Emergence of Quantised Representations Isolated to Anisotropic Functions

Anonymous authors
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Abstract

This paper presents a novel methodology for determining representational structure, which builds upon the existing Spotlight Resonance method. Particularly, this new tool is used to gain insight into how discrete representations can emerge and organise in autoencoder models, through a controlled ablation study in which only the activation function is altered. Using this technique, the validity of whether function-driven symmetries can act as implicit inductive biases on representations is determined. Representations are found to tend to discretise when the activation functions are defined through a discrete algebraic permutation-equivariant symmetry. In contrast, they remain continuous under a continuous algebraic orthogonal-equivariant definition. This confirms the hypothesis: algebraic symmetries of network primitives can carry unintended inductive biases which produce task-independent artefactual structures in representations. The discrete symmetry of contemporary forms is shown to be a strong predictor for the induction of discrete representations transformed from otherwise continuous structures — a quantisation effect. This motivates further reassessment of functional forms in common usage. Moreover, this supports a general causal model for one mode in which discrete representations may form, and could constitute a prerequisite for downstream interpretability phenomena, including grandmother neurons, discrete coding schemes, general linear features and possibly Superposition. Hence, this tool and proposed mechanism for the influence of functional form on representations may provide insights into emergent interpretability research. Finally, preliminary results indicate that quantisation of representations appears to correlate with a measurable increase in reconstruction error, reinforcing previous conjectures that this collapse can be detrimental.

1 Introduction

This introduction will begin by outlining how many of deep learning's current functions are expected to influence the representations. This is hypothesised to constitute a function-driven emergent bias, motivating a comparative analysis against analogous functions but abiding by differing symmetries. Finally, an approach is discussed for isolating such influences through a controlled ablation study.

1.1 Overview for How Functional Form Choices May Result in Biases

Many of the foundational functions in contemporary deep learning produce maps that differ as the direction changes; a property termed '*anisotropy*'. This angular variation of the functions is hypothesised to make specific directions distinct, which the network may then alter its representations about through optimisation. Hence, an angularly varying map may be expected to induce shaped angular representations. It is this connection between functional forms and representations which shall be explored in this work.

Directions singled out by a functional form's structure may be termed a 'privileged basis' (Elhage et al., 2022) or a set of 'distinguished directions' (Bird, 2025a). Such distinguished directions are commonplace through activation functions, normalisers, initialisers, regularisers, optimisers, architectures, operations, and more (Bird, 2025a). Hence, there are several avenues hypothesised through which representational influence may occur: directly through functional forms, indirectly through optimiser forms, and inherently through

neuron connectivities. This proposed triad of influences would suggest that the representational alignment phenomenon may be systematic to deep learning's anisotropic primitives and general practice. As a starting point, this work will isolate and determine the direct influence of activation functions as one of these causal influences on representations.

In particular, contemporary functional forms tend to make distinct the standard basis' vectors, $\hat{e}_i$, and in such a way that each basis vector's distinction is equal. This particular form of anisotropy can also be denoted through a permutation symmetry (Godfrey et al., 2023). This can be promoted to a *defining* characteristic relation underlying contemporary functional forms and categorised accordingly (Bird, 2025a). This permutation symmetry is often due to their elementwise application, but can appear more generally. The specific relation depends on the primitive in question; for most activation functions, this is an algebraic permutation equivariance. This permutation equivariance is displayed in *Eqn.* 1[1]. The hypothesis is that the maximal symmetries to which functional forms belong are a strong predictor of emergent representational structure.

$$\forall \mathbf{P} \in S_n, \forall \vec{x} \in \mathbb{R}^n \quad \mathbf{f}\left(\mathbf{P}\vec{x}\right) = \mathbf{P}\mathbf{f}\left(\vec{x}\right) \tag{1}$$

The Spotlight Resonance Method (Bird, 2025b) has already empirically demonstrated how such activation functions can produce a *tendency* for representational alignments about the distinguished directions. This was achieved through transformations to the standard basis, and also altering the number of distinguished directions through the functional form. It was found that corresponding changes in the representations occurred, which followed the transformed structure of the distinguished directions. The conclusion was that functional forms stimulate this tendency towards representational alignment, producing emergent task-agnostic alignment structure in representations, and hence establishing a causal relationship between the two. The observed structure showed a tendency for a greater density of representations to cluster around the functional form's distinguished directions. This work also indicated the presence of 'grandmother neurons', indicating how many clusters represent a distinct semantic and also associated their alignment with functional form choices. However, it did not establish whether discretisation itself was a phenomenon of this choice of functional form.

1.2 Motivating The Approach for this Study

Isotropic Deep Learning (Bird, 2025a) takes the consequences of such observations a step further. The Spotlight Resonance Method determined that task-agnostic structure in representations is associated with a functional form's distinguished directions. The Isotropic Deep Learning approach proposes that since this structure transforms with the functional form, the anisotropic functional form choices may be the fundamental causal mode that induces the array of interpretable structures to begin with.

In effect, anisotropic primitives provide an absolute frame, for each representation space, about which the representations organise and discretise into distinct clusters. Hence, it raises the question of whether the ubiquity of anisotropy in contemporary deep learning constitutes an underlying origin for many such interpretable and emergent-structure phenomena, which are commonly observed. If this is the case, then it must be assessed whether this is beneficial or not. Furthermore, determining the validity of such a hypothesis would indicate whether these phenomena are truly fundamental to deep learning or stimulated by, and contingent on, the specific *choices* in functional form currently in use. This could have significant implications for the approach of network interpretability. Confirmation of this hypothesis would also demonstrate that such choices do carry inherent and unappreciated biases with their implementation.

This position motivates the comparative study of this work. Determining whether one can control and demonstrate the emergence and elimination of structure through broadening deep learning's primitives to other forms, particularly those defined through differing maximal symmetries. The hypothesis is that each may provide its own inductive bias. One such proposed choice is by redefining primitives through an

[1]This is assuming a map $\rho : \mathcal{G} \to \mathrm{GL}_n\left(\mathbb{R}\right)$ representation of the group, in this case one which permutes the standard basis. This form of representation will be assumed and implicit in all groups represented as matrices moving forward.

orthogonal algebraic-equivariance (Bird, 2025a), displayed in *Eqn.* 2. This is termed an 'isotropic' definition of forms, and is a supergroup-symmetry of the original permutation symmetry, $S_n \subset \mathrm{O}(n)$.

$$\forall \mathbf{R} \in \mathrm{O}(n), \forall \vec{x} \in \mathbb{R}^n \quad \mathbf{f}(\mathbf{R}\vec{x}) = \mathbf{R}\mathbf{f}(\vec{x}) \tag{2}$$

Choosing this definition for primitives is interesting, since it can eliminate all form-distinguished directions in a network. Therefore, functions developed to adhere to this modified symmetry definition can be used as a comparative mode to determine whether functional forms can induce these interpretable structures and indicate whether downstream alignment phenomena are attributable to anisotropic choices. If this is the case, it would demonstrate that these differing forms do carry unintended inductive biases, which would warrant major reevaluation of the forms used in standard practice.

1.3 Methodological Approach

The Spotlight Resonance Method hypothesised a hierarchy of anisotropic influences, particularly through the triad discussed earlier. These interacting distinguished bases may be highly non-trivial to predict the representational alignment of. Therefore, the causal mechanism was established in a clean, isolated and minimalistic way through ablation studies of only activation functions to minimise conflating or obscuring influences. Establishing this base case of a causal mechanism from primitives to representations can then be expected to carry downstream through more general networks built on these primitive influences. The author's approach of establishing such a causal mechanism through a minimalistic approach, which can then be expected to apply more generally, will be repeated in this methodology.

Instead of rotating the privileged basis or altering the number of distinguished directions to determine alignment of representations, this study will compare representations between the presence and absence of any distinguished directions to determine if this is a causal mechanism for the production of approximately discrete representations.

Due to the expected systematic nature of this inductive bias, care was taken to prevent the unintentional reintroduction of anisotropy. To achieve this, distinguished directions will be removed network-wide to avoid these confounding and obscuring interactions. This is achieved by utilising isotropic primitives and an autoencoder model for reconstruction [2], except for an activation function which can selectively reintroduce anisotropy through changes to its form. Hence, this isolates the causality of the phenomenon to the activation functions.

This requires two activation functions, which are highly similar in action but differ in the presence or absence of anisotropy. The isotropic paper (Bird, 2025a) provides these preliminary isotropic activation functions, which enable this comparative analysis. An analogue of standard elementwise (anisotropic) tanh, displayed in *Eqn.* 3, can be compared with its orthogonal analogue Isotropic-Tanh, displayed in *Eqn.* 4 — each is displayed in multivariate form for comparison $\mathbf{f} : \mathbb{R}^n \to \mathbb{R}^n$. These functions produce equivalent non-linear maps along the standard basis directions: $f_{\text{iso}}(\alpha\hat{e}_i) = f_{\text{aniso}}(\alpha\hat{e}_i)$ forall $\hat{e}_i$ and α. Standard-Tanh is algebraically equivariant to the hyperoctahedral group (standard-basis permutation with sign-flips), B_n, whilst isotropic-tanh is algebraically equivariant to the orthogonal group, $\mathrm{O}(n)$, with $B_n \subset \mathrm{O}(n)$.

$$\mathbf{f}_{\text{aniso}}(\vec{x}; \{\hat{e}_i\}_{\forall i}) = \sum_{i=1}^{N} \tanh(\vec{x} \cdot \hat{e}_i)\, \hat{e}_i \tag{3}$$

$$\mathbf{f}_{\text{iso}}(\vec{x}) = \tanh(\|\vec{x}\|)\, \hat{x} \tag{4}$$

This enables a comparative ablation study of the influence of functional form symmetries on representations, and can determine a causal mechanism for the emergence of a discrete-like structure.

[2] The use of an autoencoder model prevents anisotropy through choices in the output layer representation. For example, one-hot encoding in classification outputs is also a choice in form defined through permutation symmetry; therefore, it could induce further spurious structure. A reconstruction task using autoencoders may therefore mitigate this and enable more data-representative and 'natural' embeddings. Moreover, it has been speculated (Bird, 2025b;a) whether the neural-collapse classification phenomenon (Papyan et al., 2020) is related to the proposed mechanisms. So autoencoder reconstruction provided a suitable minimalistic setting, free from these influences, to study form-induced representational quantisation.

This approach is also extended to a Leaky-ReLU (Maas et al., 2013) family, which are modified to adhere to the following symmetries $S_n \subset B_n \subset \mathrm{O}(n)$. This is discussed further in *App.* B.4 and indicates that algebraic symmetries are the primary predictor, since all other algebraic properties of Leaky-ReLU substantially differ from the tanh-like family of *Eqns.* 3 and 4.

This work also modifies the prior Spotlight Resonance Method (SRM). This modified tool is termed the Privileged-Plane Projective Method (PPP method), which operates on a similar principle. However, unlike SRM, this adaptation does not project out the vector length in the process. Hence, information regarding both angular and magnitude distributions is retained. This provides a more nuanced understanding of the network's representational structures; however, SRM may still be preferable in determining statistical measures of the angular representations. Furthermore, this uniquely positions the Privileged-Plane Projective method as a tool for assessing whether neural refraction (Bird, 2025a) occurs for out-of-training-distribution outlier representations.

Additionally, the PPP method does not produce any angular-falloff smearing effect related to the cone width of SRM. This modified method, therefore, enables higher-fidelity angular maps of representations, which may be beneficial in many circumstances. The following section provides a detailed overview of this tool.

Using a comparative analysis between standard-Tanh and isotropic-Tanh, and similarly on Leaky-ReLU family of functions, this method can then determine whether there is a *tendency* for discrete representation clusters to form due to the task-agnostic functional form symmetries. It indicates that algebraic permutation equivariance tends to produce a quantising inductive bias on otherwise continuous representations, rather than task-necessitated representational collapses. As a consequence, it suggests that downstream phenomena, such as interpretable neurons, are not fundamental but rather a direct consequence of anisotropic functional forms. This may have benefits in AI safety and interpretable networks; however, preliminary evidence also suggests that this task-agnostic collapse can be pathological, such as through reduced representational capacity.

1.4 Hypotheses of Function-Driven Biases

The primary hypothesis is that since isotropic functional forms are devoid of distinguished directions, they may consequently eliminate any tendency towards task-agnostic representational collapse aligned along these directions. This formed a prediction regarding why isotropic primitives may be beneficial in certain scenarios (Bird, 2025a), which is discussed further below. This motivates the importance of the present study as a starting point for probing this hypothesised representational collapse induced by primitives and establishing resultant consequences.

In particular, anisotropic forms may lead to a detectable tendency for representations to overly cluster around distinguished directions. This is due to the anisotropic functional form's nature, where some angular arrangements may become overrepresented through optimisation due to their irregularity. This task-agnostic over-density bias may be detrimental, as representations may tend to collapse towards single directions, such as aligned or anti-aligned, and consequently lose informative representational degrees of freedom, potentially damaging a network's internal expressiveness. Hence, anisotropy may result in a *quantising effect* on representations, and thus also the semantics being represented — resulting in a limited representational capacity and neural coding scheme. This may be exacerbated when the inputs and outputs are better represented continuously, and transformations between them should preserve an approximately continuous structure. Consequently, isotropic primitives are expected to remove this form-induced task-agnostic discretising bias on representations.

This may occur through several modes, hypothesised to stem from the underlying symmetry. As stated, particular symmetry-based constructions may produce distinguished directions that have more favourable maps for computations and representations shift accordingly.

Additionally, for general networks, their construction is not designed to vary predictably in response to group actions on representations. Therefore, if a network doesn't commute with actions or remain invariant to them, then a shift in representations corresponding to some group action will then impact and interact non-trivially with the rest of the network. This is argued to produce a knock-on chain of interactions within the network. This influence is expected to result in unintended biases. It also highlights why groups/symmetry, rather

than just a general action, may contribute an important characterising property since many analogous actions within a group may each contribute a similar effect in the sub/space they transform. Similarly, these biases may be expected to be largely consistent across sets of primitives that share the same maximal symmetry, due to this structure.

This is expected to differ from symmetries in end-to-end networks (Bronstein et al., 2021), where their representations are designed to transform with the symmetry, resulting in the entire model often being either equivariant or invariant to its effect. Hence, those representative degrees of freedom connected through group actions become constrained by the group structure and, as a result, represent the pose information derived from the group. This is not the case in general networks, where a symmetry action does not pass cleanly through or identically cancel with layers. Therefore, these group-connected degrees of freedom may represent more general semantics and not indicate pose. More informally, one can imagine that such symmetry actions can result in interactions within the network due to its structure and consequently alter dynamics, rather than passing straight through unimpeded by design. In this informal heuristic, a layer may 'absorb' a symmetry action in a non-invariant/equivariant manner, or have an interaction with its differing symmetry. This may mean the symmetry does, in principle, 'act' on the network and hence produce a realisable and tangible effect. This suggests that the maximal symmetry may be an important consideration in general networks, resulting in similar inductive biases, due to function-driven biases. These are felt to be underappreciated in significance.

One can then consider permutation-like symmetries about a particular basis. These result in an orthant partitioning of the space. Depending on the particular permutation symmetry, sets of these orthants may be analytically degenerate under these actions, producing equivalent maps. The network's optimisation may then shape representations about these orthants of differing and equal mapping, to achieve the desired computation. This may result in representations that organise differently over these maps related by the symmetry of the form, and in their extreme, may cluster over particular preferred regions, producing a quantisation effect on representations. This is considered a general mode through which function-driven symmetries may influence representations in permutation-defined forms, when optimisation responds to their structure. One can then compare this to an analogous function, contingent upon a non-permutation defined form, allowing for a comparison of their respective biases. This general approach will be used to study how various function-driven symmetries interact and act on the network and its representations, determining the various biases induced.

This mechanism would aid in explaining why the SRM study (Bird, 2025b) detected axis-aligned structure. Incidental alignment with directions chosen to be defined and observed as 'individual neurons' would otherwise have a vanishingly small likelihood of occurring in high-dimensional spaces. This is because there are vastly more orientations that do not align with the standard basis than those that do in high-dimensional spaces. However, if the analytic properties of permutation-based functions produce maps which differ along these directions, then the symmetry breaking of the space would single out such directions and make alignment less peculiar. Therefore, it indicates an unintended bias of the model. A comparison between anisotropic and isotropic forms can directly probe such questions by adding and removing any distinction between directions.

Quantisation is argued to have potential pathological effects on the network. One heuristic is that the underlying distributions might be better represented continuously, as this aligns with the frequently continuous real-world semantics being represented, such as broad object morphologies and arrangements, multivariate signals, lighting and shades, continuous expressions, and modelling distributions, etc. Therefore, enabling latent variables and representations to be continuous and potentially more interpolatable at various levels through a network, instead of an imposed task-agnostic structure, may be beneficial for many tasks. This may increase representational capacity and organisation of the representations.

This connects to the coding scheme of the network. Axis-aligned representations, previously observed to frequently emerge (Bau et al., 2017; Elhage et al., 2022; Bird, 2025b), approximate a local coding (Sherrington, 1940; Konorski, 1968; Barlow, 1953; Gross, 2002; Connor, 2005) scheme for the network. This is where one neuron corresponds to one semantic. This coding scheme has decreased concept-interference, but has a much lower representational capacity than other coding schemes. Models have been demonstrated to produce other interference-capacity balances with various input sparsities (Elhage et al., 2022; Bird, 2025b), suggesting that

axis-alignment is not an appropriate *universal* inductive bias — further motivating the study of alternative functional form inductive biases and their effects on representations.

A functional form that does not distinguish particular directions may therefore not deter such continuous and interpolatable structures present in the dataset, and this may be advantageous to some applications. Yet, sometimes discretisation may be appropriate, such as in classification networks, where abstracting away redundant detail can be beneficial — though in autoencoding models this would not be an expectation. In any case, rigidly imposing this through a task-agnostic, function-driven, inductive bias about a specific arrangement might be detrimental. For example, when reducing the dimensionality of a dataset inherently containing discrete representations via a linear layer, to some arbitrary lower dimension, one would not expect it to be always appropriate for those discrete directions to be best represented through an alignment to an orthonormal basis or other imposed geometry for that space — as these are as arbitrary to the bottleneck chosen.

It is essential to note that isotropic networks still enable such clustering. They retain the ability through their bias terms, but they are suggested not to disproportionately encourage it through task-agnostic biases; instead, it would likely reflect a task-necessitated collapse. Hence, there is no reason to expect isotropy in representational distributions, as the underlying data or latent layer may include discretised aspects that arise independently of model effects. Therefore, this is not a test of whether distributions are anisotropic or isotropic; instead, it is the investigation of whether the emergent structure specifically about a distinguished direction can be turned on or off through functional form choices. Therefore, isotropic networks may be expected to produce emergent structures that are more representative of the underlying data, rather than being dependent on functional forms. Hence, proposing that these choices carry representational inductive biases, where isotropy's frame independence may be a less arbitrary, and thus more preferable and natural choice.

Other speculative pathological modes are attributed to the hypothesised functional form quantisation. For example, discrete representations may be particularly susceptible to perturbations which move activations outside of the cluster, into an in-between region of representation space. Maps from these unpopulated regions may be poorly trained and fragile, due to their training-time rarity, and therefore highly unpredictable in their map. This may suggest that such a quantising inductive bias decreases may decreases the phenomenon of adversarial robustness (Goodfellow et al., 2015; Moosavi-Dezfooli et al., 2017; Ilyas et al., 2019; Tsipras et al., 2019), whereas removing this bias through isotropy may be advantageous. However, this speculation is not explored within this work.

This paper aims to assess the validity of the first prediction. The motivating questions are: do discrete-symmetry defined functional forms tend to produce *approximately* discrete representations? This would be a *quantising* of an otherwise underlying continuous data structure. This is contrasted with continuous-symmetry defined functional forms, which are expected to tend to preserve a more continuous representation. Furthermore, is the discrete construction potentially pathological in nature? Determining whether continuous representations tend to improve performance, since quantised representations may harm expressiveness. Overall, determining the validity of this prediction may provide crucial insight into the potential of Isotropic deep learning and the emergence of downstream interpretability structure, namely alignment, grandmother neurons, general interpretable directions, discrete codes, and possibly Superposition (Elhage et al., 2022) and perhaps some connection to Neural Collapse (Papyan et al., 2020).

Consequently, this study can be considered to be determining a more foundational prerequisite phenomenon than the Spotlight Resonance Method observed and causally explained. This prior method elucidated how functional forms can causally influence *alignment* structure. In contrast, this work investigates whether forms can lead to the emergence of any induced task-agnostic structure. Determining whether current forms induce representational quantisation may indicate a causal mechanism for these other downstream phenomena.

It is established that discretisation can be contingent on the functional form's maximal algebraic symmetries. It is shown that these symmetries are good predictors of the emergent task-agnostic structure in representations. Additionally, through this approach, some *preliminary* evidence is provided that such representational collapses may be pathological in nature, increasing task error. However, this study is not intended to elucidate the exact mode of the pathology, such as those proposed above, so the results remain preliminary in this regard.

Overall, the establishment of these links suggests these functional *forms* are not benign in their effect and can induce unintended biases into networks indicative of their respective maximal symmetries. It would encourage the identification and documentation of the extent of these influences, since leveraging such properties could be advantageous. It suggests that considering maximal symmetries at the primitive scale may be important, and motivates a reevaluation of the contemporary functional form of primitives in general.

2 Privileged-Plane Projective Method Implementation

The Privileged-Plane Projective Method (PPP method) operates similarly to the Spotlight Resonance Method (SRM). It appears to work on any architecture, at any layer and for any task. It only requires a set of basis vectors to operate on, typically the distinguished vectors, producing 'privileged (oriented) planes'. It provides a tool to interpret the structure of internal embeddings in high-dimensional spaces by projecting them down to privileged two-dimensional planes, where representations have been shown to align about. This differs from the SRM method, which sweeps out these planes with rotating probe cones to map the density fluctuations in representations. Instead, this method produces modified slices of the space to provide crisper details to the structure of representations through over- and under-densities — hot spots produced by the technique indicate these. This provides greater information to intuit distributions in a visual manner, including magnitude information, and is therefore proposed as a successor to the prior method. The methodology is as follows:

Given a set of distinguished unit-normalised vectors, $\left\{\hat{b}_i | \forall i\right\}$, create all non-parallel pairwise combinations or permutations of the set: $\left\{\left(\hat{b}_1, \hat{b}_2\right), \cdots\right\}$. These two choices are referred to as Combination-PPP and Permutation-PPP, respectively.

From these two vectors, oriented $\mathbb{R}^2$ planes can be formed as a subspace of the $\mathbb{R}^n$ space. These are the 'privileged planes' onto which representations can be projected. There are several ways to choose a threshold for projection, such as a thresholded closest distance to plane; however, an angular threshold was instead chosen[3].

This thresholding can be achieved through the decomposition of representation vectors, $\vec{v}$. These can be decomposed into an in-plane component and a perpendicular component $\vec{v} = \vec{v}_{\parallel} + \vec{v}_{\perp}$. This is achieved through determining the coefficients within the plane: $\vec{v}_{\perp} = \vec{v} - \vec{v}_{\parallel}$.

The pair of vectors defining a plane may not be orthogonal in non-standard sets. When displaying the two coefficients, this can produce artefactual distortion in the method. These can be removed by forming an orthonormal basis for the plane: $a\hat{b}_1 + b\hat{b}_2 = c\hat{e}_1 + d\hat{e}_2$, where $\hat{e}_i \cdot \hat{e}_j = \delta_{ij}$. This can be achieved in steps, driven by the need to preserve the plane's orientation. The unit-vector $\hat{b}_1$ is assigned to $\hat{e}_1$ and $\hat{e}_2$ is chosen such that $\hat{e}_2 \cdot \hat{b}_2 \geq 0$ — preserving the orientation. Therefore, the new basis is defined as $\hat{e}_1 = \hat{b}_1$ and through *Eqn.* 5, which is a Gram-Schmidt procedure for orthonormal basis construction.

$$\hat{e}_2 = \frac{\hat{b}_2 - \left(\hat{b}_2 \cdot \hat{b}_1\right)\hat{b}_1}{\left\|\hat{b}_2 - \left(\hat{b}_2 \cdot \hat{b}_1\right)\hat{b}_1\right\|} \tag{5}$$

These two $\mathbb{R}^n$ orthonormal vectors can then be stacked into a matrix of shape $\mathbf{E} \in \mathbb{R}^{2\times n}$, and pseudo-inverse can be used to determine the coefficients for the in-plane vector with respect to this basis: $\vec{w} = \left(\mathbf{E}^T\mathbf{E}\right)^{-1}\mathbf{E}^T\vec{v}$, with $\vec{v}_{\parallel} = \vec{w}^T\mathbf{E}$. This constitutes the desired projection into the privileged plane.

Finally, using the vector magnitudes one can produce an angular threshold: $\left\|\vec{v}_{\parallel}\right\| / \left\|\vec{v}\right\| > \epsilon$, where $\theta_{\text{threshold}} = \arccos\epsilon$. Any representations which meet this angular threshold have an associated $\vec{w}$ displayed in the PPP method's plot. This is repeated for all pairwise vectors chosen and all representations chosen.

[3]This latter one gives a better interpretation for alignment, all within a small angle of the plane, and practically was found to yield better results. However, vectors close to the origin are often outside of the angular threshold due to the vanishingly small volume. Therefore, frequently, an artefactual circular zone of absent representations is observed. Hence, other choices or a hybrid of these two approaches may also be considered, but were not included for simplicity.

The coefficients $\vec{w}$ can be displayed in many ways in a $\mathbb{R}^2$ plot. It would seem beneficial to generally have this centred around the origin with equally scaled axes. This could be achieved through a scatter plot or a density plot. The latter was chosen only for visual appeal. This required forming a high-resolution grid over a region of interest and recording the value of a narrow Gaussian centred with a mean of $\vec{w}$ and small variance $\alpha 1_2$. A Gaussian for each $\vec{w}$ was produced, and the grid represents their sum. This could then be displayed as a series of images with colour gradients scaled by the maximum value across all images. This provides an impression of representation density, which remains comparable across time steps. All the following plots are produced in such a manner. Alternatively, colour coding could be used to indicate the angle subtended between each representation and the privileged plane, within a scatter plot. This latter method would provide further angular information perpendicular to the plane, but was not used in the results of this paper.

In this paper, $\epsilon = 0.75$ was found to work well and was therefore used in the production of all results. Similar results were found for larger ϵ, but the plots had fewer representations due to the smaller volume, so structures were less definitive in their appearance. Unless otherwise stated, all measurements were taken using the combination-PPP method, using the standard basis. This was found to be beneficial compared to permutation-PPP, which could produce statistical artefacts discussed further in *App.* A.

3 Experiments and Interpretation

In this section, comparisons between isotropic and anisotropic activation functions are displayed and discussed. The examples shown are an excerpt from a larger variety of results available in *App.* B. The exact method for training these networks is discussed in *App.* D. A code repository for the PPP method is available at [URL REDACTED FOR ANONYMITY].

The first result provides a particularly clear demonstration of the quantisation phenomenon resulting from anisotropic functional forms, as opposed to the more continuous representations produced by isotropic functional forms.

In all cases from *Fig.* 1, one can observe that the anisotropic row representations form distinct highly-dense, approximately discrete structures, which through training align (horizontal and vertical) or anti-align (diagonal) with the distinguished directions. In contrast, the bottom-five isotropic rows produce more circularly symmetric, continuous representations with no specific alignment tendencies. Furthermore, this example alone is considered sufficiently indicative of a representational inductive bias deriving from functional form choices, thereby validating the hypothesis. This supports anisotropic forms being sufficient to cause discrete representational tendency with task-agnostic clustering about distinguished directions.

There are several interesting further aspects of these results.

Firstly, the construction of this specific autoencoder ensured no activation function preceded the latent layer of study, similarly to the spotlight resonance method. This eliminated the possibility that these alignment phenomena are trivially due to the bounding geometry of an activation function, including limit points. The activation functions are only applied after the latent layer of study. Hence, this indicates how the functional forms in later layers can exert a representational bias generally through optimisation throughout the network. Thus, the functional form structure biases the parameter trajectories during learning, which then transforms the representations into these discrete structures. Therefore, this represents a non-trivial representational bias due to functional forms confirming the prior prediction (Bird, 2025a) in the general case preceding any trivial bounding or neural refraction (Bird, 2025a). Further results also substantiate this.

Additionally, the results suggest that discrete-representational Superposition (Elhage et al., 2022) may arise uniquely in the anisotropic functional form. Several rows, namely two through five, display discrete directions that are either aligned with or anti-aligned with the standard basis, but are sometimes also arranged at more general angles. This is further demonstrated in *Fig.* 2, which is the same autoencoder but with a greater number of hidden latent layers.

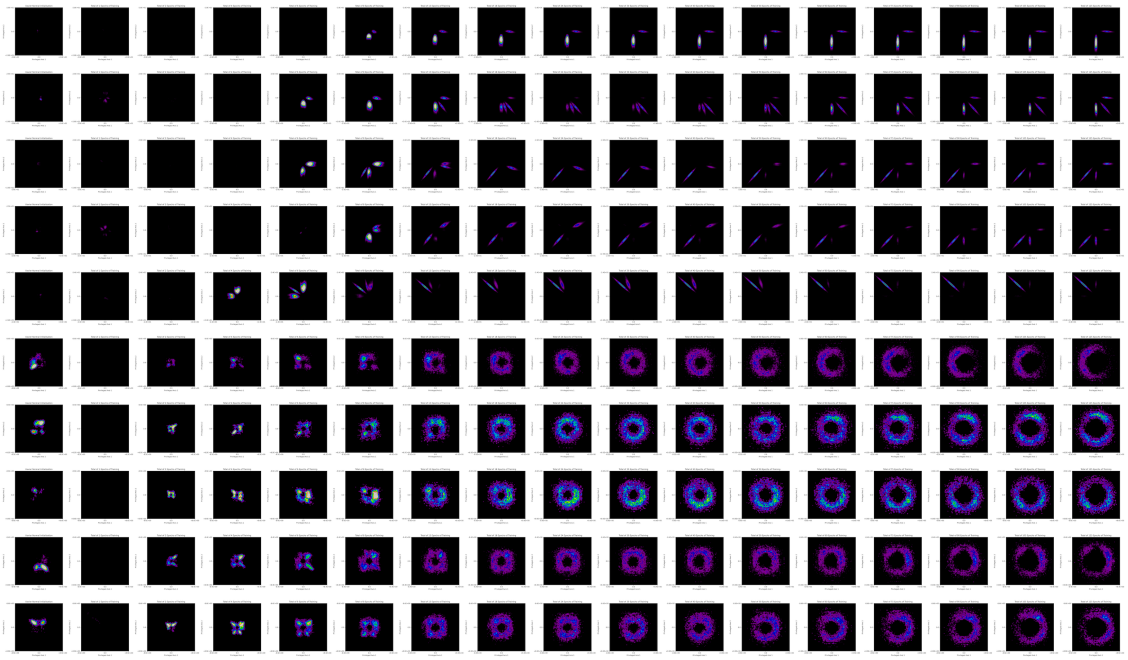

Figure 1: Displays ten rows of PPP-method's results, divided into columns. Each row represents an independent autoencoder network trained on the reconstruction of the CIFAR dataset (Alex, 2009). Each column represents the results of the PPP method at various stages of training. The leftmost column shows a freshly initialised model before training, and moving rightward, the network is progressively trained for up to 125 epochs, as shown in the rightmost column. Hot-spots indicate where the internal latent layer is particularly dense with representations — collated over all samples from the CIFAR training set. The top five rows depict networks which utilise the anisotropic activation function, standard-tanh, whilst the bottom five rows utilise the isotropic activation function, isotropic-tanh. Every other detail is identical otherwise. Figure titles indicate the exact number of epochs trained for. This specific network consists of a latent layer of 18 neurons, with standard (unnormalised) input-output pairs drawn from CIFAR. The dark centres about the origin are attributed to a vanishing volume due to an angular threshold, rather than the absence of representations.

This is believed to be indicative of a *discrete* representational structure consistent with descriptions of Superposed features[4] (Elhage et al., 2022). Additionally, it also shows that activation functions can exert influence backwards through the model, affecting representations in latent layers that precede any activation function in the forward pass. This reframes several Superposition experiments (Elhage et al., 2022), which identify the phenomenon in such cases.

This may indicate that discrete Superposition phenomena arise due to anisotropic forms, but whether these forms provide a complete description remains debatable — especially for the phenomenon's dual through parameters, which could still be applicable under continuous representations. Further analysis of individual planes from the PPP method may be necessary to assess further nuances of the Superposition, rather than relying on this more conglomerate plot over all planes. However, this would require many more samples to populate individual planes sufficiently. Additionally, several columns on isotropic networks for early-stage training also indicate directions of high density, but these progressively distribute throughout training. These are believed to be statistical in nature, as optimisation has not had the opportunity to transfer asymmetry in forms to representations yet. This is discussed further in *App.* A. Overall, it is suggestive that representational

[4]These are thought to be representational examples of the phenomenon, which differs from the original measurement, which was often concerning the autoencoding network's parameters. Thus, this potentially provides a sort of dual observation of the phenomenon. Additionally, row two demonstrates exclusively anti-aligned representations to the standard basis, which appears to diverge from the classical alignment-first features.

Superposition may be a network-adaptive emergent phenomenon predicated upon the imposed task-agnostic anisotropic biases.

Generally, anisotropic functional forms appear to produce an increasingly discrete structure in representations as training progresses, beginning with angularly arranged but more diffuse representations and slowly refining into narrow angular beams. This is consistent with a linear feature hypothesis (Elhage et al., 2022). This structure appears contingent on the anisotropic functional form, suggesting it carries a quantising inductive bias. Additionally, the anisotropic network's linear features align about both positive and negative distinguished directions, appearing to respect the sign-flip and permutation (hyperoctahedral symmetry) of the standard-tanh functional form. This may be indicative of the analytically degenerate orthants produced by such forms. This is contrasted with the isotropic form examples, which retain a general continuous representational structure which becomes decreasingly discrete through training.

Furthermore, hot spots in isotropic representations are more generally angularly distributed and broader, without forming distinct geometries as in the anisotropic cases (such as the high densities along orthogonal directions). This may suggest that the distribution produced in isotropic networks more closely represents the natural structure of the dataset, as it is likely to have more varied angular clusters. Yet, overall, this demonstrates that the representations appear to be influenced by the symmetry structure of the functional forms.

Overall, these observed structures are consistent with the sign-flip and permutation (hyperoctahedral) symmetry of the standard basis, which defines the construction of these anisotropic forms. In contrast, the continuous orthogonal functional form yields a smoother, more continuous distribution. This may indicate that the maximal symmetry family is a useful predictor for some representational inductive biases. Comparisons between additional functions derived from each form can substantiate this connection, and this is undertaken in *App.* B.4. Furthermore, it suggests that symmetry taxonomies are potentially crucial to investigate in terms of interpretability, representational capacity, and resultant performance.

Finally, regarding the development through training, one may notice the absence of PPP method signatures for early training and initialisation of anisotropic networks only. This is not an absence of representations, but a relative underdensity compared to late-stage training plots.

This is due to the colour map chosen for the PPP method, which is calculated row-wise, such that all plots on the same row have identical colour map thresholds, enabling better comparison for structure development through training. However, in later layers, the clustering towards these discrete directions is so high that the relative densities in early plots are comparatively negligible and are therefore coloured black by the colour map. This was observed in the number of samples provided by the PPP method. For these plots, the typical number of samples that met the threshold was approximately 2000 for both early-layer anisotropic networks and all isotropic networks. However, for late-stage training in anisotropic networks, this typically increases by two orders of magnitude to around 200,000 samples, indicating that a great majority of representations align with the observed structure. In contrast, isotropic representations remain more evenly distributed throughout the space throughout training.

This shows that through training, anisotropic networks vastly increase in the number of representations aligned with these structures, offering an indication that functional forms can provide a *strong* inductive bias. This is corroborated by the isotropic networks, where the maximal density is significantly lower and consistent throughout training; therefore, early-training representations appear on the colour map. Furthermore, isotropy's more even utilisation of available space suggests representation capacity may grow exponentially with network width for isotropic models, whereas anisotropic networks often *tend* to have an aligned structure, which indicates a linear growth associated with a local coding. However, more complicated Superposed arrangements can improve this. This preliminary indication of exponential representational capacity of isotropy is discussed further in *App.* B.1.

With all these results, there remains the possibility that the anisotropic representations are connected outside of the thresholded region for the projection; however, this appears highly unlikely in two regards. First, it would seem rather unlikely that such an elusive connection would form in the exact perpendicular directions that the PPP method projects over. Moreover, the exceptionally high density of representations within these

discrete clusters in anisotropic rows would suggest that there are insufficient remaining samples to connect clusters outside of the projected volume. Overall, it seems prudent to conclude that the representations follow from the symmetry-defined form of these activation functions.

A final observation is that spontaneous symmetry breaking appears to set distinct directions early during training, and later training only subtly refines these directions. This indicates a strong dependence on initialisation in networks and supports considering the initialiser's probabilistic symmetry presented in the symmetry-based taxonomy (Bird, 2025a). These may also constitute inductive biases through interactions. Additionally, in the future, this could be explored in terms of whether isotropic networks have a slightly reduced dependence on initialisation, due to momentum enabling a traversal of identically flat connected basins along the symmetry group's orbit (Bird, 2025a).

All these observations remain pertinent to *Fig.* 2, which presents measurements from a similar, yet deeper, autoencoder model.

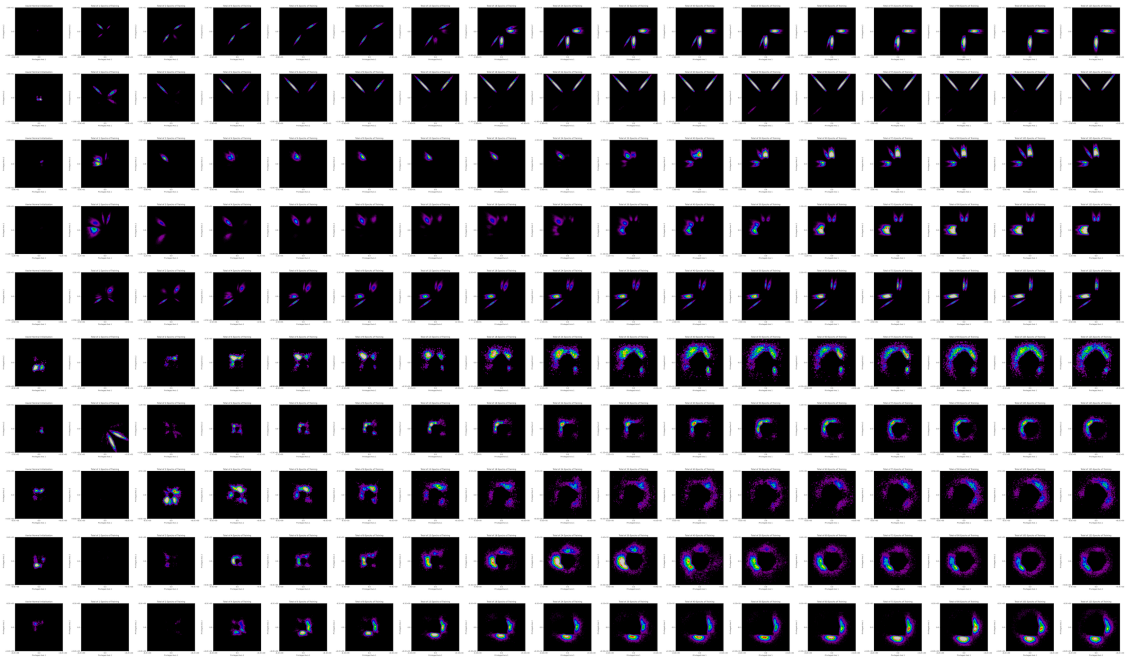

Figure 2: Displays an identical plot to *Fig.* 1, except for the results being drawn from a network with three latent layers, each with 18 neurons per layer. The latent layer studied is the first latent layer, which precedes any activation function.

This model notably produces more complicated discrete structures in anisotropic functional forms, indicating that more nuanced representational Superposition may be occurring due to the increased model depth. Additionally, the bottom five rows corresponding to isotropic functional forms have an increased amount of clustering compared to the previous, more uniform distribution of *Fig.* 1. This clustering is unaligned with the standard basis, particularly evident in rows 6, 8, and 9, with close inspection of rows 7 and 10 also revealing subtler misalignment. Together with slight clusterings in *Fig.* 1, this suggests that it is not due to an imposed structure from functional forms and is indicative of a desirable task-driven clustering.

This observation evidences that an isotropic network can still enable the phenomenon when beneficial. However, these clusters form a more general non-standard arrangement, suggesting that externally imposing discretisation along a standard basis, using contemporary anisotropic functions, may not be optimal. Additionally, the same networks were found to return to a largely smooth continuous distribution in subsequent latent layers, discussed further in *App.* B.3.

In the appendix results, there are instances where isotropic experiments display slight hotspots, which sometimes align or anti-align with the standard basis for isotropic networks. This would be surprisingly unlikely given an isotropy's uniform nature and is instead demonstrated to be a statistical artefact following further controls on experimentation in *App.* A. Namely, this is believed to be a statistical result due to averages over independent variables for anti-aligned positions, whereas averages over correlated variables for axis-aligned positions. The volumes about the distinguished vectors become overrepresented in the plot, due to the repeated intersection of privileged planes derived from the standard basis. Therefore, averages on these intersections display higher variability, due to the inapplicability of the regression-to-the-mean principle in dependent variables. Hence, under- or over-densities may be statistically more prevalent along standard basis directions, but this effect is typically subtle, although it can be observable. This appendix presents demonstrations of rotated measurement bases for identical isotropic models, which continue to display the phenomenon; therefore, it is deemed highly unlikely that persistent unintended anisotropies exist in implementations or true clusters. Instead, they are attributed to the statistical noise inherent to such conglomerated projection methods. This statistical noise may be skewing row 10 of *Fig.* 2 to appear slightly axis-aligned; alternatively, this could also be entirely coincidental to the experiment run. Nevertheless, the strong trend holds that function-derived symmetries act as inductive biases.

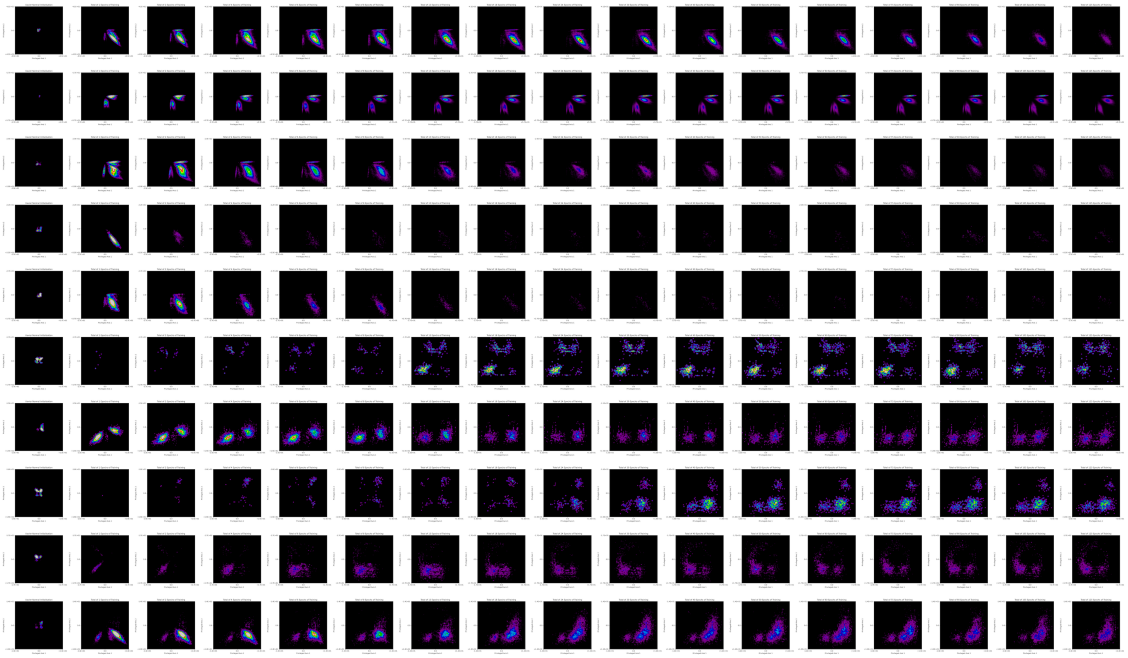

Figure 3: This plot displays identical networks, in every way, to *Fig.* 2, except from differing in the activation function applied. The top five rows utilise the standard Leaky-ReLU function, whilst the bottom five rows utilise an analogous isotropic Leaky-ReLU function, defined in *App.* B.4. Isotropic-Leaky-ReLU results appear more clustered, but don't present as discretised like the aligned representational rays in standard Leaky-ReLU. The slight alignments in isotropic examples is a statistical result, discussed in *App.* A.2, this is corroborated by further results in *App.* B.4 which mitigate the statistical phenomenon. Hence, one can conclude that standard Leaky-ReLU also induces a quantisation bias, whereas isotropic Leaky-ReLU does not.

Finally, *Fig.* 3, demonstrates a similar phenomenon in a comparison between standard Leaky-ReLU and isotropic-Leaky-ReLU functions — details of these functions and further tests can be found in *App.* B.4. Such results are significant, not only due to the ReLU family's higher prevalence than tanh in contemporary models, but also because they analytically differ from tanh in almost every regard, except for the underlying symmetry constructions. Therefore, the demonstration of quantising effects of these activation functions is highly indicative that it is the underlying algebraic symmetries which correspond to such an outcome. This isolates algebraic symmetry as a significant predictor of such phenomena, which is considered impactful for

interpretability and explainable AI approaches. Furthermore, each symmetry may correspond to a particular inductive bias, supporting the grouping of functions into taxonomic categories, which may aid in generalising the predicted emergent phenomena.

The alteration to Leaky-ReLU ensured that these effects aren't trivially due to bounding on the backwards pass either, since Tanh-like functions may produce geometric vanishing gradients in various shapes corresponding to forward-pass saturation. This is not the case for Leaky-ReLU, which is non-saturating and non-dying like ReLU. Hence, Leaky-ReLU differs in almost every property from tanh-like functions, besides the shared symmetry construction. This indicates that the symmetry group is responsible for such quantising effects on representations, and each carries an associated inductive bias. This is felt to be a significant development in representational geometry, elevating the importance of algebraic symmetries as a subject of study.

The appendices present a multitude of additional results for autoencoders of varying widths, depths, datasets, input-output normalisations, latent layer and activation-function dependencies. All of these indicate a similar general tendency towards task-agnostic structure in representations arising from the choice of functional form, particularly the algebraic symmetry involved. Moreover, they also suggest that geometries in representational superposition may be more likely a result of symmetry than the orthogonal to antipodal to Thomson geometries, which are suggested to balance representation capacity and interference (Elhage et al., 2022). This is because hyperoctahedral tanh forms continue to demonstrate orthogonal arrangements first, yet Leaky-ReLU permutation-only forms move immediately to antipodal arrangements *for the same task*. This would encourage a reconsideration of function-derived symmetries as the primary causal mode for the particular geometries produced, when balancing interference and representational capacity.

4 Conclusion

In this series of experiments, evidence is provided that functional form choices, namely anisotropic activation functions, can induce a representational collapse in latent layers. This establishes a causal mechanism for how task-agnostic structures can emerge in representations due to model choices, rather than emerging from deep learning more fundamentally.

In particular, this structure appears indicative of the maximal symmetry group to which the function algebraically belongs. This is achieved through comparisons of various activation functions with differing maximal symmetries, indicating that symmetry is the primary predictor, rather than the specifics of the chosen function. This empirically motivates a thorough investigation of all primitives in terms of their resultant inductive biases when interacting with general networks, previously encouraged in Bird (2025a).

Tanh-like activation functions are chosen in two ways. The first is when their form is defined through maximally satisfying a permutation and sign-flip algebraic equivariance of the standard basis, termed the hyperoctahedral group. This function definition results in representational clusters about standard distinguished directions, which accumulate through training, progressively approximating a discrete direction. Whereas, functional forms which maximally abide by an orthogonal algebraic equivariance produce apparent smooth continua of representations. This indicates that the hyperoctahedral *discrete* group is inducing an approximately-discrete structure to emerge in representation space, implying the functional form is acting as a quantising bias on the representations. A similar result is found for algebraic permutation symmetry standard Leaky-ReLU, which also produces a quantising bias, whereas isotropic Leaky-ReLU tends to produce smooth continua too. This is highly indicative of the algebraic symmetry corresponding to the bias, as opposed to solely function specifics, since Tanh-like and Leaky-ReLU-like functions differ substantially in analytical qualities. This empirically validates an earlier hypothesis (Bird, 2025a).

Moreover, these phenomena are demonstrated in autoencoders, where one might not typically expect a representational collapse to be beneficial due to information loss under such quantisation, which would further reduce information available for accurate reconstruction. This provides secondary heuristic evidence of the task-agnostic nature of this structure. This collapse persists in circumstances where the activation function does not precede the measured latent layer, so it is non-trivial in cause, such as from forward-pass geometrical boundaries.

Isotropic primitives are suggested to remove structural biases; this does *not* then imply that the representations must be isotropic, they merely do not tend to produce form-induced task-agnostic aligned structure to the distinguished directions. However, in the datasets studied, the isotropic networks did *tend* to form representations which smoothly filled the representation space; consequently, enabling a stronger conviction for the conclusions reached. Effectively, this was an incidentally ideal scenario for determining the validity of the hypotheses. Additionally, it is crucial to consider only the *tendency* of models to produce task-agnostic induced structure. Instances where other arrangements emerge do naturally arise, and this motivated the ensemble plots of repetitions to clarify.

Consequently, the empirical results strongly support the prediction that *choices in activation function form are not benign, but impart unintended inductive biases corresponding to their symmetry properties, which are sufficient in many cases to strongly influence representations*, confirming a previous prediction (Bird, 2025a). The phenomenon is expected to be systematic for more general anisotropic primitive forms, and follow-up studies can investigate this.

The empirical evidence thus far strongly suggests the link between algebraic symmetries and inductive biases on representations. If such a finding holds over further analyses and is determined to be generally valid over a broad scope of primitives and models, then one might conjecture that *algebraic symmetries of functions utilised in models tend to propagate their geometry into emergent representational structures through training* as a sort of principle for representational geometry. Despite the evidence of this paper, this general statement remains a tentative conjecture at the current time, requiring substantial further inquiry. Refinement of this statement and detailed mathematical modelling can continue to be evaluated. For example, this may not be expected to hold where the symmetry can not act on the network, such as in the case of algebraic end-to-end symmetries (Bronstein et al., 2021) which use it to transform representations with the data structure — unless this is reframed as a side-effect of such an inductive bias.

Additionally, combinations of network primitives are expected to exert influence on the representations of larger models, potentially in an interacting, non-trivial hierarchical manner. Understanding this is a pivotal goal of Taxonomic Deep Learning's approach (Bird, 2025a). This is partially demonstrated in the deeper models discussed in the appendices. Yet, overall, these potentially conflating and obscuring influences motivated the first-principles, minimalistic, and ablation-study approach undertaken in this paper, which isolates the cause to individual primitives in otherwise discretising bias-free autoencoders, as opposed to larger models.

This work also corroborates the findings from the Spotlight Resonance Method study (Bird, 2025b) and provides a more fundamental causal framework for its observed alignment phenomenon. Coupled with the findings of this prior study, this work suggests a function-driven, symmetry-based causal mechanism for the emergence of several interpretability phenomena, suggesting that they are predicated upon the contemporary anisotropic functional forms. This representational response to anisotropic functional forms appears to explain the downstream emergence of grandmother neurons, generally discrete linear features, axis-alignment, and the *representational* superposition of discrete features, amongst other phenomena. Hence, axis-alignment and grandmother neurons are shown to be phenomena stimulated by design choices, rather than being spontaneous and fundamental to deep learning as a paradigm. Whilst the other phenomena appear to be strongly dependent upon such choices. Overall, this strongly supports the emergence of axis-aligned findings that are frequently observed (Bau et al., 2017; Olah et al., 2019) and suggests that structural asymmetry in distributions can emerge, particularly from certain functional forms. This is considered as opposing evidence for representational uniformity (Szegedy et al., 2014). Together, these results may offer explanatory mechanisms to generalise to further representational geometry and interpretability phenomena.

The isotropic deep learning paper (Bird, 2025a) also predicts that this phenomenon extends to semantics. These results demonstrate the formation of approximately discrete representations, which, when combined with the spotlight resonance method's attribution of semantics to these representations, are considered to validate the semantic prediction too. An end-to-end analysis could also be undertaken in future work.

This direct mode for the formation of grandmother neurons is, at present, limited to deep learning and does not establish an empirical link to biological systems. Nevertheless, it could be used to formulate an interdisciplinary hypothesis.

In addition, the Privileged-Plane Projective method offers an alternative tool for determining alignment phenomena in representational spaces, while retaining both angular and radial information. This may be beneficial where visualisation of the distribution is desirable, but SRM may still be better suited to statistical analysis techniques.

Moreover, the prediction that isotropic functional forms eliminate task-agnostic discretising structure is validated (Bird, 2025a). The presence of such structure is also suggested to be often pathological (Bird, 2025a); preliminary results support this statement for autoencoding networks. Isotropic formulations are shown to enable the systematic elimination of these biases from a network, as the autoencoders tested featured entirely isotropic primitives, except for the activation functions. This establishes isotropies' inductive bias over a wider variety of primitives; follow-up can extend this for anisotropic networks by selectively reintroducing permutation-derived functions in other primitives.

Regarding informative future directions arising from this study: Establishing whether this phenomenon is systematic across other primitives and the hierarchical influence may enable a predictive approach to form-induced biases in deeper, general models. Gradient flow analysis will likely elucidate more details on how forms produce representational inductive biases, and their link to taxonomic-symmetry group structures, since the influence appears to persist non-trivially. Moreover, determining the emergent inductive biases of alternative symmetry-defined forms is speculated to be an informative avenue of research. This will indicate whether the maximal symmetry continues to be a good predictor of its emergent inductive biases and whether representational structure always follows from the symmetry group's structure. Other speculated pathological modes still require validation, such as whether the quantisation of anisotropic representations may produce untrained and unpredictable embedding-free regions, making this form of network particularly susceptible to adversarial attacks.

Additionally, this may suggest that interpretable models and AI safety are especially tractable due to anisotropic inductive biases. Thus, design choices between anisotropy, isotropy, or other definitions may allow tuning of models to balance these behaviours with representation capacity and performance — especially if the pathological nature is further validated. This provides a framework and implementable tunable mode, which earlier work encourages for greater interpretability and safety (Elhage et al., 2022). However, it would also suggest that representations generated from isotropic implementations currently act in opposition to the assumptions of many interpretability approaches. Heuristically, this indicates that isotropic networks yield more unconstrained representations, which are perhaps more natural or inherent to deep learning structures, as they are free from the human-imposed task-agnostic discretising structure produced by anisotropy. Yet, it is also often this discretising structure which is made interpretable when understanding AI mechanisms. Hence, bridging such an interpretability tool gap may be beneficial, and the PPP method offers a starting point.

The appendices present further results regarding the dependence on depth, width, dataset, activation functions and latent layer of study, all of which are found to be consistent with the validation of the hypothesis. It also includes a novel permutation and even-sign-flipped Leaky-ReLU alternative, which may be beneficial. Additionally, a GitHub link is provided for code implementations of the Privileged-Plane Projective Method.

Overall, this implicates discrete-permutation defined forms of activation functions, as stimulating a task-agnostic alignment about the standard basis, whilst continuous-orthogonal defined forms do not. This indicates that forms carry an inductive bias for representations, which appears to be indicative of the maximal symmetry group structure of the form. Activation functions are demonstrated as a direct causal mechanism for quantised representations, and several downstream emergent phenomena are established through connection to prior work (Bird, 2025b). Hence, this approach has established a causal origin for interpretable structure and several interpretability phenomena.

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A Statistical-Geometrical Artefacts

The Privileged-Plane Projective method can produce some minor statistical artefacts inherent in its construction. Notably, these artefacts can arise in the plots, which may be misleading without suitable controls. These occur through two modes, which tend to act in opposing ways. The first is the absence of a regression-to-the-mean phenomenon over privileged directions, which tends to under- or overrepresent projections in these directions due to greater variability. The second concerns how spontaneous symmetry breaking produces a slight tendency for anti-aligned representations to form under the projections of this method. The first phenomenon is particularly subtle in its effect and inherent to the methodology, yet it can noticeably persist throughout all results. It applies equally to anisotropic and isotropic networks, which, alongside its almost negligible subtlety, does not counteract any conclusions reached through the study — though it causally explains slight artefactual structure.

The second modality is more significant, but can be mitigated through appropriate normalisation, which is employed through all appendix results to remove the effect. Normalisation was not included in the main body, due to its slight contrivance; however, any stochastic pseudo-structure is inconsistent with the distinct opposing structures observed to emerge *through* training, which remain solely attributable to the functional forms exchanged. This latter artefactual structure also applies equally to both anisotropic and isotropic networks, further corroborating its lack of implication on the comparative conclusions reached. In addition, this is further mitigated by the breadth of results and numerous independent, repeated observations per plot, where true structure was repeatedly observed in distinct ways.

The following controls will demonstrate that these are pseudo-structures emerging from statistical artefacts, as opposed to true representational alignments.

A.1 Overrepresentation Artefacts

Fundamentally, the proposed method produces two-dimensional slices, projected from thresholded volumes, over a much higher-dimensional representational space. These high-dimensional spaces have a very large hypervolume; therefore, the projected planes typically do not intersect.

However, particularly for a standard basis, these planes do *repeatedly* intersect along standard basis vector directions. Due to the orthogonality of the standard basis, these overlaps also systematically accumulate in the vertical and horizontal regions of the plot. This is a geometrical and statistical consequence of such standard projections and the conglomeration of data over multiple planes. This means that the same representations within certain angles about distinguished directions get repeatedly projected into the PPP slice in these regions. If distinguished directions have a slight under- or over-density stochastically in these regions, then their effect can be amplified. In comparison, other areas in the conglomerate plot are measured over many differing hypervolumes of the larger space. This tends to suppress fluctuations through a regression-to-the-mean phenomenon, due to differing effective sample sizes.

This is believed to be an inescapable and inherent statistical phenomenon when conglomerating multiple planes derived from standard distinguished directions. This can produce misleading results stochastically, but the effects were mitigated in the results by demonstrating a breadth of various networks and repeats, allowing a more holistic interpretation and conclusion.

In this section, this geometrical phenomenon will be demonstrated. This can be achieved by performing the PPP method over random samples drawn from a standard multivariate normal distribution, whilst also choosing random orthogonal bases from which to compute PPP uniformly distributed over the $\mathfrak{so}(n)$ manifold. The repeated occurrence of slight clusters over repeatedly chosen random bases is indicative of a statistical artefact, as the underlying distribution is known to be probabilistically invariant over the orthogonal group, and similarly for the studied basis. A statistical model of such clusters may be an advantageous pursuit in future, particularly for the similar SRM method.

In *Fig.* 4, one can see that clusters about the distinguished directions are frequent despite the known approximate isotropic uniformity of the data. This is indicative of a statistical artefact which may occur, particularly when the PPP threshold provides fewer samples. This discrepancy between anti-aligned and

aligned over- and under-representations is not resolved by averaging over multiple plots or increasing the sample size; however, the disparity between regions will decrease as they converge to the mean at differing rates.

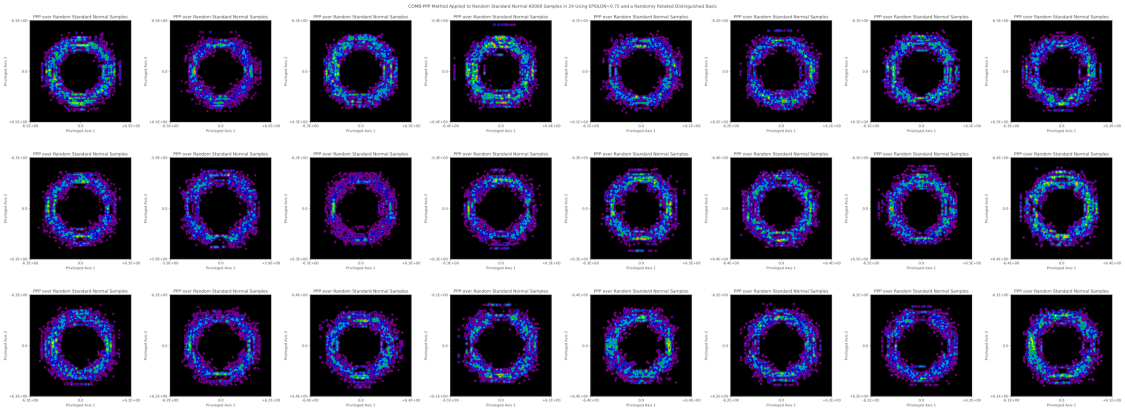

Figure 4: Displays the combination PPP-method applied to 60000 samples (identical to CIFAR training set size) drawn from a multivariate normal and applied using a random orthogonal basis. A value of $\epsilon = 0.75$ and 24 neurons was chosen to make them comparable to all other results. Each individual plot shows a different random initialisation of both samples and basis. Zero-indexed by (row, column), one can observe axis-aligned underrepresentations, particularly in plots (1, 1), (2, 6), and overrepresentations, particularly in (1, 4), (2, 4), (2, 7), and (1, 0). Yet, it is known that higher-dimensional samples are approximately angularly uniform; therefore, this is a geometrical and statistical artefact resulting from the projection method collated over multiple planes.

Finally, one might note that straight lines occur in the plot, especially clear at larger absolute values of the projection. These may suggest a rotational asymmetry, but actually represent a single representation which aligns closely to a distinguished vector. Due to this proximity, it is reprojected along multiple privileged planes, accounting for the occurrence of the same absolute value along one axis, producing the observed straight lines.

Overall, these phenomena are slight, and the weak density peaks are wholly insufficient to produce the more extreme alignments repeatedly measured in anisotropic networks. Hence, they are deemed negligible in effect and do not change conclusions drawn regarding quantisation due to functional form inductive biases. Moreover, the same phenomenon will occur in an equal stochastic manner between both results, so it does not account for the stark differences observed between anisotropic and isotropic networks.

However, awareness of them is essential to avoid misinterpreting the presence of true structure in more rotationally uniform distributions. This phenomenon is believed to wholly account for slight alignments (overrepresentations) or slight anti-alignments (underrepresentations) that are otherwise unexpected, such as in isotropic plots. This phenomenon becomes increasingly apparent in higher-dimensional spaces due to the typically sparser density of isotropic distributions, resulting in fewer samples provided by the PPP method. Additionally, permutation-PPP has a higher susceptibility due to increased overlap over these directions, which constitutes the preference for combination-PPP in these results. Additionally, combination-PPP can indicate remaining asymmetries in distribution, which permutation-PPP symmetrises out.

Finally, statistical analysis of this phenomenon is complicated due to the dependence on the basis, ϵ-threshold, and closed-form volumes for hyperspherical segments and general hypervolumes of such shapes. Although it would be a prudent future direction if found to be statistically tractable, this is currently a challenge.

A.2 Spontaneous Symmetry Breaking Artefacts

An additional statistical artefact can emerge in the PPP plot, dependent upon the dataset's subspace. This was initially observed in freshly initialised plots, which prompted further study.

Often, one might expect representations to be isotropically distributed on a fresh initialisation of the model, especially if a left- and right-flavour probabilistic invariant initialiser (Bird, 2025a) is employed. However, spontaneous symmetry breaking upon choosing a particular initialisation can produce artefactual geometry due to a dataset's subspace.

Since biases are initialised to zero, these initialisations produce linear, not affine, maps[5]. If a dataset is strongly anisotropic, such as being situated in a $[0,1]^{28\times 28}$ subspace, then when it is randomly embedded, it has a larger chance that specific directions are measured to have an anisotropy. For example, where the $\vec{1}$ becomes embedded will be angularly denser in representations than where any $\hat{e}_i$ is embedded. These embedded representational anisotropies often occur anti-aligned due to the small chance of spontaneously aligning precisely with the distinguished directions for the plot.

This is displayed in *Fig.* 5. This plot uses data which is drawn uniformly from the $[0,1]^{32\times 32\times 3}$ space, which is then embedded in a $\mathbb{R}^{24}$, intended to mimic similar conditions to the CIFAR plots, using a linear transform initialised using a random standard multivariate normal. One can see a clear tendency towards anti-aligned artefactual anisotropies resulting from the spontaneous symmetry-broken embedding and the dataset's bounds. This may give the false impression of model-imposed anisotropy, which requires mitigation.

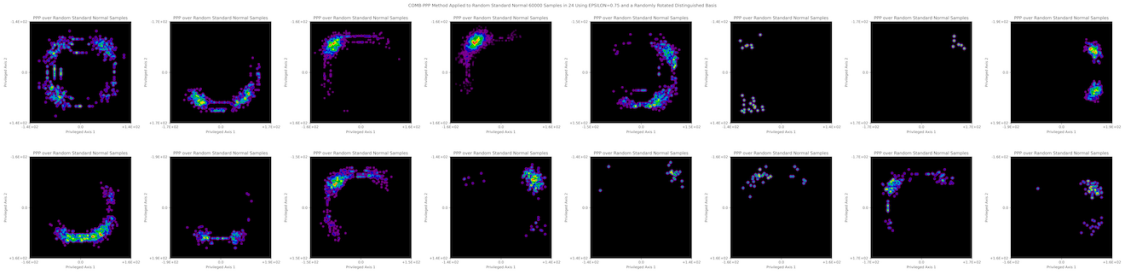

Figure 5: Each individual plot displays an independent instance of a combination-PPP $\epsilon = 0.75$ plot, of 60000 uniformly drawn samples from $[0,1]^{32\times 32\times 3}$, which are embedded in $\mathbb{R}^2 4$ using a linear map randomly drawn from a standard normal. Additionally, a random orthogonal distinguished basis was used for PPP, which was freshly sampled for each plot. One can observe a tendency towards strongly anti-aligned clusters due to the geometry of the stochastic dataset, map and PPP method. These artefactual clustered structures can be a more significant issue for interpreting PPP plots; therefore, the underlying dataset warrants normalisation efforts for better analysis and stronger conviction in conclusions. Additionally, these clustering artefacts remain inconsistent with the emergence of the highly concentrated narrow beams, which emerge through training in prior results.

The expectation is that if the dataset distribution is rescaled, it will more closely approximate a standard normal distribution while retaining its dataset's relative structure. Such distributions may reduce this artefactual structure in plots. Particularly from the overrepresented $\vec{1}$ direction, in $[0,1]^n$ bounded samples relative to the origin.

This was achieved by element-wise normalisation of samples by statistics obtained across the entire dataset. For a dataset of size $\mathbb{R}^{\text{samples}\times\text{dimension}}$, a mean value was calculated $\mu \in \mathbb{R}^{\text{dimension}}$, likewise for the standard deviation. Each sample was then consistently normalised using these tensors, elementwise subtraction of the mean and division by the standard deviation. Where the standard deviation was zero, that element was instead divided by 1 without consequence. Overall, the representational effect on manifold structure were considered negligible $f_{\text{norm}} : \mathbb{R}^{\text{samples}\times\text{dimension}} \to \mathcal{S}^{\text{samples}-2} \times \mathbb{R}^{\text{dimension}} \hookrightarrow \mathbb{R}^{\text{samples}\times\text{dimension}}$. Similar may be achieved by monotonically remapping the hypercube to an origin-centred hypersphere. Normalising by covariance was also considered but found to be infeasible due to the production of singular matrices, which prevented the calculation of inverses; therefore, only standard variances were normalised.

The plot of *Fig.* 6 is constructed identically to *Fig.* 5, yet the samples are normalised first.

[5]The success in this form of bias initialisation could be reconsidered and freshly explored under the lack of symmetry breaking perspective developed under the wider taxonomy (Bird, 2025a).

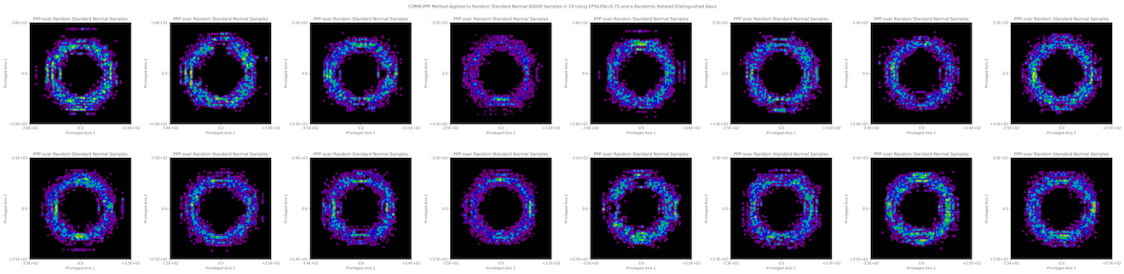

Figure 6: Each individual plot displays an independent instance of a combination-PPP $\epsilon = 0.75$ plot, of 60000 uniformly drawn samples from $[0,1]^{32\times32\times3}$, *which are then normalised as described*, following this the samples are embedded in $\mathbb{R}^2 4$ using a linear map randomly drawn from a standard normal. Additionally, a random orthogonal distinguished basis was used for PPP, which was freshly sampled for each plot. This plot demonstrates that samples are much more uniformly distributed rotationally when using the PPP method, strongly mitigating the discussed statistical artefacts. Despite the normalisation, infrequently, due to the embedded hypercuboidal distribution, slight artefactual structures persist. Additionally, one can observe the reemergence of slight clusterings resulting from the phenomenon discussed in *App.* A.1.

Despite their remaining hypercuboidal bounding, these results are much more comparable to a known embedded isotropic distribution, displayed in *Fig.* 7, which is similarly constructed, but the original samples are drawn as a standard multivariate normal over a $\mathbb{R}^{32\times32\times3}$ space and then embedded in $\mathbb{R}^{24}$ using a similarly drawn linear map. Hence, this justifies the normalisation employed in many of the appendix results.

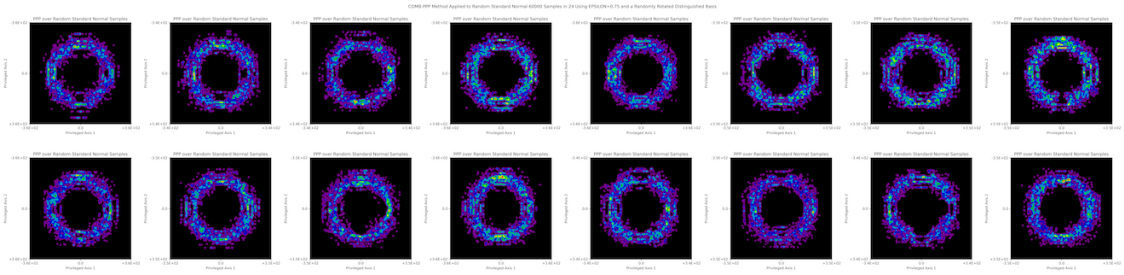

Figure 7: Each individual plot displays an independent instance of a combination-PPP $\epsilon = 0.75$ plot, of 60000 uniformly drawn samples from $[0,1]^{32\times32\times3}$, *which are then normalised as described*, following this the samples are embedded in $\mathbb{R}^2 4$ using a linear map randomly drawn from a standard normal. Additionally, a random orthogonal distinguished basis was used for PPP, which was freshly sampled for each plot. One can continue to observe the slight clusterings resulting from the phenomenon discussed in *App.* A.1.

Overall, this statistical phenomenon can be more significant than the one discussed in *App.* A.1, and hence warrants normalisation efforts to mitigate such artefacts and establish better certainty in conclusions.

This approach constitutes the majority of the results in the appendices. However, such normalisation was also perceived as an unusual imposition on the data, so the results of the main body do not display this normalisation to ensure they do not appear as contrived. Moreover, the phenomena which are concluded to occur from functional forms persist whether normalisation is used or not, though normalisation aids in a higher certainty for the conclusions drawn.

An observation of a slight impact was noted: networks trained on samples without normalisation were found to tend to produce slightly more concentrated clusters, likely due to the somewhat different training dynamics and optimisation trajectories resulting from the absence of normalisation. Such a difference may be insightful in determining the exact mechanisms through which algebraic bias induces representational structure through optimisation. Despite imparting some effect, the highly localised structures observed were unique to anisotropy; moreover, their concentration and diffusion through training for anisotropy and isotropy,

respectively, are not consistent with any statistical artefacts, but instead remain highly consistent with the conclusions drawn, supported by all appendix results. Since this pseudo-structure effect persists across both anisotropic and isotropic plots in an equal stochastic manner, it cannot account for the distinct difference observed between the ablations, which is therefore solely attributable to the functional form change. Hence, it does not alter the validity of the conclusions drawn, but instead offers further insight into altered training dynamics due to normalisation.

Overall, in all cases, statistical pseudo-structure is an insufficient explanatory mode for the comparative observations across the ablation structure. Hence, the induced bias by functional form remains the only consistent explanatory mode for the results.

B Extra Tests

The prior results exemplified how functional form choices influence representations. In this section, comparisons are made between autoencoders of varying depths, widths, dataset reconstructions, and activation functions, as well as how representations evolve through sequential latent layers. This highlights nuances of their structure, including indications of representational capacity, such as how isotropic networks appear to embed across the entire representational volume. All results undertaken were normalised as described.

Due to space restrictions, these image sizes are noticeably compressed, as otherwise it would have made the addition of many further results infeasible to include within this document. However, headings and axes titles remain consistent with prior figures, and all notable representational details across all plots remain visible. The examples shown are representative of this broader array of results.

B.1 Dependence on Network Width

Varying the autoencoder's layer width across all hidden layers tends to produce distinct changes in the representations.

Typically, one might expect the representations to become sparser as network width increases. This may be expected as hypervolume grows exponentially with width. Hence, for the fixed sample size of 60000 for CIFAR's training set, the density of representations might be expected to decrease; therefore, fewer representations may appear within PPP's projective hypervolume.

However, crucially, this was observed only in isotropic networks; whereas, anisotropic networks tended to produce denser distributions concentrated about the distinguished directions. This can be seen through plots *Fig.* 8 (18 neurons), *Fig.* 9 (24 neurons), and *Fig.* 10 (32 neurons). This was a frequently observed behaviour over many networks.

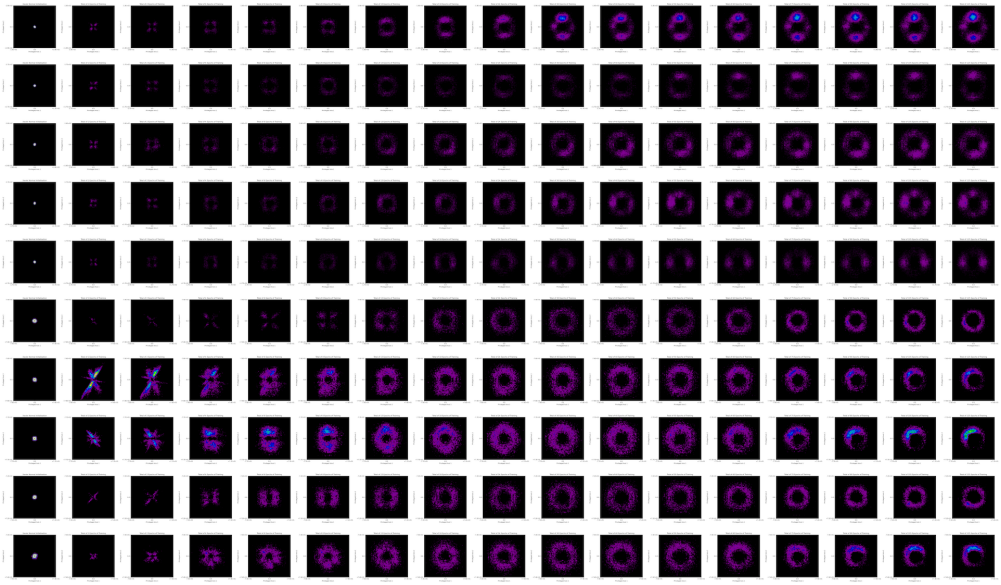

Figure 8: This network shows the PPP method applied over networks of 0 hidden layer blocks, 18 neurons and using input-output normalisation as described in *Apps.* A and D. The top five rows consist of the standard-tanh autoencoders, whereas the bottom five rows utilise isotropic-tanh. Everything else is equal between plots. Training proceeds rightwards over columns, in identical fashion to *Fig.* 1. Overall, this plot shows that anisotropy tends to result in the emergence of axis-aligned representation clusters, including several instances of apparent antipodal alignments. Whilst isotropic examples do not produce such a structure and tend to be more evenly distributed. It can be seen that under normalisation, there is a tendency for more diffuse clusters in anisotropic results, particularly evident in narrower networks.

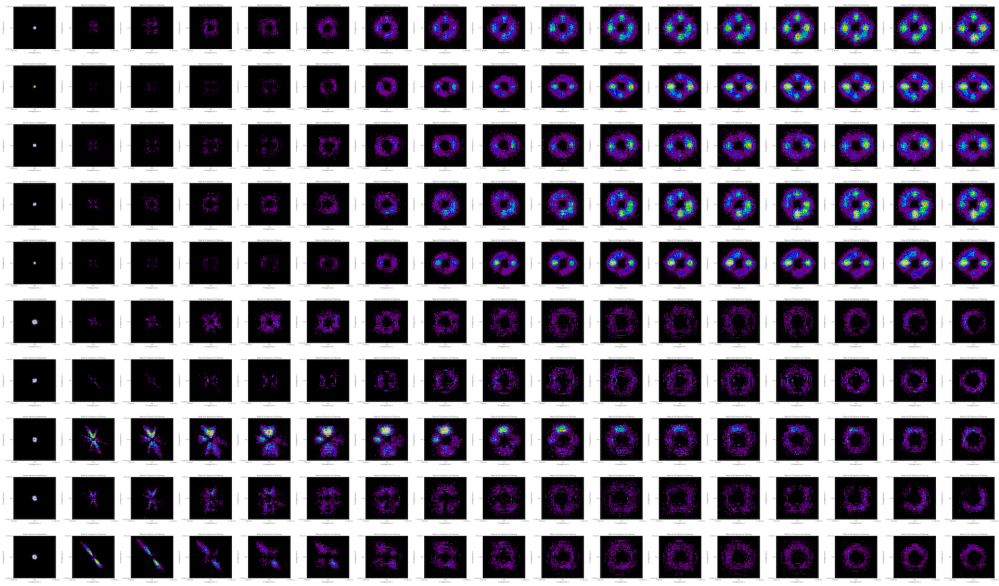

Figure 9: Similarly this network demonstrates identical setup to *Fig.* 8; however, it depicts all phenomena for networks with a width of 24 neurons. The production of axis-aligned structures in anisotropic networks is considerably more distinct, indicating that representations produce denser clusters along the distinguished directions as the width increases. Isotropic networks are noticeably sparser in representations, indicating that they are more smoothly distributed over the considerably larger angular surface in 24 dimensions as opposed to 18 dimensions. Due to this sparsity, a higher prevalence of *App.* A.1 occurs, likely resulting in the difference in row 8. Normalisation appears to again produce a more diffuse fall-off in the alignments compared to the sharper clusters in its absence.

This suggests that isotropic networks tend to occupy the entire representation space following a bottleneck, whereas anisotropic networks tend to cluster primarily along the axes. This is preliminary evidence that isotropic networks tend towards a continuous distributive code, whereas anisotropic networks tend to approximate a discrete local code. Correspondingly, this would suggest that anisotropic networks are producing dense clusters in approximately $2n$ directions for n-neuron width, whereas isotropic networks are distributing representations over $\propto e^n$ hypervolume.

This might be limited to autoencoding bottlenecks, yet it can be hypothesised that a subspace would be more evenly occupied for isotropy whenever a representational space is increased in volume, too. One might investigate whether functions which include non-monotonic foldings may then gradually fill such a volume, approximating space-filling curve behaviour. In either case, this is indicative of a significantly increased representation volume and a very different approach by isotropic networks to balancing the interference-capacity tradeoffs; finding ways to leverage such encoding may be highly beneficial — perhaps particularly in generative modelling. Additionally, for very narrow networks, such as 12 neurons, some results showed anomalously few representations produced by the PPP method in anisotropic networks, even sparser than isotropy. This is indicative of a repulsion from the distinguished directions rather than attraction to them. The latter is typically observed in wider networks. **This is speculated to be likely due to the production of a dense-coding-like representation, which the network may produce to inflate representational capacity in particularly narrow architectures — a network adaptation to strong bottlenecks when also constrained by a form's symmetry.**

Overall, the indication of isotropy producing distributed representation has potentially very significant ramifications for representational capacity and requires further study, especially for architectures which may leverage it. These networks may be able to represent underlying continuous data much more effectively without task-agnostic imposed quantisation. This may be beneficial in preserving data structures in models and indicates that increasing width may compensate for anisotropic's quantised representations. These

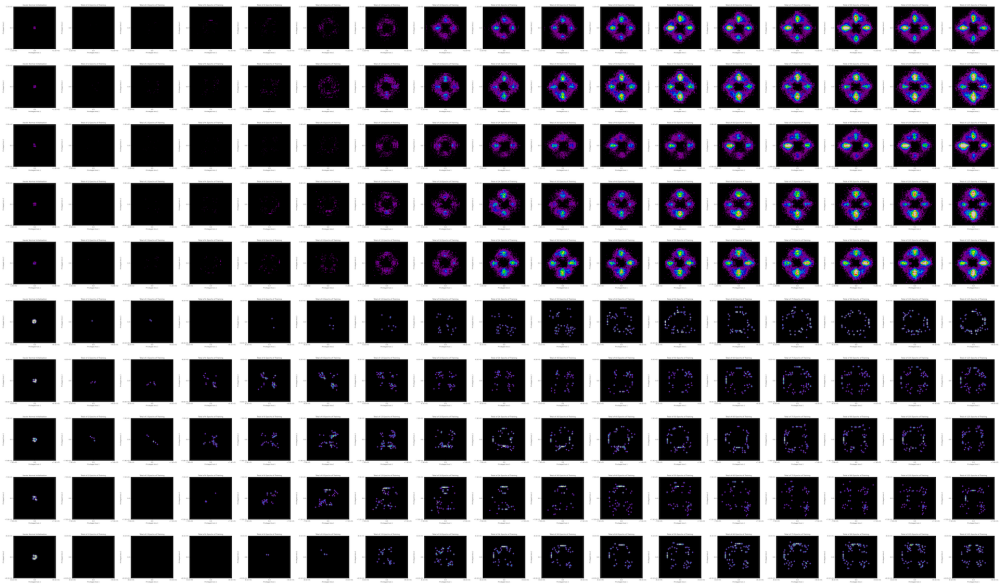

Figure 10: Finally, this network demonstrates an identical setup to *Figs.* 8 and 9; however, it depicts all phenomena for networks with a width of 32 neurons. The anisotropic results appear more sharply peaked about the distinguished directions than *Figs.* 8 and 9, especially if plots are overlaid. The aforementioned fall-off about the strong alignments appears to be shrinking slightly with width. This indicates an even greater density of representations moving towards these directions through training. All plots are the 0th latent-layer, without preceding activation functions, so this is non-trivial in effect. Furthermore, the contrast in sparsity between anisotropic and isotropic networks is very distinct, indicating the isotropic network's tendency to distribute evenly across the full representation space. Additionally, all results demonstrate that the scale of representations increases as training progresses.

continuous representations by isotropic networks may also aid in tasks that require modelling of a distribution, such as for generative applications.

B.2 Dependence on Autoencoder Depth

In many results, the dependence on depth is less conclusive. There appears to frequently be a trend where deeper networks produce more complicated structures in representations, particularly in isotropic networks, but these observations are less clear in trend. Additionally, sometimes in deeper networks, the 0th layer results demonstrated less anisotropic clustering than shallower networks; yet, clustering still emerged deeper into latent layers, making disentanglement of trivial and non-trivial causes difficult in these specific cases.

Results indicating the emergence of more complicated embedding structures are demonstrated in *Figs.* 11, 12 and 13. These results correspond to identical networks that differ only in the number of hidden layer blocks, specifically 1, 2, and 3 blocks, respectively. In all cases, the 1st latent layer is measured.

Overall, these results suggest, as may be expected, that depth produces more nuanced representational clusters indicative of the greater expressibility of deeper networks. Yet, in all cases, comparing anisotropic to isotropic activations indicates a difference in the presence of structure.

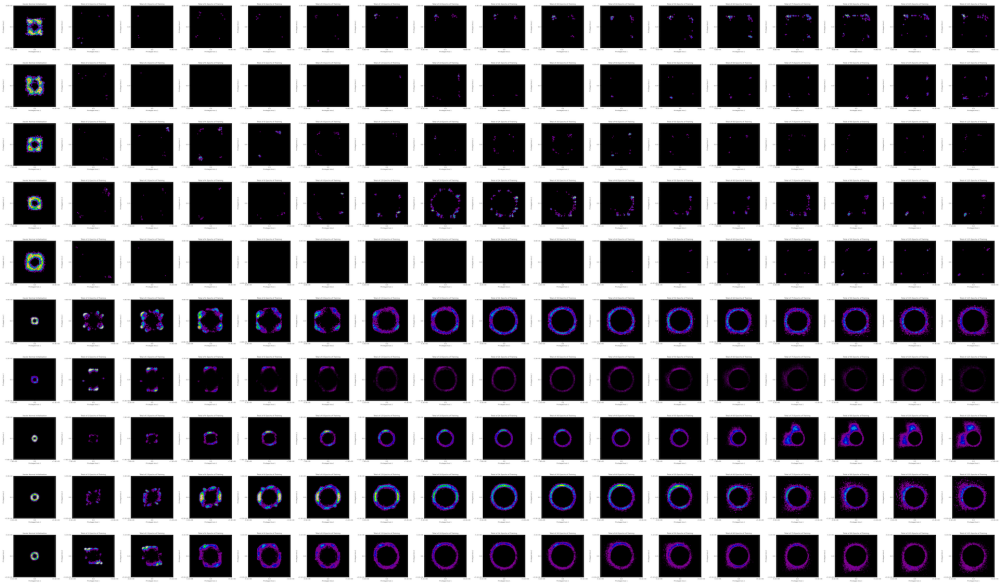

Figure 11: This network shows the PPP method applied over networks of 1 hidden layer block, 18 neurons and using input-output normalisation as described in *Apps.* A and D. The top five rows consist of the standard-tanh autoencoders, whereas the bottom five rows utilise isotropic-tanh. Everything else is equal between plots. Training proceeds rightwards over columns, in identical fashion to *Fig.* 1. It is evident from this plot that the bottom-five isotropic networks tend to produce a smooth, continuous-like distribution of representations. The top-five anisotropic plots indicate the emergence of structure tending to be anti-aligned to the standard basis. This is more sparse, even than the uniform isotropy, likely since many representations are producing narrow anti-aligned beams in the anisotropic case. The PPP method is likely only capturing the more diffuse tail of such a cluster due to the $\epsilon = 0.75$ thresholding, which is significantly more stringent than $2/\sqrt{18 \times 2}$ required to include anti-aligned diagonals. Overall, this suggests the anisotropic networks are producing an anti-aligned structure consistent with a dense-like code.

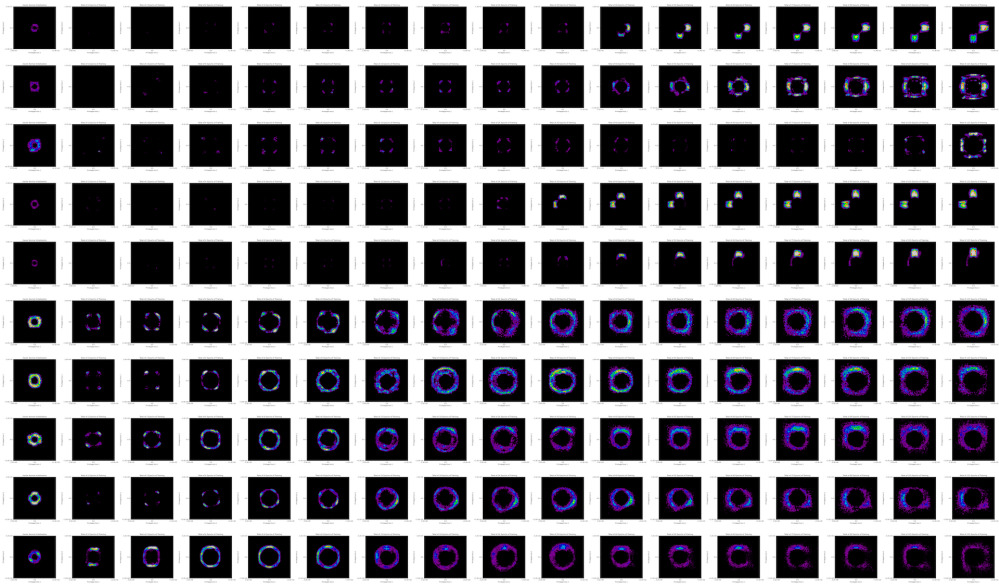

Figure 12: This plot is identical in every way to *Fig.* 11, except for the network comprising of 2 hidden-layer blocks. Anisotropic networks are shown to exhibit a more pronounced axis-aligned structure, frequently comprising of orthogonal directions across all conglomerated planes. This differs from the isotropy plots, which demonstrate a more continuous distribution. In these plots, slightly clearer divergences in dense representations and double-rings are observed compared to the simpler ring distributions in *Fig.* 11. This indicates depth corresponds to more nuanced representations, as may be expected. Rows 2 and 3, for anisotropy, indicate a more complicated structure, which is more diffuse than the typical discrete-like representations, but still demonstrates a clear axis-aligned structure.

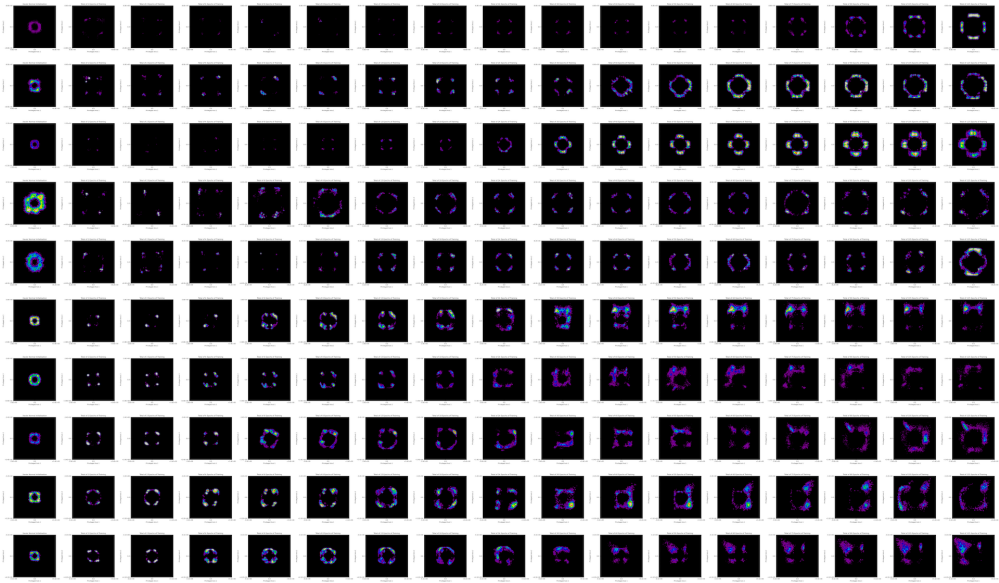

Figure 13: This plot is identical in every way to *Figs.* 11 and 12, except for the network comprising of 3 hidden-layer blocks. The anisotropic structure in the top five rows is more pronounced, with denser regions of representations in anti-aligned and aligned directions. Most interestingly, the isotropic plots show significantly nuanced structures compared to the previous, more ring-like representations. Several denser clusters are shown to form, but in a non-axis-aligned manner. The slightly anti-aligned structure is likely statistical in nature, as indicated by its presence in initialisations.

B.3 Dependence on Latent Layer of Study

Analysis of different latent layers indicates a tendency of isotropic networks to produce representations that become progressively more continuous in later latent layers, whilst the opposite was found for anisotropy. This is demonstrated in *Figs.* 14, 15, 16, and 17, which indicate the exact same networks, with PPP performed at various latent layers.

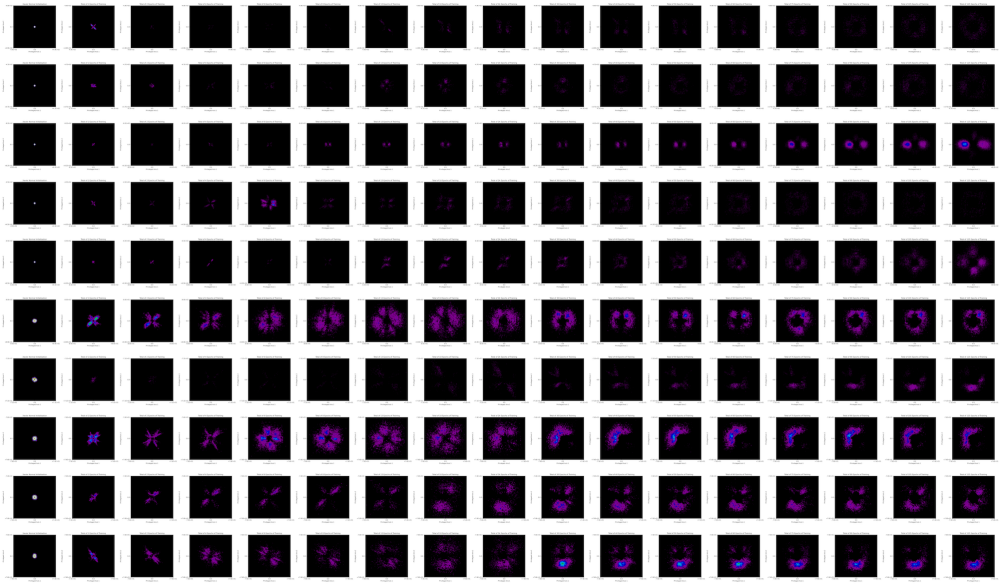

Figure 14: This network shows the PPP method applied over networks of 3 hidden layer block, 18 neurons and using input-output normalisation as described in *Apps.* A and D. PPP was applied to the 0th hidden layer. The top five rows consist of the standard-tanh autoencoders, whereas the bottom five rows utilise isotropic-tanh. Everything else is equal between plots. Training proceeds rightwards over columns, in identical fashion to *Fig.* 1. One can observe that representations are absent in anisotropic rows 1, 2, and 4, likely a result of anti-alignment, whereas some axis-aligned structure is present in rows 3 and 5. Isotropic rows demonstrate larger, more continuous representational structures, but also demonstrate clustering such that they are not distributed smoothly over the representation space.

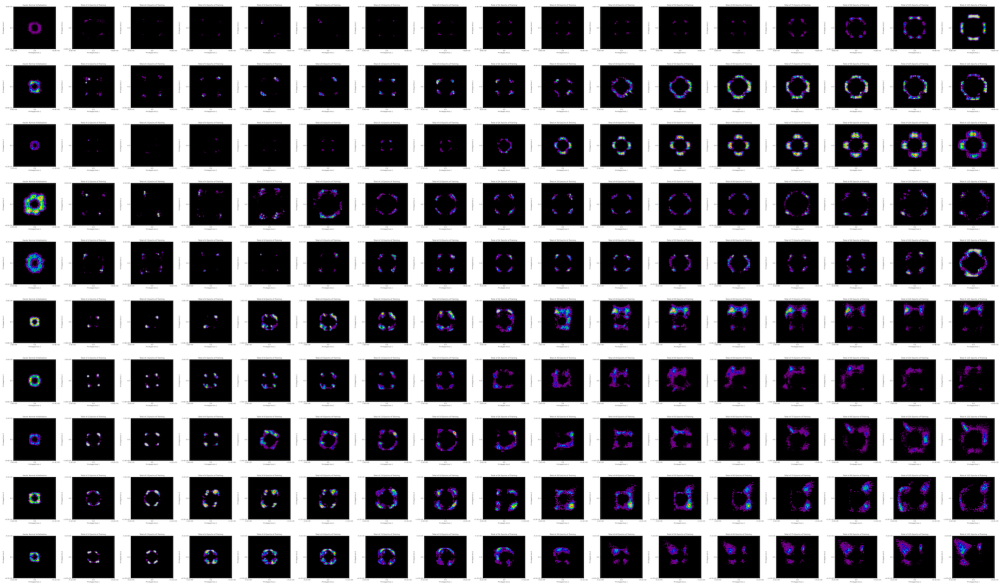

Figure 15: The results are identical to *Fig.* 14, yet demonstrate the PPP method on the 1st latent layer of the three blocks. Each row corresponds to the exact same network as *Fig.* 14. One can observe more distinct alignment structures emerging in all anisotropic rows through training; these structures are slightly more complicated than previous examples, likely due to the deeper network employed. Isotropic networks also demonstrate slightly more diffuse representations than the earlier latent layer, and some divergence consistent with the greater depth of the network.

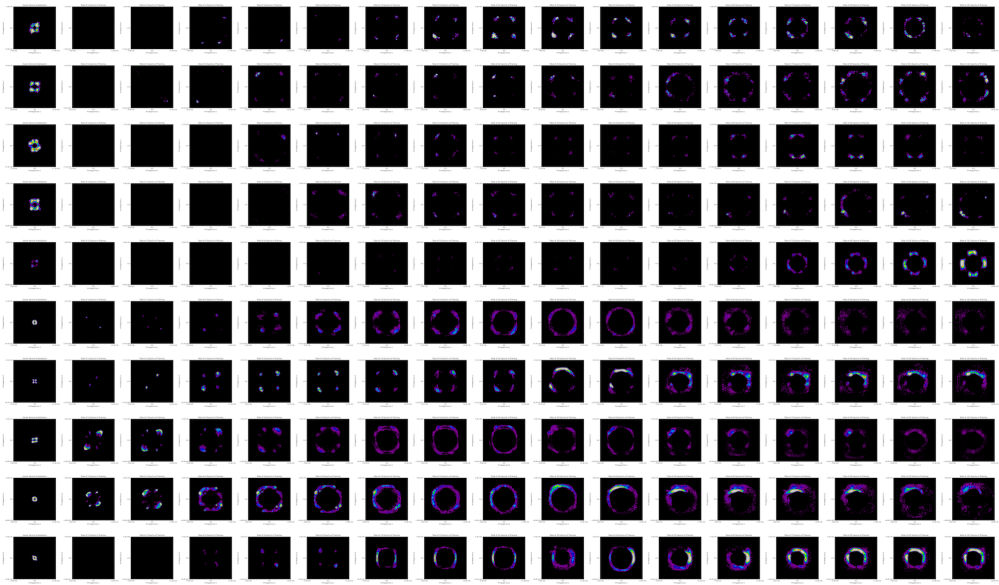

Figure 17: The results are identical to *Fig.* 14, yet demonstrate the PPP method on the 3rd latent layer of the three blocks. Each row corresponds to the exact same network as *Fig.* 14. Anisotropic structure is again present in the top five rows, yet slightly more diffuse than the previous latent layer. This diverges from the previously discussed observed trend regarding the concentration of anisotropic representations over deeper layers. The isotropic examples appear more uniform with only slight clustering, continuing the trend that later latent layers tend to be smoother for isotropic examples.

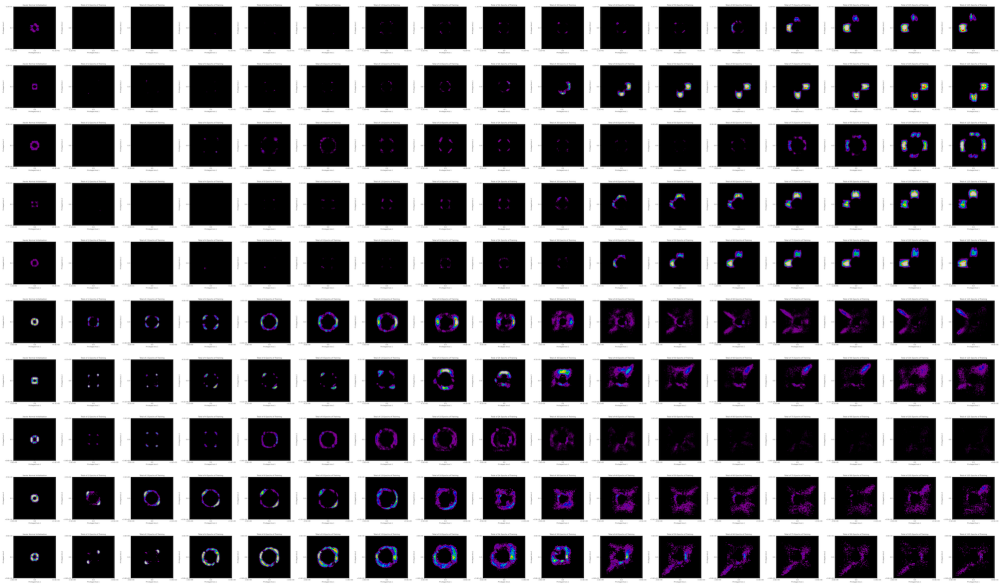

Figure 16: The results are identical to *Fig.* 14, yet demonstrate the PPP method on the 2nd latent layer of the three blocks. Each row corresponds to the exact same network as *Fig.* 14. In the anisotropic rows, even more distinct axis-aligned structures emerge, resulting in approximately discrete representational structures. An increasing number of representations appeared in these discrete directions as training progressed, and a greater amount compared to earlier latent layers in the model. Isotropic networks also tended to form more continuous representations, yet row six in particular demonstrated more quantised directions forming later in training. This indicates that isotropy can still occasionally produce such clusters without a function-driven bias, particularly emerging in deeper networks. The anti-aligned nature is also likely a result of *App.* A.2, which can reemerge when the distribution becomes uneven in deep latent layers, as inter-layer normalisation is not used. Nevertheless, there continues to be a stark difference between the structure present in the anisotropic rows compared to the isotropic rows.

Overall, in many networks tested, anisotropic structure appeared progressively clearer and denser in later latent layers, whilst isotropic networks tended to produce progressively more continuous distributions in later latent layers. This seemed to be a trend across many of the networks studied, but sporadic network-to-network differences also occurred. This may be due to the increased number of an/isotropies in the forward pass or indirectly through the backwards pass, yet further study may elucidate the exact reason why progressively clearer structure may emerge in later layers.

B.4 Results for Leaky-ReLU

Except for *Fig.* 3, all comparisons have been concerning Tanh-like functions. These have clearly demonstrated the tendency for task-agnostic structure to occur in anisotropic cases, whilst more continuous representations tend to form in isotropic variants.

Using 0th latent layers, the experiments have also demonstrated that these effects are not trivially due to forward-pass saturation geometry, yet backwards pass vanishing-gradient geometry has not been ruled out, except for *Fig.* 3.

In this section, Leaky-ReLU-like functions will be compared to demonstrate that these quantisation phenomena are not unique to the Tanh-like cases. Moreover, except for an underlying symmetry connection, Leaky-ReLU-like and Tanh-like functions are substantially different analytically. For example, Leaky-ReLU is piecewise linear, so it does not saturate or produce gradients which tend to zero[6]; therefore, geometries due to these can be ruled out. Thus, an investigation using Leaky-ReLU can isolate and establish that the symmetry relations are the likely cause of such a structure, rather than the specifics of the chosen function.

In this section, the standard Leaky-ReLU, shown in *Eqn.* 6, is compared with its isotropic counterpart, shown in *Eqn.* 7 (Bird, 2025a).

Namely, standard Leaky-ReLU features an algebraic permutation (S_n) equivariance, whilst isotropic-Leaky ReLU is defined from an algebraic orthogonal ($\mathrm{O}(n)$) equivariance.

$$\mathbf{f}\left(\vec{x};\{\hat{e}_i\}_{\forall\hat{e}_i}\right)=\sum_{i=1}^{n}\max\left(\alpha\vec{x}\cdot\hat{e}_i,\vec{x}\cdot\hat{e}_i\right)\hat{e}_i \tag{6}$$

$$\mathbf{f}\left(\vec{x}\right)=\begin{cases}\alpha\vec{x} & : \quad \|\vec{x}\|<\varepsilon\\ \vec{x}-(1-\alpha)\,\varepsilon & : \quad \|\vec{x}\|>\varepsilon\end{cases} \tag{7}$$

The permutation symmetry of standard Leaky-ReLU subtly differs from that of standard tanh. Standard tanh is equivariant under both permutation and component sign-flips, termed a hyperoctahedral symmetry (B_n), whereas standard Leaky-ReLU is only equivariant under permutation (S_n). Differences in quantised structure may be indicative of such differences between symmetry groups obeyed by the functional forms.

In all the following results, the experiments continue to use normalisation, as in all appendix results, to mitigate statistical effects discussed in *App.* A. Whereas, an unnormalised case is displayed in *Fig.* 3.

In all cases, $\alpha = 10^{-2}$ is used, as is the default in PyTorch for standard Leaky-ReLU. The radius of the isotropic-ball threshold was set at $\varepsilon = 1$ as a completely arbitrary and non-optimised choice — refinement or parameterisation (especially in a smoother function) of this value may be beneficial in practice.

The following results demonstrate the effect these functions have on representation distribution, followed by commentary on how each representation may be influenced by the algebraic equivariant symmetry through which the function was defined.

To begin, all Leaky-ReLU results also show distinct quantisation in the 0th layer, *Figs.* 18 and 19 are representative of this trend.

It is clear from both examples that the conclusions reached from tanh-like experiments are consistent with those in these Leaky-ReLU-like experiments. There is a clear emergence of structure in activations defined through a discrete permutation symmetry, whereas this task-agnostic structure is not present in the isotropically defined functions. Therefore, the symmetry classification seems to be the predominant cause of such quantisation behaviour within networks. Additionally, both of these figures are produced from PPP operating on the zeroth layer — so the effect is non-trivial.

[6]Leaky-ReLU was used as opposed to ReLU to also rule out the zero-gradient 'dead-neuron' geometry as the cause.

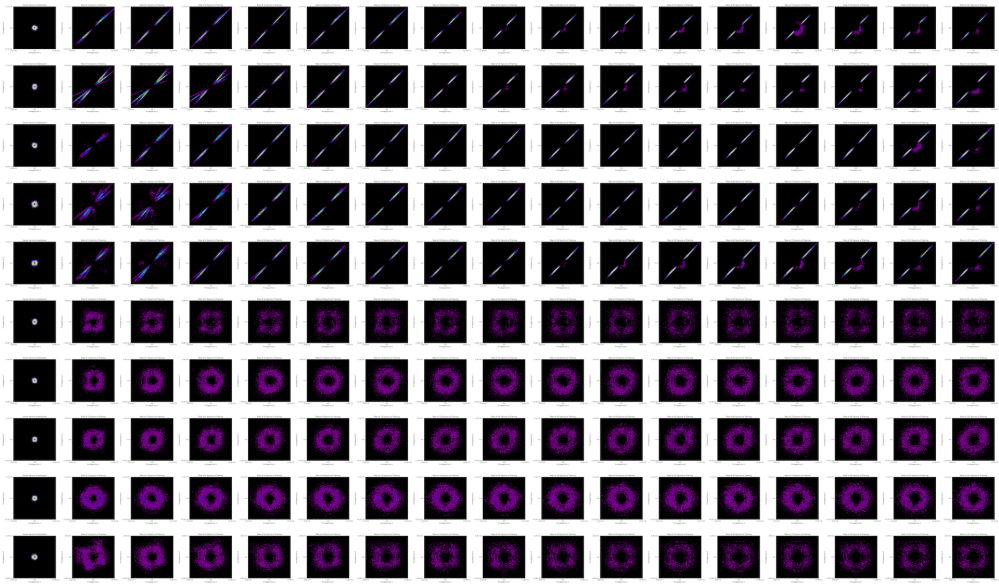

Figure 18: The results of the PPP method applied to the 0th latent layer of an autoencoder with 3 hidden layer blocks and width of 18 neurons per block. The top five rows consist of the autoencoder using the standard Leaky-ReLU, while the bottom five rows consist of the same autoencoders using the isotropic Leaky-ReLU. All five of the top five rows demonstrate clear anti-aligned quantisation in representations, predominantly in a single anti-aligned axis. These emerge early in training and become progressively more (approximately) discrete. This contrasts with the isotropic Leaky-ReLU examples, which approach a more continuous, evenly distributed embedding distribution, consistent with previous observations. Additionally, at relatively smaller magnitudes, the Leaky-ReLU results consistently show some deviation from the discrete-like rays; this remains unexplained.

Additionally, the Leaky-ReLU graphs in all 0th layers studied display a slightly differing structure from the structure present in Tanh-like networks. This seems to correspond well to the differing symmetry acting, but its emergence from other analytical differences between the functions is not ruled out.

In particular, the 0th layer standard Leaky-ReLU results always produced two narrow beams arranged antipodally, along a single diagonal. This anti-aligned structure occurs in most cases, and the standard Leaky-ReLU only rarely displays an axis-aligned structure. This single-diagonal may be indicative of the S_n group, which does not include sign flips, unlike tanh's B_n group. Therefore, only a single diagonal may appear populated, as opposed to other diagonal directions, which could result from the various mirrors applicable in the B_n group. This nuanced difference between demonstrations appears to closely follow from the differences between symmetry groups. These differing representations can be considered to support the influence of different symmetry groups on representations, with nuances following in a taxonomic fashion from the group structures. Particularly, the orthants containing $\pm\vec{1}$ are the only non-degenerate orthants produced by the S_n symmetry, and the representations appear to be aligning with these, suggesting the remaining orthants appear not to produce computationally useful maps.

The exact causal mode through which the symmetry group acts can be speculated in the Leaky-ReLU case.

Particularly, Leaky-ReLU effectively uses the condition that the activation is scaled by α if any component of the vector, decomposed along the standard basis, is negative. This results in an orthant of the domain, for which the identity map is applied, whilst the remaining space is scaled by α along various combinations of components. The relative volume of the identity-orthant follows 2^{-n} for n-neurons in a layer, whilst the various scaled regions grow as $1 - 2^{-n}$. This is a consequence of Leaky-ReLU's S_n form, whilst not exhibiting a sign-flip symmetry consistent with B_n. Similar argumentation applies to any S_n-only function. For the Leaky-ReLU case, with large widths, almost the entire domain is scaled, resulting in an exponentially

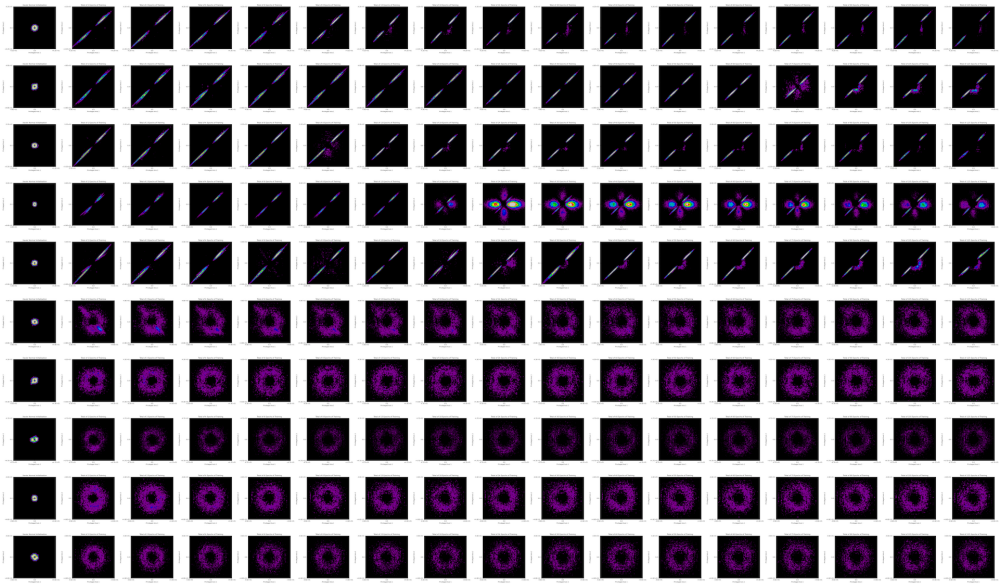

Figure 19: The results of the PPP method applied to the 0th latent layer of an autoencoder with 2 hidden layer blocks and width of 18 neurons per block. The top five rows consist of the autoencoder using the standard Leaky-ReLU, while the bottom five rows consist of the same autoencoders using the isotropic Leaky-ReLU. These results are highly consistent with *Fig.* 18, yet the 3rd row also shows the addition of axis-aligned structure.

vanishing volume fraction of the domain where the identity map acts. This differs from the univariate perspective, where the two domains occupy half the space.

Hence, in a multivariate view, an untrained network may be expected to have an exponentially vanishing number of representations which are not scaled. This may mean that the activation function approaches a state where every representation has been scaled in some combination of components by α. This appears to be undesirable to the network; consequently, training diagonalises it over the only orthant containing an identity map, such that activations cross this boundary and get scaled significantly differently.

This introduces an explainable algebraic mode through which symmetries can affect representations, since the orthant-wise behaviour is characteristic of permutation symmetries. However, crucially, this is a specific form of orthant effect that is only applicable to Leaky-ReLU and fails to provide a mode through which one can explain the structure in Tanh-like networks, though it may be generalised. The generalised orthant explanation continues to hold. Hence, the overall maximal symmetry remains the summary and most effective primary causal mechanism, which may act through various modes dependent upon the function[7].

Structure is generally more complicated in later latent layers for Leaky-ReLU-like tests, as demonstrated in *Fig.* 20 and 21 — which are representative examples of the broader array of the results. Several results, particularly the deepest layers, also showed an absence of representations or a very dense single direction. The former is likely also indicative of a narrow, strongly discrete-like anti-aligned representation, which falls outside the $\epsilon = 0.75$ thresholding.

[7]An attempt was made to produce a Leaky-ReLU-like function which partitions the space into orthants with alternating scaling and identity maps. This was termed a global-parity Leaky-ReLU and obeyed a permutation with *even* sign flips (denoted D_n, not to be confused with dihedral groups). It was constructed by decomposing the vector along the standard basis, then taking the sign of the product of (the sign of) components to determine either a scaling or identity map. This equal partitioning was hoped to be beneficial; however, this function *failed to train in all cases* and produced no influence on the representations. Perhaps future work could improve this approach by creating a working activation function with such symmetry. One could then explore its effect on representations, and explore the resultant taxonomic chain: $S_n \subset D_n \subset B_n \subset \mathrm{O}(n)$.

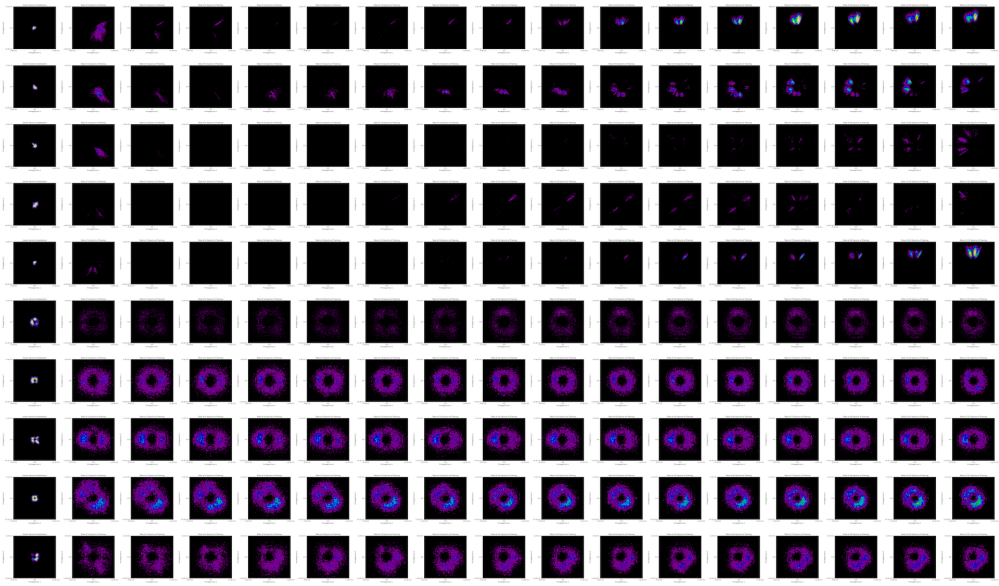

Figure 20: Shows the same networks and in the same order as *Fig.* 18, but results arise from the 1st hidden layer. As is typical for isotropy, the bottom five rows demonstrate smooth, continuous-like representations filling the space. In anisotropic cases, the emergence of dense, ray-like clusters of representations can be observed again, although some are slightly more diffuse than those in the zeroth layer. Additionally, many of these occupy more general angles about the distinguished directions, possibly a further indication of discrete representational Superposition.

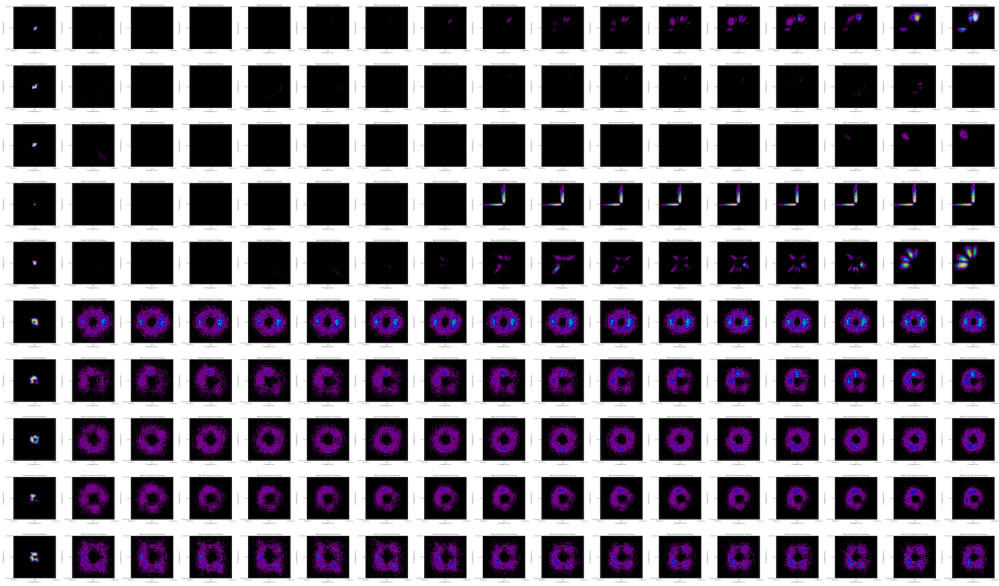

Figure 21: Shows the same networks and in the same order as *Fig.* 19, but results arise from the 1st hidden layer. Again, as is typical for isotropy, the bottom five rows demonstrate smooth, continuous-like representations that fill the space. In comparison, anisotropic examples in the top five rows produce narrow, ray-like distributions. Notably, these are more axis-aligned than *Fig.* 21, but continue to frequently display discrete Superposition-like clusters, particularly in anisotropy's row 5. Unlike the prior plots, the anisotropic networks all align upwards and towards the left, potentially indicating a differing desirable orthant mapping in this case.

Therefore, it appears that many findings identified in Tanh-like networks similarly occur in Leaky-ReLU-like networks, with only slight differences appearing to correspond to the slightly different maximal permutation symmetries to which the functions abide. This significantly bolsters the certainty of conclusions, due to the maximal symmetry being the only comparable analytical quality between the Leaky-ReLU-like and Tanh-like networks. It also rules out trivial backwards-pass geometry as a cause. Additionally, a specific explanatory mode through which the symmetry group may affect representations is suggested for Leaky-ReLU. Overall, the comparisons between anisotropic and isotropic Leaky-ReLU results, in combination with the Tanh-like comparative results, establish symmetry as the primary cause of the observed representational structure. It suggests that discrete groups tend to produce a quantising effect on representations, whilst more continuous groups remove such structure. Differences between Leaky-ReLU and Tanh experiments also indicate that nuances of the group structure may additionally affect the representations. This encourages a broader analysis of the various symmetry groups through which primitives can be defined and their corresponding inductive biases on representations.

B.5 MNIST Results

The MNIST results remain consistent with the overall conclusion and show little difference overall. Several representative examples are displayed in this section, which illustrate this, and continue to use a normalisation produced across all MNIST training samples and an/isotropic-tanh.

An initial example is displayed in *Fig.* 22 and 23 — the latter showing the same plot, with colour levels adjusted to make faint structure more observable for analysis. Both are included for comparability and transparency.

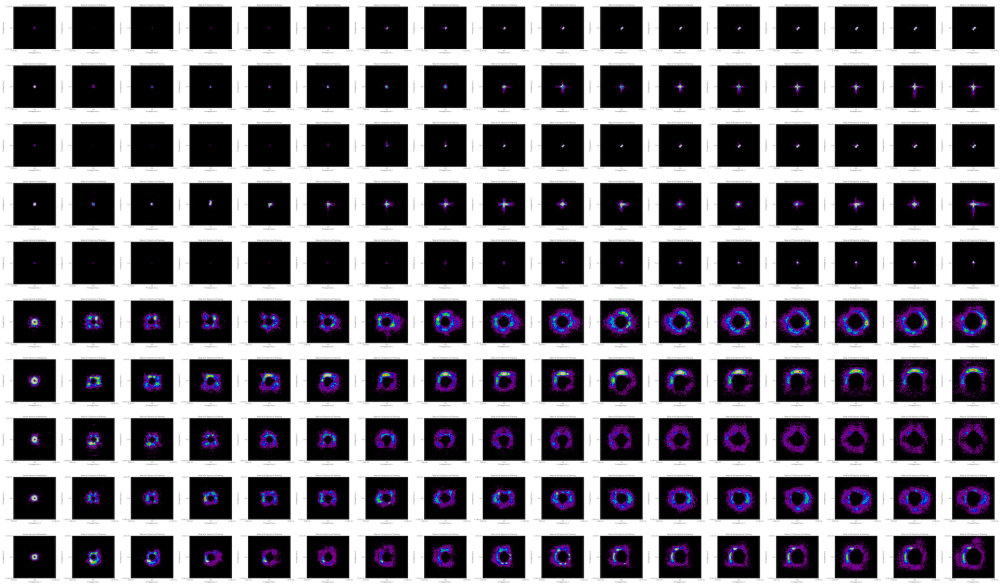

Figure 22: Displays the PPP method applied to the 0th latent layer of an autoencoder with 3-hidden-layer blocks consisting of 18 neurons per block. This architecture is comparable to those in *App.* D in every way except for the dimensions of CIFAR, which is exchanged for MNIST shape on input-output layers. Overall, one can observe that isotropic networks in the bottom five rows continue to produce smooth distributions that fill the representation space. In comparison, anisotropic networks on the top five rows tend to have many representations centred around the origin, and some produce axis-aligned features.

Several of the 0th layer plots show a closer grouping of representations about the origin. This is believed to be due to many of the MNIST examples' components reaching the extreme values for the space, 0 and 1, with fewer intermediate values. Often, this occurs repeatedly in specific patches due to the overlapping morphologies of MNIST numbers, which may produce clustered representations inherent to the dataset. This makes the MNIST dataset more anisotropic, featuring already dense, discrete clusters about the corners of an embedded hyper-cube — significantly different from the more intermediate RGB values arising from CIFAR. Slight band-groupings of representations are also sometimes observable, likely due to the same representation being projected in multiple planes, as well as the precision of the dataset, which produces slight clusterings. However, MNIST's greater inherent anisotropy appears not to significantly alter the results from CIFAR, likely due to the layer bottleneck embedding these higher-dimensional representations more evenly in the latent layer during initialisation.

Similar results continue to occur in later latent layers, where axis-aligned clustering becomes progressively more pronounced in deeper layers for anisotropy, whilst typically more diffuse for isotropy. This is demonstrated in *Fig.* 24.

Overall, this section corroborates that such a function-imposed structure generalises across other datasets and emphasises the task-agnostic production of such a structure through the inductive biases associated with functional forms.

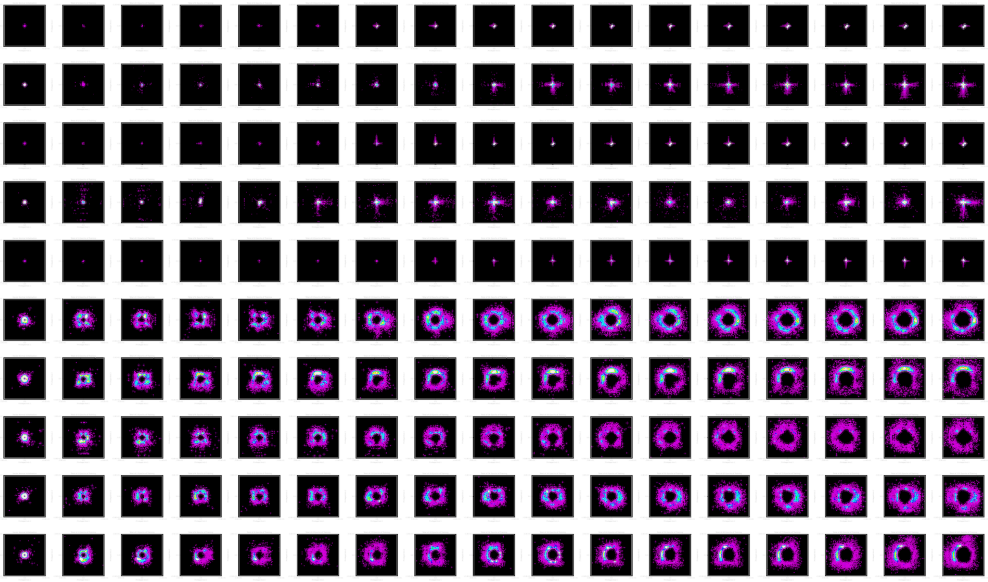

Figure 23: Displays the exact same plot as *Fig.* 22, with the colour map levels adjusted in post-processing to make the faint representations more observable. In this plot, the axis-aligned representations of anisotropic networks are more observable. This demonstrates how anisotropic tanh produces task-agnostic structure in MNIST reconstruction autoencoders as well.

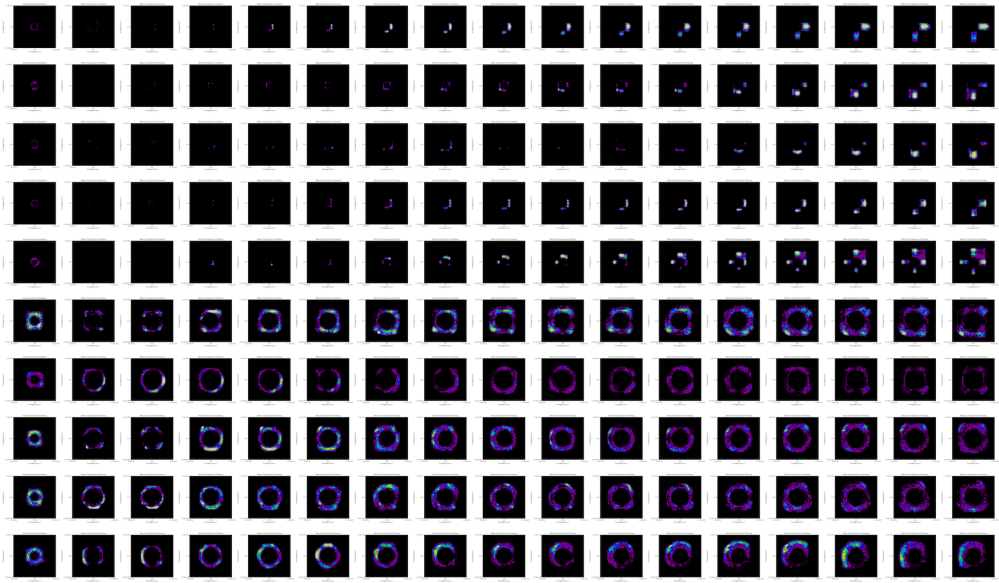

Figure 24: Displays the PPP method applied to the 1st latent layer of an autoencoder with 3-hidden-layer blocks consisting of 18 neurons per block. Row-wise, these are the exact same networks as displayed in *Fig.* 22 and 23, but for the next latent layer. One can observe an axis-aligned structure in the top five rows, corresponding to anisotropic standard-tanh, and this is consistent with all previous experiments. In contrast, a smoother, approximately continuous distribution is observed for the bottom five rows, which are isotropic, and is consistent with this trend.

C Analysis of Performance and Pathological Indications

This section displays the reconstruction errors for several of the networks tested. Normalised and Isotropic networks tend to outperform all other networks, though several exceptions do occur. The results should be taken as preliminary, since there were fewer CIFAR reconstructions computed using unnormalised datasets, due to limited compute resources and performance not being the primary study of this paper — particularly since Isotropic-Tanh is considered a placeholder activation function which is likely suboptimal and only made to appear superficially similar to standard-Tanh (Bird, 2025a). Nevertheless, they are indicative of a general trend where isotropic networks tend to outperform anisotropic networks on this specific task.

Within normalised networks, isotropic activation functions *always* outperform otherwise identical anisotropic networks through training. In unnormalised networks, they frequently tie or vary slightly, with instances where anisotropic networks do perform better. However, from the results gathered, unnormalised networks typically perform poorer overall — an exception to this is demonstrated.

The unnormalised and normalised instances can be compared by correcting unnormalised reconstruction errors, with the same normalisation steps to make the two forms of errors comparable. When this occurs, normalised-isotropic networks tend to always outperform the three other combinations: "unnormalised-isotropic", "normalised-anisotropic" and "unnormalised-anisotropic". Though when exceptions do occur, it tends to be "unnormalised-isotropic" slightly outperforming "normalised-isotropic", and sometimes "unnormalised-anisotropic" outperforming all others, but this is relatively infrequent.

Each plot shown represents a specific architecture, with isotropic and anisotropic activations plotted in different colours. Sometimes with their normalised and unnormalised counterparts overlaid where relevant. There are five samples per variant (each plotted faintly), along with the mean and standard deviation. These are all for the unseen testing-set reconstruction error against the number of epochs trained.

Figure 25 displays all the normalised results obtained for CIFAR reconstruction. The isotropic networks show significantly lower reconstruction error in all cases for *Fig.* 25.

In *Fig.* 26, the results between normalised and unnormalised networks for CIFAR reconstruction are overlayed.

Notably, in every example, the plots for unnormalised anisotropic networks featured significantly greater noise in reconstruction error on the testing set than the unnormalised isotropic networks. This may be indicative of smoother training dynamics, indicated for isotropic functions (Bird, 2025a). However, this observation is insufficiently rigorous to draw a conclusive statement regarding smoother optimisation dynamics in isotropic networks.

The tendency for unnormalised anisotropic networks to outperform normalised anisotropic networks may be due to the unnormalised dataset displaying a greater degree of initial anisotropy. This is because the unnormalised samples are bound between $[0, 1]^{32\times32\times3}$ and rather densely cover this space. Hence, the unnormalised dataset is strongly anisotropic, only populating these directions from the origin. This may be better leveraged by the anisotropic primitives, and hence demonstrate improved reconstruction error. This is in contrast to the normalised dataset, which is more uniformly distributed about the origin, as shown in *App.* A.2. This may also explain why isotropic networks perform better on these normalised cases. However, this does not appear to explain the later Leaky-ReLU results of *Fig.* 30, where anisotropic Leaky-ReLU performed more poorly on the unnormalised case compared to the normalised case — though this may be because the normalised inputs resulted in initialised activation which better straddle the non-linear primitive's piecewise boundary.

An instance of 32 neurons was also computed, and this example did show unnormalised-anisotropic functions performing better as shown in *Fig.* 27. However, these were not the best-performing models overall.

Similar findings were observed for MNIST examples, as shown in *Fig.* 28, which also features Tanh-based networks.

For the unnormalised against normalised case tested in MNIST networks, isotropic networks continue to outperform with a significant margin, as seen in *Fig.* 29.

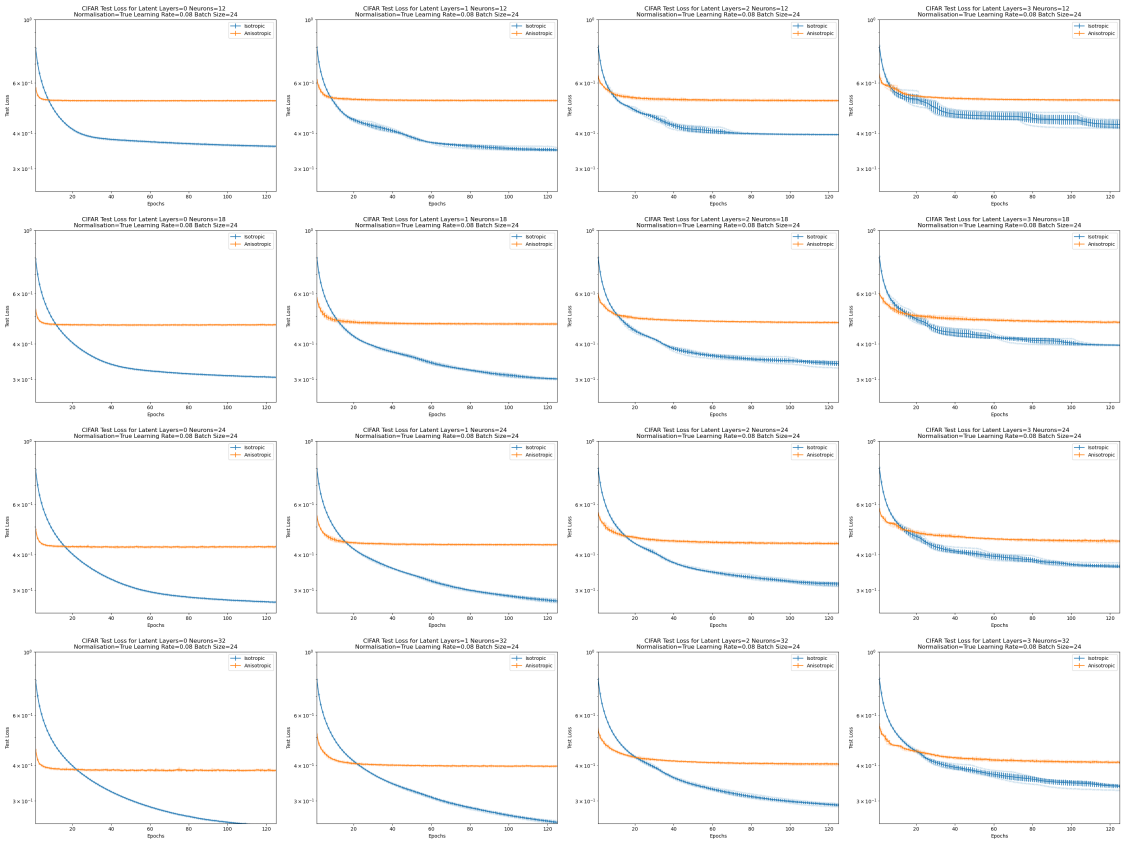

Figure 25: Displays the tanh-like test-set reconstruction errors across all normalised-CIFAR experiments using an autoencoder reconstruction task. Network depth increases along rightward columns, whilst width increases along downwards rows. In every case, isotropic networks (in blue) exhibit the lowest reconstruction error; therefore, they are the best-performing activation functions. Per graph, the axes show reconstruction error against the number of epochs trained for. These graphs are scaled identically, and one can see that width tends to lower the reconstruction error, while depth often increases it. Repeats are very consistent, showing very small deviation between repeats.

Additionally, in all Leaky-ReLU cases, the isotropic networks demonstrated significant improvements. This is shown in *Fig.* 30.

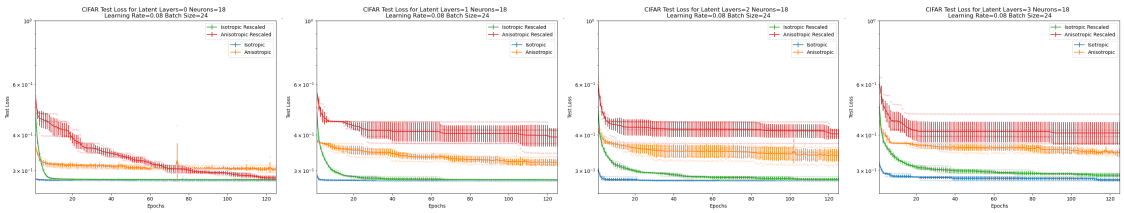

Figure 30: These plots show the Leaky-ReLU-like normalised anisotropic (orange) and normalised isotropic (blue) overlayed over the unnormalised anisotropic (red) and unnormalised isotropic (green) reconstruction errors on test-set CIFAR against the number of training epochs. The networks have a width of 18 neurons, and their depth increases to the right. In all instances, normalised or unnormalised isotropic-Leaky-ReLU reaches the lowest reconstruction error by a large margin. Anisotropic networks also appear to exhibit significantly greater noise and sample-to-sample variation in test-set accuracies across the differing training epochs.

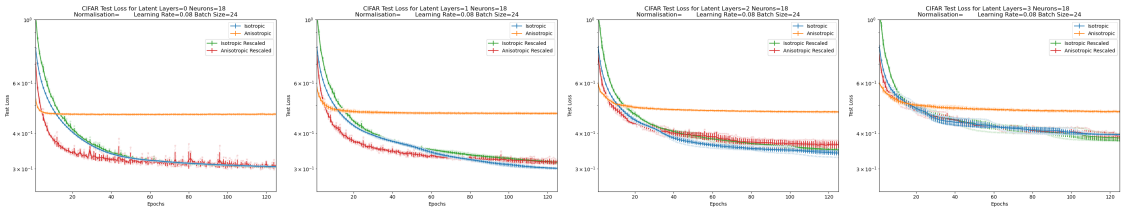

Figure 26: These plots show the tanh-like normalised anisotropic (orange) and normalised isotropic (blue) overlayed over the unnormalised anisotropic (red) and unnormalised isotropic (green) reconstruction errors on test-set CIFAR against the number of training epochs. The networks have a width of 18 neurons, and their depth increases to the right. In the leftmost plot, unnormalised isotropy has the lowest error by a very slight margin. The central two plots show that normalised isotropic networks have the lowest error by a large margin. The rightmost plot again shows unnormalised isotropy with the lowest error and a larger margin. Overall, a trend is not apparent, but isotropy tends to outperform by a greater margin.

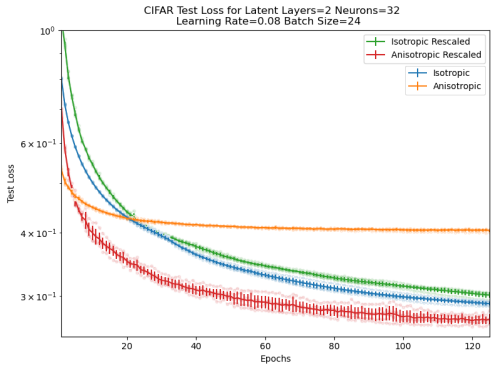

Figure 27: This plot shows the tanh-like normalised anisotropic (orange) and normalised isotropic (blue) overlayed over the unnormalised anisotropic (red) and unnormalised isotropic (green), reconstruction error on test-set CIFAR against the number of training epochs. The networks have a width of 32 neurons, and 2 hidden layer blocks. In this counterexample, the unnormalised-anisotropic network had the lowest reconstruction error.

Overall, this shows a clear tendency for isotropic-defined functions to outperform anisotropic counterparts across most tests, with only limited exceptions. This is interesting, as the isotropic functions are considered only a placeholder, intended to imitate the appearance of the anisotropic counterparts superficially. Thus, they have not undergone a selection process to optimise their functionality, leveraging their distinctly different isotropic properties, so they can likely be improved substantially. These results are a promising indication, but remain preliminary, and are so far only applicable to autoencoding reconstruction, where one may expect isotropy to be particularly favourable in preserving information for reconstruction.

These improvements may not extend to larger models such as transformers. For example, the structure of these models may also be partially a product of selection over anisotropic primitives, and may constitute a circular reinforcement of such forms (Bird, 2025a). Therefore, these improvements for isotropic primitives may not be applicable. A careful approach, and perhaps symmetry-principled redesign/rediscovery, of larger models may be necessary for determining isotropy improvements. Nevertheless, these preliminary results offer some support for their adoption in autoencoding reconstruction tasks, even for these illustrative placeholder activation functions, which were not intended for actual usage (Bird, 2025a).

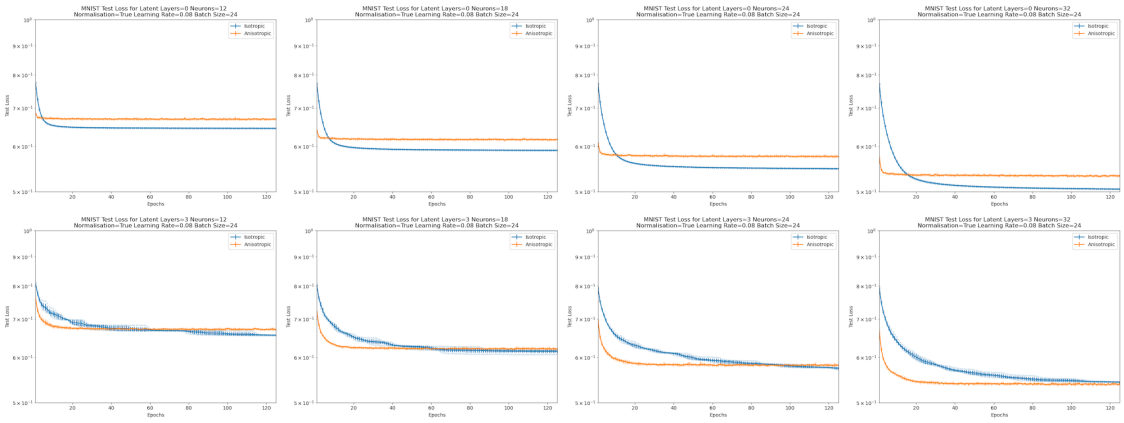

Figure 28: This plot shows the tanh-like normalised anisotropic (orange) and normalised isotropic (blue) reconstruction errors for test-set MNIST against the number of training epochs, network width increases rightward over columns, and depth increases downward over rows (flipped ordering from *Fig.* 25). It can be observed that reconstruction error is lower in wider and less-deep networks. Isotropic networks outperform anisotropic networks in every case, except for the 3-hidden-layer block and 32 neurons, where anisotropic networks exhibit a slight marginal success. The best performing network is the isotropic network with 0 hidden layer blocks and 32 neurons — this network is also thought to have the greatest representation capacity.

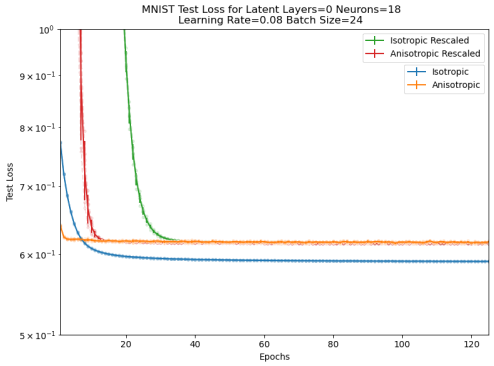

Figure 29: These plots show the tanh-like normalised anisotropic (orange) and normalised isotropic (blue) overlayed over the unnormalised anisotropic (red) and unnormalised isotropic (green), reconstruction errors on test-set MNIST against the number of training epochs. The networks have a width of 18 neurons, and a depth of 0 hidden layer blocks. It can be observed that all networks tend to a similar reconstruction error, except for the normalised-isotropy graph, which reaches a significantly lower reconstruction error.

D Further Details: Network Architectures and Training

This section discusses the various details required to reproduce these results, including architectures, hyper-parameter details and how the plots were generated. Besides the unusual isotropic activation function, all training details are felt to be conventional choices.

Autoencoder networks are studied in these results, due to their lack of one-hot classification head, which could impose anisotropy on results[8]. The autoencoders are comprised of an encoding, decoding, and hidden section. Separately categorising the 'hidden' layer is perhaps unorthodox but important for the study. All

[8]Some anisotropy may remain due to the spatialised nature of the image data; however, this is inherent to the data and the nature of visual datasets. Residual anisotropy through data is not the remit of the hypothesis being tested nor the overarching algebraic symmetry framework being studied. Though its effect was considered and discussed in *App.* A.

networks tested are derived from the one shown in *Fig.* 31. This diagrammatic depiction is consistent with open-sourced standardisation available (Bird, 2025b) at [REDACTED FOR ANONYMITY].

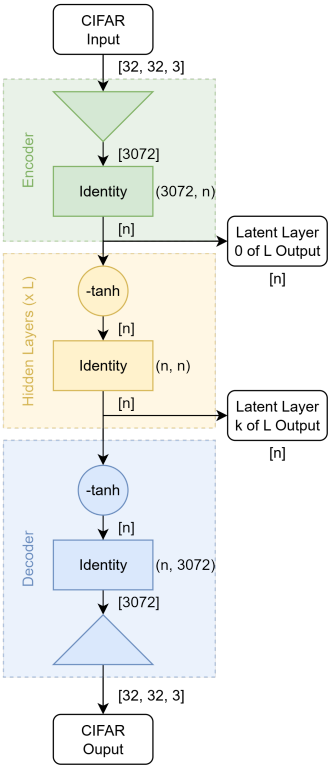

Figure 31: Shows an autoencoding architecture for reconstruction of CIFAR data, in a standardised diagrammatic key system (Bird, 2025b). It is comprised of three blocks: encoder, hidden layers and decoder. The encoder flattens the tensor representations into a vector of dimension 3072 and then performs an affine transformation down to n dimensions. Following this, each hidden layer consists of the application of an activation function, which is either standard or isotropic-tanh, followed by another affine transformation from n to n dimensions. This hidden layer process is repeated L times. Finally, the decoder applies the chosen activation function again, followed by an affine map from n to 3072 dimensions, before reshaping the vector into its classical representation. Various latent layers are drawn from the model, particularly after the encoder, denoted as layer 0, or after a hidden-layer block, denoted as k. Therefore, all latent layers of the study are n-dimensional. The parameters of all affine maps are optimisable through gradient descent.

This depicts the architectures used across all results, where n varies in width and L varies in depth of the autoencoder model. The latent layer of study is indexed by integers $k \in [0, L]$. For MNIST (LeCun et al., 2010) models, the tensor representations are changed from $[32, 32, 1] \to [28, 28, 1]$ and $[3072] \to [784]$ in all instances, with corresponding changes in affine maps. This ensures these results follow from a similar and comparable model.

Finally, following from *App.* A, the MNIST and CIFAR datasets are sometimes normalised over their training sets to reduce statistical geometry artefacts. This involves an element-wise calculation of the mean tensor over all training samples, as well as for the standard deviation statistic. Where the standard deviation is found to be 0, those elements are replaced with the value 1. When normalisation is used, every ingoing sample per batch is standardised by subtracting the mean and dividing by the standard deviation, where the non-zero standard deviation is made equal to one.

Throughout all experiments, a batch size of 24 was maintained, alongside a learning rate for PyTorch's (Paszke et al., 2019) momentum gradient descent, with momentum 0.9, a learning rate 0.08, and using a

mean-squared error loss for reconstruction. Parameter initialisation was the standard Xavier-Normal (Glorot and Bengio, 2010) for weights and zero-initialised for biases, this is due to their left-, right- probabilistic invariances (Bird, 2025a). However, standard multivariate normal or orthogonal initialisation would have been equally valid choices. Still, Xavier-Normal was deemed more conventional, though its gain is only optimised for anisotropic activation functions (Bird, 2025a). All values were kept in float64.

Networks were trained for a total of 125 epochs; however, intermediate measurements were gathered after training for each of the incremental following amount of epochs: $[1, 1, 2, 2, 2, 5, 5, 6, 6, 10, 10, 10, 15, 15, 15, 20]$ corresponding to a cumulative epoch total of $[1, 2, 4, 6, 8, 13, 18, 24, 30, 40, 50, 60, 75, 90, 105, 125]$. This was chosen arbitrarily, but was found to give meaningful insight into the formation of the representation structures.

Data was gathered using combination-PPP, with $\epsilon = 0.75$, which was found to be a good overall value. Plots were compiled using Gaussians centred at each representation's projected coordinates, and the colour map indicates representation density per region, with a maximum value of the mean plus five standard deviations and a minimum of zero. Additionally, in the anisotropic cases, so many representations became aligned with the axes that computing the Gaussian maps became intractable due to the number of computations. Therefore, a random subset of the samples generated by PPP was plotted. The size of this subset was chosen to be the closest integer of the larger set raised to the power of 0.9. Hence, the number of representations plotted monotonically increased with the number of PPP samples, yet remained computationally tractable for very large numbers of representations. This approach was used in *all* cases.