Section M-4 — Multi-Node Entropic Hamiltonian and Entanglement Geometry

Section M-4 generalizes the CUWF formalism from single-node geometry to multi-node systems. The central insight is that CUWF does not treat multiple collapse nodes as independent objects placed inside a pre-existing background. Instead, multiple nodes jointly curve the entropic field and generate cross-curvature coupling. This cross-curvature is the CUWF analogue of entanglement.

In this formulation, entanglement is not introduced through Hilbert-space tensor products, density matrices, or algebraic separability conditions. It appears geometrically, through the inseparability of curvature blocks in the total entropic field.

This section formalizes the multi-node configuration manifold, the entropic Hamiltonian H_{ent}, cross-curvature terms H_{link}, the entanglement Hessian, and the stability spectrum for N-node systems.

All higher CUWF papers that require multi-node behavior, including quantum tunnelling, Future Vector Deflection (FVD), gravitational cross-curvature, and the CUWF interpretation of entanglement, depend on the framework introduced here.

M-4.1 Multi-Node Configuration Manifold $\mathcal{M}_N$

For a system of N collapse nodes, the total configuration space is the Cartesian product of N copies of the single-node configuration space C:

$$\mathcal{M}_N = C \times C \times \cdots \times C \quad \text{(N copies)}$$

Equivalently, a point in the multi-node configuration manifold may be written as

$$x = (x_1, x_2, \ldots, x_N), \quad \text{with} \quad x_i \in C.$$

The dimension of the multi-node configuration manifold is therefore

$$\dim(\mathcal{M}\_N) = N \cdot \dim(C).$$

Each node x_i may also possess its own internal degree-of-freedom coordinates. In many CUWF derivations, these DOF variables are treated as a separate fiber structure attached to the configuration manifold, rather than as part of the base configuration coordinates themselves.

Thus, the multi-node structure may be understood as a base manifold $\mathcal{M}$_N equipped with internal DOF fibers. This distinction allows CUWF to separate spatial-configuration curvature from internal entropic deformation while still allowing both to interact through the total entropic field.

M-4.2 Entropic Field for N-Node Systems

The global entropic field for an N-node system is defined as a scalar function over the multi-node configuration manifold and the DOF manifold:

$$E\_total : \mathcal{M}\_N \times M\_DOF \longrightarrow \mathbb{R}.$$

The total field decomposes into self-entropic contributions and link-induced cross-curvature contributions:

$$E\_total(x_1, \ldots, x\_N, DOF) = E_1(x_1) + E_2(x_2) + \cdots + E\_N(x\_N) + E\_link(x_1, \ldots, x\_N).$$

Here:

E_i(x_i) represents the self-entropic curvature of node i.

E_link represents the cross-curvature generated jointly by multiple nodes.

E_total encodes both local collapse tendencies and multi-node relational deformation.

The term E_link is the mathematical origin of entanglement in CUWF. If E_link vanishes, the nodes are curvature-separable. If E_link is nonzero, the total entropic field cannot be decomposed into independent node-wise fields, and the system displays geometric entanglement.

M-4.3 Multi-Node Entropic Hamiltonian

The multi-node entropic Hamiltonian is defined as

$$H_{ent} = \Sigma_i H_i + \Sigma_{\{i<j\}} H_{link}(ij).$$

The self-Hamiltonian term for node i is

$$H_i = \Delta_E^{(i)} E_i,$$

where $\Delta_E^{(i)}$ acts only on the coordinates of node i.

The link Hamiltonian between nodes i and j is

$$H_{link}(ij) = \Delta_E^{(i,j)} E_{link}(x_i, x_j),$$

where $\Delta_E^{(i,j)}$ captures the curvature contribution arising jointly from the pair of nodes.

The link Hamiltonian is responsible for:

cross-curvature;

correlated collapse behavior;

entanglement;

multi-node stability;

collective mode formation.

Thus, H_{ent} is the CUWF analogue of an interacting Hamiltonian in many-body quantum mechanics. However, unlike the many-body Hamiltonian of standard quantum theory, H_{ent} does not act on a Hilbert-space tensor product. It is a geometric Hamiltonian defined through entropic curvature, cross-curvature, and collapse structure.

In CUWF, interaction is therefore not fundamentally a force between objects. It is the inseparability of curvature contributions inside E_{total}.

M-4.4 Entanglement as Cross-Curvature (Formal Definition)

For a two-node system, labelled 1 and 2, define the entropic Hessian block matrix:

$$H = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix}$$

where each block is defined by

$$H_{ab} = \partial^2 E_{total} / \partial x_a \partial x_b.$$

The diagonal blocks H_{11} and H_{22} measure the self-curvature of each node. The off-diagonal blocks H_{12} and H_{21} measure how curvature in one node direction changes with respect to the configuration of the other node.

Thus:

H_{12} and H_{21} quantify cross-curvature between nodes;

if $H_{12} = H_{21} = 0$, the two-node system is curvature-separable;

if H_{12} or H_{21} is nonzero, the nodes are geometrically inseparable;

entanglement corresponds to nonzero cross-curvature blocks.

Therefore, in CUWF:

entanglement = geometric inseparability of curvature.

This differs fundamentally from standard quantum mechanics, where entanglement is defined through tensor-product inseparability, and from quantum information theory, where it is often expressed through density-matrix correlations. In CUWF, entanglement is neither algebraic nor probabilistic at the fundamental level. It is a property of the curvature structure of E_total.

The CUWF interpretation can be summarized as follows: when the total entropic field cannot be decomposed into independent curvature sectors, the nodes are entangled.

M-4.5 Multi-Node Laplacian and Stability Operator

The entropic Laplacian generalizes from a single-node operator to an N-node operator. For a scalar function f defined on the multi-node manifold, the multi-node entropic Laplacian is written as

$$\Delta_E^N f = \Sigma_i \, g_E^{(i)ab} \nabla_a^{(i)} \nabla_b^{(i)} f + \Sigma_{\{i<j\}} \text{ cross-terms from } E_{link}.$$

The first summation captures self-curvature smoothing for each individual node. The second summation captures cross-curvature smoothing produced by E_link. These cross-terms are the operator-level expression of entanglement geometry.

The N-node stability operator is defined as

$$\hat{S}_N = \text{Hessian}(E_{total}).$$

The eigenvalues λ_k of $\hat{S}_N$ determine the modal stability of the system:

$\lambda_k > 0$ corresponds to stable modes;

$\lambda_k = 0$ corresponds to marginal modes;

$\lambda_k < 0$ corresponds to unstable or tunnelling-ready modes;

eigenvectors spanning more than one node correspond to entangled collective modes.

This structure will be used directly in Section M-5, where the stability spectrum and the quantum-classical boundary are defined in terms of the eigenstructure of Hessian(E_total).

The stability classification can be summarized as follows:

Eigenvalue condition	CUWF mode type	Physical interpretation
$\lambda_k > 0$	Stable mode	Attractor-like or classically persistent structure
$\lambda_k = 0$	Marginal mode	Boundary between stability and instability
$\lambda_k < 0$	Unstable / tunnelling-ready mode	Collapse transition or tunnelling channel
multi-node eigenvector	Entangled collective mode	Curvature inseparability across nodes

M-4.6 Role of M-4 in CUWF Physics

Section M-4 provides the mathematical backbone for every CUWF domain in which multiple collapse nodes interact. In particular, it supports:

Paper A-4: quantum tunnelling, through multi-node stability collapse;

Paper A-6: Future Vector Deflection (FVD) and correlated motion;

Paper A-7: gravity as cross-curvature geometry;

Papers A-9 and A-10: the CUWF formulation of entanglement.

The central conclusion is that CUWF becomes a multi-node geometric theory rather than a single-node wave theory. The geometry of interaction replaces Hilbert-space tensor products. Entanglement becomes cross-curvature. Correlation becomes curvature inseparability. Multi-body dynamics become collective evolution on $\mathcal{M}_N$.

Section M-4 therefore establishes the mathematical structure required for entanglement geometry, multi-node collapse, interacting entropic Hamiltonians, and stability-spectrum analysis. It provides the bridge from single-node entropic geometry to the collective geometry required for the full CUWF framework.