

# **Paper 2 — The Mechanism of Abstraction (Horizontal)**

## **0. Abstract**

This paper describes the mechanism of abstraction as a three-stage structural process: isolation of a coherent substructure, lifting that substructure into a higher layer, and activation of the expanded degrees of freedom available in that layer. The mechanism satisfies the constraints established in Paper 1 and provides a substrate-agnostic account of how upward transitions occur in layered systems. Horizontal composition is examined as the independent operation of multiple mechanisms. The mechanism of abstraction implies the existence of a complementary downward operator, but compression and duality are not defined here. This paper completes the upward side of the framework and prepares the ground for the structural definition of compression in Paper 3.

## **1. Introduction**

Paper 1 defined abstraction as an upward structural operator: a transformation that lifts a coherent substructure from a base layer into a higher layer while preserving invariants and coherence, expanding degrees of freedom, and enabling new diagnostic capabilities. That definition established what abstraction is. This paper describes how abstraction occurs.

The mechanism of abstraction is not cognitive, symbolic, or representational. It is a structural process that operates across layers of a system. The mechanism must satisfy the constraints introduced in Paper 1: it must preserve invariants, maintain coherence, expand degrees of freedom, and activate diagnostics in the higher layer. It must also produce a stable structure in the higher layer that can participate in further operations.

This paper focuses exclusively on horizontal abstraction: a single upward transition applied independently to different substructures. Vertical abstraction—recursive upward transitions across multiple layers—requires additional primitives and is not developed here.

The mechanism is presented as a three-stage process: isolation of a coherent substructure, lifting into the higher layer, and activation of expanded degrees of freedom. These stages describe the internal dynamics of the upward operator. They are not optional steps or implementation details; they are the structural requirements for abstraction to occur in any system.

The mechanism presented here prepares the ground for the definition of compression (Paper 3), the mechanism of compression (Paper 4), and the duality between the two operators (Paper 5). Abstraction must be mechanistically defined first, because the downward operator depends on the structure established by the upward operator.

## **2. Requirements for a Mechanism**

The mechanism of abstraction must satisfy the structural constraints established in Paper 1. These constraints define the conditions under which an upward operator can exist. Any mechanism that fails to satisfy these requirements cannot perform abstraction, regardless of substrate.

### **2.1 Preservation of Invariants**

A mechanism of abstraction must preserve the invariants of the substructure being lifted. Invariants anchor identity across layers. If invariants are lost or altered, the resulting structure in the higher layer is no longer the same structure, and the operator collapses into a reductive transformation.

### **2.2 Preservation of Coherence**

The mechanism must preserve the internal coherence of the substructure. Coherence refers to the stability of internal relationships, constraints, and organizational patterns. If coherence is disrupted, the structure fragments during the upward transition.

### **2.3 Expansion of Degrees of Freedom**

The mechanism must relocate the structure into a layer that offers more degrees of freedom than the base layer. The higher layer must support operations or representational possibilities that the lower layer cannot. Without degree-of-freedom expansion, the mechanism is not performing abstraction.

### **2.4 Activation of Diagnostic Capabilities**

The mechanism must enable diagnostic operations in the higher layer that are unavailable in the lower layer. Diagnostics include analysis, evaluation, manipulation, transformation, and error detection. These capabilities justify the upward transition.

## **2.5 Stability of the Lifted Structure**

The mechanism must produce a stable structure in the higher layer. Stability means the structure remains coherent after the transition, can participate in operations native to the higher layer, and does not require continuous reference to the lower layer to maintain identity.

## **2.6 Compatibility With the Target Layer**

The mechanism must ensure that the lifted structure is compatible with the representational and operational constraints of the higher layer. This includes matching the structure to the representational space of the higher layer, ensuring the higher layer can host the structure without distortion, maintaining separation between layers, and preventing collapse of layer boundaries during the transition.

## **2.7 Independence Under Horizontal Composition**

Because this paper focuses on horizontal abstraction, the mechanism must support independent upward transitions for different substructures. This requires no interference between mechanisms, no shared state that couples transitions, and no cross-contamination of invariants.

## **2.8 Summary**

A valid mechanism of abstraction must preserve invariants, preserve coherence, expand degrees of freedom, activate diagnostics, produce a stable structure in the higher layer, respect layer boundaries, and support independent horizontal composition. These requirements define the structural envelope within which the mechanism must operate.

# **3. The Three-Stage Mechanism of Abstraction**

The mechanism of abstraction is a three-stage process that satisfies the constraints defined in Section 2. These stages describe the internal dynamics of the upward operator. They are not optional steps or implementation details; they are the structural requirements for abstraction to occur in any system.

## **3.1 Stage 1 — Isolation of a Coherent Substructure**

The mechanism begins by isolating a coherent substructure within the base layer. This requires identifying a substructure whose internal relationships are stable, ensuring its invariants are internally consistent, confirming that the substructure is self-contained enough to be lifted, and

preventing interference from adjacent or overlapping structures. Isolation prepares the structure for upward transition by establishing a clean boundary around it.

### **3.2 Stage 2 — Lifting Into the Higher Layer**

The second stage performs the upward transition. During the lift, the substructure is relocated into the representational space of the higher layer, invariants are preserved, coherence is preserved, and the structure is re-expressed in a form compatible with the higher layer. No reduction or simplification occurs. The lift is a structural relocation across layers.

### **3.3 Stage 3 — Activation of Expanded Degrees of Freedom**

Once the structure is stable in the higher layer, the mechanism activates the expanded degrees of freedom available at that layer. This activation enables new operations, transformations, analyses, diagnostics, and forms of manipulation that were not available in the base layer. A structure that has been lifted but cannot activate new degrees of freedom has not been abstracted; it has merely been relocated.

### **3.4 Summary of the Mechanism**

The mechanism of abstraction consists of isolation, lifting, and activation. This three-stage process satisfies all structural requirements and defines how abstraction occurs in any system that supports layered architecture.

## **4. Constraints and Failure Modes**

The mechanism of abstraction operates within strict structural constraints. When these constraints are violated, the upward transition cannot occur, or the resulting structure in the higher layer becomes unstable, distorted, or non-functional. Failure modes are structural breakdowns that prevent abstraction from being possible in any substrate.

### **4.1 Loss of Invariants**

If the mechanism fails to preserve the invariants of the substructure, the lifted structure no longer corresponds to the original. This produces identity drift, structural distortion, and incompatibility with higher-layer operations.

## **4.2 Loss of Coherence**

If internal relationships or constraints within the substructure are disrupted during the transition, the structure fragments. Fragmentation leads to partial structures, incoherent expressions, and unstable or unusable forms in the higher layer.

## **4.3 Insufficient Degrees of Freedom in the Higher Layer**

If the higher layer does not provide more degrees of freedom than the base layer, the mechanism cannot complete the upward transition. This produces collapsed transitions, degenerate mappings, and structures that cannot activate new capabilities.

## **4.4 Diagnostic Collapse**

If the higher layer does not support diagnostic operations unavailable in the lower layer, the upward transition has no functional purpose. Diagnostic collapse results in structures that cannot be analyzed, manipulated, evaluated, or transformed.

## **4.5 Boundary Violations Between Layers**

If the mechanism fails to maintain separation between the base and higher layers, the transition collapses. Boundary violations include mixing representational spaces, leaking constraints across layers, and requiring continuous reference to the lower layer to maintain identity.

## **4.6 Incompatibility With the Target Layer**

If the structure cannot be expressed in the representational or operational space of the higher layer without distortion, the mechanism fails. This includes mismatched representational formats, incompatible constraints, and insufficient structural capacity in the higher layer.

## **4.7 Interference Under Horizontal Composition**

Horizontal abstraction requires independent transitions for different substructures. Failure modes include cross-contamination of invariants, shared state that couples transitions, interference between mechanisms, and structural collisions in the higher layer.

## **4.8 Summary**

The mechanism of abstraction fails when invariants cannot be preserved, coherence is disrupted, degrees of freedom do not expand, diagnostics cannot activate, layer boundaries are violated, the

target layer cannot host the structure, or horizontal independence is broken. These failure modes apply only to the upward transition itself. The ongoing stability of the lifted structure in the higher layer is a property of the operator architecture, not the mechanism. The mechanism completes once the structure is successfully lifted and its expanded capabilities are activated.

## **5. Horizontal Composition of Mechanisms**

Horizontal abstraction allows different substructures within a system to be abstracted independently and in parallel. This section describes how the mechanisms of abstraction compose without interference.

### **5.1 Independent Isolation**

Each mechanism begins by isolating a coherent substructure in the base layer. For horizontal composition to hold, isolation boundaries must not overlap, invariants must not depend on other substructures, coherence must be internally maintained, and isolation must not alter the conditions required for another mechanism to operate.

### **5.2 Independent Lifting**

During the upward transition, each mechanism lifts its substructure into the higher layer. The lifting of one structure must not distort the representational space needed by another, and invariants and coherence must be preserved independently.

### **5.3 Independent Activation of Degrees of Freedom**

Once lifted, each structure activates the degrees of freedom available in the higher layer. Horizontal composition requires no competition for representational capacity, no interference in diagnostic activation, and no coupling of operations across structures.

### **5.4 Non-Interference as a Mechanistic Constraint**

Horizontal composition is a mechanistic constraint: each instance of the mechanism must be able to run independently. This requires independent invariant preservation, coherence preservation, compatibility with the higher layer, and diagnostic activation.

## 5.5 Parallelism Without Coupling

Horizontal composition does not imply concurrency. It implies parallelism without coupling: mechanisms may run at the same time or at different times, but they do not share internal state, require synchronization, or impose constraints on each other's transitions.

## 5.6 Summary

Horizontal composition of mechanisms requires independent isolation, lifting, and activation, with no interference across mechanisms. This ensures that multiple abstractions can occur within the same system without structural conflict.

# 6. Substrate-Agnostic Examples of the Mechanism

The mechanism of abstraction is substrate-agnostic. The examples below demonstrate how the three-stage mechanism operates across different substrates without relying on domain-specific interpretation.

## 6.1 Machine Learning Systems

**Isolation:** Local spatial patterns form coherent substructures in the pixel layer.

**Lifting:** These patterns are re-expressed in the first hidden layer.

**Activation:** The higher layer enables feature interactions and diagnostic signals.

## 6.2 Biological Regulatory Networks

**Isolation:** A regulatory motif forms a coherent substructure in the molecular-interaction layer.

**Lifting:** The motif is expressed as a functional unit in the network-motif layer.

**Activation:** The higher layer enables dynamical analysis and robustness evaluation.

## 6.3 Distributed Systems

**Isolation:** A message-passing pattern forms a coherent substructure in the protocol-primitive layer.

**Lifting:** The pattern is expressed in the protocol-layer representation.

**Activation:** The higher layer enables verification, optimization, and deadlock detection.

## 6.4 Mathematical Systems

**Isolation:** A geometric configuration forms a coherent substructure in Euclidean space.

**Lifting:** The configuration is expressed as a similarity class.

**Activation:** The higher layer enables transformation analysis and equivalence reasoning.

## 6.5 Cognitive-Independent Perceptual Systems

**Isolation:** A stable relational pattern forms a coherent substructure in the sensory-input layer.

**Lifting:** The pattern is expressed in a higher relational-structure layer.

**Activation:** The higher layer enables prediction and structural comparison.

## 6.6 Summary

Across all substrates, the mechanism follows the same sequence: isolation, lifting, and activation. These examples demonstrate that the mechanism is not domain-specific but structural.

# 7. Implications for Compression

The mechanism of abstraction has direct implications for the existence of a complementary downward operator.

## 7.1 The Mechanism of Abstraction Implies a Downward Operator

The upward transition produces a structure in the higher layer that preserves invariants and coherence, occupies a more capable representational space, and supports diagnostics. The system must also be able to return the structure to the lower layer while preserving identity and restoring compatibility. This downward transformation is compression.

## 7.2 Why Compression Cannot Be Defined Here

Compression has different directionality, different structural constraints, and requires primitives not yet introduced. Introducing it here would collapse the altitude of the exposition. Compression is defined in Paper 3.

### **7.3 Why Duality Cannot Be Introduced Yet**

Duality requires complete definitions of both abstraction and compression. Without both operators fully defined, duality cannot be articulated. It is developed only after Papers 3 and 4.

### **7.4 Summary**

The mechanism of abstraction implies the necessity of a downward operator and the need for a separate definition of compression. This paper completes the upward side of the framework.

## **8. Conclusion**

This paper described the mechanism of abstraction as a three-stage structural process: isolation, lifting, and activation. The mechanism satisfies the constraints established in Paper 1 and provides a substrate-agnostic account of how upward transitions occur in layered systems. Horizontal composition was shown to arise from the independence of mechanisms operating on different substructures.

The mechanism of abstraction implies the existence of a complementary downward operator capable of returning structures to lower layers while preserving identity and restoring compatibility. Because the downward operator has different directionality and structural requirements, it cannot be defined within this paper. Its definition is the focus of Paper 3.

With the upward operator now defined both structurally (Paper 1) and mechanistically (Paper 2), the framework is prepared for the introduction of compression and, subsequently, the duality between the two operators. The next paper develops the structural definition of compression, completing the foundation required for the full bidirectional account of cross-layer transformations.

