M6 – Bundled Loop Structures and Persistent Matter on Scalar–Conformal NUVO Space

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Notation and Conventions

- $\mathcal{M}$ denotes the spacetime manifold.
- η denotes the reference Lorentzian metric (typically Minkowski in a global chart).
- g denotes the physical metric.
- The scalar field $\Lambda : \mathcal{M} \to \mathbb{R}_{>0}$ is the NUVO modulation field.
- The physical metric is scalar–conformal:

$$g_{\mu\nu} = \Lambda^2 \, \eta_{\mu\nu}.$$

- $\Lambda_0 > 0$ denotes the baseline scalar availability level supported by the intrinsic delivery structure of the underlying field. In the absence of localized structural occupation the scalar field satisfies $\Lambda(x) = \Lambda_0$.
- The dimensionless scalar diagnostic is

$$\mathcal{A}(x) := \frac{\Lambda(x)}{\Lambda_0}.$$

- The scalar field represents the *locally available structural capacity* of the underlying delivery field. Localized structures may reduce this availability through occupation or transport, but the intrinsic delivery baseline Λ_0 remains fixed.
- Greek indices $\mu, \nu, \ldots$ range over spacetime coordinates $0, 1, 2, 3$.
- We use the Einstein summation convention unless explicitly stated otherwise.

[*]Bibliography is provisional. Cross-references to companion NUVO-series papers (M-, SR-, Q-, QB-, QM-series) will be updated with Zenodo DOIs in subsequent versions.

Notation convention. We reserve distinct symbols for fundamental fields and derived quantities. The scalar field Λ represents structural availability, while $\mathcal{A}$ denotes a derived normalized response field. These should not be conflated.

Remark 0.1. *Unless otherwise stated, the background signature is* $(-,+,+,+)$.

Abstract

This paper introduces bundled loop structures as the minimal structural objects used to represent persistent matter configurations on scalar–conformal NUVO space. Building on the geometric, exchange, and coherence results of M1–M5 [1–5], we define closed loops, open loops, and dynamic loops, and formalize how closed and open loops may combine into admissible bundled configurations.

The purpose of the present paper is deliberately limited. We do not attempt to construct a full particle ontology or a phenomenological classification of known matter species. Instead, we identify the minimal bundle data, admissibility conditions, persistence classes, and structural invariants needed to describe persistent matter structures within the scalar–conformal framework.

These constructions provide a structural object model for later studies of specific matter configurations, bundle transitions, and composite organization on scalar–conformal NUVO space.

1 Introduction

The preceding papers in this series established the geometric and transport structure of scalar–conformal NUVO space. In particular:

- M1 [1] introduced the scalar–conformal manifold and the canonical NUVO equation governing the structural capacity field.
- M2 [2] formalized the structural capacity availability field as an interpretive layer for the scalar field on the manifold.
- M3 [3] showed how anchored depletion structures generate scalar field gradients corresponding to the gravitational sector.
- M4 [4] introduced the exchange sector, defining oriented exchange structures that mediate interaction without contributing to anchored depletion.
- M5 [5] established the holonomic coherence condition governing admissible transport cycles on scalar–conformal manifolds.

Together these results provide a description of the geometric substrate, the scalar availability interpretation, and the exchange/coherence structure governing admissible loop configurations on NUVO space.

However, one structural element remains undeveloped: the mathematical definition of persistent matter configurations.

Earlier work introduced the conceptual idea that matter is associated with bundled loop structures composed of closed and open loop components. Closed loops correspond to anchored depletion structures that source scalar gradients, while open loops correspond to exchange structures that mediate oriented interaction without anchored depletion. Dynamic loops represent propagating radiative structures of the exchange sector.

The purpose of the present paper is to provide a minimal mathematical formalization of these bundled loop structures within the scalar–conformal framework already established in M1–M5.

The objective is deliberately limited. We do not attempt to construct a complete particle ontology or a phenomenological model of known particle species. Instead, we introduce the smallest set of structural definitions required to describe admissible bundled configurations that may serve as persistent matter structures.

The central idea is that matter does not correspond to individual loops taken in isolation. Rather, admissible matter configurations arise from bundled collections of loops whose internal structure satisfies the scalar admissibility conditions, the exchange-sector rules, and the holonomic coherence constraint established in the previous papers.

Within this framework we introduce:

- loop structures on scalar–conformal manifolds,
- bundled loop configurations,
- admissibility conditions for bundled structures,
- persistence and stability classes of bundles,
- structural invariants associated with bundled matter configurations.

These constructions provide the minimal object model required to represent persistent matter within the scalar–conformal NUVO framework. The results serve as the structural foundation for later developments in which specific particle structures, interaction mechanisms, and correspondence with existing physical theories will be investigated.

2 Loop Structures on Scalar–Conformal Manifolds

Let $(\mathcal{M}, g, \Lambda)$ denote the scalar–conformal Lorentzian manifold introduced in M1 [1]. Matter structures in the present framework arise from distinguished one–dimensional submanifolds embedded in spacetime. We refer to these objects collectively as *loops*.

A loop is therefore a one–dimensional oriented submanifold

$$\ell \subset M.$$

Depending on their structural role within the capacity framework, loops fall into three distinct classes: closed loops, open loops, and dynamic loops.

2.1 Closed Loops

A *closed loop* is a compact one–dimensional submanifold

$$C \subset M$$

with no boundary.

Closed loops play a special role in the NUVO framework because they support anchored depletion structure. When a closed loop supports a depletion density

$$\rho_C : C \to \mathbb{R}_{\geq 0},$$

it becomes an *anchor*.

Anchors act as localized structures that enforce scalar capacity consumption, producing depletion profiles in the surrounding field. Through the canonical NUVO equation established in M3 [3], the presence of the depletion density ρ_C generates gradients in the scalar field Λ. These gradients determine the geometric sector associated with inertial and gravitational behavior.

Closed loops therefore determine the anchored geometric content of matter configurations.

2.2 Open Loops

An *open loop* is a one–dimensional oriented submanifold

$$O \subset M$$

with boundary.

The boundary points of an open loop correspond to attachment locations on closed loops. Formally, if

$$\partial O = \{p_1, p_2\},$$

then each boundary point satisfies

$$p_i \in C_j$$

for some closed loop C_j.

Open loops do not support anchored depletion. Instead they mediate oriented exchange structure within the manifold. Each open loop carries an intrinsic orientation

$$\sigma(O) \in \{+1, -1\},$$

which determines the direction of the associated exchange orientation.

Open loops therefore represent the exchange sector structures introduced in M4 [4]. Although they participate in exchange interaction between anchored regions, they do not contribute to the local depletion density and therefore do not source scalar gradients.

2.3 Dynamic Loops

A *dynamic loop* is a closed one–dimensional submanifold

$$\gamma \subset M$$

that supports propagating radiative structure.

Dynamic loops are not attached to anchors and do not support capacity consumption. Instead they represent radiative dynamic-loop structures that propagate through the manifold as part of the exchange sector.

Dynamic loops interact with matter only through the exchange structures associated with open loops. In particular, they may couple to open loops during admissible transitions in which exchange configuration is transferred between the anchored and radiative sectors.

2.4 Loop Classes

We therefore distinguish three fundamental loop classes:

- Closed loops C, which may support anchored depletion.

- Open loops O, which mediate oriented exchange structure.
- Dynamic loops γ, which represent propagating radiative dynamic-loop structures.

Closed and open loops appear only as components of bundled matter configurations defined in the following section, whereas dynamic loops exist as independent structures of the radiative transport sector.

3 Bundled Loop Configurations

Closed and open loops do not appear in isolation in admissible matter configurations. Instead they occur as components of structured collections that we refer to as *bundles*. A bundle specifies how loop structures are combined and how exchange structure connects anchored regions of spacetime.

3.1 Bundle Data

A bundled loop configuration is specified by the tuple

$$\mathcal{B} = (\mathbf{C}, \mathbf{O}, \mathcal{R}, \sigma),$$

where

- $\mathbf{C} = \{C_1, \ldots, C_n\}$ is a finite set of closed loops embedded in M,
- $\mathbf{O} = \{O_1, \ldots, O_m\}$ is a finite set of open loops,
- $\mathcal{R} \subset \mathbf{O} \times \mathbf{C}$ is an attachment relation specifying which anchors are connected by a given open loop,
- $\sigma : \mathbf{O} \to \{+1, -1\}$ assigns an intrinsic orientation to each open loop.

The pair $(\mathbf{C}, \mathbf{O})$ determines the loop content of the bundle, while the relation $\mathcal{R}$ and the orientation function σ determine the internal exchange structure.

3.2 Minimal Bundle Structure

A bundled configuration represents a candidate matter structure whenever it contains both anchored and exchange components. In particular we require

$$|\mathbf{C}| \geq 1, \qquad |\mathbf{O}| \geq 1.$$

This minimal condition ensures that the configuration contains at least one anchored depletion structure and at least one exchange structure.

3.3 Exchange Graph

Each bundle naturally determines a directed graph that represents the exchange connectivity between anchors.

The vertices of the graph correspond to the closed loops

$$V = \mathbf{C},$$

and each open loop defines a directed edge between the anchors to which it attaches.

We denote this directed graph by

$$G(\mathcal{B}).$$

The exchange graph provides a convenient representation of the exchange structure within the bundle and will play a central role in defining admissibility and coherence conditions in the following sections.

4 Admissibility Conditions

Recall from M5 [5]. Coherent exchange cycles are constrained by a holonomic condition expressed through the exchange connection A. For any closed exchange cycle γ, admissibility requires that the exchange holonomy $\Theta(\gamma) = \oint_\gamma A$ lie within an admissible return class. This condition provides the global coherence constraint imposed on bundled loop configurations.

The bundle data introduced in the previous section specifies the structural components of a candidate matter configuration. Not every such configuration corresponds to a physically realizable structure. Admissible bundles must satisfy compatibility conditions arising from the scalar field, the exchange sector, and the holonomic coherence constraint established in M5.

4.1 Exchange Cycles

Let $\mathcal{B} = (\mathbf{C}, \mathbf{O}, \mathcal{R}, \sigma)$ be a bundle.

The exchange graph $G(\mathcal{B})$ defined in the previous section determines a family of directed cycles corresponding to closed exchange paths within the bundle.

We denote the set of all such cycles by

$$\Gamma(\mathcal{B}).$$

Each element $\gamma \in \Gamma(\mathcal{B})$ represents a closed sequence of open-loop exchange segments connecting anchors in the bundle.

4.2 Holonomic Coherence

The holonomic coherence condition derived in M5 requires that circulation around any closed exchange cycle return consistently on the scalar–conformal manifold.

Let A denote the exchange connection introduced in M5. For any cycle $\gamma \in \Gamma(\mathcal{B})$ we define the exchange holonomy

$$\Theta(\gamma) := \oint_\gamma A.$$

A bundle is said to satisfy the holonomic coherence condition if

$$\Theta(\gamma) \in \mathcal{H}_{\text{adm}} \qquad \text{for all } \gamma \in \Gamma(\mathcal{B}).$$

This condition ensures that the internal exchange structure of the bundle is globally consistent with the scalar–conformal geometry.

4.3 Bundle Admissibility

A bundled loop configuration

$$\mathcal{B} = (\mathbf{C}, \mathbf{O}, \mathcal{R}, \sigma)$$

is said to be *admissible* if the following conditions hold:

1. The bundle contains both anchored and exchange components,

$$|\mathbf{C}| \geq 1, \qquad |\mathbf{O}| \geq 1.$$

2. The exchange attachment relation $\mathcal{R}$ defines a well-formed exchange graph $G(\mathcal{B})$.

3. The holonomic coherence condition holds for all cycles in $\Gamma(\mathcal{B})$.

Admissible bundles represent candidate matter configurations within the scalar–conformal NUVO framework.

4.4 Pair Generation Constraint

The creation of bundled structures is constrained by the exchange sector.

Whenever bundles are generated, the process must produce open-loop structures in oriented source–sink pairs. In particular, if a generation event produces open loops

$$O_1, \ldots, O_k,$$

their orientations must satisfy

$$\sum_{i=1}^{k} \sigma(O_i) = 0.$$

This condition ensures that exchange orientation remains globally balanced during bundle generation.

In particular, the minimal generation event produces a source–sink pair of open loops, which may attach to newly formed or preexisting closed loops to form admissible bundled configurations.

5 Persistent Bundles

The admissibility conditions introduced in the previous section identify bundled loop configurations that are compatible with the scalar–conformal geometry and the exchange transport structure. Admissibility alone does not guarantee that a configuration will persist through time. In general, admissible bundles may evolve, reconfigure, or decay through interactions with the surrounding scalar environment and exchange sector.

We therefore distinguish a subset of admissible bundles that maintain their structural identity over extended evolution. These configurations are referred to as *persistent bundles*.

5.1 Temporal Evolution of Bundles

Because loops are defined as one–dimensional submanifolds of the spacetime manifold M, bundled configurations naturally extend along the temporal direction. Closed loops supporting anchor consumption therefore trace worldline structures through spacetime, while open loops trace oriented exchange connections between these worldlines.

Let

$$\mathcal{B}(t)$$

denote the bundle configuration restricted to a spacelike slice labeled by time parameter t.

Temporal evolution of the bundle corresponds to continuous deformation of the loop structures and attachment relations

$$(\mathbf{C}, \mathbf{O}, \mathcal{R}, \sigma).$$

5.2 Persistence

An admissible bundle $\mathcal{B}$ is said to be *persistent* if its structural data remain admissible under temporal evolution.

More precisely, let $\mathcal{B}(t)$ denote the time-evolved bundle. The bundle is persistent if

$$\mathcal{B}(t)$$

remains admissible for all t within a finite interval of evolution.

Persistence therefore requires that the anchored depletion structure, the exchange network, and the holonomic coherence conditions remain satisfied during the evolution.

5.3 Persistence Classes

Not all persistent bundles exhibit the same degree of structural stability. It is therefore useful to distinguish several classes of persistence.

Free Persistent Bundles A bundle is *free persistent* if its admissibility conditions remain satisfied without requiring external constraints from the surrounding environment.

Such configurations represent isolated matter structures whose internal loop structure maintains coherence under free evolution.

Environment Persistent Bundles A bundle is *environment persistent* if its admissibility conditions remain satisfied only when embedded within a larger configuration or external capacity environment.

These bundles may become unstable when removed from the environment that supports their coherence.

Transient Bundles Admissible bundles that fail to maintain their admissibility conditions under temporal evolution are referred to as *transient bundles.* These configurations typically reconfigure into other bundles or reconfigure into dynamic loops or radiative exchange structures.

5.4 Transitions

Transitions between bundles may occur through processes in which loop structures reconfigure while preserving global exchange balance and bundle admissibility.

During such transitions closed loops may form or decay, open loops may reconnect, and dynamic loops may be generated or absorbed. These processes reconfigure structure between the anchored, exchange, and dynamic sectors while maintaining the admissibility conditions appropriate to the transition.

A detailed analysis of transition mechanisms lies beyond the scope of the present paper and will be addressed in future work [6].

6 Structural Invariants of Bundles

The internal structure of a bundled configuration can be characterized by quantities that remain invariant under admissible deformations of the loop configuration. These quantities provide a structural classification of bundles independent of their specific embedding in spacetime.

We refer to such quantities as *bundle invariants*.

6.1 Anchor Number

The most basic invariant of a bundle is the number of anchored closed loops that it contains.

For a bundle

$$\mathcal{B} = (\mathbf{C}, \mathbf{O}, \mathcal{R}, \sigma)$$

the anchor number is defined as

$$N_C(\mathcal{B}) = |\mathbf{C}|.$$

The anchor number determines the total number of consumption structures within the bundle and therefore records the number of anchored structures associated with the configuration.

6.2 Exchange Number

The exchange number counts the number of open loops participating in the bundle.

$$N_O(\mathcal{B}) = |\mathbf{O}|.$$

This invariant characterizes the complexity of the exchange network connecting the anchors.

6.3 Exchange Orientation

Each open loop carries an intrinsic orientation

$$\sigma(O) \in \{+1, -1\}.$$

The net exchange orientation of the bundle is defined as

$$Q(\mathcal{B}) = \sum_{O \in \mathbf{O}} \sigma(O).$$

This quantity measures the net orientation imbalance between source-oriented and sink-oriented exchange structures.

Generation processes described in the previous section impose the constraint that exchange orientations must be created in balanced pairs. Consequently, the net exchange orientation remains balanced under admissible generation events.

6.4 Cycle Structure

The cycle structure of the bundle is determined by the cycle set

$$\Gamma(\mathcal{B})$$

defined by the directed cycles of the exchange graph $G(\mathcal{B})$.

The number and topology of these cycles characterize the internal exchange circulation of the bundle.

6.5 Coherence Class

Bundles may be classified according to the holonomic coherence properties of their exchange cycles.

Two bundles are said to belong to the same coherence class if their exchange graphs admit cycle sets that satisfy the same holonomic coherence conditions

$$\Theta(\gamma) = \oint_\gamma A \in \mathcal{H}_{\text{adm}} \quad \text{for all } \gamma \in \Gamma(\mathcal{B}).$$

The coherence class therefore provides a structural classification of bundles according to the allowed exchange cycle configurations.

6.6 Invariant Character

The invariants introduced above depend only on the internal bundle structure and not on the specific geometric embedding of the loops within the manifold.

Consequently they remain unchanged under continuous deformations of the bundle that preserve the attachment relations and exchange orientations.

7 Composite Bundle Configurations

The bundled loop structures introduced in the previous sections represent the elementary matter configurations of the scalar–conformal NUVO framework. These bundles need not exist in isolation. Multiple bundles may combine to form larger configurations through admissible interactions mediated by their loop structures.

We refer to such aggregated structures as *composite bundle configurations.*

7.1 Composite Systems

Let

$$\mathfrak{C} = \{\mathcal{B}_1, \dots, \mathcal{B}_n\}$$

be a finite collection of admissible bundles.

A composite bundle configuration consists of a set of bundles together with interaction relations that couple their loop structures. These interactions may involve exchange connections between bundles or scalar-field-mediated interactions between their anchored depletion structures.

The individual bundles remain identifiable as structural components, but their interactions may produce collective behavior that differs from that of isolated bundles.

7.2 Interaction Modes

Interactions between bundles arise through the loop structures that compose them. Two fundamental interaction modes occur naturally in the NUVO framework.

Exchange Interaction Open loops mediate oriented exchange structure between anchors. When open-loop structures belonging to different bundles couple through the exchange sector, exchange structure may couple between bundles without necessarily modifying their anchored depletion structure.

Such interactions preserve the anchor numbers of the participating bundles while modifying their exchange connectivity.

Anchor Interaction Anchors support localized depletion structure. When anchors belonging to different bundles approach one another, their anchored structures interact through the surrounding scalar field.

This interaction arises from the overlap and adjustment of scalar gradients generated by the anchored consumption densities. The resulting interaction may produce bound composite configurations whose stability depends on the surrounding capacity environment.

7.3 Composite Persistence

A composite configuration

$$\mathfrak{C} = \{\mathcal{B}_1, \ldots, \mathcal{B}_n\}$$

is said to be persistent if the bundle components remain admissible and their interaction relations remain compatible with the scalar, exchange, and coherence constraints introduced earlier.

As with individual bundles, composite configurations may exhibit different persistence classes depending on the stability of their internal interaction structure.

In particular, composite configurations may exist that are stable only within specific scalar environments, while others may remain persistent under free evolution.

7.4 Hierarchy of Matter Structures

Composite bundle configurations provide the structural mechanism by which larger matter systems can arise from elementary bundled loop structures.

The framework therefore supports a hierarchical organization in which elementary bundles combine to form progressively larger structures while preserving the admissibility rules governing the scalar–conformal manifold and the exchange sector.

8 Discussion

The preceding sections introduced a minimal mathematical framework for describing matter structures within the scalar–conformal NUVO theory. Building on the geometric and exchange/coherence structures established in M1–M5, the present work formalizes the concept of bundled loop configurations as admissible matter objects.

The central result of this paper is the identification of bundled collections of closed and open loops as the fundamental structural entities capable of supporting persistent matter configurations. Closed loops support anchored depletion structure and therefore determine the anchored geometric content of the bundle, while open loops mediate exchange structure without contributing to anchored depletion. Dynamic loops represent propagating radiative structures that interact with bundles through the exchange sector.

Within this framework we introduced a precise description of bundle data, exchange connectivity, and admissibility conditions governing the internal structure of bundled configurations. Holonomic coherence, inherited from the transport constraints established in M5, ensures that the exchange network of a bundle is globally compatible with the scalar–conformal geometry.

The resulting structure provides a minimal object model for matter within the NUVO framework. Persistent bundles arise when anchored depletion structures, exchange networks, and coherence constraints remain compatible under temporal evolution. Structural invariants of bundles provide a natural classification of these configurations independent of their particular embedding in the manifold.

The framework further allows multiple bundles to combine into composite configurations through interactions mediated by the exchange sector and the scalar field. This provides a mechanism for the hierarchical organization of matter structures without introducing additional fundamental objects beyond the loop structures defined here.

The constructions presented in this paper establish the structural foundation required to analyze specific matter configurations within the NUVO framework. Future work will examine the dynamics of bundle transitions, the detailed mechanisms governing bundle reconfiguration between anchored and dynamic sectors, and the correspondence between bundle invariants and the observable properties of known particle systems.

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