

Dynamic Symmetry as a Physics Principle: From Effective Field Theories to Discrete Quantum Geometry

Abstract: Dynamic Symmetry Theory proposes that many adaptive systems operate most effectively in a regime where order and disorder remain jointly active, rather than at either extreme. This note recasts that intuition as a standard physics problem by formulating “dynamic symmetry” as an internal symmetry and vacuum structure in a minimal two-scalar Effective Field Theory. The resulting model supports a ring-like manifold of vacua at non-zero total activity, with heavy radial and light angular modes, and its renormalisation-group flow is analysed as a candidate realisation of a balance band in the infrared. The same structure is embedded in an Einstein–scalar action to define holographic renormalisation-group flows from a UV AdS extremum to a dynamically symmetric region in field space. A complementary non-equilibrium construction expresses dynamic symmetry in terms of entropy production, steady-state currents and response in finite-state Markov processes, while a discrete quantum-gravity realisation is proposed via dynamic-symmetry weights in Causal Dynamical Triangulations. Across these settings, the theory yields explicit, falsifiable targets: the existence of robust infrared balance regimes in EFT and gravity, response-optimising bands in non-equilibrium models, and CDT phases where extended four-dimensional geometry correlates with an intermediate geometric balance index.

1. Introduction and motivation

Dynamic Symmetry Theory has so far been articulated chiefly as a qualitative framework for describing systems that appear to function most effectively in an intermediate regime between excessive order and excessive disorder. In that form, the theory has heuristic value across a wide range of domains, from biological regulation and neural dynamics to social organisation and market behaviour. Yet if it is to be evaluated within fundamental physics, or even brought into serious contact with mathematical physics, it must be reformulated in a more conventional language. In particular, it must be expressed in terms of explicit fields, symmetries, operators and flows, so that its claims can be assessed by the standards ordinarily applied to effective theories, statistical field theories and candidate models of emergent geometry.

The present note takes a first step in that direction. Its working hypothesis is not that Dynamic Symmetry Theory has already earned the status of a physical principle, but rather that it may be possible to reinterpret its central intuition as a statement about the vacuum structure and renormalisation behaviour of a suitably chosen field theory. On this reading, the language of “order” and “disorder” is not treated as an informal philosophical pairing, but as a prompt to identify two coupled sectors of low-energy degrees of freedom whose interaction gives rise to a preferred band of balanced states. The main question is then whether such

a band can be encoded as a mathematically controlled feature of an effective action, and whether that feature survives coarse-graining, admits embedding into gravitational settings, and yields non-trivial predictions.

Effective Field Theory provides a natural entry point because it does not require detailed knowledge of the microscopic substrate. Its logic is instead to identify the relevant long-wavelength degrees of freedom, impose the symmetries thought to govern them, and then write the most general local action consistent with those symmetries, organised by operator dimension and the scale at which the description breaks down. This makes it particularly well suited to the present problem. If dynamic symmetry can be stated as a genuine symmetry principle, or at least as a controlled symmetry-breaking pattern, then it should be possible to build a minimal EFT that realises it. If no such formulation can be found without ad hoc choices or hidden fine-tuning, that failure would itself be informative.

The broader programme has six linked aims. First, one seeks a minimal EFT in which dynamic symmetry is represented by an internal relation between two sectors and by a vacuum structure that favours neither rigid order nor unbounded disorder. Second, one asks whether the resulting theory possesses renormalisation-group flows that stabilise a non-trivial intermediate regime in the infrared. Third, one explores whether the same structure can be embedded in a gravitational setting, for example through Einstein-scalar systems and holographic RG flows. Fourth, one examines whether non-equilibrium statistical mechanics provides a natural language for quantifying the exchange between entropy production and large-scale structural constraint. Fifth, one asks whether a discrete spacetime framework such as Causal Dynamical Triangulations can implement an analogous balance condition through modified weights on microscopic configurations. Sixth, and most importantly, one asks whether any of these constructions yields a falsifiable prediction rather than an interpretive redescription.

The ambition of the note is therefore limited but precise. It does not attempt to establish Dynamic Symmetry Theory as a universal law. It aims only to determine whether its central idea can be reformulated as a disciplined physics problem. The criterion of success is not rhetorical reach but technical traction: a small set of fields, a well-posed symmetry principle, a controlled effective action, and a sequence of calculations that can in principle succeed or fail.

2. Dynamic symmetry as an internal symmetry

To translate dynamic symmetry into field-theoretic language, one must first decide what aspect of the theory is to count as “symmetry” in the ordinary physical sense. In standard quantum field theory, symmetries are transformations of the fields that leave the action invariant and thereby constrain the admissible operators in the Lagrangian. If Dynamic Symmetry Theory is to become more than a suggestive

metaphor, its core claim must therefore be expressed as a restriction on field content and interaction structure. The simplest possibility is that the distinction between ordered and disordered tendencies is represented not by two unrelated behaviours, but by two sectors of the theory that are placed on an equal footing at the level of the underlying action.

A minimal implementation begins with two real scalar fields, $\phi(x)$ and $\chi(x)$, interpreted as coarse-grained order-like and disorder-like modes of some more microscopic substrate. At this stage the interpretation is schematic. The important point is that these fields are not introduced as independent substances, but as paired coordinates in an effective description. Dynamic symmetry is then represented by an internal transformation that exchanges them,

$$\phi \leftrightarrow \chi,$$

which ensures that the theory does not assign a fundamental priority to one sector over the other. A stronger version is an approximate continuous $O(2)$ symmetry in the (ϕ, χ) plane, under which the pair transforms as a doublet. In either case, the theory is built so that the distinction between order and disorder appears only through the state of the system, not through an asymmetry written into the action from the outset.

This move has an immediate conceptual consequence. Dynamic symmetry ceases to mean static geometric symmetry in the classical sense, and instead becomes a statement about the equal admissibility and coupled evolution of two competing modes. The physical content of the theory then depends on how the potential arranges the vacuum structure in the space of these fields. If the action favoured only $\phi \neq 0$ with $\chi = 0$, the theory would describe a regime of pure order. If it favoured only $\chi \neq 0$ with $\phi = 0$, it would describe a regime of pure disorder. Neither option matches the intended meaning of dynamic symmetry. What is required instead is a potential whose energetically preferred states occupy an intermediate region in field space where both sectors are present with non-zero weight.

It is useful at this point to introduce two composite variables that reorganise the field space into radial and angular directions,

$$S(x) = \phi^2(x) + \chi^2(x), \theta(x) = \arctan \frac{\chi(x)}{\phi(x)}.$$

The variable S measures the total amplitude of the two sectors combined, while θ measures their relative mixture. In these variables, the most natural realisation of dynamic symmetry is a theory whose preferred configurations lie not at $S = 0$ or at a single isolated point in the (ϕ, χ) plane, but on or near a ring of minima at some non-zero $S = S_0$, with only weak dependence on θ . Such a structure expresses, in precise field-

theoretic terms, the idea that stable or generative behaviour occurs in a band where total activity is neither absent nor unbounded and where neither order nor disorder overwhelmingly dominates.

From the point of view of symmetries, this picture is familiar. A continuous or approximate continuous symmetry often gives rise to a vacuum manifold with a non-trivial geometry, together with radial and angular excitations around it. What is unusual here is the interpretation assigned to that geometry. The angular direction is not merely an abstract Goldstone coordinate; it parameterises the relative weighting of order-like and disorder-like modes. The radial direction measures motion away from the balanced band, either towards frozen, low-activity states or towards regimes of excessive amplitude and instability. Dynamic symmetry is thus encoded not only in the invariance of the action under field exchange, but also in the requirement that the vacuum manifold privilege a non-trivial intermediate region of the field space.

This formulation is intentionally modest. It does not claim that every instance of order and disorder in nature can be reduced to a two-scalar model. It claims only that if the core intuition of Dynamic Symmetry Theory is to be made precise, the most economical starting point is an internal symmetry acting on a paired field sector together with a potential that favours balanced mixtures over extreme phases. Once stated in this way, the theory becomes accessible to standard tools: one can write the corresponding effective action, classify allowed operators, study renormalisation-group flow, couple the fields to gravity, and ask whether the resulting structure has any predictive or explanatory value beyond its original heuristic appeal.

3. A minimal Dynamic-Symmetry Effective Field Theory

A natural way to test whether dynamic symmetry can serve as a genuine organising principle is to encode it in the most conservative setting available: a renormalisable scalar effective field theory in four dimensions. The guiding rule is straightforward. Once the light degrees of freedom and their symmetries have been identified, the Lagrangian must contain all local operators built from those fields that are compatible with the symmetries, ordered by their mass dimension and suppressed by appropriate powers of a cutoff scale. In the present case, the aim is to specify the simplest such theory whose vacuum structure reproduces the intended dynamic-symmetry band between order and disorder.

We begin with two real scalar fields, $\phi(x)$ and $\chi(x)$, which are treated as low-energy collective modes representing, in schematic form, ordered and disordered aspects of an underlying quantum substrate. At this stage, no detailed microscopic interpretation is assumed. The fields are simply the relevant coordinates in which the effective potential is to display a particular symmetry and vacuum geometry. Dynamic symmetry is implemented as an internal equivalence between these two modes. The minimal choice is a discrete interchange symmetry, $\mathbb{Z}_2^{\text{ex}}$, acting as $\phi \leftrightarrow \chi$, which ensures that the theory does not assign a fundamental priority to order over disorder or vice versa. A slightly stronger possibility is an approximate

$O(2)$ invariance in the (ϕ, χ) plane, softly broken by small terms that introduce only a mild bias. Both viewpoints are useful, but the discrete exchange symmetry provides the minimal core.

In flat Minkowski space, and in the absence of gauge or fermionic degrees of freedom, the most general renormalisable Lagrangian density compatible with Lorentz symmetry and the exchange symmetry takes the form

$$\mathcal{L} = \frac{1}{2}(\partial_\mu \phi)(\partial^\mu \phi) + \frac{1}{2}(\partial_\mu \chi)(\partial^\mu \chi) - V(\phi, \chi),$$

with potential

$$V(\phi, \chi) = \frac{m_\phi^2}{2}\phi^2 + \frac{m_\chi^2}{2}\chi^2 + \frac{\lambda_\phi}{4!}\phi^4 + \frac{\lambda_\chi}{4!}\chi^4 + \frac{\lambda_{\phi\chi}}{4}\phi^2\chi^2.$$

The exact exchange symmetry requires $m_\phi^2 = m_\chi^2$ and $\lambda_\phi = \lambda_\chi$, although it is useful to retain the more general notation at first in order to display explicitly which terms are constrained and to allow, in later sections, for controlled symmetry breaking. No cubic interactions appear, since they are excluded by the discrete reflections $\phi \rightarrow -\phi$ and $\chi \rightarrow -\chi$, together with the exchange symmetry.

To make the connection with dynamic symmetry more transparent, it is convenient to reorganise the field space in terms of radial and angular variables,

$$S(x) = \phi^2(x) + \chi^2(x), \theta(x) = \arctan \frac{\chi(x)}{\phi(x)}.$$

The variable S measures the total amplitude of the two sectors taken together, while θ parametrises their relative mixture. In these coordinates, the dynamic-symmetry picture becomes geometrically clear. Frozen or overly rigid configurations correspond to very small S , where both sectors are suppressed. Overly turbulent or unstable configurations correspond to very large S , where total activity becomes excessive. The desired intermediate regime is one in which the energetically preferred configurations lie near a non-zero value $S = S_0$, with only weak variation in the potential as a function of θ . Such a structure amounts to a ring, or narrow trough, of minima in field space.

This ring-of-minima structure can be realised by choosing the quartic couplings so that the potential develops a non-trivial minimum at finite radius while remaining approximately degenerate in the angular direction. In the fully symmetric limit, where $m_\phi^2 = m_\chi^2 \equiv m^2$ and $\lambda_\phi = \lambda_\chi \equiv \lambda$, the potential depends only on the total amplitude and the mixed quartic coupling. Appropriate positive quartic couplings then ensure that motion away from the preferred radius is energetically costly, while motion around the ring is

comparatively inexpensive. The resulting vacuum manifold is therefore neither a single ordered phase nor a single disordered phase, but a continuous band of balanced states with non-zero total activity.

The physical interpretation of fluctuations around this vacuum structure is straightforward. Small perturbations in the radial direction change the total activity S and move the system away from the preferred band, either towards inert low-activity states or towards regimes of excessive amplitude. These modes are naturally heavy if the radial curvature of the potential is large. Small perturbations in the angular direction change the relative weighting of ϕ and χ while leaving the total activity almost unchanged. These modes are naturally light when the angular dependence of the potential is shallow. In this way the model produces a simple hierarchy of excitations: heavy radial modes that penalise departure from the dynamic-symmetry band, and lighter angular modes that explore the internal balance between order-like and disorder-like contributions.

From the standpoint of effective field theory, the construction is entirely orthodox. The field content is minimal, the symmetry is an ordinary internal symmetry, and the potential is the generic renormalisable polynomial consistent with those assumptions. What distinguishes the model is the interpretive constraint placed on the vacuum structure. Dynamic symmetry is not identified with exact stasis or with unbounded fluctuation, but with a band of non-trivial minima at finite total amplitude, together with approximate degeneracy in the relative mixture of the two sectors. Expressed in this form, the theory becomes amenable to the standard machinery of quantum field theory. One can classify operators, compute renormalisation-group flows, study symmetry-breaking patterns, couple the fields to gravity, and ask whether the resulting structure yields predictive content rather than merely a suggestive metaphor.

4. RG flow and the balance band as an infrared structure

If dynamic symmetry is to play a genuine role in physics, it must be possible to express it not only as a feature of a bare Lagrangian, but also as a property that is preserved, or at least naturally generated, under coarse-graining. The appropriate language for this question is the renormalisation group. In an Effective Field Theory, the bare parameters in the action are understood as scale-dependent couplings; integrating out high-momentum modes induces a flow in the space of couplings, and infrared behaviour is controlled by the structure of this flow. The question, in the present context, is whether there exist RG trajectories for the two-scalar theory described above that lead, at long distances, to a regime that still exhibits a non-trivial balance band in field space rather than collapsing into a purely ordered or purely disordered phase.

To frame this more concretely, it is useful to revert temporarily to the Cartesian fields ϕ and χ and to work with a symmetric truncation of the general Lagrangian. Imposing the exact interchange symmetry $\phi \leftrightarrow \chi$, one can set $m_\phi^2 = m_\chi^2 \equiv m^2$ and $\lambda_\phi = \lambda_\chi \equiv \lambda$. The potential then becomes

$$V(\phi, \chi) = \frac{m^2}{2}(\phi^2 + \chi^2) + \frac{\lambda}{4!}(\phi^4 + \chi^4) + \frac{\kappa}{4}\phi^2\chi^2,$$

where $\kappa \equiv \lambda_{\phi\chi}$ is the mixed quartic coupling. In this reduced parameter space, the dynamical symmetry of the action is explicit, and the vacuum structure described in the previous section is encoded in the relative magnitudes and signs of m^2 , λ and κ . For suitable positive values of λ and κ , the classical potential exhibits a minimum at non-zero radius in the (ϕ, χ) plane with a comparatively shallow angular dependence, corresponding to the desired ring of balanced states.

The renormalisation-group flow of this theory can be studied in the usual way, either in a Wilsonian formulation with a sliding momentum cutoff or within a perturbative scheme such as minimal subtraction. In either case, the quartic couplings and mass parameter become functions of a running scale μ , and their evolution is described by beta functions of the form

$$\beta_\lambda = \mu \frac{d\lambda}{d\mu}, \beta_\kappa = \mu \frac{d\kappa}{d\mu}, \beta_{m^2} = \mu \frac{dm^2}{d\mu}.$$

In four dimensions, and to one-loop order, the beta functions for quartic couplings in a two-scalar model have a polynomial structure in λ and κ ; the precise coefficients depend on normalisation conventions, but the qualitative behaviour is robust. In particular, if λ and κ are initially positive and small at some reference scale, they remain positive under downward flow to the infrared until they become non-perturbative, and the symmetry under $\phi \leftrightarrow \chi$ is preserved by the flow. This means that the exchange symmetry, which is central to the dynamic-symmetry interpretation, is not destabilised by coarse-graining, at least within the range where perturbation theory is reliable.

From the dynamic-symmetry point of view, the central object of interest is not the precise numerical value of the quartic couplings at any scale, but the structure of the flow near regions where the potential continues to support a balance band. The classical analysis showed that such a band appears when the mass parameter and quartic couplings are tuned so that the potential develops a non-trivial minimum at finite radius with weak angular dependence. Under RG flow, these conditions translate into requirements on the running couplings: the effective mass squared $m^2(\mu)$ should not be driven so negative that the potential collapses onto a pair of isolated minima along the axes, nor so positive that the origin becomes the unique minimum; the quartic combination that fixes the radial curvature should maintain a sign and magnitude that preserve a finite preferred radius; and the ratio $\kappa(\mu)/\lambda(\mu)$ should remain in a regime where the angular variation does not become dominant.

It is useful to restate this in infrared terms. At long distances, one would like the effective theory to exhibit three qualitative properties. First, the radial mode corresponding to fluctuations in the total activity $S =$

$\phi^2 + \chi^2$ should be heavy, so that the system is confined near a finite radius and does not wander freely into very low- or very high-activity regimes. Second, the angular mode $\theta = \arctan(\chi/\phi)$, which controls the relative mixture of order-like and disorder-like contributions, should remain comparatively light, so that the system can still explore different balance configurations along the band without large energetic cost. Third, the vacuum manifold should not fragment into a few isolated points but should retain a band-like character, at least approximately, so that the notion of dynamic symmetry continues to be meaningful. These conditions define, in effect, an infrared balance regime in the space of couplings.

The renormalisation-group question can then be formulated as follows. Given a range of symmetric ultraviolet initial conditions $(m^2(\mu_0), \lambda(\mu_0), \kappa(\mu_0))$, do the flows $(\lambda(\mu), \kappa(\mu), m^2(\mu))$ approach an infrared region in which the conditions for a balance band are satisfied? If so, is this region attractive for a non-trivial basin of initial data, or does it require fine-tuning? If not, does the flow instead run to a phase of effective pure order, effective pure disorder, or more complicated symmetry breaking? These are standard RG questions, but with an interpretive twist: the existence of a robust infrared balance regime would mean that dynamic symmetry, as encoded in the minimal two-scalar model, is not merely a choice of bare parameters but a structural feature of the coarse-grained theory.

Even purely at the schematic level, a few qualitative scenarios can be distinguished. In one scenario, the RG flow has an infrared fixed point or fixed line at finite positive values of λ and κ , with $\beta_\lambda = \beta_\kappa = \beta_{m^2} = 0$, and the corresponding effective potential retains a ring of minima. In that case, the dynamic-symmetry band is literally an infrared fixed structure of the theory. In another scenario, the quartic couplings grow but their ratio approaches a finite constant, so that the shape of the potential in field space stabilises even as its overall scale changes; the band survives in a rescaled form. In a third scenario, the flow drives the theory towards a corner of coupling space where the potential favours either ϕ or χ alone, effectively breaking dynamic symmetry and collapsing the band into a single ordered or disordered phase.

From the perspective of the broader programme, the first two scenarios would be encouraging: they would show that a dynamic-symmetry band can arise and persist as a renormalisation-group phenomenon in a simple, controllable model. The third scenario would be equally informative, because it would indicate that the minimal two-scalar implementation does not sustain the desired behaviour and that any viable version of Dynamic Symmetry Theory must either rely on additional fields, more subtle symmetry structures, or different classes of models. In either case, the point is that the question can be posed and pursued in the usual RG framework, with no need for special pleading. The same machinery that is routinely applied to scalar field theories, critical phenomena and symmetry-breaking patterns can be brought to bear on the dynamic-symmetry hypothesis, turning it into a set of concrete flow problems rather than leaving it as an abstract generality.

5. Embedding the balance band in gravity and holographic RG

The two-scalar model described above is sufficiently simple that it can be treated not only as a stand-alone Effective Field Theory but also as a matter sector in a gravitational theory. Doing so makes it possible to ask whether the dynamic-symmetry band can appear as a genuine geometric feature of a spacetime solution and, in an AdS/CFT setting, whether it can be interpreted as the infrared endpoint of a boundary renormalisation-group flow. The aim here is not to propose a realistic model of our universe, but to identify the simplest Einstein–scalar system in which the intuitive “edge” between rigid order and unstructured disorder corresponds to a well-defined region of bulk field space and to a class of domain-wall geometries.

Consider a $(d + 1)$ -dimensional bulk with metric g_{MN} and two real scalars ϕ and χ , governed by the action

$$S_{\text{bulk}} = \int d^{d+1}x \sqrt{-g} \left[\frac{1}{2\kappa_{d+1}^2} (R - 2\Lambda) - \frac{1}{2} (\partial\phi)^2 - \frac{1}{2} (\partial\chi)^2 - V(\phi, \chi) \right],$$

where $\Lambda < 0$ is a bare cosmological constant. The potential V is chosen so that the origin $(\phi, \chi) = (0, 0)$ is an AdS extremum,

$$\partial_\phi V(0, 0) = \partial_\chi V(0, 0) = 0, V(0, 0) = -\frac{d(d-1)}{2L^2},$$

with L the AdS radius, while away from the origin the potential supports a ring-like set of minima at some non-zero total amplitude. To make the dynamic-symmetry structure transparent, it is helpful to rewrite V in terms of the radial and angular variables in field space,

$$S = \phi^2 + \chi^2, \theta = \arctan \frac{\chi}{\phi}.$$

A simple class of potentials with the desired features is

$$V(S, \theta) = -\frac{d(d-1)}{2L^2} + \frac{\lambda_S}{4} (S - S_0)^2 + V_{\text{soft}}(\theta),$$

with $\lambda_S > 0$ and $S_0 > 0$. The constant term fixes the cosmological constant at the origin; the λ_S term drives the system towards a ring of minima at $S = S_0$. The angular term $V_{\text{soft}}(\theta)$ controls any bias between order-like and disorder-like mixtures. In the exactly symmetric case, $V_{\text{soft}}(\theta)$ is set to zero or taken to be parametrically small, so that the ring is approximately degenerate; in more realistic situations, it can be used to introduce a slight tilt that favours some mixtures over others without destroying the band structure.

In an AdS/CFT context, one typically looks for domain-wall solutions that interpolate between different regions of field space as a function of a radial coordinate interpreted as an energy scale. A standard ansatz is

$$ds^2 = dr^2 + e^{2A(r)} \eta_{\mu\nu} dx^\mu dx^\nu,$$

with scalar profiles $\phi(r)$, $\chi(r)$, or equivalently $S(r)$, $\theta(r)$. Near the ultraviolet boundary, $r \rightarrow \infty$, the geometry approaches AdS with radius L and the scalars tend to zero. This corresponds to an undeformed conformal field theory on the boundary, with ϕ and χ dual to scalar operators whose scaling dimensions are determined by the second derivatives of V at the origin. Turning on a deformation of the boundary theory associated with a particular linear combination of these operators is encoded by specifying appropriate boundary conditions for the scalars, which in turn drive a bulk flow away from the AdS extremum.

The dynamic-symmetry picture suggests that a natural class of flows is one in which the scalar trajectory in field space starts at the origin and moves towards the ring $S = S_0$, settling into or approaching that manifold in the interior. In such solutions, the radial profile $S(r)$ grows from zero to a value near S_0 , while the angular variable $\theta(r)$ either tends to a constant or remains slowly varying along the ring. In the dual picture, the boundary theory is deformed by an operator that turns on both order-like and disorder-like contributions, and the renormalisation-group flow carries it from a UV fixed point with vanishing expectation values into an infrared regime in which certain combinations of the dual operators have non-zero expectation but still retain a balanced character. The ring of minima then plays the role of a dynamic-symmetry band in field space, while the associated domain-wall geometry encodes the corresponding “edge-like” regime in the bulk.

It is instructive to relate this back to the excitations identified in the flat-space EFT. Fluctuations in the radial direction correspond to motion orthogonal to the balance band, changing the total magnitude S . Their mass is determined by the curvature of the potential in the S direction around $S = S_0$. If λ_S is large, these modes are heavy and can be integrated out at low energies, leaving an effective description dominated by the angular degree of freedom. Fluctuations in θ correspond to motion along the band, changing the relative mixture of ϕ and χ while leaving S approximately fixed. Their effective mass depends on the form and size of $V_{\text{soft}}(\theta)$. If V_{soft} is flat or nearly flat, the angular mode is massless or light, representing a marginal or nearly marginal deformation on the boundary. In the AdS/CFT dictionary, such light modes are associated with operators whose scaling dimensions are close to the marginal value. It is precisely these operators that often control slow, near-critical flows and “walking” behaviour in holographic models.

Within this framework, an “edge-of-chaos” boundary state can be thought of as a region in the space of couplings where the radial mode has effectively frozen out, pinning the system near $S = S_0$, while the angular mode remains active and only weakly biased. Correlation functions of the dual operators then reflect a non-trivial mixture of ordered and disordered features: neither sector dominates, and the long-distance physics is governed by the interplay of both. The bulk geometry in such a regime is expected to be asymptotically AdS in the UV, deformed in the interior by the non-zero scalar profiles, and possibly approaching another AdS-like geometry or a scale-covariant domain-wall solution in the IR. From the point of view of the overall programme, this provides a concrete geometric realisation of the dynamic-symmetry band: it is not simply a picture in field space, but a region where the bulk solution spends a significant radial interval and where the dual field theory exhibits balanced, near-critical behaviour.

This construction also leads naturally to testable questions. One can ask whether there exist choices of λ_s , S_0 and V_{soft} for which regular domain-wall solutions from the origin to the ring exist, and whether these solutions are stable. One can compute the spectra of linearised fluctuations around such backgrounds to determine the scaling dimensions and mixing of the dual operators, and in particular to check whether the light angular mode behaves as a nearly marginal deformation. One can study entanglement measures along the flow, using holographic prescriptions, to see whether measures of predictive or structural information peak in the region where the scalar trajectory lies close to the band. In all these cases, the dynamic-symmetry hypothesis becomes a set of concrete statements about which classes of Einstein–scalar potentials and their associated geometries exhibit a ring-like vacuum structure and what this implies for the boundary theory.

The virtue of this approach is that it does not require any new gravitational machinery. The model is a conventional multi-scalar domain-wall system of the kind widely used in holographic studies of relevant deformations. Dynamic symmetry enters only through the specific shape of the potential and the interpretation of the radial and angular modes. If the resulting bulk solutions and boundary flows display the expected features of a balance band, that would provide a first gravitational foothold for the theory. If they do not, or if such solutions are highly fine-tuned or unstable, that would indicate that the ring-like EFT implementation of dynamic symmetry is not easily compatible with gravitational and holographic structure. In either case, the question is translated into the standard language of Einstein–scalar systems and holographic renormalisation, where it can be addressed with familiar analytic and numerical tools.

6. Non-equilibrium balance: dynamic symmetry, Onsager structure, and entropy production

To turn dynamic symmetry into a quantitative statement about non-equilibrium behaviour, it is helpful to work in a setting where the relevant objects are already well defined: a finite-state continuous-time Markov process with a unique steady state. Such processes underpin a wide range of models in physics, chemistry and biology, and they come with standard notions of entropy production, steady-state currents and linear response. In this section, the aim is not to survey that literature, but to show how the key ingredients of Dynamic Symmetry Theory – a pairing of order-like and disorder-like observables and a balance band between them – can be expressed directly in this language.

Consider a Markov process on a finite state space with transition rates w_{ij} from state j to state i . Let $p_i(t)$ denote the probability to occupy state i at time t , evolving according to the master equation $\dot{p}_i(t) = \sum_j [w_{ij}p_j(t) - w_{ji}p_i(t)]$. Suppose there exists a unique steady state π such that $\sum_j [w_{ij}\pi_j - w_{ji}\pi_i] = 0$ for all i . The stationary probability currents are defined by $J_{ij} = w_{ij}\pi_j - w_{ji}\pi_i$, with $J_{ij} = -J_{ji}$. When detailed balance holds, all J_{ij} vanish and the system is at equilibrium. When detailed balance is broken, there are non-zero cycles of probability flow and the system produces entropy even in the steady state.

In the stochastic-thermodynamic description, the steady-state entropy production rate is

$$\dot{S}_{\text{prod}} = \frac{1}{2} \sum_{i,j} J_{ij} A_{ij},$$

where $A_{ij} = \ln \frac{w_{ij}\pi_j}{w_{ji}\pi_i}$ is the thermodynamic affinity associated with the transition between i and j . This quantity is non-negative and vanishes if and only if detailed balance holds. It is a natural candidate for the “disorder” or “randomness consumption” term in Dynamic Symmetry Theory, because it measures the rate at which microscopic irreversibility generates entropy in the environment. At the same time, the steady state π has a Shannon entropy $H(\pi) = -\sum_i \pi_i \ln \pi_i$, which quantifies the spread of the stationary distribution over state space. Depending on the application, either $\dot{S}_{\text{prod}}$ or a normalised version of $H(\pi)$ may serve as the disorder coordinate.

The corresponding “order-like” quantity should capture persistent, organised asymmetry in the system’s dynamics. One natural choice, in this Markov setting, is a normalised measure of current magnitude. For example, one can define

$$K = \sum_{i < j} |J_{ij}|,$$

and then construct a dimensionless order parameter by dividing by an appropriate reference scale, such as the maximum current magnitude over a class of models or an empirical upper envelope. Alternatively, one may focus on a particular network structure and define K as the magnitude of cycle currents along selected loops, or on spectral quantities such as the gap between the leading eigenvalue and the rest of the spectrum of the rate matrix, which governs the system's relaxation structure. In all these cases, the aim is to obtain a scalar that is small when the system is effectively quiescent or fully disordered, and large when it sustains coherent, directional flows.

Dynamic Symmetry Theory then suggests combining the order-like coordinate K and a disorder-like coordinate, say a normalised entropy production σ , into a bounded balance index. A simple example is

$$B = 4 \frac{K}{K_{\max}} \frac{\sigma}{\sigma_{\max}} \left(1 - \left| \frac{K}{K_{\max}} - \frac{\sigma}{\sigma_{\max}} \right| \right),$$

with $K_{\max}$ and $\sigma_{\max}$ serving as reference scales for normalisation. This particular form is not unique, but it illustrates the desired properties: B vanishes when either order or disorder is negligible, declines when one dominates the other, and takes its largest values when both are simultaneously substantial and comparable in magnitude. In that sense, it plays the same conceptual role in the Markov setting as S and θ did in the two-scalar EFT: it identifies a band in which the system's dynamics exhibit a non-trivial balance between structured flow and stochastic forcing.

Near equilibrium, small deviations from detailed balance can be described by linear response. One introduces thermodynamic forces X_α – for example, small changes in chemical potentials, temperature gradients or affinity parameters – and corresponding fluxes J_α , defined as linear combinations of the microscopic currents. In this regime, the flux-force relations take the Onsager form $J_\alpha = \sum_\beta L_{\alpha\beta} X_\beta$, with $L_{\alpha\beta}$ a symmetric matrix of phenomenological coefficients under appropriate microscopic reversibility conditions. The entropy production is then $\dot{S}_{\text{prod}} = \sum_\alpha J_\alpha X_\alpha$. Here the balance index B can be thought of as a coarse descriptor of how the system sits in this linear-response landscape: very low B corresponds to regimes where both fluxes and dissipation are negligible, very high B to regimes where certain forces drive large dissipation but coherent structure may be degraded, and intermediate B to regimes where multiple fluxes are active and the system exhibits significant but finite response to perturbations.

Beyond linear response, fluctuation theorems provide a more detailed characterisation of entropy-production statistics in non-equilibrium steady states. For many Markov models, the probability distribution of time-integrated entropy production satisfies a symmetry of the form $P(\Delta S)/P(-\Delta S) \sim e^{\Delta S}$ over long times. The dynamic-symmetry viewpoint encourages a specific kind of question in this context: whether there is a regime in parameter space where the combination of entropy-production fluctuations

and current structure is particularly favourable to responsiveness and stability, and whether that regime can be identified by intermediate values of B . For example, one might conjecture that in families of driven Markov networks, the time-integrated response to small perturbations is maximised, subject to constraints on stability, in regions where B lies in a bounded interior interval, and that this can be seen as a refinement of minimum-entropy-production principles.

The merit of formulating dynamic symmetry in this Markov–Onsager setting is that the resulting claims are now both concrete and testable. Given any specific model – a biochemical reaction network, a transport system, or a coarse-grained model of a financial or ecological process – one can compute the steady-state distribution, the entropy production, the currents and the linear-response coefficients, construct K , σ and B , and then ask empirically whether regimes of high B coincide with regimes of large but controlled response, favourable stability properties or enhanced predictive information. If they do, the dynamic-symmetry narrative acquires quantitative support. If they do not, or if such regimes are rare or highly fine-tuned, the theory must either be revised or restricted in scope. In this way, the abstract idea of a balance band between order and disorder is translated into a concrete structure in non-equilibrium statistical mechanics, expressed in the same mathematical language used to analyse entropy production and response.

7. Dynamic-symmetry weights in Causal Dynamical Triangulations

The continuum constructions described above suggest that dynamic symmetry may be realised as a band of configurations in which geometric order and local irregularity remain jointly active. Causal Dynamical Triangulations (CDT) provide a natural laboratory in which to test this idea at the level of discrete quantum geometry. In CDT, spacetime is approximated by a sum over causally well-behaved triangulated geometries, and a four-dimensional de Sitter-like universe emerges dynamically in a particular phase of the theory. This makes it possible to ask, in a fully non-perturbative setting, whether a Dynamic Symmetry Theory-inspired weighting of configurations can sharpen, stabilise or disrupt that emergent behaviour.

In standard four-dimensional CDT, the partition function takes the form

$$Z_{\text{CDT}} = \sum_T \exp(-S_{\text{CDT}}[T]),$$

where the sum runs over triangulations T compatible with a chosen causal structure and global topology, and $S_{\text{CDT}}[T]$ is a Regge-type discretisation of the Einstein–Hilbert action with a cosmological term and possibly additional couplings. Monte Carlo simulations of this ensemble reveal a phase diagram with several distinct regions. In one region, often denoted phase C, the triangulations assemble into an extended, four-dimensional, de Sitter-like universe whose large-scale properties agree with a minisuperspace

description. In other regions, the geometry is either crumpled or highly branched and does not resemble a smooth spacetime. From the perspective of Dynamic Symmetry Theory, phase C is the most natural candidate for a geometric balance band, but the existing CDT formulation does not yet encode any explicit preference for such configurations beyond what is implied by the action.

To bring a dynamic-symmetry perspective into CDT, one can enrich the weight assigned to each triangulation by introducing a factor that depends on simple geometric observables defining order and disorder. Let $O[T]$ be an “order-like” functional that measures large-scale coherence of the triangulation. Examples include the smoothness of the volume profile as a function of discrete time, the closeness of that profile to a de Sitter-like shape, or the extent to which quantum Ricci curvature estimates are approximately constant on sufficiently large scales. Let $D[T]$ be a “disorder-like” functional that quantifies local irregularity, such as the variance of vertex coordination numbers, the dispersion of deficit angles around their mean, or fluctuations of the local spectral dimension. Normalising both quantities to the unit interval yields two bounded scalar observables $O[T]$ and $D[T]$ that capture, in discrete geometric language, the same tension between order and disorder that was expressed by fields in the EFT and by currents and entropy production in the Markov setting.

A balance index $B[T]$ can then be defined by a bounded coupling of $O[T]$ and $D[T]$, for instance by a function that vanishes when either is negligible, declines when one dominates the other, and takes its largest values when both are simultaneously substantial and comparable. The precise form of $B[T]$ is not unique and can be chosen to mirror the constructions used in non-equilibrium models, but its role is clear: it identifies triangulations whose geometry lies in an intermediate regime between rigid regularity and unstructured irregularity. With this object in hand, a Dynamic Symmetry Theory-inspired modification of the CDT partition function can be written as

$$Z_{\text{DST}} = \sum_T \exp(-S_{\text{CDT}}[T]) F(B[T]),$$

where F is a positive, bounded function of the balance index. Choosing F to favour an intermediate band of $B[T]$ values – for example by giving higher weight to triangulations with $B[T]$ in a specified interior interval and suppressing those with very low or very high $B[T]$ – implements dynamic symmetry at the level of the discrete path integral. The resulting ensemble remains a sum over the same space of triangulations, but the measure is now explicitly sensitive to how each geometry balances large-scale order against local irregularity.

The question is then whether this modification shifts, sharpens or undermines the emergence of extended four-dimensional spacetime. CDT simulations already monitor several observables that are directly relevant to this question. These include the average spatial volume as a function of discrete time (the “blob”

that resembles a Euclidean de Sitter universe in phase C), the effective Hausdorff and spectral dimensions of spatial slices and of the full triangulation, and more refined probes such as quantum Ricci curvature on larger scales. With the DST-weighted ensemble, one can still measure these quantities and map out the phase diagram as a function of the usual CDT couplings together with one or more parameters controlling the strength and shape of the function F .

Dynamic Symmetry Theory suggests a specific pattern of results. If the balance-band idea is compatible with CDT, there should exist a non-trivial region of parameter space in which: an extended, approximately four-dimensional, de Sitter-like phase persists; typical triangulations sampled from the ensemble have balance indices $B[T]$ lying in an intermediate range rather than clustering near zero or one; and attempts to push the system into regimes of very low or very high $B[T]$ drive it into CDT's non-geometric phases rather than yielding alternative extended universes. In that case, the DST weight would not create a new phase out of nothing, but it would identify and reinforce a region of the phase diagram where geometric order and local irregularity are already finely balanced.

Conversely, several outcomes would count against the usefulness of the present dynamic-symmetry construction in CDT. If the function F has only a mild or negligible effect on the phase structure and on the distribution of observables, then the balance index $B[T]$ may not be capturing a genuinely relevant aspect of the geometry. If strong DST weighting is required to enforce intermediate $B[T]$ values and this systematically destroys the extended four-dimensional phase, then the particular balance constraint embodied in $B[T]$ is incompatible with the conditions under which CDT produces macroscopic spacetime. In both cases, the failure would not necessarily undermine dynamic-symmetry ideas in general, but it would show that this specific choice of order and disorder functionals, and this specific way of incorporating them into the measure, is not appropriate.

The advantage of this CDT-based formulation is that it turns a qualitative slogan into a concrete Monte Carlo question. One can simulate both the standard and the DST-weighted ensembles, measure $B[T]$ alongside existing geometric observables, and ask whether the emergence and stability of extended four-dimensional spacetime correlates with a balance band in $B[T]$. If it does, the CDT results would provide non-perturbative, computational evidence that dynamic symmetry picks out a structurally privileged region of discrete quantum gravity. If it does not, the DST weighting can be revised or rejected in light of explicit data. Either way, the theory's claims become testable within a well-developed numerical framework.

8. Predictions and falsifiable targets

The constructions above have a common aim: to turn the central intuition of Dynamic Symmetry Theory into a set of standard physics problems rather than a free-standing metaphor. That aim can only be met if the framework yields concrete, falsifiable targets. This section collects such targets in four domains – effective field theory and RG, gravity and holography, non-equilibrium statistical mechanics, and discrete quantum geometry – and states, in each case, what would count as support for or against the present implementation of dynamic symmetry.

In the Effective Field Theory and renormalisation-group setting, the central prediction is that the minimal two-scalar model admits an infrared regime in which the dynamic-symmetry band is realised as a robust structural feature rather than a finely tuned artefact. More precisely, there should exist an open set of ultraviolet couplings for which RG trajectories flow towards a region where the effective potential has an approximate ring of minima at non-zero S_0 , the radial mode around that ring is heavy, and the angular mode is light. In this region, large departures from S_0 are suppressed, while motion along the ring remains comparatively easy. If such an infrared regime is found to exist and to attract a non-trivial basin of initial conditions, the EFT implementation of dynamic symmetry would be vindicated at the level of field theory. If, on the contrary, the ring-like structure is either washed out under RG flow or requires fine-tuning of couplings to a set of measure zero, then this simple EFT realisation of the balance band would be ruled out or at least sharply limited in scope.

On the gravity and holographic side, the key prediction is that there exist regular Einstein–scalar domain-wall solutions that interpolate between an AdS extremum at $S = 0$ and a ring-like region at $S = S_0$, with a light angular mode representing a nearly marginal boundary deformation. Technically, this means that for some open range of λ_S , S_0 and angular potential parameters, one can find smooth solutions in which the scalar trajectory in field space runs from the origin into the neighbourhood of the ring, the radial fluctuations are heavy, and the angular fluctuations correspond to operators whose scaling dimensions are close to marginal. If such solutions exist and are stable, and if the associated boundary flows exhibit near-critical, edge-like behaviour in correlation functions or entanglement measures, the gravitational embedding of dynamic symmetry would be strongly supported. If instead no such flows can be found, or they prove generically unstable or unphysical, then the particular ring-based potential proposed here is not compatible with a viable holographic realisation and would need to be abandoned or substantially revised.

In the non-equilibrium statistical-mechanics setting, the prediction is that in suitable families of driven Markov processes, intermediate values of the balance index B are not merely aesthetically appealing but coincide with regimes of maximal useful response or information transfer under explicit constraints. Concretely, in a given model class, one can compute steady-state entropy production, currents,

linear-response coefficients and information-theoretic quantities such as predictive mutual information. The claim is that, after appropriate normalisation, there exists a bounded interior interval of B values on which response and predictive structure are large but finite, while both tails of the B distribution correspond to regimes that are either too rigid or too noisy to support favourable behaviour. If these patterns are observed across representative models – biochemical networks, transport systems, or stylised financial processes – then the non-equilibrium implementation of dynamic symmetry will have picked out a genuinely useful structural regime. If, by contrast, response and information measures routinely peak near extreme B values or show no consistent dependence on B , the present way of encoding dynamic symmetry in Markov systems would be disconfirmed.

Finally, in the CDT framework for discrete quantum geometry, the prediction is that DST-weighted ensembles reveal a correlation between an intermediate geometric balance index and the emergence of extended four-dimensional spacetime. With a specific choice of order and disorder functionals on triangulations and a corresponding balance index $B[T]$, the Dynamic Symmetry Theory modification of the CDT partition function introduces a tunable preference for intermediate $B[T]$. The claim is that there should exist a region in the enlarged parameter space where: the familiar extended, four-dimensional, de Sitter-like phase appears; typical triangulations in that region have balance indices in an interior band rather than near the extremes; and attempts to drive $B[T]$ to very low or very high values push the system into non-geometric CDT phases instead of generating alternative extended universes. Observing such behaviour would provide non-perturbative, computational evidence that dynamic symmetry identifies a structurally special region of discrete quantum gravity. If, instead, DST weighting has only negligible impact on the phase diagram, or if enforcing intermediate $B[T]$ systematically destroys the extended phase, then this particular geometric realisation of dynamic symmetry would be falsified.

Taken together, these targets turn the overall programme into a finite list of technical questions. Each question can be answered with standard tools in its respective domain, and each answer has clear implications for the viability of the present Dynamic Symmetry Theory implementation. If even one of the central predictions is borne out in a way that cannot be reduced to already known structures, that will be a genuine step forward. If none are, then the framework described here will have done its job in a different way: it will have clarified why the intuitive appeal of dynamic symmetry does not, in this form, translate into a workable physics model.

9. Conclusion

This note has recast Dynamic Symmetry Theory as a set of standard physics problems rather than as a free-standing metaphor. On the field-theoretic side, it has introduced a minimal two-scalar Effective Field Theory in which dynamic symmetry appears as an internal equivalence between sectors and as a ring-like vacuum manifold at non-zero total activity, and it has framed the resulting renormalisation-group flow as a candidate realisation of a balance band in the infrared. The same structure has been embedded in an Einstein–scalar model to define holographic flows from a UV AdS extremum towards a dynamically symmetric region in bulk field space. In parallel, a non-equilibrium formulation has expressed dynamic symmetry in terms of entropy production, steady-state currents and response in finite-state Markov processes, and a discrete quantum-gravity realisation has been proposed via dynamic-symmetry weights in Causal Dynamical Triangulations.

The central contribution is therefore architectural. It identifies a small collection of familiar formalisms—Effective Field Theory and RG, gravity and holography, non-equilibrium statistical mechanics, and CDT—in which the core intuition of Dynamic Symmetry Theory can be stated as a precise structural requirement, and it specifies explicit tests that these requirements must pass. The framework does not claim that dynamic symmetry has already been established as a physical principle. It claims only that the theory can now be posed as a disciplined physics problem with clear success and failure modes. The next step is not further conceptual elaboration but calculation: mapping RG flows in the two-scalar model, constructing and analysing domain-wall solutions in the Einstein–scalar setting, testing balance indices against response and information measures in Markov models, and implementing dynamic-symmetry weights in CDT simulations. If these investigations reveal robust balance bands with non-trivial predictive power, Dynamic Symmetry Theory will have gained a concrete foothold in physics. If they do not, the present programme will at least have clarified which avenues are unpromising and where alternative implementations must differ.