# Visual Experiences and Their Neural Substrate as Parts of a Dynamic Whole

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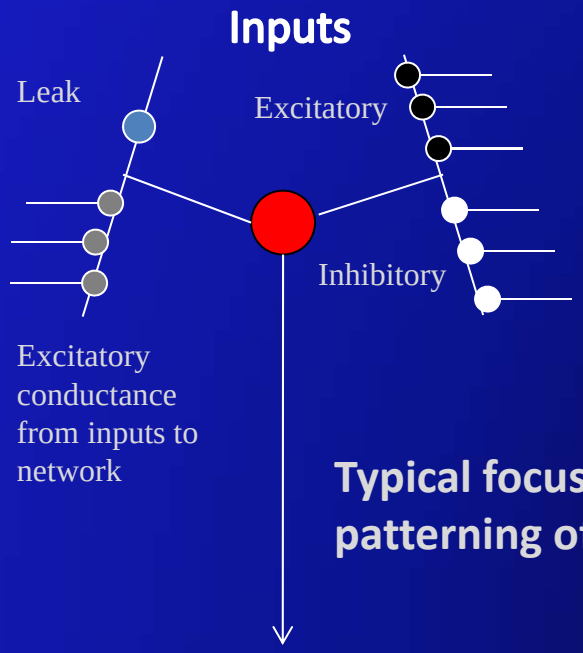
Perceptual organization and the identification of holistic percepts as visual primitives provide objective properties that might anchor phenomenal vision to neural activities.

Focus: *Inputs* to neurons – ionic conductance values that constitute the information that each neuron has about the state of its network.

A visual gestalt might be a large-scale, holistic, and complex information state that organizes ionic conductance values.



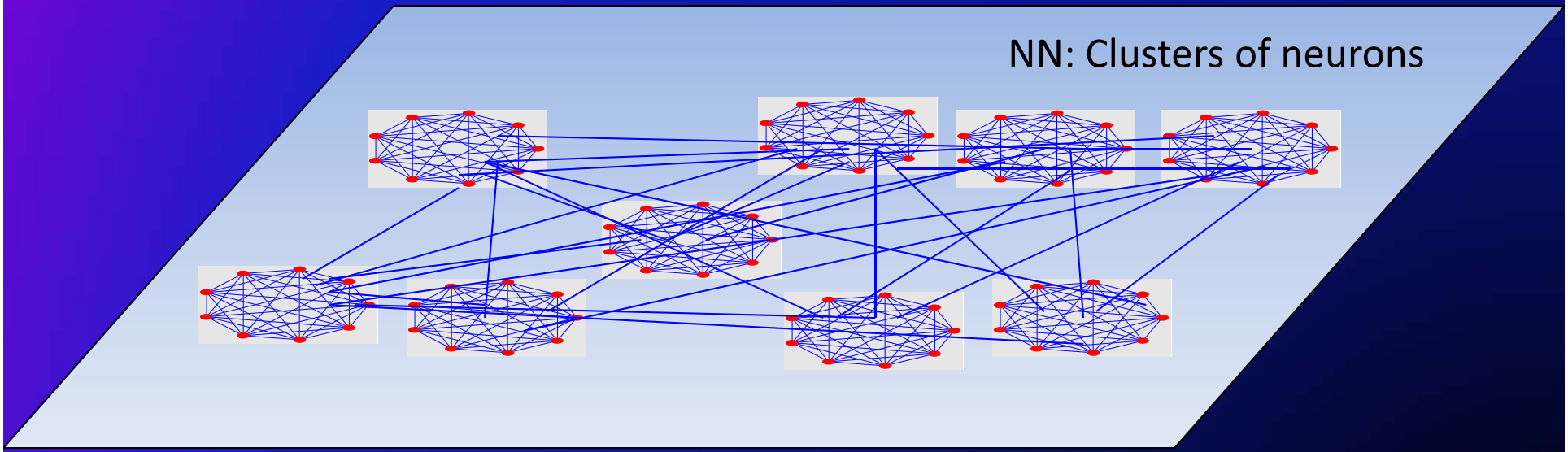

**Information about the state of the network: Ionic conductance values due to other network neurons**

**Typical focus: frequency and temporal patterning of outputs – action potentials.**

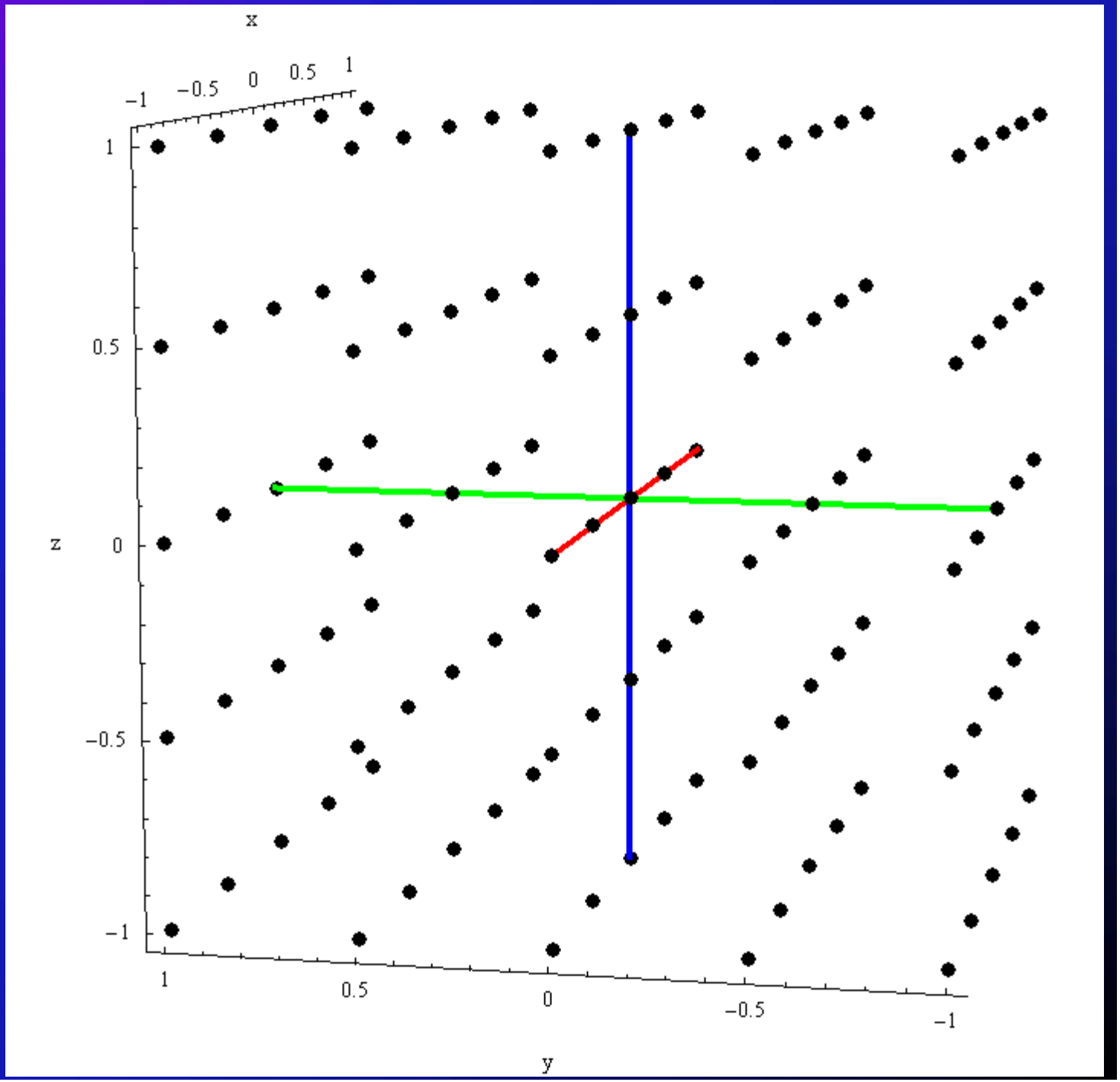
# Neural Network Models and Simulations

Group neurons into clusters.

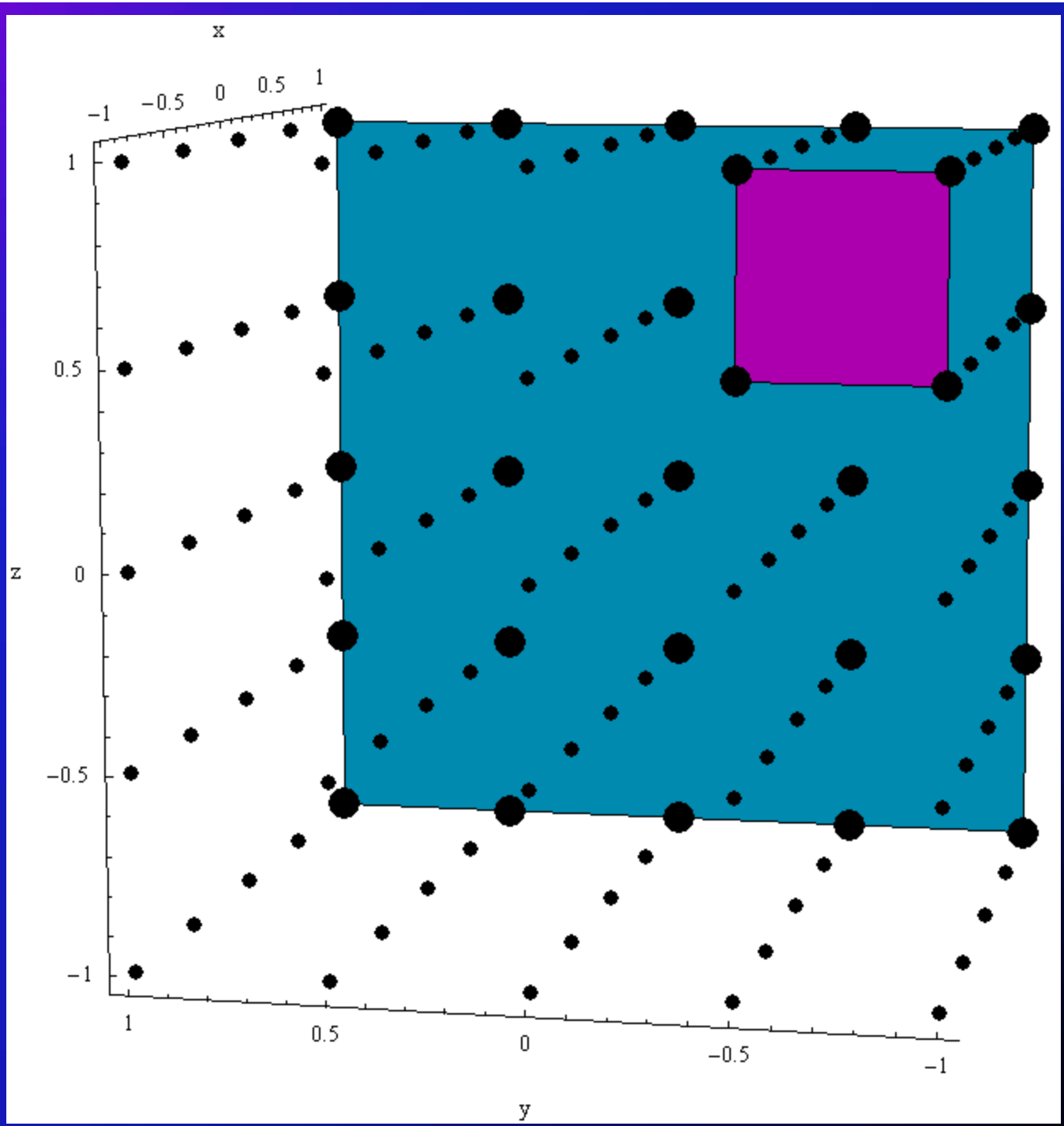
All neurons in a source cluster have equivalent effects on all neurons in a target cluster (up to random variation).



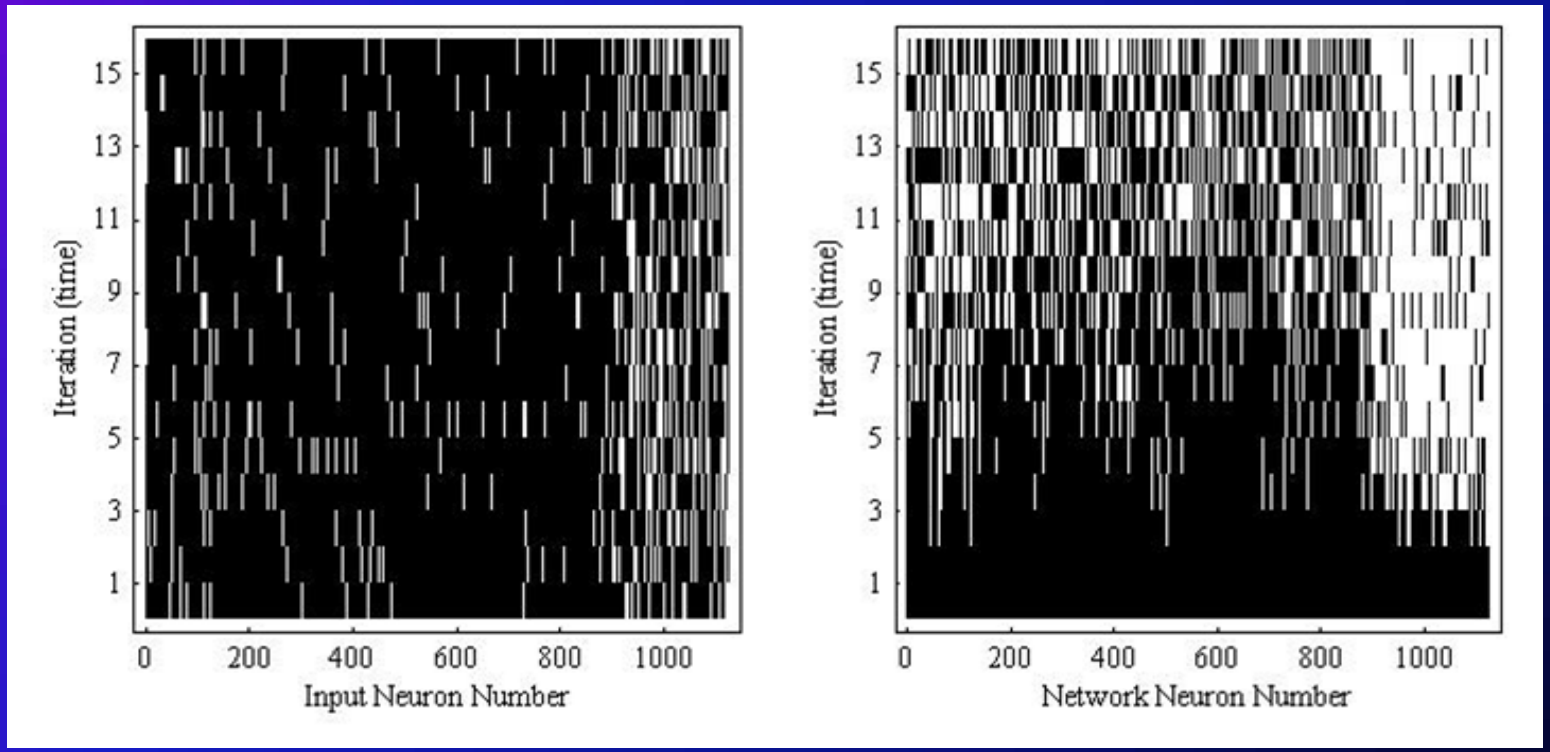
Fictional three-dimensional positions were used to set synaptic strengths from neurons in each source cluster to neurons in each target cluster.



Excitatory inputs above a random baseline were applied to four clusters on the “first sheet” and to all 25 clusters on the “fifth sheet.”



Example of excitatory input (AP depicted by white bar) to NN provided by 1125 neurons (left) and APs in 1125 excitatory network neurons (right).




Input Neurons Network Neurons

From Pavloski, 2010.

# The information that the network has about its own state is indexed by a 125 x 125 matrix *G* of sodium ion conductance values

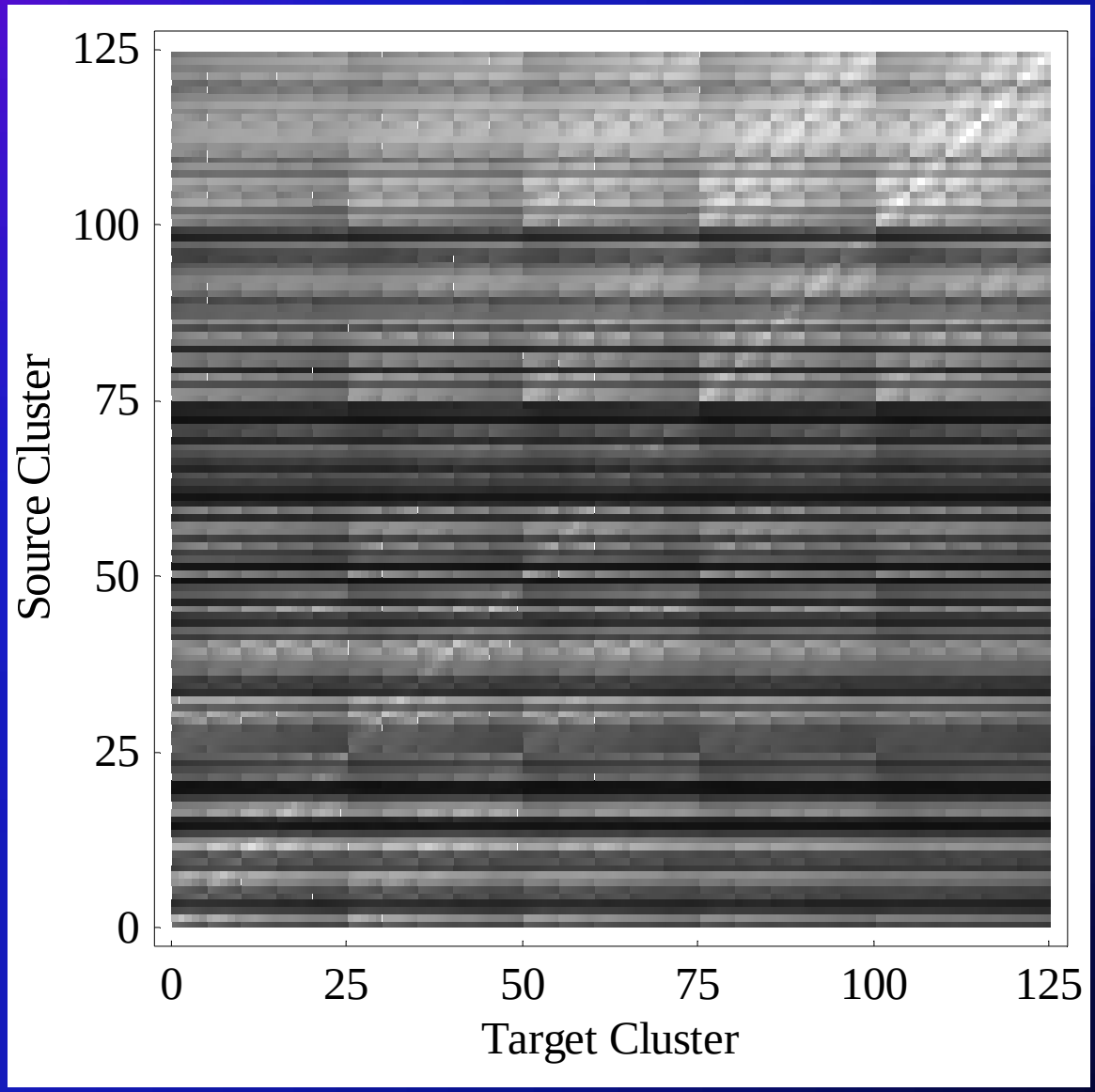
Target Cluster

Source Cluster

| | 1 | 2 | … | *i* | … | *j* | … | *k* | … | *m* |
|---|---|---|---|---|---|---|---|---|---|---|
| *m* | $G_{m1}$ | $G_{m2}$ | | $G_{mi}$ | | $G_{mj}$ | | $G_{mk}$ | | $G_{mm}$ |
| ⋮ | | | | | | | | | | |
| *k* | $G_{k1}$ | $G_{k2}$ | | $G_{ki}$ | | $G_{kj}$ | | $G_{kk}$ | | $G_{km}$ |
| ⋮ | | | | | | | | | | |
| *j* | $G_{j1}$ | $G_{j2}$ | | $G_{ji}$ | | $G_{jj}$ | | $G_{jk}$ | | $G_{jm}$ |
| ⋮ | | | | | | | | | | |
| *i* | $G_{i1}$ | $G_{i2}$ | | $G_{ii}$ | | $G_{ij}$ | | $G_{ik}$ | | $G_{im}$ |
| ⋮ | | | | | | | | | | |
| 2 | $G_{21}$ | $G_{22}$ | | $G_{2i}$ | | $G_{2j}$ | | $G_{2k}$ | | $G_{2m}$ |
| 1 | $G_{11}$ | $G_{12}$ | | $G_{1i}$ | | $G_{1j}$ | | $G_{1k}$ | | $G_{1m}$ |

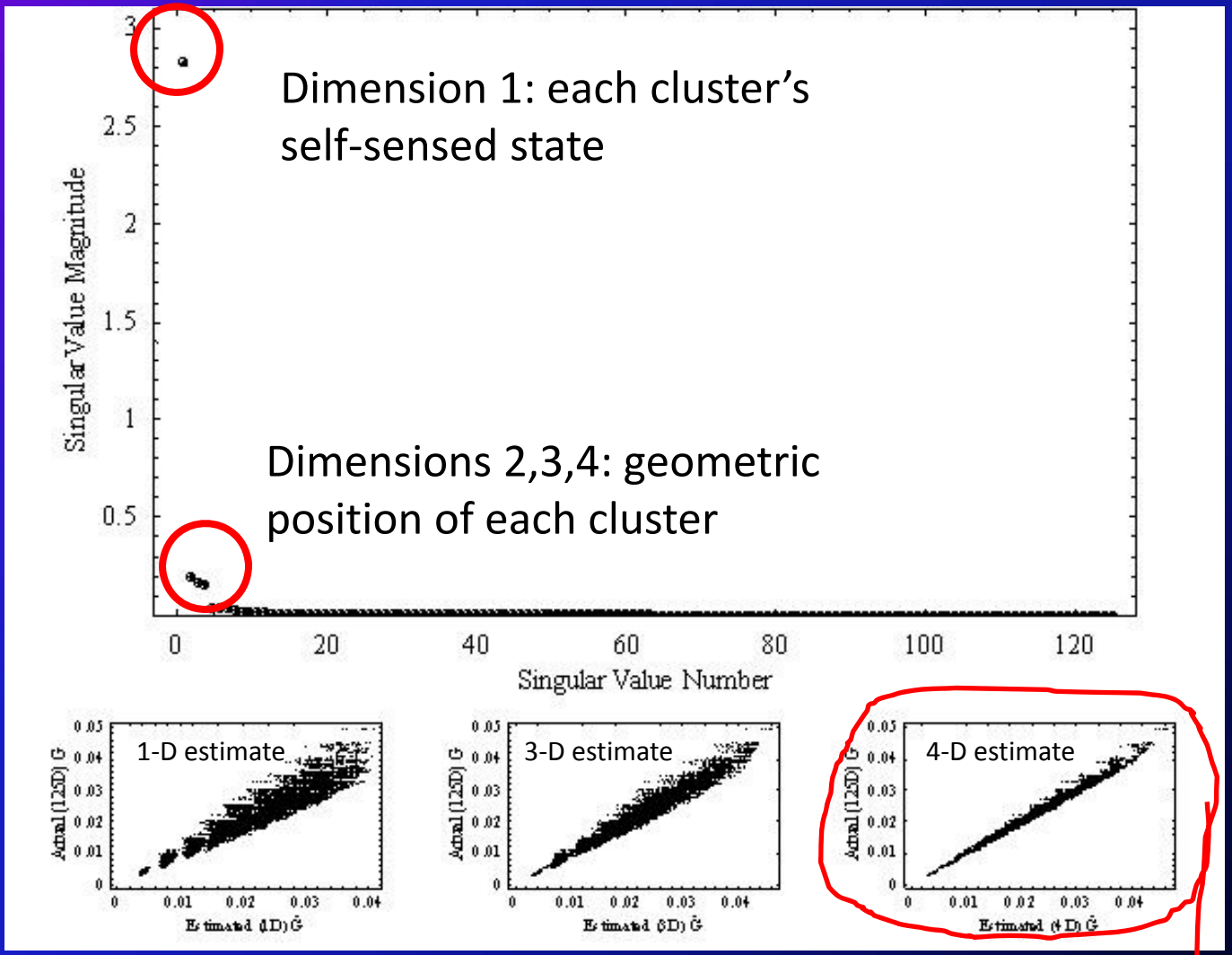
Row *i* specifies the information that all clusters of the network have about the state of cluster *i*.

Density plot of *G* (conductance data) for update 15 is shown (lighter shades depict higher conductances).




From Pavloski, 2010.

Singular value decomposition of *G* reveals that over 99% of variance in values is accounted for by *4* dimensions (instead of 125):




Regress entries of *G* on entries of a matrix $\hat{G}$ using only the first 4 singular values: Adjusted $r^2$ = 0.991, Est. Var. = $2.22 \times 10^{-7}$

From Pavloski, 2010.

# Simulation Results and Inferences

- Ionic input conductance values constitute the information that the neural network has about its own state.

- Neural network dynamics is such that a *pattern of relationships* among neural network information states comes into existence.

- The dimensions along which these relationships exist might define the organization of a gestalt.

# Bidirectional Strategy (Pavloski, 2011)

Properties of a "visual-primitive" gestalt having an organization specified by neural substrate

*explanans*

*"Bottom-down"*

*explanandum*

*explanandum*

*"Top-up"*

*explanans*

Relations among neural information states that provide the organization of the gestalt

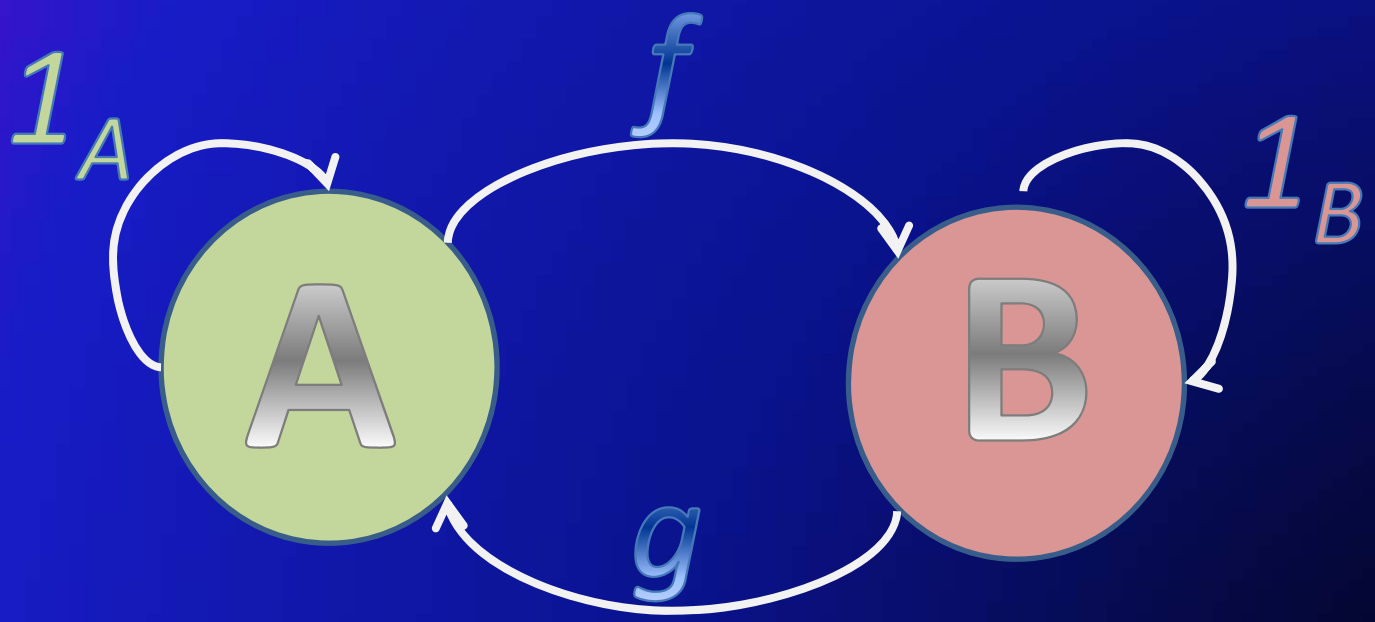
- Ionic input conductance values constitute the information that the neural network has about its own state.

- Neural network dynamics is such that a *pattern of relationships* among neural network information states comes into existence.

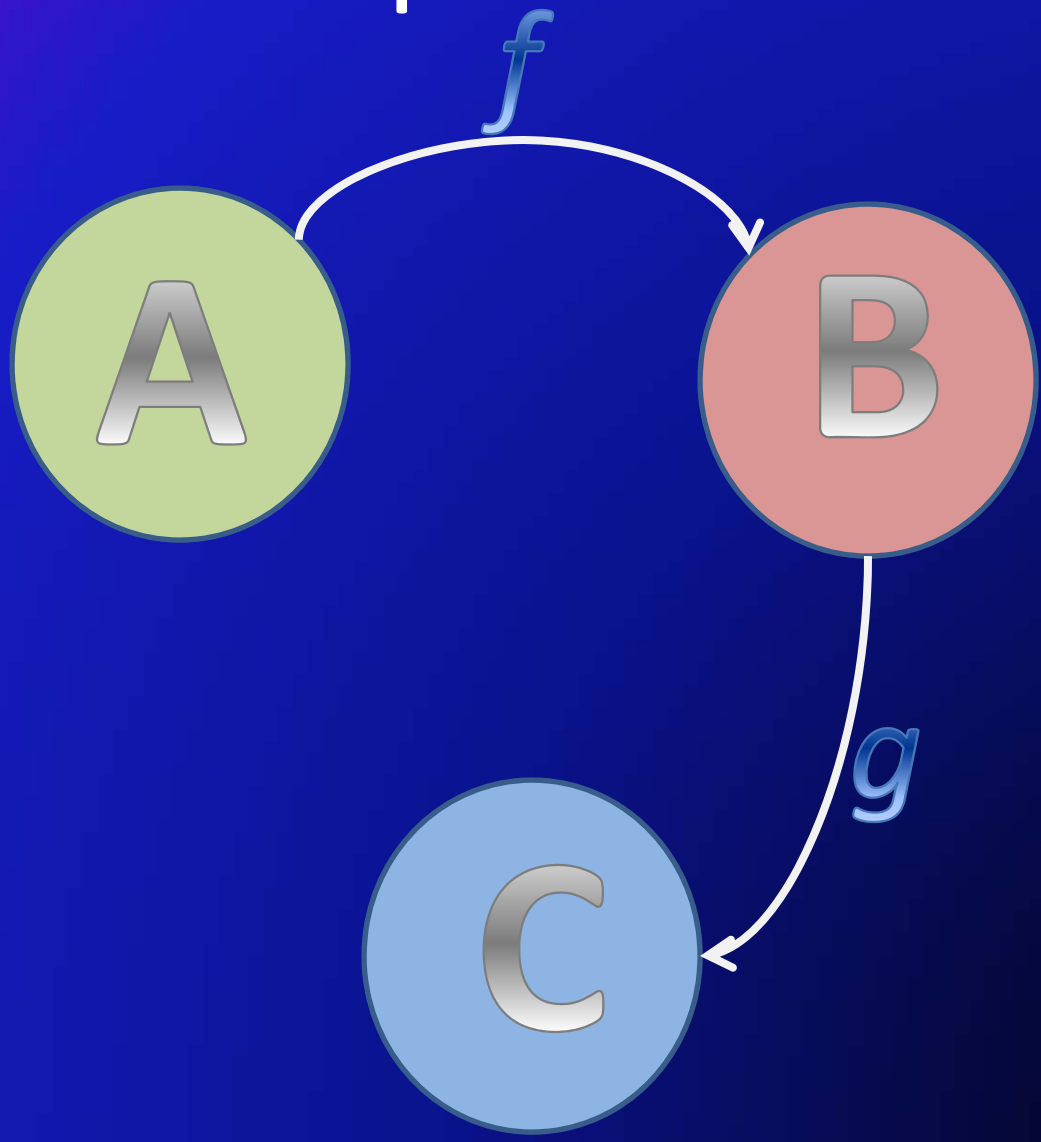
- The dimensions along which these relationships exist might define the organization of a gestalt.

- **What modeling tool can describe both a pattern of relationships among neural information states and a gestalt?**

A category (Adámek et al. 2009; Awodey 2010; Lawvere & Schanuel 1997) consists of *objects* and *arrows:*



# Every sequential pair of arrows has a composite:



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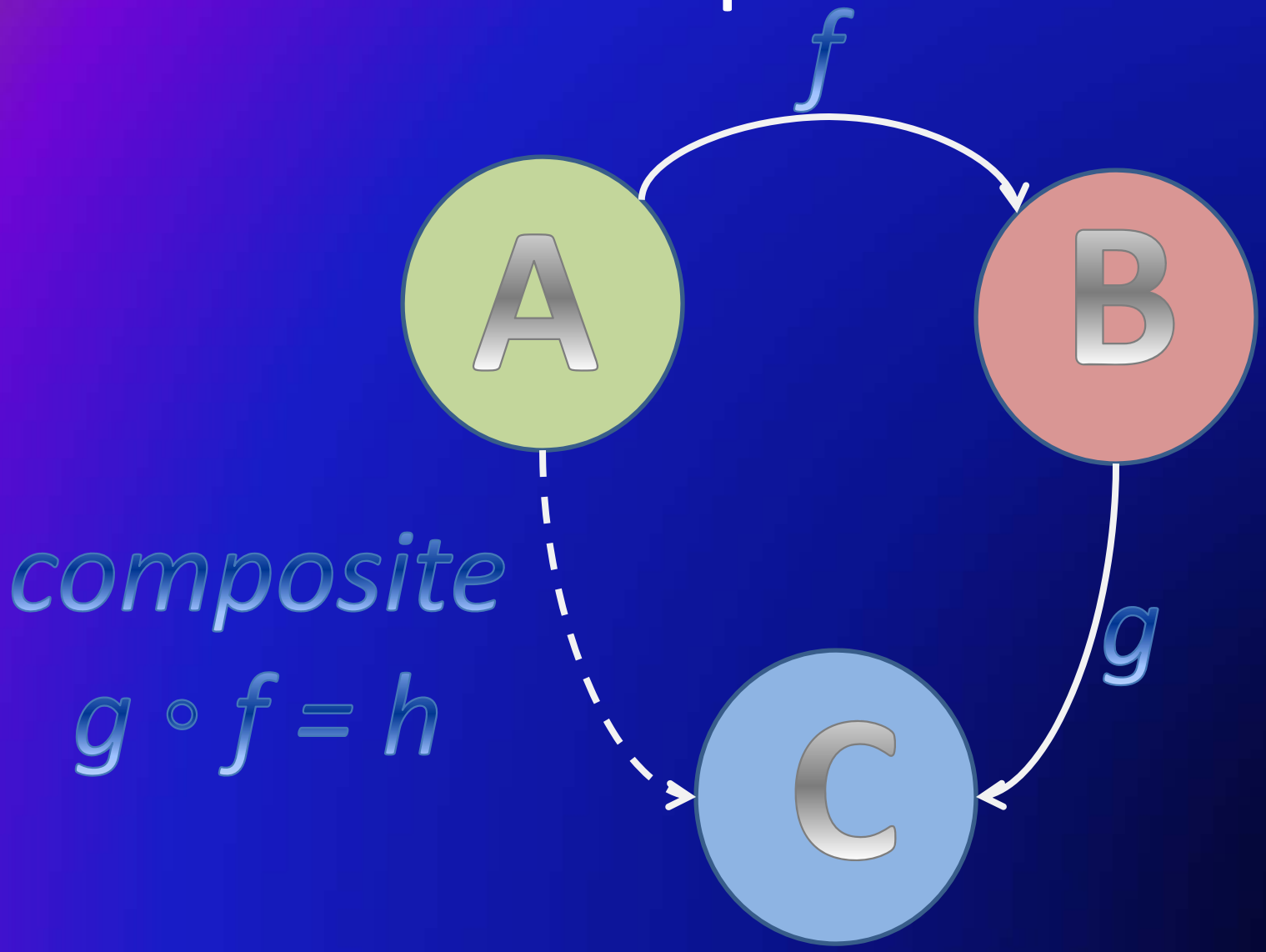
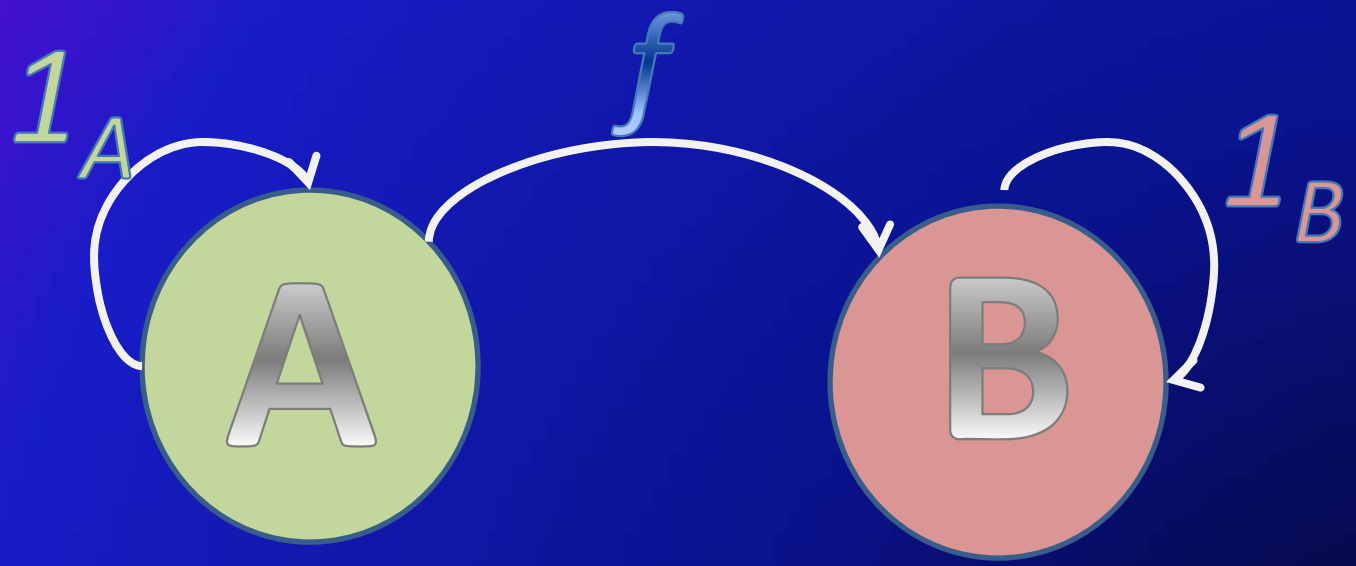
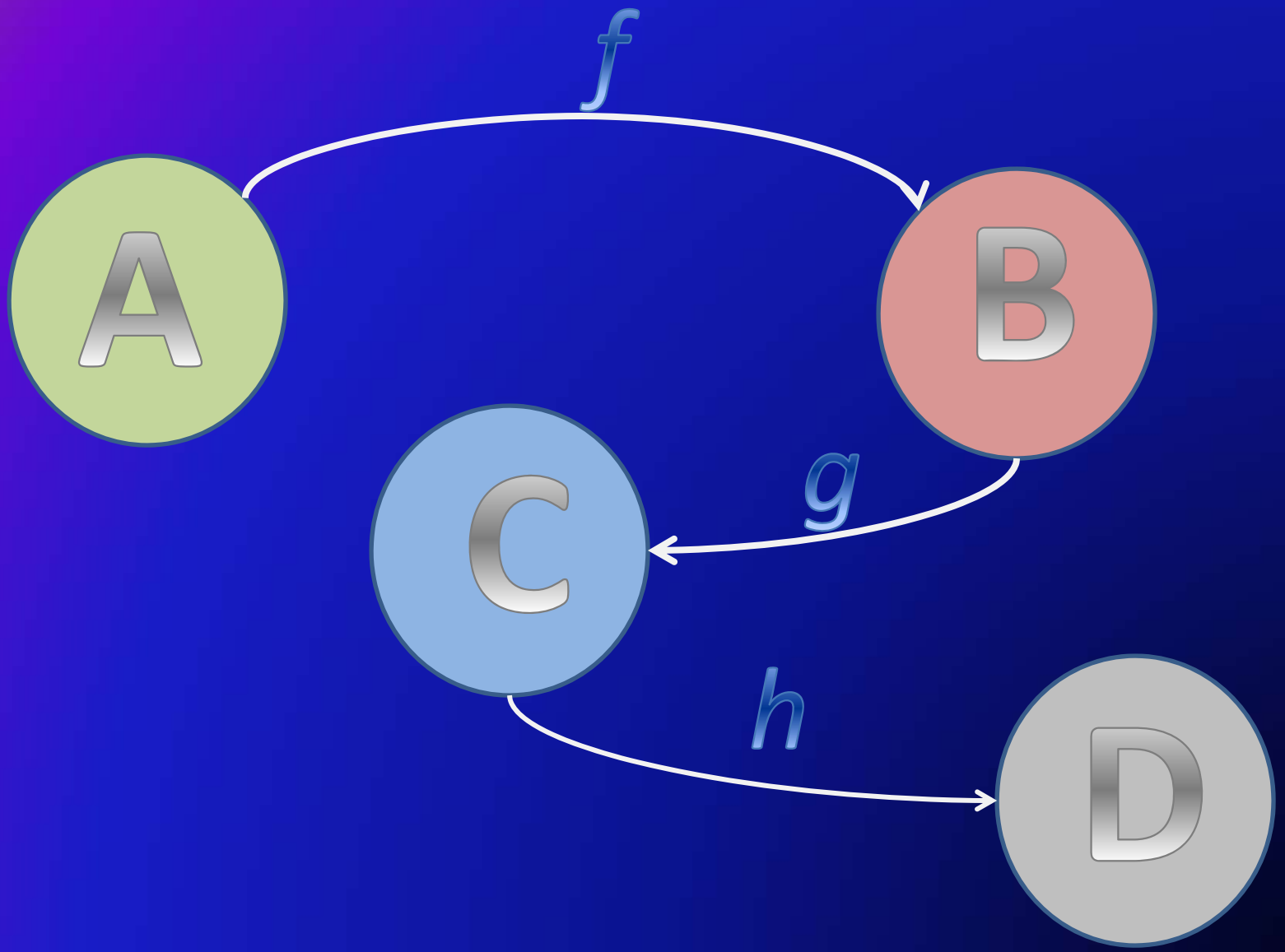


# Every object has an identity arrow:




$$f \circ 1_A = f = 1_B \circ f$$

# Composition is associative:



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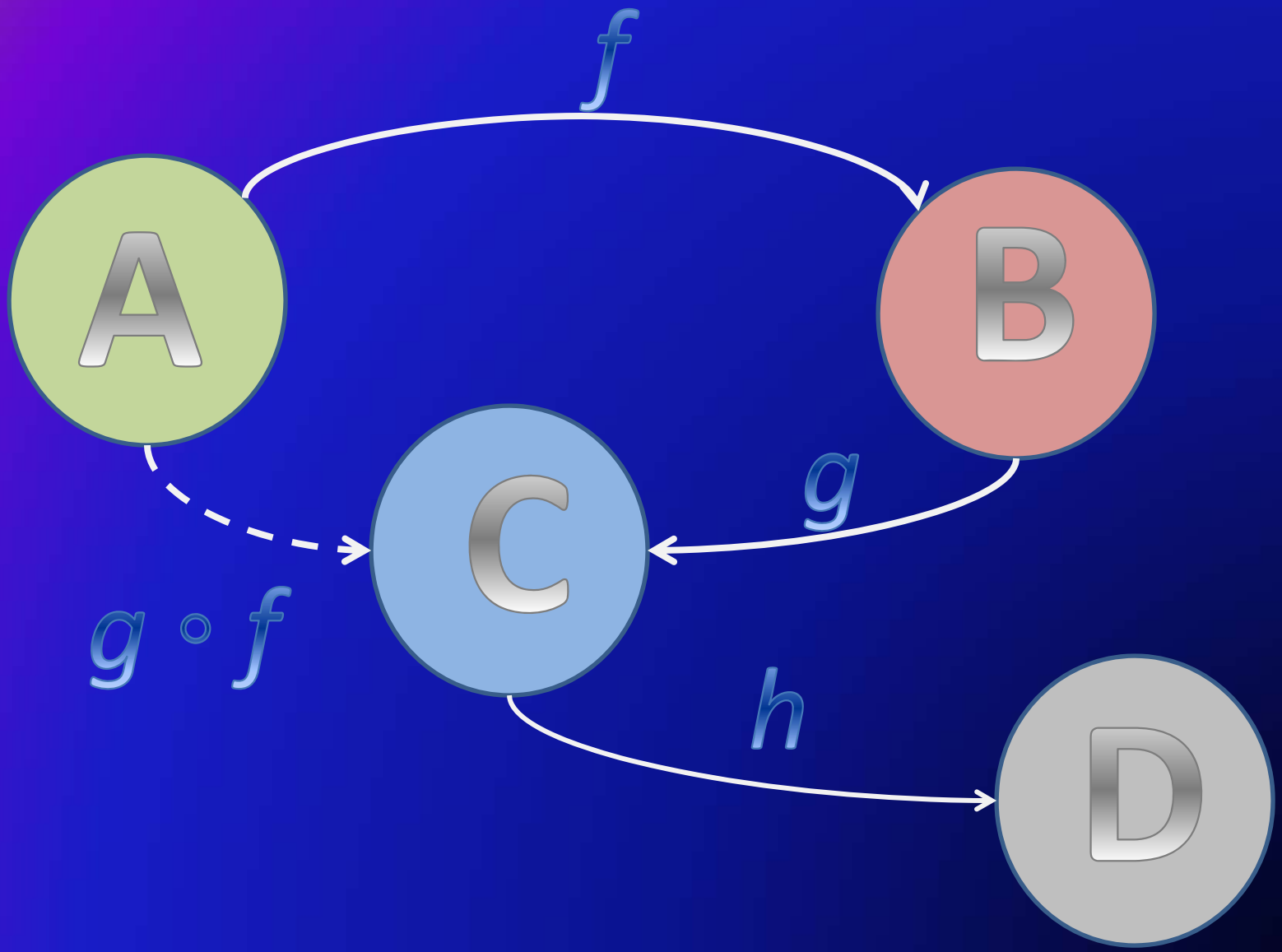

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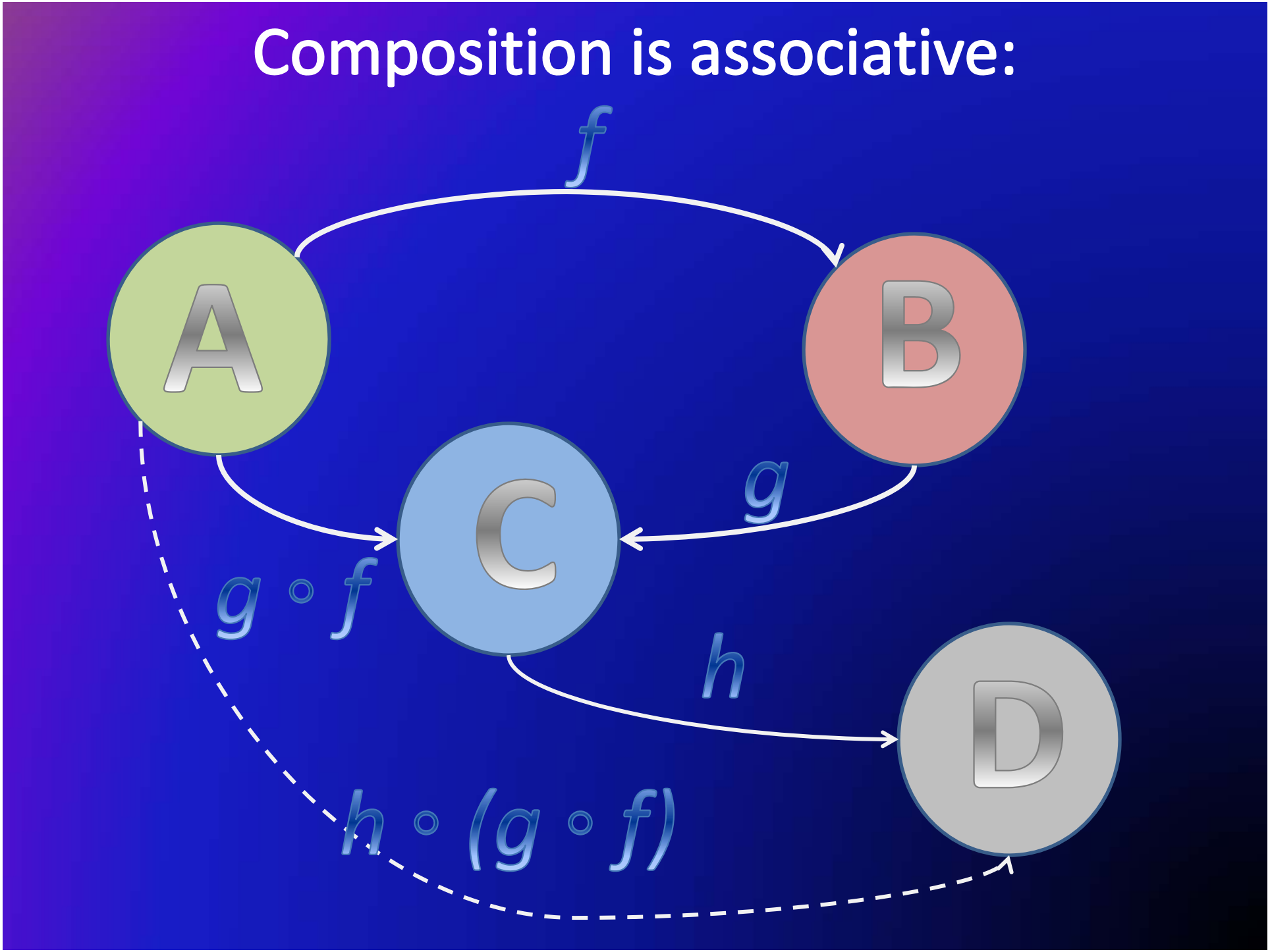

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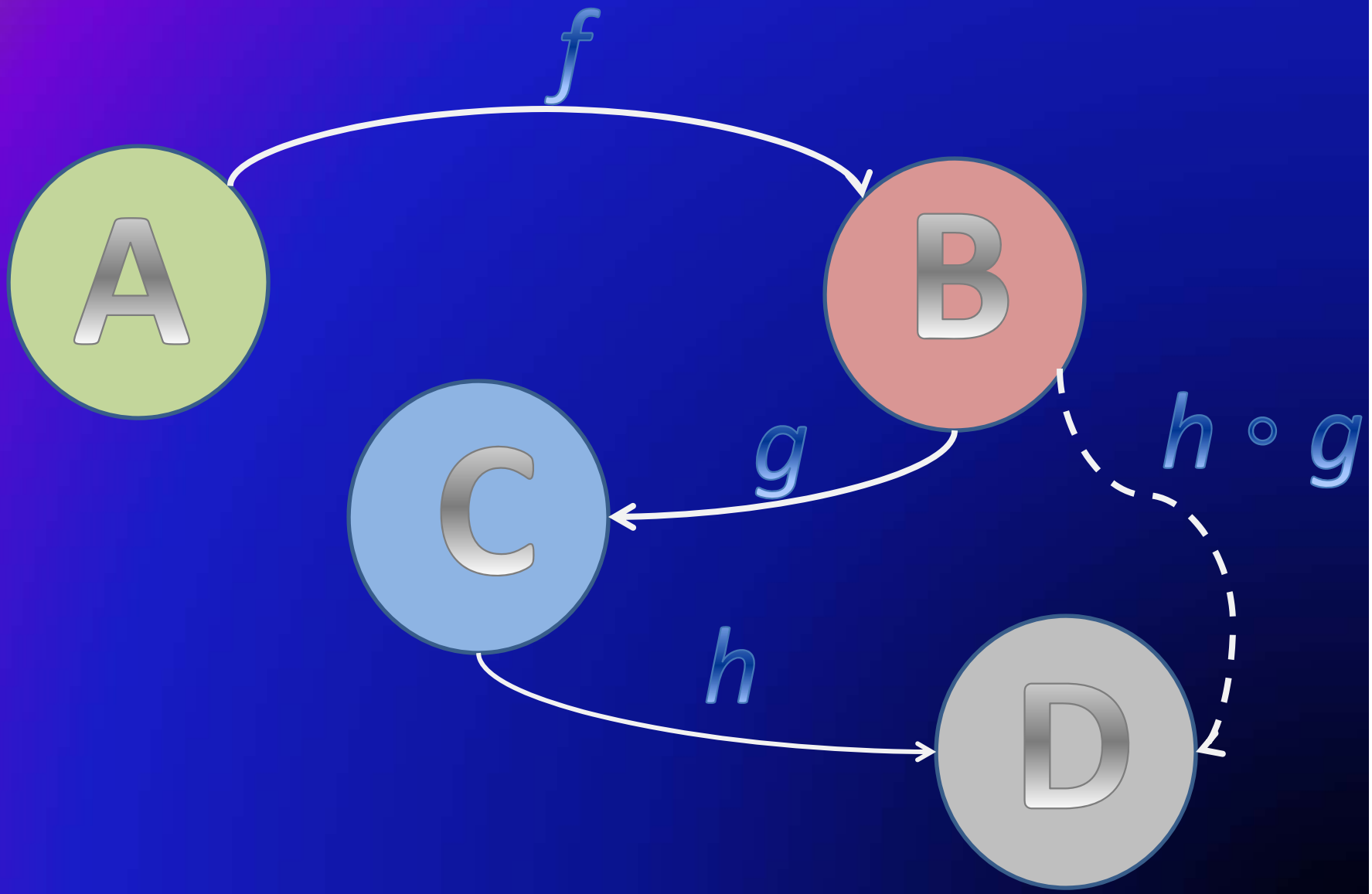

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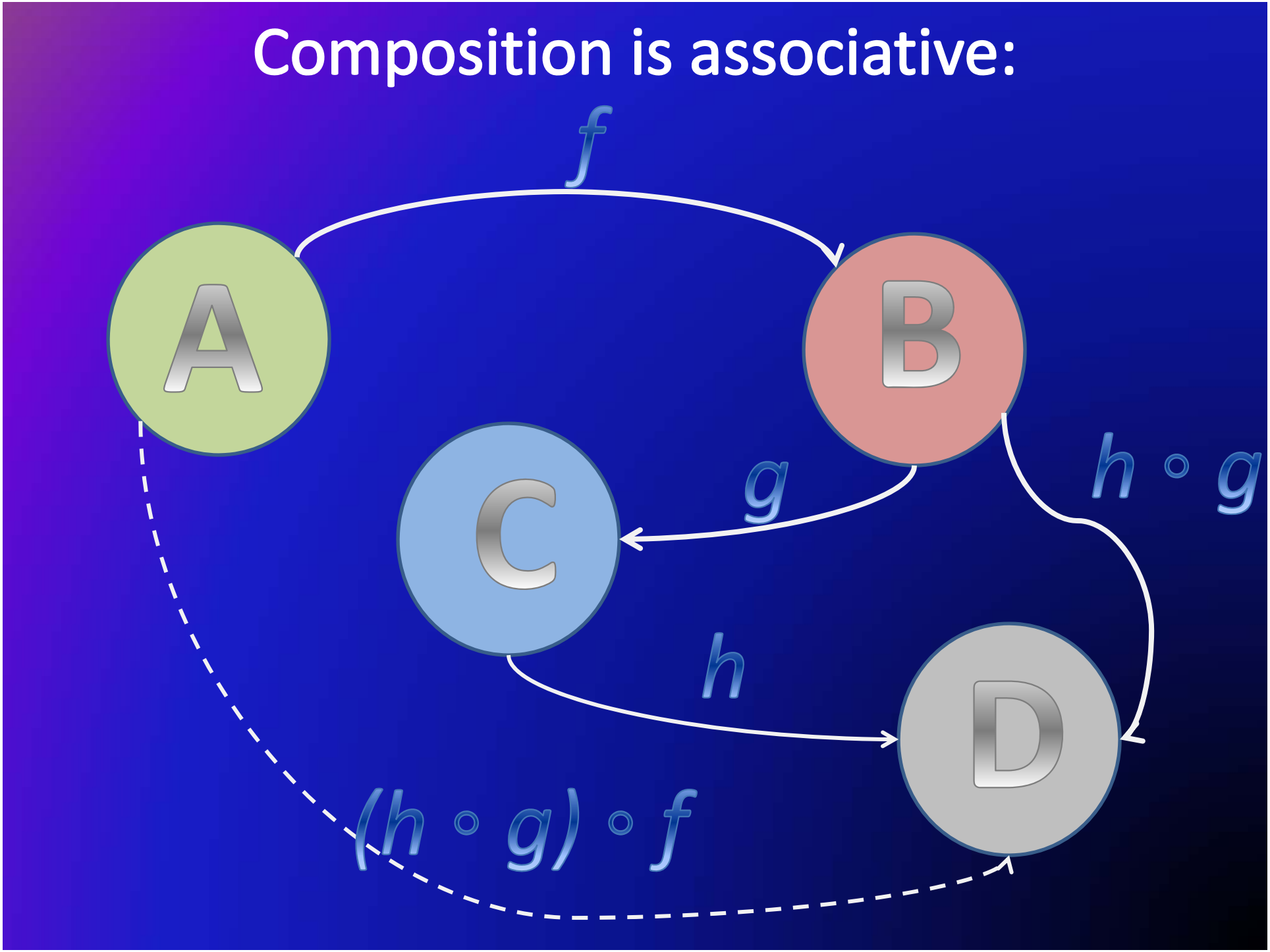
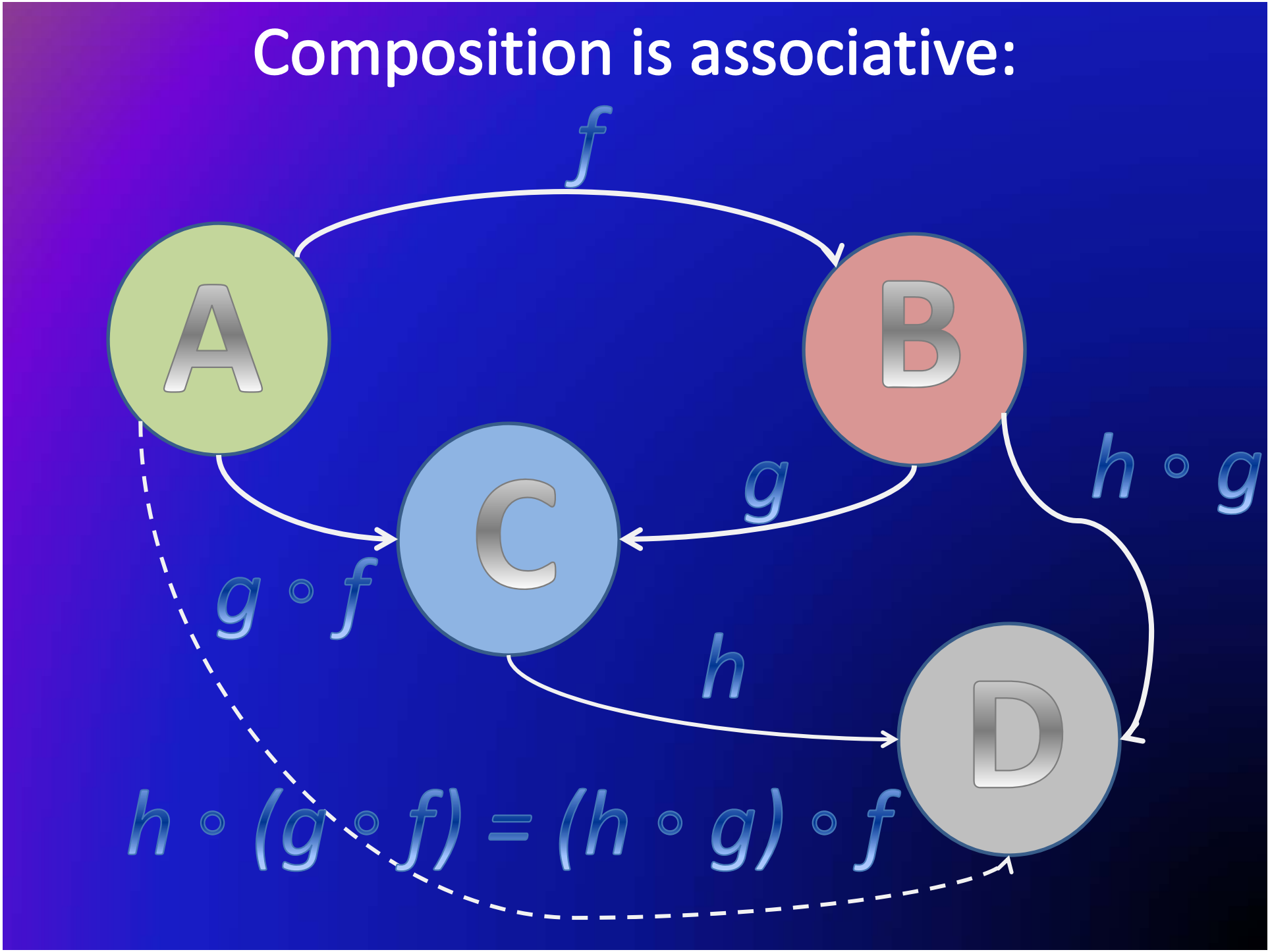


# Composition is associative:



A category is an algebra of arrows –

- "Large" categories represent entire areas of mathematics (e.g., the category of sets and functions between sets, the category of vector spaces; Adámek et al. 2009; Awodey 2010).

- Categories have been used to model biological systems (Ehresmann and Vanbremeersch, 2007; Rosen, 1958a,b).

Ehresmann and Vanbremeersch (2007): A category captures the *configuration* of a natural or social system at or around a given time

- An object corresponds to a component of the system
- An arrow depicts a relation (e.g., spatial, causal, energetic, constraint) between the source and target object

Goal: depict the information that a neural network has about each cluster of neurons as an object, and the relations among objects as arrows. Composition requires that there is an algebra of relations among information states.

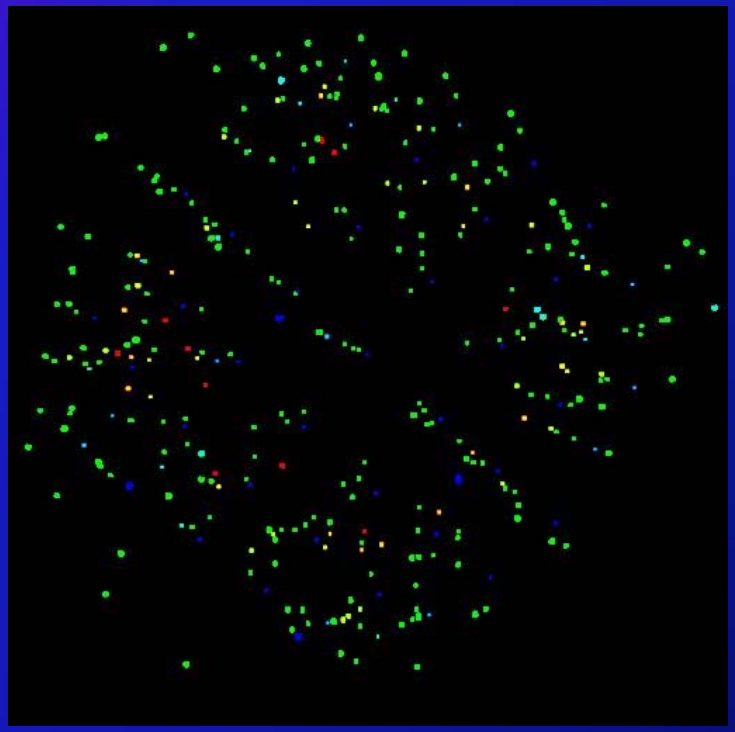
This raises the possibility that real neural network dynamics can bring into existence a category that is an algebra of relationships among neural network information states.

A *colimit* is an object that might represent a gestalt (Kainen, 1992):

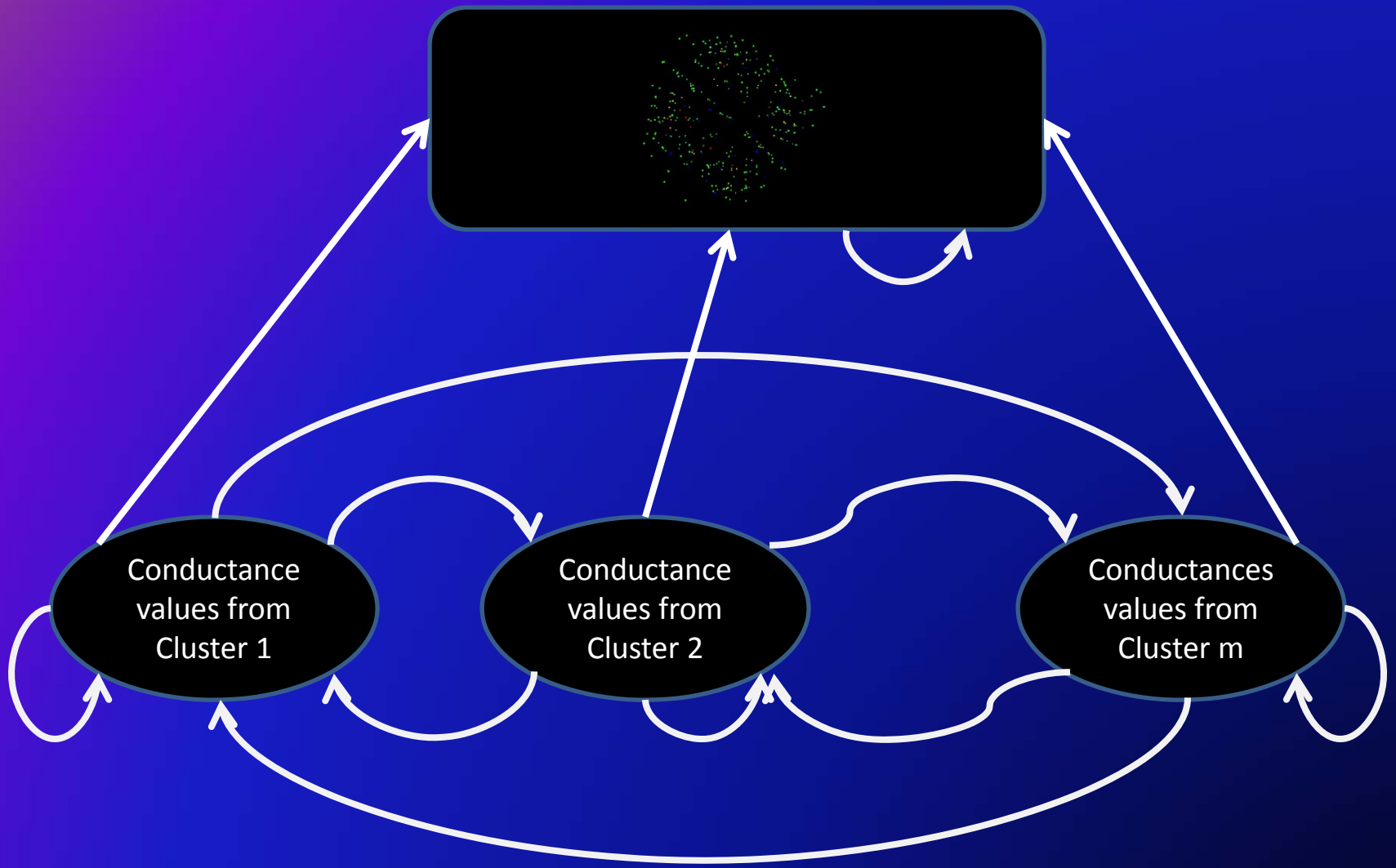
- it binds a pattern of objects and arrows; and
- it is functionally equivalent to that pattern operating collectively (Ehresmann & Vanbremeersch, 2007).

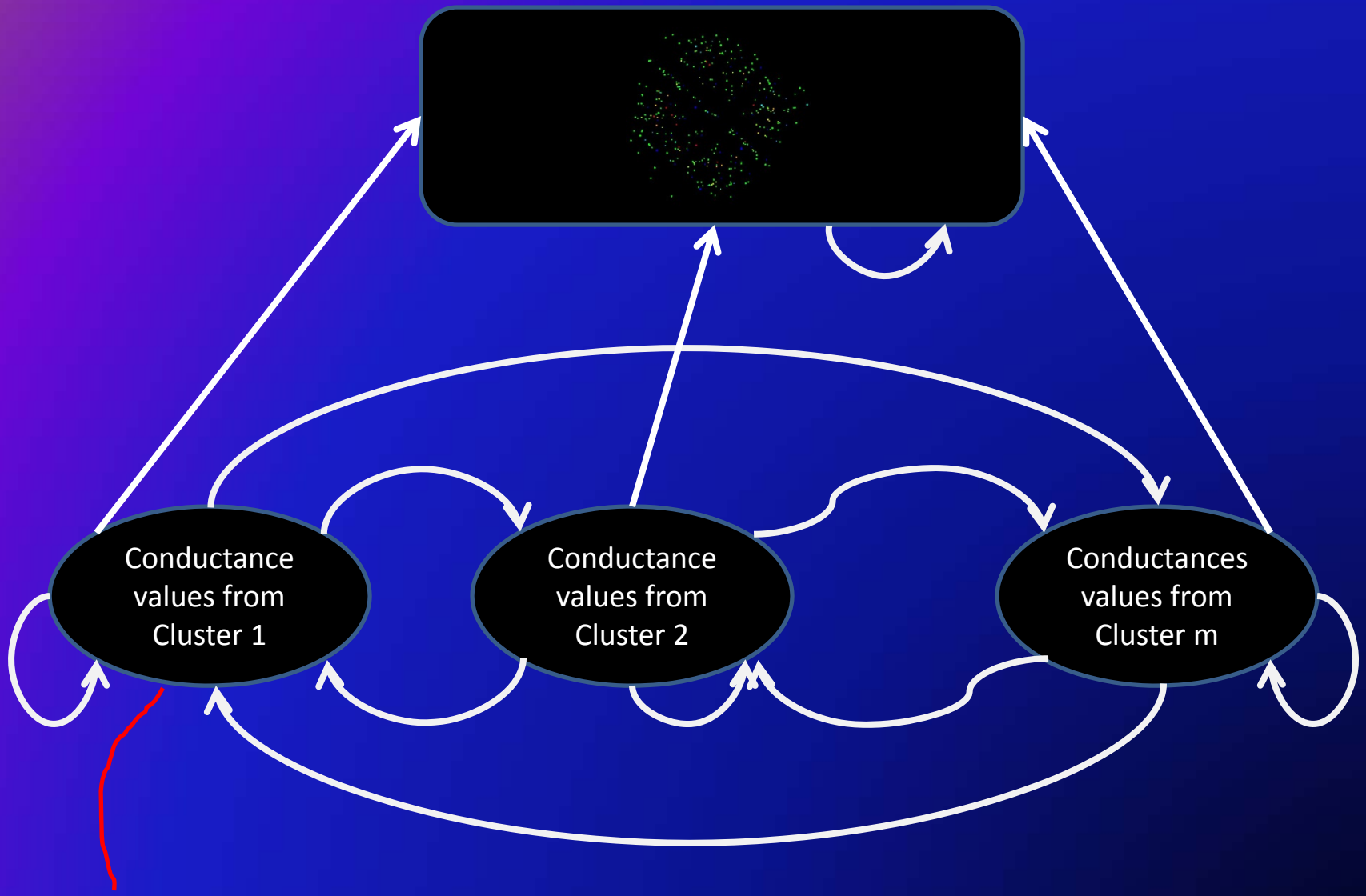
Example category from neural network simulation:

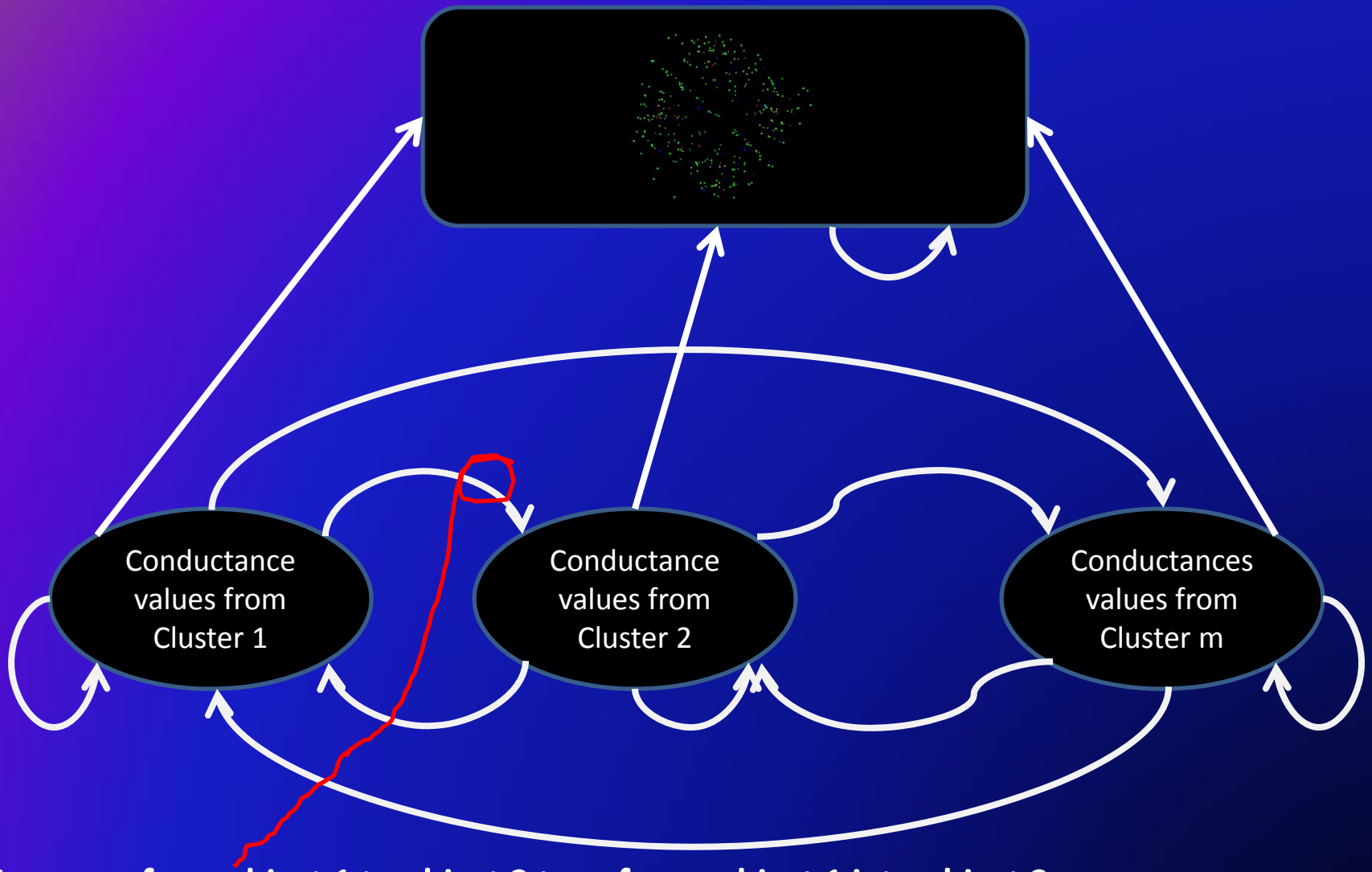
- A gestalt (visual spatial structure) is modeled by a colimit.



- The organization of the gestalt is provided by a pattern of relationships among neural network information states – “brightnesses” of objects and “distances” between them.


Conductance values from Cluster 1
Conductance values from Cluster 2
Conductances values from Cluster m

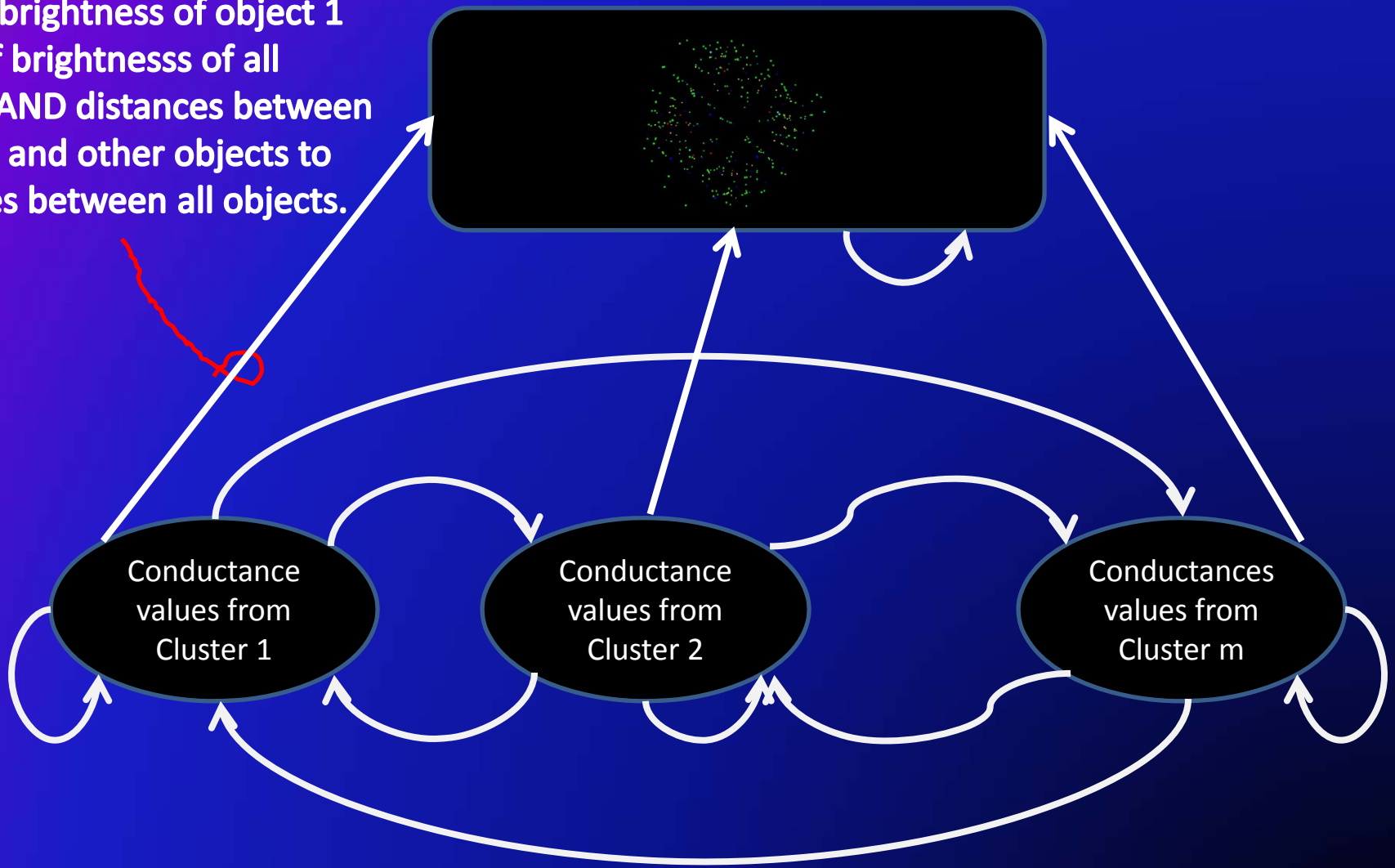

Conductance values from Cluster 1
Conductance values from Cluster 2
Conductances values from Cluster m
1
$G_{11}$
$G_{12}$
$G_{1i}$
$G_{1j}$
$G_{1k}$
$G_{1m}$

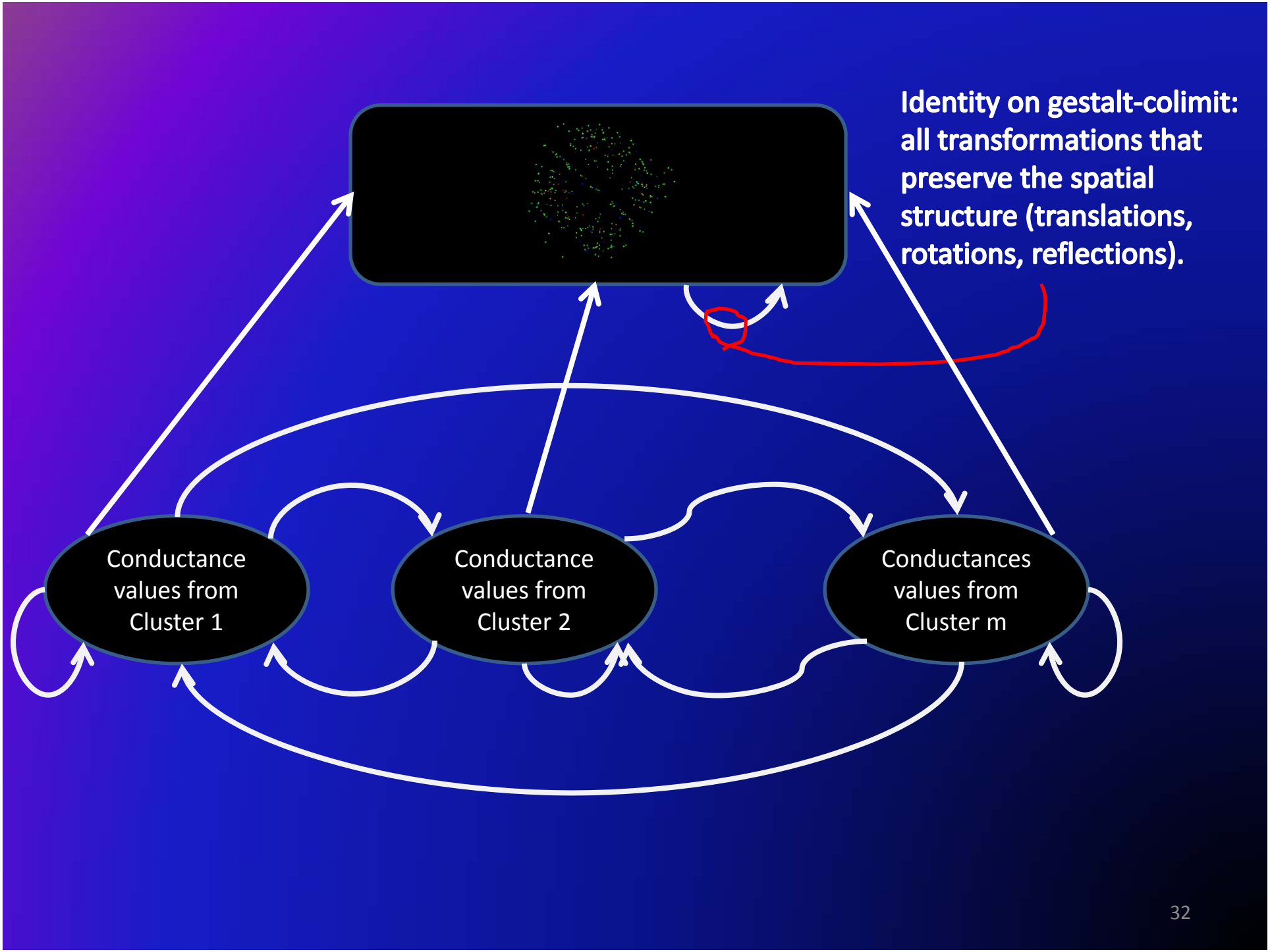


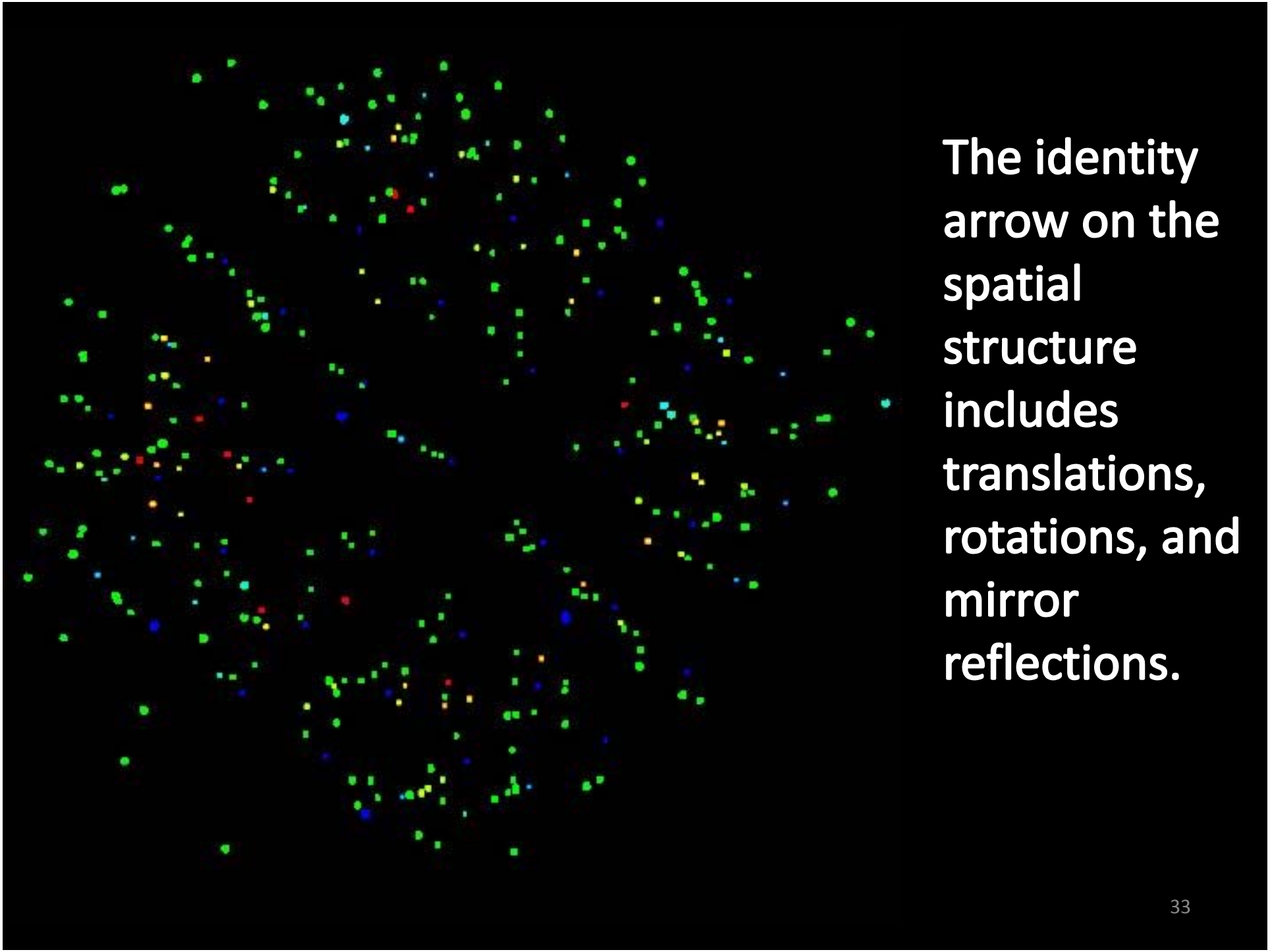

**An arrow from object 1 to object 2 transforms object 1 into object 2:**

**Change brightness of object 1 to brightness of object 2 AND distances between object 1 and other objects to distances between object 2 and other objects.**

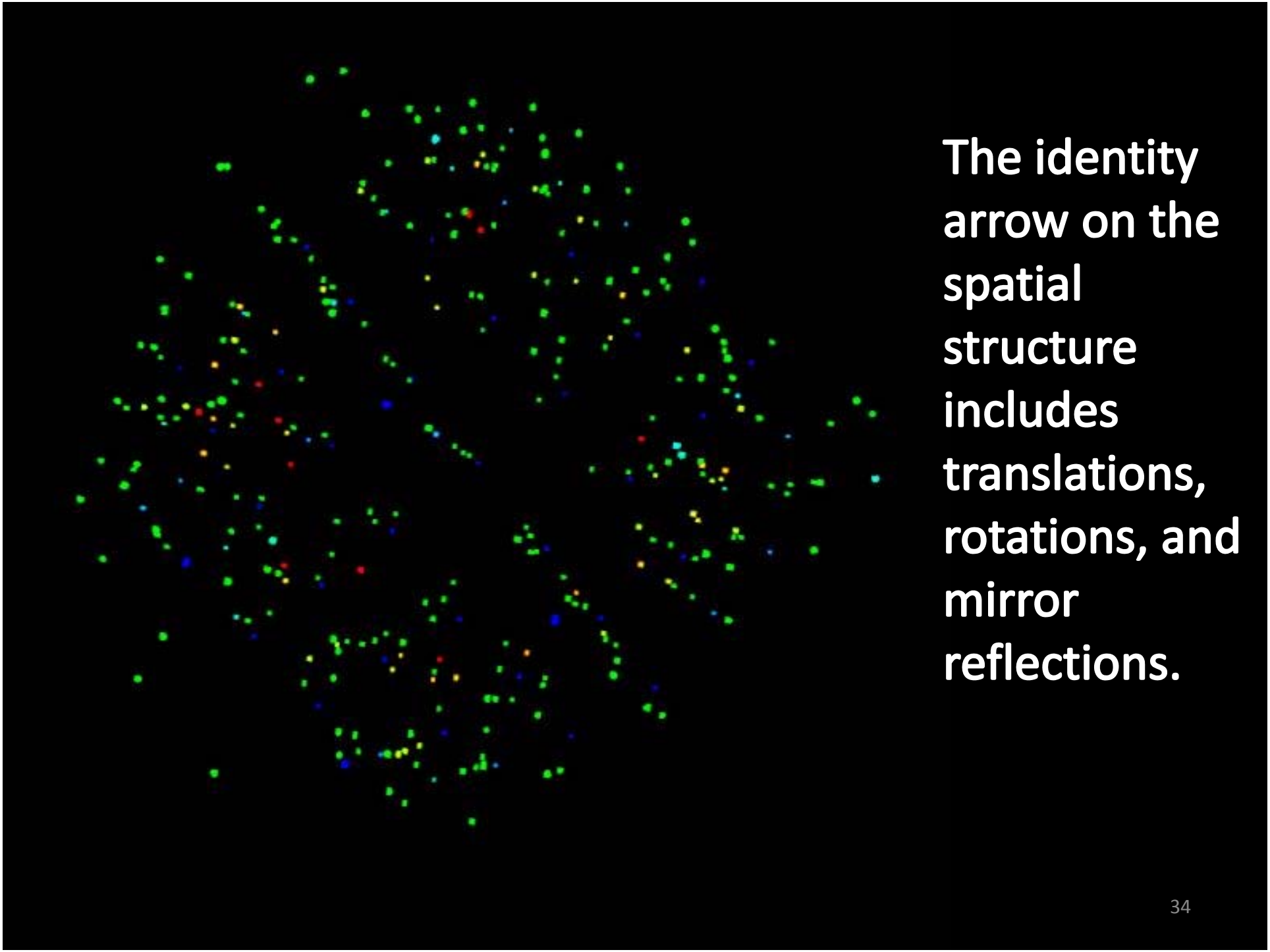
**Change brightness of object 1 to set of brightnesss of all objects AND distances between object 1 and other objects to distances between all objects.**




Identity on gestalt-colimit: all transformations that preserve the spatial structure (translations, rotations, reflections).
Conductance values from Cluster 1
Conductance values from Cluster 2
Conductances values from Cluster m



The identity arrow on the spatial structure includes translations, rotations, and mirror reflections.



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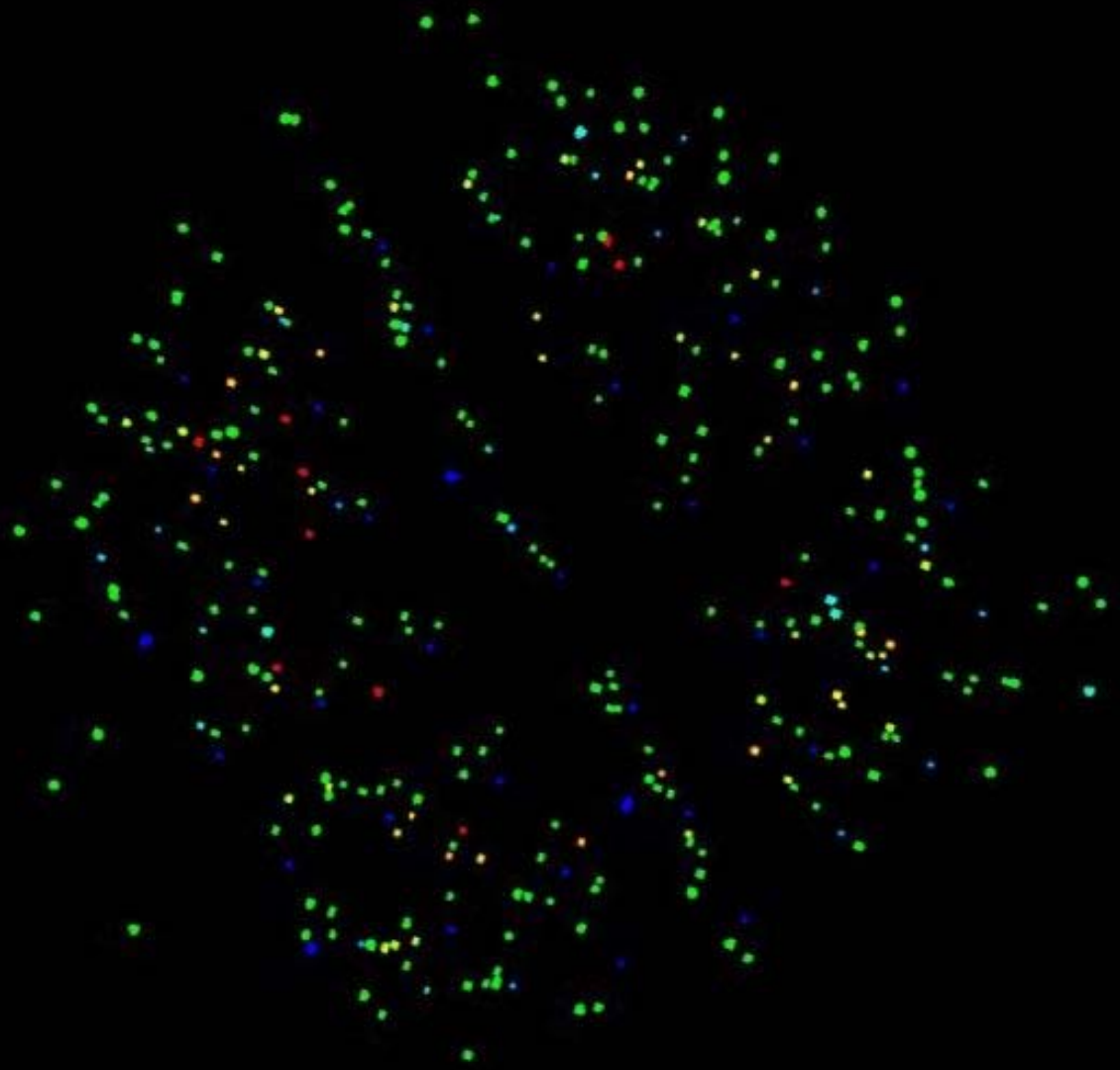

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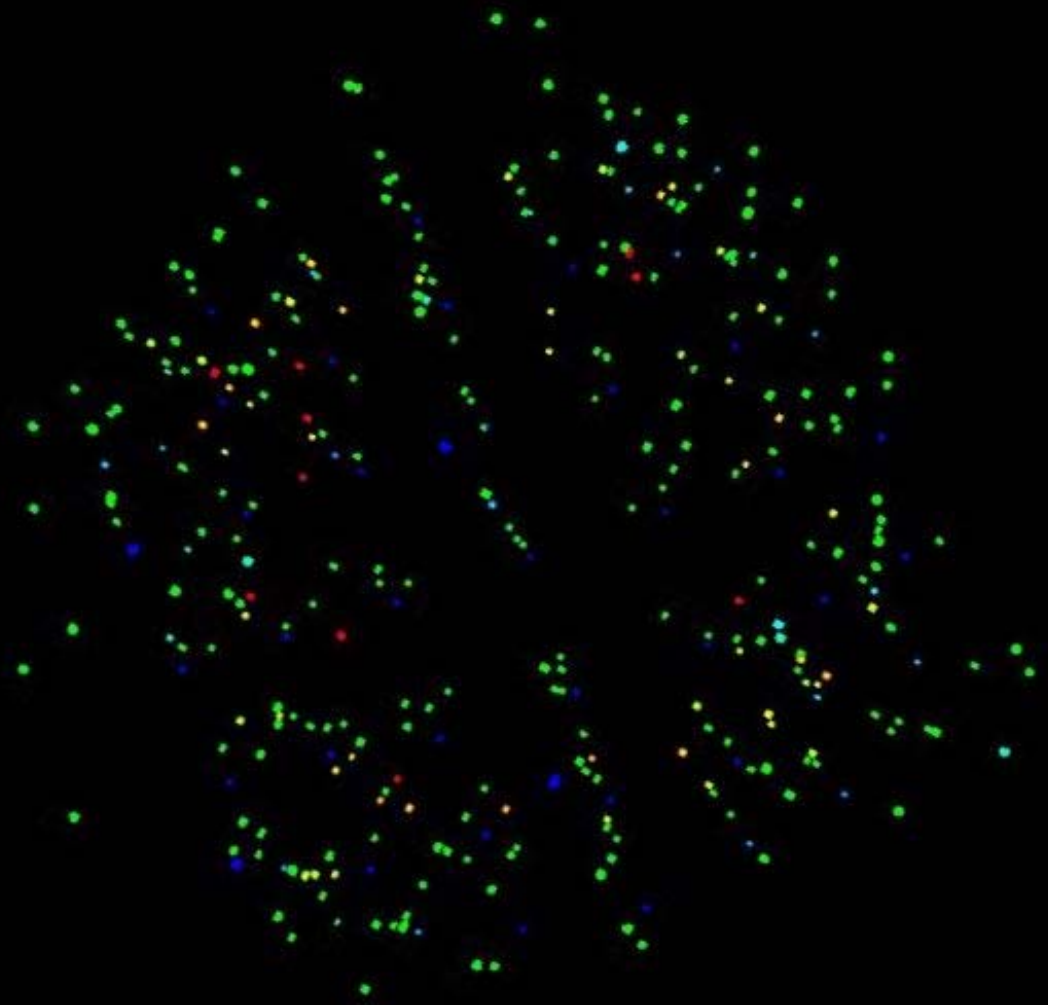

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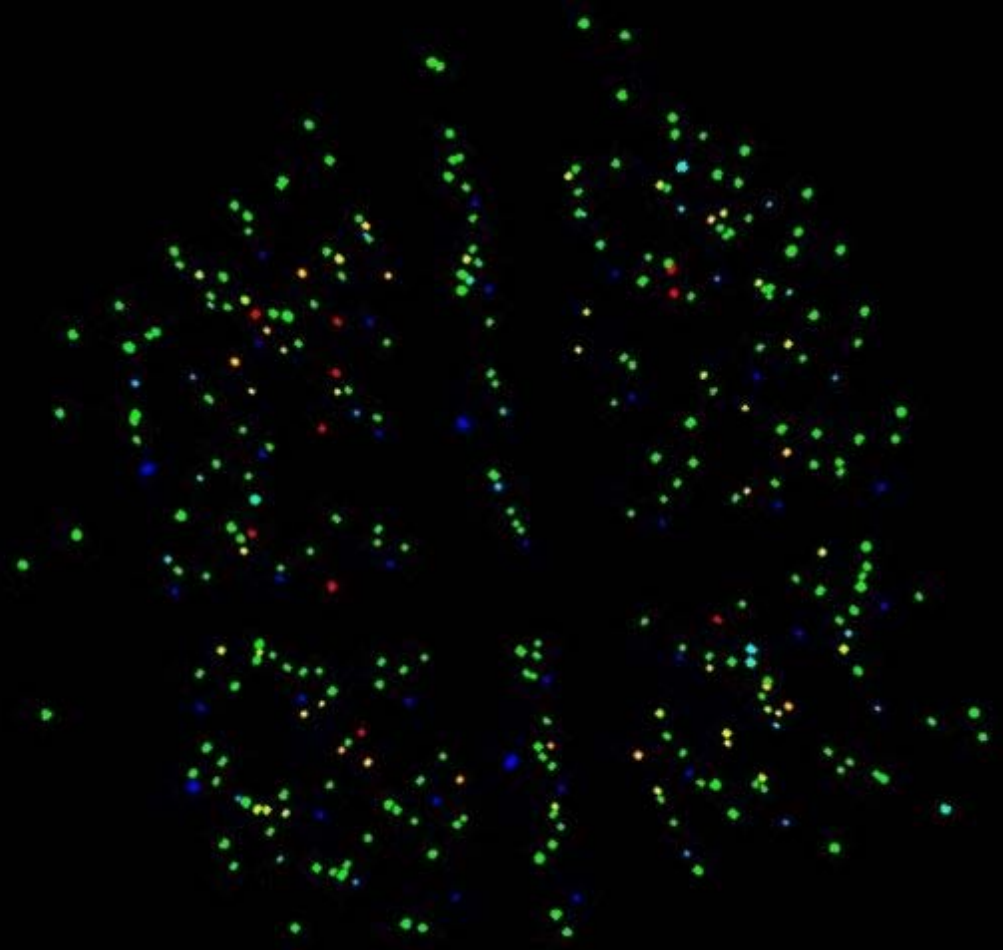

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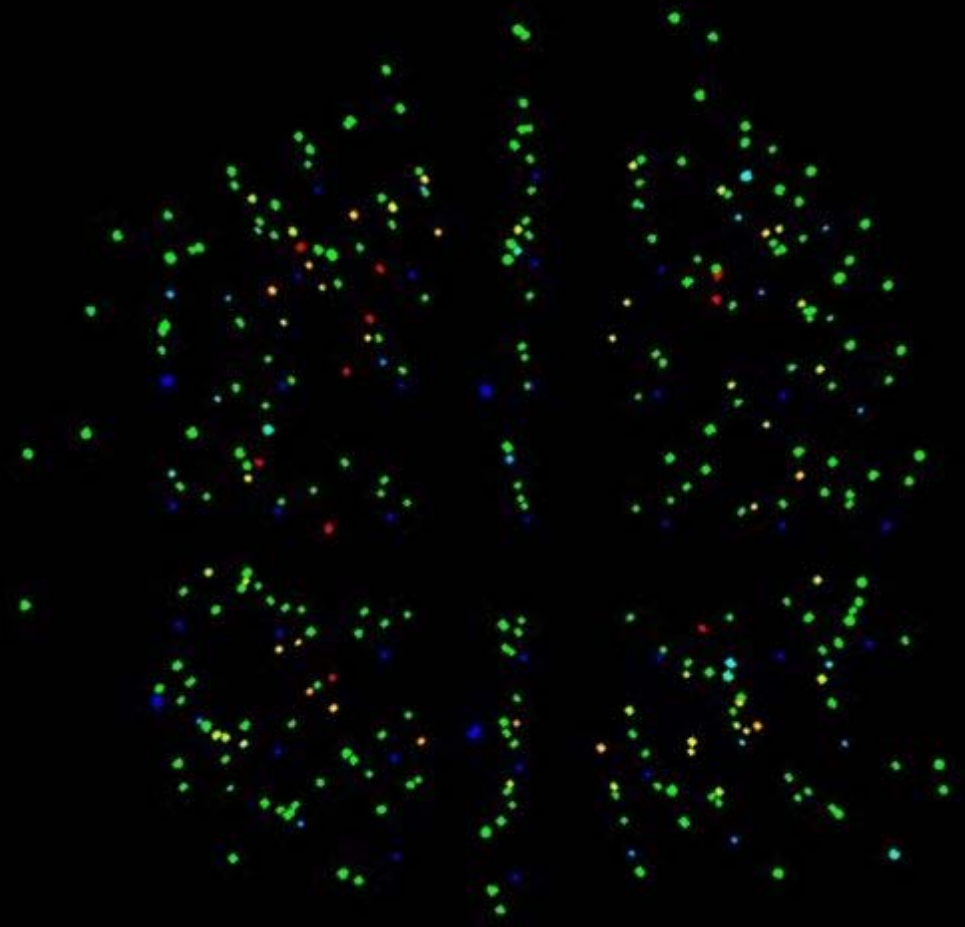

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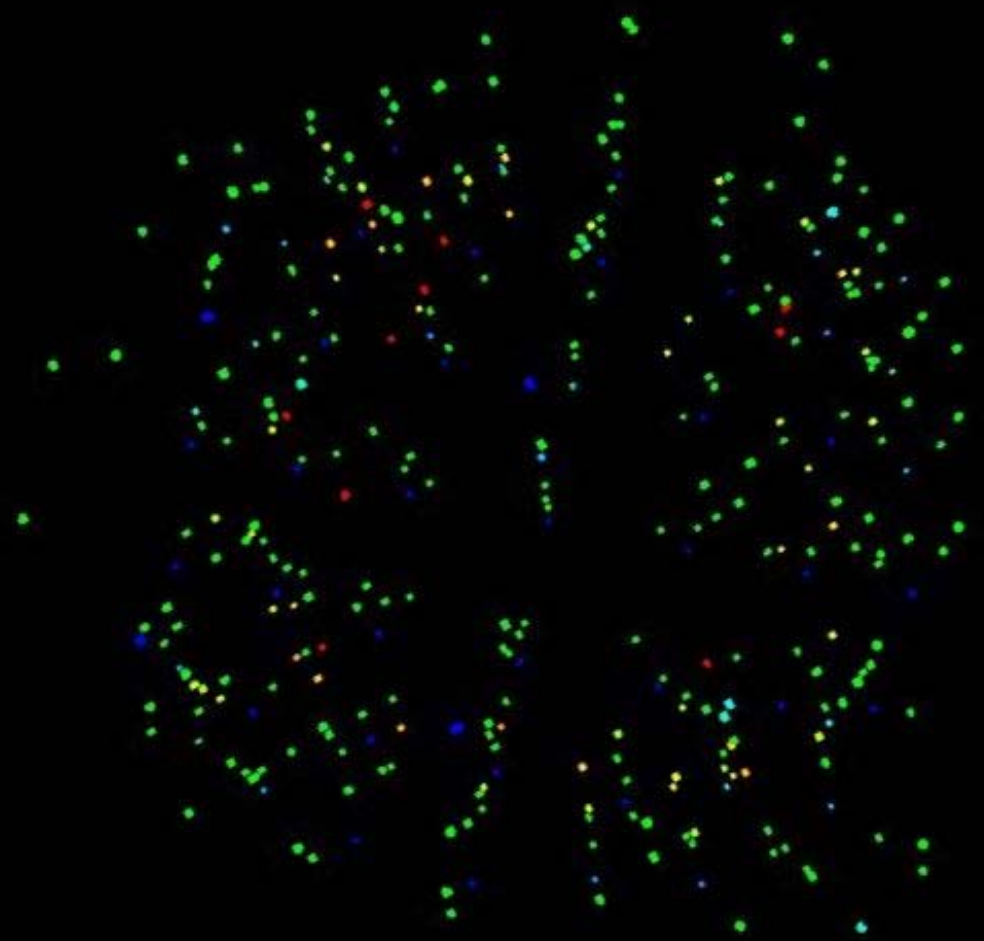
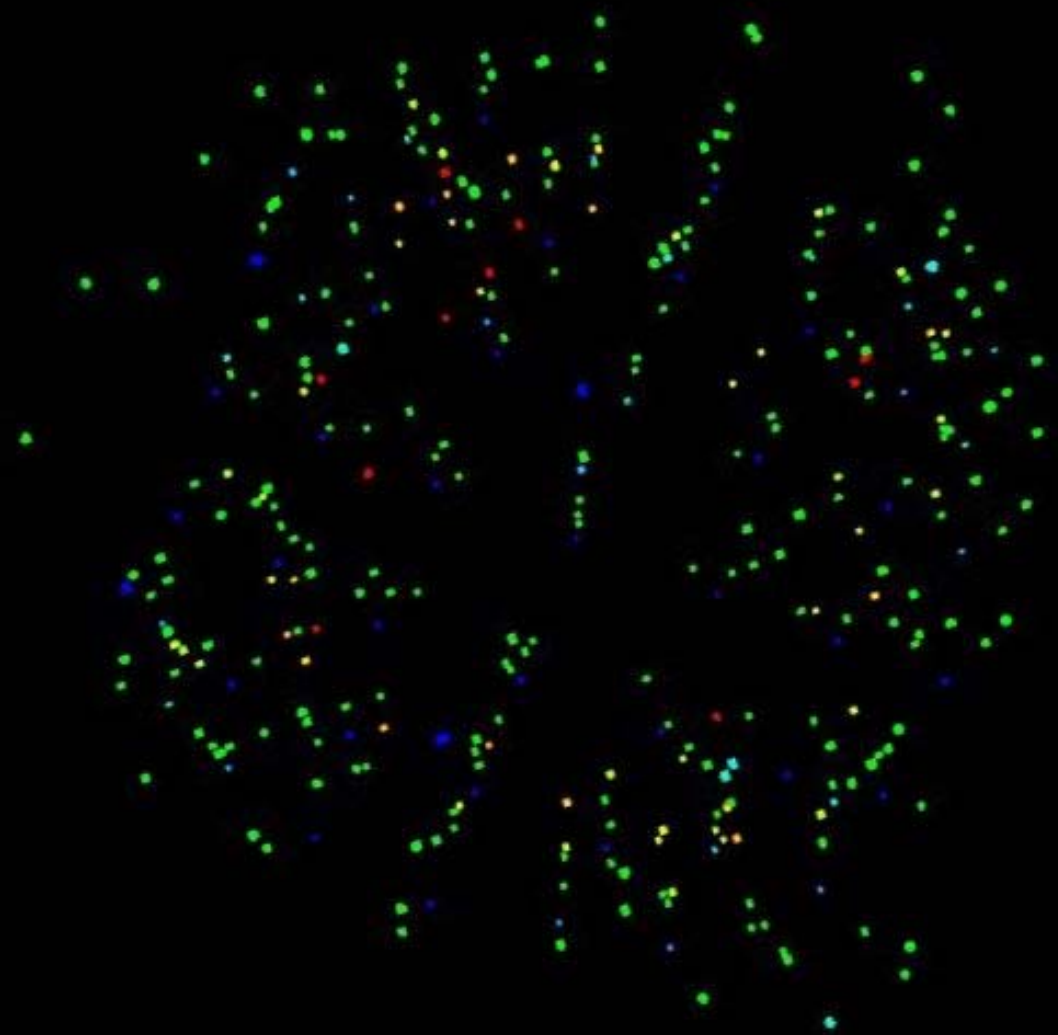


The identity arrow on the spatial structure includes translations, rotations, and mirror reflections.



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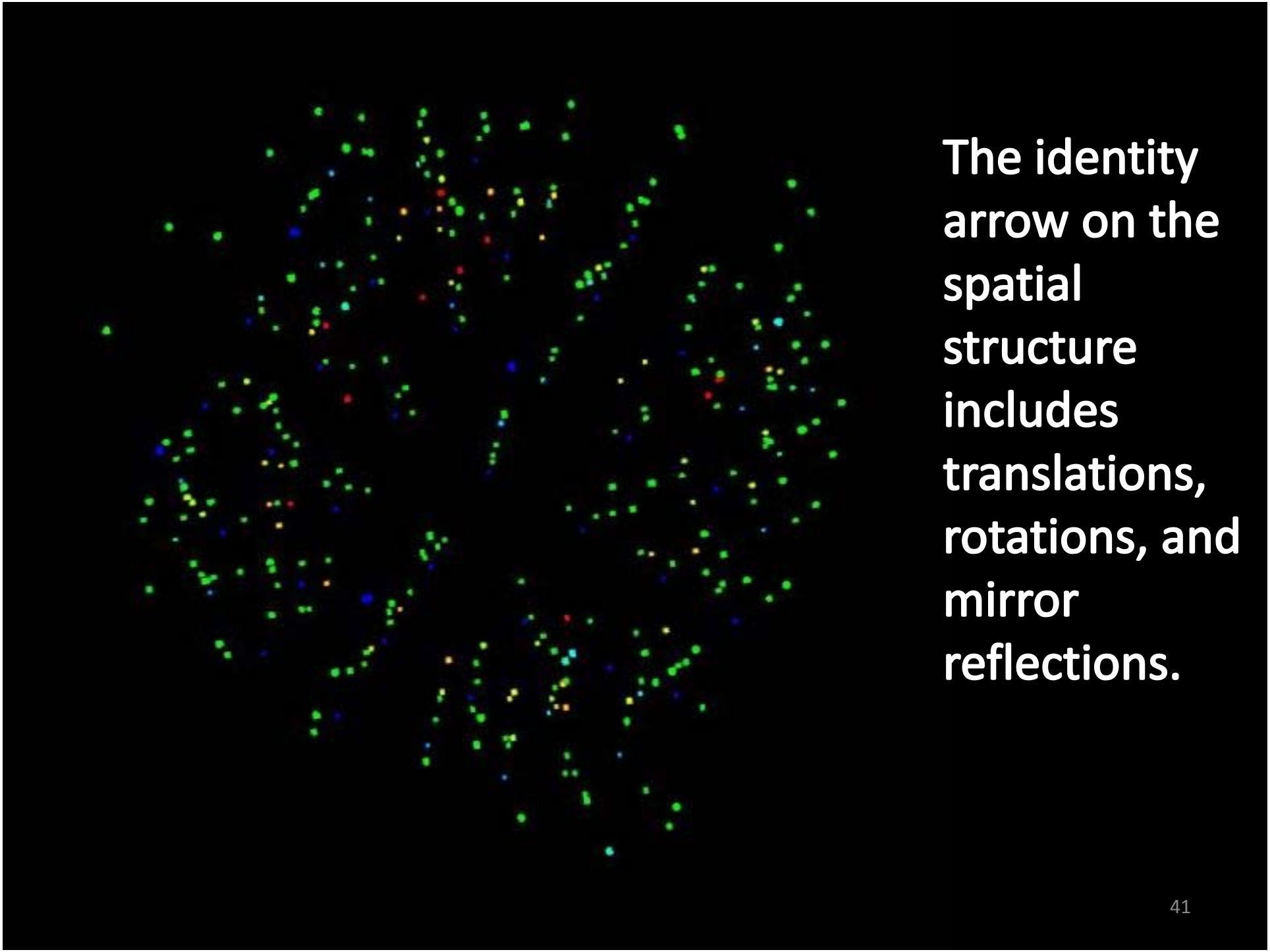

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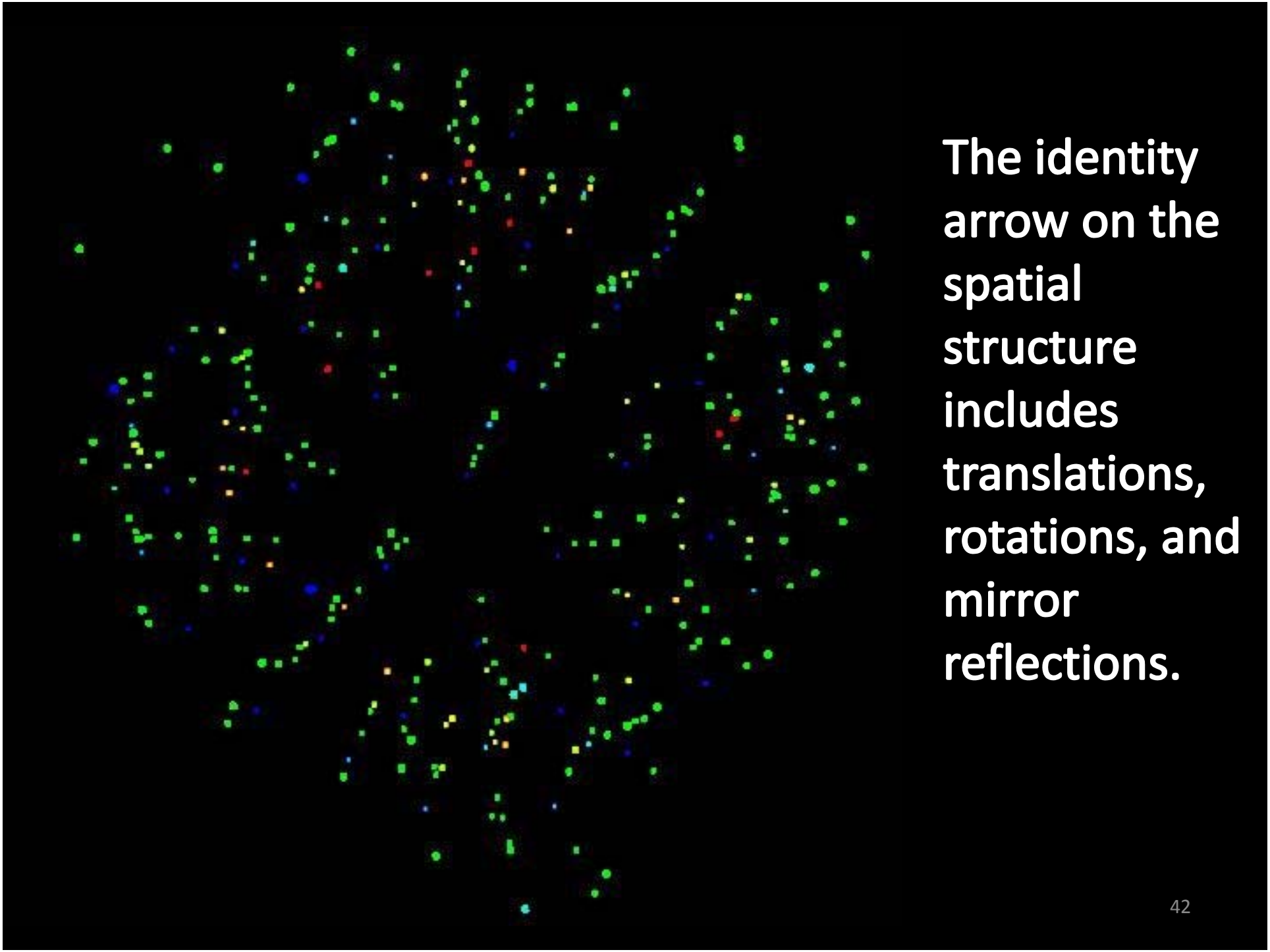
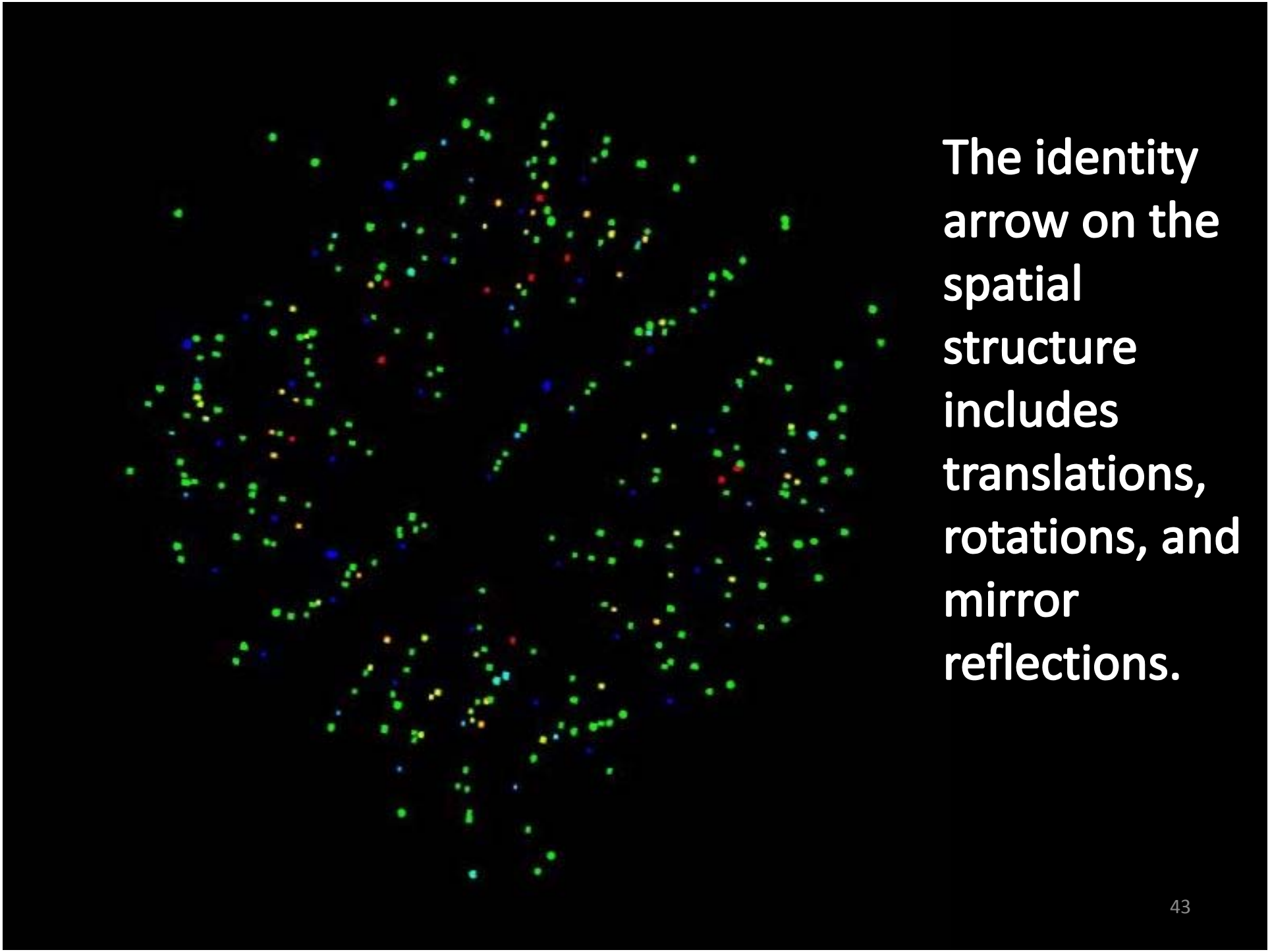
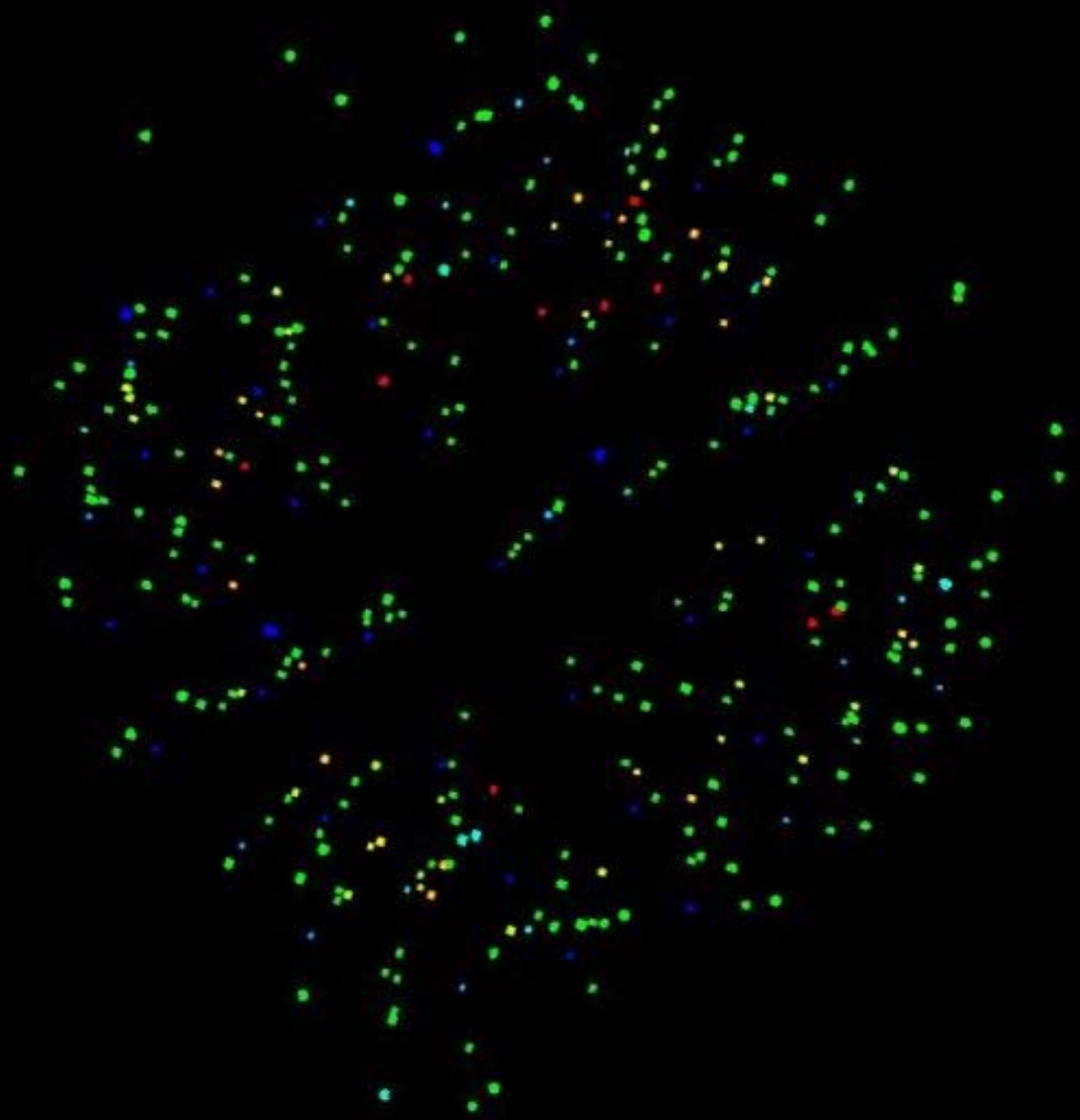


The identity arrow on the spatial structure includes translations, rotations, and mirror reflections.



The identity arrow on the spatial structure includes translations, rotations, and mirror reflections.



The identity arrow on the spatial structure includes translations, rotations, and mirror reflections.

The categorical model constitutes a theory of the coexistence of a visual gestalt and its neural substrate:

- Each object consists of information that the network has about the state of one of its constituents.
- An arrow from a source object to a target object consists of those transformations of phenomenal properties of the source object that yield the target object.
- The identity arrow on the visual gestalt consists of all transformations over which the gestalt is invariant.

Where to go from here:

- Extend work on gestalt-colimits to include relations among gestalts.
- Devise models in which a gestalt-colimit is invariant over topological transformations (Chen, 2005).
- Establish neural correlates of categories with topologically-invariant gestalt-colimits. Explore the use of large-scale brain simulations (Benjaminsson et al, 2012).

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