its behavioral significance through its relationship to the person encountering it. A request, disagreement, or opportunity may support participation in a group, challenge a valued role, or change a person’s ability to influence an outcome. Reasoning about that event therefore involves

more than identifying its observable features. It also involves deciding what matters, how the event relates to existing commitments, and which consequences deserve priority.

EPS proposes an account of this internal organization. Its subject is human-centered reasoning: the interpretation of situations and organization of responses through personally and socially significant concerns. In this paper, adaptive behavior means a capacity to revise interpretation and response in relation to circumstances, objectives, and constraints. Such behavior can be affective and culturally conditioned. Adaptation does not guarantee an objectively correct conclusion, successful coordination, or an ethically desirable outcome.

The framework integrates three explanatory levels. Sociology supplies the patterns of collective life to be explained, including participation, roles, authority, and institutional continuity. Psychology describes the meanings, motives, and affective processes through which people participate in those patterns. Neuroscience supplies the physical mechanisms capable of implementing the proposed operations. The connection among these levels is the central claim of the paper.

We develop that connection through a first-principles construction. We begin with an objective, identify constraints and available tools, and construct a path from those conditions to a possible solution. The formulation is summarized as Tools plus Constraints equals Objective. Here, the expression means that a workable strategy must use tools that actually address the constraints preventing an objective from being achieved. It is a reasoning method, rather than a mathematical identity or an empirical law.

The resulting EPS pipeline organizes contextual filtering, value mapping, motivational allocation, emotional modulation, and existential state confirmation. Pattern recognition, memory retrieval, and problem solving can contribute to its operation. EPS's proposed contribution is the organization of those capabilities around human significance and motivational priorities. We present a neural execution hypothesis, specify an abstract recurrent implementation, and examine its operation through controlled synthetic experiments. This separates the construction of a possible mechanism from tests of its computational behavior and from future validation of human or neural correspondence.

2 Constructing EPS from objectives tools and constraints

The objective of continued existence

We take continued existence as the organizing objective of the EPS construction. At the individual level, this includes maintaining viability and the conditions under which a person can continue to function. In human social life, it also includes sustaining dependable relationships, preserving meaningful commitments, and improving valued circumstances. These concerns need *not* be consciously articulated before they influence behavior.

This is a functional starting point for the framework. Evolutionary selection operates through differences in survival and reproduction across generations; it does not require organisms to possess an explicit goal called existence. Likewise, the construction does not assume that early organisms had only one motive, or that physiological and reproductive demands disappeared when social life became more elaborate. EPS asks how capacities serving basic regulation could contribute to increasingly complex social objectives.

The distinction matters because the objective of a person, the declared purpose of a group, and the evolutionary consequences of behavior are different quantities. A group may pursue a project, its

members may pursue partly compatible interests, and participation may affect their welfare in different ways. The framework must represent those differences rather than treat a collective as one organism with a single mind.

Auditing the premises

The construction uses several premises with different statuses. Bodies and environments impose limits on available time, resources, and information. People also encounter tasks that depend on the actions of others. Those conditions motivate a coordination problem. The proposition that a particular group solves that problem faster or more efficiently than separate individuals is conditional: cooperation has to produce benefits that exceed its costs.

Further propositions belong to the EPS construction itself. Continued existence is the selected organizing objective. BIP is the proposed motivational organization of recurring social problems. The five-stage pipeline is the proposed process architecture. These choices are sufficiently explicit to guide a model, but they are not consequences that follow uniquely from resource limitation or group living.

Table 1. Premises and their roles in the first-principles construction.

Element	Role in the construction	Status
Limited time resources and information	Restrict which responses are feasible and affordable	General constraints
Dependence on other agents	Creates a need to anticipate and coordinate behavior	A condition of the social problems considered
Benefits from collective action	Motivate participation in a group	Conditional on the task and organization
Continued existence	Organizes the framework's account of objectives	EPS functional premise
Belonging Identity and Power	Organize participation roles and influence	Proposed motivational dimensions
The five EPS stages	Specify how situations acquire significance and guide response	Proposed process architecture

Group participation as a strategy

Group participation can distribute effort, combine capacities, and make support available when an individual cannot meet a challenge alone. Evidence that social relationships can have survival relevance comes from observations of female baboons: stronger and more stable social bonds predicted greater longevity (Silk et al., 2010). That association supports the evolutionary motivation for studying social relationships without establishing the EPS architecture.

Collective action also creates additional constraints. Participants may disagree about priorities, possess different capabilities, contribute unevenly, or have unequal access to decisions. Communication, reciprocal expectations, and dependable coordination become part of the problem. Greater speed or efficiency is therefore an objective of some forms of organization, rather than a guaranteed property of being in a group.

Some constraints are hard within a particular task, such as a deadline or the requirement that two physical actions be coordinated. Others are adjustable, such as role assignments, communication conventions, or decision rights. EPS proposes psychological tools through which individuals interpret and respond to these conditions. Institutions can make the tools' social expression more durable by stabilizing expectations and rules. North's (1991) account of institutions as arrangements that structure interaction provides a relevant description of that external organization.

3 Belonging Identity and Power as motivational tools

The central group constraint is the organization of distinct individuals into a collective capable of coordinated action. We propose three recurring problems within that organization: sustaining participation, differentiating contribution, and managing influence over consequential outcomes. BIP names the corresponding motivational dimensions. Their derivation is a functional argument about the problems the framework addresses. It does not, by itself, establish three independent biological adaptations or a complete inventory of human needs.

Belonging and sustained participation

Belonging concerns inclusion, connection, and the expected availability of valued relationships. In the group construction, it is foundational because coordination depends on people remaining sufficiently connected to participate. A shared objective becomes behaviorally useful only when participants can recognize one another as relevant partners and maintain expectations about continued involvement.

The proposed motivational function is sensitivity to acceptance, exclusion, and relational reliability. These concerns can encourage participation and alignment with collective expectations. They can also motivate withdrawal from one group in order to preserve connection with another. Alignment is therefore relative to a valued relationship or reference group, rather than universal agreement with everyone present.

Belonging does not imply identical objectives, unconditional compliance, or the absence of conflict. A person can want continued inclusion while disagreeing about how the group should proceed. This distinction permits EPS to explain participation and disagreement within the same motivational organization.

Identity and meaningful differentiation

Identity concerns the continuity, expression, and recognition of self-relevant roles, commitments, and memberships. Collective activity often benefits from differentiated contribution: people undertake tasks, acquire expectations about one another, and recognize capacities that matter to the group's objective. EPS proposes that identity helps organize the person's internal relationship to those distinctions.

Role definition is consequently one route through which Identity supports coordination. A participant may understand what contribution is expected, why it matters, and how it relates to the kind of person they consider themselves to be. This gives a role significance beyond its formal assignment. However, occupying a role does not guarantee identification with it. An imposed role can conflict with a person's commitments, and a meaningful identity can extend beyond any particular group.

The proposed motivational function is sensitivity to recognition and consistency of self-relevant commitments. It may support sustained contribution, resistance to a conflicting expectation, or revision of an earlier role. Identity can align with Belonging when membership recognizes a valued contribution, and conflict with it when acceptance requires the person to disavow that contribution.

Power and consequential influence

Power concerns the capacity to influence outcomes and manage dependence. A collective must make decisions, coordinate execution, and respond when actions interfere with one another. EPS proposes that sensitivity to influence helps people evaluate whether their efforts can affect what happens and whether important outcomes remain outside their control.

Hierarchy is one arrangement through which decision authority can be organized. Authority can also be shared, negotiated, or distributed among participants with different responsibilities. The necessary function in this construction is workable coordination of consequential decisions. A fixed hierarchy is an organizational possibility, rather than a requirement of every group.

Power can support collective effectiveness when influence is recognized and coordinated. It can also generate rivalry, dependency, or exclusion. Formal rank, prestige, coercive dominance, and practical control are related but distinct social conditions. The framework should represent the form of influence involved rather than infer one motive from a job title or an observed act of leadership.

Coactivation and conflict

BIP dimensions can operate together. Taking responsibility for a shared task may strengthen connection, express a valued role, and increase effective influence. Their relationship changes with circumstances. A decision that preserves participation may weaken a commitment; a demand for influence may undermine others' willingness to cooperate.

The same outward action can therefore result from different motivational combinations. EPS proposes relative motivational allocation, rather than a rule that each behavior belongs to exactly one driver. Any construction of competition among drivers must also specify when they support one another and which limited resources make their simultaneous pursuit difficult.

4 Survival Stability and Quality in an evolutionary account

EPS distinguishes three regulatory orientations within continued existence. Survival concerns immediate viability and protection from serious threat. Stability concerns dependable conditions and continuity of relationships, resources, and functioning. Quality concerns improvement in valued experience, capability, meaning, and future possibilities.

Table 2. Regulatory orientations within the objective of continued existence.

Orientation	Regulatory concern	Illustrative social implications
Survival	Immediate viability and serious threat	Protection assistance and urgent access to resources
Stability	Dependability and continuity	Reliable participation recognized expectations and predictable coordination
Quality	Improvement in valued circumstances	Development meaningful contribution and expanded possibilities

These orientations may coexist. Urgent danger can narrow priorities, while adequate security can permit wider ambitions. A person can nevertheless accept material risk to protect a commitment or relationship. EPS therefore proposes changing weights among orientations, rather than a compulsory sequence in which every person completes one state before entering the next.

BIP and these orientations perform different functions. BIP describes proposed dimensions of social motivation. Survival, Stability, and Quality describe conditions the person seeks to establish or protect. Their relationship is many-to-many: an alliance may support protection and influence, while a meaningful role may support stability and improved quality of life.

The evolutionary account is continuity with elaboration. EPS proposes that capacities contributing to ancestral regulation and social coordination were modified and reorganized as later behavior became more complex. Functional specialization can occur in interacting systems spanning several regions. Expansion of a capability may involve altered connectivity, differentiation, and learning as well as changes in overall brain size.

Comparative measurements of primate prefrontal pyramidal neurons document differences in dendritic structure across sampled species (Elston et al., 2011). Such findings motivate investigation of changing integrative capacity. They do not identify a conserved EPS algorithm directly. In this paper, an algorithm means an organized set of biological operations; the claim that particular operations were conserved remains distinct from continuity of broad function.

5 The psychological operations of the EPS pipeline

The pipeline connects a situation to its significance for the person and to the organization of a response. Its stages distinguish computational roles. They are not five anatomically isolated compartments or a claim that the brain executes each operation once in a fixed temporal order. Existing priorities and learned expectations can shape initial interpretation, and later consequences can revise earlier processing.

Contextual filtering

Contextual filtering constructs a relevant situation from available information. It concerns which cues receive influence, how they are related to prior experience, and what possibilities the person considers. The psychological operations include selection, attention, retrieval, and interpretation.

The input consists of information about the event, relationships, prior experience, and present conditions. The output is a contextual representation sufficient to guide subsequent appraisal.

Candidate situation classes may include threat, cooperation, exclusion, recognition, or changed access to influence. These are working psychological categories, rather than claims that a neuron carries an explicit category label.

Filtering regulates influence rather than simply discarding everything outside one category. A representation may contain competing interpretations with different confidence or relevance. Ambiguity can persist while a person gathers information or acts under time pressure.

Value mapping

Value mapping assigns significance to the contextual representation in relation to needs, commitments, learned expectations, and possible outcomes. It asks how circumstances support or obstruct what matters to the person. This operation can integrate immediate material consequences with the significance of relationships and roles.

Learned expectations influence the significance assigned to contextual information. Within EPS, the Cultural Matrix more specifically represents learned relationships through which valuations influence the BIP motivational dimensions. It is an individual's model component, shaped by experience and social transmission. People exposed to related norms can still differ in interpretation and priority. Cultural influence can affect several stages; it is not reduced to a fixed numerical type assigned to every member of a population.

The output is a pattern of valuations. These may conflict or change with circumstances. A useful neural and computational account must distinguish the representation of an outcome from the importance assigned to it.

Motivational allocation

Motivational allocation converts valued possibilities into relative priorities for Belonging, Identity, and Power. It concerns how strongly the available response options are influenced by inclusion, self-relevant commitment, and consequential control. The same valuation can affect several dimensions.

Allocation depends on present concerns and on which options are available. Strong motivation for inclusion cannot produce participation if every available option blocks it. Likewise, influence can be pursued by seeking authority, negotiating shared decisions, or leaving a relationship of dependence. The output is therefore a motivational organization of possible responses, rather than the response itself.

Emotional modulation

Emotional modulation changes the influence, urgency, and persistence of ongoing processing. An interpreted threat, opportunity, or conflict can affect the intensity with which a person attends, evaluates, or prepares to act. Affective processing also responds to bodily condition and expected consequences.

This stage can influence earlier operations. Heightened urgency may change which cues dominate contextual interpretation; reassurance may permit broader consideration; frustration may alter willingness

to persist. EPS represents these effects as modulation of interacting processes. It does not reduce all emotions to one chemical concentration or assume that emotion always begins after deliberation.

Existential state confirmation

Existential state confirmation integrates what the current circumstances, proposed response, and anticipated or experienced outcomes imply for continued existence. It is a provisional assessment of Survival, Stability, and Quality. Confirmation here means an ongoing estimate that can be revised, rather than certainty that a response will succeed.

The output informs whether the person maintains a course of action, seeks more information, changes a priority, or reorganizes participation. This operation can assess expected consequences before action and update the assessment after consequences occur. The three orientations are framework-level interpretations of regulatory conditions; their neural representation cannot be supplied by attaching three names to one undifferentiated signal.

6 Constructing the neural execution model

We infer candidate neural mechanisms by identifying the operation required, specifying the relevant neuronal property, and explaining how that property could contribute to the operation. The connection is strongest when it includes input, connectivity, synaptic effect, and output. Regional activation alone supplies a less specific account.

The proposed mechanism can reuse cell classes across stages. Similar pyramidal or inhibitory neurons can participate in different computations because their inputs, connections, and targets differ. The psychological content is attributed to patterns of activity in their task context. A cell's morphology or molecular marker does not determine that content by itself.

Inhibitory selection and pyramidal integration

Contextual filtering requires a circuit to regulate which signals influence a representation and to integrate the selected information. Cortical inhibitory interneurons provide candidate tools for the first operation. Excitability describes a cell's responsiveness to input; excitation describes its effect on another cell. Cortical GABAergic interneurons generally inhibit their targets. Inhibition of another inhibitory population can instead release a target population from suppression.

Pfeffer et al. (2013) demonstrated subtype-dependent inhibitory connectivity in mouse visual cortex. Zhang et al. (2014) showed that frontal inputs recruited local circuits to facilitate and suppress visual processing. Somatostatin-positive interneurons contributed preferentially to surround suppression, while vasoactive intestinal peptide-positive interneurons were important for center facilitation. These findings identify input-control mechanisms relevant to the filtering operation.

Pyramidal neurons provide an integration mechanism. In rat Layer 5 cells, coincident back-propagating action potentials and distal dendritic input can produce calcium-dependent burst output; dendritic inhibition can block this interaction (Larkum et al., 1999). This supplies a concrete property through which inputs arriving at different cellular compartments can jointly influence transmission.

EPS accordingly proposes interacting inhibitory, disinhibitory, and pyramidal populations that construct a context-sensitive representation. Filtering and integration occur through their recurrent interaction.

Interneurons do not have to complete all processing before pyramidal neurons begin. Superficial-layer contextual representations and deeper-layer projection outputs are candidate anatomical assignments, whose suitability depends on the region and task.

Valuation populations and learned significance

Value mapping requires a representation whose influence changes with the significance of an expected outcome. Ballesta et al. (2020) showed in monkeys that manipulating orbitofrontal activity altered subjective valuation and economic choices. This provides causal evidence for a circuit component connecting value representation to decision behavior.

EPS proposes that valuation populations receive contextual information together with signals reflecting experience, commitments, and present needs. Learned connectivity would help determine how strongly a contextual pattern influences valuation. The Cultural Matrix then specifies the proposed mapping from those valuations to motivational priorities. The monkey findings concern economic choices; extending the valuation mechanism to culturally conditioned social significance is the EPS inference.

Distributed representations contributing to BIP

Motivational allocation requires connections between valuation and representations of socially significant outcomes. The proposed BIP dimensions would be expressed through distributed population activity and its influence on response selection. Learned synaptic relationships connecting valuation with these populations are a candidate biological interpretation of the Cultural Matrix. The construction does not require separate Belonging, Identity, and Power cell types.

For Belonging, Matthews et al. (2016) found in mice that dorsal raphe dopamine neurons changed following acute isolation, and that their manipulation affected subsequent social seeking. These results demonstrate a mechanism sensitive to social conditions and capable of changing approach to others. They supply a candidate ingredient for affiliation-related motivation without locating the complete human construct in the dorsal raphe.

For Identity, Kelley et al. (2002) associated medial prefrontal activity in human imaging with self-referential judgments. Self-relevance is a plausible ingredient in representing personally meaningful roles and commitments. The bridge from a trait-judgment task to role identification is a further proposal; the imaging result does not establish that the region implements all Identity functions.

For Power, Wang et al. (2011) found stronger excitatory inputs to medial prefrontal Layer 5 pyramidal neurons in higher-ranking mice. Increasing or decreasing synaptic efficacy changed social rank. This links synaptic organization to consequential social behavior, while human authority, agency, and dependence require a broader account than rank alone.

Relational representation may connect these components. Tavares et al. (2015) found that human hippocampal activity during a social interaction task tracked a representation organized by affiliation and power. The finding supports investigation of neural representations of social relationships. In EPS, such representations would contribute information about who is involved and how a possible outcome changes the person's relationship to others. They are inputs to motivational allocation, rather than a complete BIP architecture.

Affective signals and modulatory learning

Emotional modulation requires signals capable of altering the effect of an interpretation on continuing processing. Namburi et al. (2015) identified mouse basolateral amygdala projection populations with different synaptic changes following reward and fear conditioning. Manipulating the populations affected reinforcement and conditioning. Their projection targets help explain how learned associations can contribute to different behavioral effects.

EPS proposes that affective signals influence processing through circuit interactions and changes in effective gain. Neuromodulatory learning supplies an additional mechanism for revising later responses. Steinberg et al. (2013) showed that temporally controlled dopamine-neuron activation altered cue-related learning in rats. These experiments support a role for outcome-related signals in learning; they do not make dopamine interchangeable with emotion.

Within the EPS construction, a learning mechanism would connect the information active during an event with the consequences experienced afterward. A candidate synaptic account would need to identify the participating connections and explain how feedback modifies their future influence. A single global increase applied equally to every motivational pathway would not, by itself, produce differentiated learning among those pathways.

Bodily and inferred state integration

Existential state confirmation requires information about the organism's condition and about circumstances that may be only partly observable. Critchley et al. (2004) associated anterior insular activity with accuracy of bodily awareness in a human heartbeat task. Schuck et al. (2016) found human orbitofrontal representations of inferred task states. These provide candidate ingredients for bodily monitoring and situational state estimation.

EPS proposes that these kinds of information interact with valuation, motivation, and affect to estimate whether present conditions protect viability, sustain continuity, or improve valued circumstances. Survival, Stability, and Quality are the framework's interpretation of that joint estimate. Neither cited study identifies three discrete existential states or a single region that confirms them.

From integrated priorities to action

The five psychological stages require an interface with response preparation and execution. Candidate action circuits include cortical and striatal systems through which representations influence movement and learned behavior. Cui et al. (2013) observed concurrent activation of direct and indirect striatal pathways around action initiation in mice. This cautions against reducing the interface to one pathway that simply permits action and another that simply prevents it.

EPS proposes that the integrated motivational and regulatory state biases which response is prepared, sustained, or revised. The action then changes the body, the social interaction, or the environment. Those consequences return as information for later contextual interpretation, valuation, and state assessment. The execution hypothesis is therefore a loop connecting neural processing with continuing interaction.

7 Integrating the psychological and neural descriptions

The following mapping summarizes the construction. Each row specifies a functional operation and a candidate neural contribution. The rows should not be read as an established sequence of anatomical pathways.

Table 3. Functional operations and candidate neural contributions.

EPS operation	Required transformation	Candidate neural contribution
Contextual filtering	Available cues become a relevant situation representation	Inhibitory and disinhibitory input control interacting with pyramidal integration
Value mapping	The situation becomes a pattern of personal and social significance	Valuation populations influenced by context and learned connectivity
Motivational allocation	Valuations become relative BIP priorities	Distributed representations of affiliation self-relevance and influence coupled to response preparation
Emotional modulation	Affective conditions change the influence and persistence of processing	Affective circuit interactions and modulatory effects on processing and learning
Existential state confirmation	Expected or experienced circumstances become a regulatory assessment	Integration of bodily state inferred circumstances and consequential significance

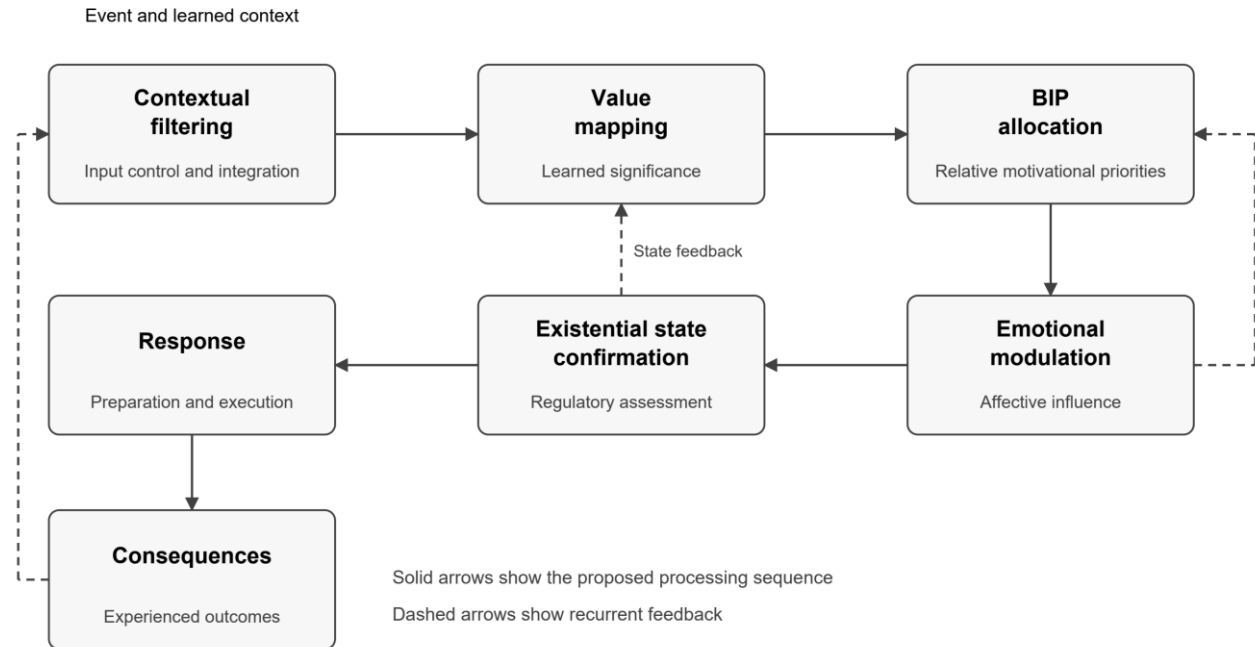


Figure 1. Proposed information flow in EPS. The main sequence distinguishes psychological operations. Feedback arrows show recurrent dependencies and learning from consequences. The diagram is a functional specification, not a measured connectome or a claim about fixed neural timing.

The physical proposal consists of changing activity across connected populations. Inhibitory and disinhibitory interactions regulate influence; pyramidal integration combines incoming signals; projection pathways transmit representations; affective and regulatory signals alter continuing processing; and experience can modify the connections that influence future responses. This connects the pipeline to biological operations without assigning a psychological label to every individual neuron.

Cultural conditioning enters through learned expectations and their influence on these operations. The same encounter can activate different associations and motivational priorities because people have different histories and commitments. The framework allows affective and culturally conditioned reasoning to operate alongside explicit problem solving. Its proposed explanatory contribution is the organization of significance that determines which problems and outcomes the person prioritizes.

8 A worked example of adaptive social reasoning

Consider a participant whose contribution is publicly questioned during a group project. This is a constructed example of the pipeline, not participant data. The event provides words, tone, an audience, and an existing relationship among people. Contextual filtering can represent it as helpful correction, a threat of exclusion, or a challenge to a valued role. Multiple interpretations may remain active.

Value mapping relates those possibilities to what matters to the participant. Preserving the project, maintaining trust, receiving recognition for competence, and retaining decision influence can have different importance. Learned norms affect the significance of public disagreement. The same words may carry a different meaning in another relationship or under a different expectation about authority.

Motivational allocation organizes those meanings through BIP. Belonging may favor preserving participation, Identity may favor defending a meaningful contribution, and Power may favor securing an opportunity to shape the decision. Emotional modulation changes the urgency and persistence of these concerns. Existential assessment considers whether an available response would protect immediate welfare, preserve a dependable role, or improve future participation.

The resulting response may combine concerns, such as requesting clarification while affirming commitment to the shared objective. Its consequences can support the initial interpretation or contradict it. A constructive reply may revise the apparent threat; continued exclusion may require another response. EPS describes how that revision is organized. It does not guarantee that the person initially interprets the event correctly or that one response is optimal for every group.

9 Computational methods

Operationalizing the construction

We implemented EPS version 0.2 as an abstract model of interacting populations. The earlier scalar reference model remains available for regression comparison. The revised implementation represents four contextual cue rates C , three valuation rates V , three BIP driver rates D , two affective components M , and three regulatory support estimates Q . Larger Q components indicate greater support for Survival, Stability, and Quality. Inhibitory and disinhibitory populations regulate cue influence before contextual activity contributes to valuation. The rates are functional variables, without a claim that the simulated populations identify particular cells or cortical layers.

The Cultural Matrix W_{DV} retains its value-to-driver meaning. In this implementation, a weight represents a learned relationship between an active value channel and the utility of mobilizing a BIP response pathway. Negative weights can suppress recruitment. This is an operational choice for the present study, not a complete model of cultural acquisition. A separate matrix W_{CV} encodes context into values, and W_{QV} relates value channels to regulatory support. Cue meanings, reliability, response affordances, utility, and regulatory effects are declared task inputs.

M contains signed outcome valence and arousal. Valence records the preceding outcome, while arousal changes driver gain and the concentration of action probabilities. This limited abstraction does not implement a complete emotion theory, and its outcome signal is not a physiological dopamine measurement. Q combines experienced conditions with a modest anticipated-support contribution and returns information to valuation and disinhibition. Actions are selected from the integrated EPS activity rather than from the hidden successful-response label.

Population dynamics and action learning

Time is expressed in simulation units rather than calibrated milliseconds. All population targets are calculated from the previous state, and population updates occur together. For a population x with target x^* and time constant τ_x , the integration rule is:

$$x_{t+1} = x_t + (1 - \exp(-\Delta t/\tau_x))(x_t^* - x_t) \quad (1)$$

In the following equations, the clipping operator Π_{01} restricts each component to $[0, 1]$, products of vectors are componentwise, and ε_0 denotes a small positive denominator safeguard. Regulatory need n and its contextual projection a are:

$$n = \Pi_{01}(W_{QV}^T(1 - Q)), \quad a = \Pi_{01}(W_{CV}^T n) \quad (2)$$

For supplied cue reliability r , inhibitory activity I_f and disinhibitory activity H_f have targets:

$$I_f^* = 12(1 - r), \quad H_f^* = 0.5a \quad (3)$$

The influence gate reduces the effect of unreliable cues, with disinhibition reducing the inhibitory influence:

$$g = \frac{1}{1 + I_f/(1 + H_f)} \quad (4)$$

Contextual integration and value mapping then have targets:

$$C^* = \Pi_{01}(sg + 0.1C) \quad (5)$$

$$V^* = \Pi_{01}((W_{CV}C)(1 + 0.8n)) \quad (6)$$

Let m_a be arousal, $G = 1 + 0.5m_a$ the driver gain, and $\text{sum}(D)$ the sum of BIP activity. For driver i , the input combines valuation, recurrence, and competition:

$$u_i = G(W_{DV}V)_i + 0.1D_i - 0.25(\text{sum}(D) - D_i) \quad (7)$$

Set d_i to the positive part of $\tanh(u_i)$. A shared capacity limits total recruitment while permitting coactivation:

$$D^* = d \min \left(1, \frac{1.5}{\max(\text{sum}(d), \varepsilon_0)} \right) \quad (8)$$

The valence target equals the preceding received utility y_{prev} , initialized at zero. Arousal combines current driver activity with the magnitude of that feedback:

$$m_a^* = \Pi_{01}(0.25\bar{D} + 0.75|y_{\text{prev}}|) \quad (9)$$

Here, $\bar{D}$ denotes the mean of the three driver components. Given experienced regulatory condition b , the support estimate is:

$$Q^* = \Pi_{01}(b + 0.1(W_{QV}V)\bar{D}) \quad (10)$$

A leaky trace z retains valuation active before action. It updates after the population step using the newly calculated V :

$$z_{t+1} = z_t + (1 - \exp(-\Delta t/\tau_z))(V_{t+1} - z_t) \quad (11)$$

Each response has a declared BIP affordance profile. Let A contain those profiles and let the response score be $l_k = (AD)_k$. In the benchmark, all three responses are feasible and optional action costs and direct regulatory-effect terms are zero. Selection combines a softmax with uniform exploration:

$$P(k) = (1 - \varepsilon) \frac{\exp(l_k/\theta)}{\sum_j \exp(l_j/\theta)} + \frac{\varepsilon}{3} \quad (12)$$

Exploration epsilon is 0.12, and temperature theta is 0.12 divided by $(1 + 0.5m_a)$. The general interface also accepts mixed affordances, costs, expected regulatory effects, and feasibility masks; the present benchmark does not test all of those options.

Normalize the executed affordance profile to p . Before receiving its consequence, store the eligibility matrix $E = pz^T$ and prediction $W_{DV}z$. On receipt of utility y , prediction error delta and bounded learning are:

$$E = pz^T, \quad \delta = y - W_{DV}z \quad (13)$$

$$W_{DV}^{\text{next}} = \Pi_{[-1.5, 1.5]}(W_{DV} + 0.15 \text{diag}(\delta)E) \quad (14)$$

In Equation 14, each error component multiplies the corresponding row of E . Thus only response pathways and value channels with nonzero eligibility receive credit. The stored pre-action trace can survive later cue disappearance until the single pending consequence arrives. This is an abstract

outcome-gated eligibility rule; its executed-response profile is not recorded postsynaptic activity. It supplies differentiated learning without establishing a biological plasticity mechanism.

Experienced regulatory effects update b by adding the supplied consequence vector and clipping to $[0, 1]$. Between episodes, contextual, valuation, driver, filtering, and eligibility activity is reset. Learned W_{DV} , experienced regulatory conditions, and the preceding feedback are retained; Q is initialized from the experienced condition and M from the retained feedback. Within-event recurrence and between-event retention are therefore distinct parts of the implementation. Table 4 gives the selected parameters. Noise was zero in the reported experiments.

Table 4. Parameters used for the full recurrent implementation. Time constants are in simulation units. All comparison configurations and full numerical precision are retained in the experiment archive.

Parameter group	Value	Role
Integration step	1	Common simulation time increment
Time constants	2, 3, 4, 4, 5, 6, 8	Filtering, context, value, driver, modulation, state, eligibility
Inhibition and disinhibition	12 and 0.5	Cue influence control and regulatory feedback to the gate
Context and driver recurrence	0.1 and 0.1	Persistence within an event
Regulatory feedback to value	0.8	Influence of unsupported regulatory conditions
Driver competition and budget	0.25 and 1.5	Competition and maximum total recruitment
Modulation gain	0.5	Arousal influence on drivers and action temperature
Anticipated state contribution	0.1	Valuation and driver contribution to Q
Temperature and exploration	0.12 and 0.12	Response concentration and uniform exploration
Learning rate and bounds	0.15 and -1.5 to 1.5	Outcome-gated update and bounded weights
Initial Cultural Matrix	0.2 in every entry	Equal driver associations before experience
Initial regulatory condition	0.6 in each component	Supplied starting SSQ support
Noise amplitude	0	Deterministic population dynamics conditional on events

Synthetic coordination and reversal task

The task isolates learning and revision of a response contingency. It does not simulate a complete group or the public-criticism example in Section 8. Each episode supplies one of three situation cues and an independent distractor. Situation cues are one-hot signals; distractor amplitude is drawn uniformly from 0.5 to 1.0. Reliability is $[1, 1, 1, 0]$. The context-to-value matrix consists of a three-channel identity mapping plus a distractor column of 0.4 in every row, while W_{QV} is the identity matrix. These supplied representations provide controlled ambiguity and interference without claiming discovery of psychological categories.

The three response options are coordinating participation, asserting a role, and directing a plan. They have one-hot Belonging, Identity, and Power affordances respectively. Such profiles are experimental assumptions, not claims that those actions express only one motive in human interaction. Each seed

generates a hidden permutation linking situation cues to successful responses. After episode 300, the successful response for every situation changes to the next response cyclically. The agent receives the event cues and available responses before action; the hidden target is used by the environment only after selection to determine completion.

Completion supplies utility +1 and regulatory effects [0.01, 0.04, 0.02]; failure supplies utility -1 and effects $[-0.01, -0.03, -0.02]$, in Survival, Stability, and Quality order. These effects are stipulated numerical consequences. They do not measure physiological survival or social wellbeing. The agent has 24 integration steps before each action, and the Cultural Matrix starts with all entries equal to 0.2, so initial driver differences are not supplied as learned cultural differentiation.

Comparison conditions and interventions

We ran eight conditions with matched event schedules and hidden contingencies within each seed. The full recurrent model used response-specific learning. Frozen weights retained population processing and received affective and regulatory feedback while preventing Cultural Matrix updates. Broadcast learning applied equal increments to all driver rows. Unrelated feedback supplied an independent sequence of positive and negative outcomes, breaking the connection between selected response and the feedback used for learning.

Three component removals examined configured contributions. Removing filtering set inhibition and disinhibition to zero. Removing affective gain eliminated arousal-dependent driver gain and the change in action temperature. Removing regulatory feedback eliminated Q -to-value and Q -to-disinhibition effects while retaining the Q readout. These interventions do not isolate every possible function of the corresponding psychological construct.

The final comparison was a direct linear contextual action-value learner. It received the same declared cues, reliability, response options, utilities, initial weights, learning rate, bounds, exploration, and baseline temperature. It used the known reliability gate and value encoder directly, without recurrent EPS dynamics or affective and regulatory feedback. The comparison examines whether those additional mechanisms are required to solve this task; it is not a comparison of equal neural capacity, computational cost, or human validity.

Separate population interventions examined a pulse against a no-input control, distractor influence with filtering on and off, BIP coactivation with competition on and off, arousal-dependent gain, and unequal regulatory conditions with valuation feedback on and off. These tests measure consequences of the implemented equations. They do not locate their operations in brain tissue.

Evaluation and reproducibility

Seeds 0 through 9 were used for 600 episodes in each of the eight conditions, producing 48,000 interactions. We evaluated four 60-episode windows: episodes 1-60, 241-300, 301-360, and 541-600. Success percentages and sample standard deviations are calculated across seed-level window means. Episodes within a seed are not treated as independent experimental replications. Comparisons with the linear learner also use paired seed-level differences; no formal significance test or superiority margin was specified.

The engineering criteria required at least 70% success before reversal and in the final block, a final advantage of at least 20 percentage points over frozen weights, broadcast learning, and unrelated

feedback, emergence of differentiated weights from equal initialization, and the five expected population-intervention effects. Parameters and criteria were fixed for this executed run without a search over benchmark outcomes. This is an exploratory computational study rather than a preregistered psychological experiment.

Sixteen functional and regression checks passed, covering dimensions, selective and bounded updates, delayed credit, feasibility, feedback, seeded reproducibility, numerical refinement, and preservation of the legacy scalar result. Artifact verification checked all 48,000 episode records against stored outcomes and summaries, confirmed matched schedules and targets across conditions, and replayed the full model for seed 0 with identical recorded fields. Python 3.13.1, NumPy 2.5.3, and Matplotlib 3.11.2 were used. Source hashes, configurations, seed-level results, raw trajectories, and artifact checksums are retained for reproduction.

10 Computational results

Learning and recovery after reversal

The full model reached 92.0% success in the final block before reversal, decreased to 39.3% during the first 60 episodes after reversal, and recovered to 91.5% in the final block. Table 5 reports every condition with variability across seeds. Frozen weights and broadcast learning both reached 30.8% in the final block, while unrelated feedback reached 26.3%. These comparisons support the contribution of response-specific, contingent learning on the declared task. A uniform random response has an expected success rate of one third.

Table 5. Success percentages as mean with sample standard deviation in parentheses across ten seeds. Every column covers 60 episodes: first block 1-60, before reversal 241-300, after reversal 301-360, and final block 541-600.

Model or control	First block	Before reversal	After reversal	Final block
Recurrent EPS	84.3 (4.3)	92.0 (4.2)	39.3 (9.7)	91.5 (3.4)
Frozen weights	31.2 (4.8)	30.2 (5.6)	33.5 (6.6)	30.8 (10.3)
Broadcast learning	31.2 (4.8)	30.2 (5.6)	33.5 (6.6)	30.8 (10.3)
Unrelated feedback	31.5 (10.6)	35.0 (14.1)	37.2 (11.0)	26.3 (12.0)
Filtering removed	66.0 (11.8)	92.0 (4.2)	26.7 (4.4)	91.5 (3.4)
Affective gain removed	82.3 (5.2)	91.8 (4.2)	35.3 (7.9)	91.3 (3.1)
Regulatory feedback removed	84.7 (4.4)	92.0 (4.2)	39.3 (10.2)	91.5 (3.4)
Linear learner	81.2 (6.0)	93.2 (3.4)	46.7 (11.9)	90.8 (3.4)

The linear learner reached 90.8% in the final block, close to the full model. The mean paired final difference was 0.67 percentage points, with sample standard deviation 4.39 percentage points and a range from -6.67 to 5.00. These descriptive comparisons do not establish an EPS performance advantage. Both architectures can solve the constructed contingency using the supplied representations and experienced outcomes. Figure 2 shows the course of learning and recovery alongside the controls.

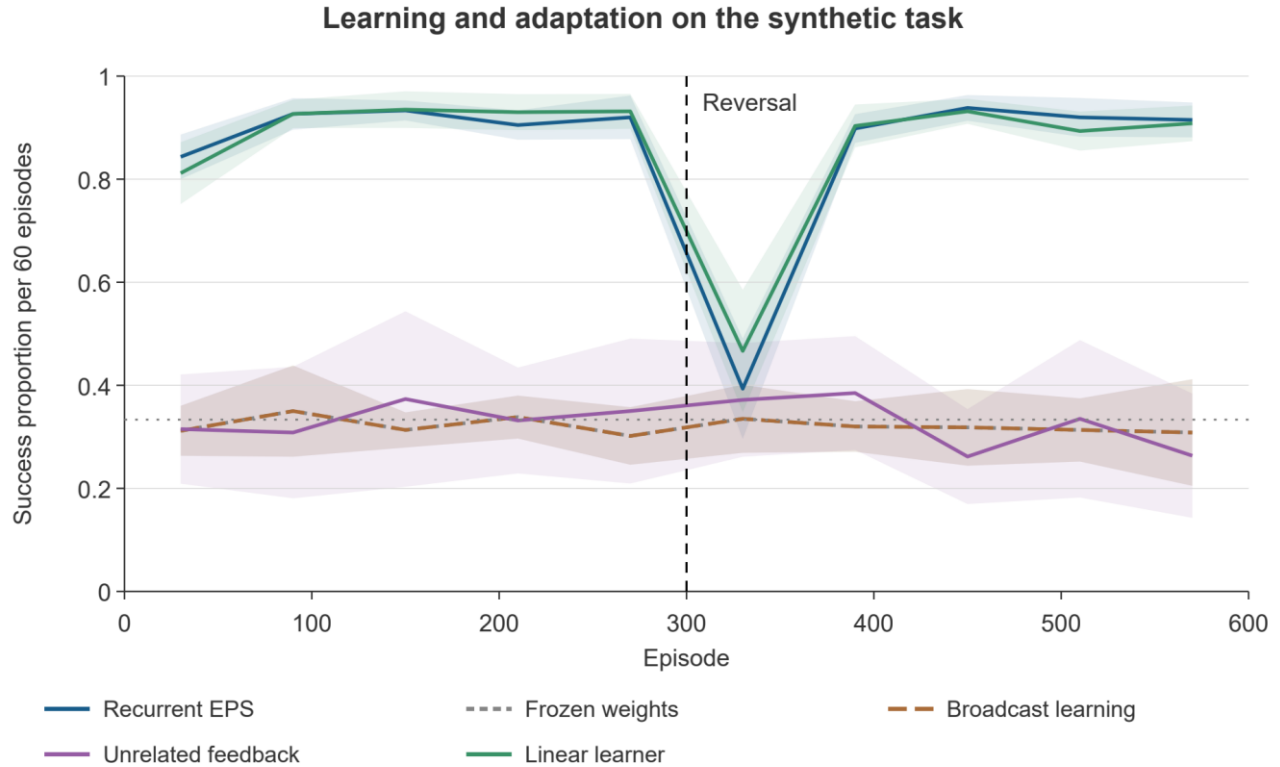


Figure 2. Learning on the synthetic coordination task. Lines show mean success in nonoverlapping 60 -episode blocks across ten seeds, and shaded regions show one sample standard deviation across seeds. The dashed vertical line marks reversal after episode 300; the dotted horizontal line marks the one -third random-choice expectation. Frozen and broadcast trajectories overlap. Variability bands describe simulated seed variation, not uncertainty in population-level human behavior.

Component effects and learned associations

Removing filtering reduced first-block success from 84.3% to 66.0% and first post-reversal-block success from 39.3% to 26.7%, while final performance converged to 91.5% in both conditions. Filtering therefore affected early learning and the initial response to change in this configuration. Affective-gain removal yielded 91.3% final success, and regulatory-feedback removal yielded 91.5%. Similar final outcomes limit the task’s ability to demonstrate the necessity of those configured components. They do not show that emotion or regulatory assessment is unnecessary in human behavior.

Response-specific updates produced different value-to-driver associations from identical initial weights, and those associations changed following reversal. Figure 3 illustrates one seed without treating it as evidence of acquired human personality. The equal-row broadcast condition retained equal rows from its symmetric initialization, whereas the full learning rule could strengthen and weaken different pathways. The resulting matrix is a learned task representation whose psychological interpretation remains an additional hypothesis.

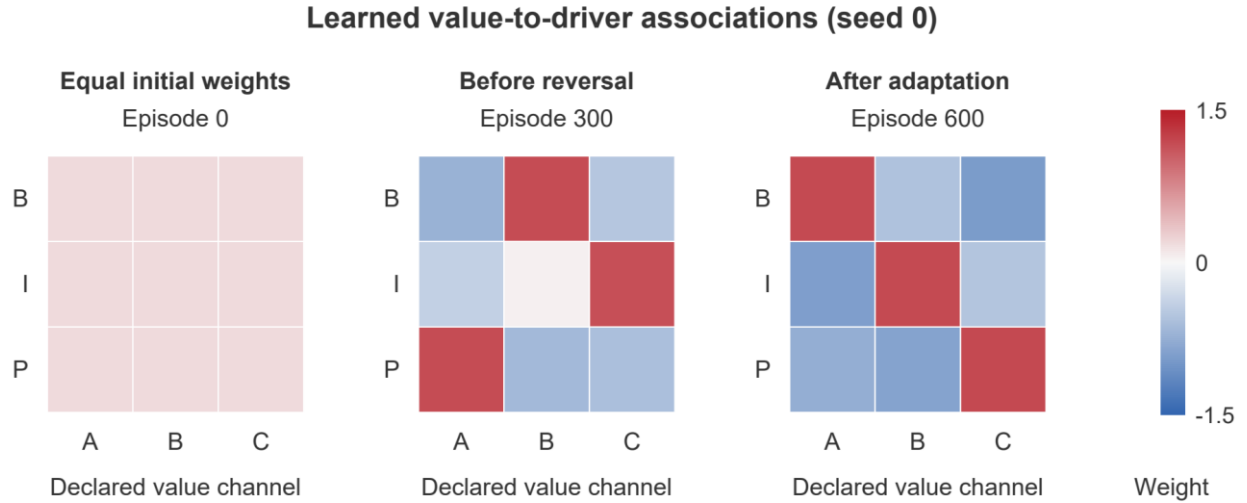


Figure 3. Cultural Matrix W_{DV} for full-model seed 0 at initialization, after episode 300, and after episode 600. Rows are BIP response pathways and columns are declared value channels A, B, and C. The common color scale spans the configured weight bounds. This example demonstrates differentiated and revisable task associations; it does not measure cultural learning or personality in people.

Population interventions

The no-input control produced zero driver area under the curve. A pulse on one situation cue produced pulse-minus-control area 6.1497 in each driver channel under the equal initial weights. These are simulation-rate-by-time units. They are not directly comparable with absolute areas from the legacy scalar model, which uses different parameters and a positive no-input baseline.

Filtering reduced final distractor context activity from 1.0000 to 0.1038, a reduction of 89.6%. With three equally stimulated value channels and weights of 0.25, competition permitted all three drivers to remain active while reducing final per-driver activity from 0.5000 to 0.3895. Total driver activity with competition peaked at approximately 1.1686, below the 1.5 capacity budget. These outcomes demonstrate influence regulation and coactivation within the selected equations.

Under a retained positive feedback signal, affective gain increased final per-driver activity from 0.1422 to 0.1981. For supplied regulatory conditions [0.1, 0.5, 0.9] and equal cue amplitudes, valuation feedback produced rates [0.7644, 0.6222, 0.4800], compared with [0.4444, 0.4444, 0.4444] when the feedback was removed. The lower supported dimension consequently received more valuation activity. These numerical mappings follow from the configured support relationships; they are not observed bodily or emotional responses.

Controlled interventions on the abstract population model

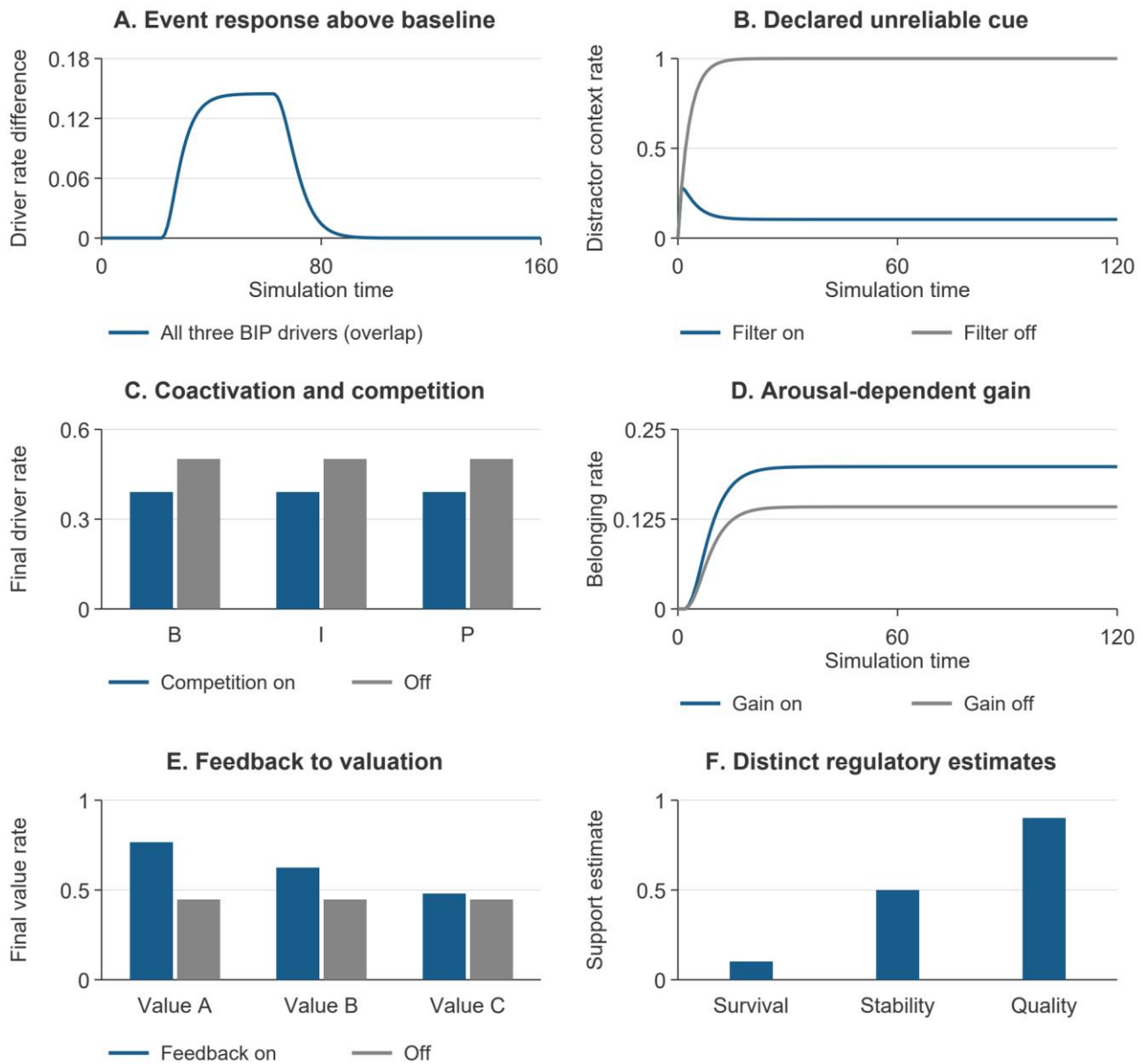


Figure 4. Controlled interventions on the abstract population model. The panels show pulse -minus-control driver activity, filtering of a declared unreliable cue, coactivation under competition, arousal -dependent gain, feedback to valuation, and distinct supplied regulatory support estimates. These conditions test mathematical execution of proposed functional ingredients rather than the anatomy of the EPS pathway.

All eleven engineering criteria were met. This finding concerns the specified computational tests and does not combine them into a measure of neural, psychological, or ecological validation.

11 Discussion and unresolved assumptions

The construction and experiments contribute at different levels. First-principles reasoning identifies a possible organization through which contextual significance, BIP priorities, affective influence, and regulatory assessment can guide a response. The implementation makes selected relationships explicit and shows that they can operate in a loop with received consequences. The control comparisons establish that differentiated contingent learning, rather than equal increases in all motivational pathways, supports adaptation on the present task.

The neuron-property argument remains relevant to this construction. Inhibitory and disinhibitory influence control and pyramidal integration supply candidate biological tools for contextual representation. The computational population interventions show how abstract versions of those operations can affect information flow. They do not establish that the particular populations, connections, or temporal properties used here are the ones that execute EPS in a human brain. No measured cell types, cortical layers, connectome, neurotransmitter concentrations, or neural recordings entered the simulation.

The successful simpler learner and the component-removal results limit stronger architectural claims. This task does not require natural-language interpretation, negotiation of roles, changing cultural expectations, conflicting social commitments, or reasoning about other agents' mental states. Reliability and action-to-BIP profiles are supplied, and utility is based on a hidden response contingency. An agent's ability to learn that contingency therefore does not establish comprehensive human-centered reasoning. Broader coverage should be assessed through tasks that distinguish the contribution of the proposed motivational and regulatory organization.

BIP remains a proposed account of social motivation. The results do not establish that its dimensions exhaust human needs or that one response uniquely identifies one driver in natural settings. The three-component Q readout likewise implements a chosen regulatory interpretation, not a validated measure of Survival, Stability, or Quality. Learned weights represent utility associations in this study; identifying them with human cultural conditioning requires independent construct evidence.

Social patterns motivate the phenomena to explain and can constrain a psychological account, but they do not uniquely determine microscopic neural mechanisms. Ecological studies should examine prediction across varied interactions using independently assessed context, value, motive, and outcome measures. Circuit studies should test specific proposed cell properties, connectivity, and perturbation effects. These are distinct validation tasks. The present paper advances from conceptual construction to computational testing while leaving those psychological, ecological, and anatomical bridges unresolved.

12 Conclusion

EPS proposes that human-centered reasoning is organized through contextual interpretation, value mapping, BIP motivation, affective modulation, and regulatory assessment. Its first-principles rationale begins with continued existence and the conditional benefits of group participation. The neural execution hypothesis connects these functional requirements to candidate biological tools while keeping the proposed correspondence open to revision.

The revised recurrent implementation adds multidimensional representations, influence gating, driver competition with coactivation, separate regulatory estimates, response selection, and differentiated learning from consequences. Across the reported synthetic study, it learned a response contingency

and adapted when that contingency changed. Performance was similar to that of a simpler contextual learner, and several component removals had little effect on final success. The contribution is therefore an explicit and reproducible computational realization of selected EPS operations, together with evidence of contingent adaptation and clear limits on what the present task distinguishes.

Data and code availability

The executed run is identified as EPS recurrent 0.2, run 20261002. Its archive is stored under `output/experiments/eps_recurrent_0_2/20261002/` in the project repository. The archive contains `summary.json`, `episodes.csv`, `trajectories.npz`, the three experimental figures, `manifest.json`, and `verification.json`. The numerical target labels in the episode records are evaluation metadata, not policy inputs.

The implementation is in `src/eps/recurrent.py`, `src/eps/learning.py`, and `src/eps/simulation.py`; the experiment suite is in `src/eps/experiments/recurrent_suite.py`. The command-line entry point and artifact verifier are `scripts/run_experiment.py` and `scripts/verify_experiments.py`. Exact model contracts and equations are documented in `docs/EPS_RECURRENT_MODEL.md`, and `requirements.lock.txt` records the executed environment.

The experiment manifest records the working-tree source hashes in addition to the baseline Git revision; the baseline revision alone does not identify the revised implementation. No public dataset release or ecological participant study is claimed.

References

- Ballesta, S., Shi, W., Conen, K. E., and Padoa-Schioppa, C. (2020). Values encoded in orbitofrontal cortex are causally related to economic choices. *Nature*, 588, 450-453. <https://doi.org/10.1038/s41586-020-2880-x>
- Critchley, H. D., Wiens, S., Rotshtein, P., Ohman, A., and Dolan, R. J. (2004). Neural systems supporting interoceptive awareness. *Nature Neuroscience*, 7(2), 189-195. <https://doi.org/10.1038/nn1176>
- Cui, G., et al. (2013). Concurrent activation of striatal direct and indirect pathways during action initiation. *Nature*, 494, 238-242. <https://doi.org/10.1038/nature11846>
- Elston, G. N., Benavides-Piccione, R., Elston, A., Manger, P. R., and DeFelipe, J. (2011). Pyramidal cells in prefrontal cortex of primates: Marked differences in neuronal structure among species. *Frontiers in Neuroanatomy*, 5, 2. <https://doi.org/10.3389/fnana.2011.00002>
- Kelley, W. M., Macrae, C. N., Wyland, C. L., Caglar, S., Inati, S., and Heatherton, T. F. (2002). Finding the self? An event-related fMRI study. *Journal of Cognitive Neuroscience*, 14(5), 785-794. <https://doi.org/10.1162/08989290260138672>
- Larkum, M. E., Zhu, J. J., and Sakmann, B. (1999). A new cellular mechanism for coupling inputs arriving at different cortical layers. *Nature*, 398, 338-341. <https://doi.org/10.1038/18686>
- Matthews, G. A., et al. (2016). Dorsal raphe dopamine neurons represent the experience of social isolation. *Cell*, 164(4), 617-631. <https://doi.org/10.1016/j.cell.2015.12.040>
- Namburi, P., et al. (2015). A circuit mechanism for differentiating positive and negative associations. *Nature*, 520, 675-678. <https://doi.org/10.1038/nature14366>

- North, D. C. (1991). Institutions. *Journal of Economic Perspectives*, 5(1), 97-112. <https://doi.org/10.1257/jep.5.1.97>
- Pfeffer, C. K., Xue, M., He, M., Huang, Z. J., and Scanziani, M. (2013). Inhibition of inhibition in visual cortex: The logic of connections between molecularly distinct interneurons. *Nature Neuroscience*, 16, 1068-1076. <https://doi.org/10.1038/nn.3446>
- Schuck, N. W., Cai, M. B., Wilson, R. C., and Niv, Y. (2016). Human orbitofrontal cortex represents a cognitive map of state space. *Neuron*, 91(6), 1402-1412. <https://doi.org/10.1016/j.neuron.2016.08.019>
- Silk, J. B., et al. (2010). Strong and consistent social bonds enhance the longevity of female baboons. *Current Biology*, 20(15), 1359-1361. <https://doi.org/10.1016/j.cub.2010.05.067>
- Steinberg, E. E., Keiflin, R., Boivin, J. R., Witten, I. B., Deisseroth, K., and Janak, P. H. (2013). A causal link between prediction errors, dopamine neurons and learning. *Nature Neuroscience*, 16(7), 966-973. <https://doi.org/10.1038/nn.3413>
- Tavares, R. M., Mendelsohn, A., Grossman, Y., Williams, C. H., Shapiro, M., Trope, Y., and Schiller, D. (2015). A map for social navigation in the human brain. *Neuron*, 87(1), 231-243. <https://doi.org/10.1016/j.neuron.2015.06.011>
- Wang, F., Zhu, J., Zhu, H., Zhang, Q., Lin, Z., and Hu, H. (2011). Bidirectional control of social hierarchy by synaptic efficacy in medial prefrontal cortex. *Science*, 334(6056), 693-697. <https://doi.org/10.1126/science.1209951>
- Zhang, S., Xu, M., Kamigaki, T., Do, J. P. H., Chang, W. C., Jenvay, S., Miyamichi, K., Luo, L., and Dan, Y. (2014). Long-range and local circuits for top-down modulation of visual cortex processing. *Science*, 345(6197), 660-665. <https://doi.org/10.1126/science.1254126>