Slides available ↑

Paper ↓

2025 Oct 3 @UniPd.

Nao Tsuchiya (Monash U, Australia; ATR, Japan)

Outline

1. Background:
2. Qualia Structure paradigm: *Characterizing my red structually*
3. Empirical Research Examples
    a. *Color qualia in periphery*
    b. *Color qualia in young children*
    c. *Color qualia of color-typical and atypical people*
        i. Unsupervised alignment approach
4. Future Outlook

1. Background

Qualia = {phenomenal consciousness, subjective experience, contents of consciousness, qualitative aspects of consciousness, feelings, what-it-is-like}

Non-qualia : anything you do not have experience

Qualia in Narrow(er) vs Broad(er) sense

Have you ever wondered if your red is the same red as my red?

Q1. Do you think it is possible to deal with qualia scientifically?

The Hard Problem: What is the link between the phenomenal and the physical?

Q2. Do you think the Hard Problem is scientifically addressable?

Q. Can we deal with qualia scientifically?

Traditional answer: No.

1. Ineffable 2. Enigmatic (Unclear biological functions)
3. Private 4. Intrinsic (cannot quantify) - (Dennett 1988)

Most empirical research: Give up “qualia”.

Focus on finding neural correlates, using “binary responses”.

Resulting studies have not provided strong constraints on theories.

-> Explosion of consciousness theories

(Bayne & Seth 2023, Kleiner 2024, Kuhn 2025)

My answer: Yes!

Via Qualia Structure, Integrated Information Theory, and future scientific approaches

Tsuchiya 2024 Qualia Structure

2. What is the qualia structure paradigm?

qualia-structure.jp

Funded by the Japan Society for the Promotion of Science (2023- 2028)

2. the Qualia Structure project

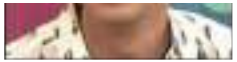
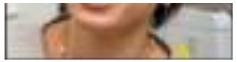
Tsuch

Three pillars of our approach

- We aspire to arrive at novel ways to understand others' minds.
- Towards that end, we will advocate **structural approaches to qualia**.
- With the **structural approaches**, we will internationally lead the next generation consciousness research.

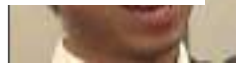

Taguchi Ishihara

Phenomenology

Moriguchi Nakano

Development

Oizumi Horii

Information structures

2. Q-str + IIT: Summer school 2025

(Qstr summer school in Okinawa, 2026?)

Neuroscience, Maths (category-sheaf theory), Philosophy, Integrated Information Theory

What is it like? Youtube!









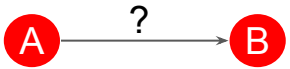






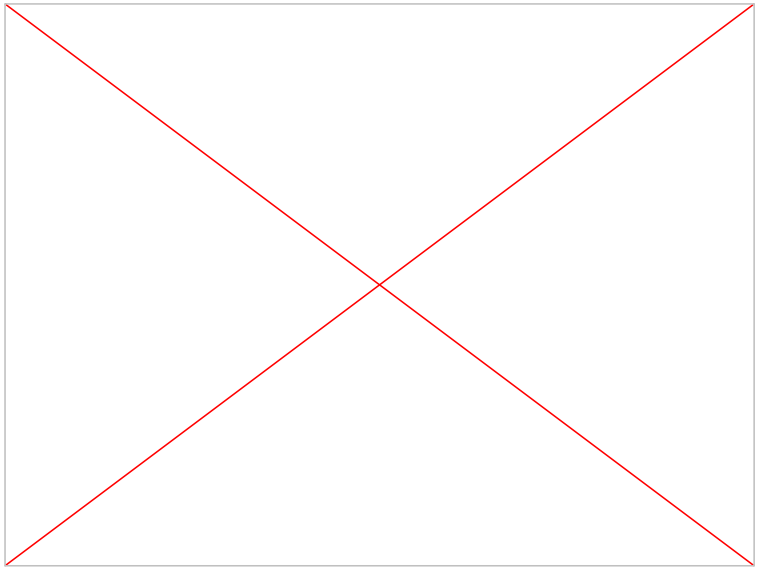
2. Quantifying Qualia Structures through a Massive Relationships among Qualia!

Idea: Can we characterize something that is difficult to define through relationships?



hA ≅ hB ⟹ A ≅ B : If the relations are the same, the two are the same.

Analogy: **Meaning of words, Properties of animals/plants in ecosystem, Black Holes, Infinity in maths, Personality**

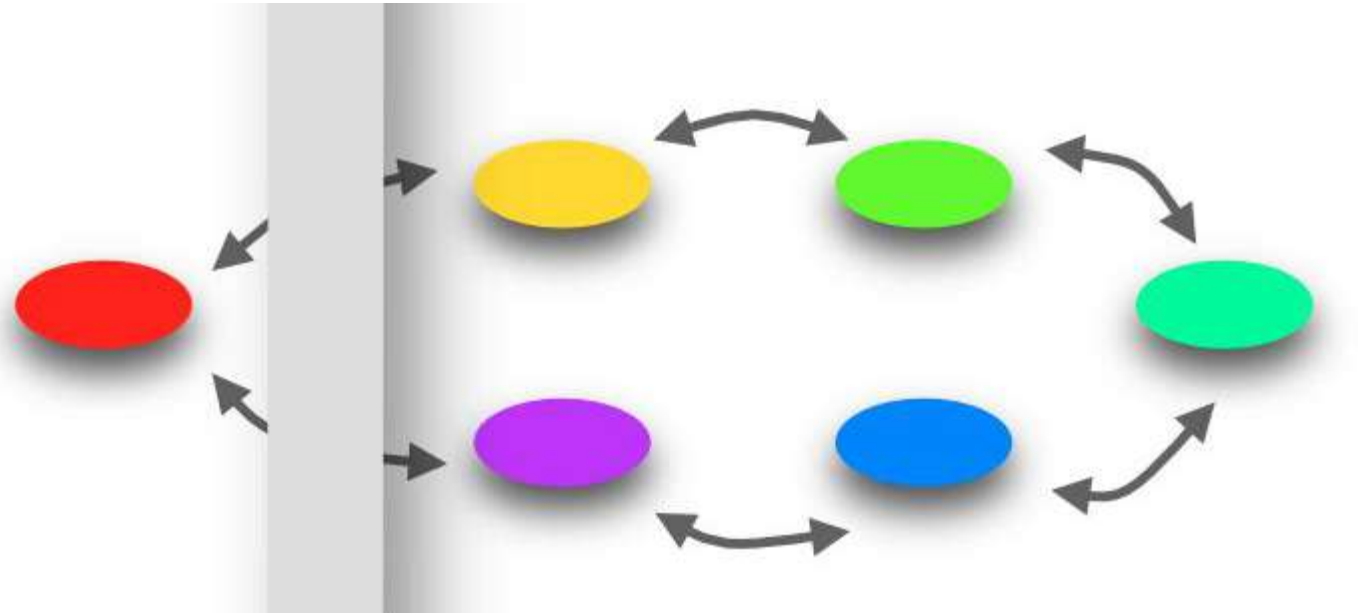


Mathematical proof: **Yoneda lemma in Category Theory**
(Lemma is like a pre-theorem for a major theorem)
Hom(Hom(A,-), F) ≅ F(A)

Tsuchiya & Saigo 2021 Neurosci Consciousness,
Tsuchiya, Phillips, Saigo 2022 Consciousness & Cognition

Structures of qualia: Infer through a massive web of relationships among qualia (the Yoneda perspective)

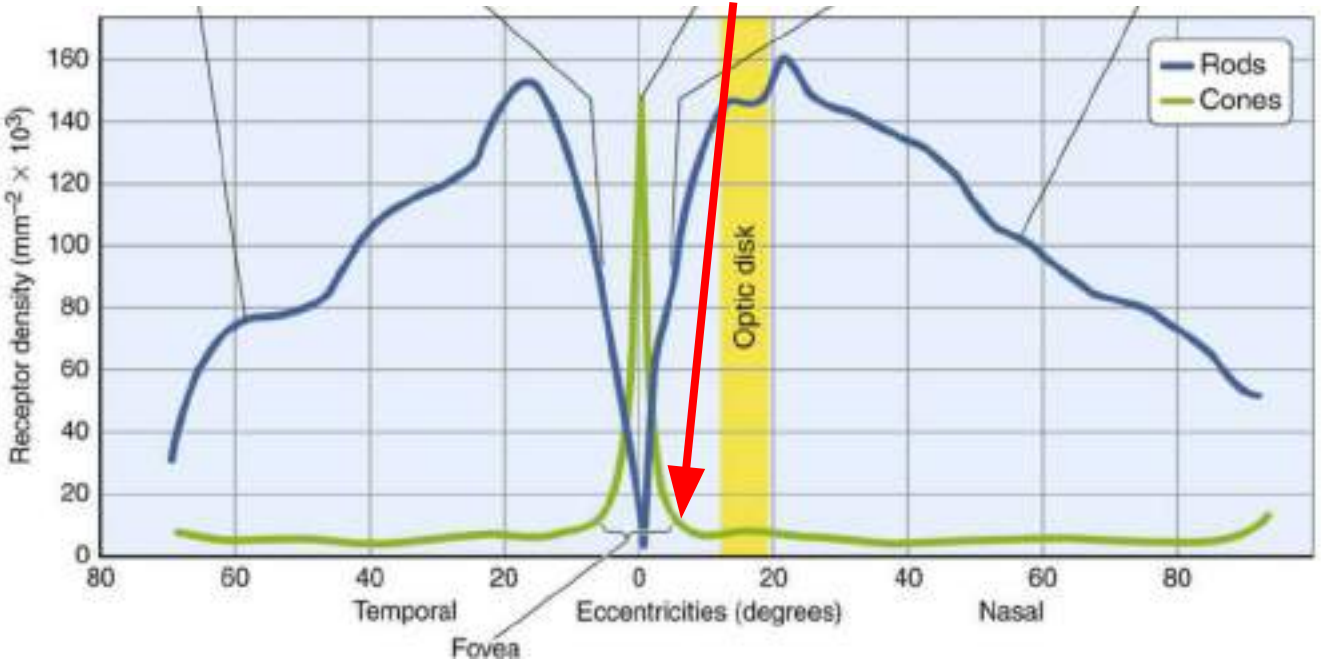
Example: similarity-based relationships



How can we use the Yoneda lemma in research?

Q1. Are our color qualia at periphery illusory?

At the edge of display (5-10 deg vis angle), nearly no color receptors?



Qualia are illusory!

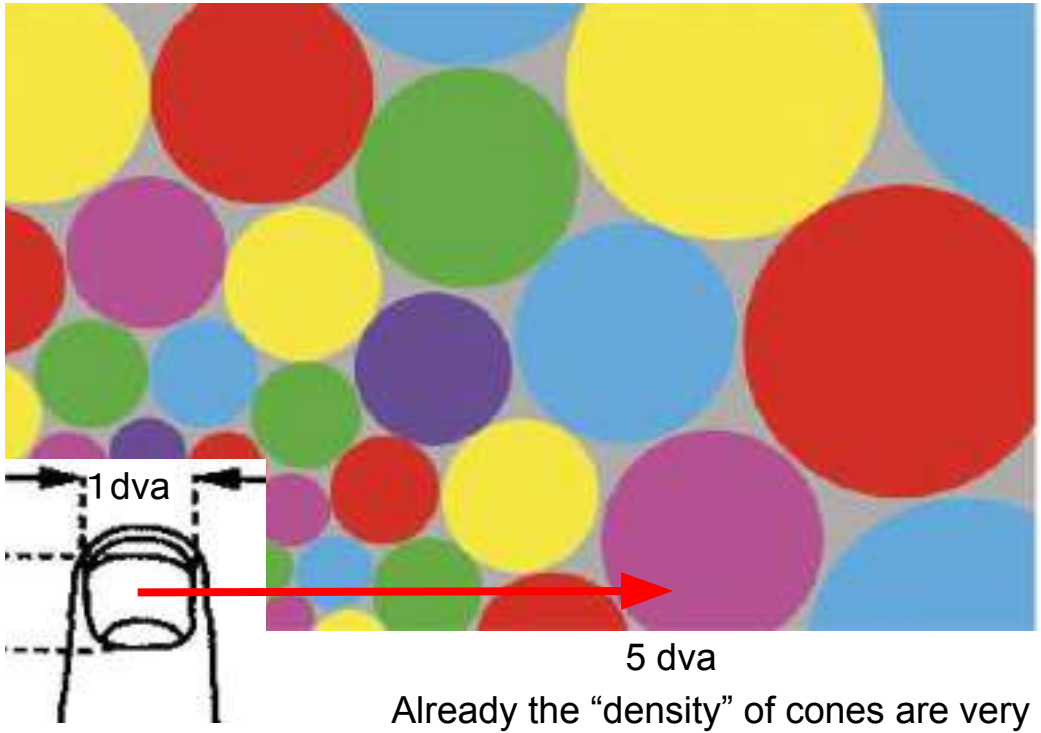
Dennett (1991-) Illusionism

Dehaene (2001-) GNW

Refrigerator illusion?

Yoneda-lemma inspired experiments:
Q1. Are our color qualia at periphery illusory?

Can we deny the reality of subjective color?



Already the “density” of cones are very low.

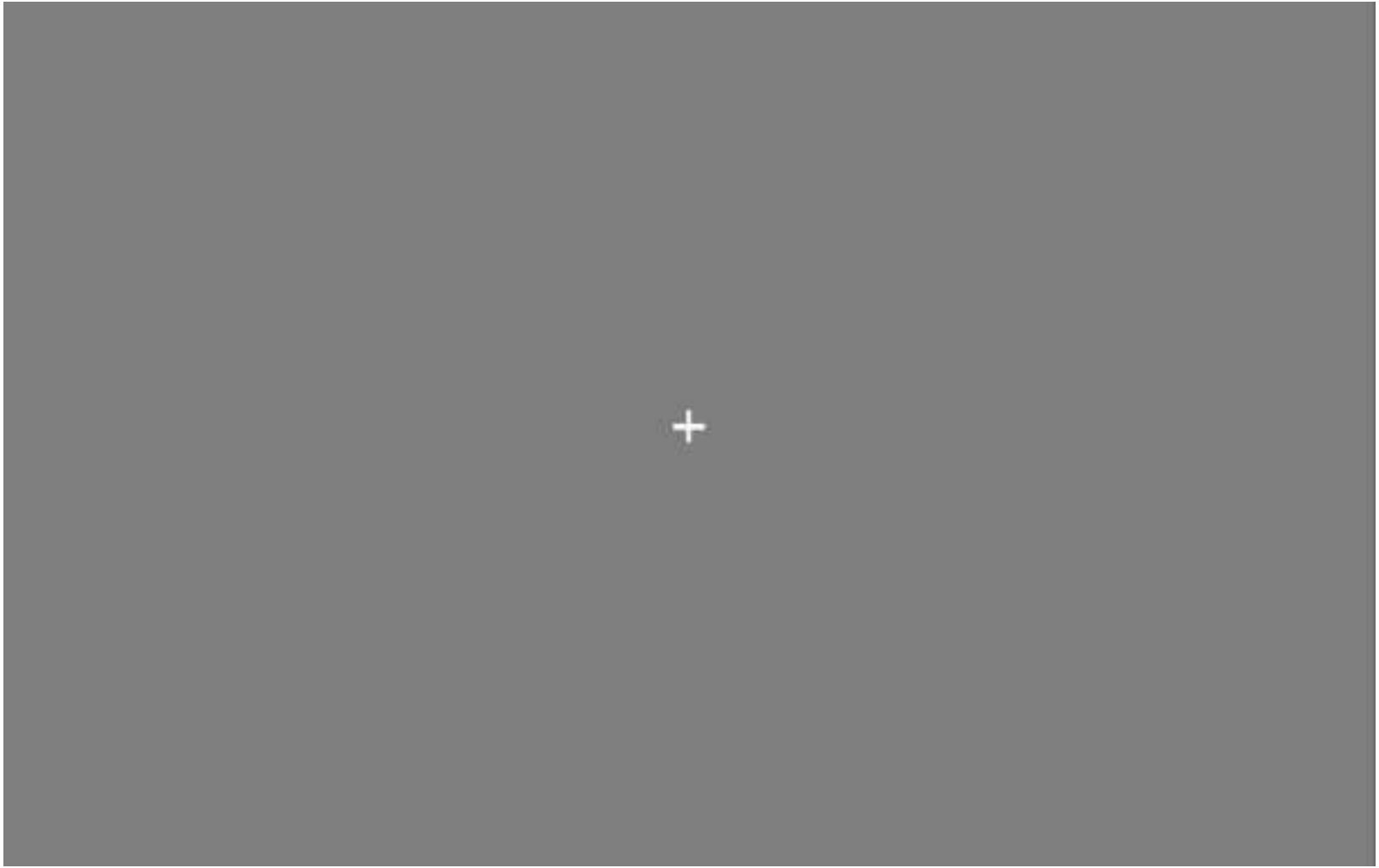
Qualia are the reality!

Tononi (2004-)
IIT

Chalmers

Lamme (2004-)
Recurrency

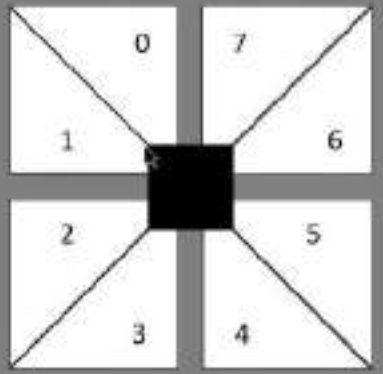
Haun, Tononi, Koch, Tsuchiya (2017)
Neuroscience of Consciousness



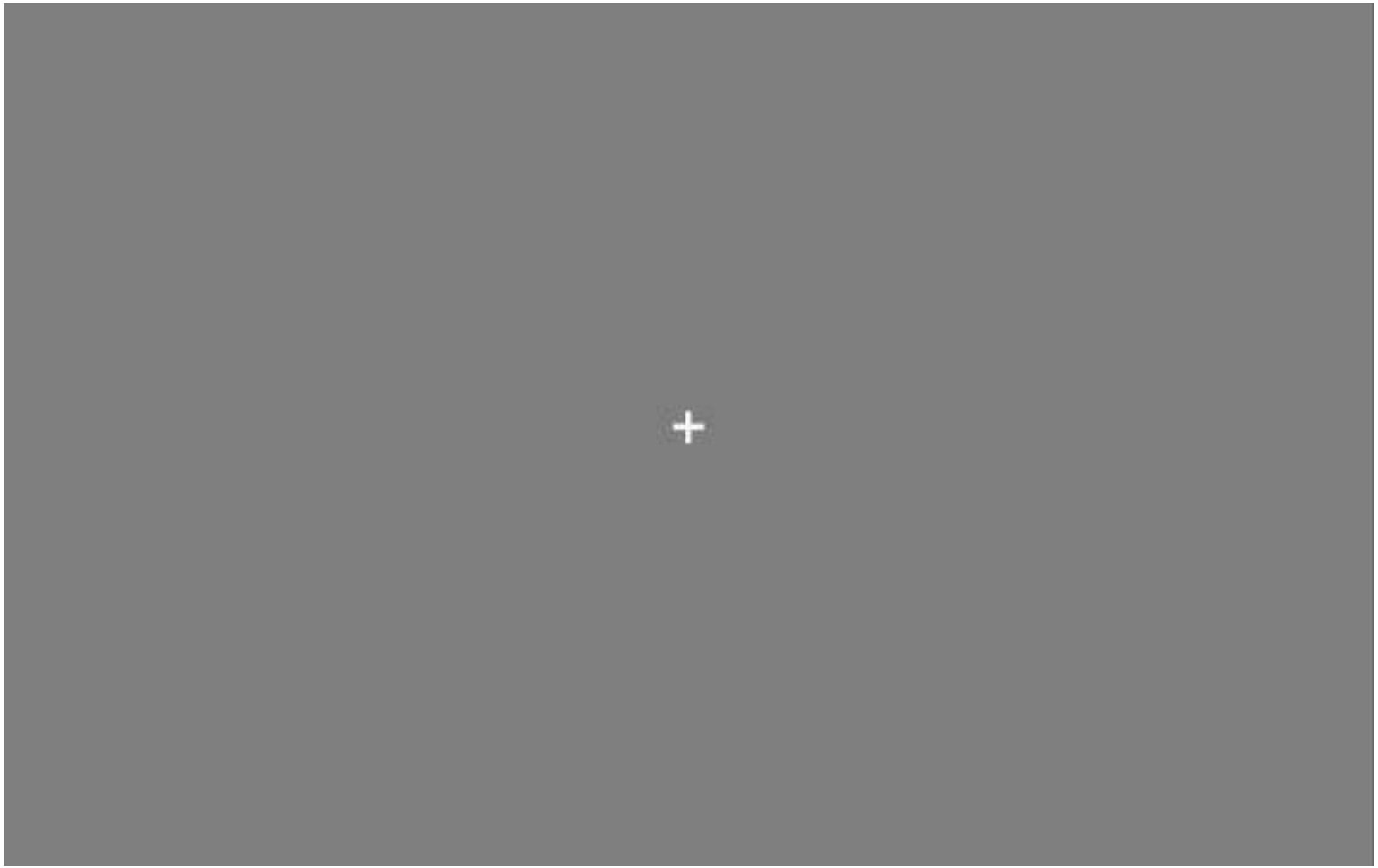
250 ms

Practice Trial

Dissimilarity Level

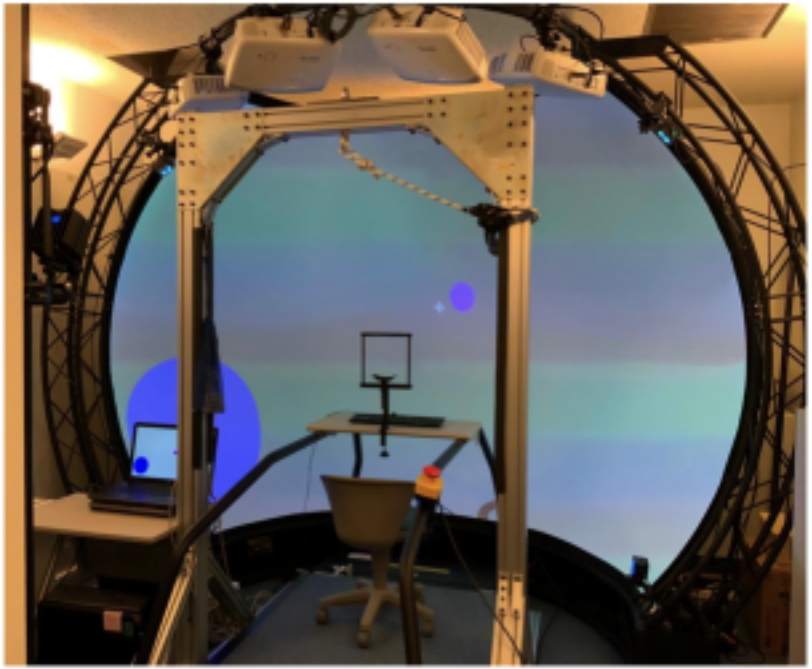


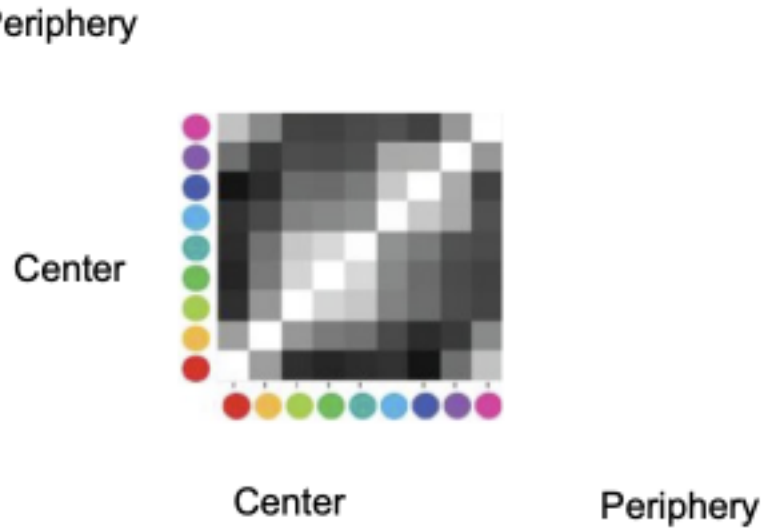
Please choose the dissimilarity level of previous 2 circles
0 => Most Similar
7 => Most Dissimilar



Zeleznikow-Johnston, Aizawa, Yamada, Tsuchiya (2023) Journal of Cognitive Neuroscience

Registered report: Are the peripheral color illusory? Is the structure of color qualia same?





Zeleznikow-Johnston, Aizawa, **Yamada, Tsuchiya** (2023) J of Cog Neuro

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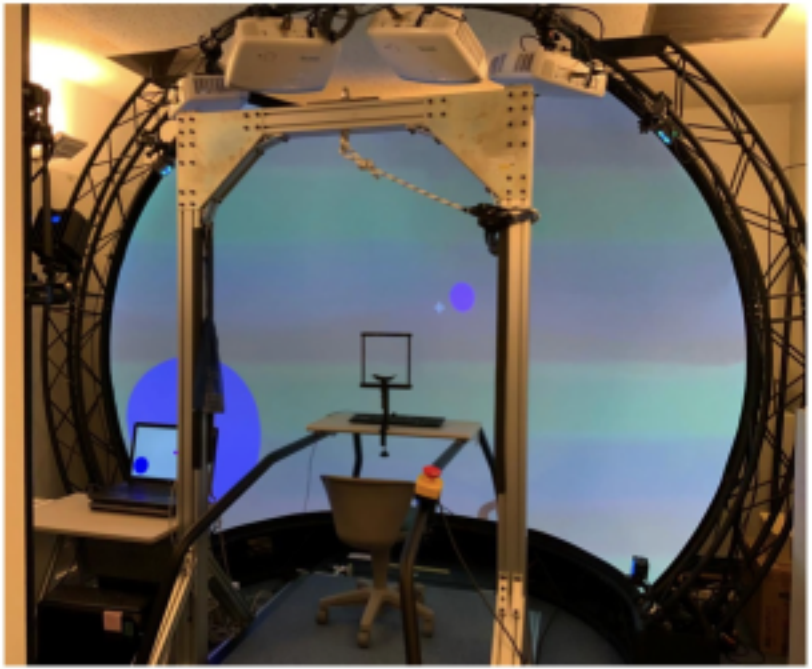
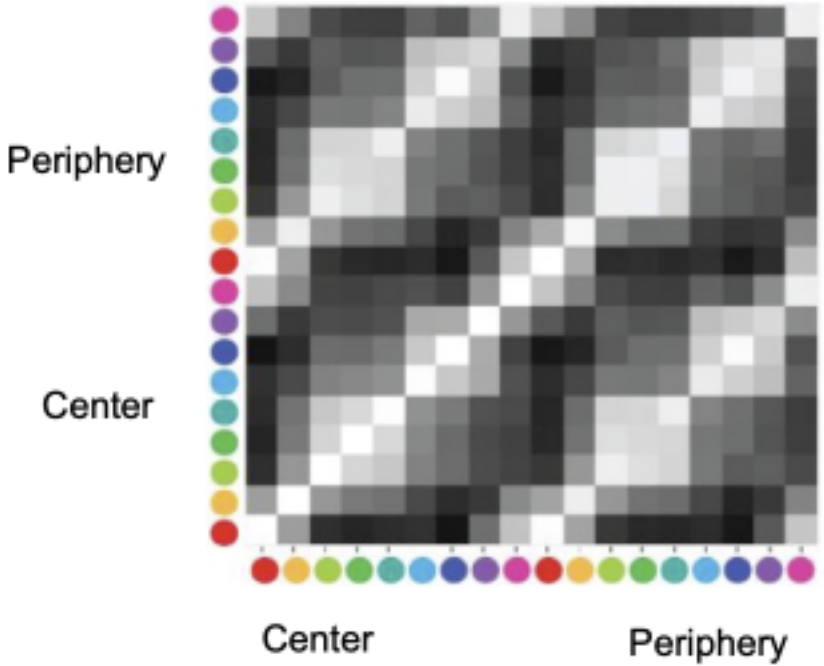
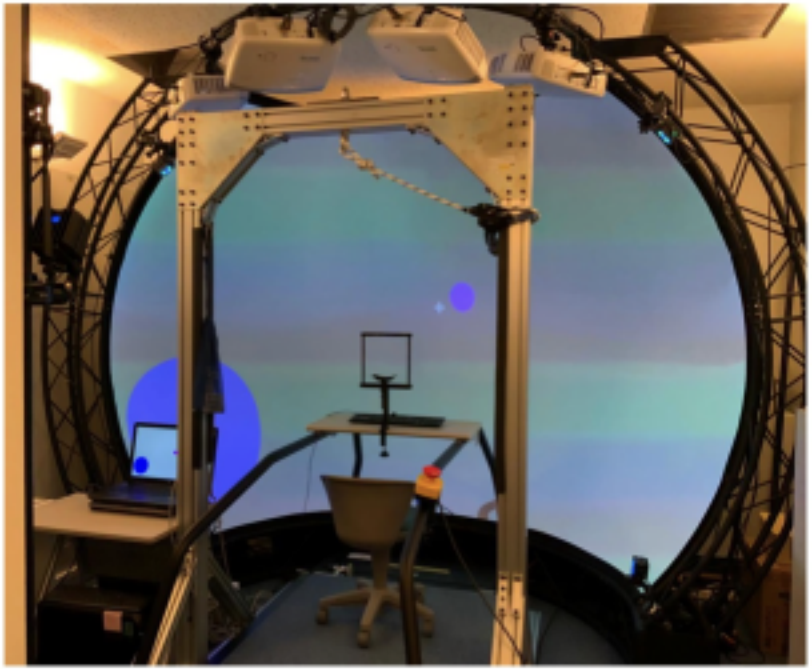




Zeleznikow-Johnston, Aizawa, **Yamada, Tsuchiya** (2023) J of Cog Neuro

The structures of color qualia are the same!

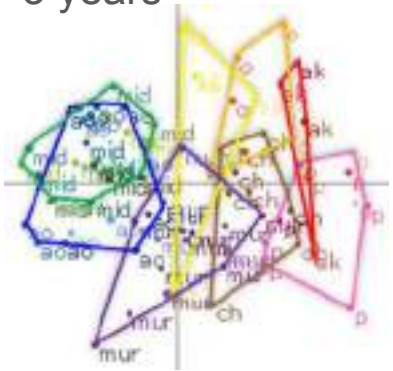


Zeleznikow-Johnston, Aizawa, **Yamada, Tsuchiya** (2023) J of Cog Neuro

Developmental comparison of color qualia structures through a similarity task

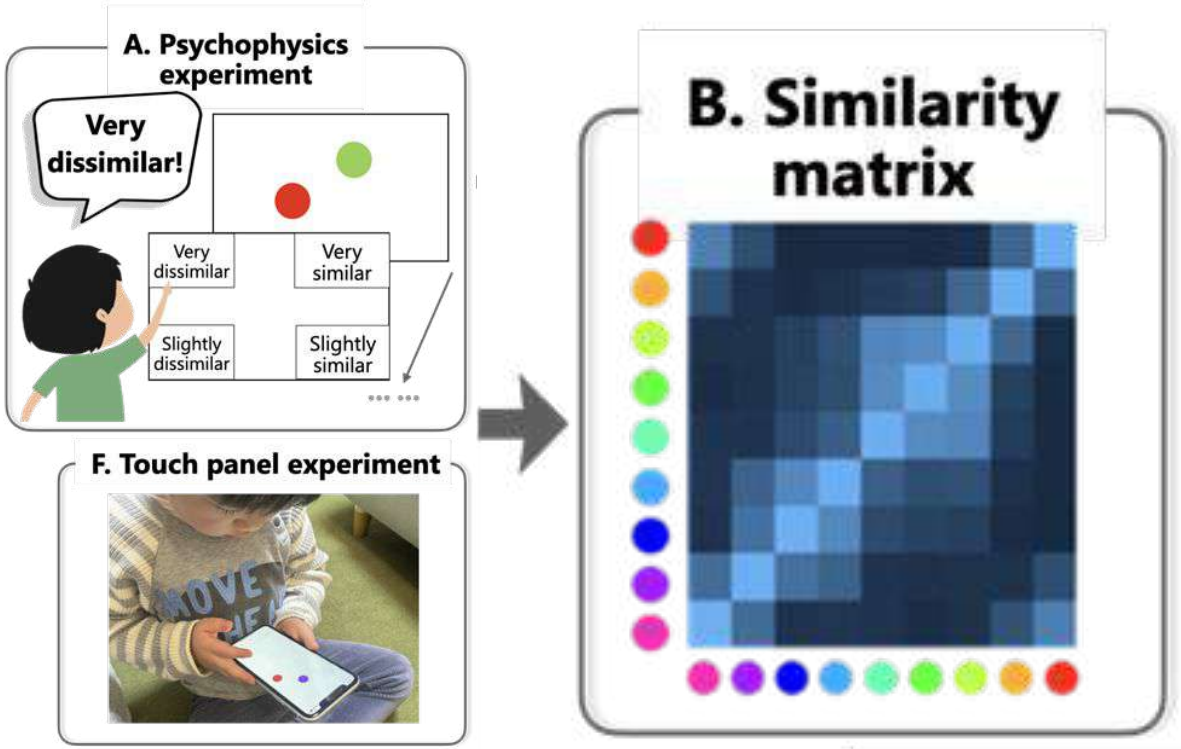
Saji et al 2020 Cog Sci
(93 colors, verbal)

3 years



Adults

Moriguchi et al 2025 PNAS (9 colors, similarity)



Developmental comparison of color qualia structures through a similarity task

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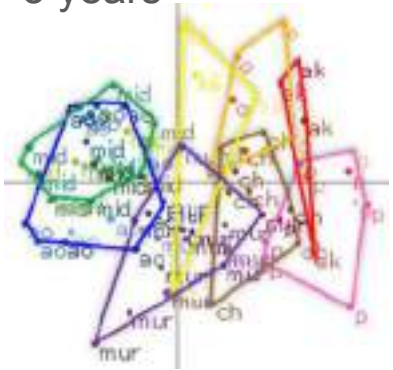

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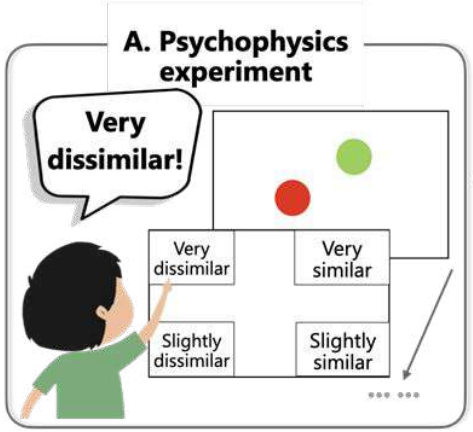

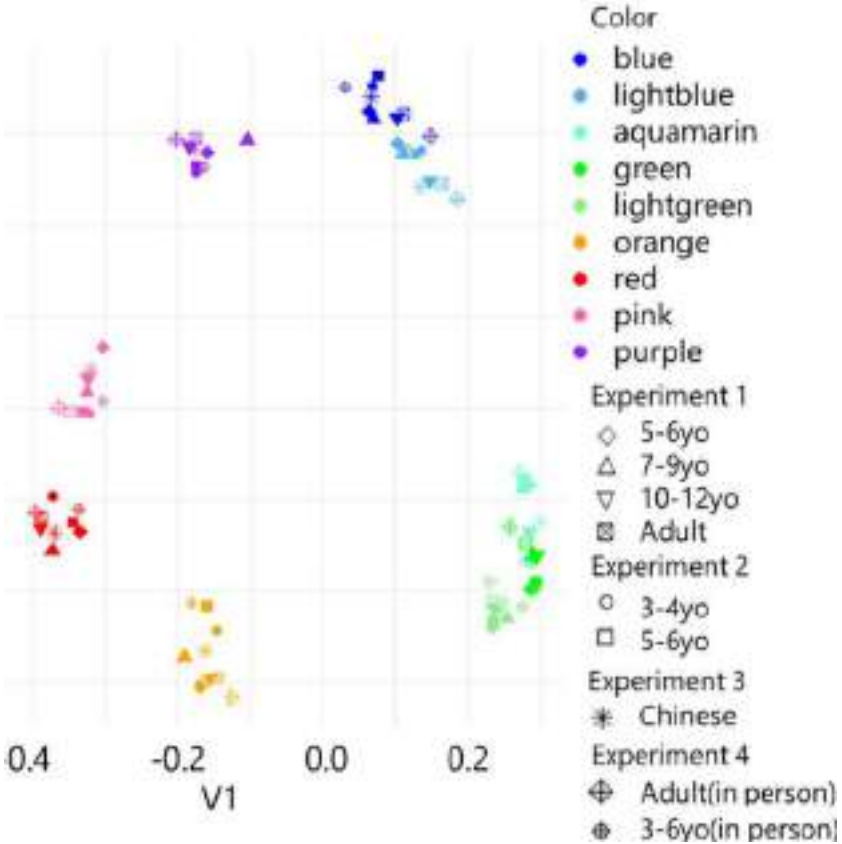

Developmental comparison of color qualia structures through a similarity task

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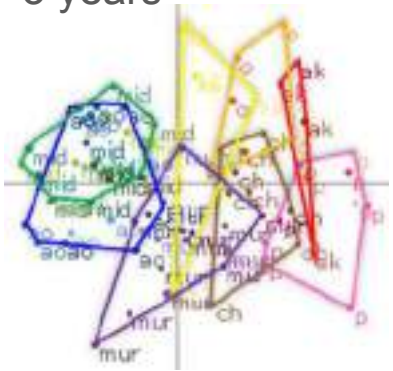

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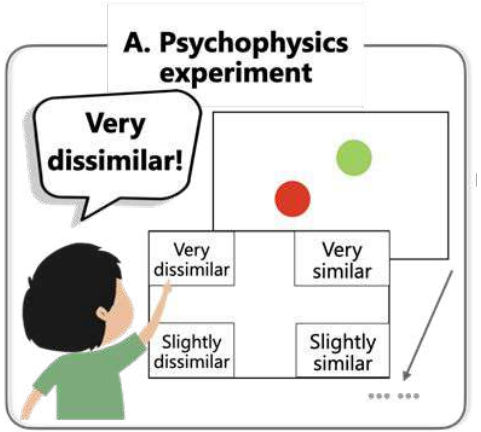
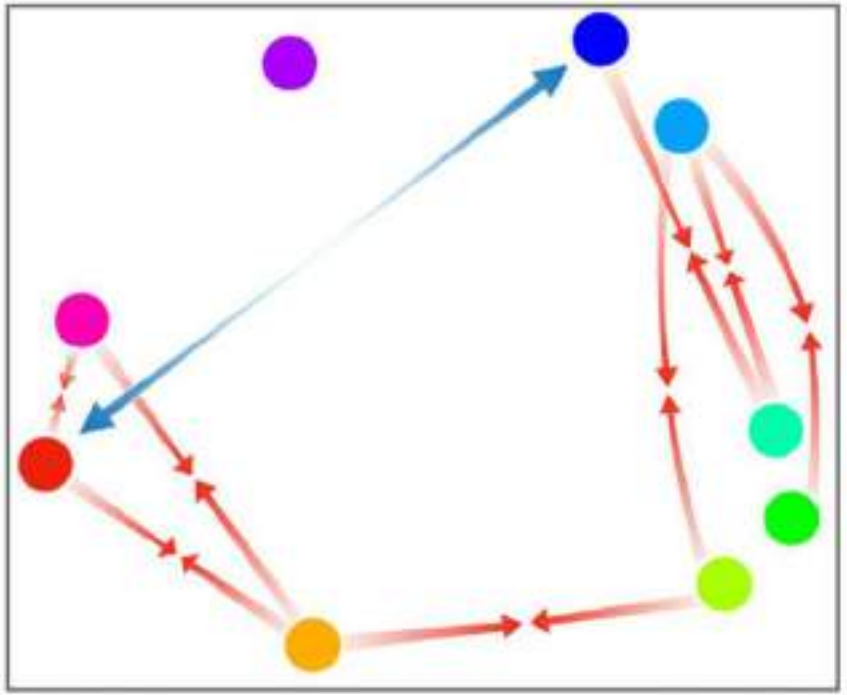




Do we experience “blueness” in the same way?

- Can we make it scientific?

Extend 9 x 9 color similarity ratings
into 93 x 93 color similarity ratings
(>300,000 trials online)

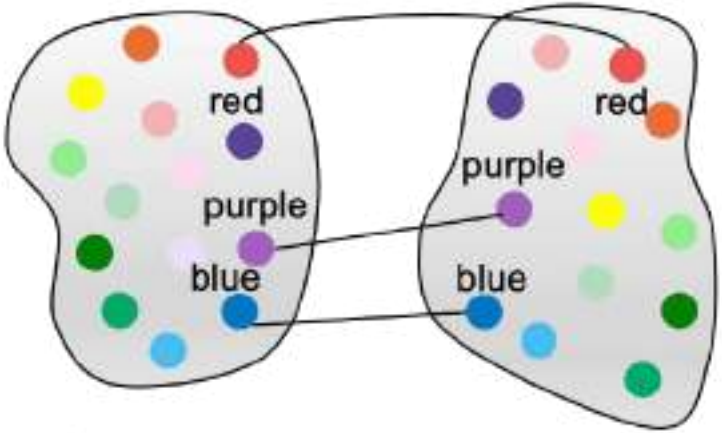
and

Unsupervised *(blind)* ***structural alignment***

Is My “Red” Your “Red”?

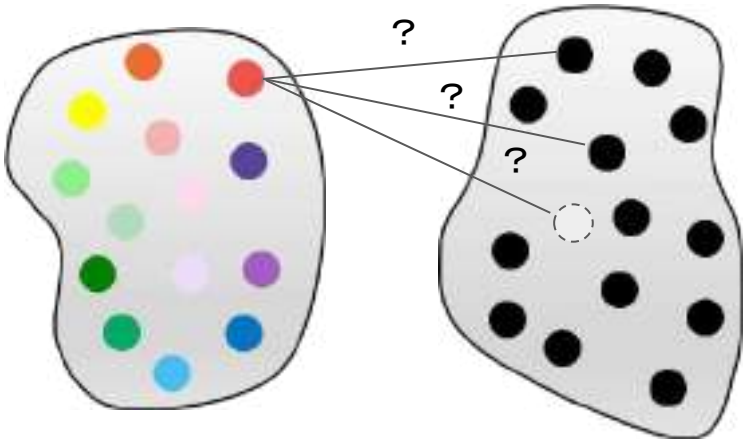
x Traditional method:

- Alignment between labeled ***objects***

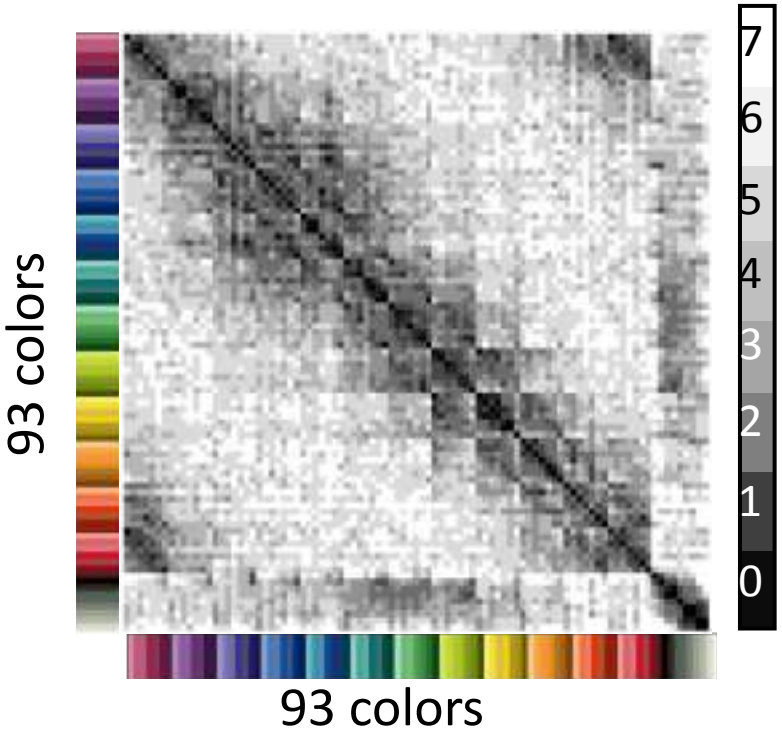


◯ Our novel structural approach:

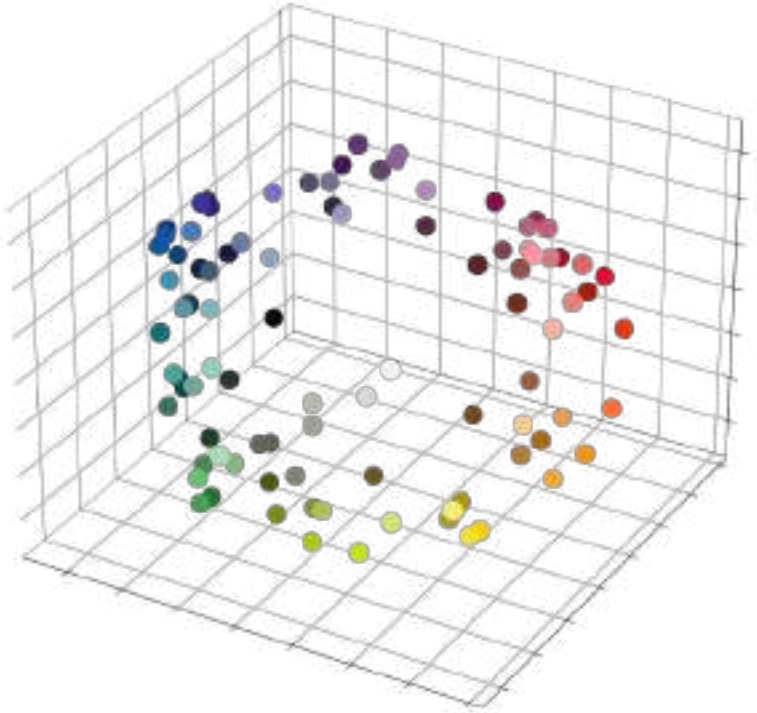
- Alignment between ***relationships***

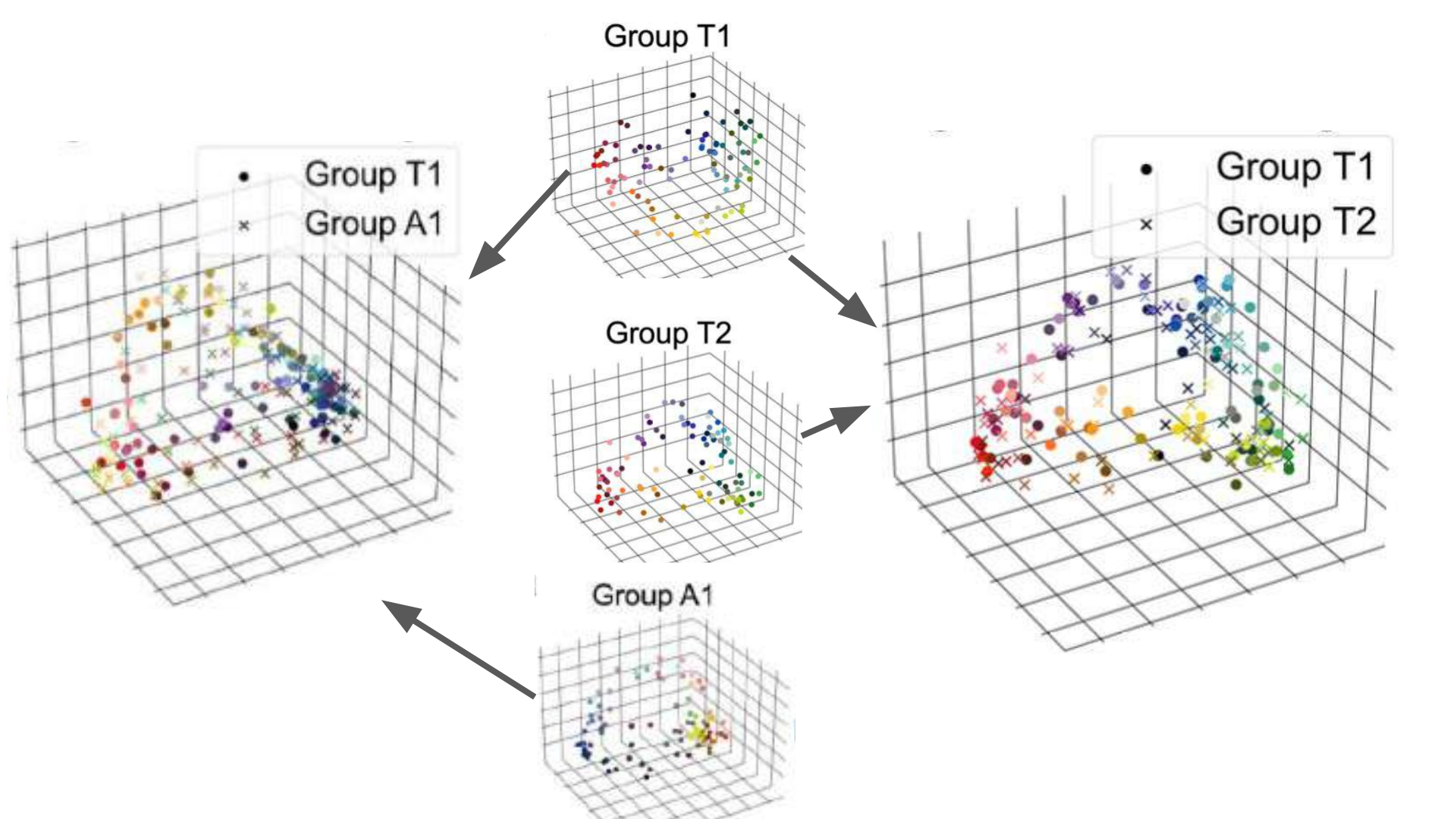


Dissimilarity matrix



Structure of color qualia



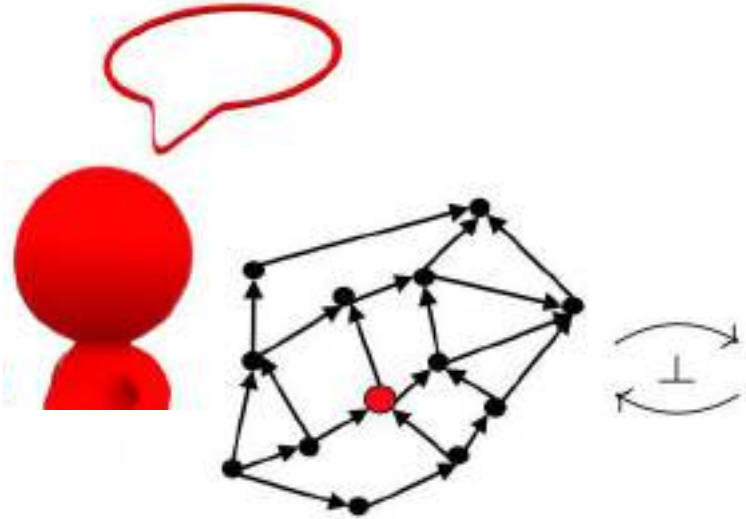

Group T1
Group T1
Group A1
Group T2
Group T1
Group T2
Group A1

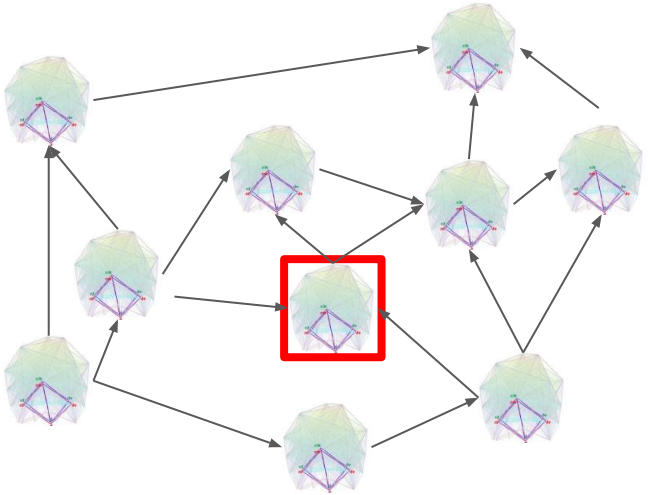
The Qualia structure project

1) Structural characterization of qualia
   a) Is my color qualia structure similar to yours?
2) Quantifying structures
3) Aligning qualia structures without labels

→ Applicable to many other qualia (e.g., emotion)

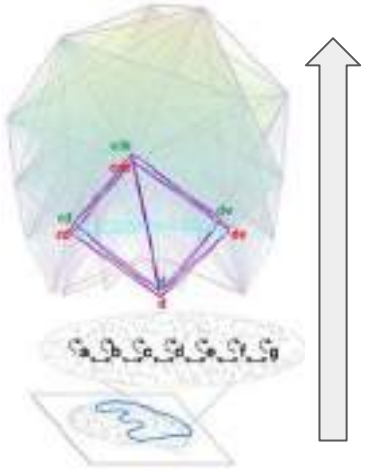
Next step:
Aligning between Qualia Structures and Causal Structures





Category of causal structures
in person A's brain

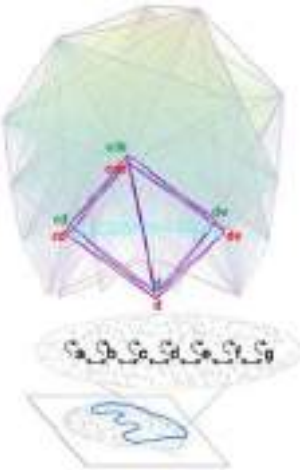
Causal
structure

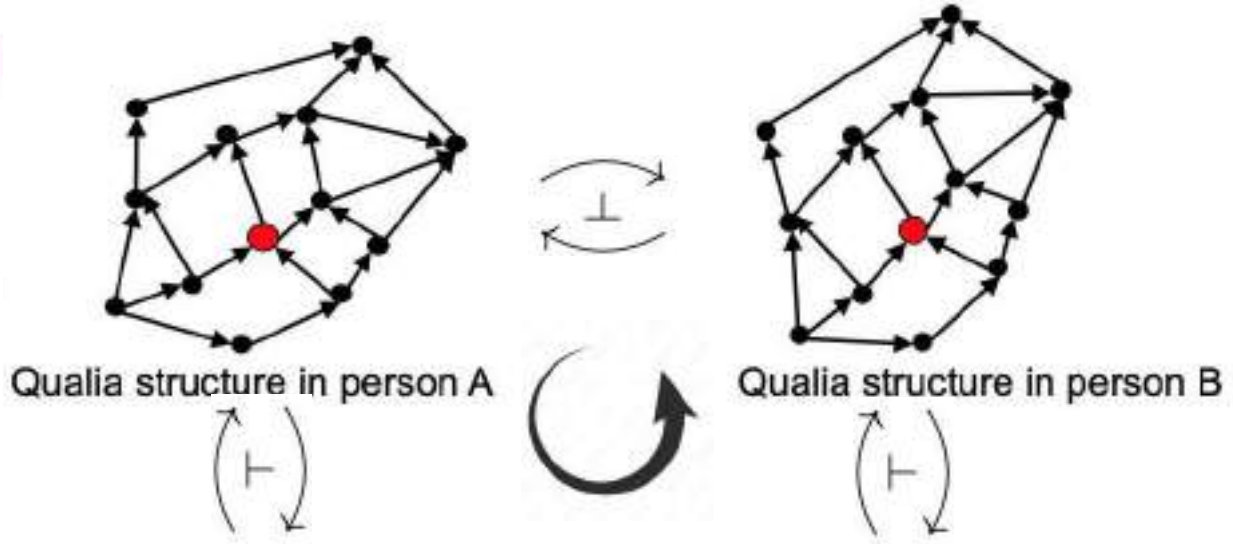


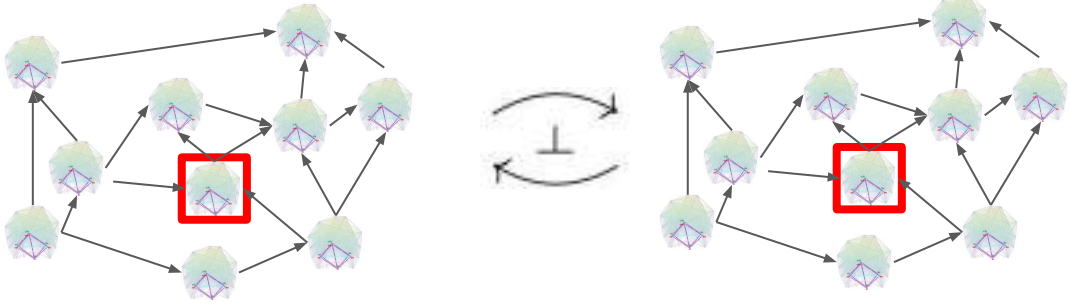
Physical
structure

E.g. IIT
Tononi et al 2025 Nat Neuro

Answer: Is my qualia structure the same as yours?







Does this diagram commute?

Conclusions

Establishing a paradigm to study qualia scientifically

- Beyond binary, NCC paradigms

A relational, structural approach

- Math tool: Category theory
- Empirical: Measure similarity (& other relations) with psychophysics.

[Neural recording+connectivity → Causal structures from physical structures]

[Constructing Qualia Periodic Table (Mendeleevian approach)

- Dissolve the Hard Problem of Qualia]

Thank you for your qualia!

Funding support: Australian Research Council (ARC), National Health Medical Research Council (NHMRC), Fundamental Question Institute (FQXi), Japan Society for Promotion of Sciences (JSPS)
Further information: tlab home page, twitterX, BLSK
@conscious_tlab @naotsuchiya

Retest : Q1. Do you think it is possible to deal with qualia scientifically?

The Hard Problem: What is the link between the phenomenal and the physical?

Q2. Do you think the Hard Problem is scientifically addressable?

Any Questions? Comments? Possible further chats for further ideas?

The Qualia structure project: ***Ongoing and Future***

Aligning object similarity structures with vs without **attention** (Rowe et al, 2025 psyArxiv)

Aligning imilarity structures about **words** on colors and emotions with vs without **depression** (Sanders, Kusano, Tsuchiya, in preparation)

Aligning **emotional** movie similarity structures with vs without **alexithymia** (Li et al, in preparation)

Japanese sounds (Saji, Asano,... in prep), Autism (Nakano,... in prep), individuals (Togashi, et al)

-> ***Why colors feel like colors? Unlike tastes? Smells? Pains?*** -> *Structural-level relationship? Categorical explanation?*

-> Gold standard challenge: Can any theory of consciousness explain/predict the qualia structures from neural activity/connectivity?

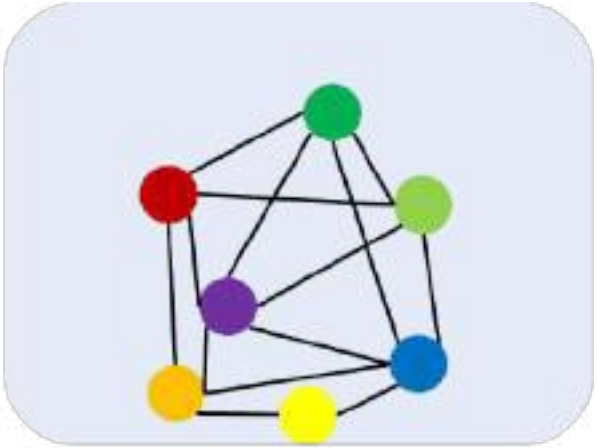
“Similarity” between qualia structures

Is my experience of “red” same as your experience of “red”?

Qualia structure of person A

How similar?

$$\mathrm{St}(C_A) \approx \mathrm{St}(C_B)$$



Qualia structure in person B

We need a measure to quantify the “dissimilarity” or “distance” between qualia structures. $\mathrm{Dis}\left(\mathrm{St}(C_A), \mathrm{St}(C_B)\right)$

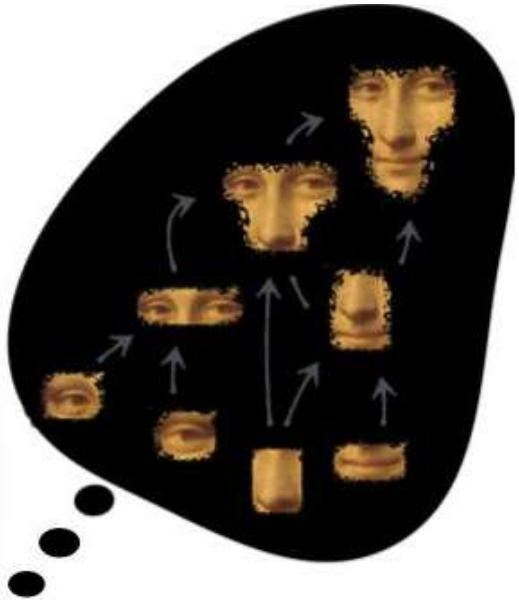
Any quale is structured

Space: reflexivity, inclusion, connection, fusion (Haun & Tononi 2019)

Time: As above, but cirected (Comolatti, Grasso, Tononi in prep)

Object: whole-parts (Grasso in prep)

Broader quale: combinations of narrower qualia - (pre-)sheaf?

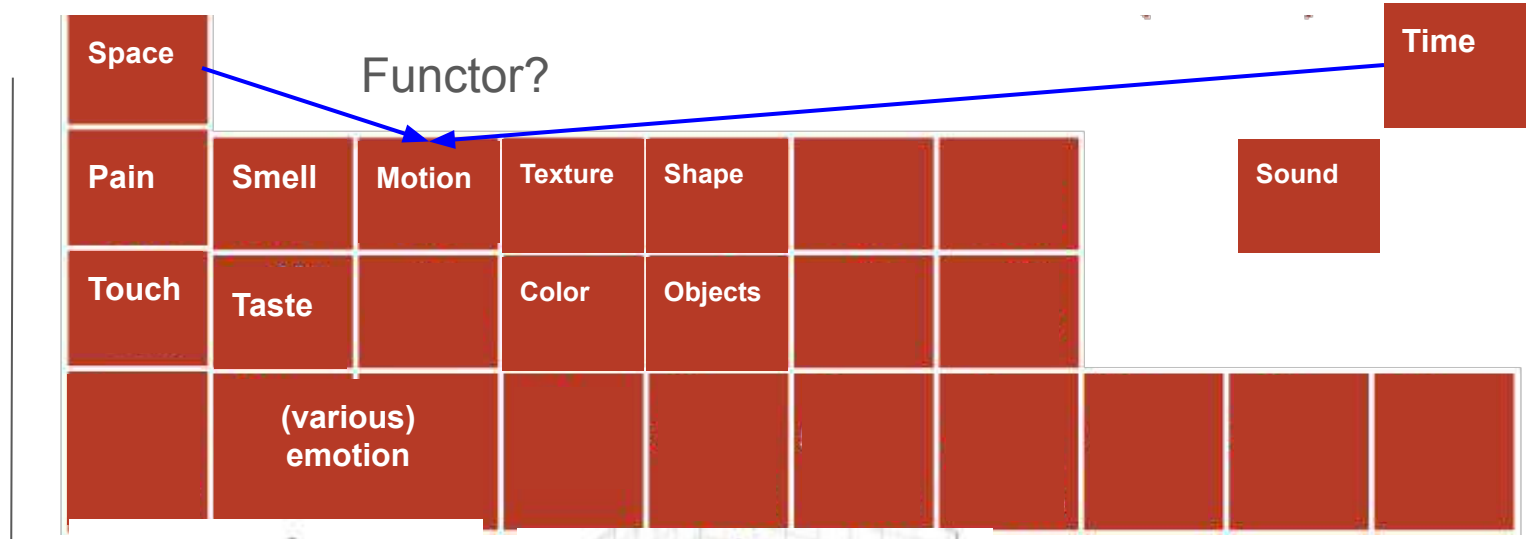


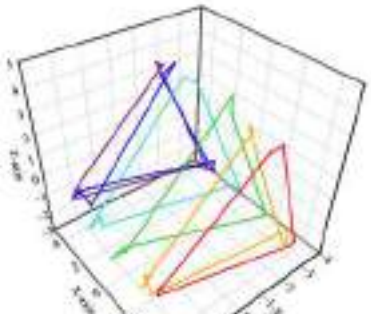
Mendeleev's Periodic Table (1869)

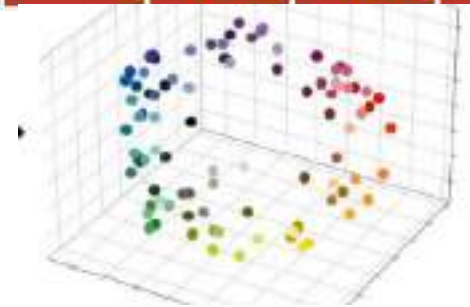
H 1.01									
Li 6.94	Be 9.01	B 10.8	C 12.0	N 14.0	O 16.0	F 19.0			
Na 23.0	Mg 24.3	Al 27.0	Si 28.1	P 31.0	S 32.1	Cl 35.5			
k 39.1 Cu 63.5	Ca 40.1 Zn 65.4		Ti 47.9	V 50.9 As 74.9	Cr 52.0 Se 79.0	Mn 54.9 Br 79.9	Fe 55.9	Co 58.9	Ni 58.7
Rb 85.5 Ag 108	Sr 87.6 Cd 112	Y 88.9 In 115	Zr 91.2 Sn 119	Nb 92.9 Sb 122	Mo 95.9 Te 128	I 127	Ru 101	Rh 103	Pd 106
Ce 133 Au 197	Ba 137 Hg 201	La 139 Ti 204	Pb 207 Th 232	Ta 181 Bi 209	W 184 U 238		Os 194	Lr 192	Pt 195

Qualia Periodic Table? (2024)

(Category of categorie? Standard models through group theory?)





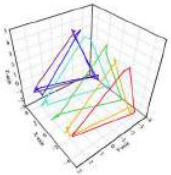


Neural correlates (?)
Cause-effect structures
(Category of categories)

Psycho-physical laws?
Equivalence?

Functor: F

G



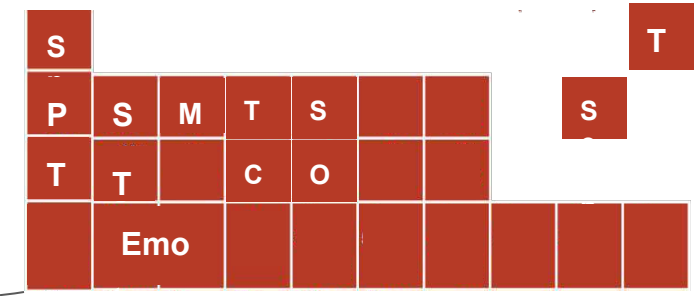
Functor: Structure preserving mapping
Welcome any theory that does not collapse category into two dots!

Qualia structures
(Category of Categories)

Cause-effect structures

Physics, Topology, Logic and Computation: A Rosetta Stone
Baez 2009

Rossetta stone →



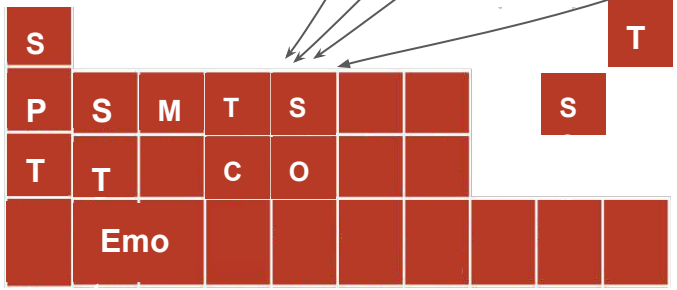
F_IIT4.0

F_IIT_continuous

F_IIT_no_exclusion

F_IIT_infinite

Category of Functors



Qualia structures

Natural Transformation: Structure preserving mapping between Functors
—> At the bottom of science: Natural Law

Q1. How can we inter the structure of qualia?

By *estimating them through massive collection of similarity ratings!*

Genji Kawakita

Ariel Zeleznikow-Johnston

Ken Takeda

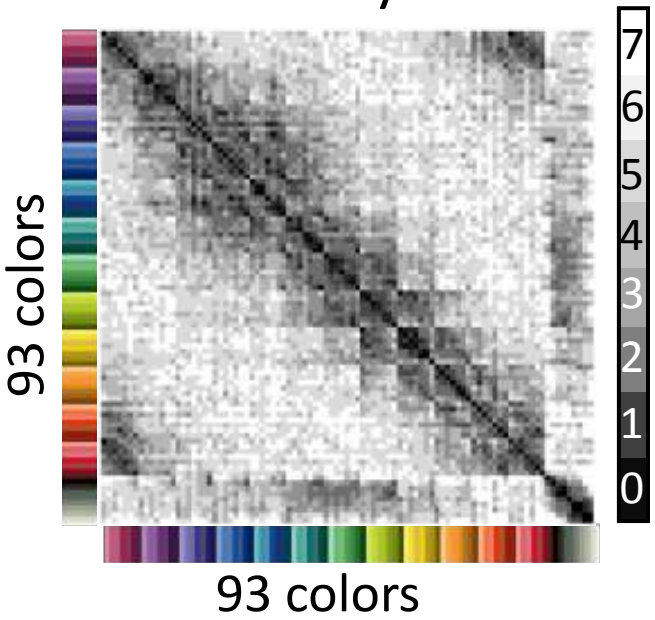
Nao Tsuchiya

Masafumi Oizumi

Kawakita et al 2025 *iScience*

Infer Qualia Structures from Similarity Ratings

Dissimilarity matrix

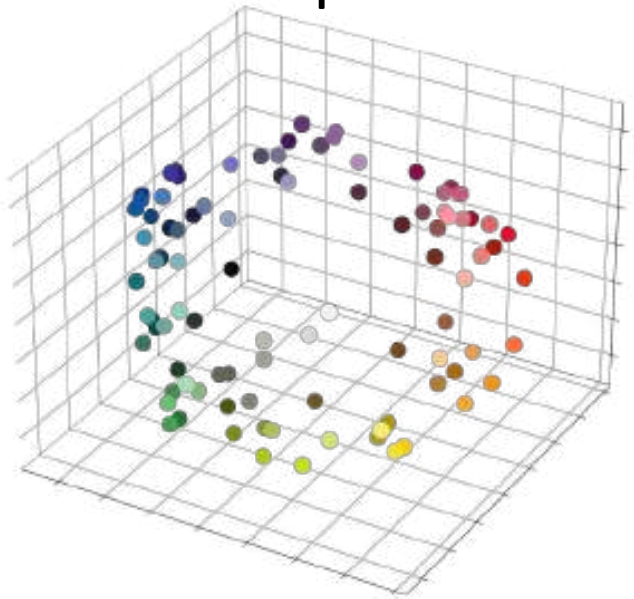


Measure relational properties of qualia

Dissimilarity

Estimate the structure (e.g. MDS, etc.)

Structure of color qualia



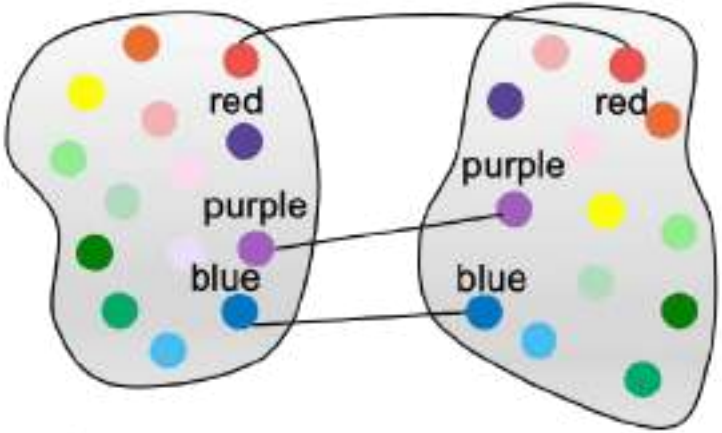
Not necessarily in the Euclidean space

Is my “red” your “red”?
*→ Now ask this in **structural** terms!*

*Is my color **qualia structure** the same as yours?*

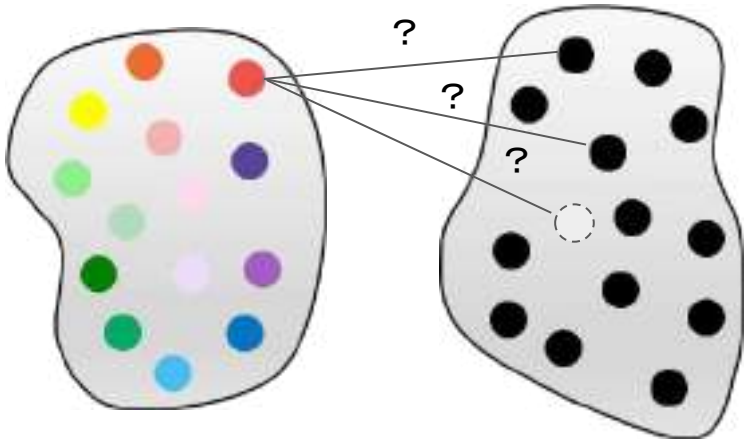
*Q. How can we **compare structures**?*
A. By unsupervised (unlabeled) alignment!

Traditional supervised method:
- Alignment between labeled ***objects***



E.g., Correlations, representational similarity analysis, etc.

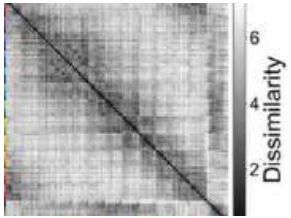
A more structural approach:
- Alignment between ***relationships***

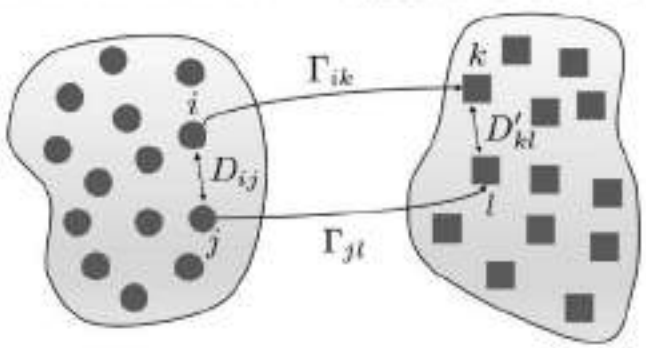


Primary: relationships.
Objects: place holders.
E.g., Optimal transport (via Gromov Wasserstein Distance)

Q. How can we align structural relationships?
E.g., Minimizing the Gromov Wasserstein Distance (GWD)

Unlabeled dissimilarity matrix



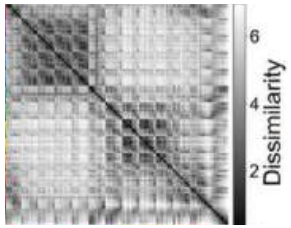


$$\mathrm{GWD} = \min_{\Gamma} \sum_{i,j,k,l} (D_{ij} - D'_{kl})^2 \Gamma_{ik} \Gamma_{jl}$$

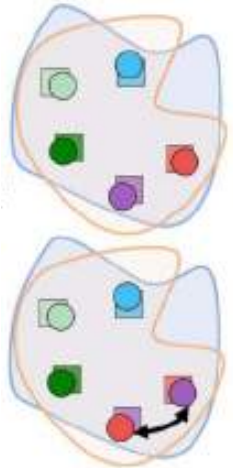
(Mémoli, 2011)

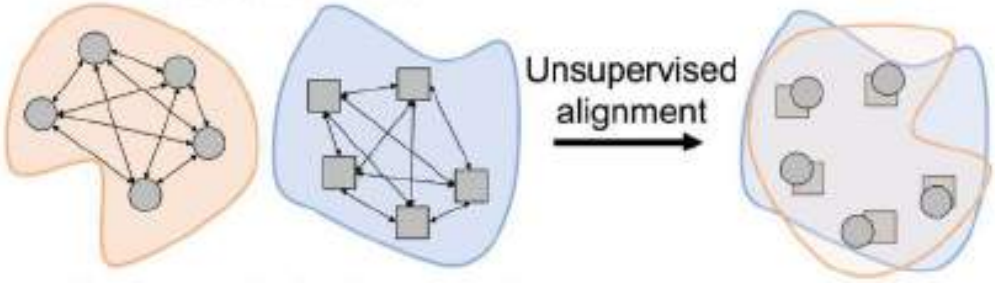
Γ :Transportation matrix.

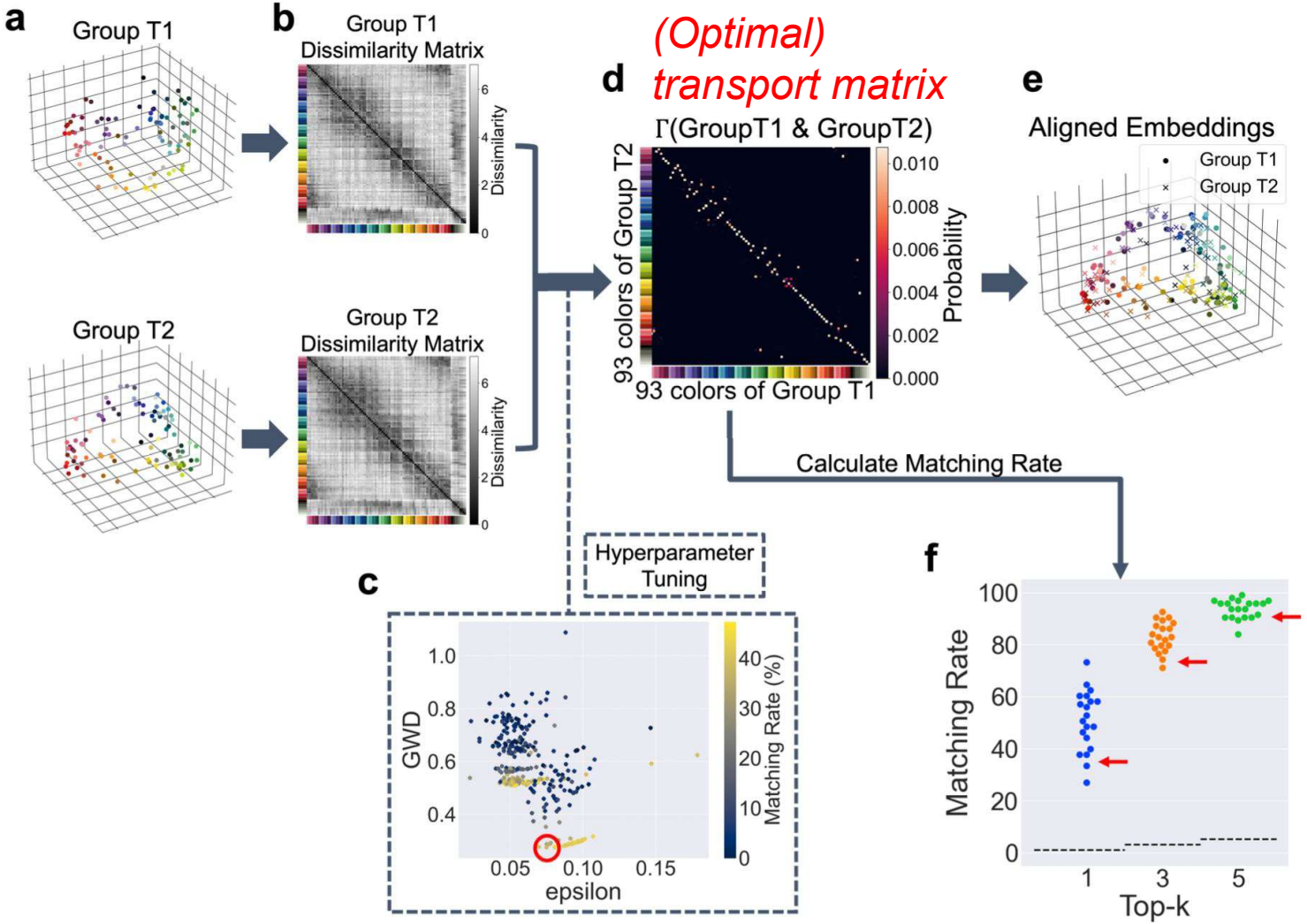
Unlabeled dissimilarity matrix

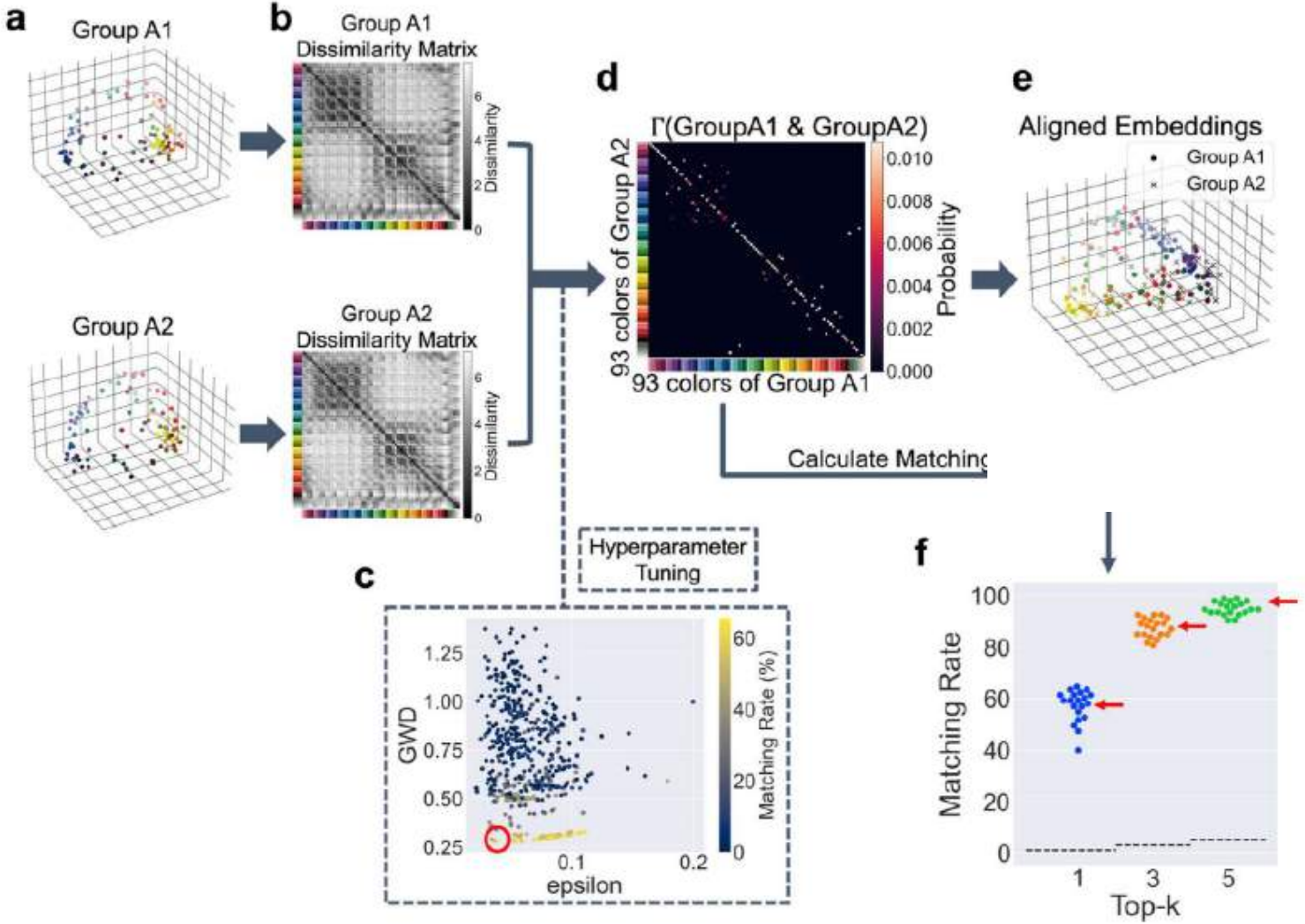


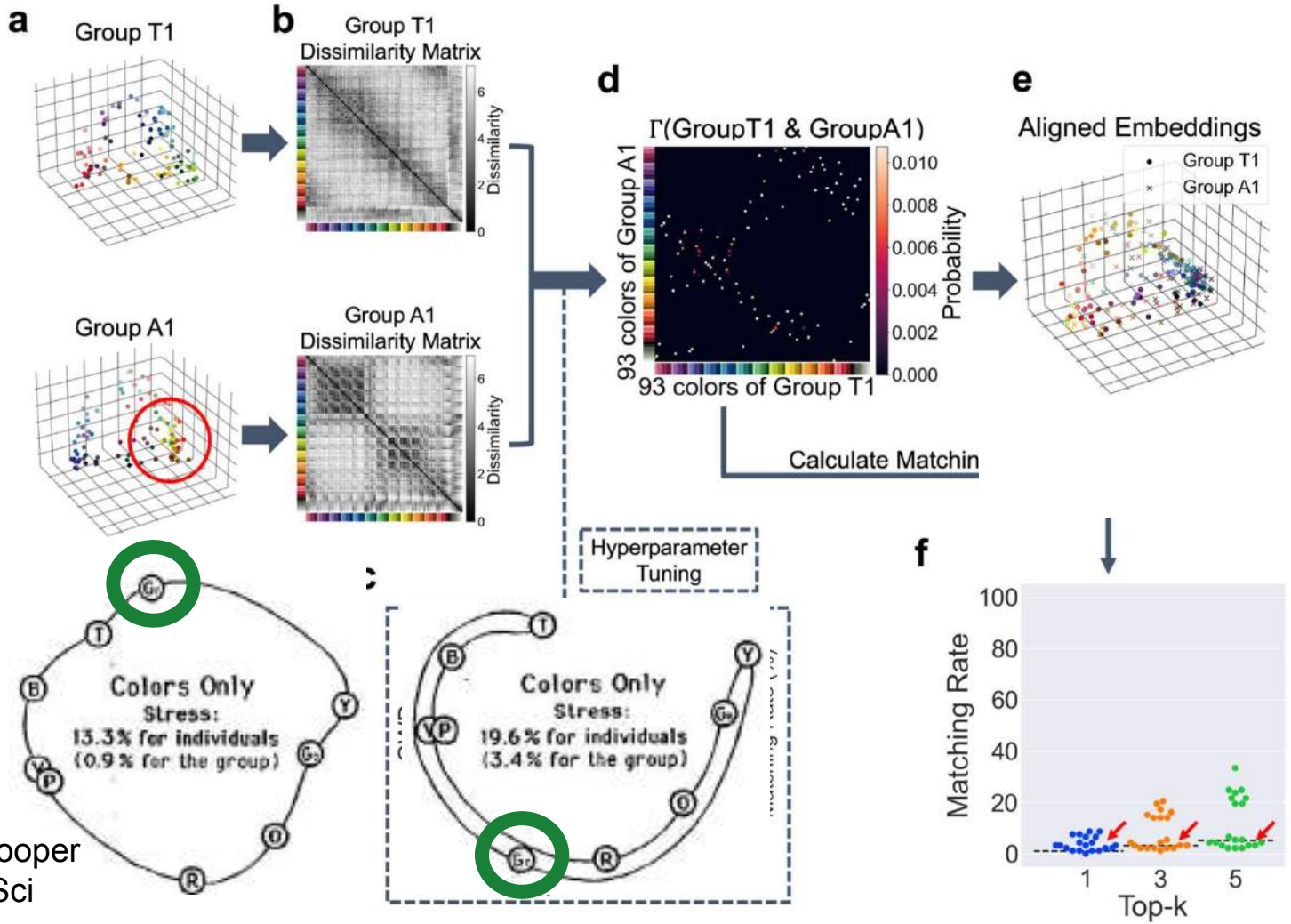
Finally, use the labels to quantify structural equivalence!






a
Group T1
b
Group T1
Dissimilarity Matrix
Dissimilarity
Group T2
Group T2
Dissimilarity Matrix
Dissimilarity
(Optimal)
transport matrix
d
Γ(GroupT1 & GroupT2)
93 colors of Group T2
93 colors of Group T1
Probability
e
Aligned Embeddings
Group T1
Group T2
Calculate Matching Rate
Hyperparameter
Tuning
c
GWD
epsilon
Matching Rate (%)
f
Matching Rate
Top-k


a
Group A1
Group A2
b
Group A1
Dissimilarity Matrix
Group A2
Dissimilarity Matrix
Dissimilarity
d
Γ(GroupA1 & GroupA2)
93 colors of Group A2
93 colors of Group A1
Probability
0.010
0.008
0.006
0.004
0.002
0.000
Calculate Matching
e
Aligned Embeddings
Group A1
Group A2
Hyperparameter
Tuning
c
GWD
epsilon
Matching Rate (%)
f
Matching Rate
Top-k

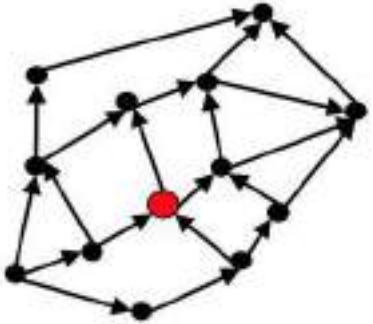


Shepard & Cooper
1992 Psych Sci

The Qualia structure project

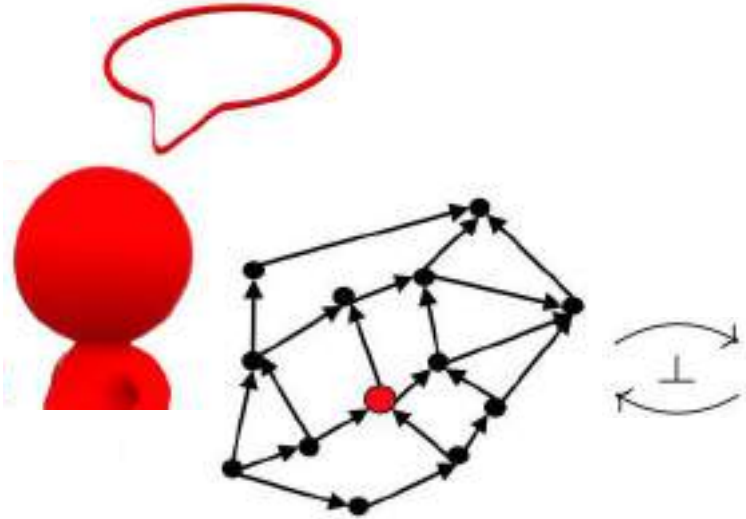
1) Yoneda-lemma inspired characterization of qualia
2) Quantifying similarity structures among qualia using a large-scale psychophysics
3) Aligning qualia structures without labels
    a) High accuracy of alignment among normal trichromats
    b) Low accuracy between trichromats and deuteranomaly

Next step:
Aligning between Qualia Structures and Causal Structures

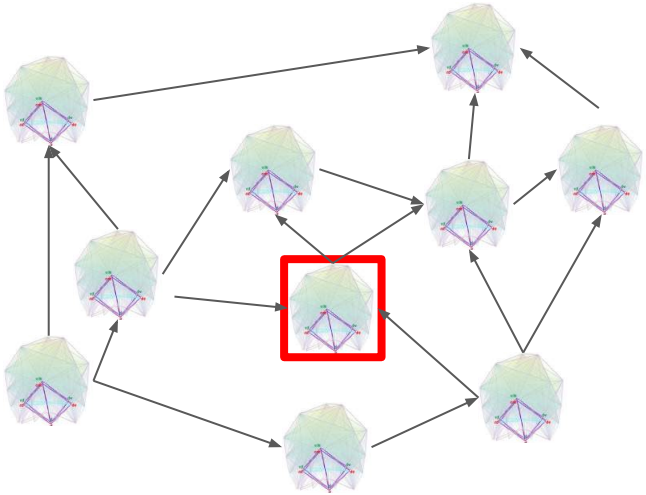


Qualia structure in person A

Next step:
Aligning between Qualia Structures and Causal Structures

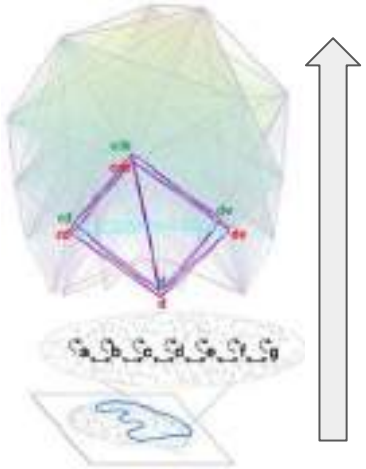


Qualia structure in person A



Category of causal structures
in person A's brain

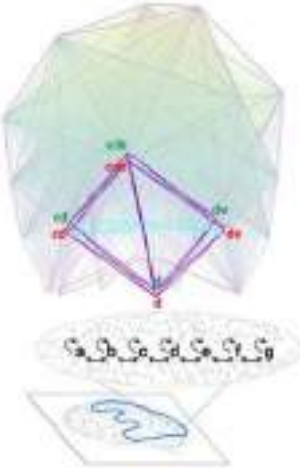
Causal
structure

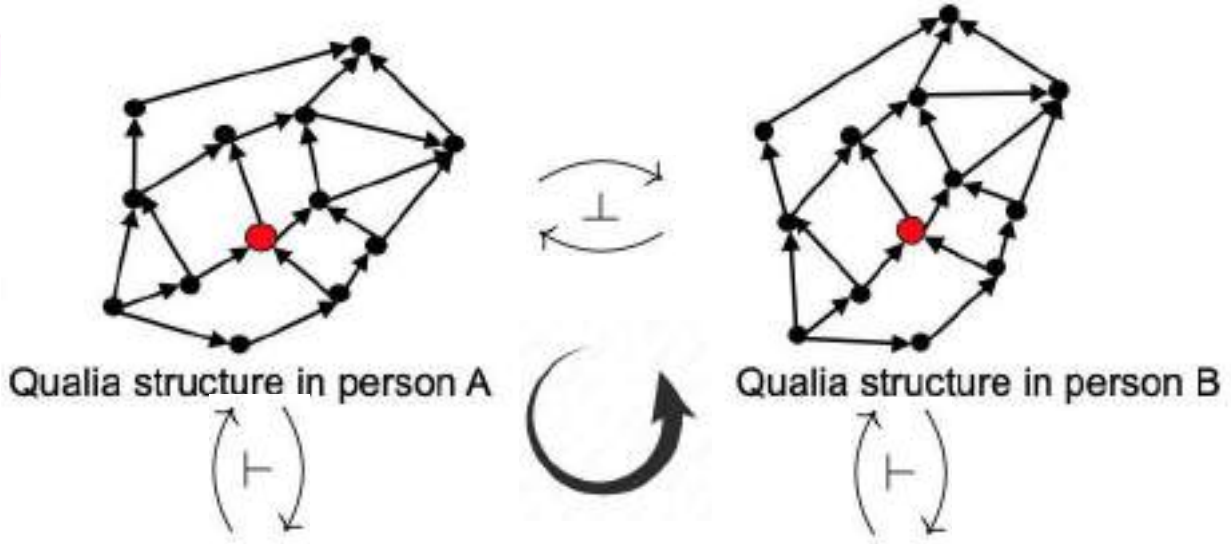


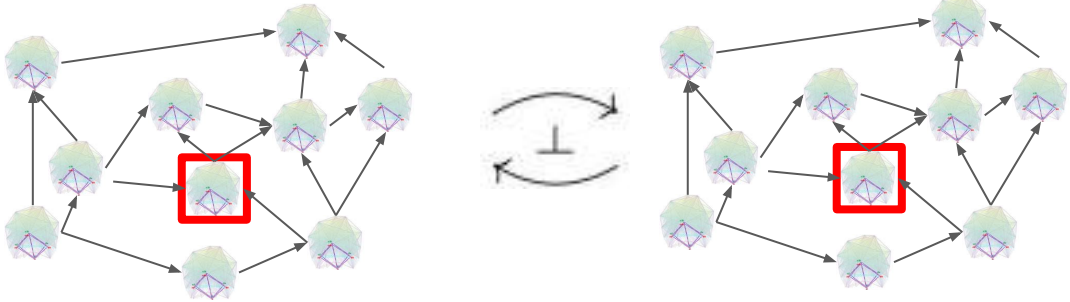
Physical
structure

E.g. IIT
Tononi et al 2025 Nat Neuro

Answer: Is my qualia structure the same as yours?







Does this diagram commute?