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Agent-based color categorization: The role of population and color-stimulus heterogeneities

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Color as a signaling system

In nature, color is thought to signal across species ....

Autumn colors may signal insects a message from trees.

Signaling Systems and Convention ...

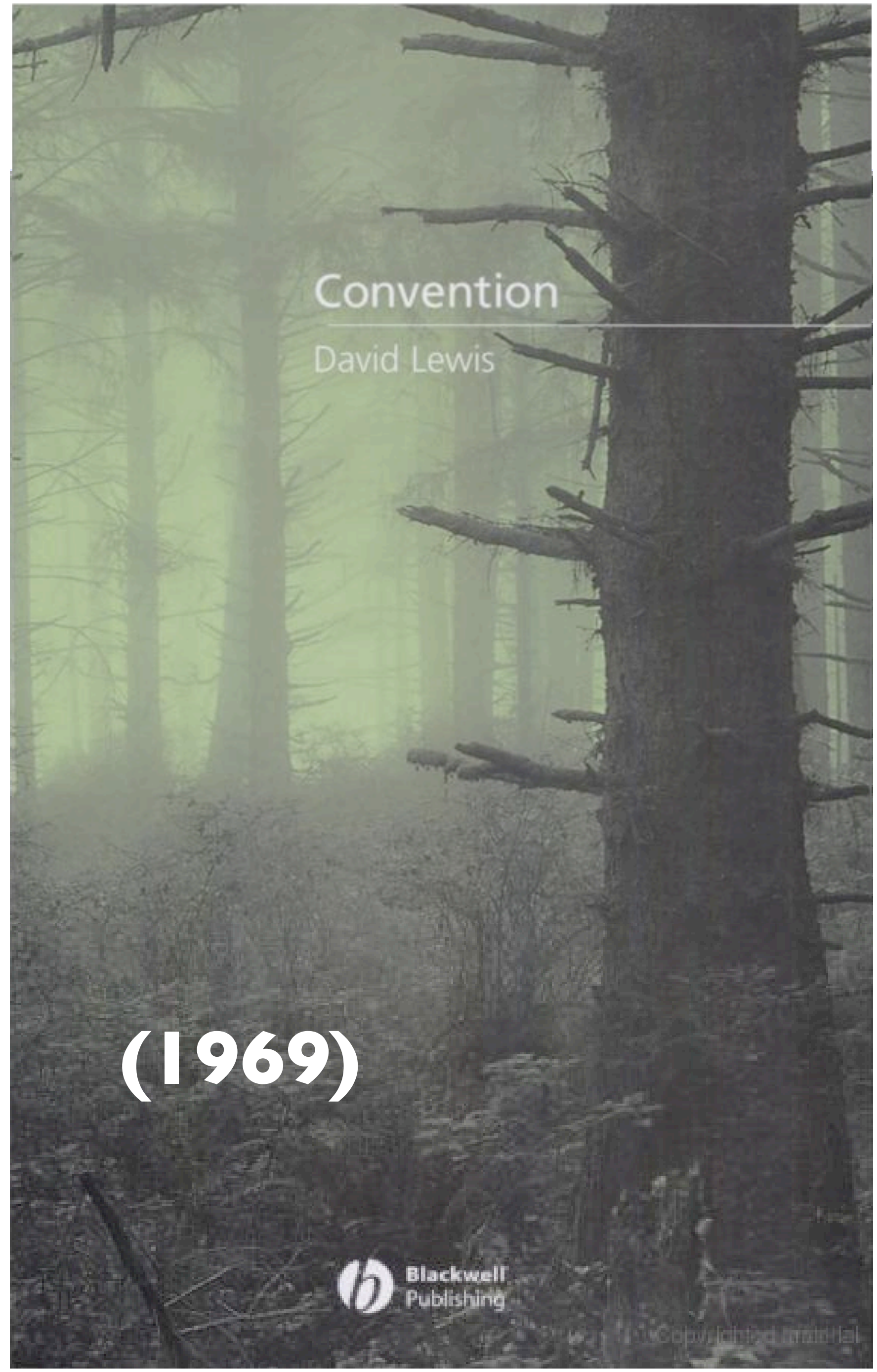
Skyrms (2004). *The Stag Hunt and The Evolution of Social Structure*.

Maynard-Smith & Harper (2003). *Animal Signals*.

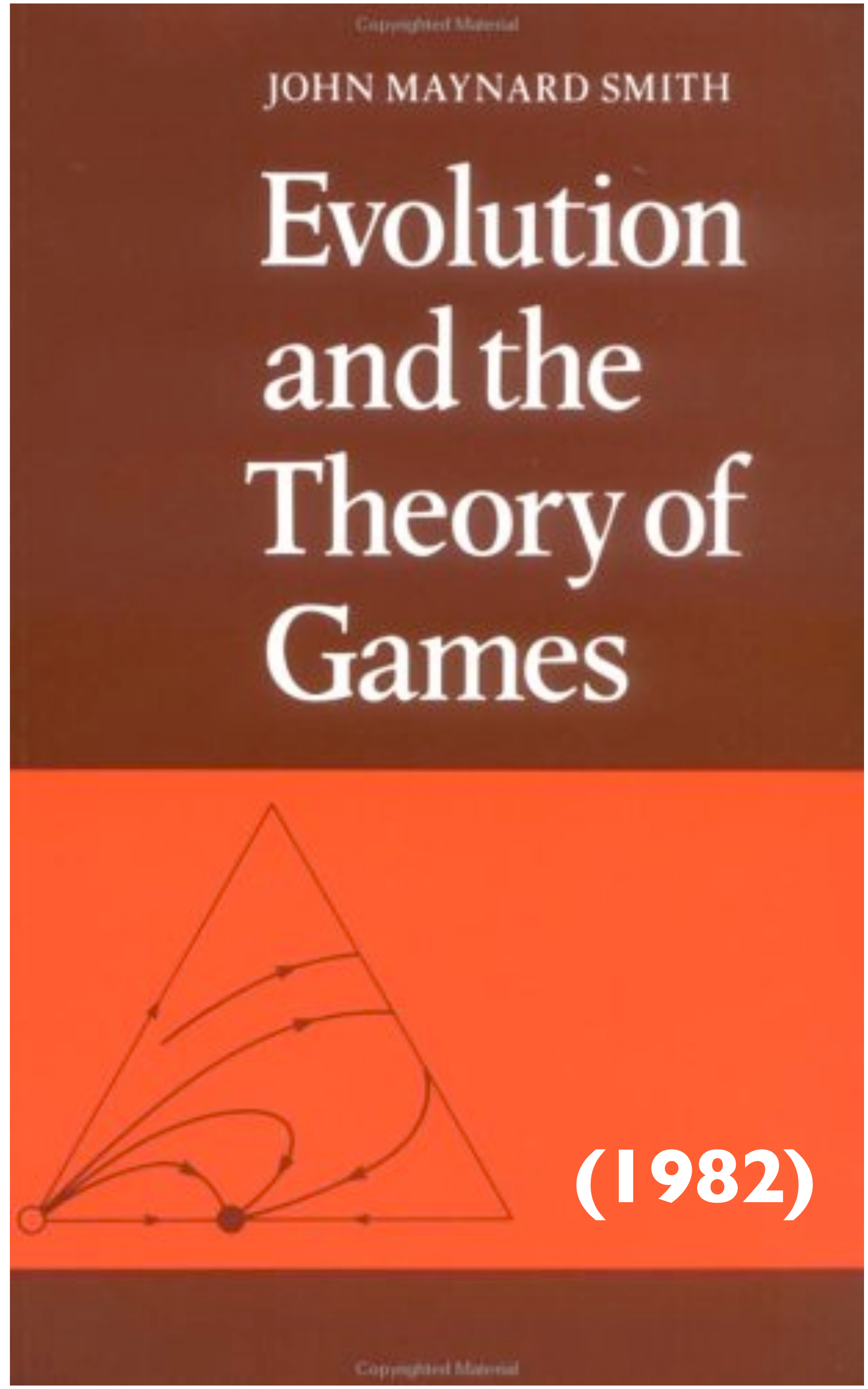
Lewis (1969). *Convention: A Philosophical Study*.

... are formalized in Evolutionary Game Theory and extensively studied and used successfully in many areas of human study.

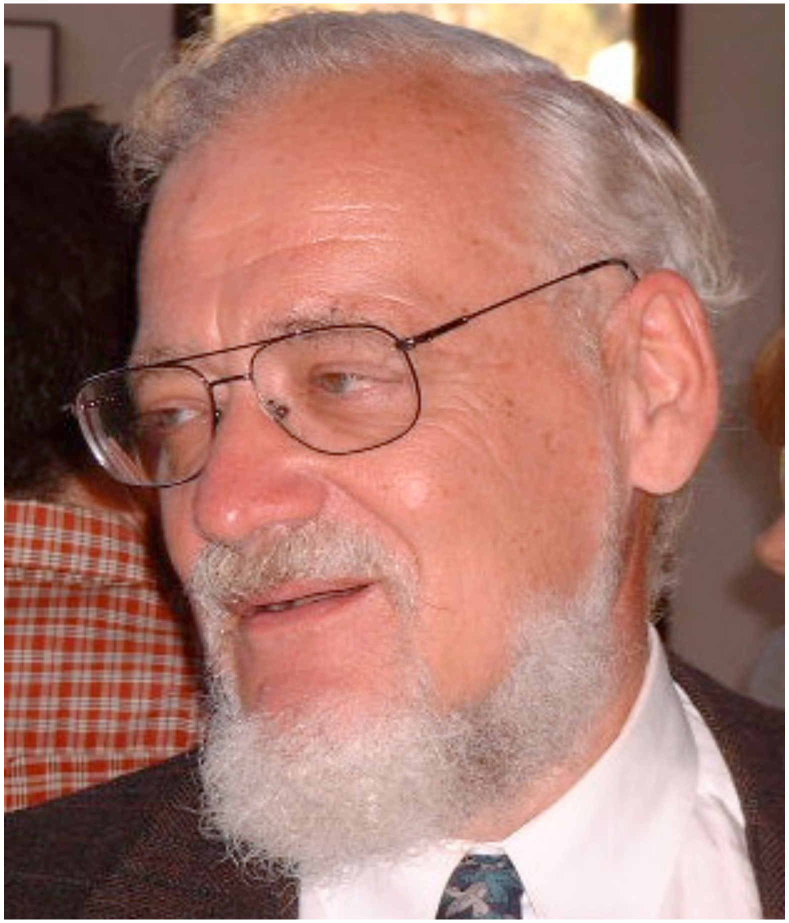
David K. Lewis



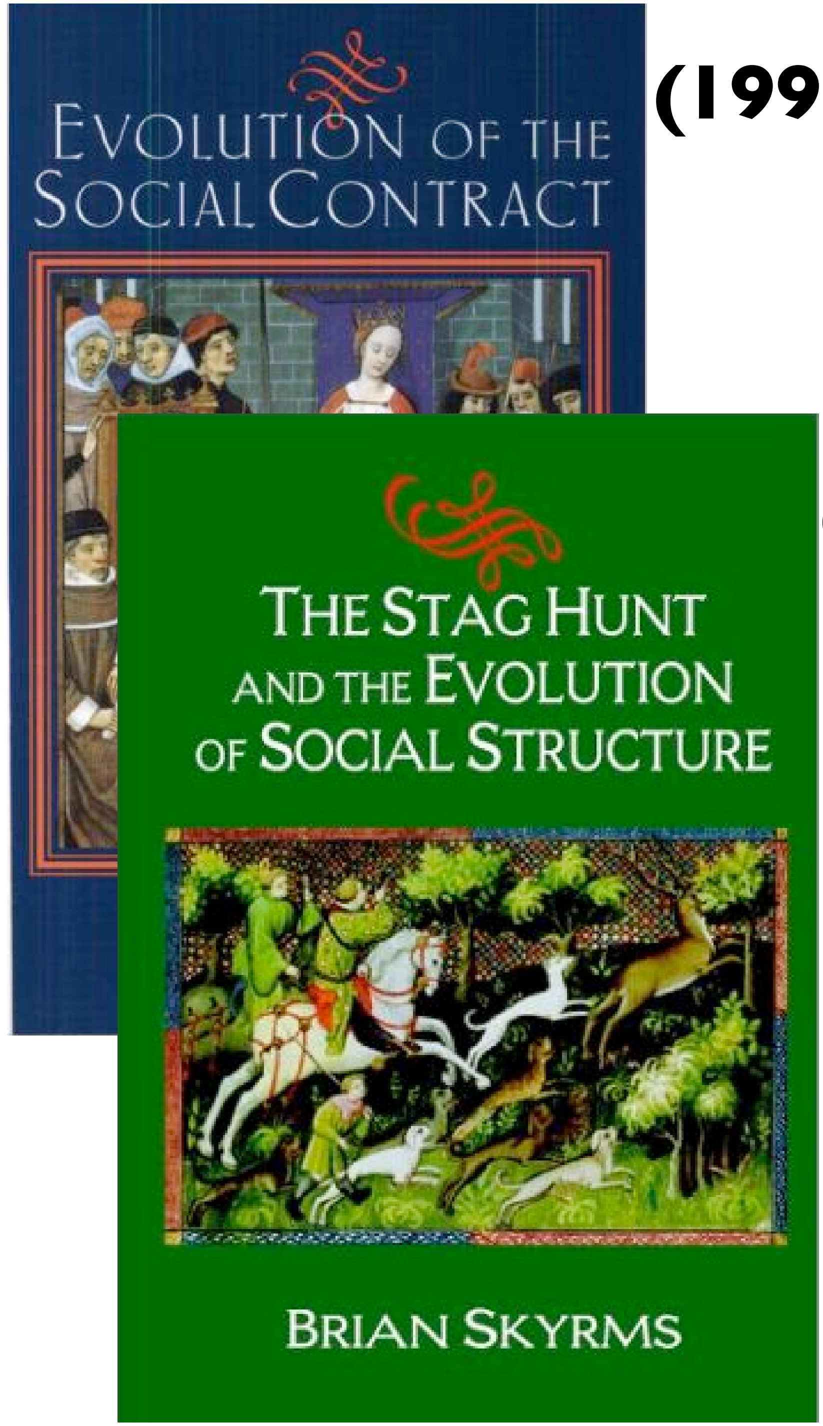
John Maynard-Smith



(1982)



Brian Skyrms



(1996)

(2004)

Several Evolutionary Game Theory Nobel Prizes:

T. C. Schelling & R. J. Aumann (2005)

D. Kahneman (2002)

W. Vickrey & J. Mirrlees (1996)

J. Nash, J.C. Harsanyi & R. Selten (1994)

H. Simon (1979)

Color as a signaling system

Displaying and perceiving color play important roles in mate choice in many species.

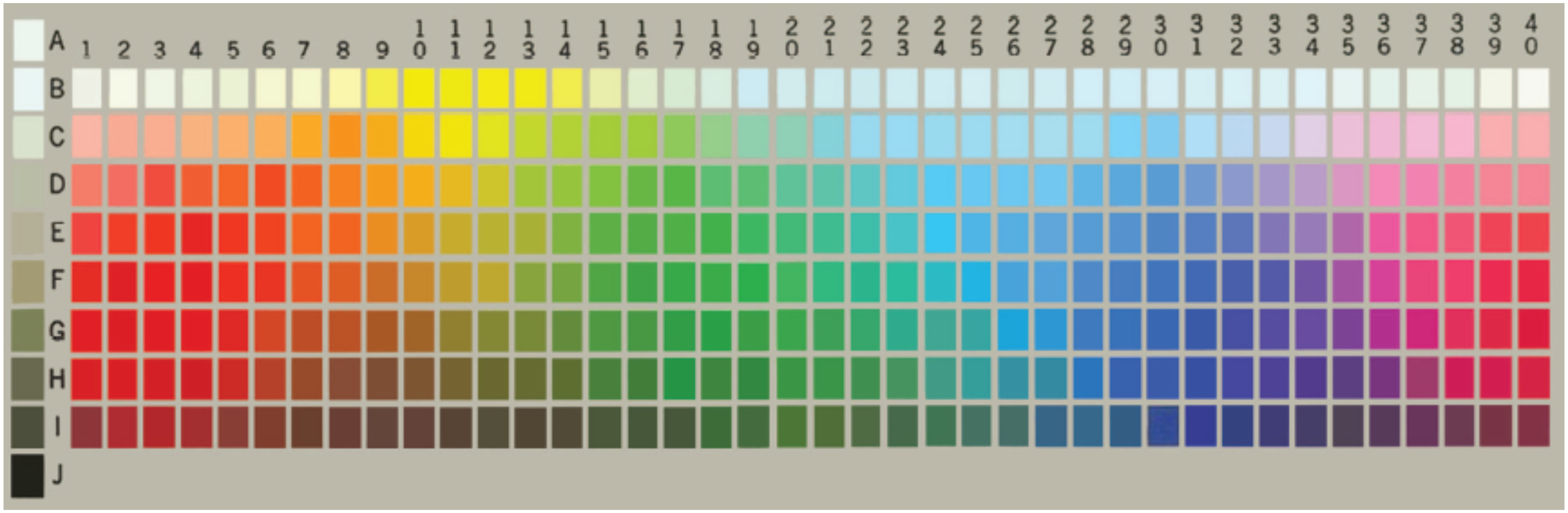
Color naming as a signaling system

Human color naming is an example of a signaling system, with a color name signaling a color.

The Mainstream Theory

- Berlin & Kay (1969)
- Heider-Rosch (1971, 1972)
- Boynton & colleagues:
  - Boynton & Olson (1987, 1990)
  - Boynton, MacLaury, & Uchikawa (1989)
  - Boynton, Fargo, Olson, & Smallman (1989)
  - Uchikawa & Boynton (1987)
- World Color Survey (WCS, 1991, 1997, 2000)
  - Kay, Regier, Cook & colleagues (2005-2007)

WCS Color Stimulus



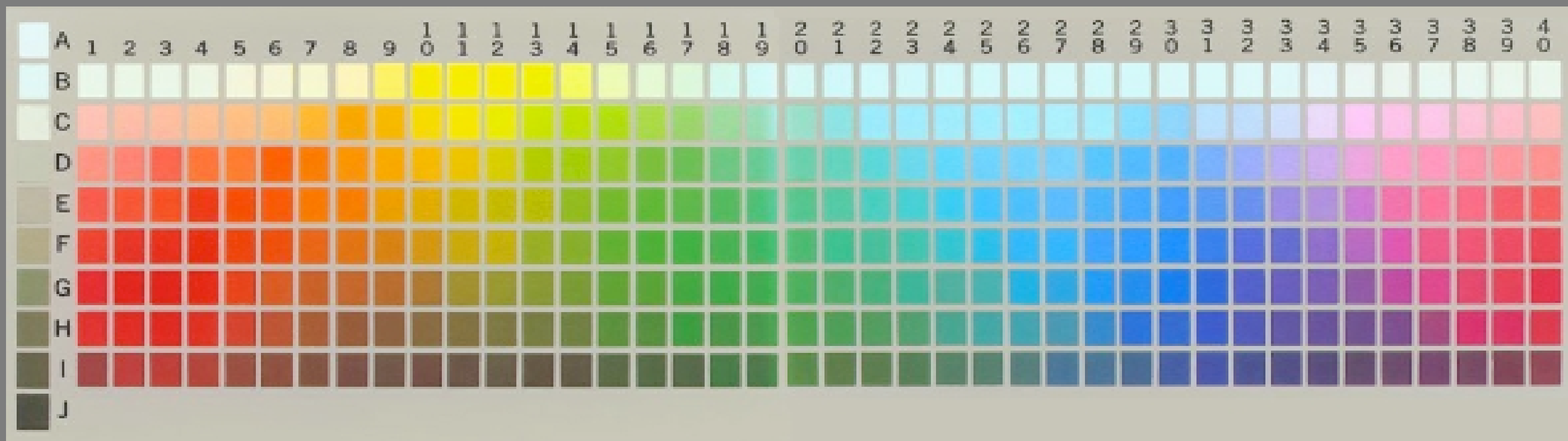
The World Color Survey: Color categories from 110 unwritten languages from pre-industrialized societies.

Regier, T., Kay, P. & Cook, R. S. (2005). Focal colors are universal after all. *Proceedings of the National Academy of Science, 102*, 8386–8391.

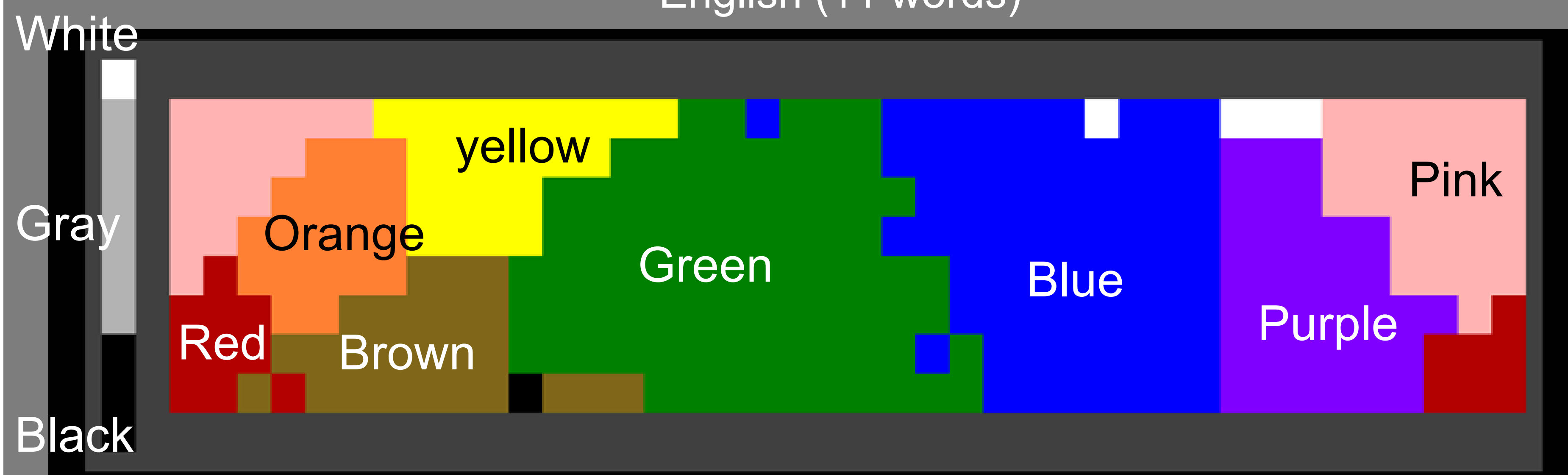
Cook, R. S., Paul K. & Regier, T. (2005) The World Color Survey database: History and use. In Cohen, Henri and Claire Lefebvre (eds.) *Handbook of Categorisation in the Cognitive Sciences,* (p. 223-242). Amsterdam and London: Elsevier.


5Y
10Y
5G
5BG
5B

Basic Color Terms name all the colors:

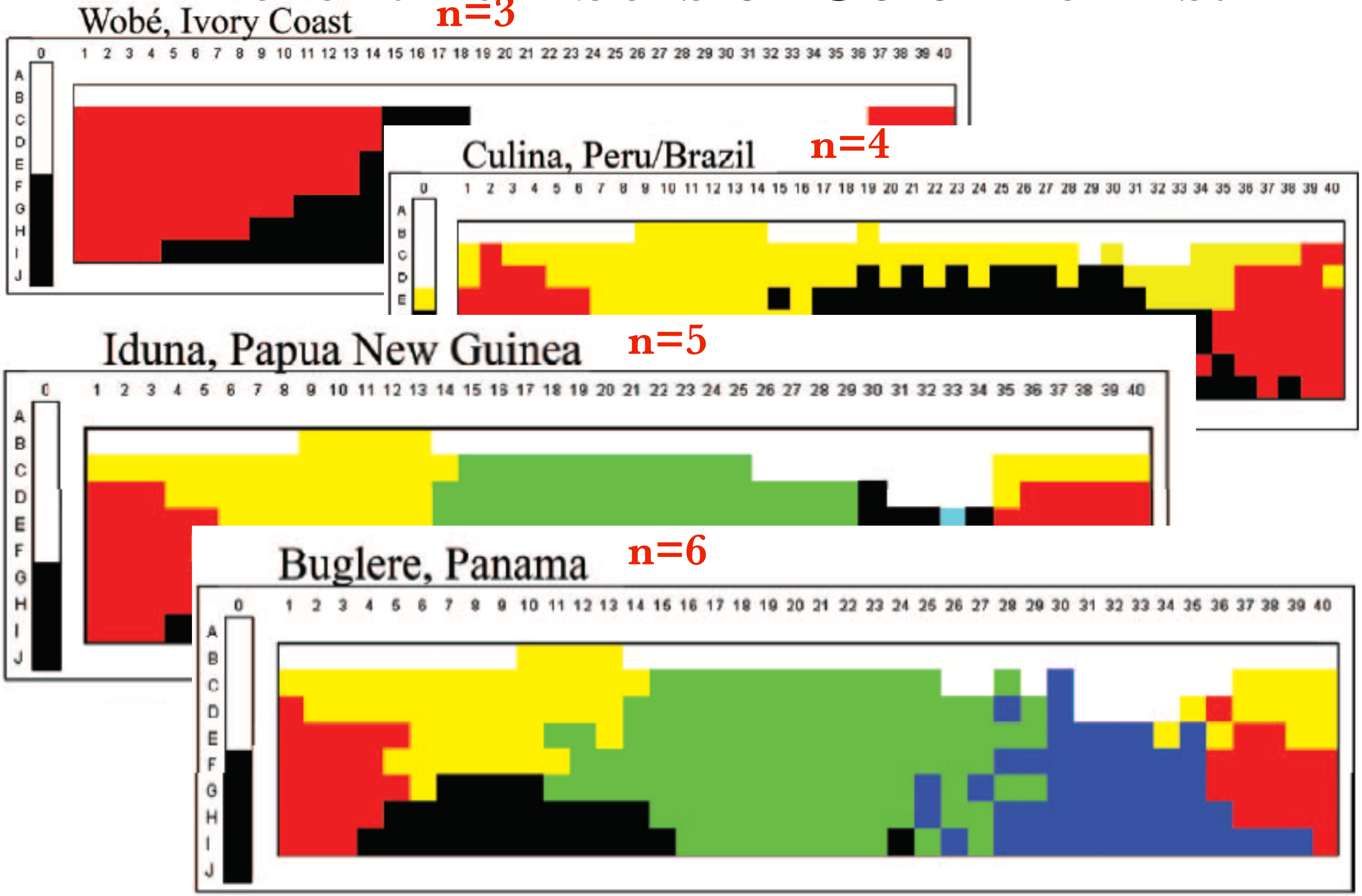


English (11 words)



Courtesy of Lindsey & Brown (2006). *PNAS, 102.*

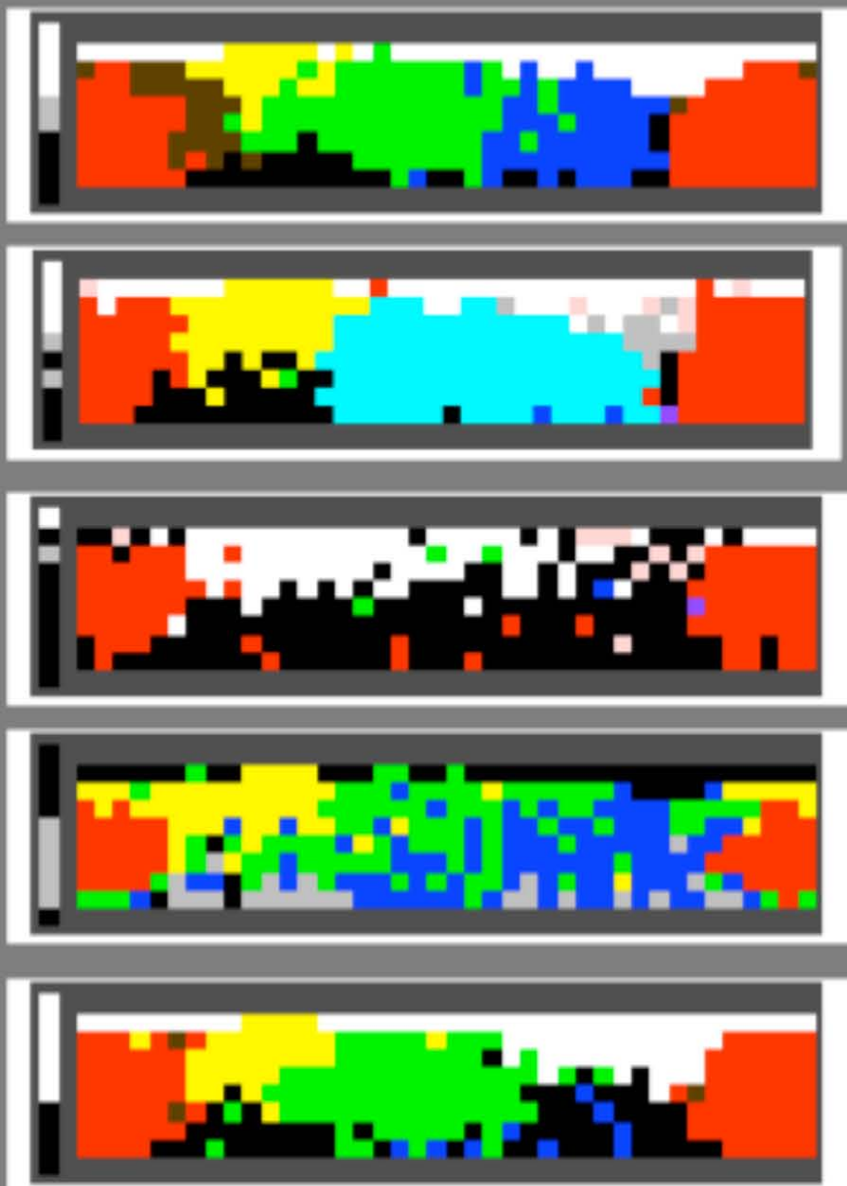
Different numbers of Color Terms:



T. Regier et al, PNAS 104, 2007

And Individual Differences within Languages:

Berik, Indonesia



Subject # 1

Subject # 21

Subject # 13

Subject # 14

Subject # 2

World Color Survey Data (Cook, Kay & Regier 2004). Figure Credit: D. T. Lindsey (2007).

Individual differences in human color categorization have not been emphasized.

- Berlin & Kay (1969)
- Heider-Rosch (1971, 1972)
- Boynton & colleagues:
  - Boynton & Olson (1987, 1990)
  - Boynton, MacLaury, & Uchikawa (1989)
  - Boynton, Fargo, Olson, & Smallman (1989)
  - Uchikawa & Boynton (1987)
- World Color Survey (WCS, 1991, 1997, 2000)
  - Kay, Regier, Cook & colleagues (2005-2007)

Emphasis of optimal partitioning of the perceptual space

- The mainstream view has recently begun to shift the empirical discussion from color salience based explanations to an emphasis on optimal partitioning of color space.

Regier, T., Kay, P., & Khetarpal, N. (2007). Color naming reflects optimal partitions of color space. *Proceedings of the National Academy of Sciences, 104.*

How do simulation studies further inform us about human color categorization research?

Simulated category learning in populations of artifical agents:

Steels & Belpaeme (2005). Coordinating perceptually grounded categories: A case study for colour. *Behavioral and Brain Sciences*, *28.*

Belpaeme & Bleys (2005). Explaining universal color categories through a constrained acquisition process. *Adaptive Behavior*, *13.*

Griffin (2006). The basic colour categories are optimal for classification. *Journal of the Royal Society: Interface, 3.*

Dowman (2007). Explaining color term typology with an evolutionary model. *Cognitive Science, 31.*

Puglisi, Baronchelli & Loreto (2007). Cultural route to the emergence of linguistic categories. http://arxiv.org/abs/physics/0703164.

Simulated category learning in populations of artifical agents:

Komarova, Jameson & Narens (2007). Evolutionary models of color categorization based on discrimination. *Journal of Mathematical Psychology, 51*, 359-382.

Komarova & Jameson (2007). Population heterogeneity and color stimulus heterogeneity in agent-based color categorization. (under review). *Journal of Theoretical Biology*.

Jameson & Komarova (2007). Evolutionary models of color categorization: Investigations based on realistic population heterogeneity. (manuscript).

Our investigations of color categorization emphasize:

Simulated Naming ≠ Human Naming

(1.) Signaling systems under observer heterogeneity

Pragmatic Human Communication:

Under a shared visual capacity ...

for homogeneous observer models.

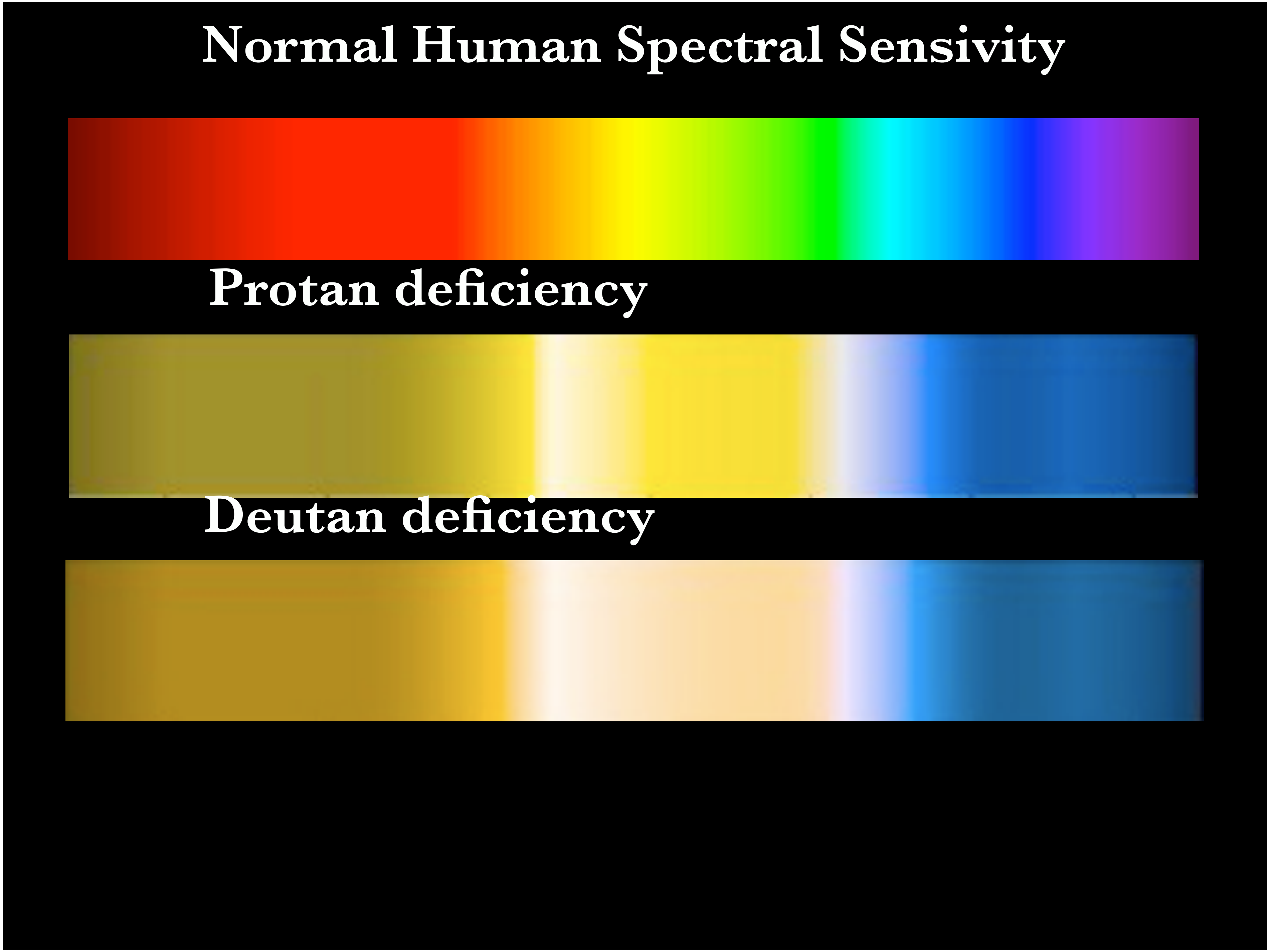
Pragmatic Human Communication:

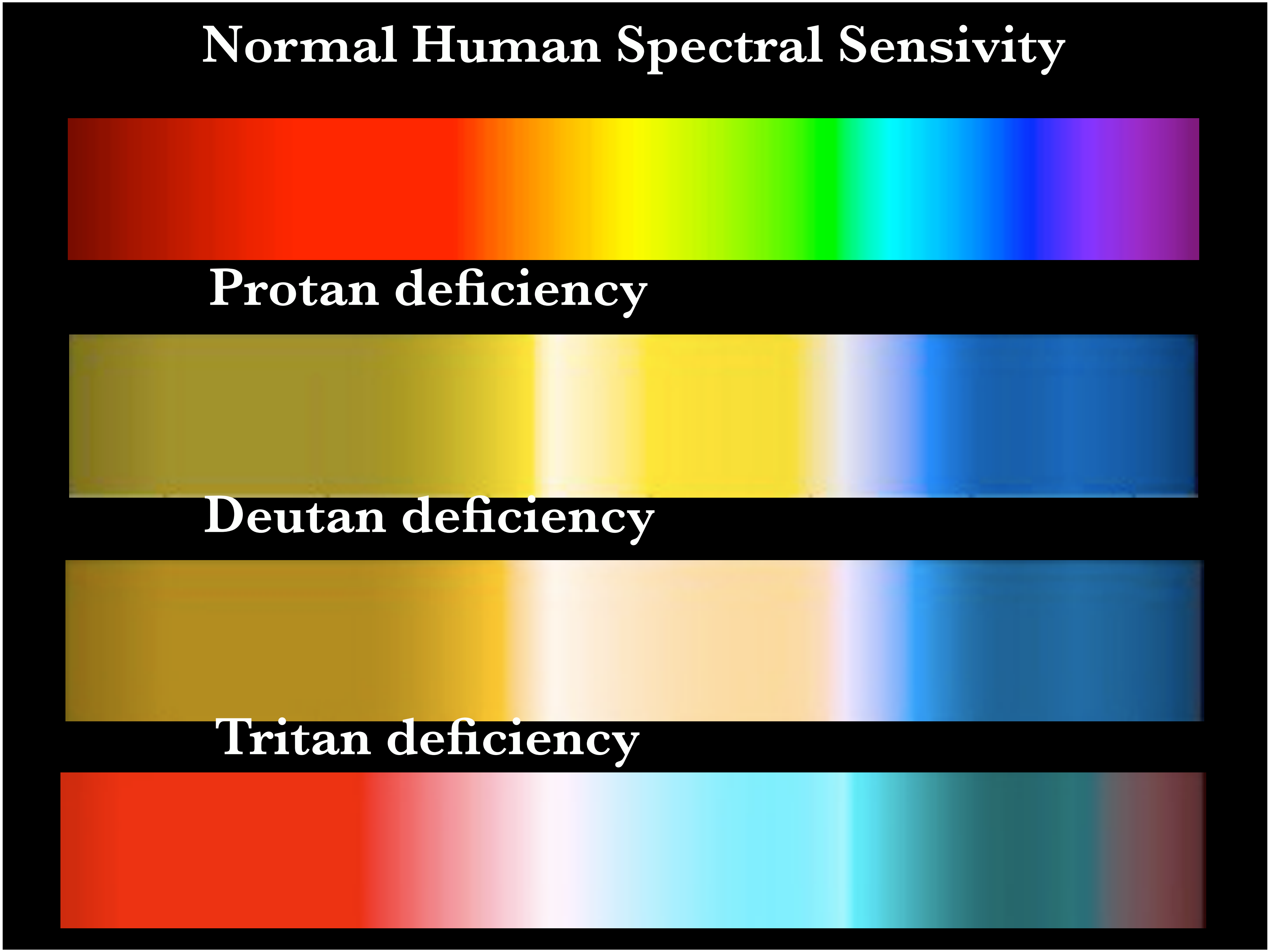
Under observer heterogeneity.

Normal Human Spectral Sensivity

Normal Human Spectral Sensivity

Protan deficiency

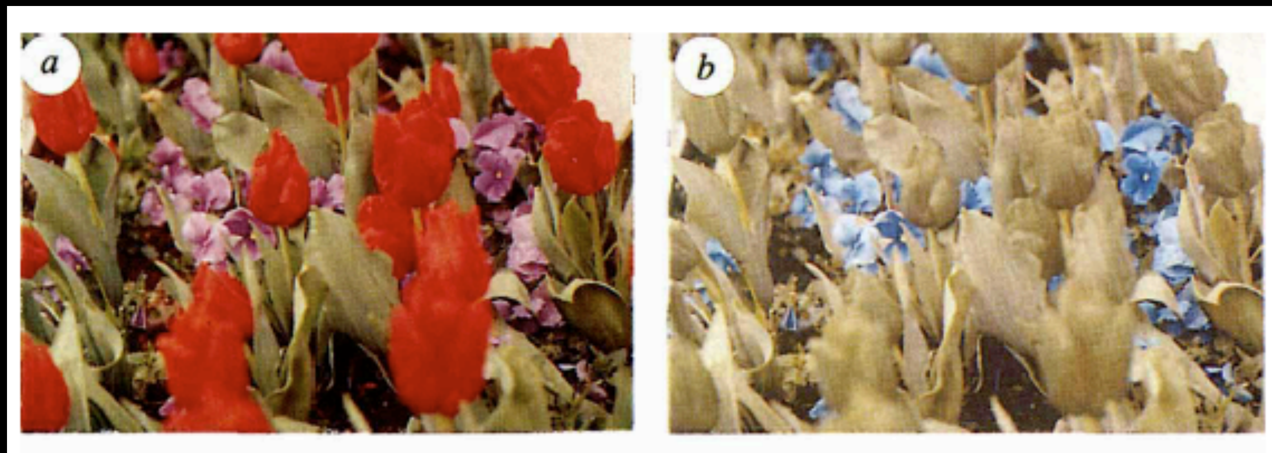

Normal Human Spectral Sensivity
Protan deficiency
Deutan deficiency


Normal Human Spectral Sensivity
Protan deficiency
Deutan deficiency
Tritan deficiency

a. Trichromat

Simulations from Viénot et al. (1995). *Nature, 376*.

a. Trichromat **b. Protanope**



Simulations from Viénot et al. (1995). *Nature, 376*.

a. Trichromat **b. Protanope**

c. Deuteranope

Simulations from Viénot et al. (1995). *Nature, 376*.

a. Trichromat **b. Protanope**

d. Tritanope **c. Deuteranope**

Simulations from Viénot et al. (1995). *Nature, 376*.

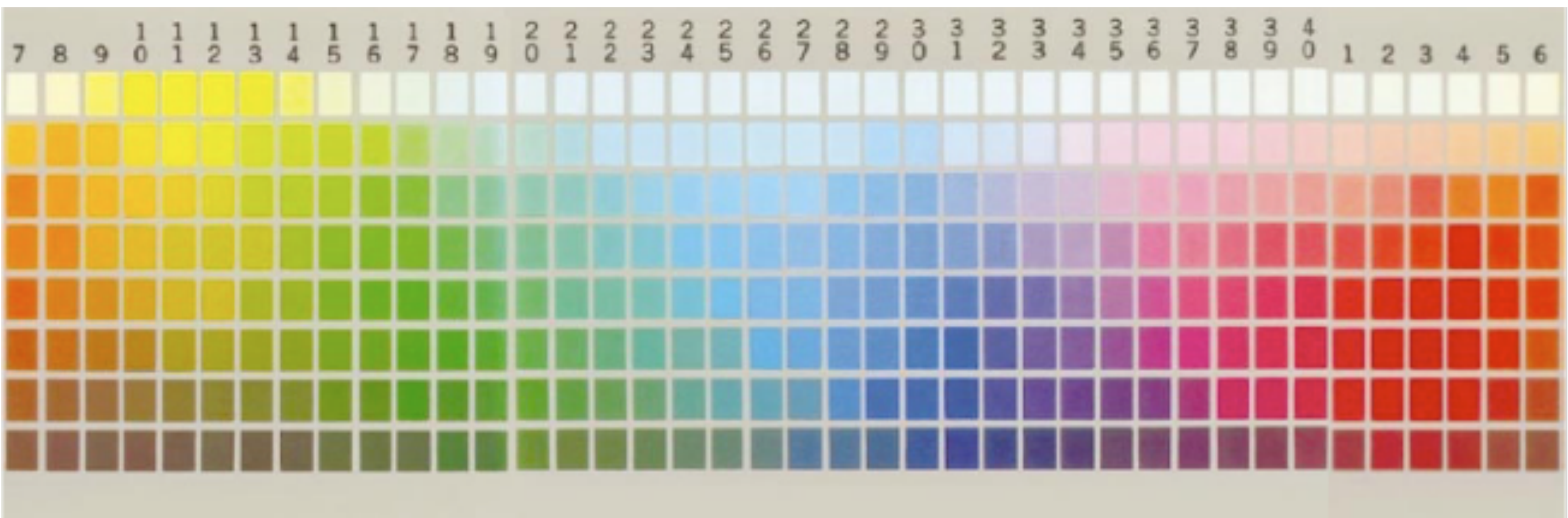
Frequencies of X-chromosome linked color vision deficiencies vary across ethnicity

Groups	% Male color deficient	% Female color deficient
European descent	7.40	0.50
Asian	4.17	0.58
African	2.61	0.54
Australian Aborigines	1.98	0.03
Native American	1.94	0.63
South Pacific Islanders	0.82	---

Incidence of red-green deficiencies from 67 studies. Sharpe et al. (1999).

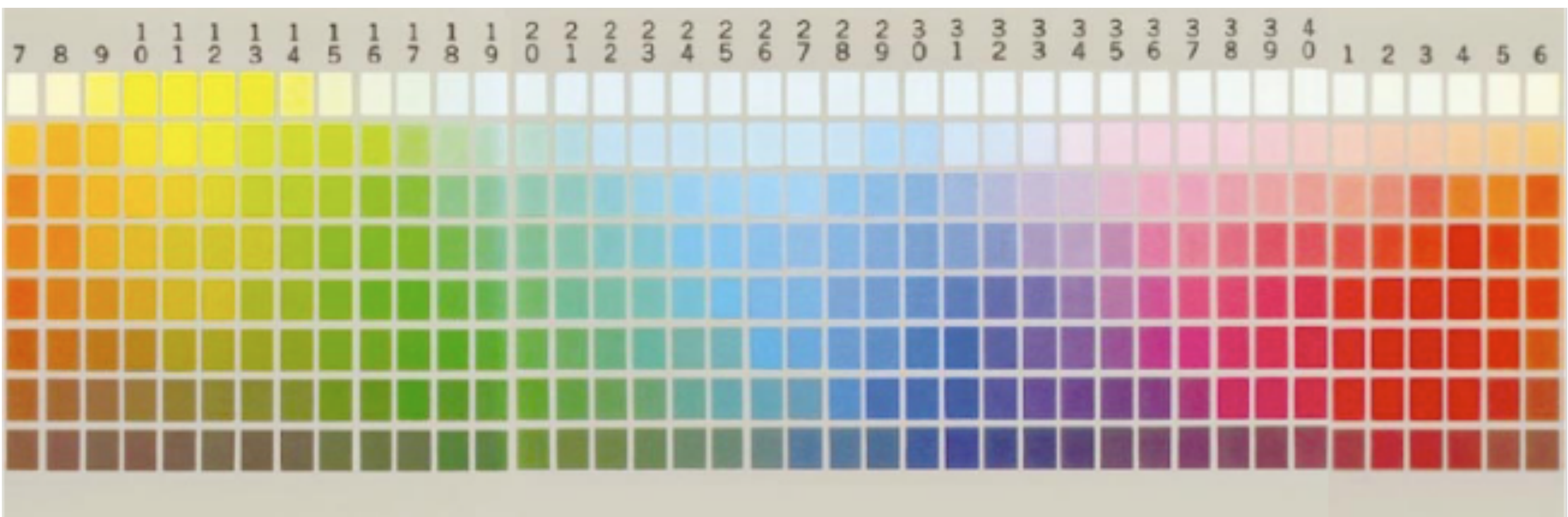
Possible Consequences?

Individuals are asked to name each chip in isolation. This provides the experimenter with a list of color terms.



Individuals are asked
Where are the examples of ...

“yellow” “green” “blue” “red”

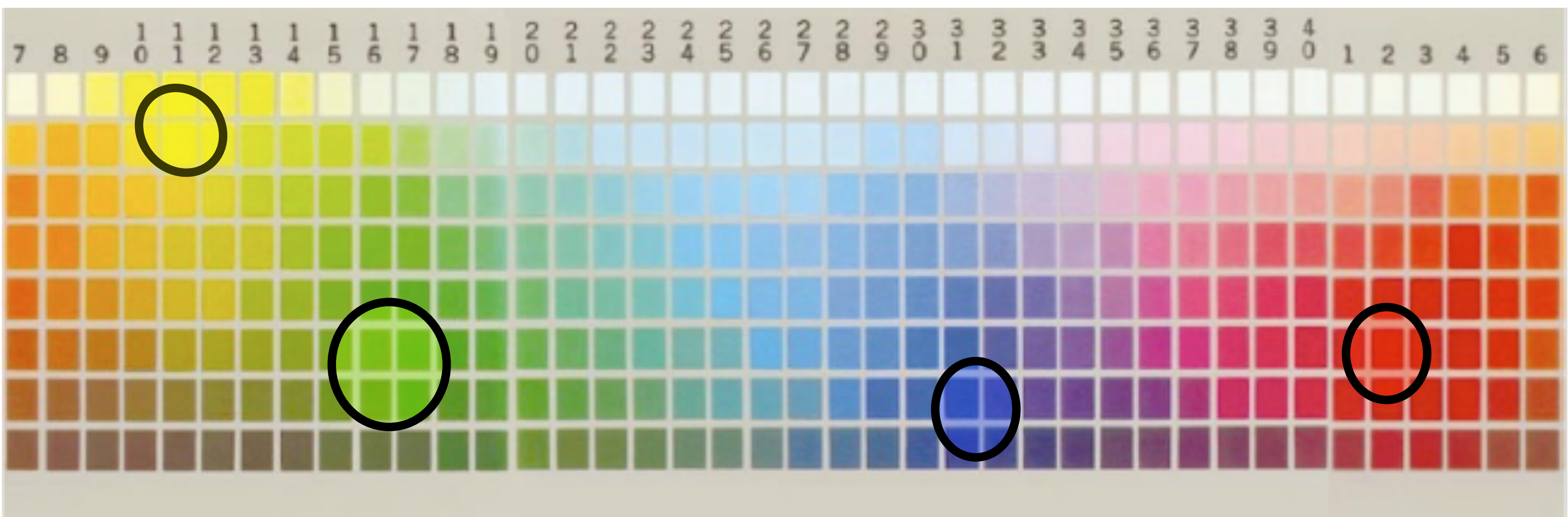


A cartoon of possible outcomes:

Where are the examples of ...

"yellow" "green" "blue" "red"

at the **individual choice** level:

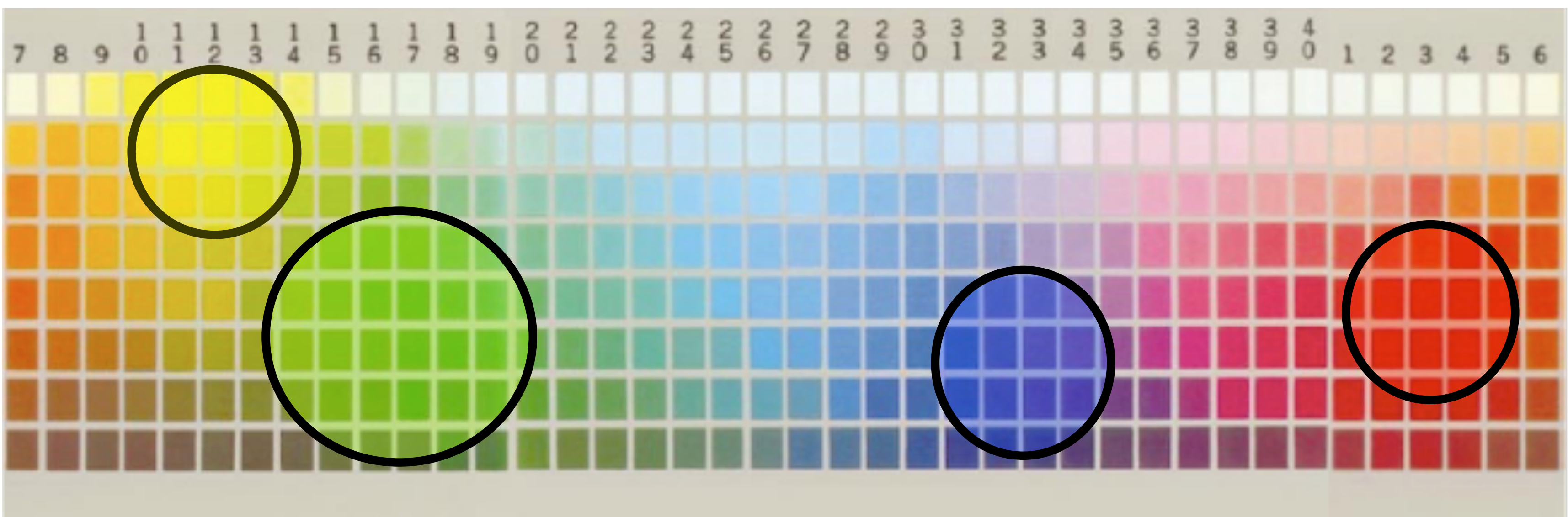


A cartoon of possible outcomes:

Where are the examples of ...

“yellow” “green” “blue” “red”

at the **language group aggregate** level:

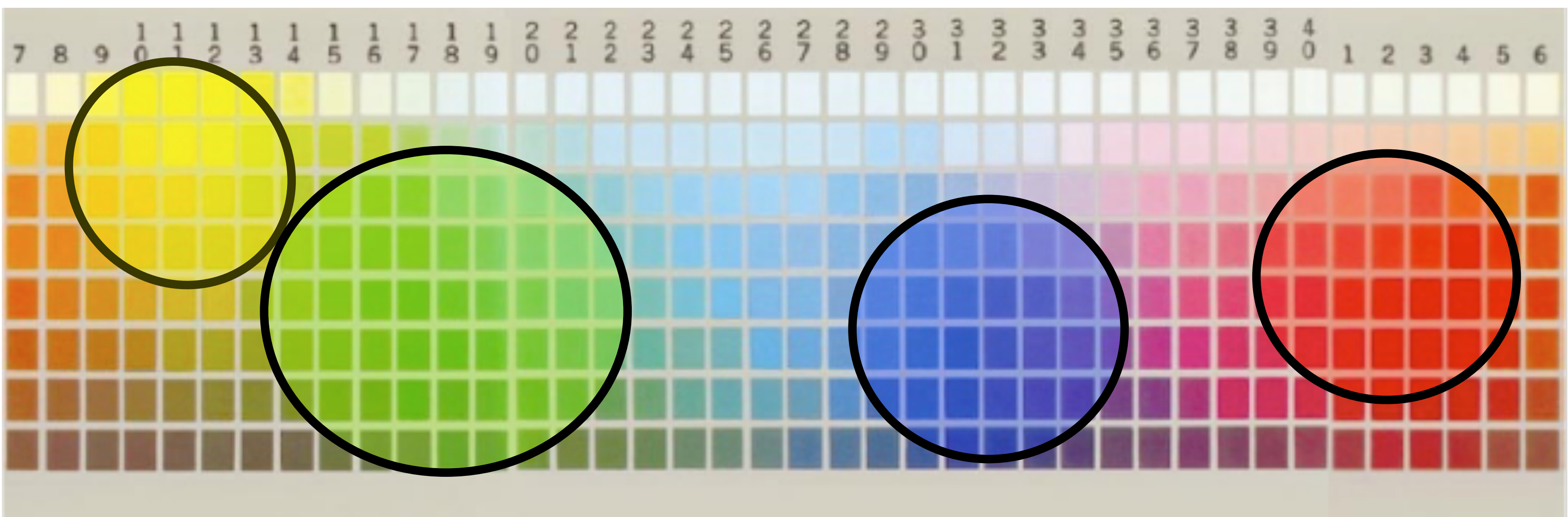


A cartoon of possible outcomes:

Where are the examples of ...

“yellow” “green” “blue” “red”

and **across language groups** you find:



It is this sort of observer variation that simulation investigations can help clarify.

(2.) Color category systems in the context of stimulus heterogeneity

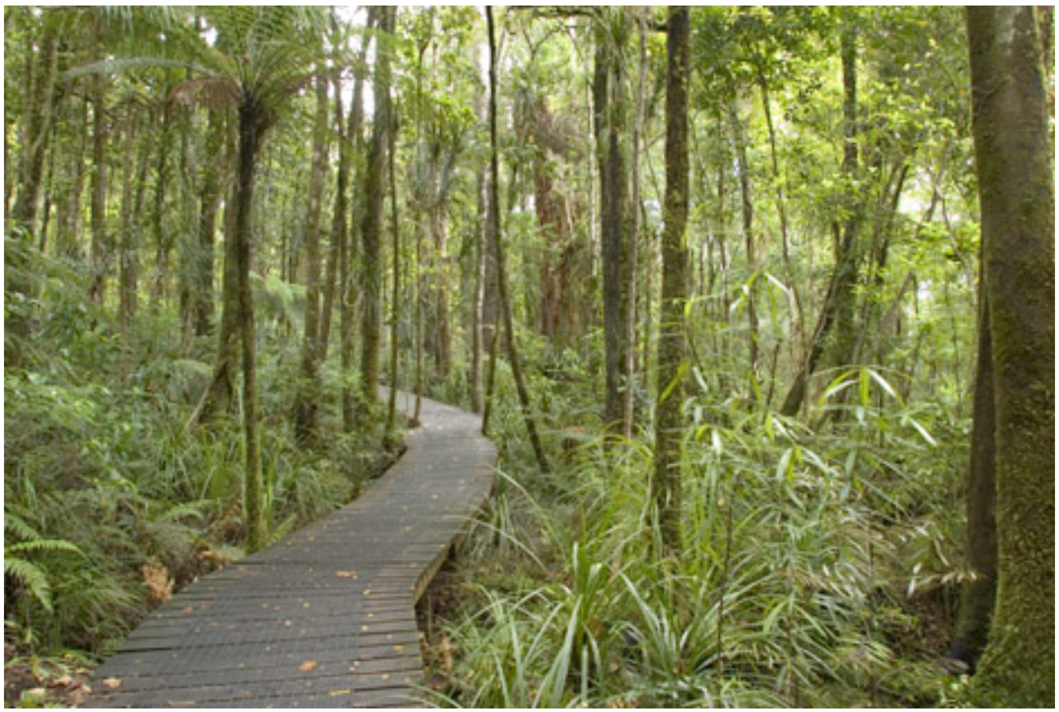
Environmental color serves a function

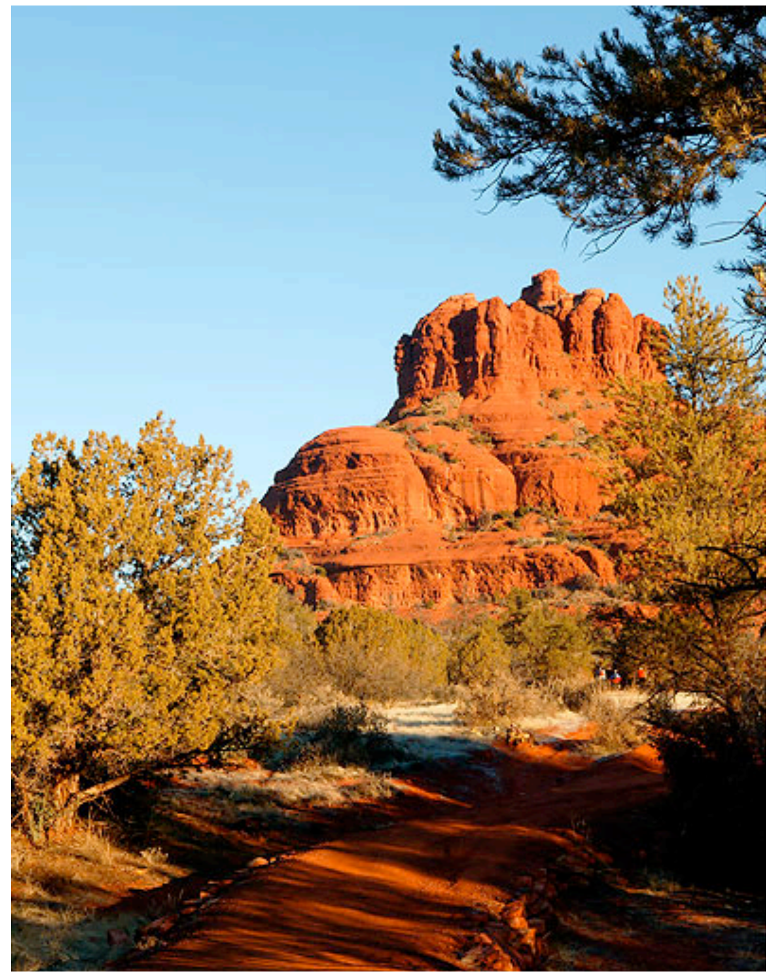
It could signal calorie rich food sources for some species:

- The biological basis for color vision in primates, including humans, reflects positive selection for identifying ripe fruit or tender leaves.

- Sumner & Mollon (2003). Did primate trichromacy evolve for frugivory or folivory? In *Normal & Defective Color Vision*. Mollon, Porkorny, Knoblauch (Ed.s).

How does environmental color variation, or differences in color utility, impact color categorization?





These are the kinds of issues we examine using simulated color category learning, to compare with existing empirical results & study the possible tradeoffs among factors thought to influence categorization.

The simulation studies

Important questions:

(1) What is the minimum one needs to evolve a color categorization systems?

And

(2) How do two or more factors which simultaneously influence color naming behaviors, trade off in the process of developing a stable color naming system?

Important difference:

We start with a Simplest-case Approach.

We begin by assuming very little about the phenomenon at all levels of observer features, environmental stimulus, socio-pragmatic influences on color signaling systems.

In particular, we do not incorporate any color perception model into our simulated agent observers.

We Assume Only:

(1) Individual agents detect differences in stimulus continua.

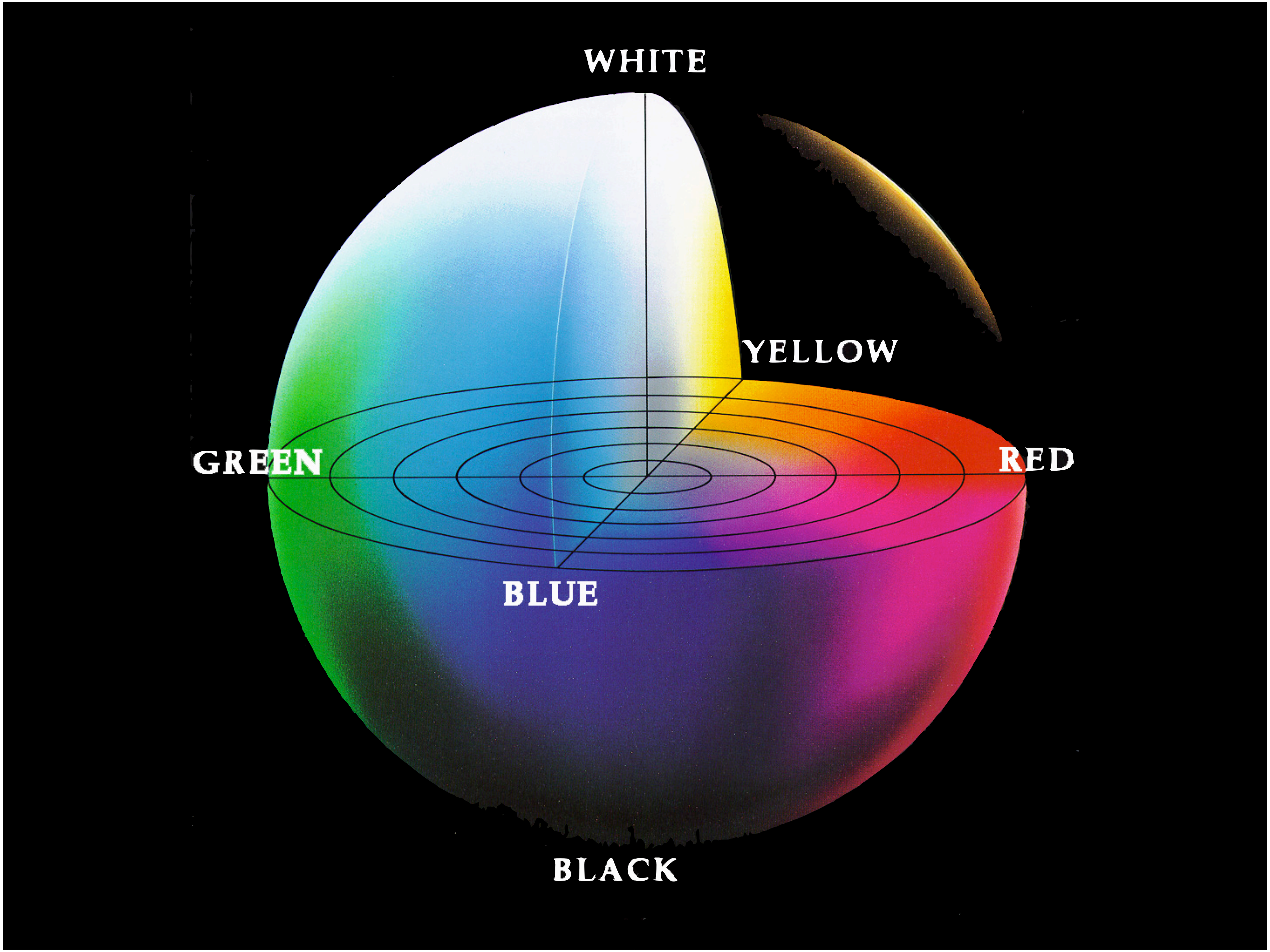
(2) Continuous stimulus domains are approximated by discrete samples that individuals can evaluate in discrimination games.

(3) Some need for categorization exists.

(4) Two agents can communicate via a discrimination game, with minimal pragmatic communication features assumed.

Categorization Domain:

- A subspace of the 3-dimensional space of color appearance: A Continuous Hue Circle.

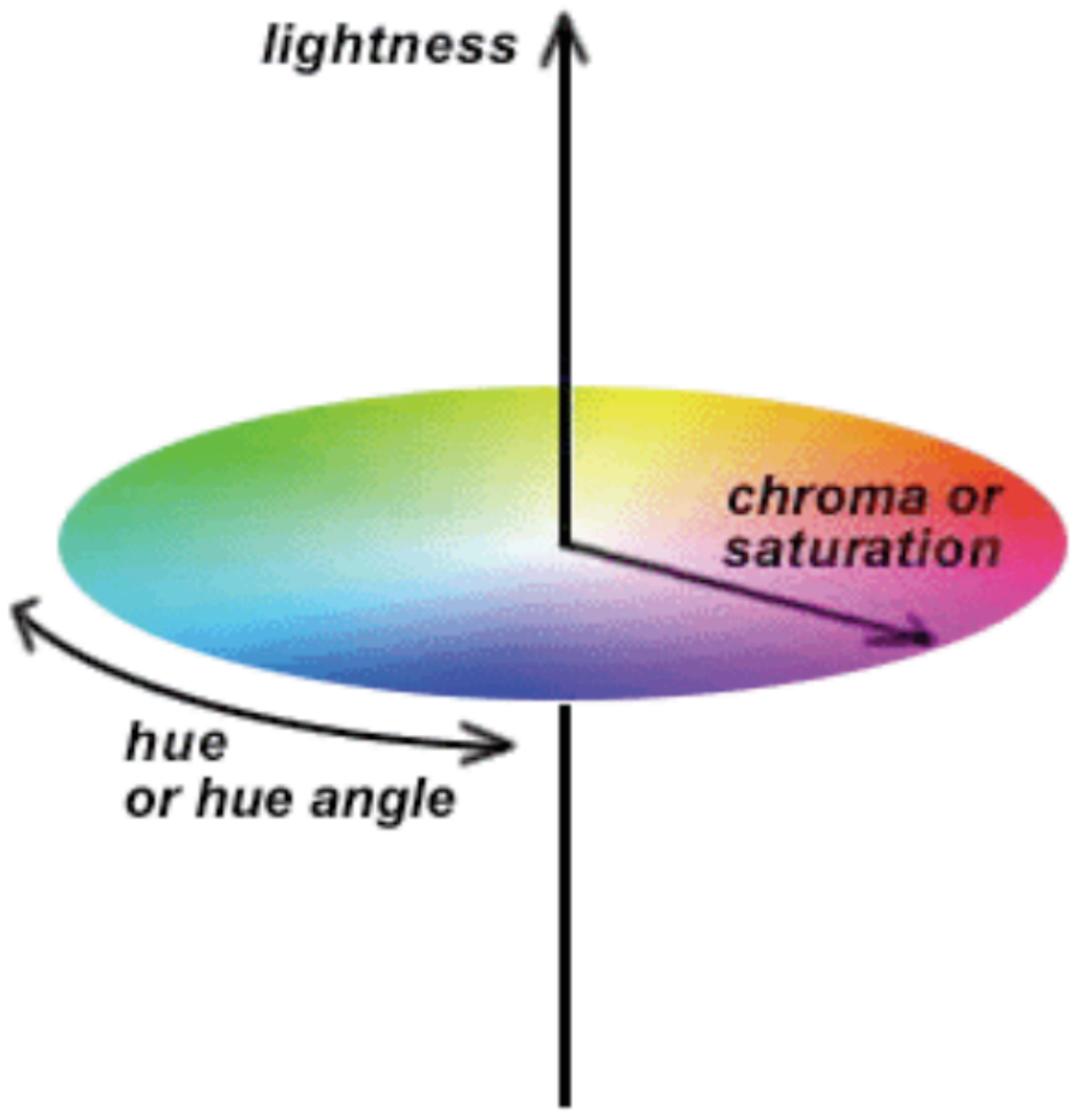

WHITE
YELLOW
GREEN
RED
BLUE
BLACK

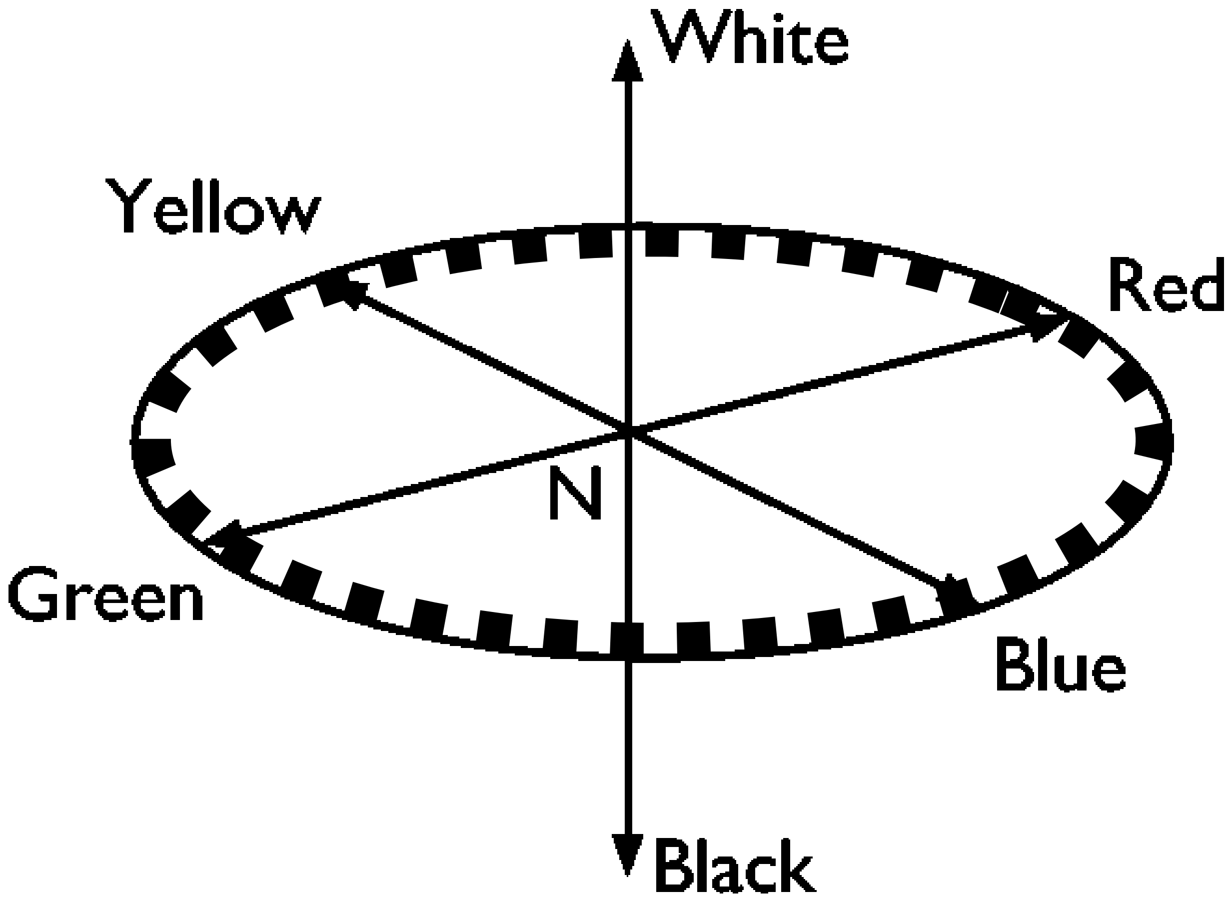
Why the Hue Circle?

- From a formal modeling standpoint, accepted color theory suggests it is the most natural one-dimensional reduction of the color space.

- The hue circle is an outcome of dimension reduction of spectral functions having any possible spectral form to three dimensions. (Kuehni 2003).

Color Space Dimensions




White
Yellow
Red
N
Green
Blue
Black

Sampled Hue Circle Continuum:

The Hue Circle Categorization Domain:

$\mathbf{1} \quad \ldots \quad \boldsymbol{i} \quad \ldots \quad \boldsymbol{j} \quad \ldots \quad \boldsymbol{n}$

- Allows comparisons between simulated category contours and empirically obtained category contours for structural similarity.

Relates to existing Cross-Cultural stimulus:

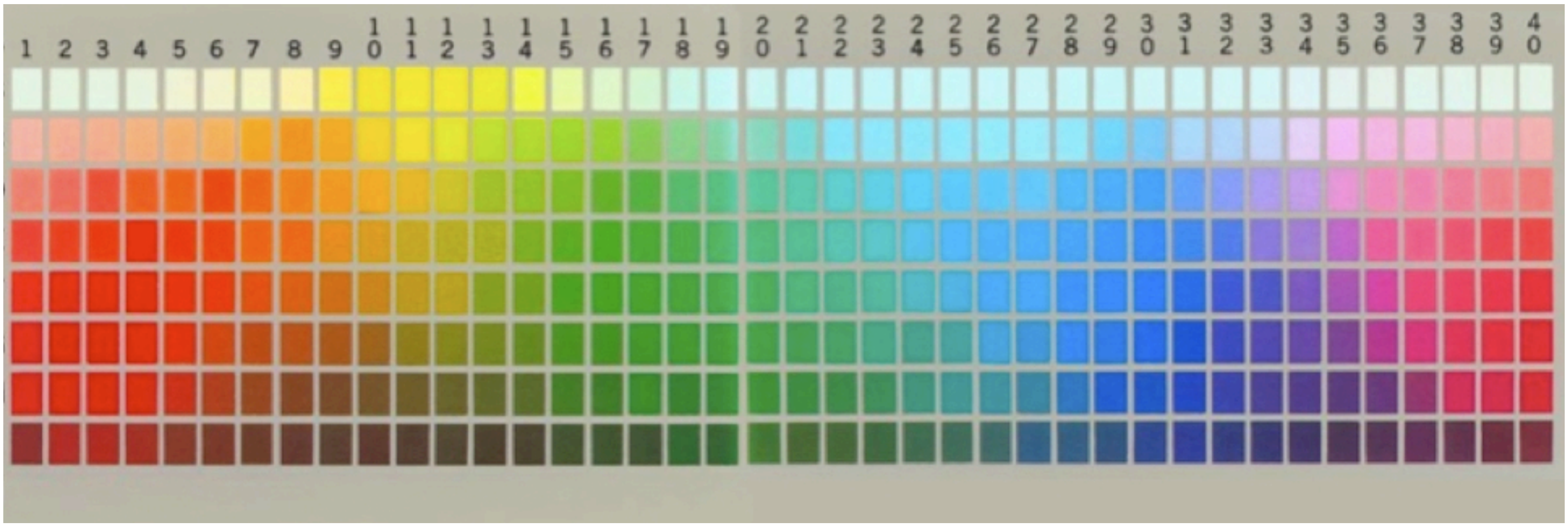


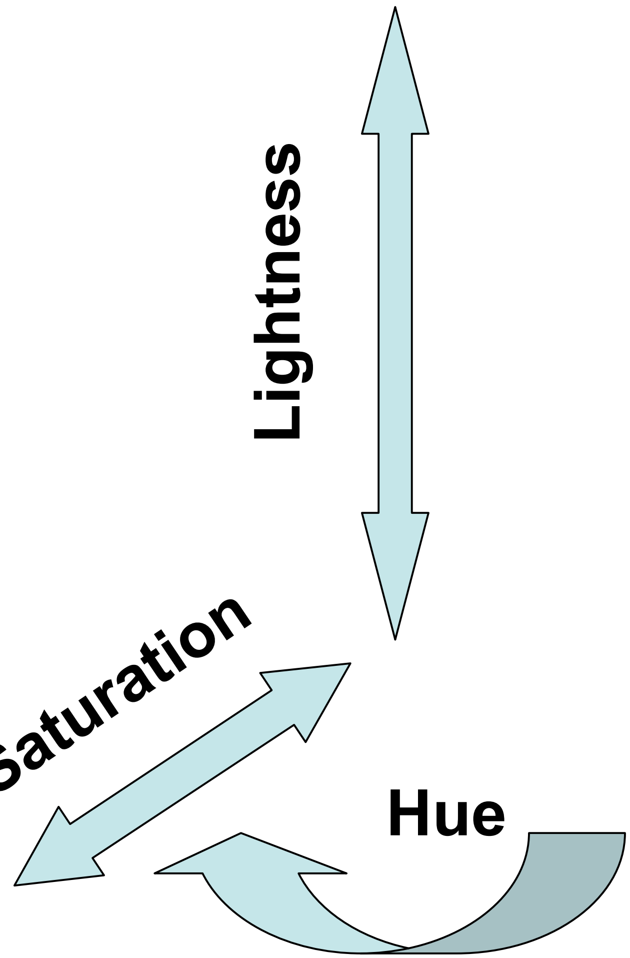
Image: Kay & Regier (2003). Resolving the question of color naming universals. *Proceedings of the National Academy of Science, 100*.

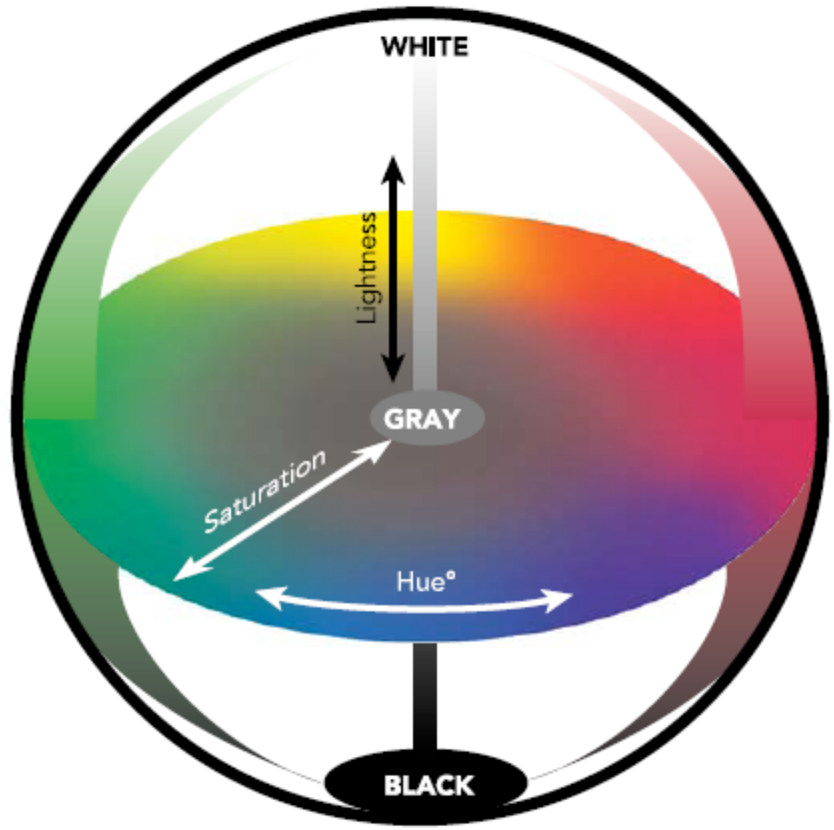
However:

Simulated color naming investigations do not tell us *how* humans categorize and name, but they may help clarify issues central to empirical investigations, and provide insight into some largely uninvestigated factors thought to play a role in human color categorization & naming behaviors.

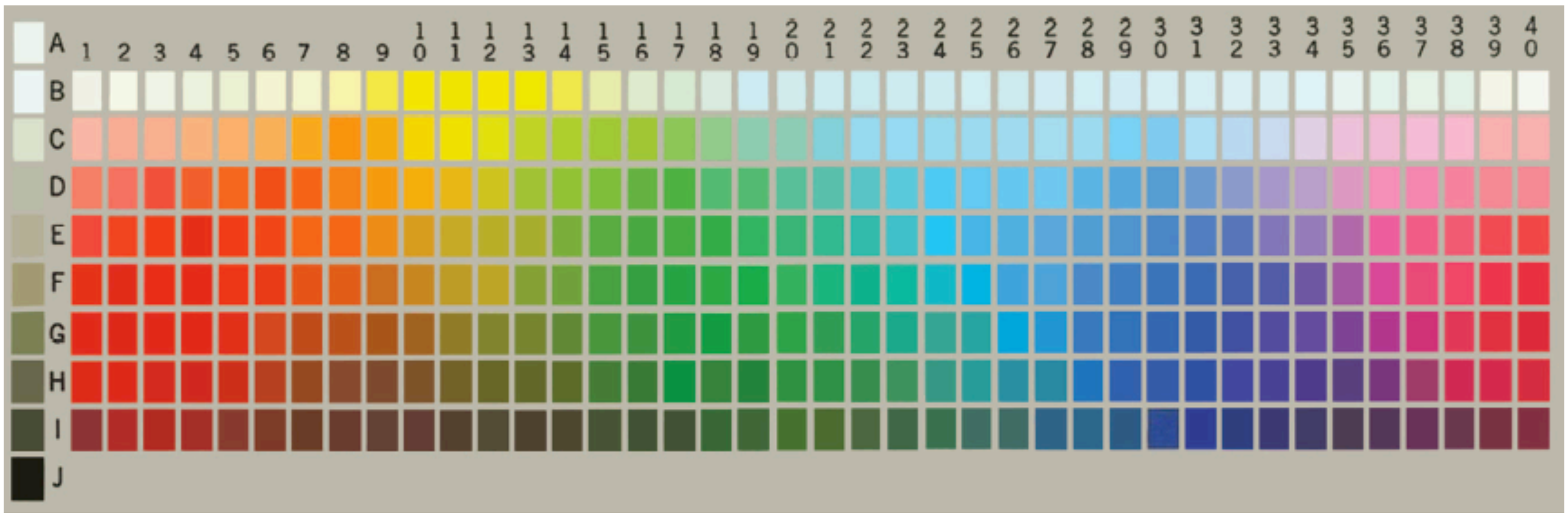
Simulated Naming ≠ Human Naming

Perceptual dimensions of the color space

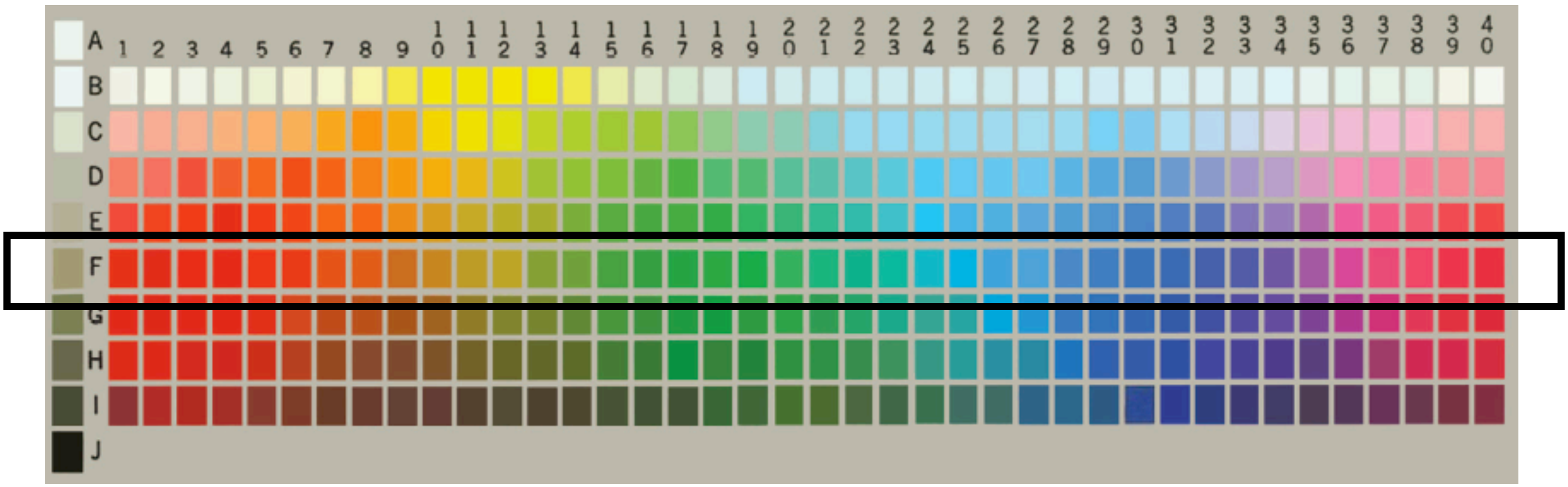




The “skin” of the color solid



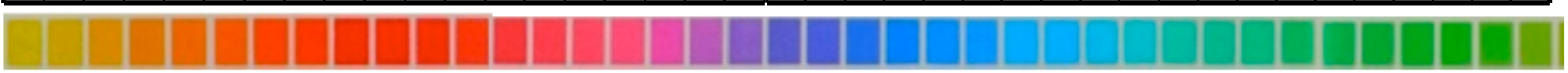
The “skin” of the color solid



The “hue circle”

Color categorization as a probabilistic strategy

A	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0
B	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	1.0	0.1	0.1	0.0	0.0	0.0	1.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
C	0.3	0.0	0.3	0.1	0.3	0.3	0.0	0.7	0.3	0.1	0.3	0.0	0.7	0.3	0.0	0.3	0.7	0.7	0.1	0.3	0.0	0.1	0.1	0.3	0.3	0.3	0.0	0.1	0.7	0.1	0.0	0.7	0.1	0.7	0.0	0.0	0.1	0.3	0.3
D	0.5	0.0	0.5	0.0	0.5	0.5	0.0	0.1	0.5	0.0	0.5	0.8	0.1	0.5	0.8	0.5	0.1	0.1	0.0	0.5	0.0	0.5	0.5	0.5	0.5	0.5	0.0	0.5	0.1	0.5	0.0	0.1	0.5	0.1	0.0	0.0	0.5	0.5	0.5
E	0.2	1.0	0.2	0.0	0.2	0.2	1.0	0.1	0.2	0.0	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.0	0.2	0.0	0.1	0.1	0.2	0.2	0.2	0.0	0.1	0.1	0.1	1.0	0.1	0.1	0.1	1.0	1.0	0.1	0.2	0.2
F	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1



Color categorization as a probabilistic strategy

red	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0
orange	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	1.0	0.1	0.1	0.0	0.0	0.0	1.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
yellow	0.3	0.0	0.3	0.1	0.3	0.3	0.0	0.7	0.3	0.1	0.3	0.0	0.7	0.3	0.0	0.3	0.7	0.7	0.1	0.3	0.0	0.1	0.1	0.3	0.3	0.3	0.0	0.1	0.7	0.1	0.0	0.7	0.1	0.7	0.0	0.0	0.1	0.3	0.3
green	0.5	0.0	0.5	0.0	0.5	0.5	0.0	0.1	0.5	0.0	0.5	0.8	0.1	0.5	0.8	0.5	0.1	0.1	0.0	0.5	0.0	0.5	0.5	0.5	0.5	0.5	0.0	0.5	0.1	0.5	0.0	0.1	0.5	0.1	0.0	0.0	0.5	0.5	0.5
blue	0.2	1.0	0.2	0.0	0.2	0.2	1.0	0.1	0.2	0.0	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.0	0.2	0.0	0.1	0.1	0.2	0.2	0.2	0.0	0.1	0.1	0.1	1.0	0.1	0.1	0.1	1.0	1.0	0.1	0.2	0.2
purple	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1

Color categorization as a probabilistic strategy

A	**0.0**	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0
B	**0.0**	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	1.0	0.1	0.1	0.0	0.0	0.0	1.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
C	**0.3**	0.0	0.3	0.1	0.3	0.3	0.0	0.7	0.3	0.1	0.3	0.0	0.7	0.3	0.0	0.3	0.7	0.7	0.1	0.3	0.0	0.1	0.1	0.3	0.3	0.3	0.0	0.1	0.7	0.1	0.0	0.7	0.1	0.7	0.0	0.0	0.1	0.3	0.3
D	**0.5**	0.0	0.5	0.0	0.5	0.5	0.0	0.1	0.5	0.0	0.5	0.8	0.1	0.5	0.8	0.5	0.1	0.1	0.0	0.5	0.0	0.5	0.5	0.5	0.5	0.5	0.0	0.5	0.1	0.5	0.0	0.1	0.5	0.1	0.0	0.0	0.5	0.5	0.5
E	**0.2**	1.0	0.2	0.0	0.2	0.2	1.0	0.1	0.2	0.0	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.0	0.2	0.0	0.1	0.1	0.2	0.2	0.2	0.0	0.1	0.1	0.1	1.0	0.1	0.1	0.1	1.0	1.0	0.1	0.2	0.2
F	**0.1**	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1

Color categorization as a probabilistic strategy

A	0.0	**0.0**	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
B	0.0	**0.0**	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
C	0.3	**0.0**	0.3	0.1	0.3	0.3	0.0	0.7	0.3	0.1	0.3	0.0	0.7	0.3	0.0	0.3	0.7	0.7	0.1
D	0.5	**0.0**	0.5	0.0	0.5	0.5	0.0	0.1	0.5	0.0	0.5	0.8	0.1	0.5	0.8	0.5	0.1	0.1	0.0
E	0.2	**1.0**	0.2	0.0	0.2	0.2	1.0	0.1	0.2	0.0	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.0
F	0.1	**0.0**	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.0

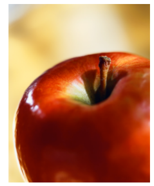
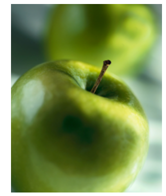
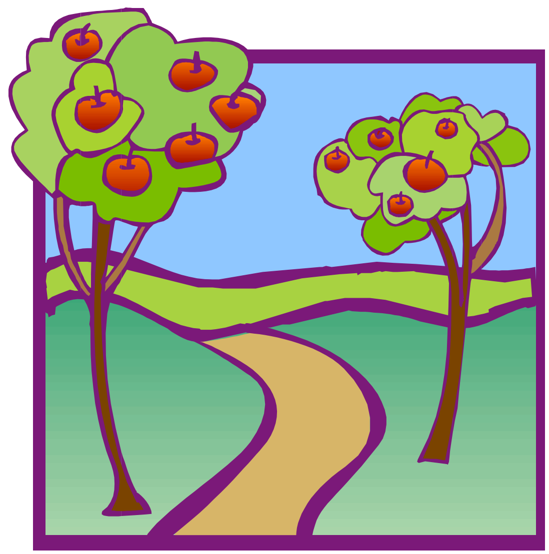
A	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0
B	0.0	1.0	0.1	0.1	0.0	0.0	0.0	1.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
C	0.3	0.0	0.1	0.1	0.3	0.3	0.3	0.0	0.1	0.7	0.1	0.0	0.7	0.1	0.7	0.0	0.0	0.1	0.3	0.3
D	0.5	0.0	0.5	0.5	0.5	0.5	0.5	0.0	0.5	0.1	0.5	0.0	0.1	0.5	0.1	0.0	0.0	0.5	0.5	0.5
E	0.2	0.0	0.1	0.1	0.2	0.2	0.2	0.0	0.1	0.1	0.1	1.0	0.1	0.1	0.1	1.0	1.0	0.1	0.2	0.2
F	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1

Pragmatic considerations

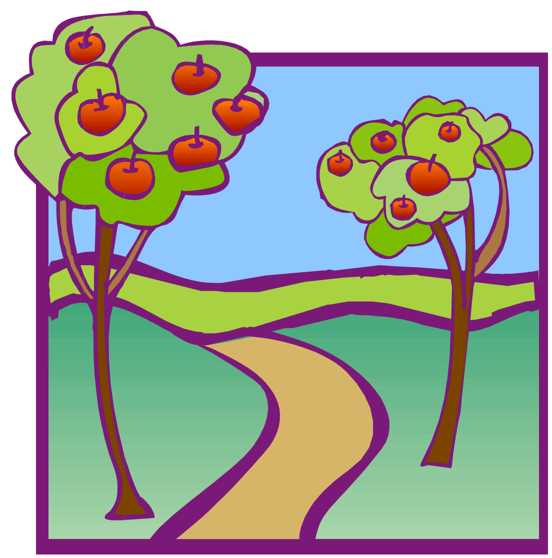
- Objects of similar colors are likely to have similar properties
- Objects of different colors are likely to have different properties

Pragmatic considerations

Pragmatic considerations

Pragmatic considerations



Pragmatic considerations

- It is useful to call similar colors the same name
- It is useful to call “far away” colors different names

Pragmatic considerations

- It is useful to call similar colors the same name
- It is useful to call “far away” colors different names
- It is also useful to be able to communicate with others…

The individual discrimination game

- Two colors chips are picked from a distribution
- The agent (probabilistically) assigns color categories

	Chips nearby	Chips far apart
Same category	Success	Failure
Different category	Failure	Success

The individual discrimination game

- Two colors chips are picked from a distribution
- The agent (probabilistically) assigns color categories

	Chips closer than ***k-sim***	Chips farther apart than ***k-sim***
Same category	Success	Failure
Different category	Failure	Success

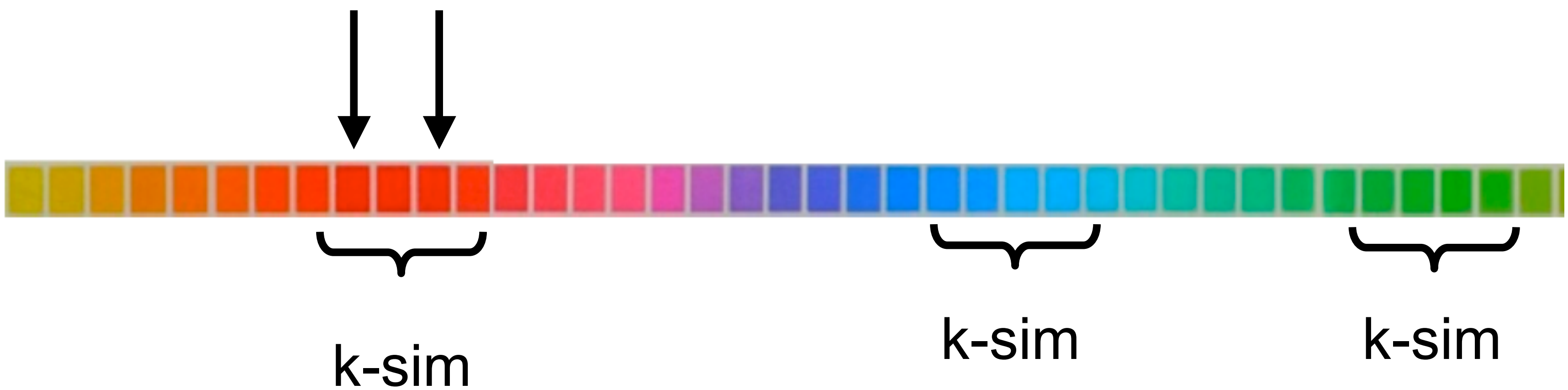
Similarity range, k-sim

Similarity range, "**K-*sim***" (K-similarity), is

The minimum difference between the color chips for which it becomes important to treat them for pragmatic purposes (and not for perceptual purposes) as different color categories.

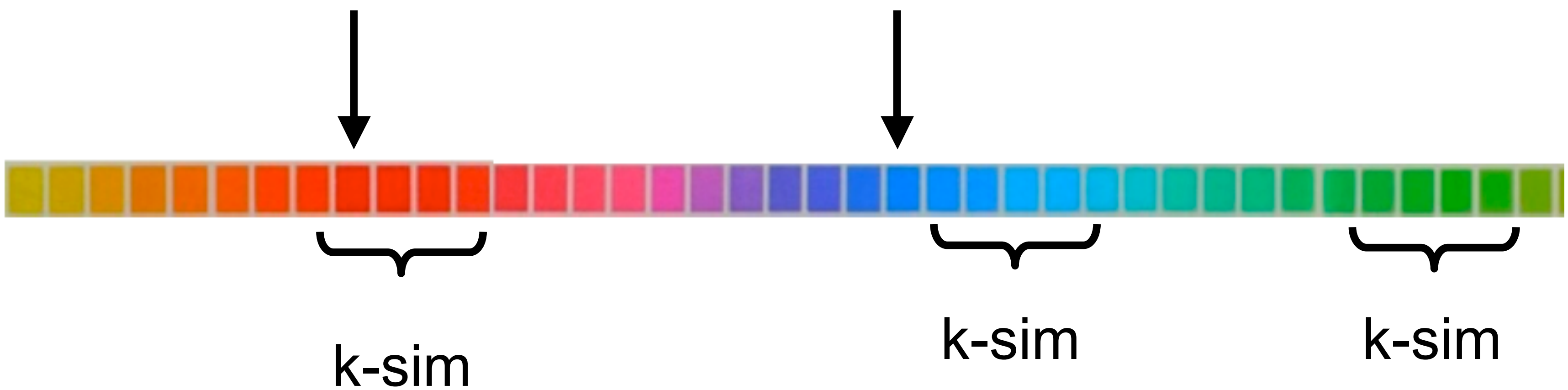
Note, K-*sim* is not another form of *just-noticable-difference* (although it is related to color j.n.d. as a minimum bound).

The measure of similarity



For success I need to put these in the same category

The measure of similarity



For success I need to put these in different categories

Success rate

- Given acategorization, let us play N discrimination games. Then

$$S = \lim_{N \to \infty} \frac{\text{Number of successful games}}{N}$$

- This is the probability for a given categorization that a game is successful

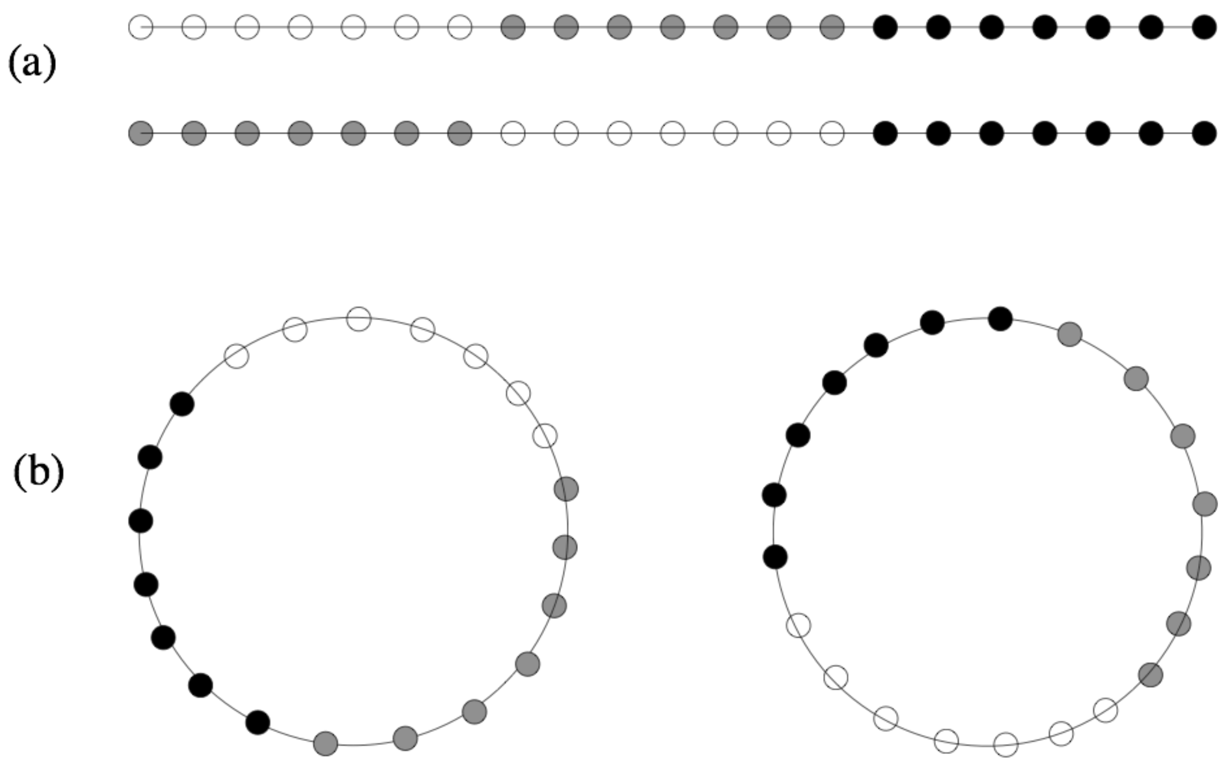
The optimal categorization

- The optimal categorization is the one that maximizes the probability of success of discrimination/communication games

The optimal categorization

- The optimal categorization is the one that maximizes the probability of success of discrimination/communication games
- This can be found theoretically in the simplest scenarios
- Otherwise, we study the evolutionary dynamics numerically

Optimal categorizations for (a) an interval and (b) a circle



m = 3 color categories, and n = 21 stimuli

The optimal categorization: analytical results

- The optimal categorization is deterministic (one category for each chip)

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- The optimal categorization is deterministic (one category for each chip)
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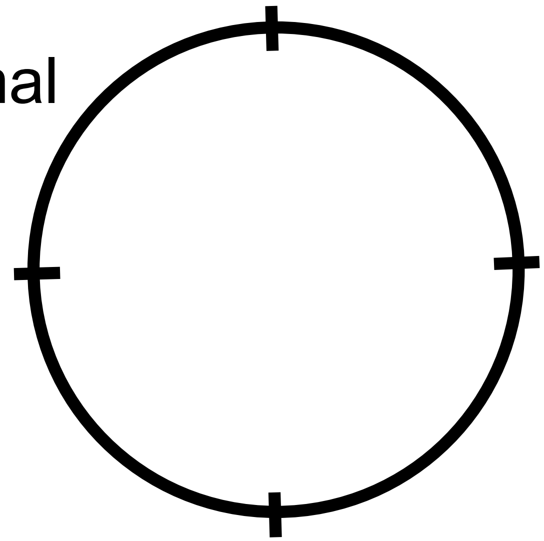
$$m_{opt} = \frac{n}{\sqrt{2k_{sim}(k_{sim}+1)}}$$

- They are rotationally invariant

Optimal categorization

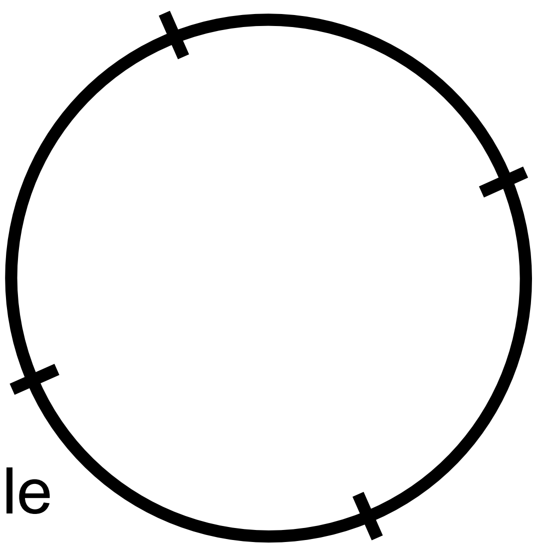
We can prove that the optimal number of categories is:

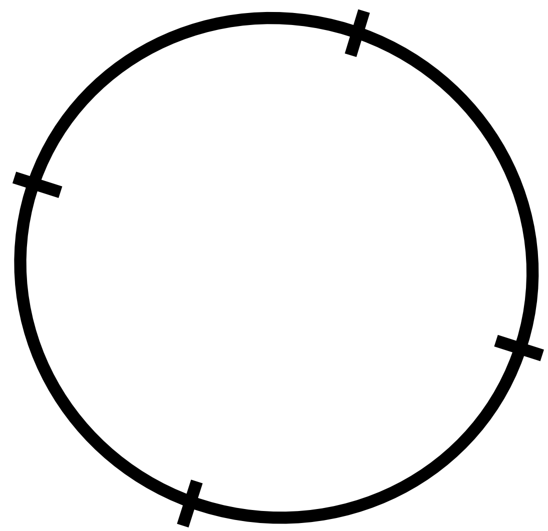
$$m_{opt} = \frac{n}{\sqrt{2k_{sim}(k_{sim}+1)}}$$



Categories have an equal size.

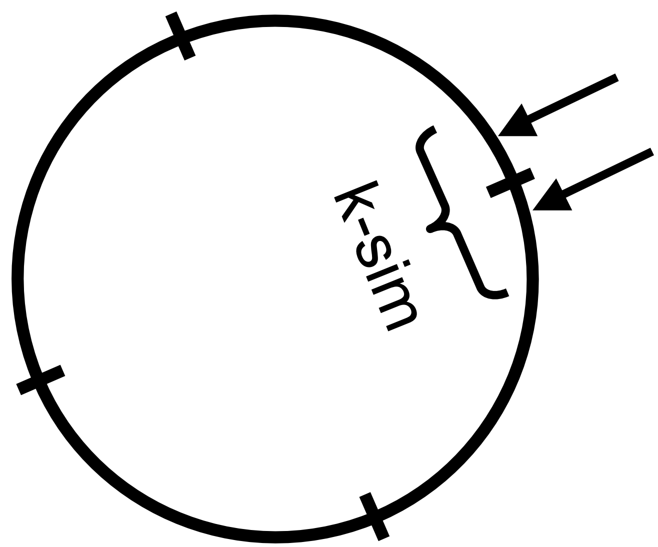
Categorization is rotationally invariant





n = the total number of distinguishable chips

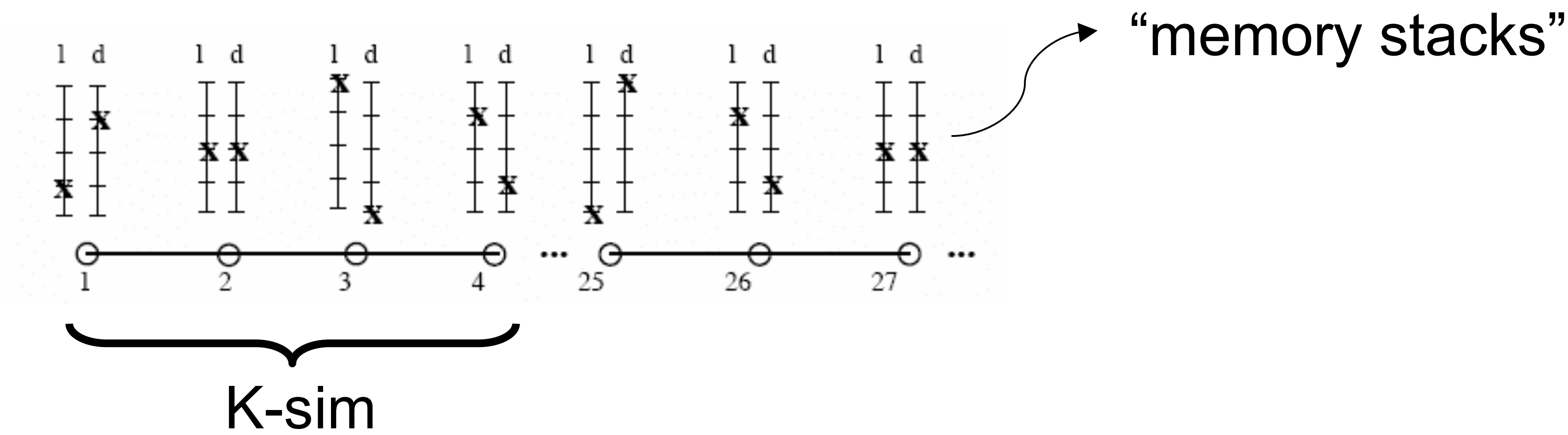
Success rate can never be one



Evolutionary dynamics

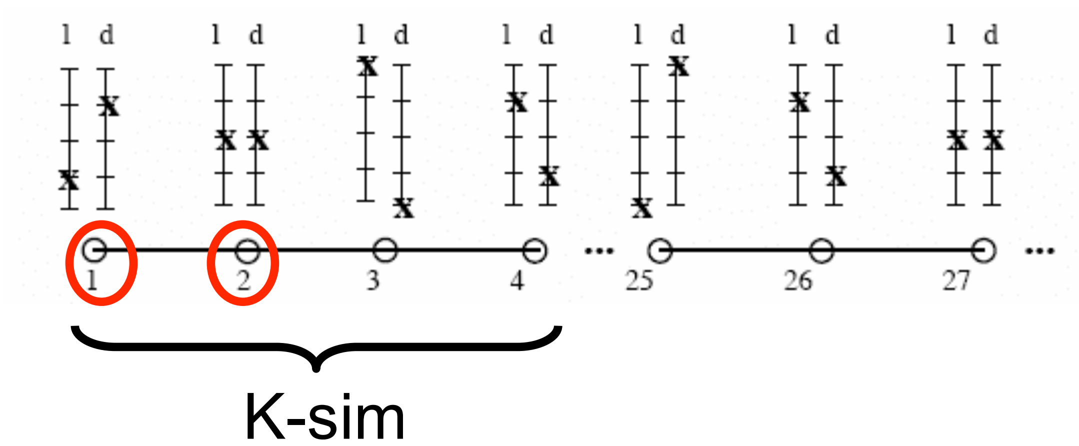
- A player starts from a random categorization
- Rounds of the discrimination game are played
- In case of “success”, the category is strengthened, in case of “failure” it is weakened…

Reinforcement learners

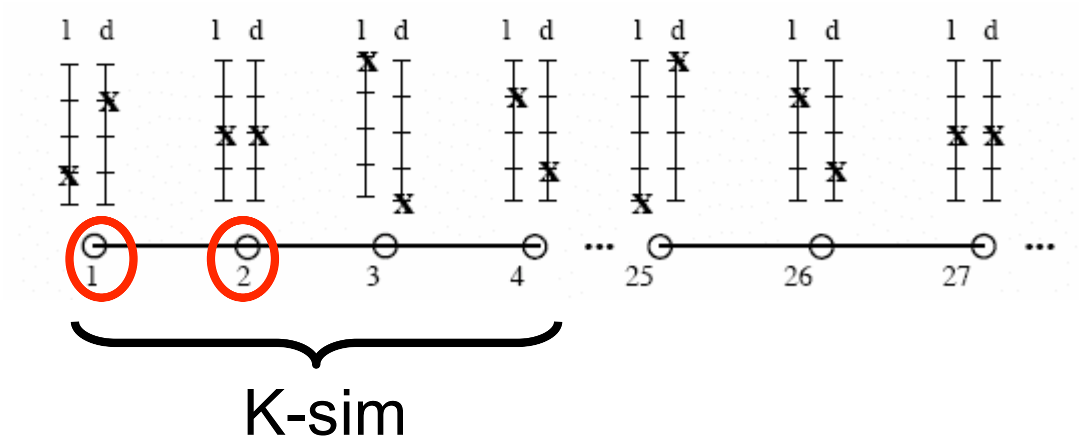


Only two color terms:
l="light" and d="dark"

Reinforcement learners

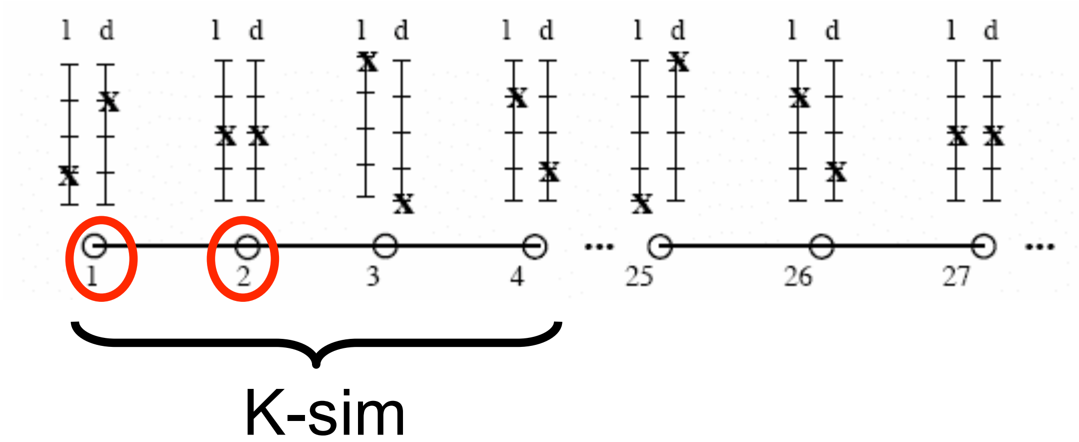


Reinforcement learners



Assign: 1=dark, 2=light

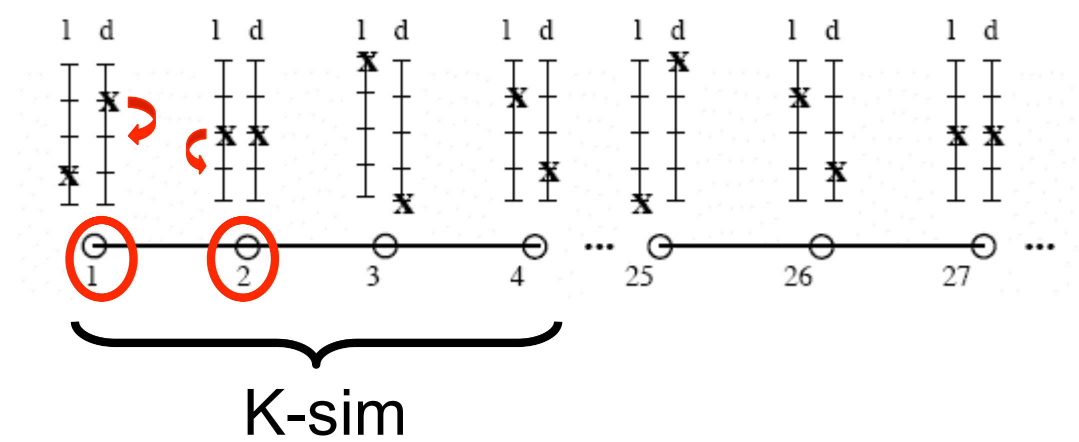
Reinforcement learners



Assign: 1=dark, 2=light

Failure!

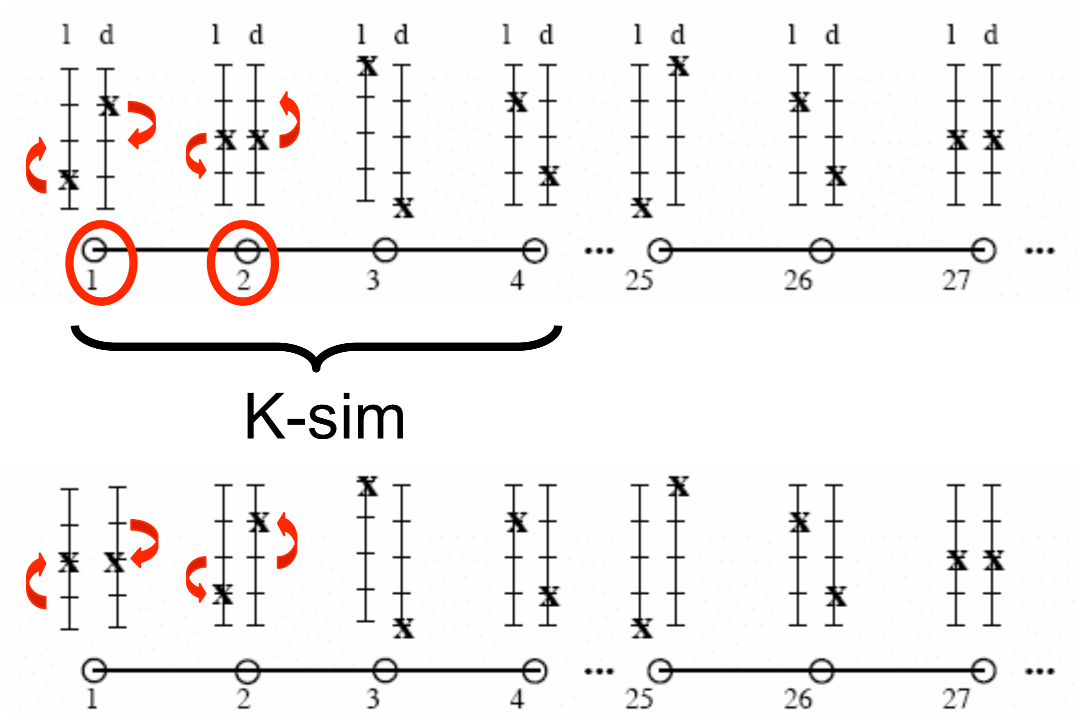
Reinforcement learners



Assign: 1=dark, 2=light

Failure!

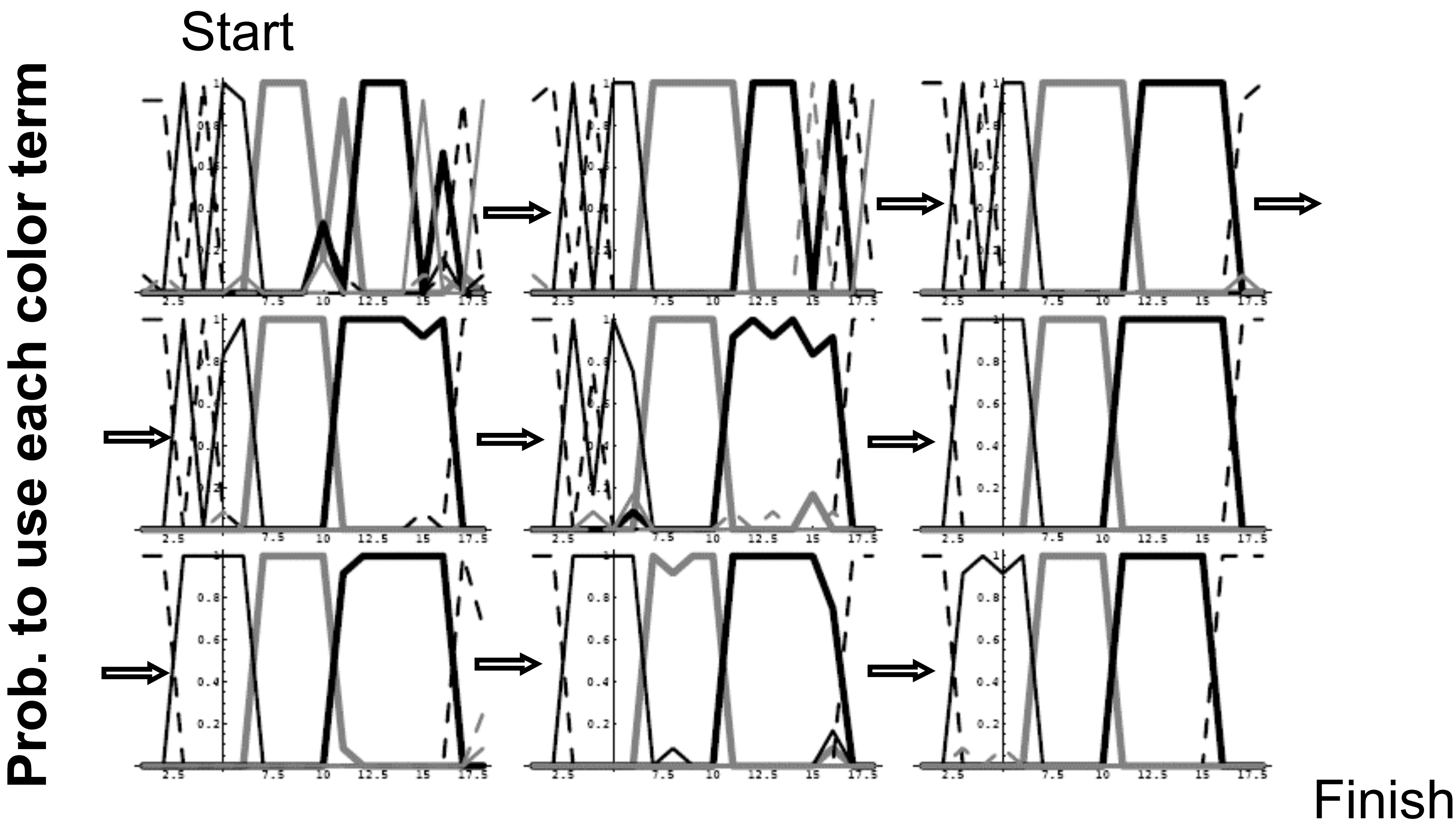
Reinforcement learners



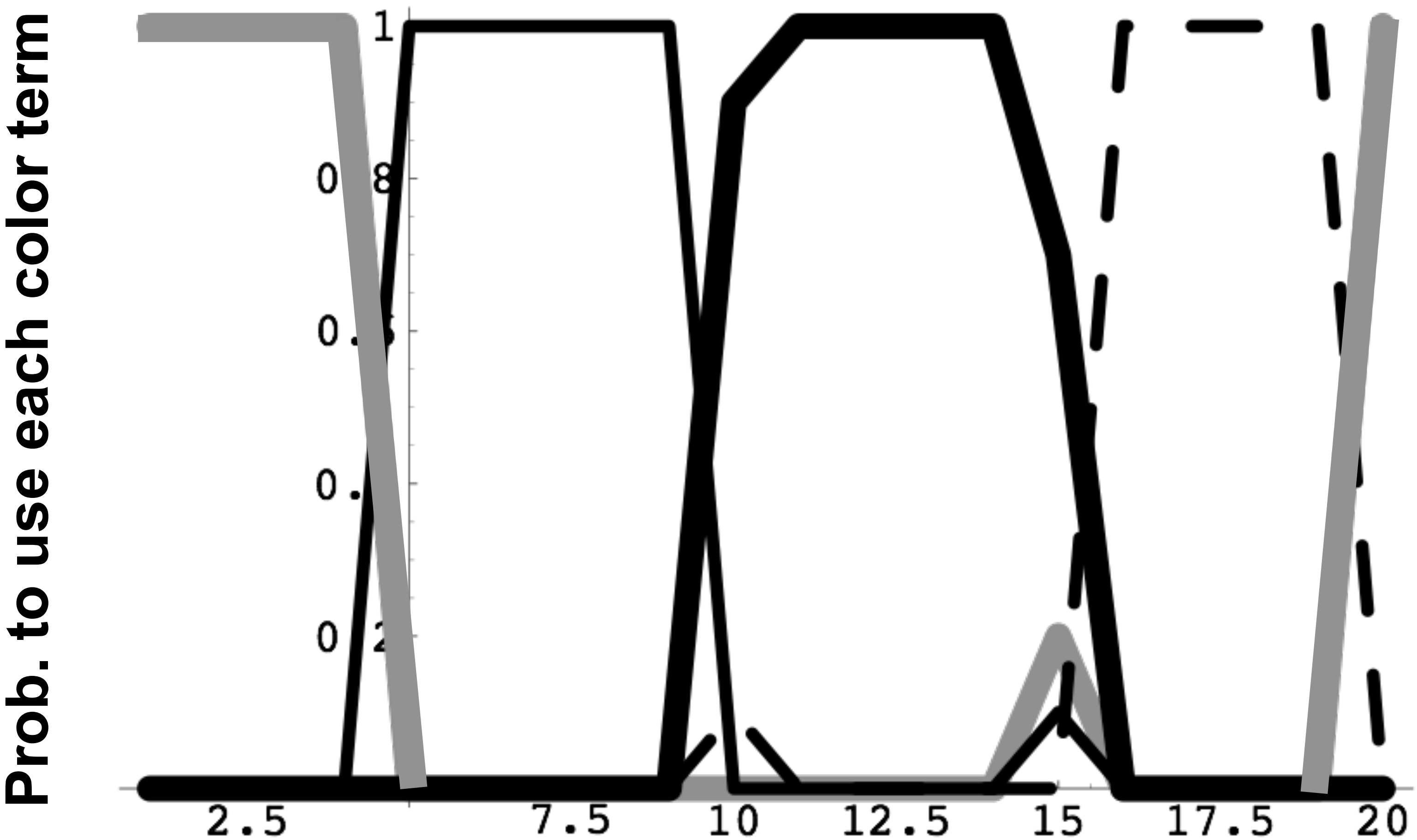
Assign: 1=dark, 2=light

Failure!

Rounds of individual discrimination game

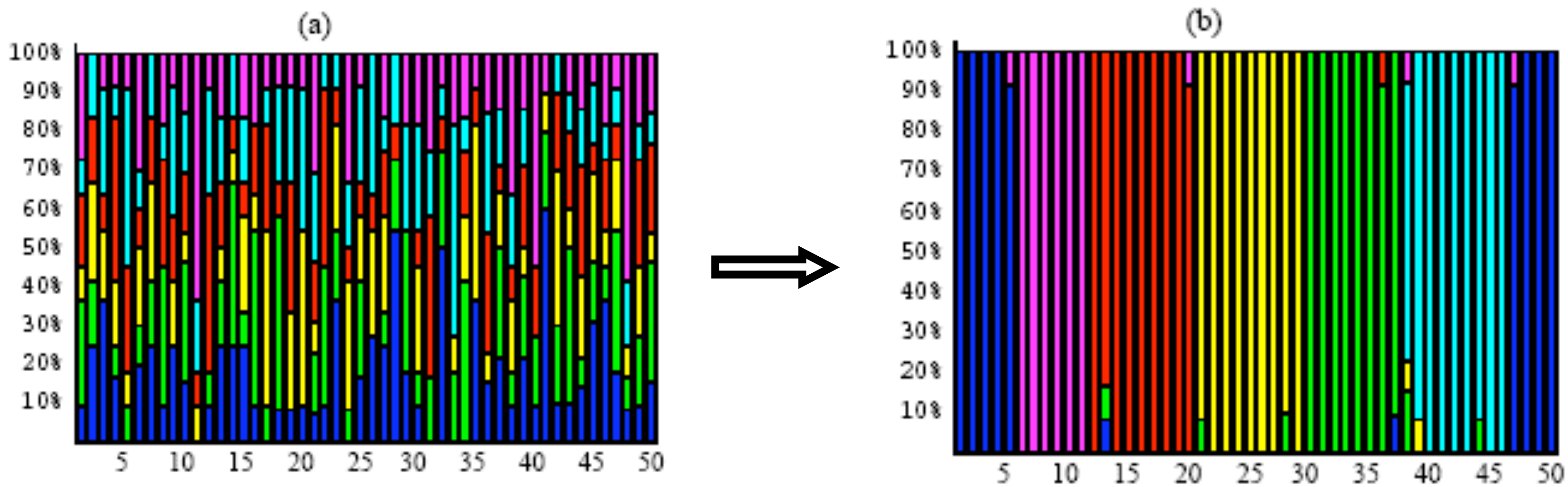


One agent's color categorization



4 categories after 44,000 runs

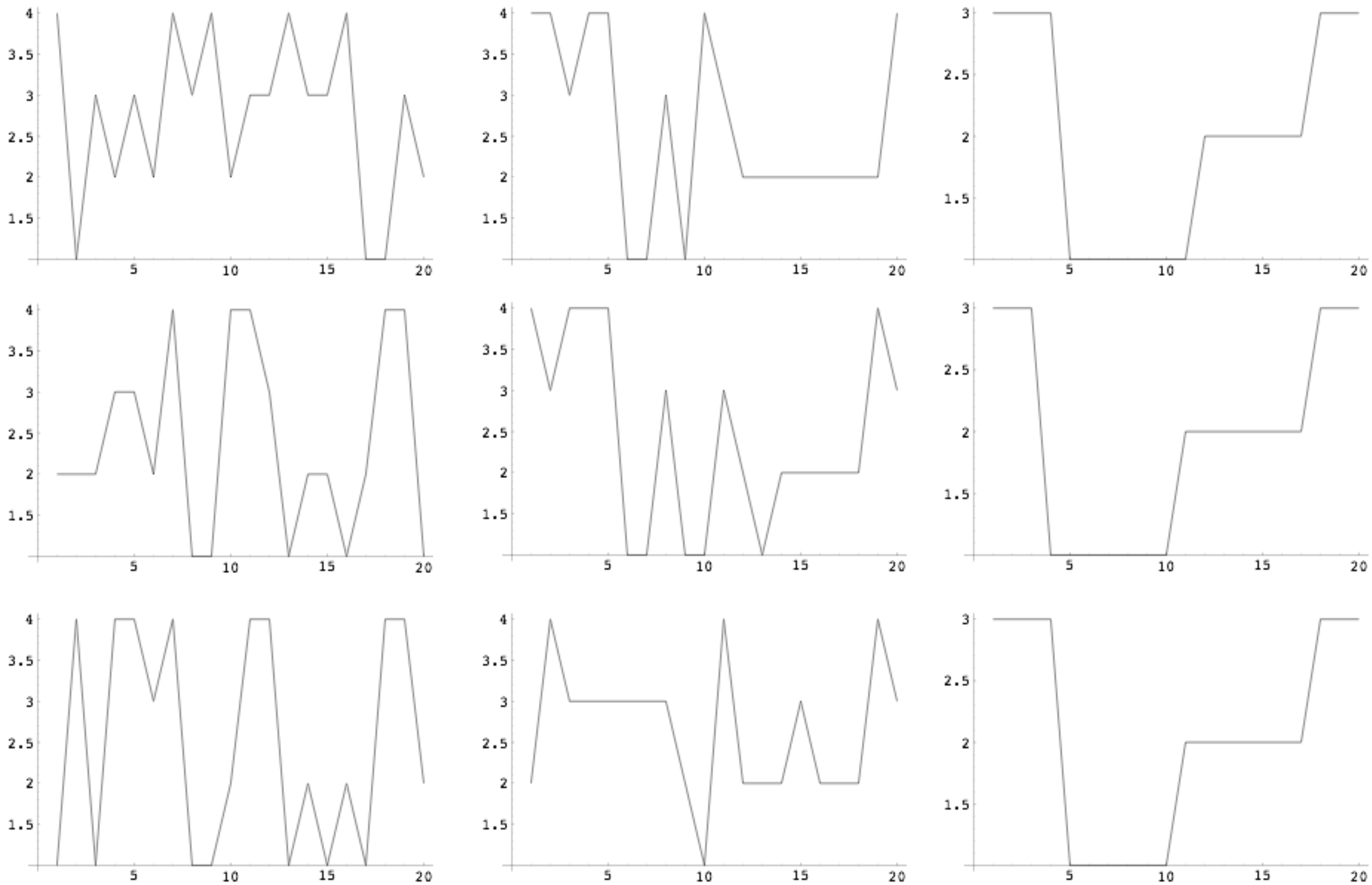
Color categorization of individual agents



Communication game

- Two individuals play the discrimination game
- If one succeeded and the other failed, the failed individual learns from the successful one
- If both succeeded, the teacher is chosen at random
- If both failed, both update their categorization as in the individual game

Population Color Categorization:



Agent 1

Agent 2

Agent 3

Run 1 | Run 10,000 | Run 70,000

Population solutions: the winning categories

- For a given chip, each player has the most likely category, the second most likely etc.
- For this chip, suppose color k is the most likely category for $n_1^{(k)}$ agents, the second most likely category for $n_2^{(k)}$ agents etc
- Form the score for each color: $s_k = \sum_{i=1}^{m} \xi_i n_i^{(k)}$
- The color with the largest score is the winning color

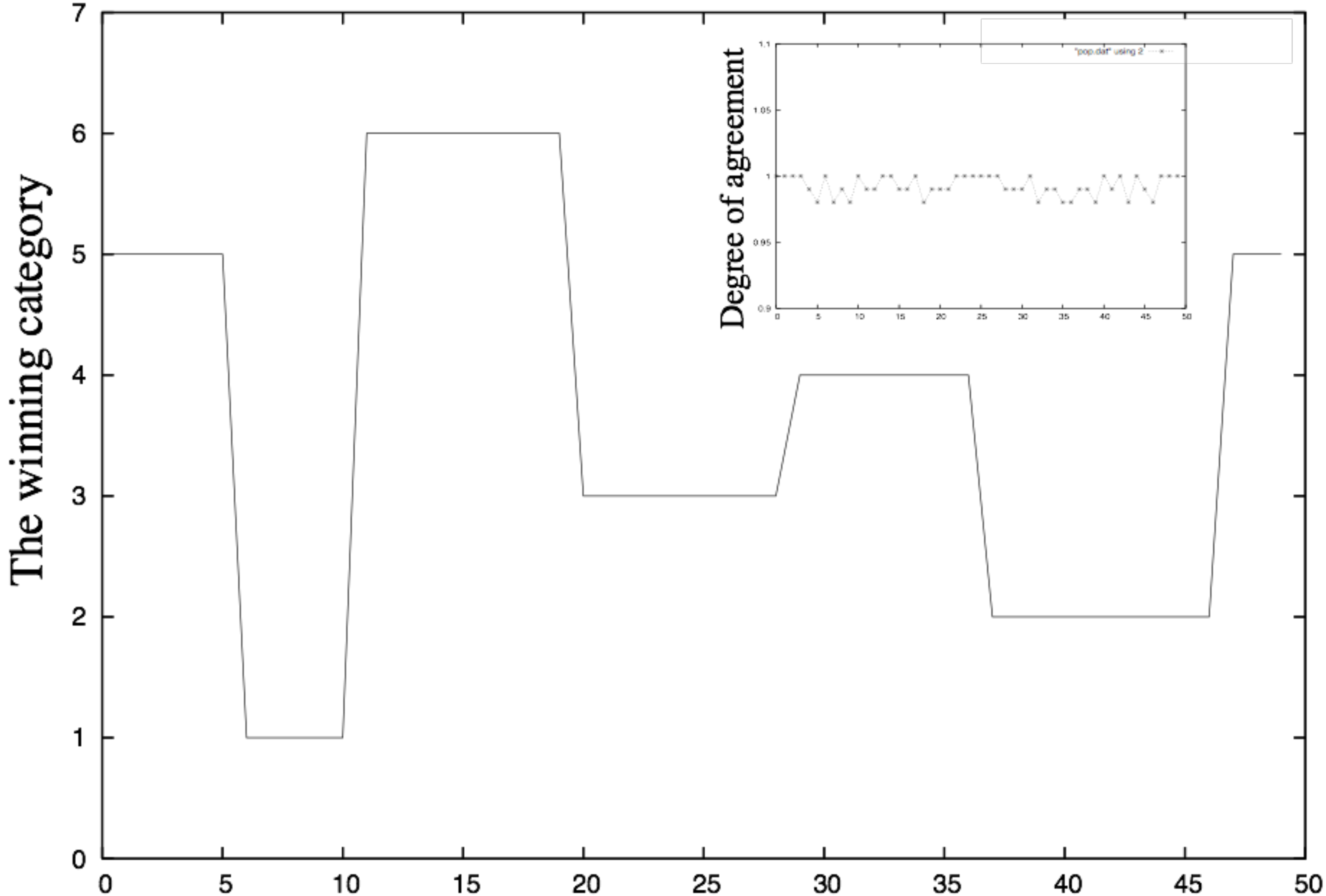
The winning category

- The score for color *k* is: $s_k = \sum_{i=1}^{m} \xi_i n_i^{(k)}$
- $\xi_1 = 1, \quad \xi_i = 0, i > 1$ plurality vote
- $\xi_i = m - i$ Borda count

The winning category: plurality and Borda scores compared

Number of rounds		*The winning categories:*
	plurality / *Borda*	
10,000	plurality	2 6 2 1 4 4 5 4 3 4 6 3 4 1 1 1 5 5 6 4 2 3 1 3 4 3 6 2 2 3 1 1 1 5 5 2 3 3 1 6 3 1 4 6 1 2 4 3 3 1
	Borda	5 6 2 1 4 4 5 4 3 1 6 3 4 4 1 1 5 5 6 4 2 3 1 3 4 3 6 2 2 3 2 1 1 6 5 2 3 3 2 6 1 4 4 6 1 4 4 1 5 1
20,000	plurality	5 1 4 1 4 4 4 4 2 4 6 1 4 1 1 6 5 1 6 3 2 3 2 2 3 3 6 2 2 3 2 2 2 3 5 2 6 3 6 6 6 4 4 6 1 5 4 1 5 1
	Borda	5 4 4 1 4 2 4 4 2 4 6 1 4 1 1 6 5 1 6 3 2 5 2 2 3 3 5 2 2 2 2 2 2 2 5 2 6 6 6 6 6 4 4 6 1 5 5 1 5 1
30,000	plurality	5 5 4 4 4 4 4 4 4 4 6 1 4 1 1 1 5 1 1 3 2 3 2 2 3 3 2 2 2 2 2 2 2 2 2 2 6 6 6 6 6 4 6 6 6 5 4 1 5 1
	Borda	5 1 4 4 4 4 4 4 4 4 6 1 1 1 1 1 5 1 1 3 2 3 2 3 2 3 3 2 2 3 2 2 2 2 2 2 6 6 6 6 6 4 6 3 1 5 5 1 5 1
40,000	plurality	5 5 4 4 4 4 4 4 4 4 1 1 4 1 1 1 1 1 1 3 3 3 2 2 3 3 2 2 2 2 2 2 2 2 2 2 6 6 6 6 6 6 6 6 6 5 5 1 5 4
	Borda	5 5 4 4 4 4 4 4 4 4 1 1 4 1 1 1 5 1 1 3 3 3 3 2 3 3 3 2 2 2 2 2 2 2 2 6 6 6 6 6 6 6 6 6 6 5 5 1 5 5
50,000	plurality	5 5 4 4 4 4 4 4 4 4 1 1 1 1 1 1 1 1 1 3 3 3 3 3 3 3 2 2 2 2 2 2 2 2 2 2 6 6 6 6 6 6 6 6 6 5 5 5 5 5
	Borda	5 5 5 4 4 4 4 4 4 4 4 1 4 1 1 1 1 1 1 3 3 3 2 3 3 3 2 2 2 2 2 2 2 2 2 6 1 6 6 6 6 6 6 6 6 5 5 5 4 5
60,000	plurality	5 5 4 4 4 4 4 4 4 4 1 1 1 1 1 1 1 1 1 3 3 3 3 3 3 3 2 2 2 2 2 2 2 2 2 2 6 6 6 6 6 6 6 6 6 5 5 5 5 5
	Borda	5 5 4 5 4 4 4 4 4 4 1 1 1 1 1 1 1 1 1 3 3 3 3 3 3 3 2 2 2 2 2 2 2 2 2 2 6 6 6 6 6 6 6 6 6 5 5 5 5 5
70,000	plurality	5 5 4 4 4 4 4 4 4 4 1 1 1 1 1 1 1 1 1 3 3 3 3 3 3 3 2 2 2 2 2 2 2 2 2 6 6 6 6 6 6 6 6 6 6 5 5 5 5 5
	Borda	5 5 4 4 4 4 4 4 4 4 1 1 1 1 1 1 1 1 1 3 3 3 3 3 3 3 2 3 2 2 2 2 2 2 2 2 6 6 6 6 6 6 6 6 6 5 5 5 5 5
80,000	plurality	5 5 4 4 4 4 4 4 4 4 1 1 1 1 1 1 1 1 1 3 3 3 3 3 3 3 2 2 2 2 2 2 2 2 2 6 6 6 6 6 6 6 6 6 6 5 5 5 5 5
	Borda	5 5 4 4 4 4 4 4 4 4 1 1 1 1 1 1 1 1 1 3 3 3 3 3 3 3 3 3 2 3 2 2 2 2 2 6 6 6 6 6 6 6 6 6 5 5 5 5 5 5
90,000	plurality	5 5 4 4 4 4 4 4 4 4 1 1 1 1 1 1 1 1 1 3 3 3 3 3 3 3 2 2 2 2 2 2 2 2 2 6 6 6 6 6 6 6 6 6 6 5 5 5 5 5
	Borda	5 5 4 5 4 4 4 4 1 4 1 1 1 1 1 1 1 1 1 3 3 3 3 3 3 3 3 2 2 2 2 2 2 2 2 6 6 6 6 6 6 6 6 6 5 5 5 5 5 5
100,000	plurality	5 5 4 4 4 4 4 4 4 4 1 1 1 1 1 1 1 1 1 3 3 3 3 3 3 3 3 2 2 2 2 2 2 2 2 6 6 6 6 6 6 6 6 6 6 5 5 5 5 5
	Borda	5 5 4 4 4 4 4 4 4 4 1 1 1 1 1 1 1 1 1 3 3 3 3 3 3 3 2 2 2 2 2 2 2 2 2 6 6 6 6 6 6 6 6 6 5 5 5 5 5 5

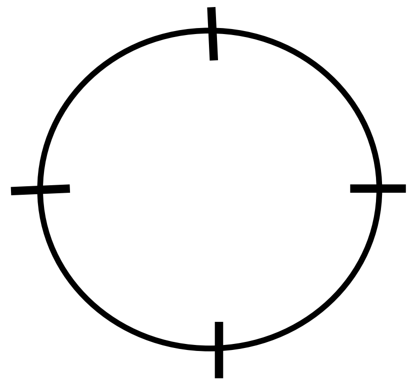
A population solution



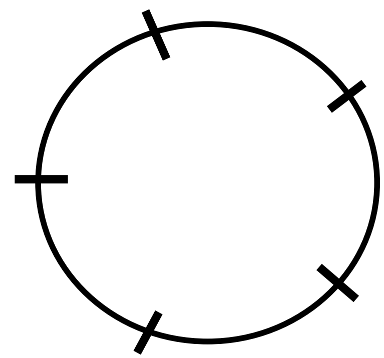
10 million games; *m*=6; *k-sim*=6; *N*=100

Rotational invariance

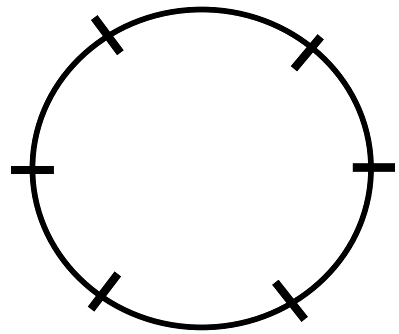
4-category



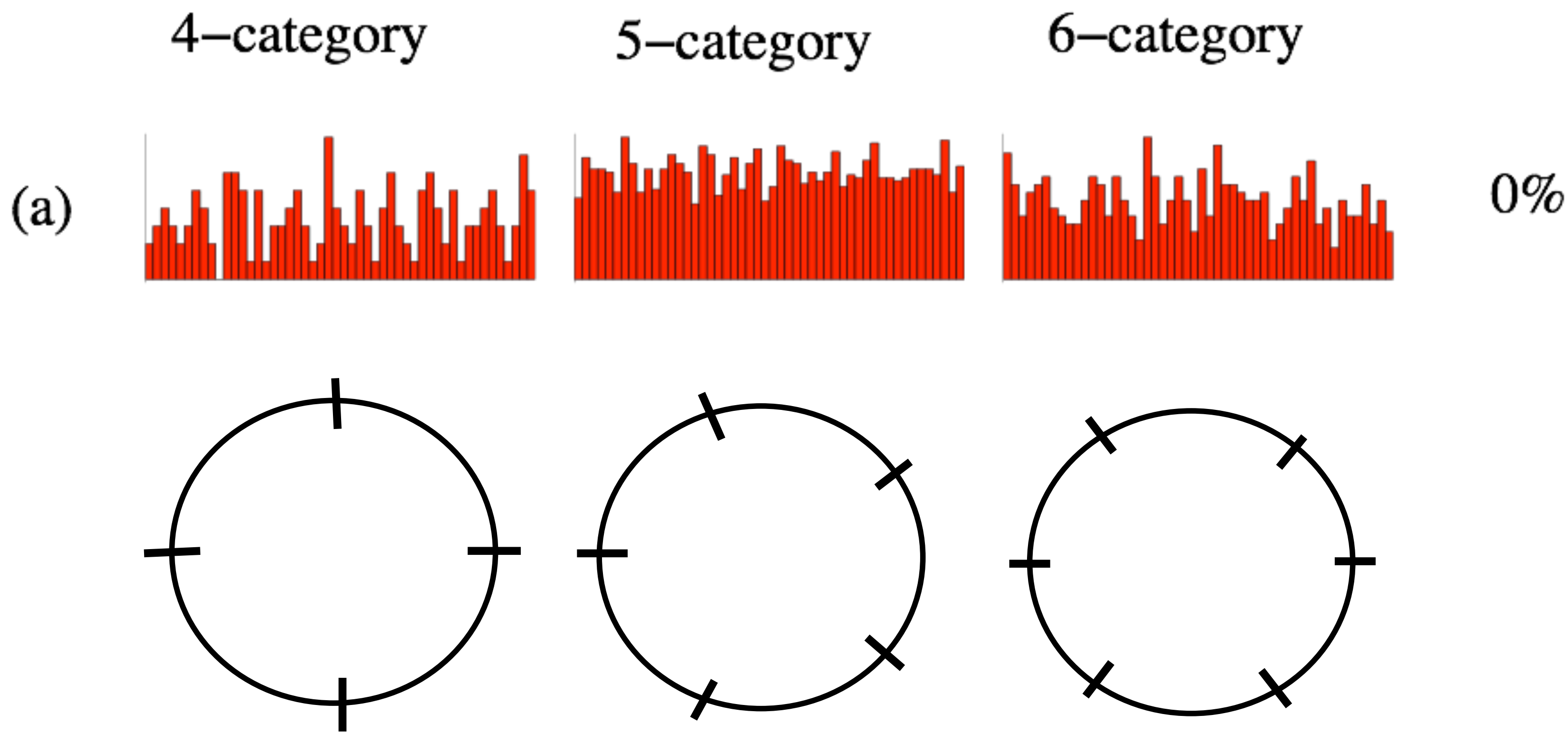
5-category



6-category

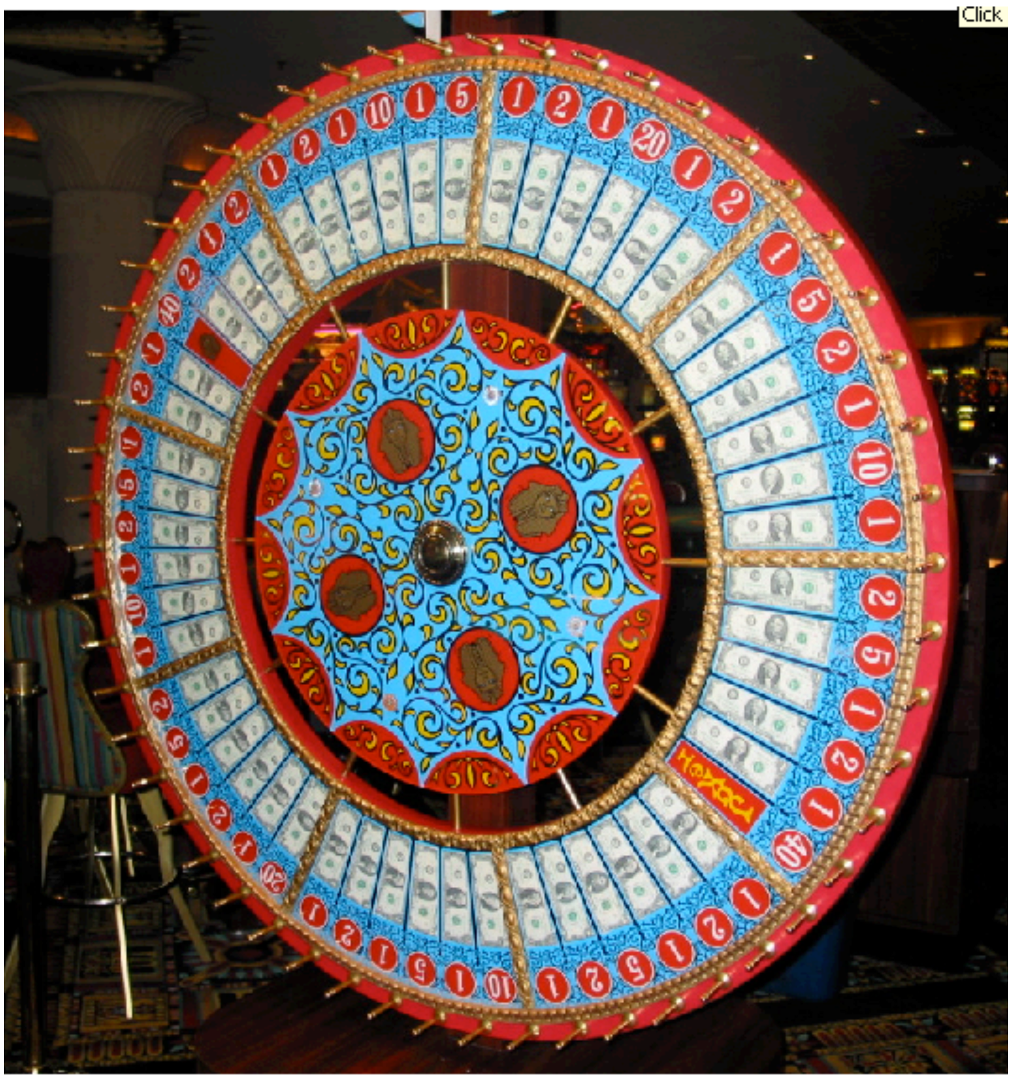


Rotational invariance

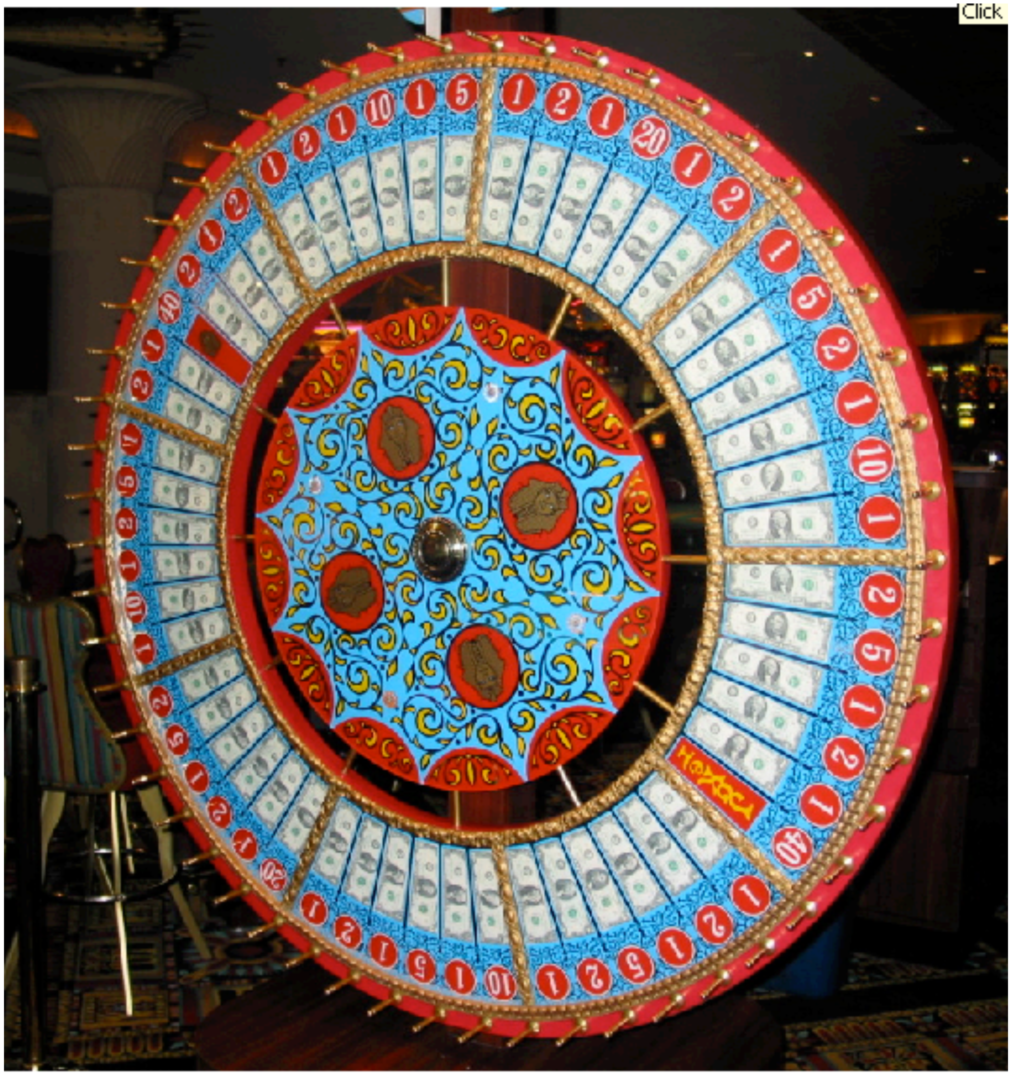


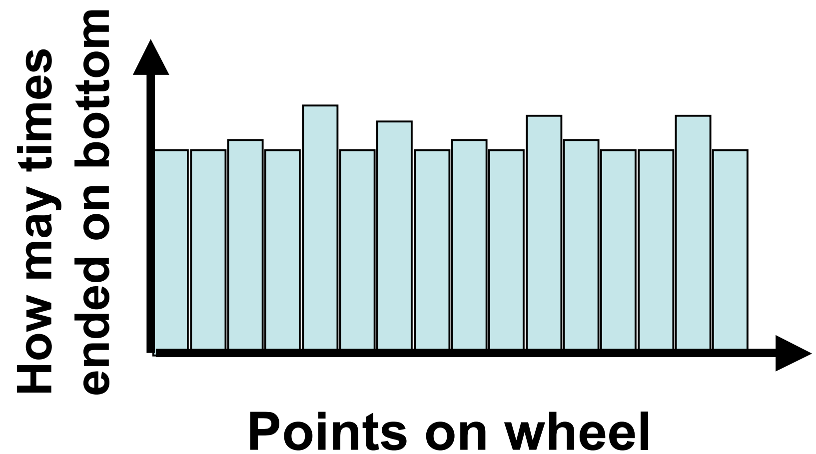
d

Frequency diagrams: A wheel of fortune



Frequency diagrams: A wheel of fortune





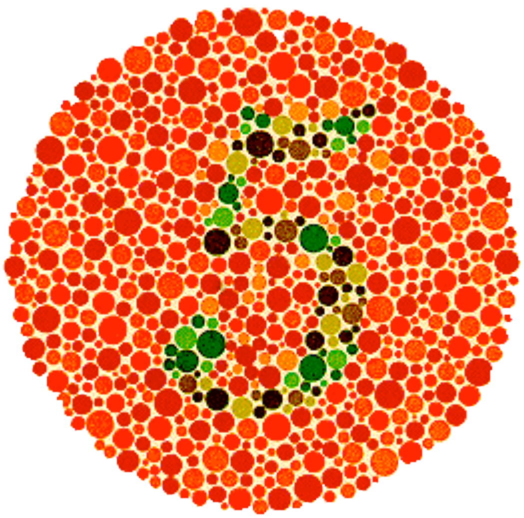
So far,

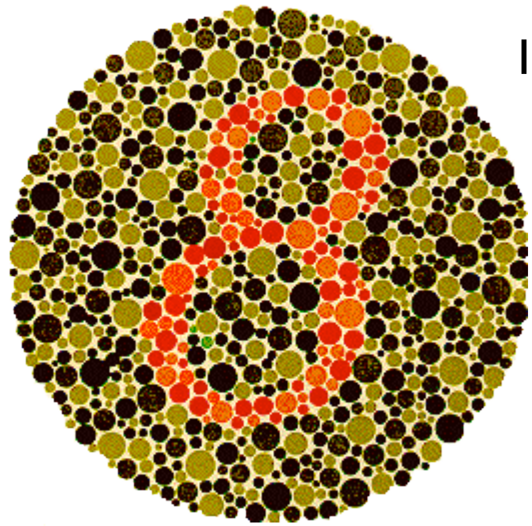
- The homogeneous population of agents converges to a common, nearly-optimal color categorization
- The homogeneous color space is split in a (predictable) number of equal color categories
- The solution is defined up to an arbitrary rotation, that is, the boundaries of the color categories can be anywhere along the circle…

Introduce inhomogeneities

1. Inhomogeneity in the population
2. Inhomogeneity in the color space

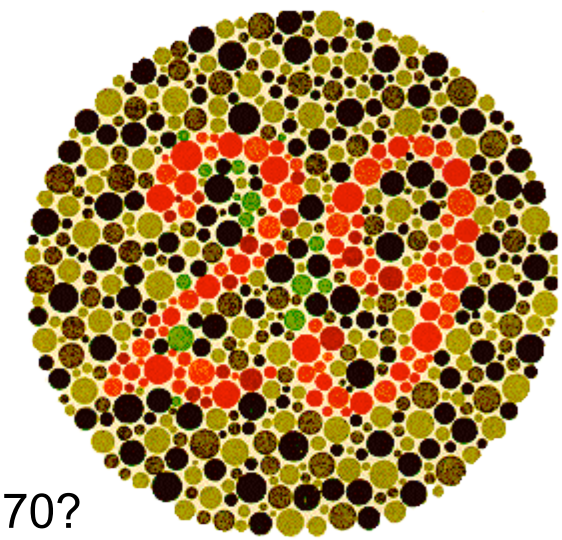
1. Inhomogeneous populations (“dichromat” agents)

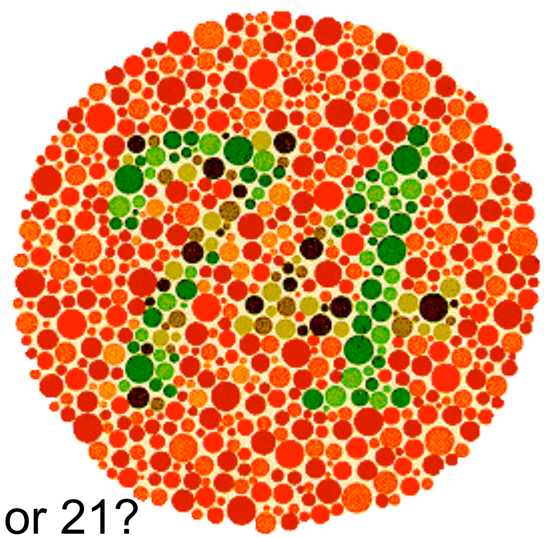




Is this 8 or 2?

Is this 5 or 3?

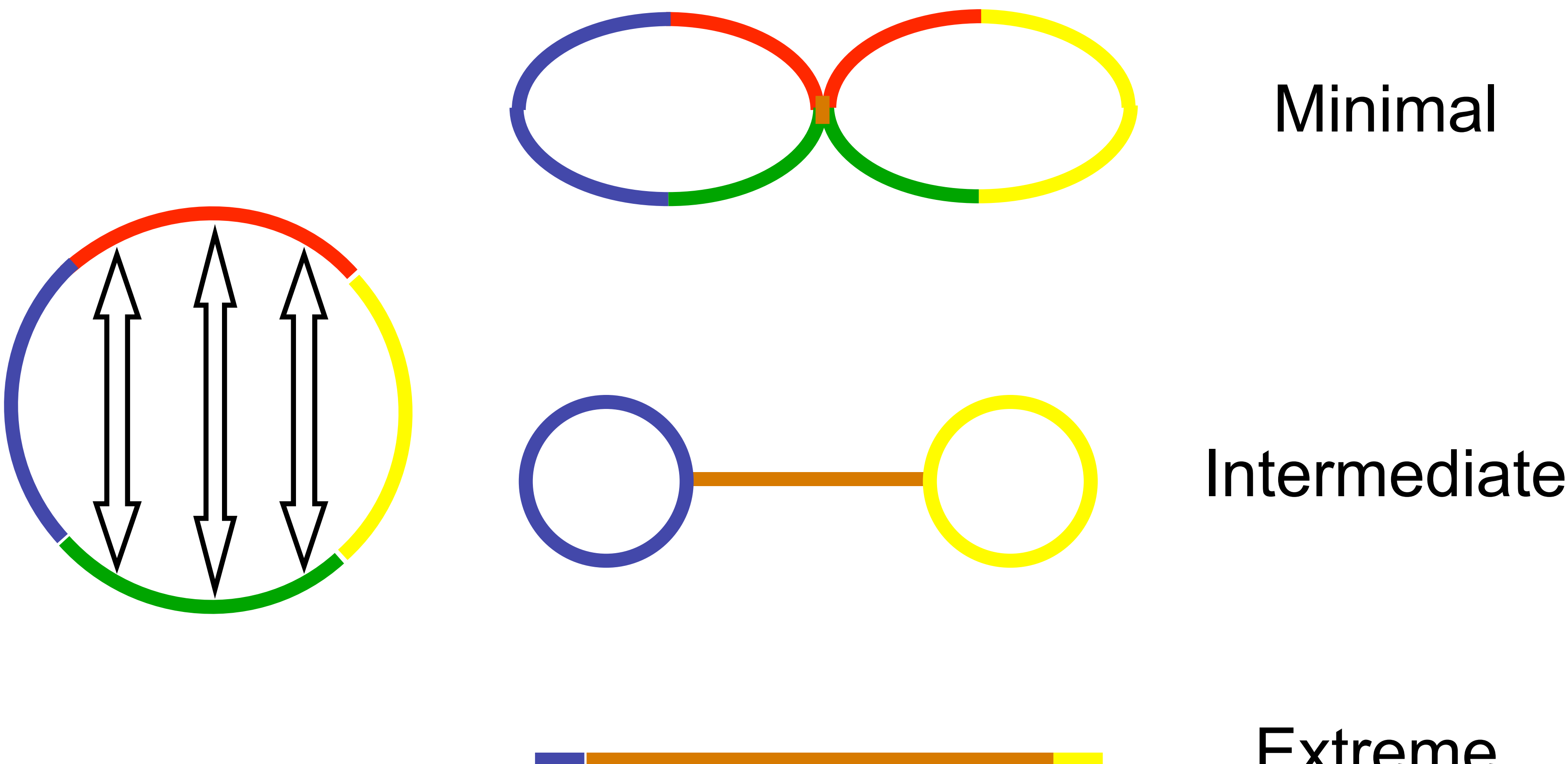




Is this 29 or 70?

Is this 74 or 21?

The color space of a dichromat



Psychophysical transformation

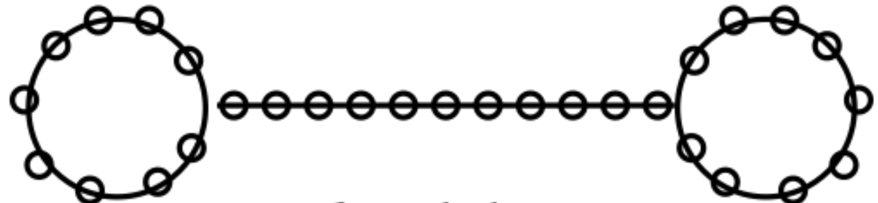
$$i \rightarrow \mathcal{F}(i) = \begin{cases} n+2-i, & \frac{3n}{4} - \frac{l-1}{2} + 1 \leq i \leq \frac{3n}{4} + \frac{l-1}{2} + 1, \\ i, & \text{otherwise}, \end{cases}$$

Physical space of stimuli

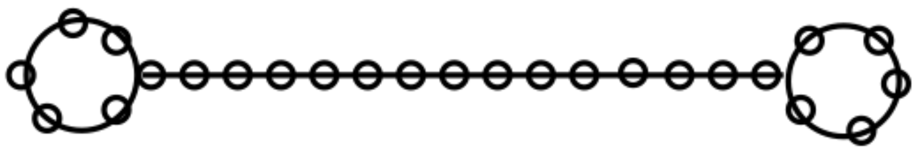
Perceptual space of an agent

Varying types of "dichromats"

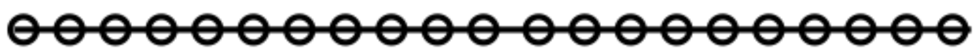
N=40



l=11

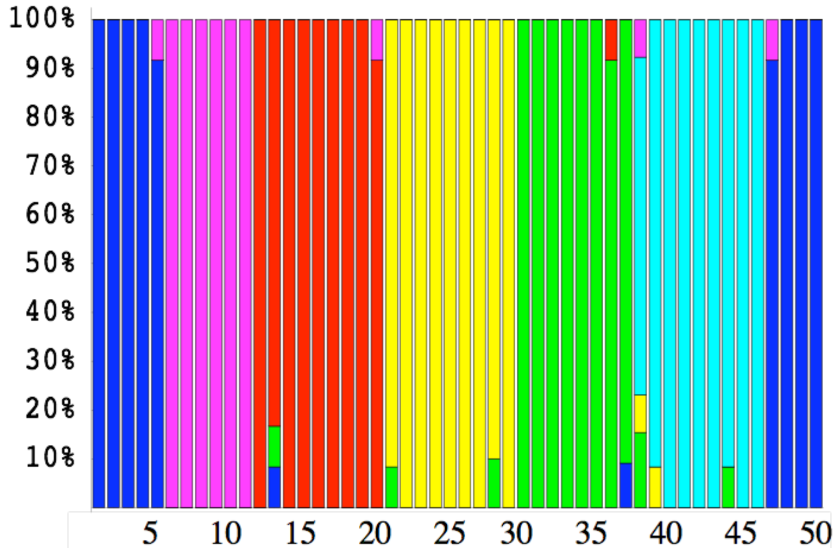


l=15



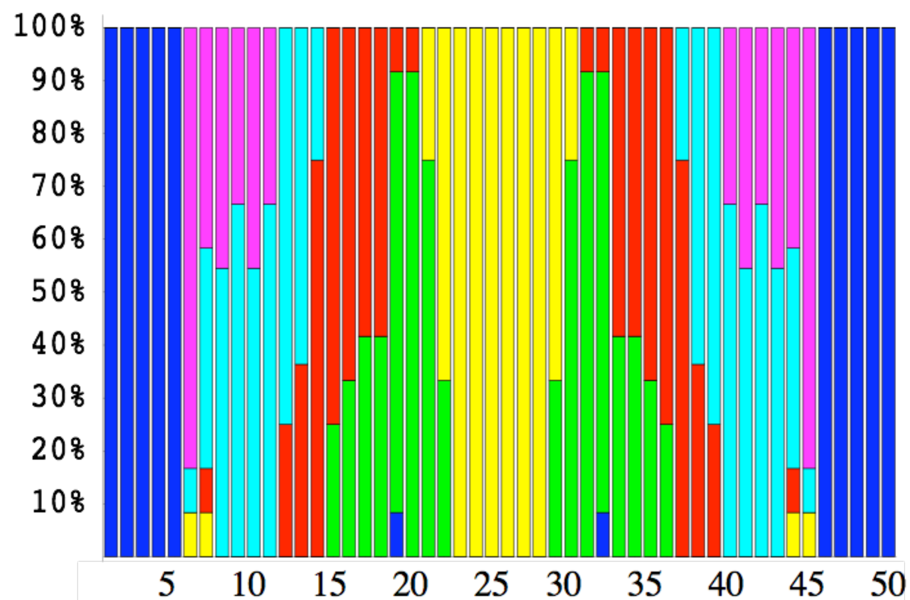
l=19

Categorization solutions for normals and dichromats

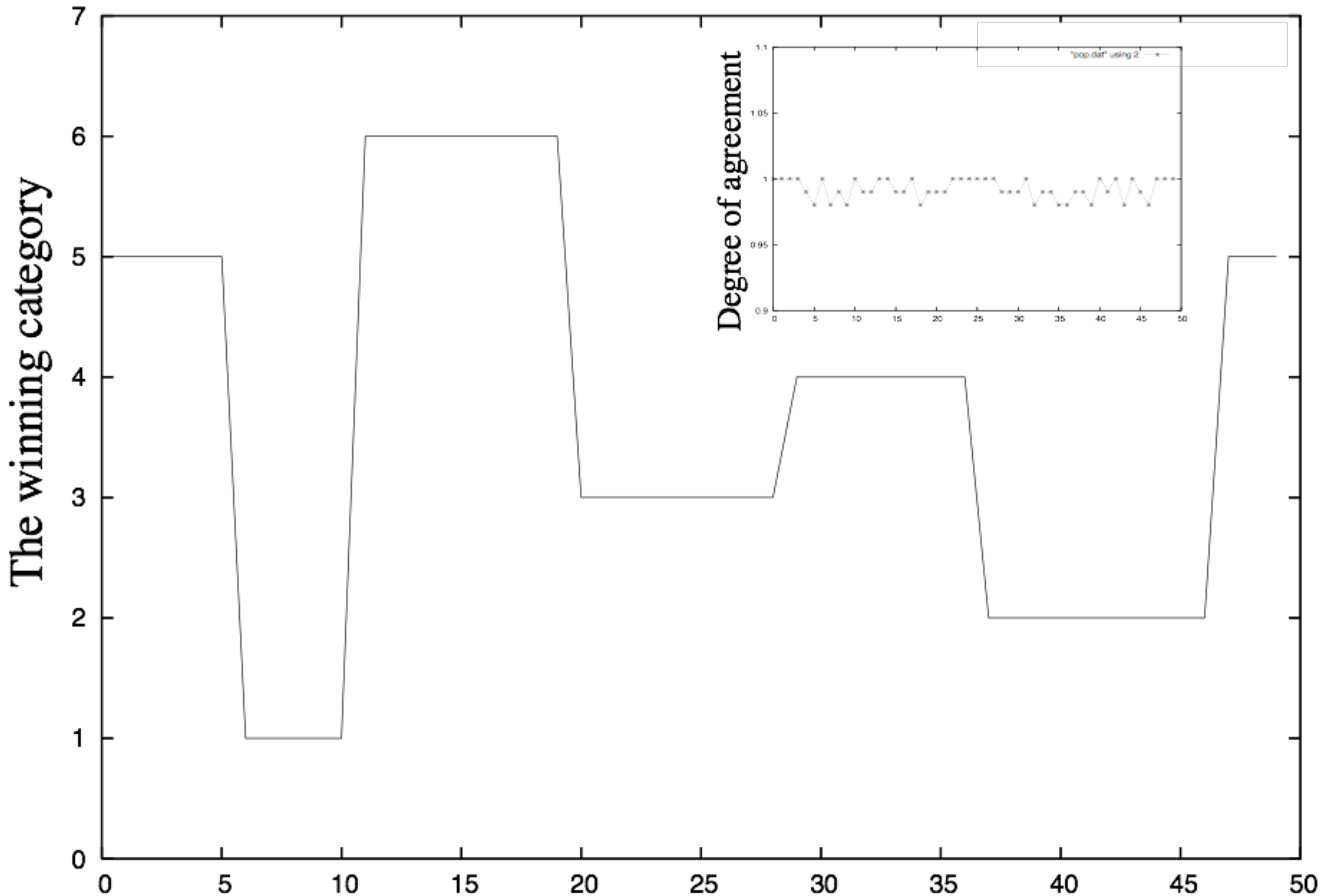


A normal agent

A dichromat

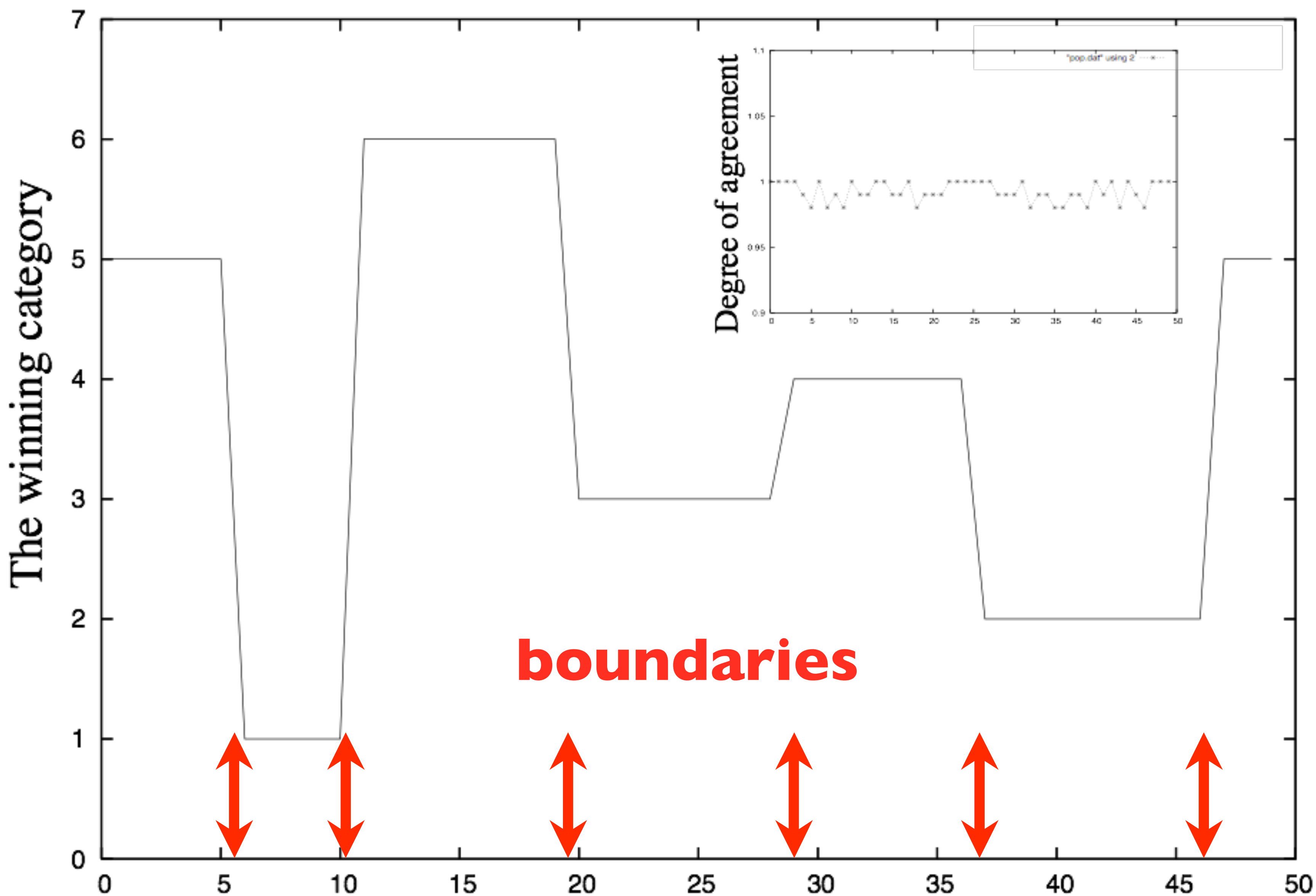


A heterogeneous population solution



10 million games; *m*=6; *k-sim*=6; *N*=100; *Nd*=2 ($l=n/2-1$)

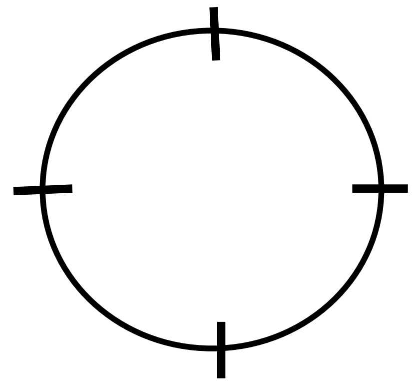
A heterogeneous population



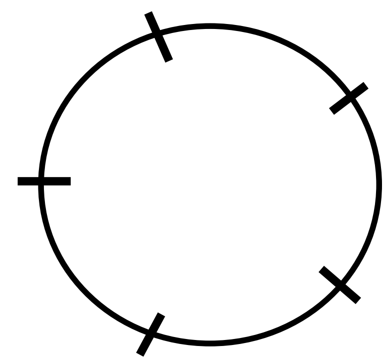
10 million games; *m*=6; *k-sim*=6; *N*=100; *Nd*=2 (line model)

Most common solutions

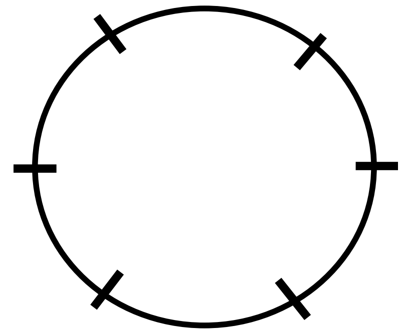
4-category



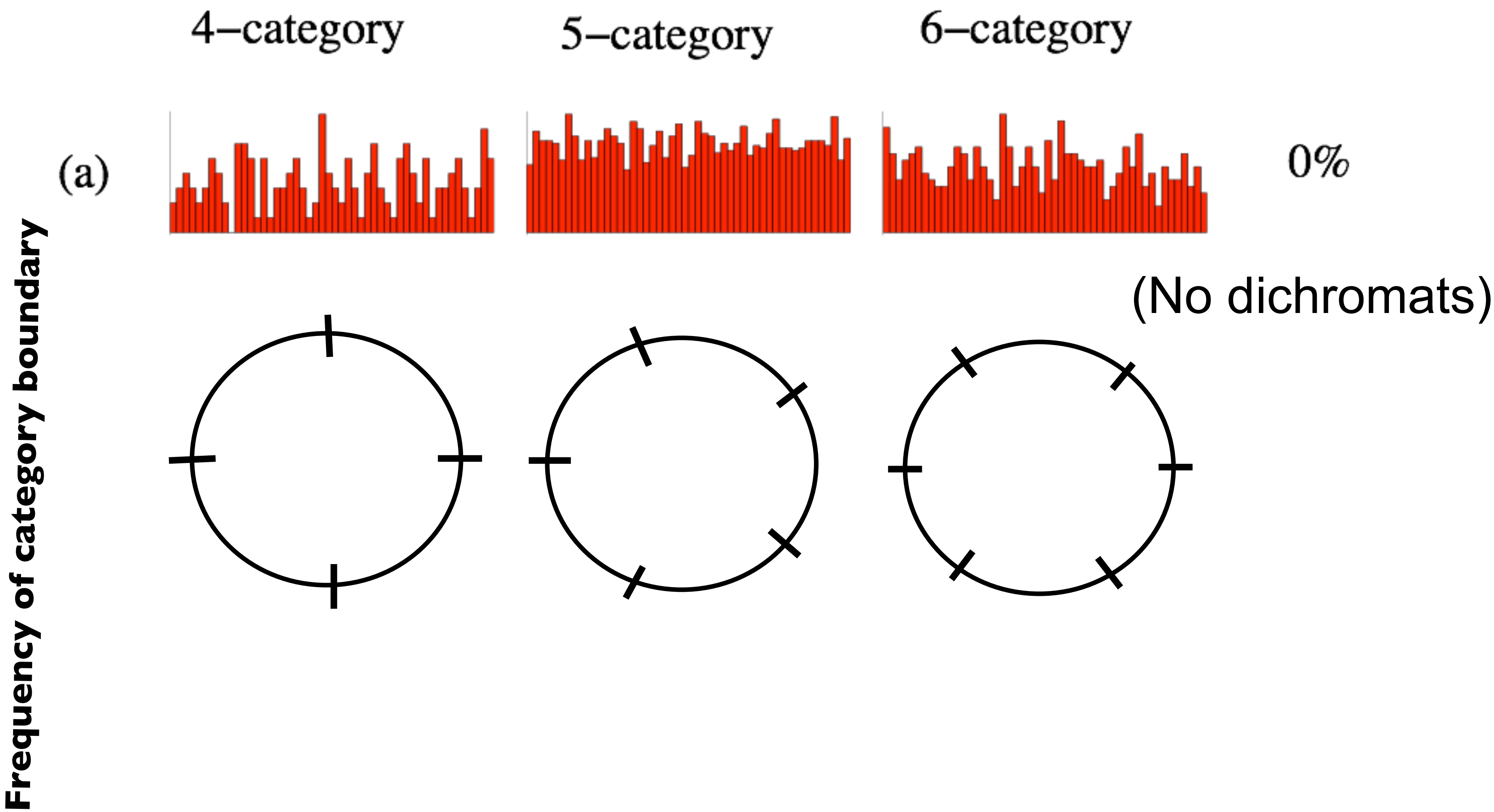
5-category



6-category

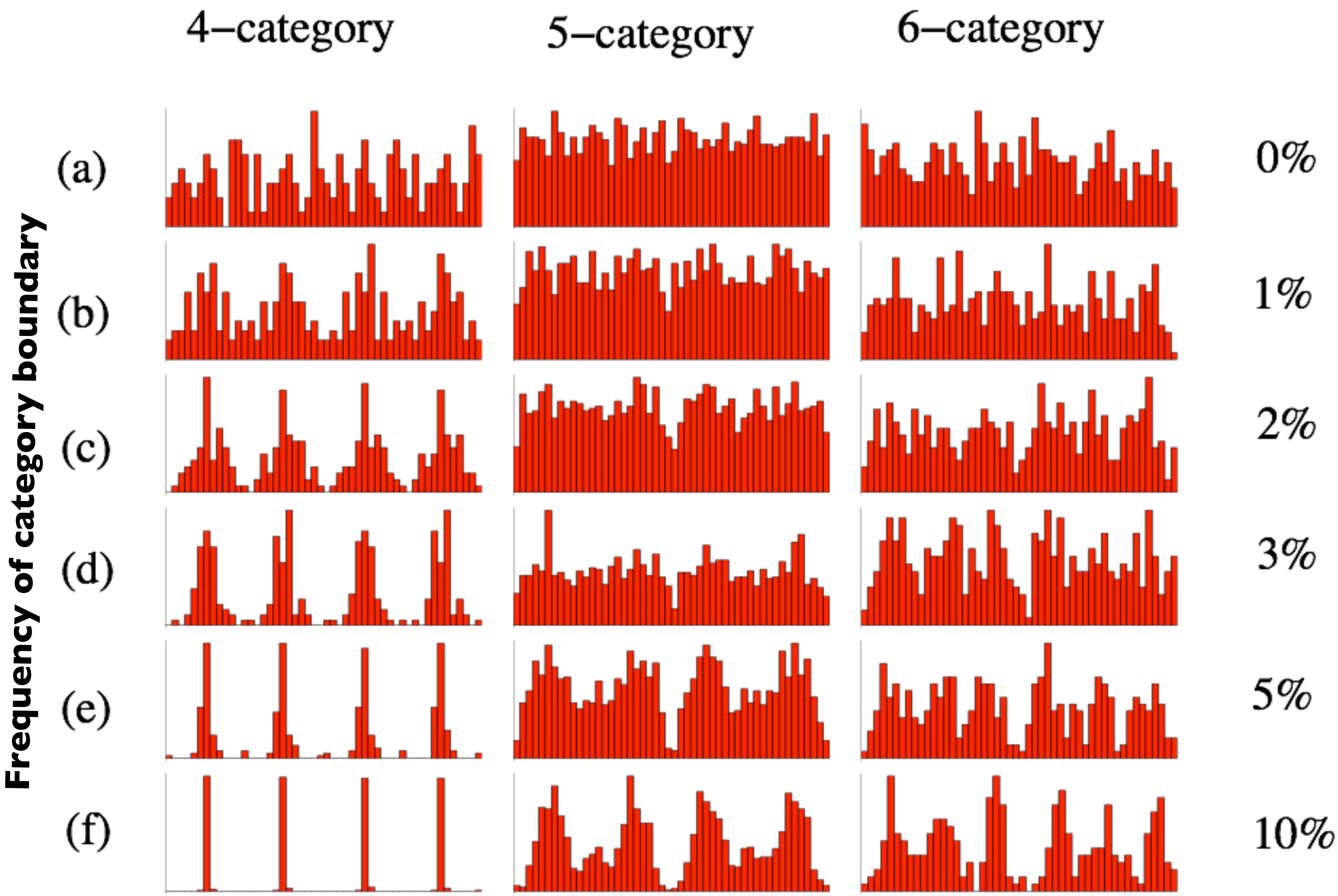


Boundaries under agent heterogeneity



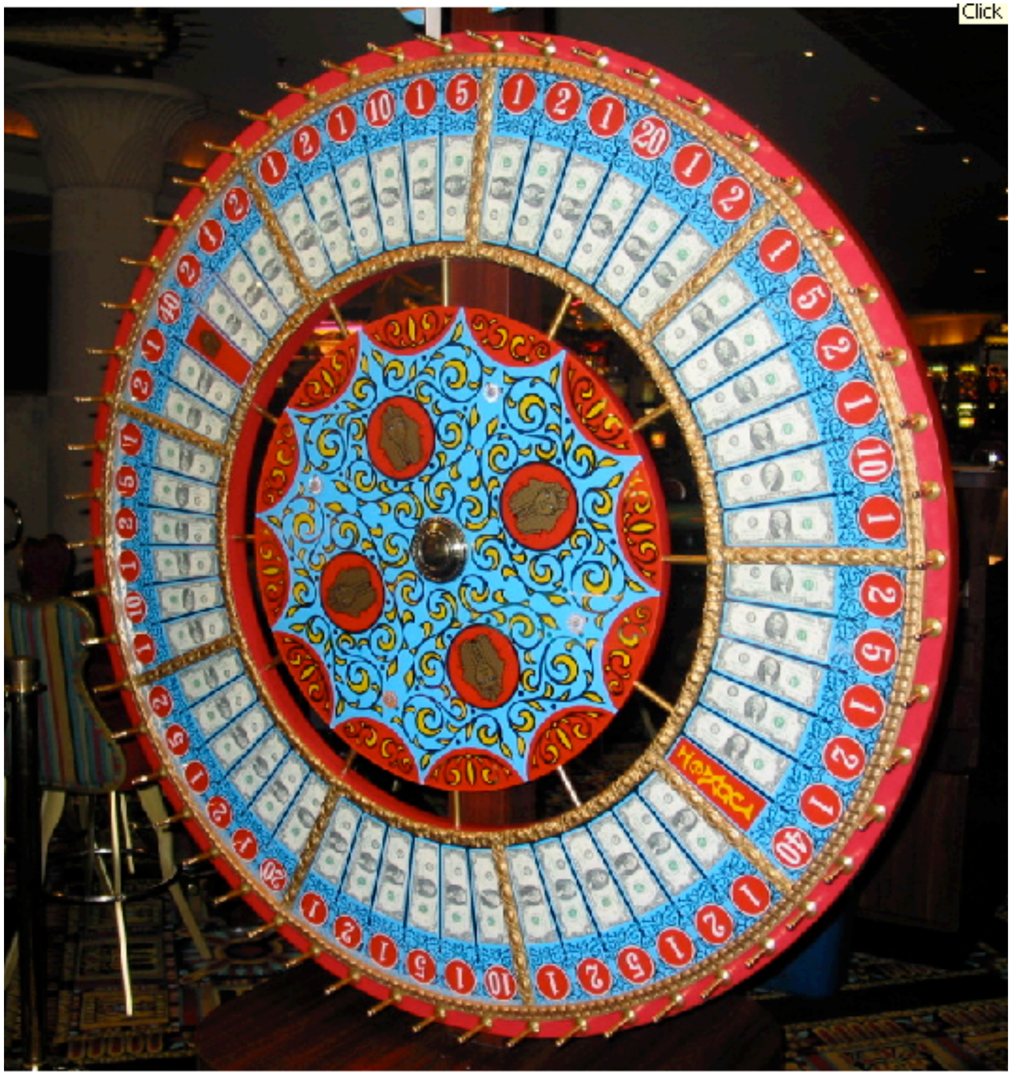
d

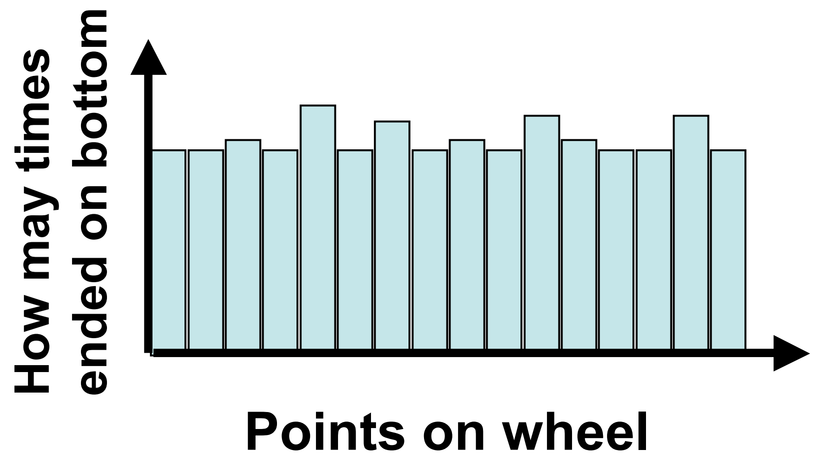
Boundaries under agent heterogeneity



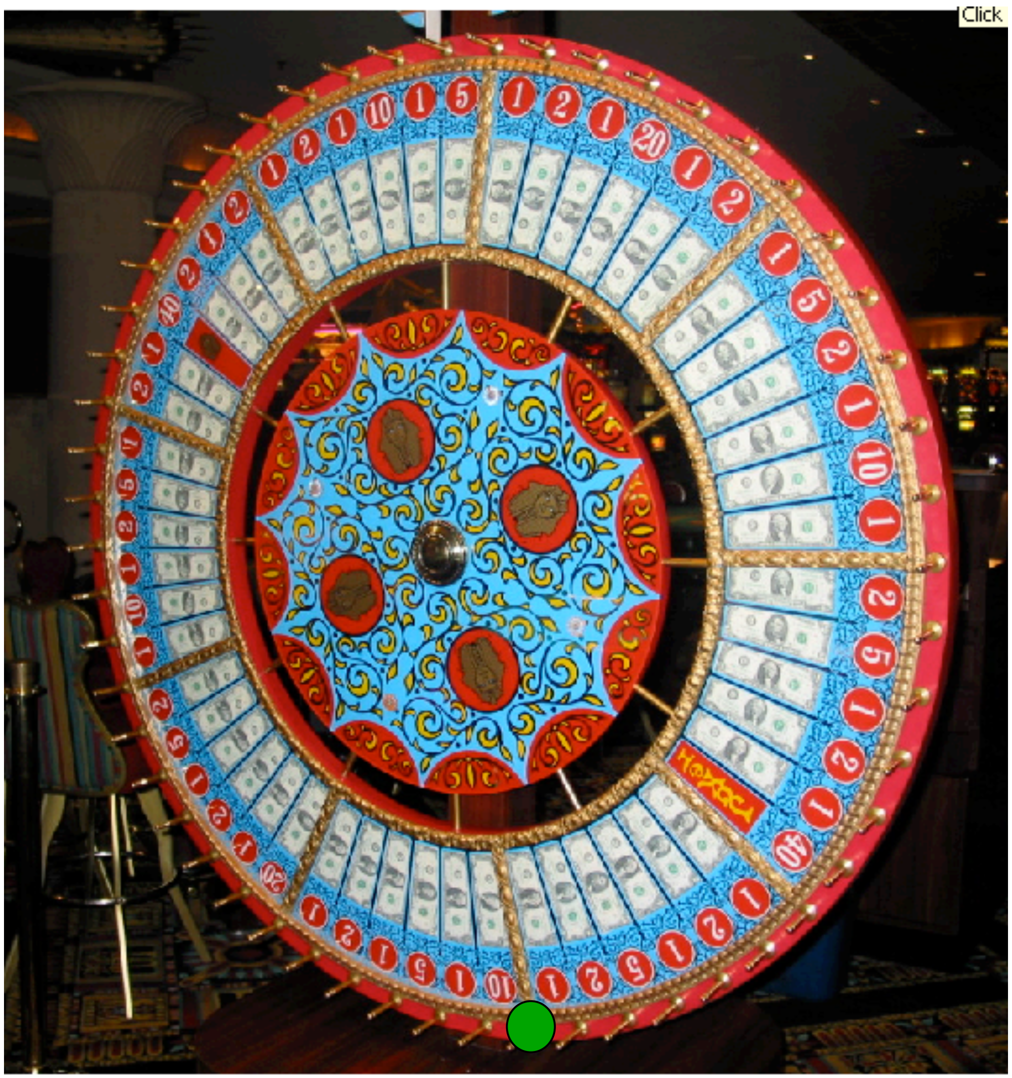
As dichromats increase (< 20%) boundaries are refined

Symmetry breaking: A wheel of fortune

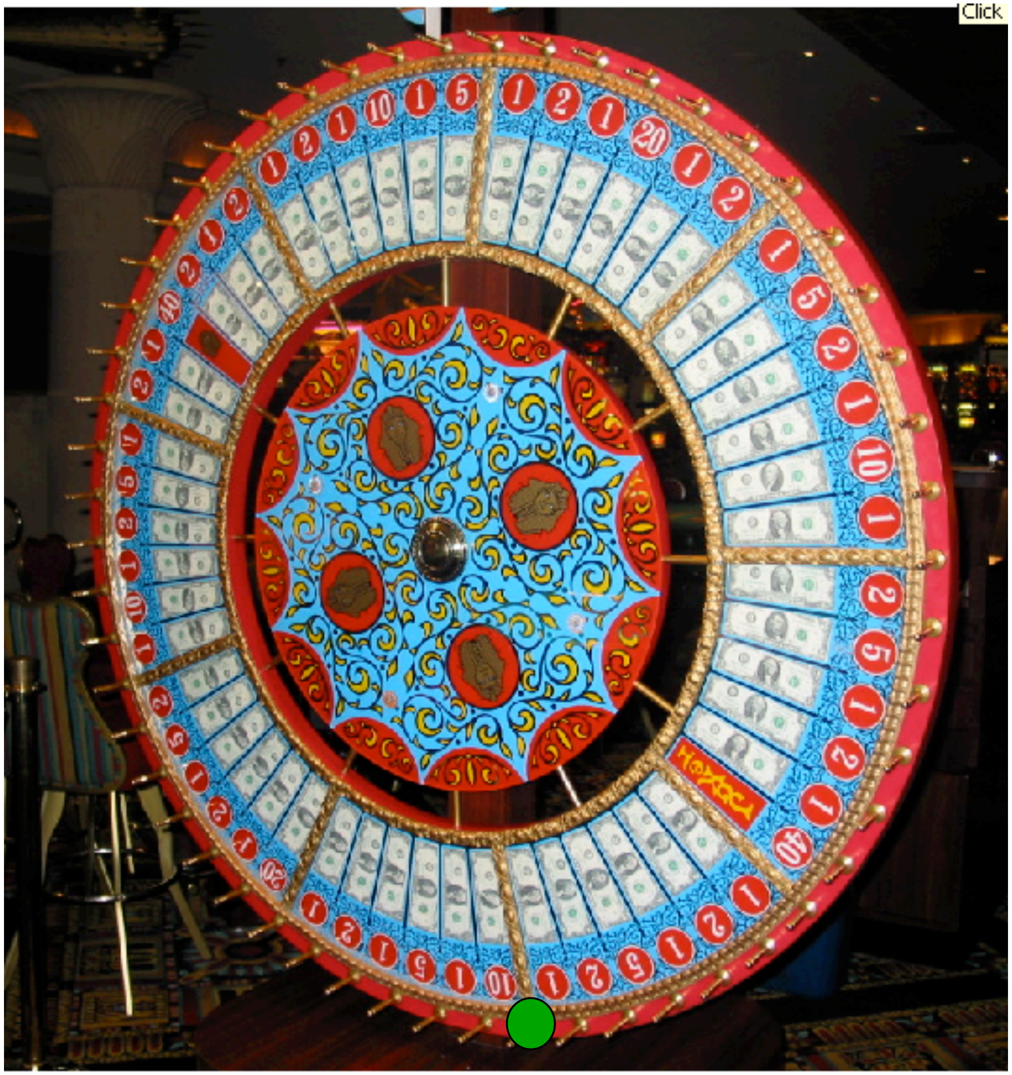


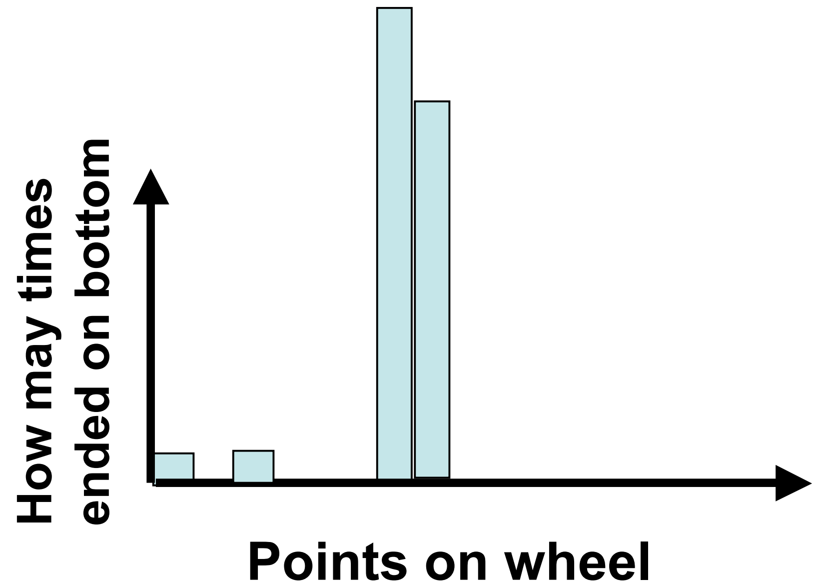


Symmetry breaking: A wheel of fortune

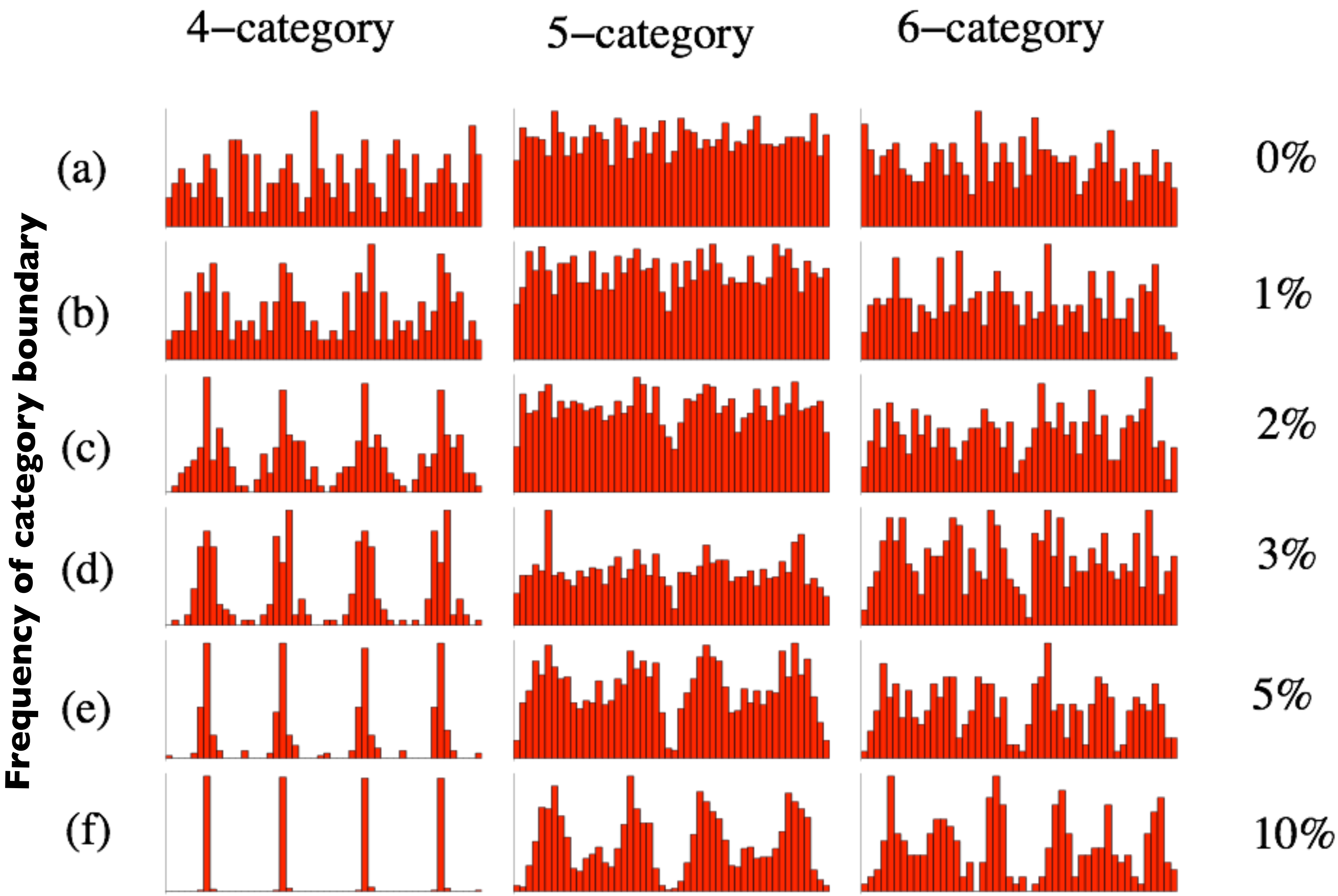


Symmetry breaking: A wheel of fortune



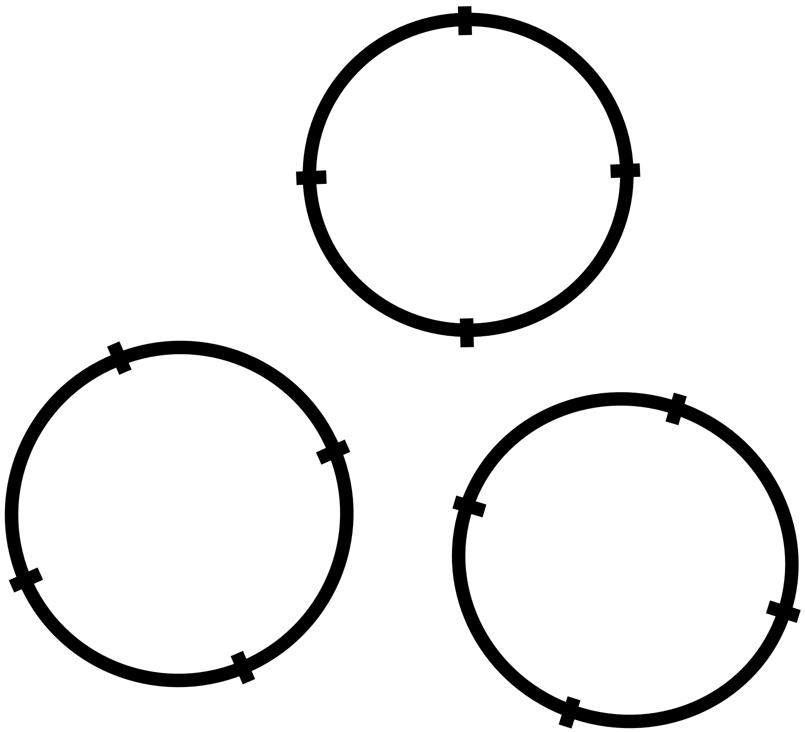


Boundaries under agent heterogeneity



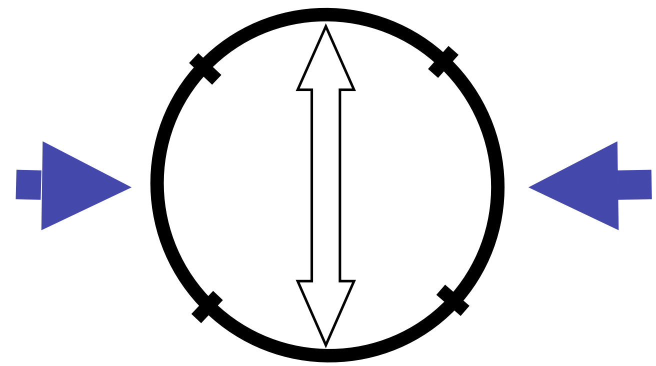
As dichromats increase (< 20%) boundaries are refined

Dichromats remove solution rotational invariance



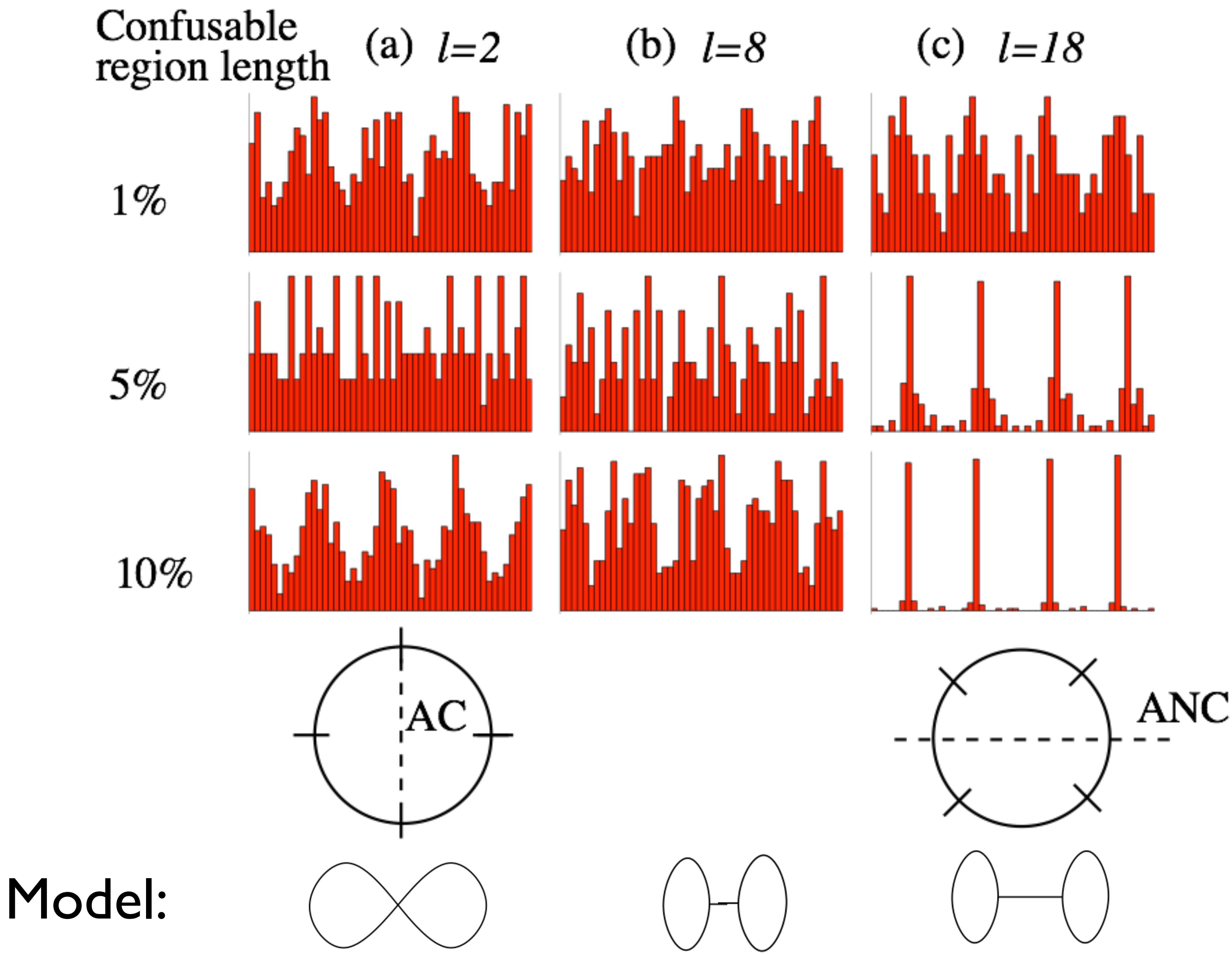
Normals: any rotation of the optimal solution is an optimal solution

A non-ambiguous axis

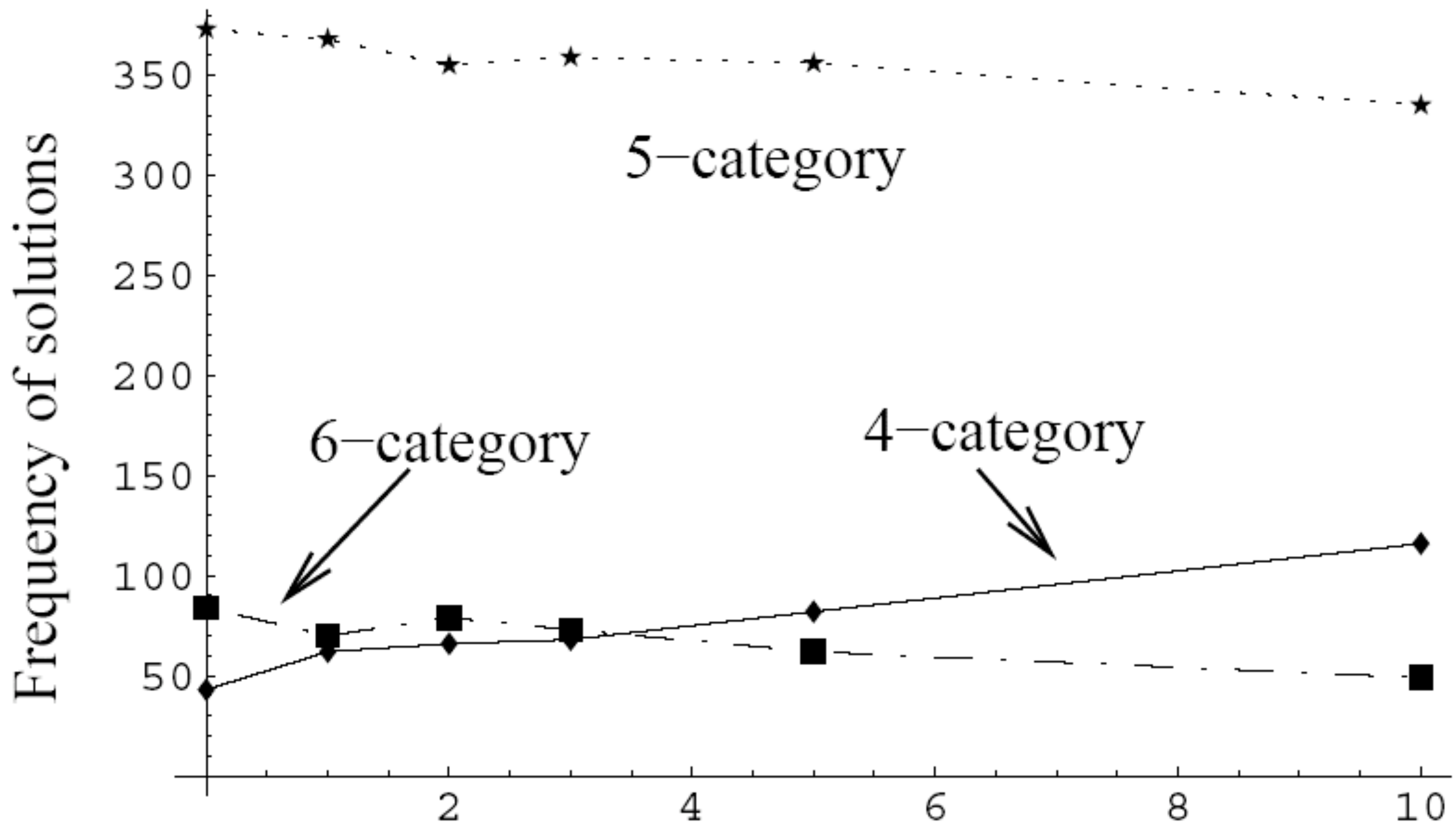


Normals & Dichromats: preferred solution has ancored boundaries

Mildly impaired *vs.* more impaired dichromats



The number of categories can change



Percentange of dichromats

Summary for dichromats

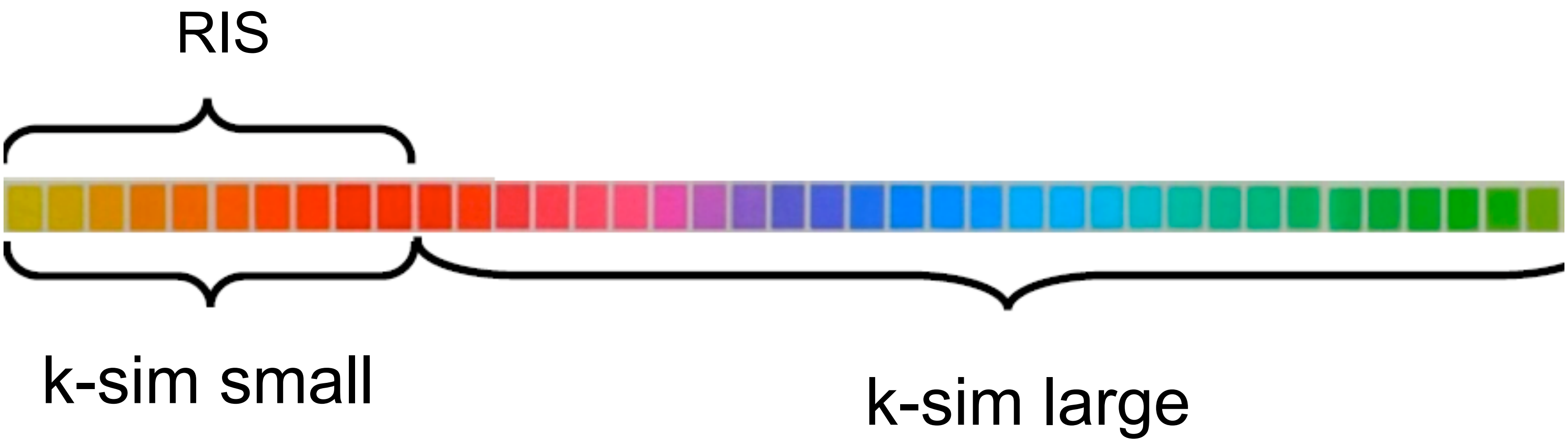
- For different degrees of dichromat impairment, and different proportions of impaired agents, the statistics of solutions changes
- ANC attracts & AC repels color boundaries, and both interact to anchor boundaries and define category centers even when proportion of impaired agents is small.

http://aris.ss.uci.edu/~kjameson/KomarovaJameson2007.pdf

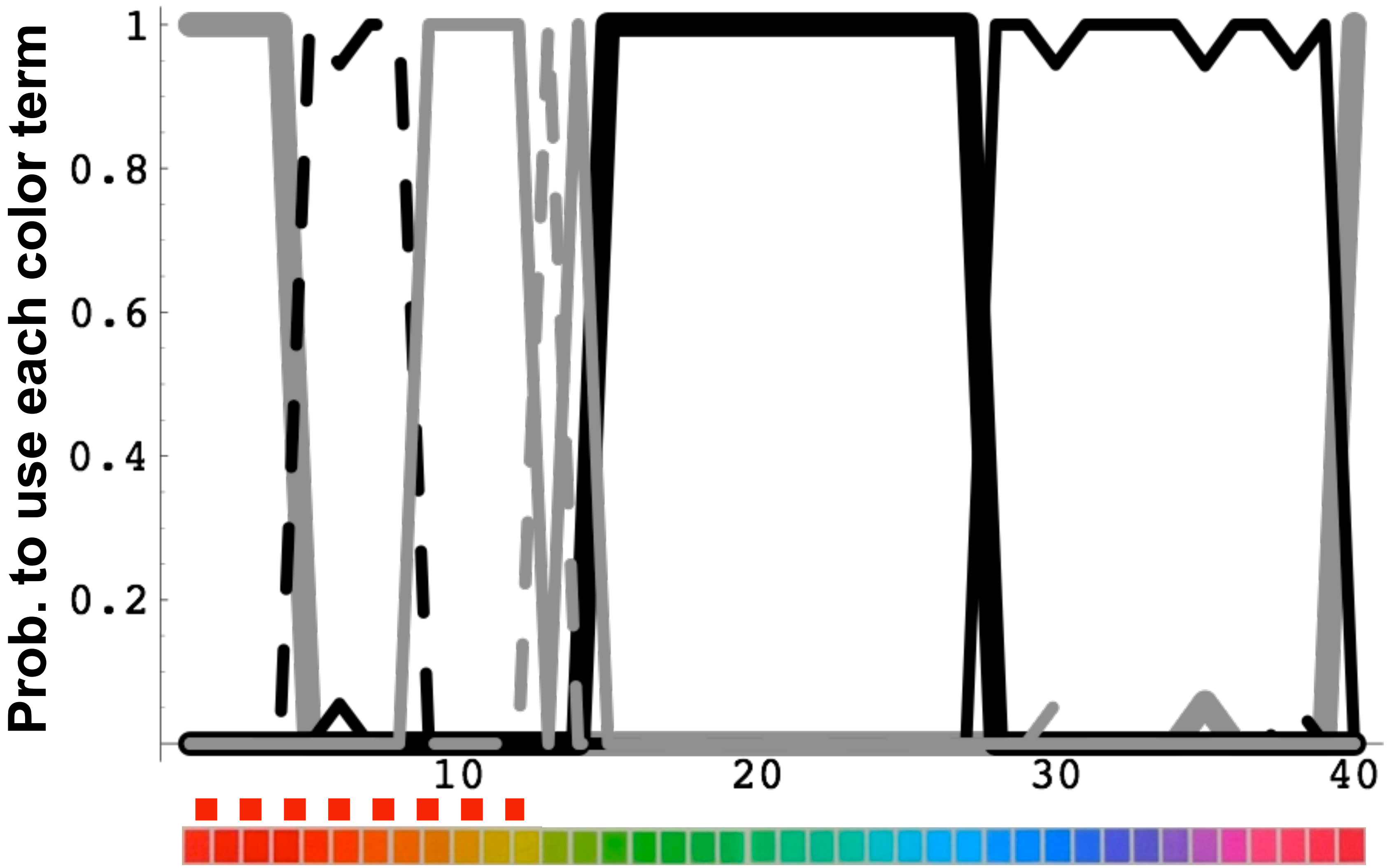
2. Inhomogeneous color space (Regions of Increased Salience)

Region of increased salience (RIS)

- The parameter k-sim is non-constant throughout the color space
- There is one region where k-sim is smaller than in the rest of the space

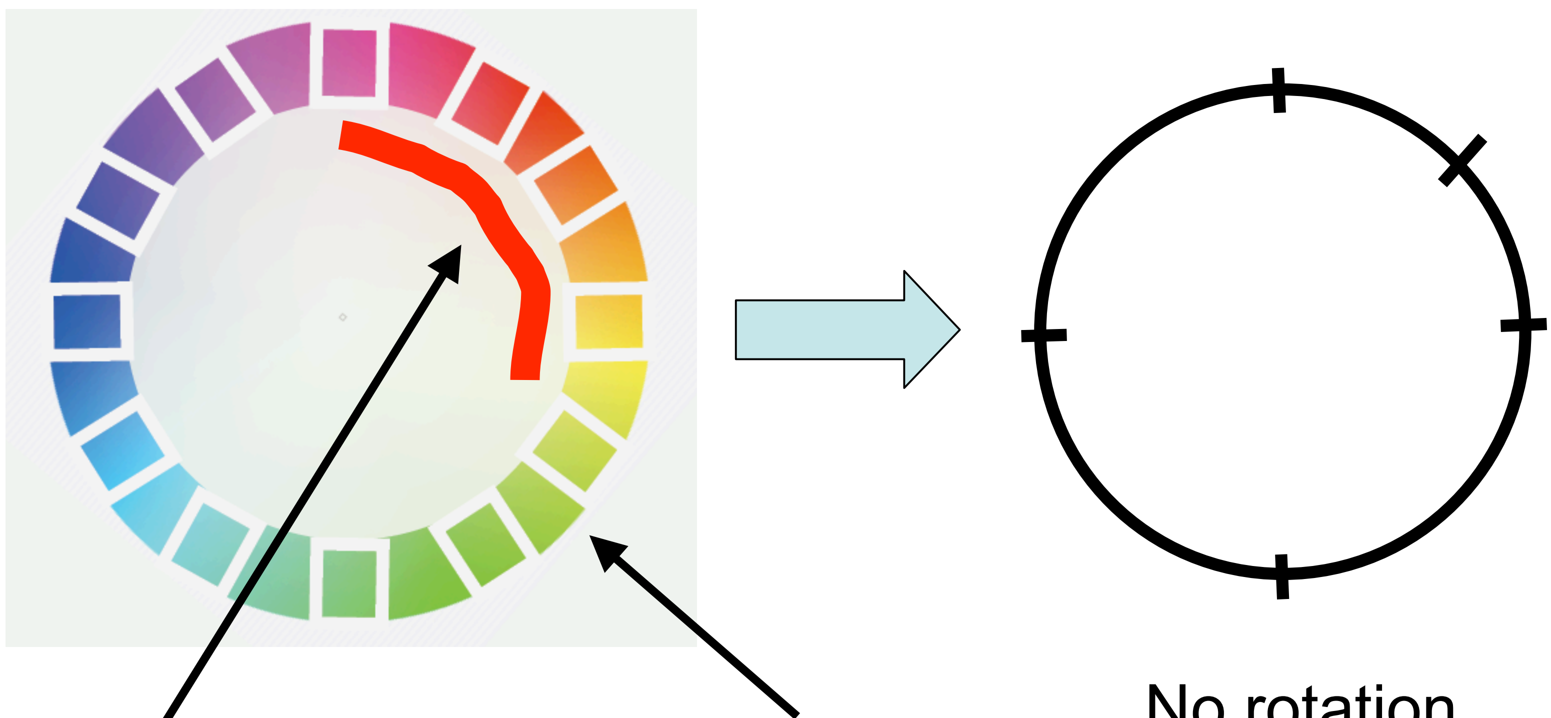


The presence of a RIS



5 categories after 10 million runs

Non-equal categories, and symmetry breaking



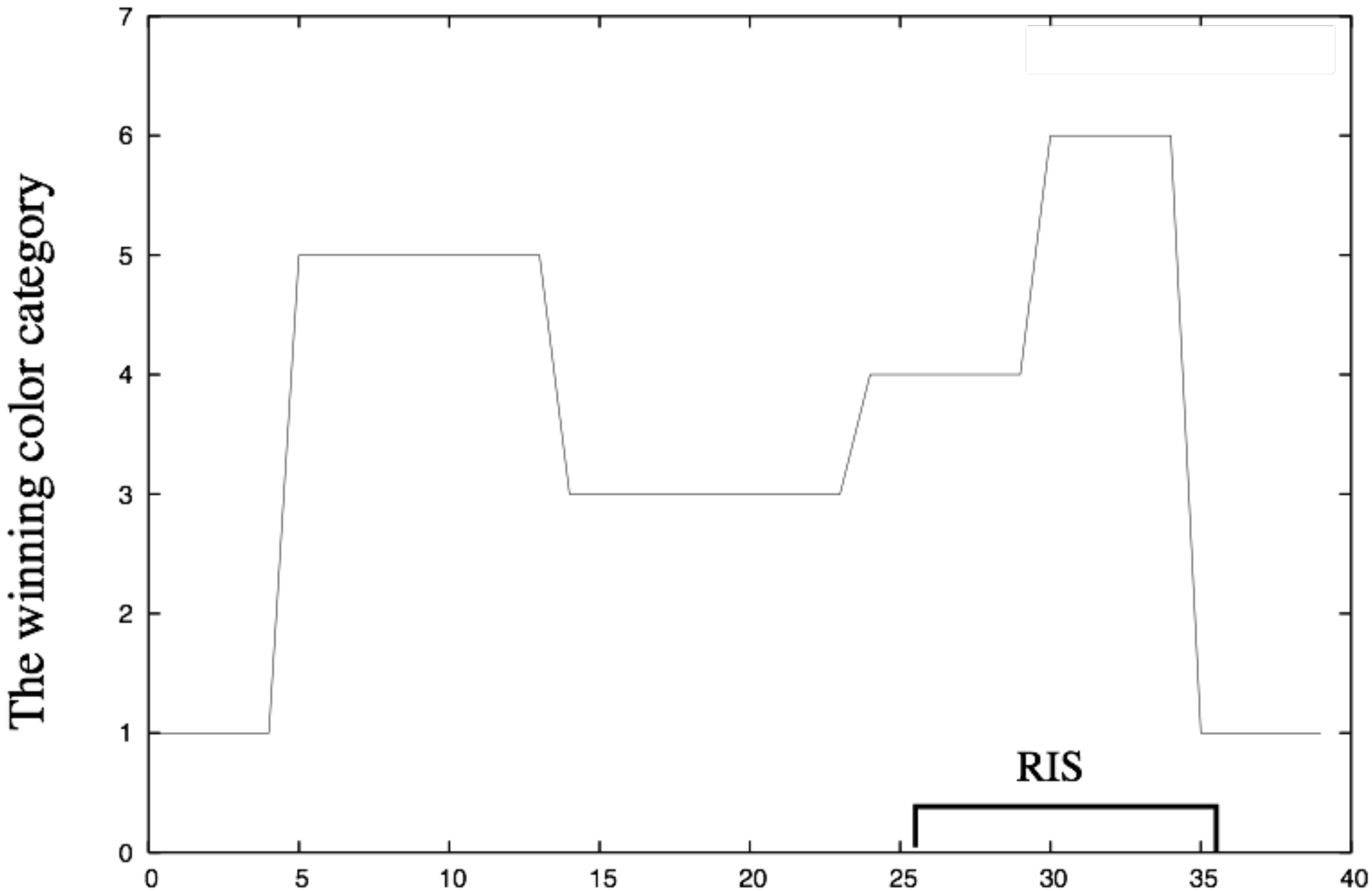
k-sim=k-RIS small

k-sim=k-normal

No rotation

Size and number of categories are defined by k-hot and k-normal

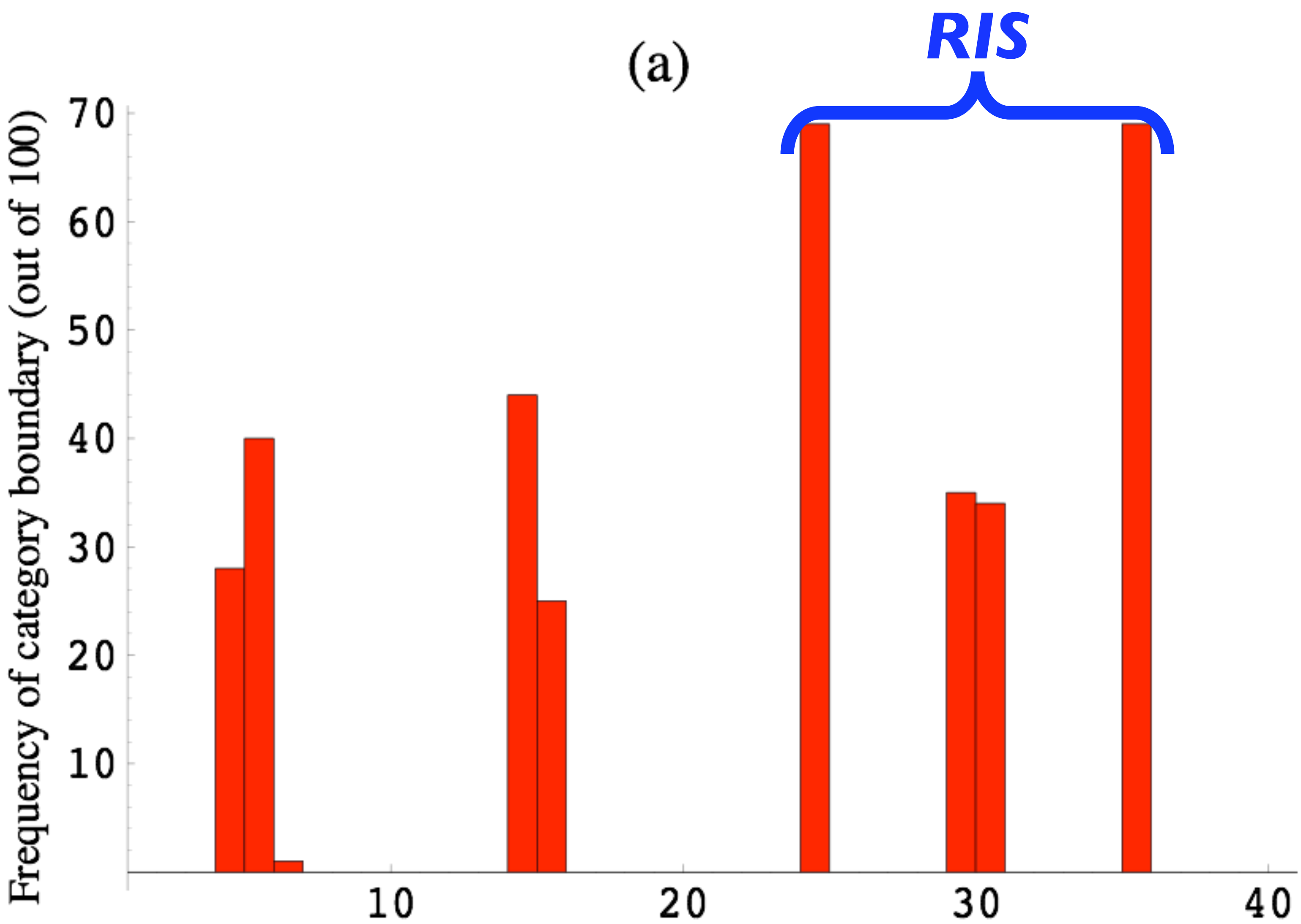
Varying color utility in the stimulus space:



homogeneous unimpaired population

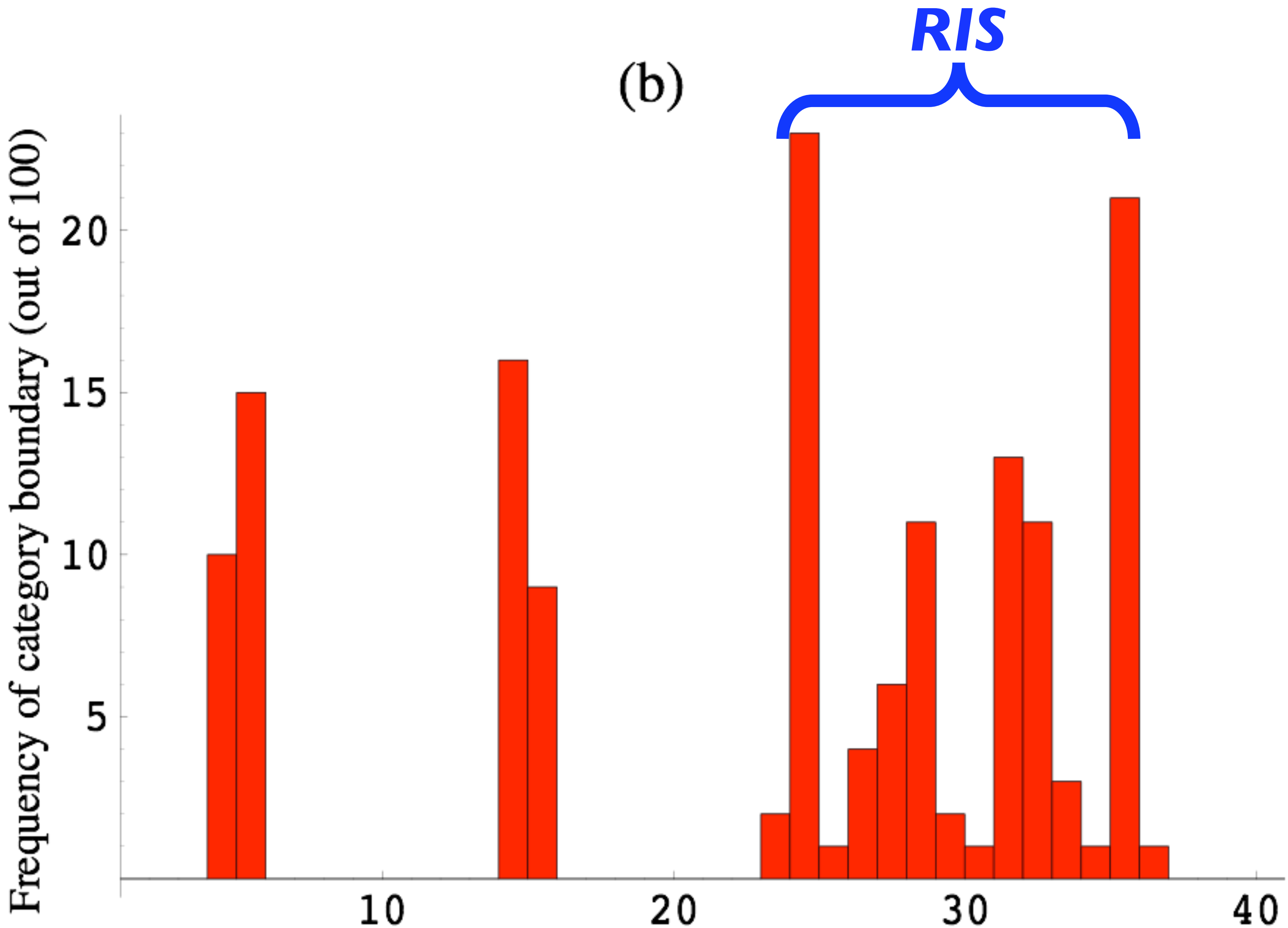
10 million games; *m*=5; *k-norm*=6; *k-RIS*=3; *N*=10; *RIS iL=26* & iR=*36*

homogeneous unimpaired population



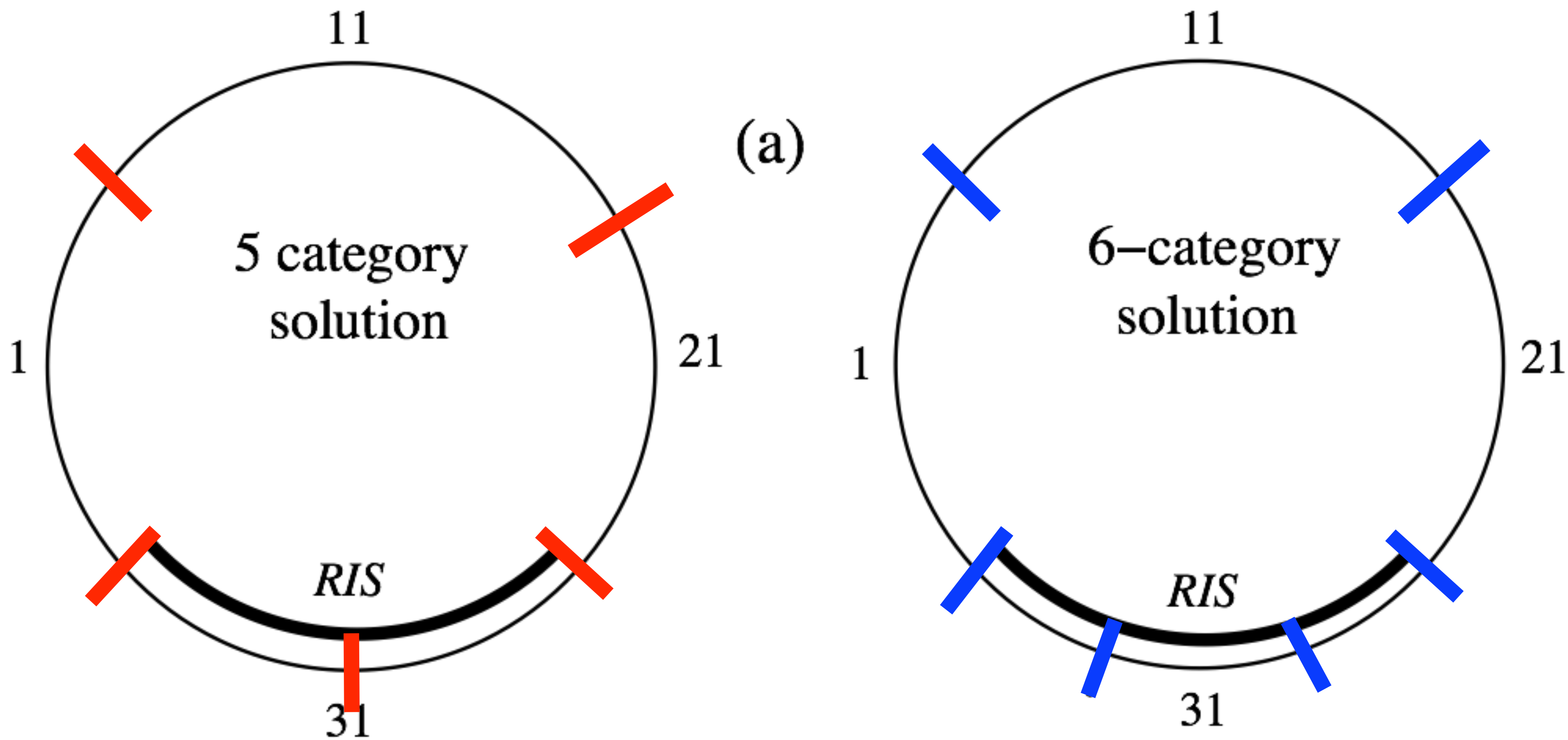
5-category solution

6-category solution (~**25%** of the time)



10 million games; *m*=5; *k-norm*=6; *k-RIS*=3; *N*=10; *RIS iL=26* & iR=*36*

Schematics of 5- & 6-category solutions under *RIS*



(~**70%** of the time)

(~**25%** of the time)

RIS summary

- For homogeneous populations, a RIS removes solution rotational invariance.
- Categories are refined by a RIS.
- Number of categories in a solution can vary

See articles online:

http://aris.ss.uci.edu/~kjameson/ResearchArticles.html

RIS and dichromats

Inhomogeneity in the *k-sim* measure (RIS):

Inhomogeneity in the population (dichromats):

RIS and dichromats

Inhomogeneity in the k-sim measure (RIS):

- Removes rotational invariance
- Changes category number and sizes

Inhomogeneity in the population (dichromats):

- Removes rotational invariance
- Changes category number and sizes

RIS and dichromats

Inhomogeneity in the k-sim measure (RIS):

- Removes rotational invariance by aligning category boundaries with the RIS
- Changes category number and sizes (smaller categories inside the RIS)

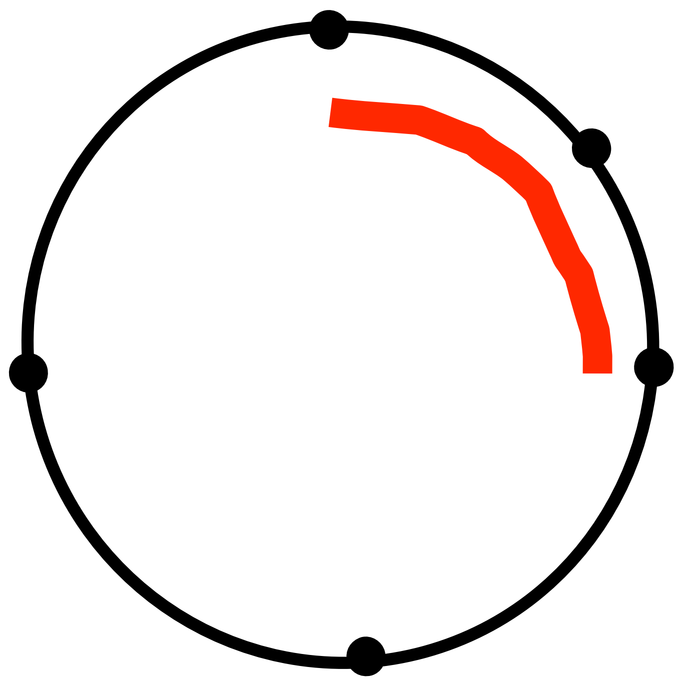
Inhomogeneity in the population (dichromats):

- Removes rotational invariance by aligning category boundaries with the ambiguity axis
- Changes category number and sizes according to the non-ambiguous axis orientation

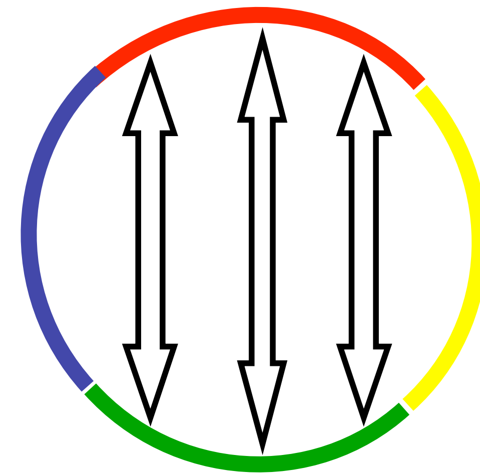
Interations between the two types of inhomogeneity

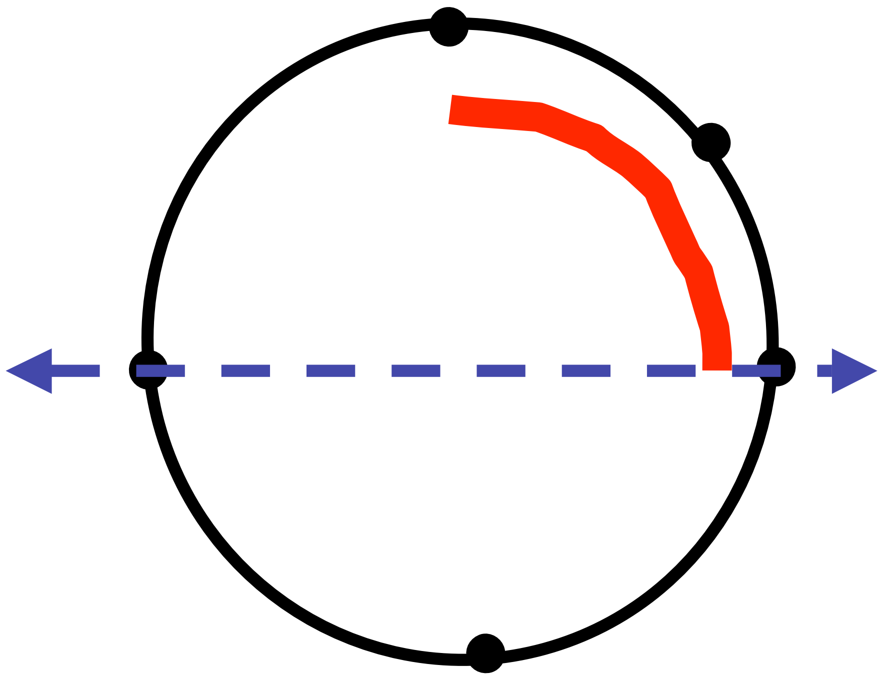
- Consider a population of normals and dichromats
- Include a RIS in the color space

Solution found by a population of normals with a RIS

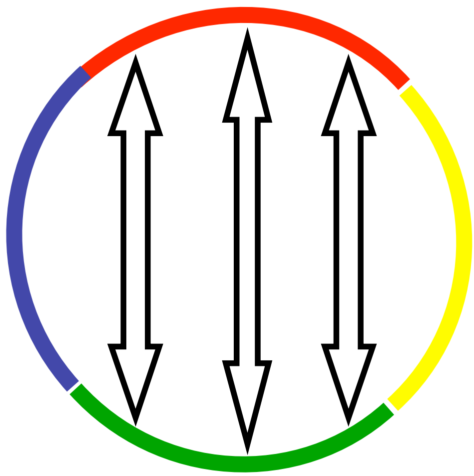


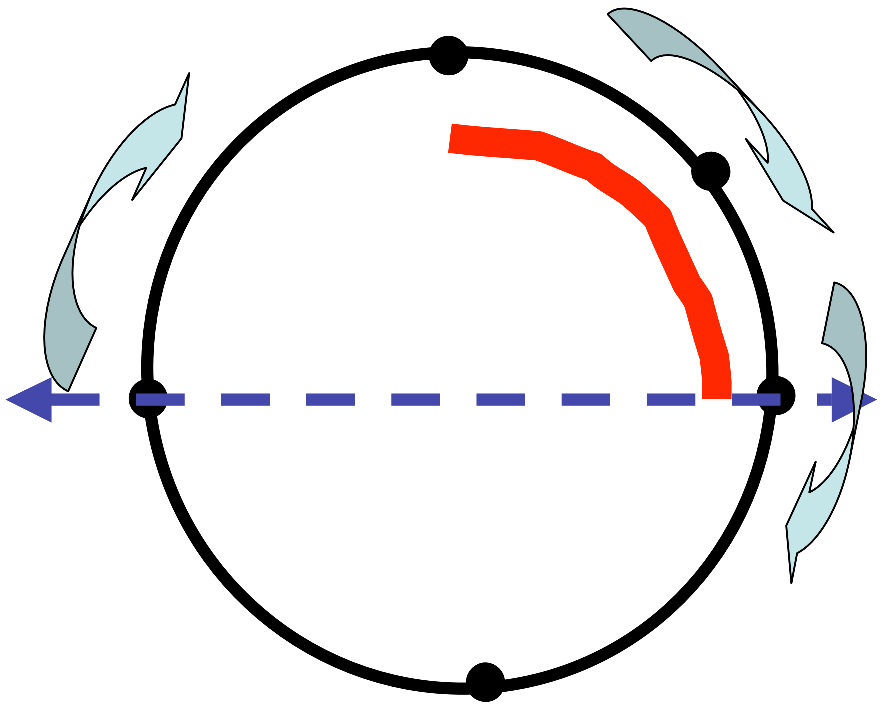
Add dichromats



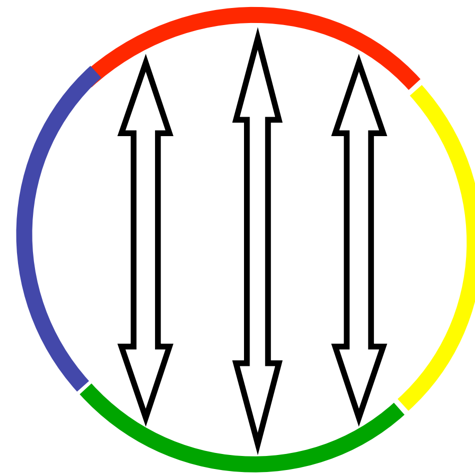


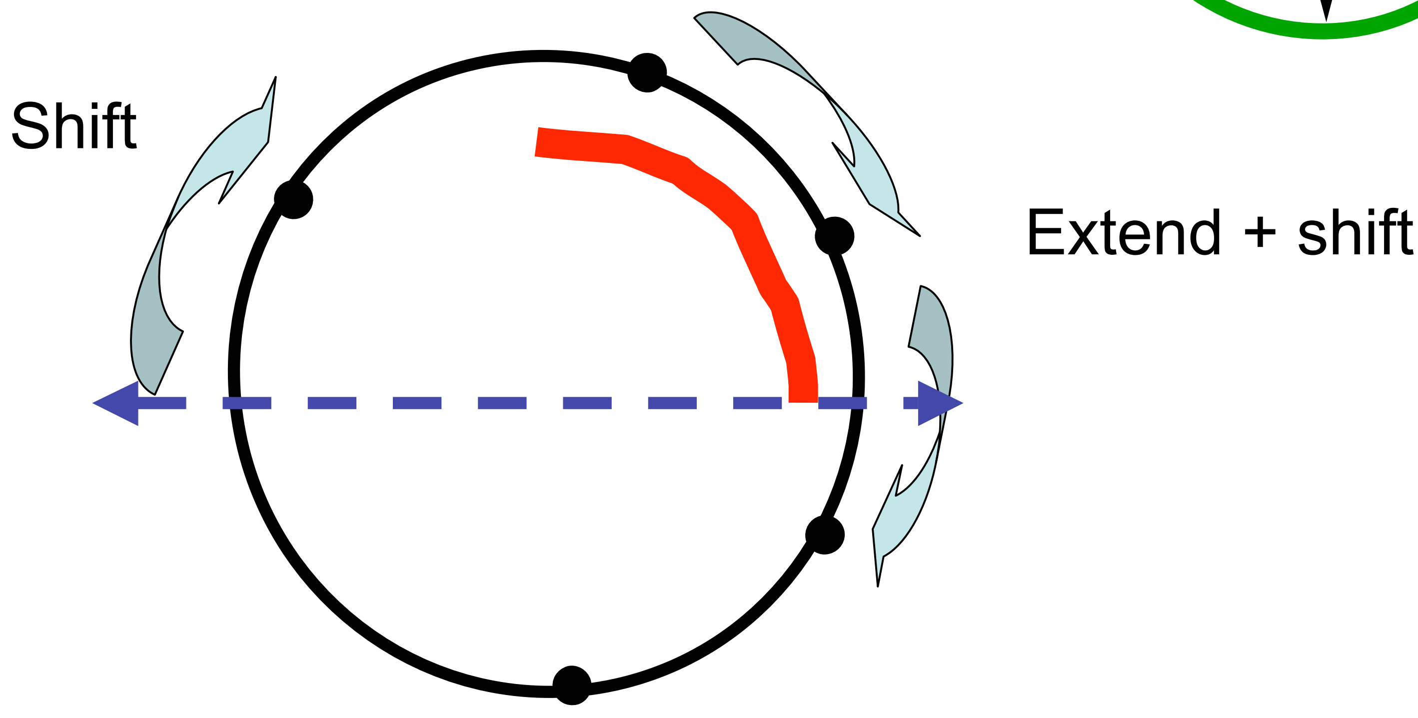
Add dichromats



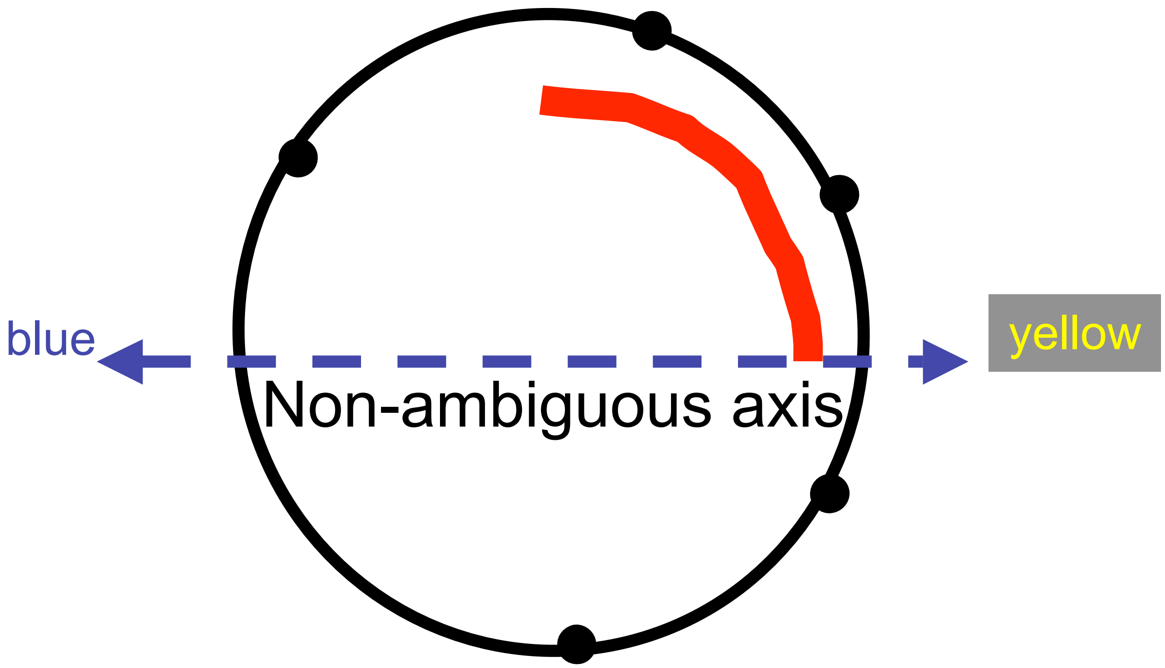


Add dichromats





Solution for an inhomogeneous population



Summary

- For a uniform color space and a homogeneous population of viewers, the categorization is a *rotationally invariant equipartitioning* of the circle
- In the presence of inhomogeneities in the color space (RIS), or in the population (dichromats), the color boundaries are fixed, and color categories may have different size

Summary

- Dichromats align the color categories along the non-ambiguous (blue-yellow) axis.
- *k-sim* inhomogeneities decrease category size inside the RIS.
- Different populations may have different RISs and different types of color vision variability
- This theory has a potential to explain the observed variations in color categorization

Quick Peeks:

(1.) Category solutions based on similarity.

(2.) Homogeneous vs. Heterogeneous Population Category Solutions.

(3.) Pragmatic Color Salience and Inhomogeneous Color Utility.

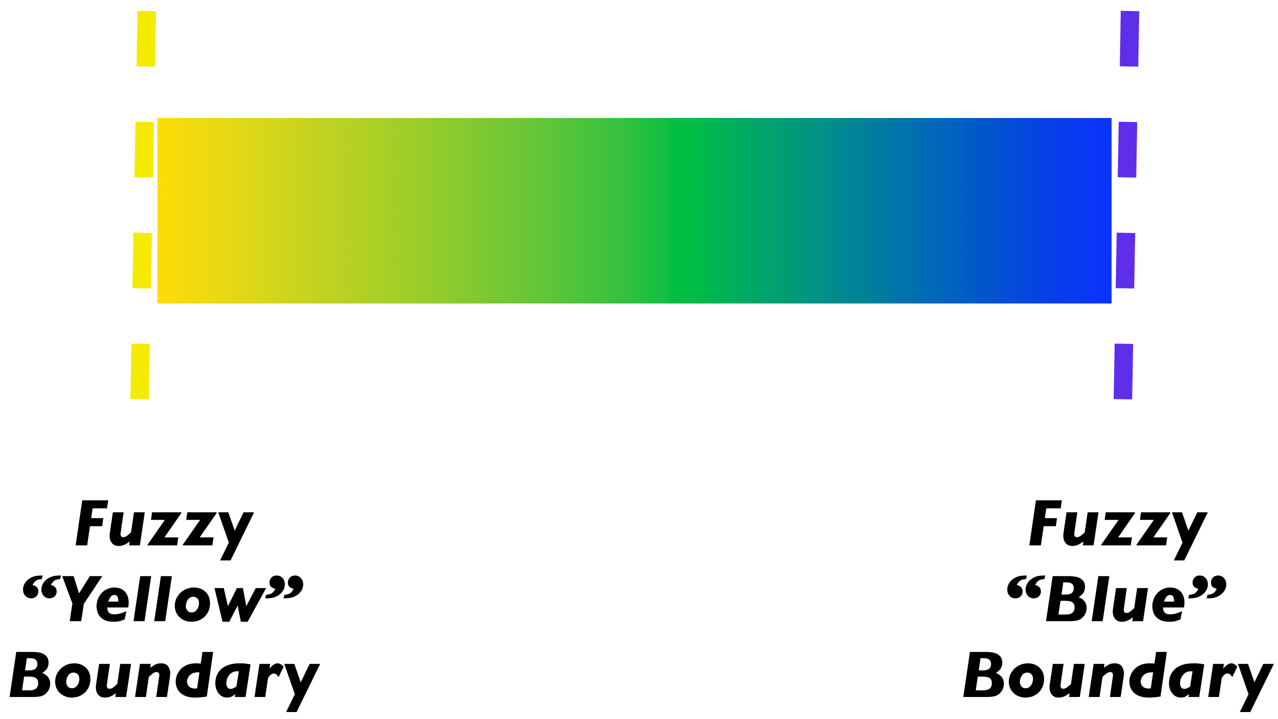
(4.) Simulated Category Solutions compared to Empirical Category Solutions.

(1.) Category solutions based on similarity

How do observers use similarity to categorize color?

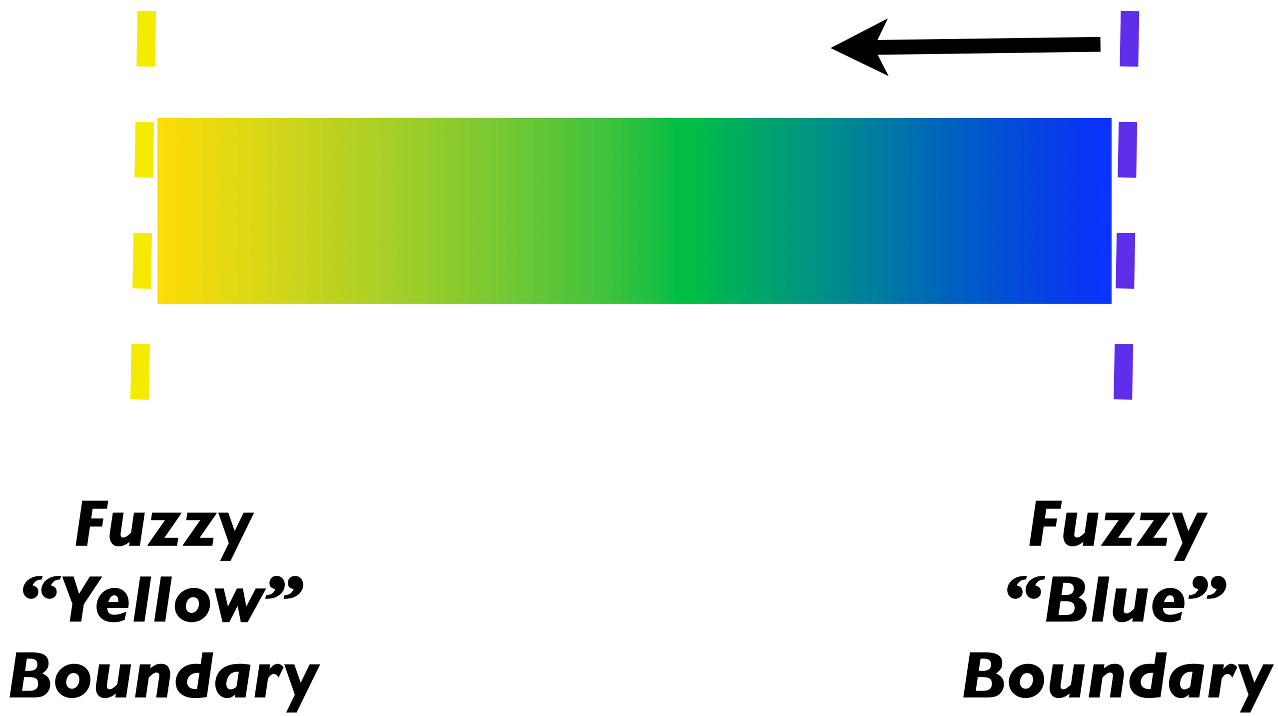
Unpacking Color Similarity Dynamics

- “pick a good example of *green*”



Choosing color best exemplars

- Strategy: Pick the appearance furthest from the *blue* boundary, and furthest from the *yellow* boundary.



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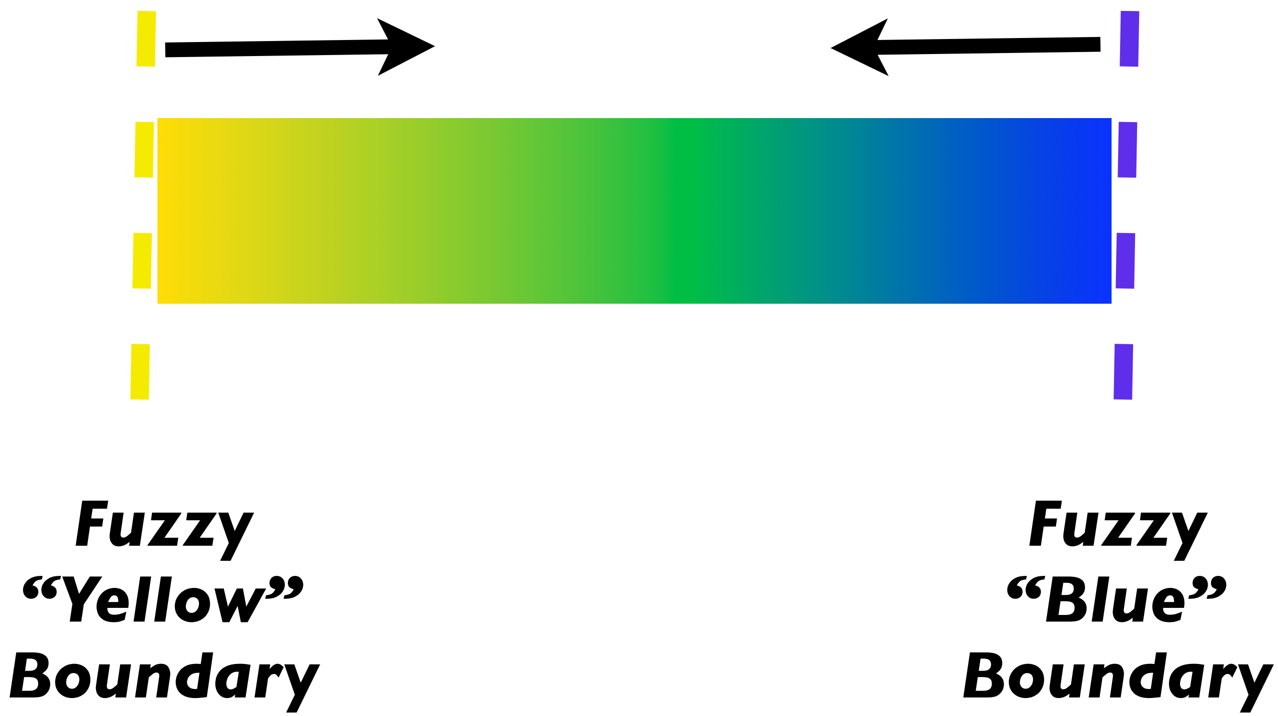
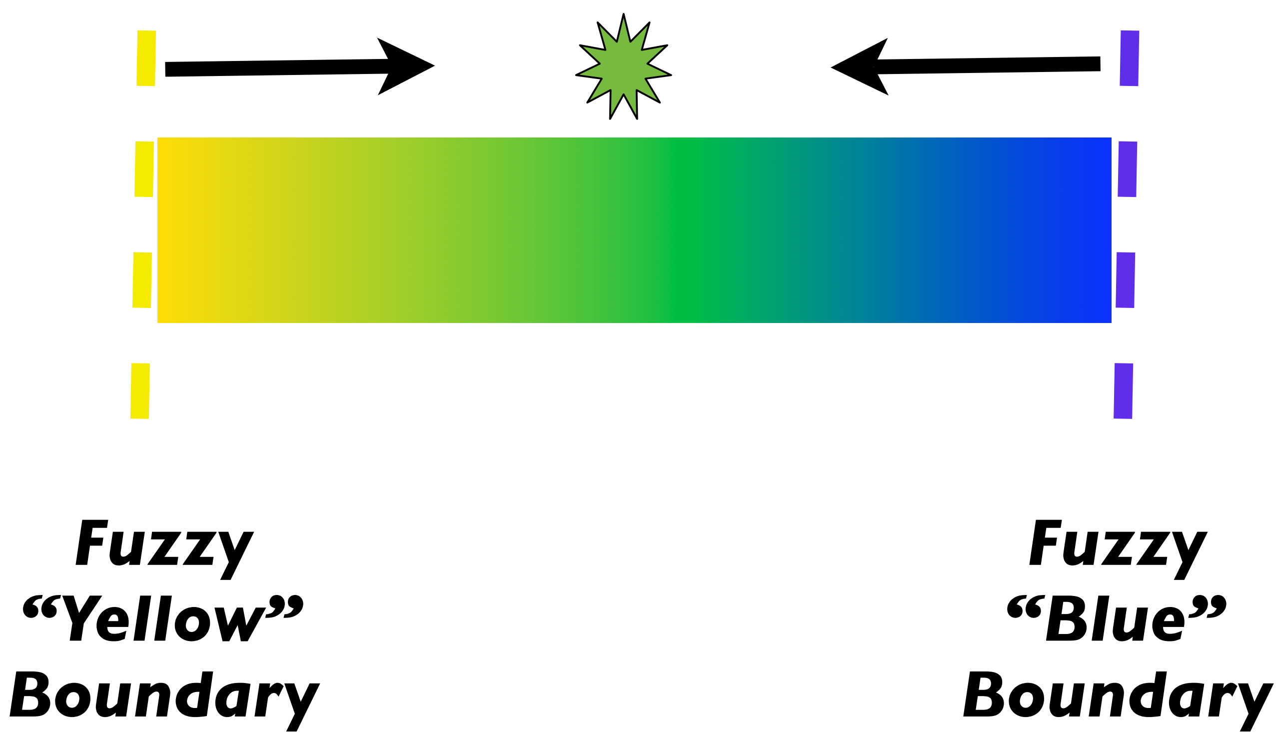


Choosing color best exemplars

- Boundaries repel, so best category best exemplars could tend toward some midpoint between categories.



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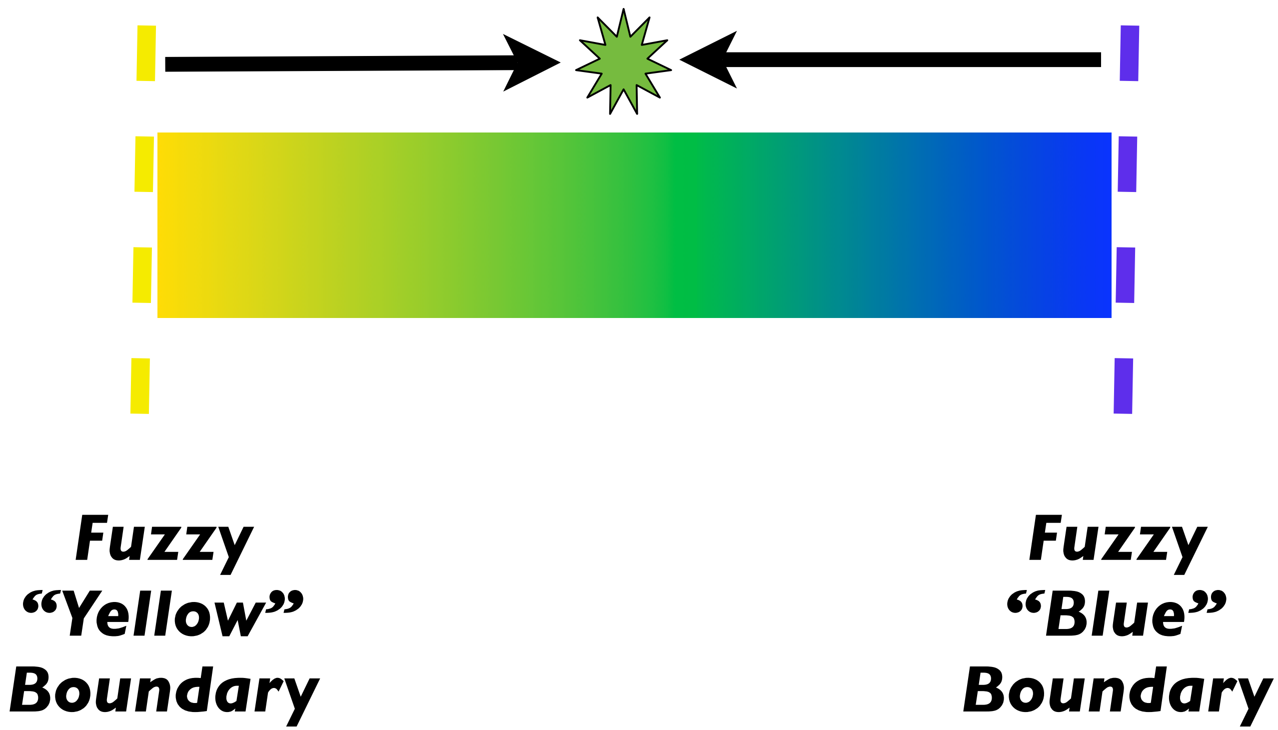
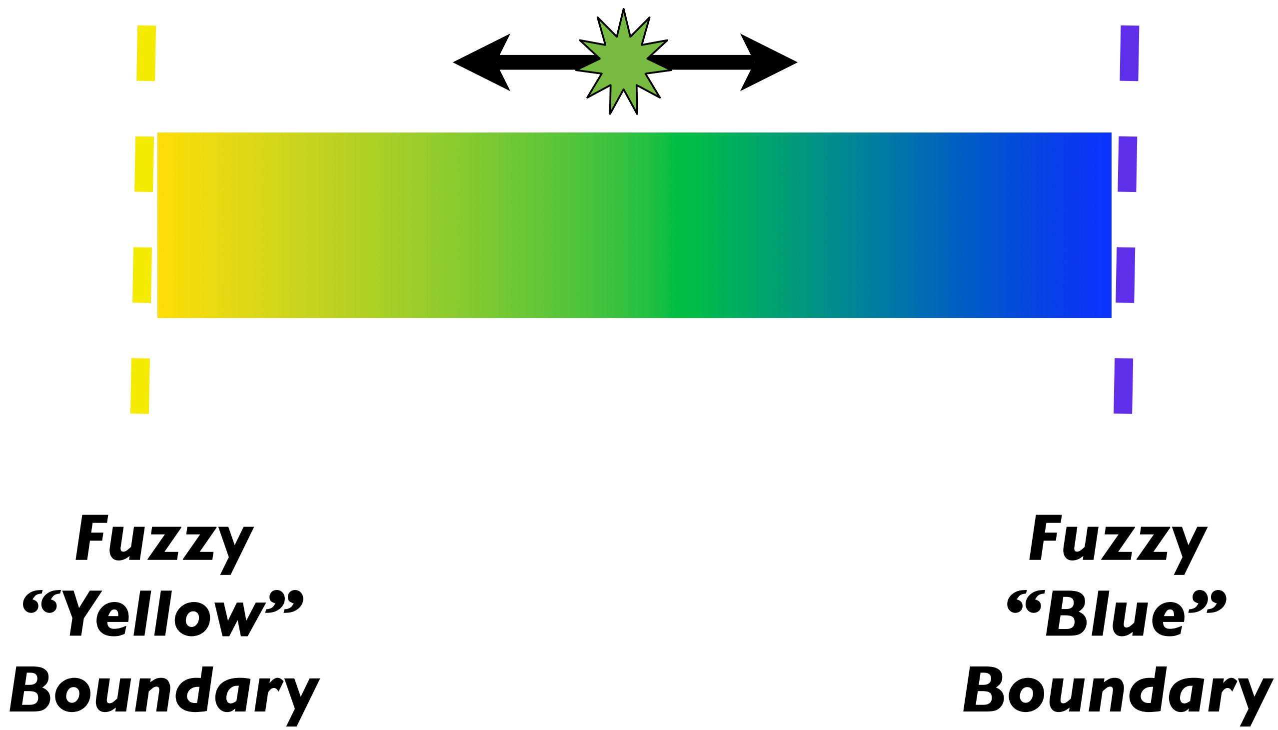


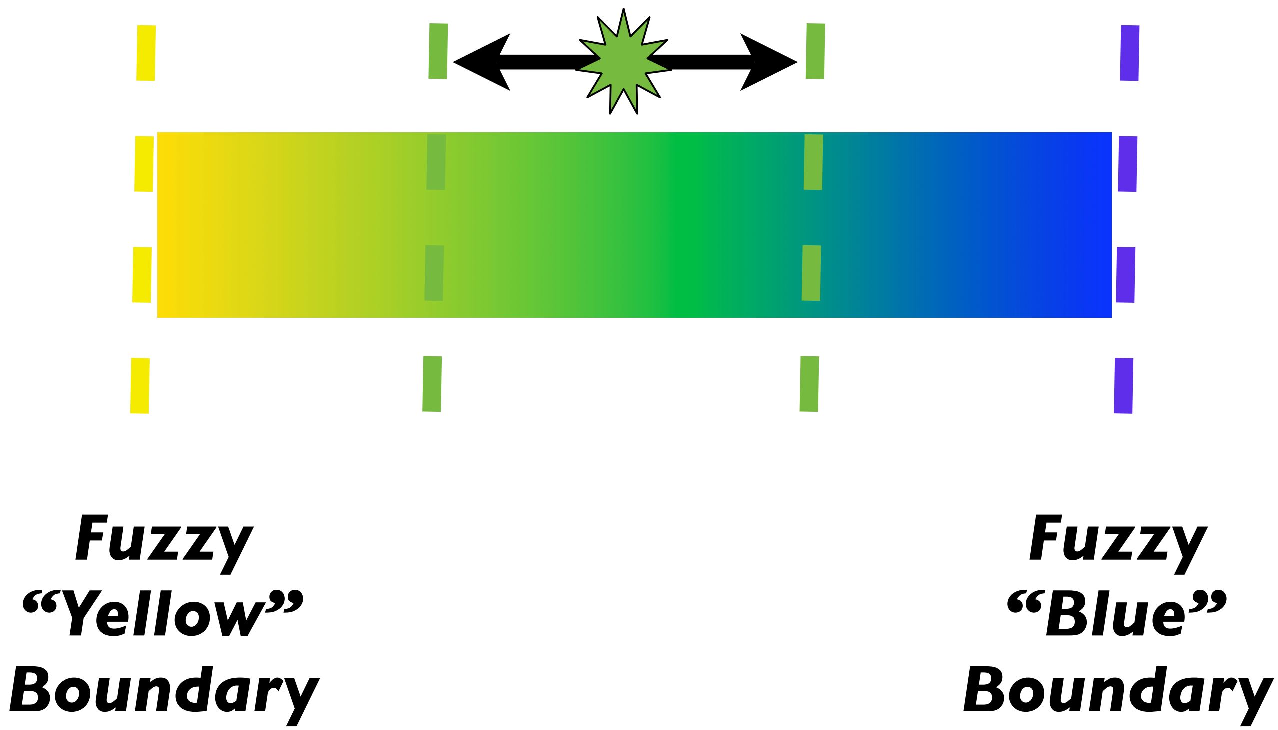
Choosing color category ranges: "Show me all the *Greens*"

- Strategy: Pick all the appearances that are most similar to some best exemplar point, while also not too similar to neighboring category exemplars.



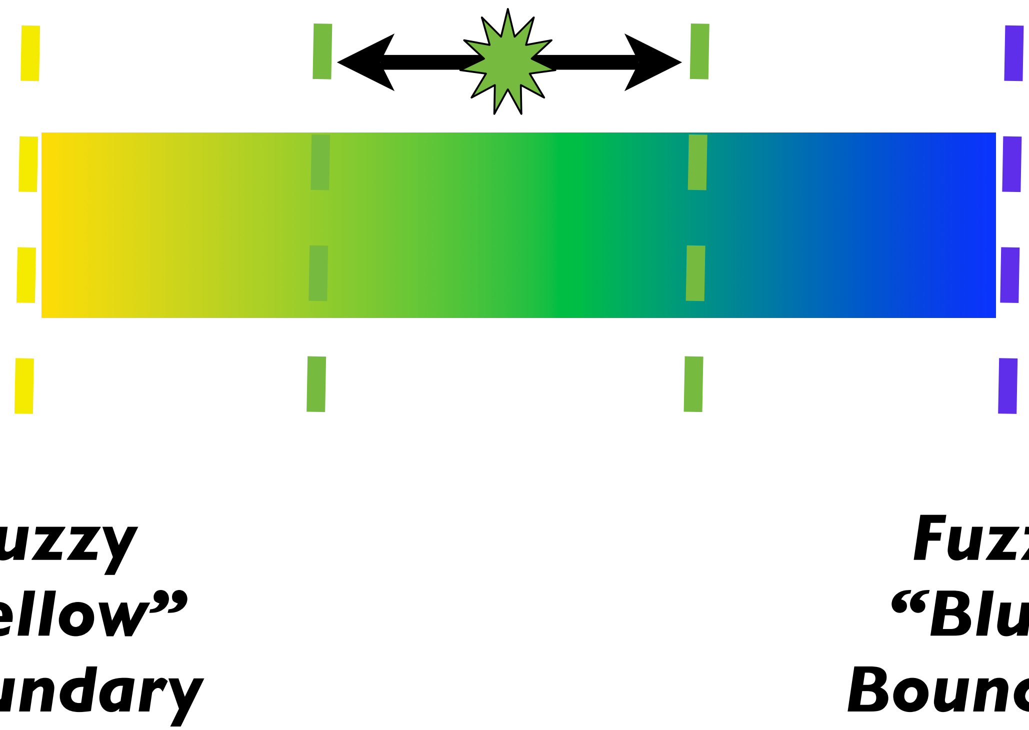
Choosing color category ranges: "Show me all the *Greens*"

- Strategy: Pick all the appearances that are most similar to some ideal example point, while also not too similar to neighboring category exemplars.



Choosing color category ranges: "Show me all the *Greens*"

- The construct of a central exemplar, which all category members resemble, attracts or anchors boundaries.



Color Similarity Dynamics

- What happens if for normal observers within an ethnolinguistic group, the basis for this similarity-based idea of best exemplar varies?

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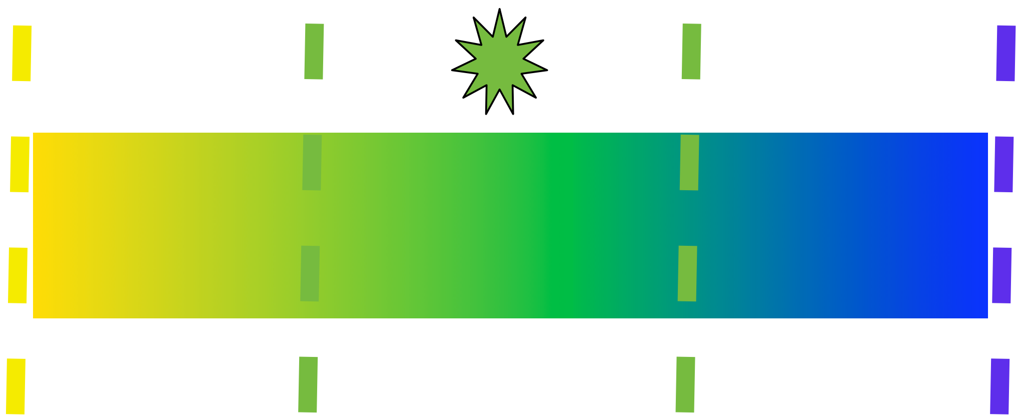

Fuzzy "Yellow" Boundary

Fuzzy "Blue" Boundary

Color Similarity Dynamics

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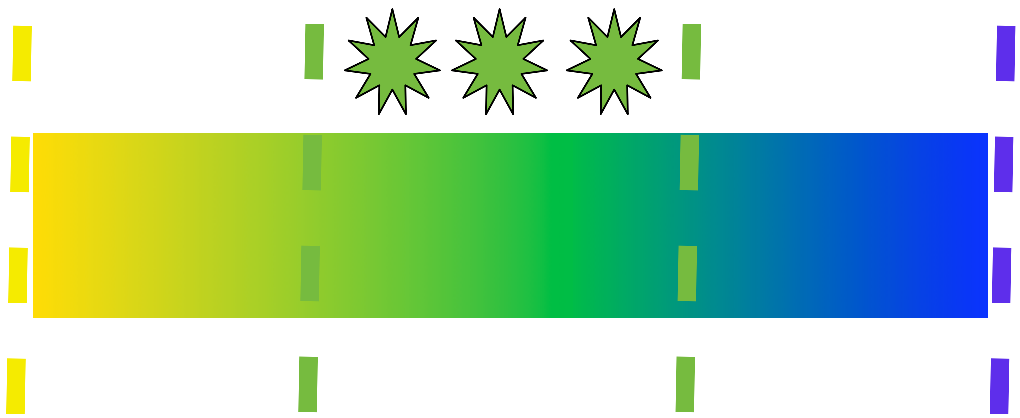


Fuzzy "Yellow" Boundary

Fuzzy "Blue" Boundary

Perception Varies Even in Normal Observer Groups

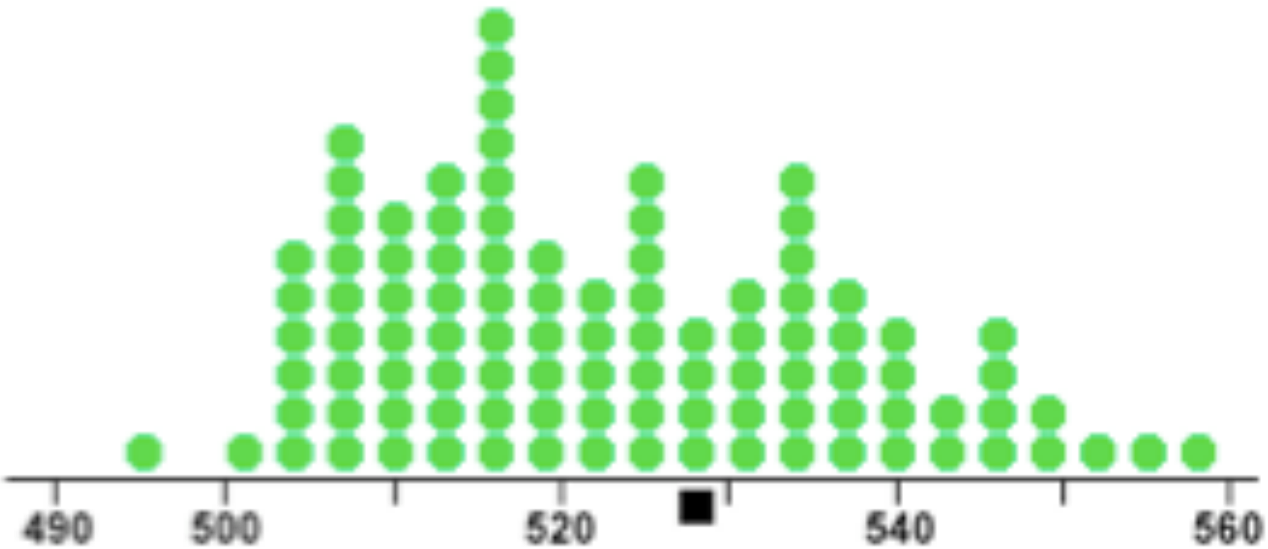
- Ranges of individual color perception differences are greater than have been acknowledged in the color cognition and categorization literature.
- The extent of these ranges raises questions about the idea of uniformly shared perceptual color space as the explanation for color category uniformity across individuals.
- An example: unique hue percepts.

Unique Hues

- “There exist four colors, the *Urfarben* of Hering, that appear phenomenologically unmixed. The special status of these ‘unique hues’ remains one of the central mysteries of colour science.”

- Mollon, J.D. & Jordan, G. (1997). On the nature of unique hues. In C. Dickinson, I. Murray and D. Carden (Eds), John Daltons Colour Vision Legacy, p. 381-392.

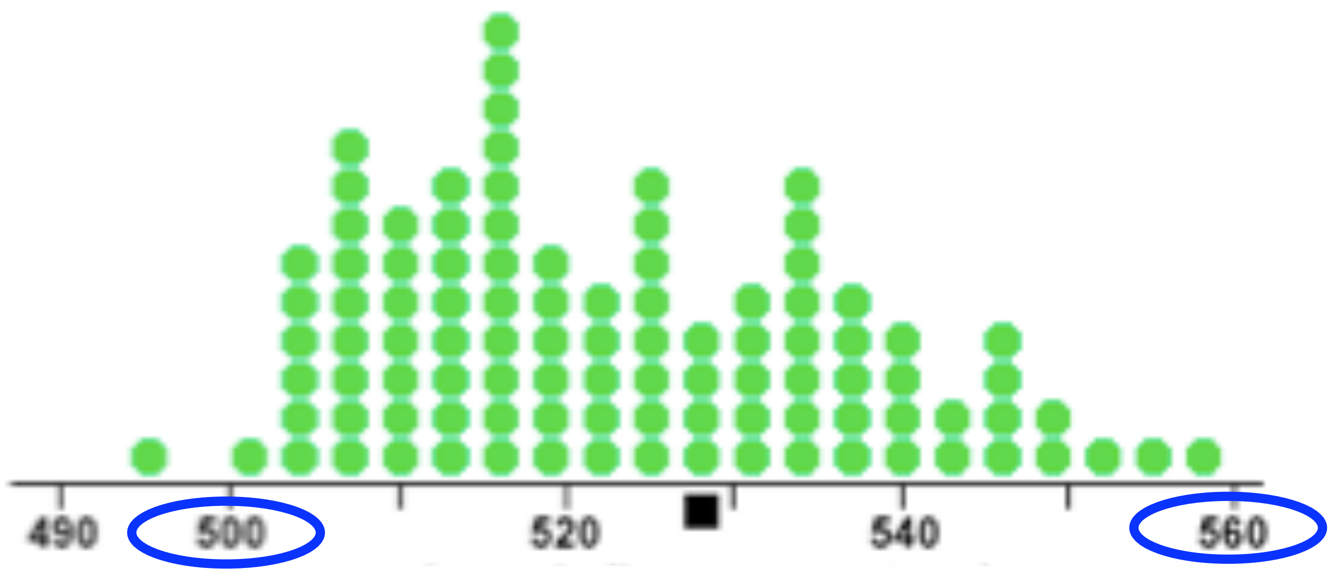
Normal Variation for Unique Green



black square indicates average unique green; data from Volbrecht, Nerger & Harlow (1997).

Image Credit: www.handprint.com. Bruce MacEvoy.

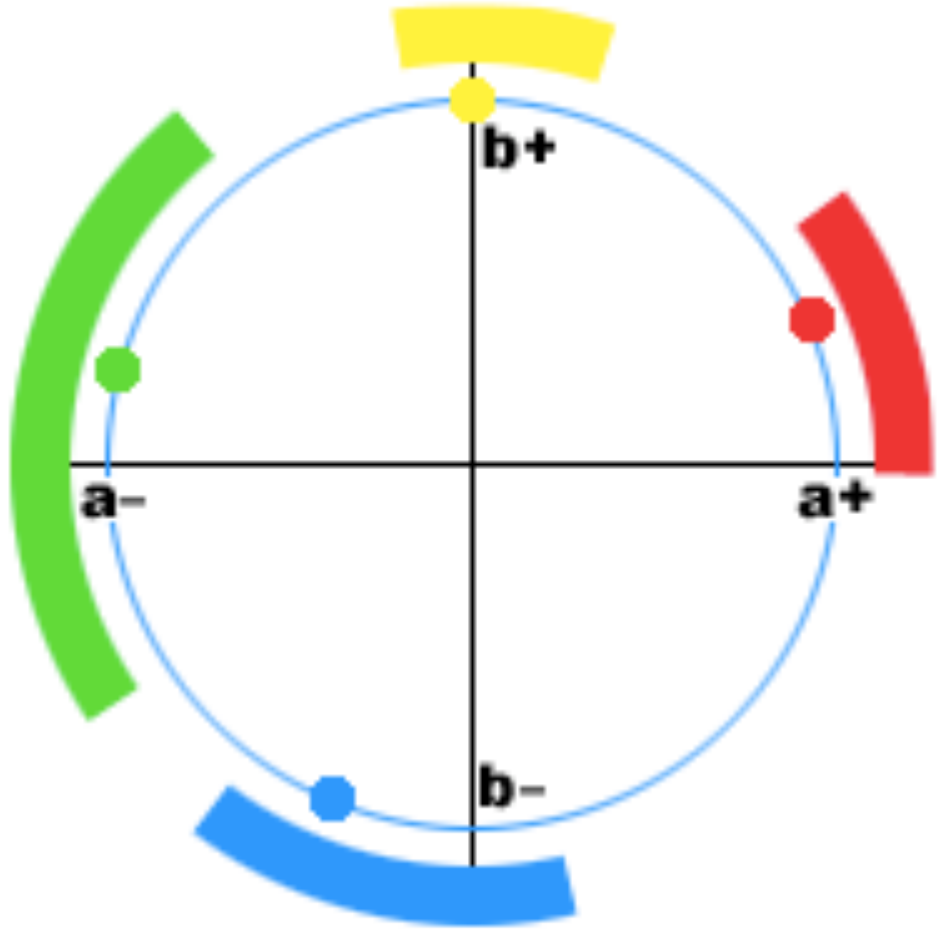
Normal Variation for Unique Green



Wavelength

A span of ~60 *nm* for a pure green setting ...

Image Credit: www.handprint.com. Bruce MacEvoy.



Unique Hue Choices on a Color Circle (Kuehni, 2004)

Image Credit: www.handprint.com. Bruce MacEvoy.

Color Similarity

- What happens if for normal observers within an ethnolinguistic group, the basis for this similarity-based idea of best exemplar varies?
- The structure of individual color similarity varies.
- Possible consequences for population category solutions?
    - (i) none - all individual category solutions are statistically the same.
    - (ii) some yet known consequence?

Color Similarity

- Possible consequences for population category solutions?

- (ii) some yet known consequence?
  - At a minimum it seems that something else is helping along systems that begins with perceptual constraints in achieving the goal of a shared color signaling system.

Human Communication Pragmatics: Linguistic Charity.

Linguistic Charity

- *For the sake of communication, I will allow a certain amount of "inaccuracy" in your color communications* (works both ways, ideally).

- Putnam, H. (1988). *Representation and Reality*. The MIT Press.
- Freyd, J. J. (1983). Shareability: The social psychology of epistemology. *Cognitive Science, 5,* 121–152.
  - Jameson (2005) *J. Cog. & Cultr.*
  - Jameson & Alvarado (2003) *Phil. Psych.*

http://aris.ss.uci.edu/~kjameson/kjameson.html

Linguistic Charity

- *For the sake of communication, I will allow a certain amount of "inaccuracy" in your color communications* (works both ways, ideally).
- So, calling a color by the name of an adjacent, near category (or even simply an adjacent category) is permissible, and accommodated by normal discourse.
  - Analytically this can be shown to as a decreasing imposition on discourse as the number of categories shared increases.

Linguistic Charity

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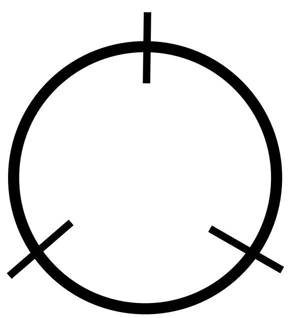
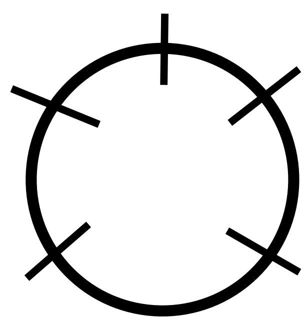
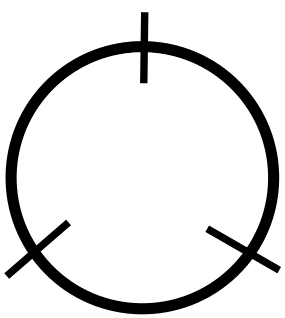


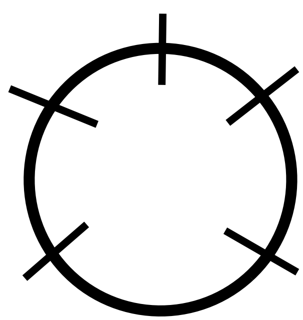


For systems with more categories, a categorization error is not as dramatic of an error as it is in a system with just few categories.

Linguistic Charity

- So, calling a color by the name of an adjacent, near category (or even simply an adjacent category) is permissible, and accommodated by normal discourse.
  - Analytically this can be shown to as a decreasing imposition on discourse as the number of categories shared increases.





For systems with more categories, a categorization error is not as dramatic of an error as it is in a system with just few categories.

(2.) Homogeneous vs. Heterogeneous Population Category Solutions

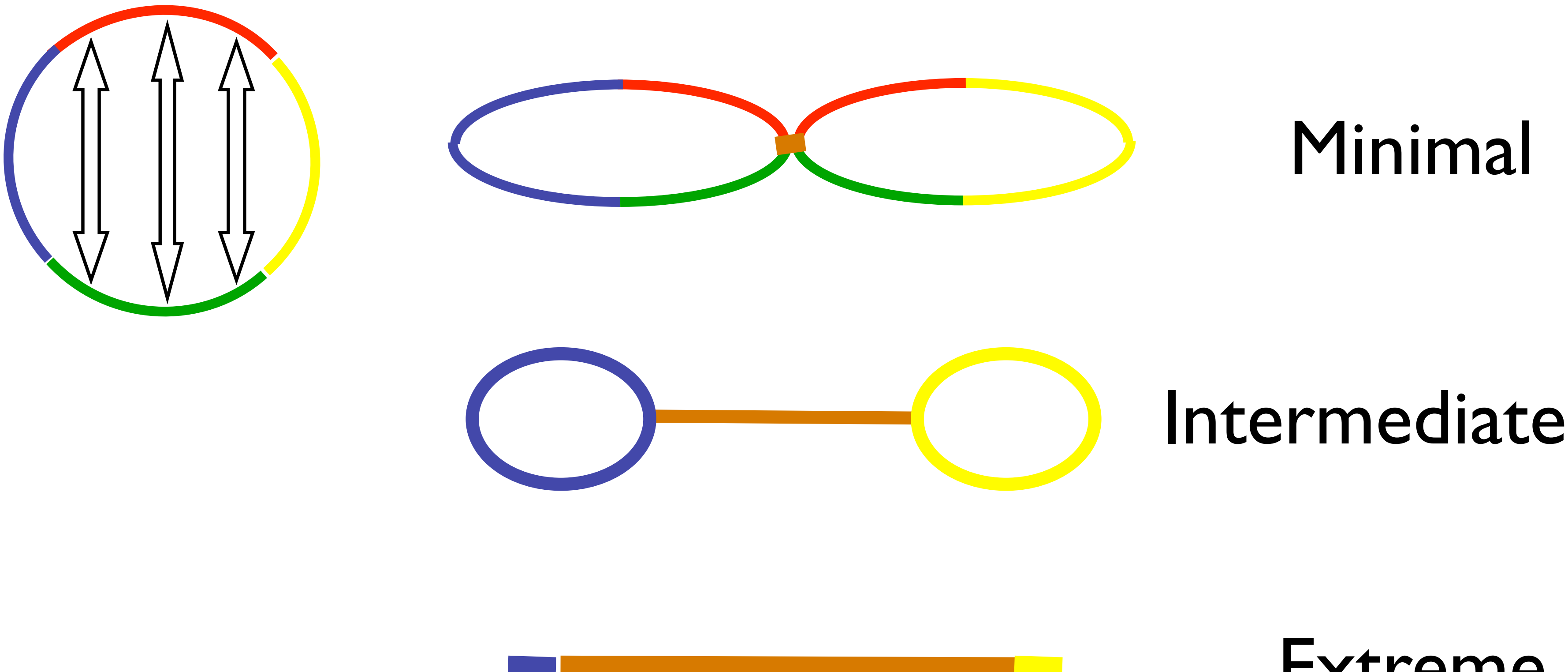
Steels & Belpaeme (2005). Coordinating Perceptually Grounded Categories: A Case Study for Colour. *Behavioral and Brain Sciences, 28,* 469-529.

Steels & Belpaeme (2005). *BBS*.

The possibility exists that in heterogeneous populations, category distinctions may be influenced by a need to disambiguate the communication of categories among varying observer types.

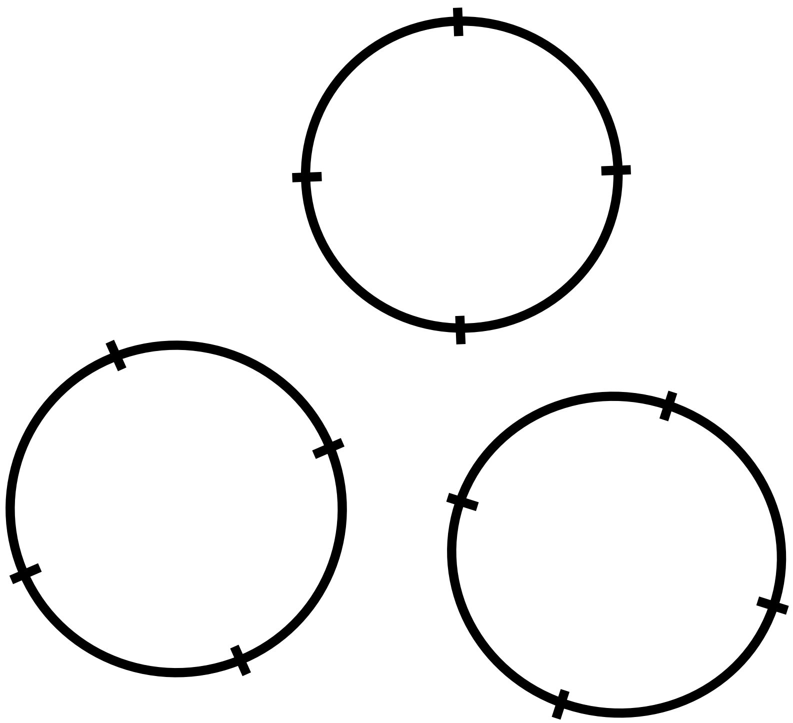
Jameson (2005, *JCC*).

“Dichromat” models tested:



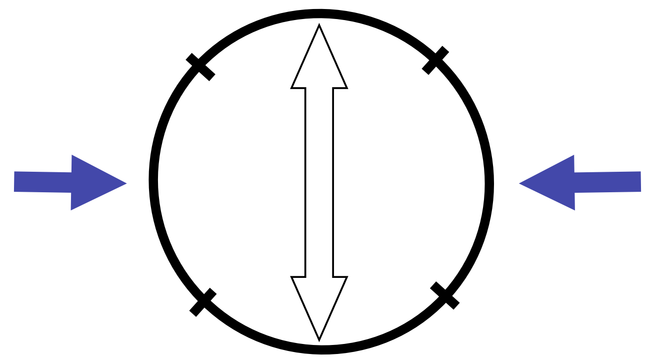
Systematically varying dichromats by varying anchors regions of perceptual confusion.

Dichromats remove solution rotational invariance

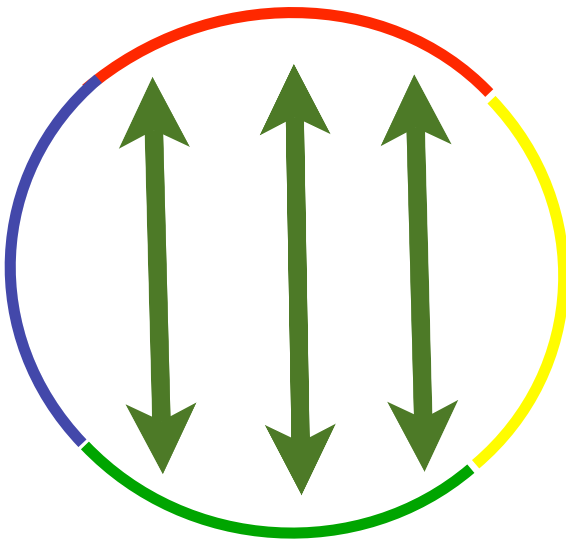


Normals: any rotation of the optimal solution is an optimal solution

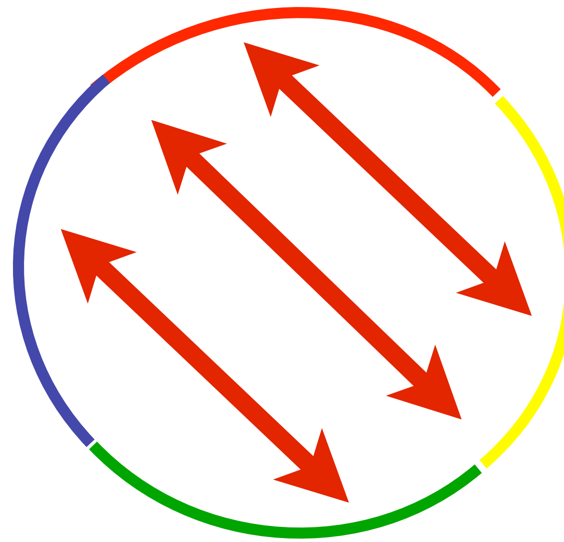
A non-ambiguous axis



Normals & Dichromats: Only one solution



Deuteranope



Protanope

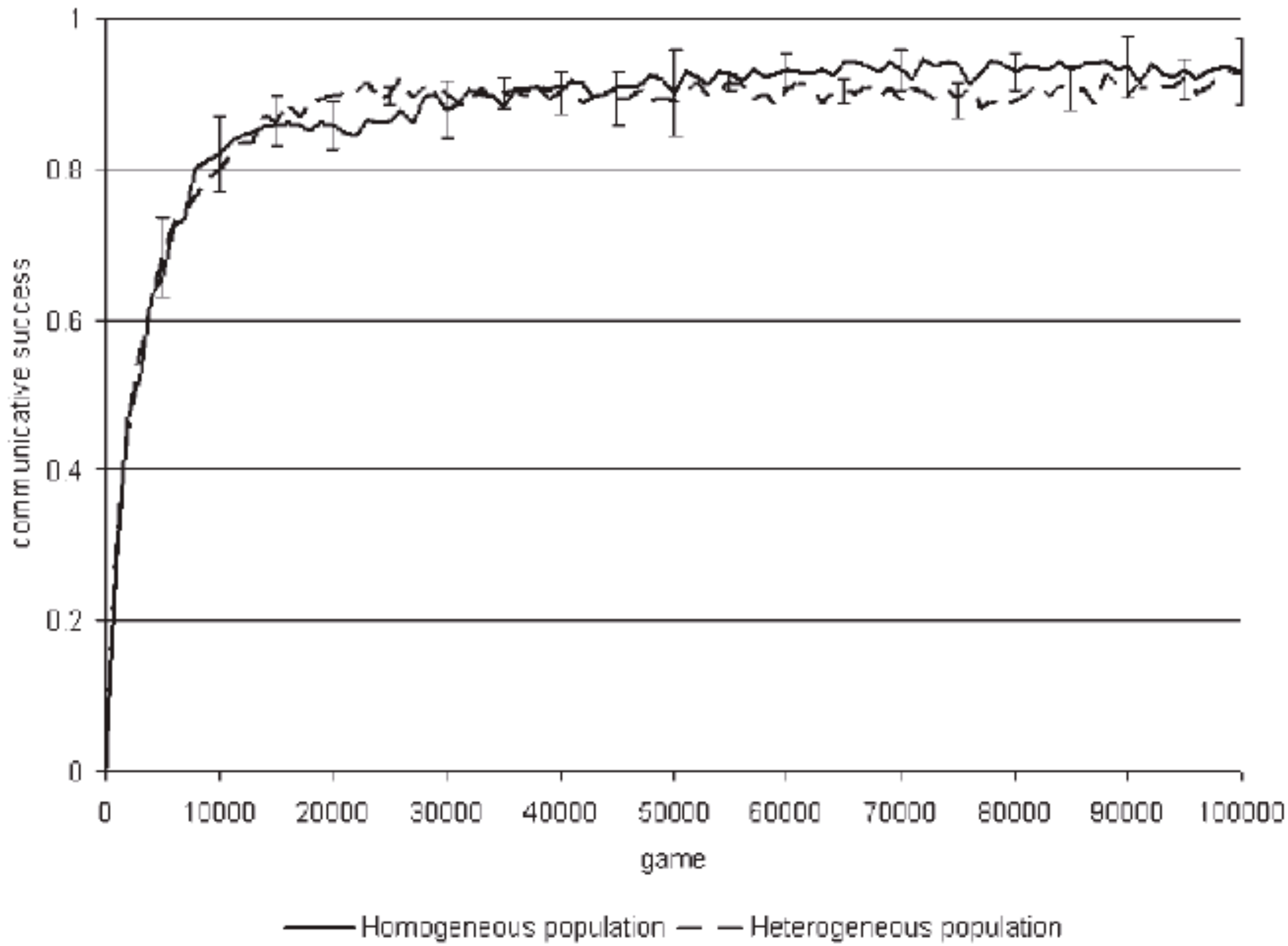
Steels & Belpaeme (2005). *BBS*.

- Modeling heterogeneity:
- "In the heterogeneous population, each individual had a **random variation** on its colour perception, implemented as a normal variation (with a standard deviation of 10) on each of the *L**, *a**, and *b** dimensions."

Steels & Belpaeme (2005). *BBS*.

- They considered:
- “The average communicative success of five populations consisting of identical agents [*homogeneous populations*] versus the average success of five populations consisting of agents having variations in their chromatic perception [*heterogeneous populations*],” With each population having 20 agents.

Steels & Belpaeme (2005). *BBS*.



Steels & Belpaeme (2005). *BBS*.

- They Conclude: “The communicative success of both kinds of agents evolves in the same way, showing that perceptual variations have very little influence on the communication of colour.”

Steels & Belpaeme (2005). *BBS*.

- They Conclude: "The communicative success of both kinds of agents evolves in the same way, showing that perceptual variations have very little influence on the communication of colour."
- Three ways to model, three expectations:
  - Random *vs.* systematic observer variation.
  - Realistic ("normal" + "variable") variation.
  - Confusion axis symmetry breaking.

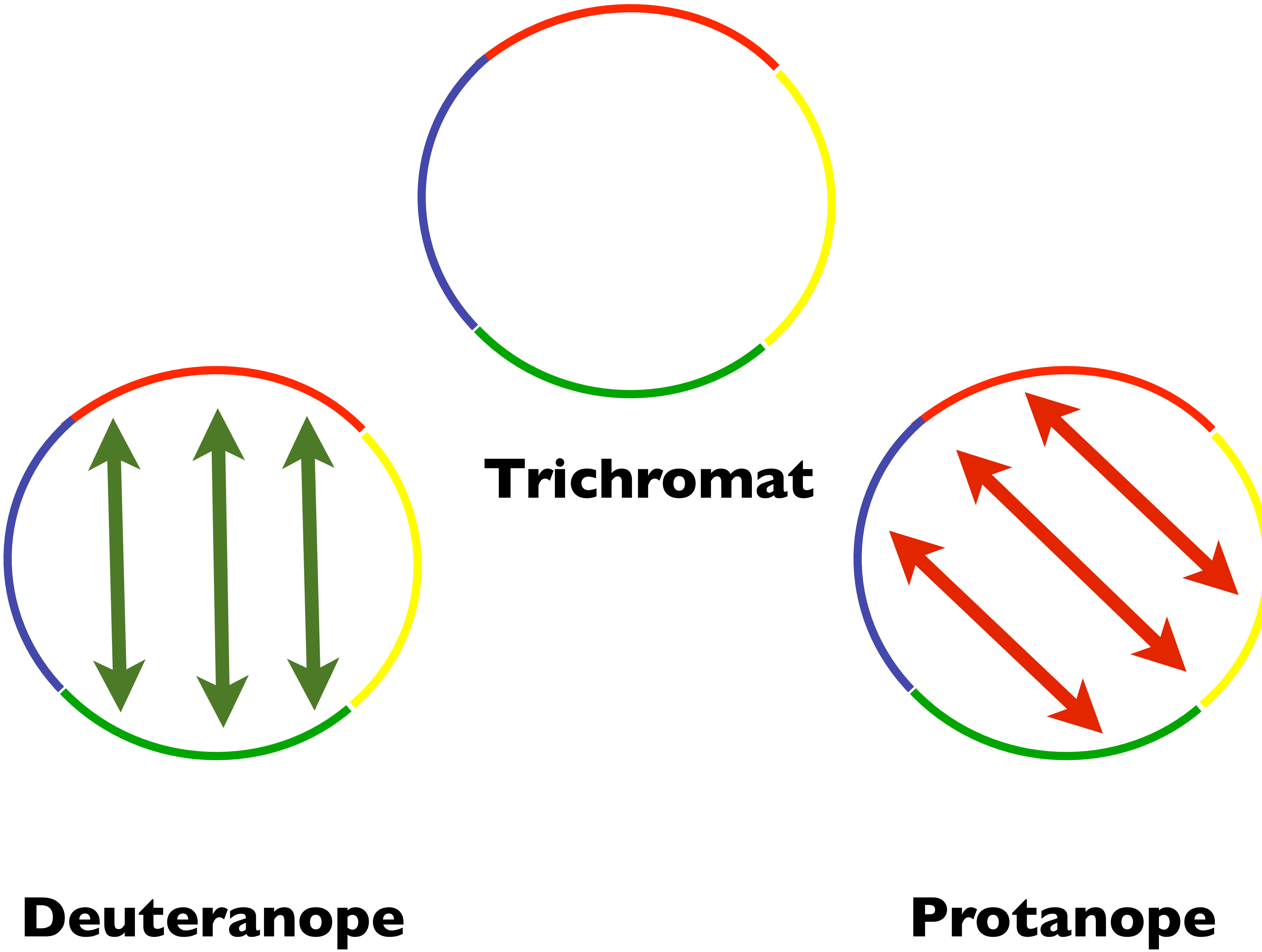
Importance of Cognitive Processes

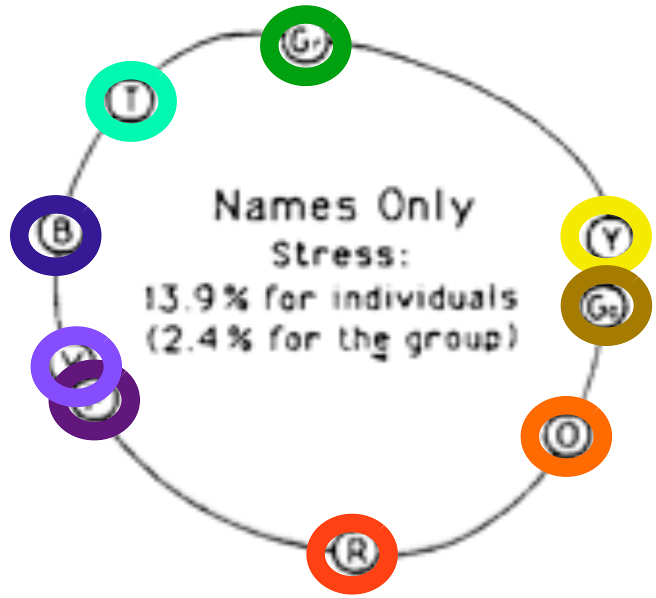
- When individual differences exist, language can gloss differences and permit meaningful communication.
- This requires a cognitive process to link normative lexical terms (names) to individual mental representations of color.
- Because people see color, even when their language contains no word for color itself, clearly color mental representation exists.
  - Lack of color perception does not exclude participation in shared linguistic knowledge.

Shepard and Cooper (1992). Representation of colors in the blind, color--blind, and normally sighted. *Psychological Sci*ence, 3(2).

Universal use of Color Similarity

- " ...Young children (from two very different cultures) group colours on the basis of perceptual similarity before they acquire any colour categories (Roberson et al. 2004), as does an adult patient with colour anomia, who had lost the ability to categorise colours explicitly (Roberson et al. 1999). Drawing children's attention to the relative similarity of colours through linguistic contrast, also promotes faster category learning (Au & Laframboise 1990; O'Hanlon & Roberson 2004). **If categories are initially formed based on the relative similarity of stimuli, as Dedrick (1996) and Roberson et al. (2000) have argued, then both the range of available stimuli in the environment and variability in the need to communicate about colour should affect the eventual set that a community arrives at.**" **Roberson & O'Hanlon (2005)**


Trichromat
Deuteranope
Protanope

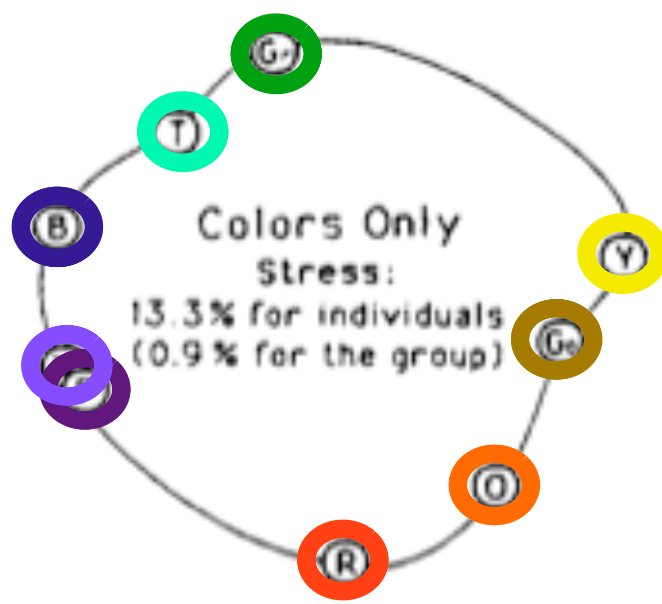


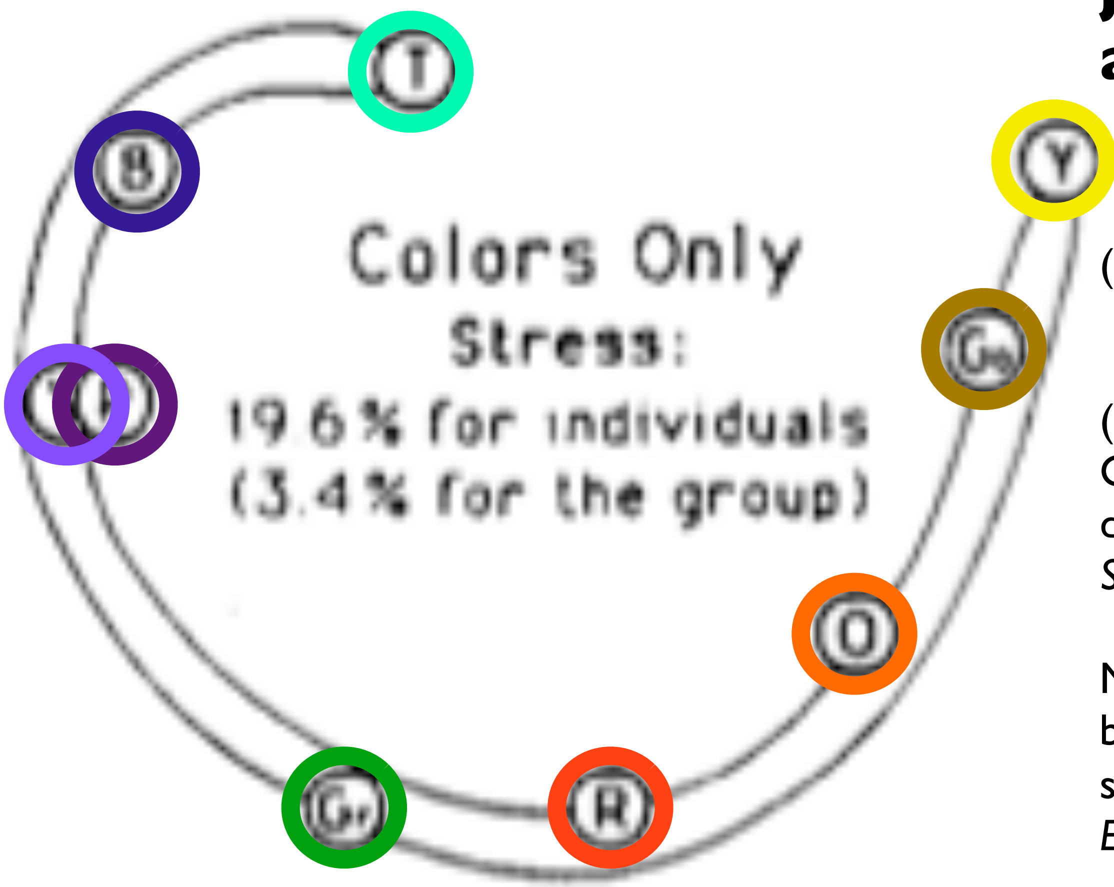
Trichromat judgments for color terms and color appearances.

Adapted from Shepard and Cooper (1992). *Psych. Sci*.

Shepard & Cooper's Interpretation:

Structure preserving cognitive representation between color appearances and color names.



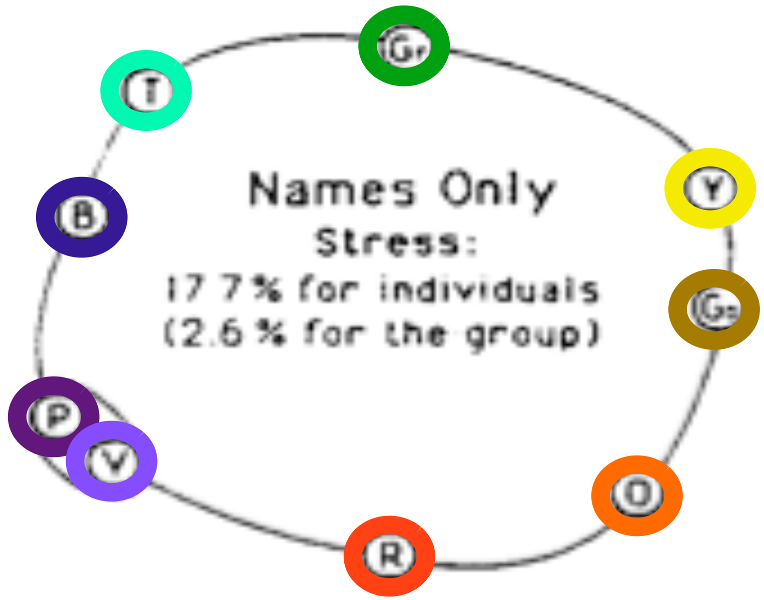


Dichromat similarity judgments for color appearances.

Adapted from Shepard and Cooper (1992). *Psych. Sci.*,3.

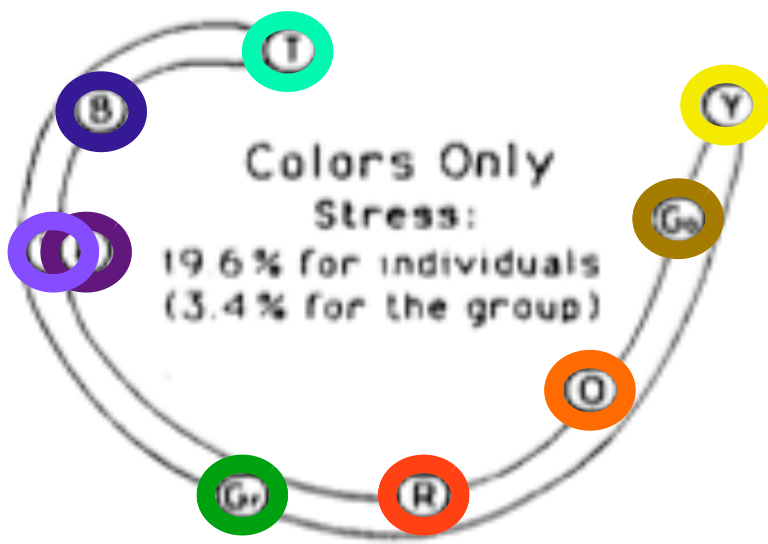
(Cf, Jameson & Hurvich. 1978. Dichromat Color Language: "Reds" and "Greens" don't look alike but their colors do. *Sensory Processes, 2.*

Marmor. 1978. Age at the onset of blindness and the development of the semantics of color names. *Journal of Experimental Child Psychology, 25.*)



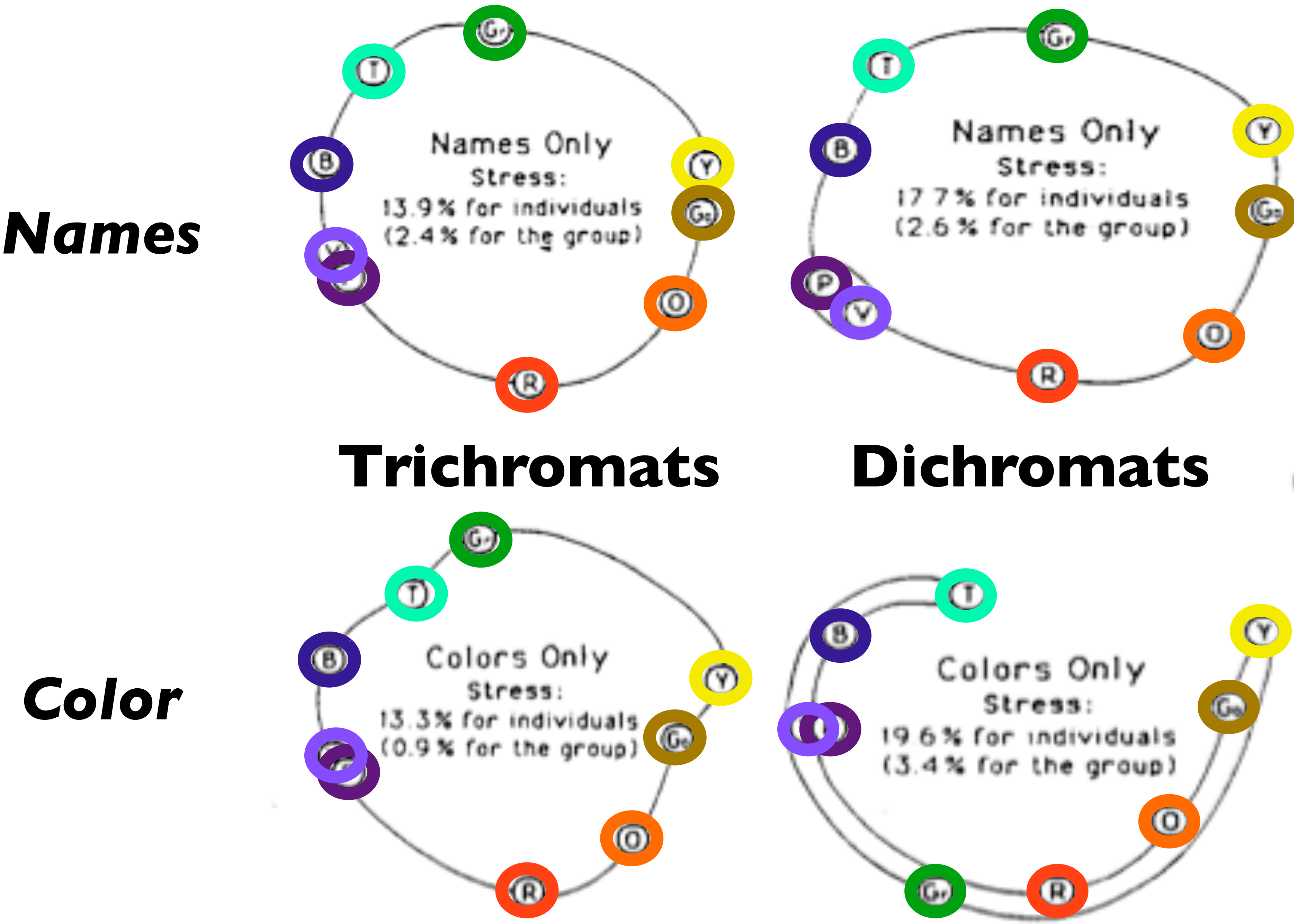
Dichromats:
Comparison of judgments for color terms and color appearances.

Adapted from Shepard and Cooper (1992). *Psych. Sci.*,3.



(c.f., **Jameson & Hurvich. 1978. Dichromat Color Language: "Reds" and "Greens" don't look alike but their colors do. *Sensory Processes, 2.***

Marmor. 1978. Age at the onset of blindness and the development of the semantics of color names. *Journal of Experimental Child Psychology, 25.*)


Names
Color
Trichromats
Dichromats
Names Only
Stress:
13.9% for individuals
(2.4% for the group)
Names Only
Stress:
17.7% for individuals
(2.6% for the group)
Colors Only
Stress:
13.3% for individuals
(0.9% for the group)
Colors Only
Stress:
19.6% for individuals
(3.4% for the group)
Gr
T
B
Y
Gs
O
R
P
V

Implying Universal Similarity Structure for Color Names?

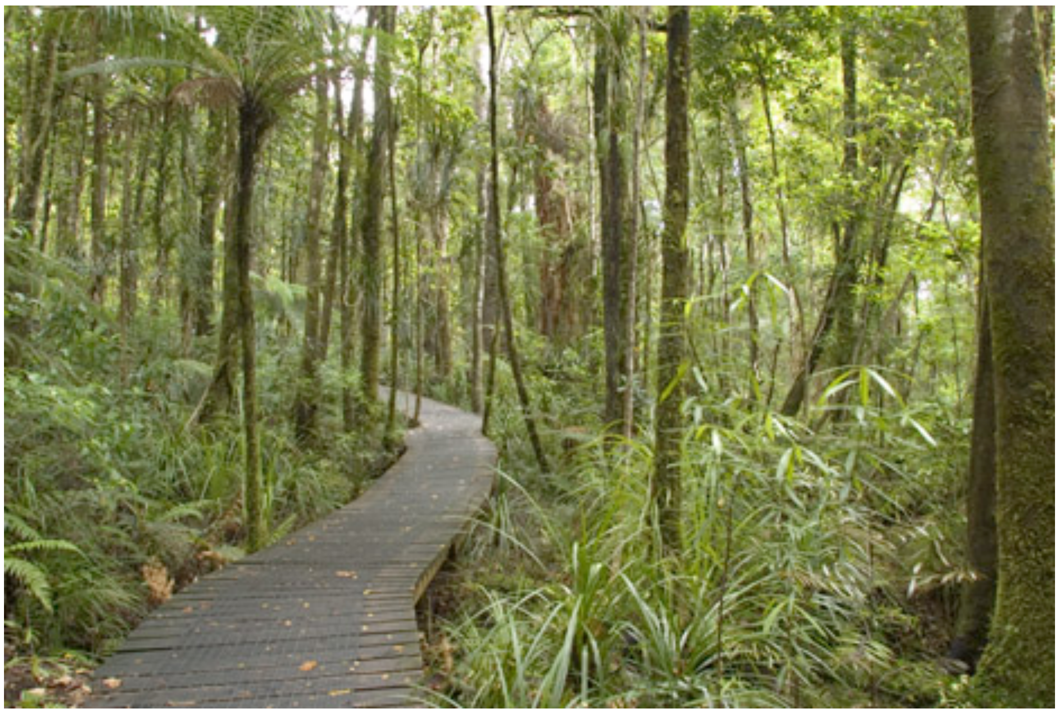
- Which can perhaps be thought of an example of acquiring the correct category cognitive constructs in the absence of the perceptual distinctions to correctly apply those constructs.

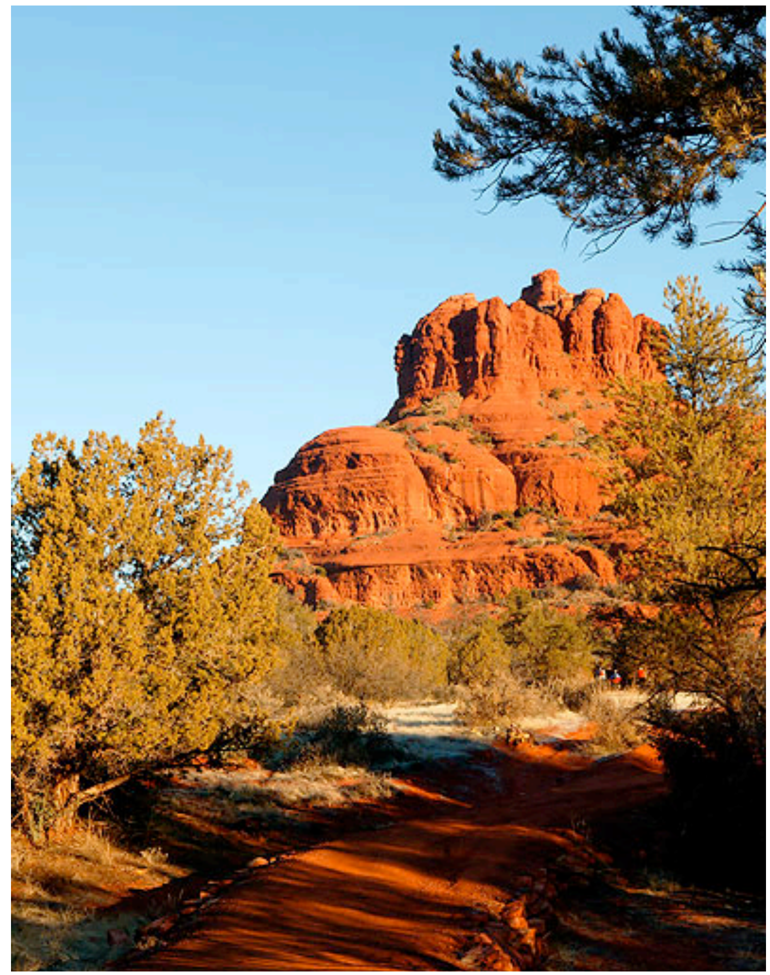
(3.) Pragmatic Color Salience and Inhomogeneous Color Utility

Heterogeneous Color Salience

Review a list of factors that are likely to influence human categorization, which can be addressed using simulation methods.

(1.) How does environmental color variation, or differences in color utility, impact color categorization?



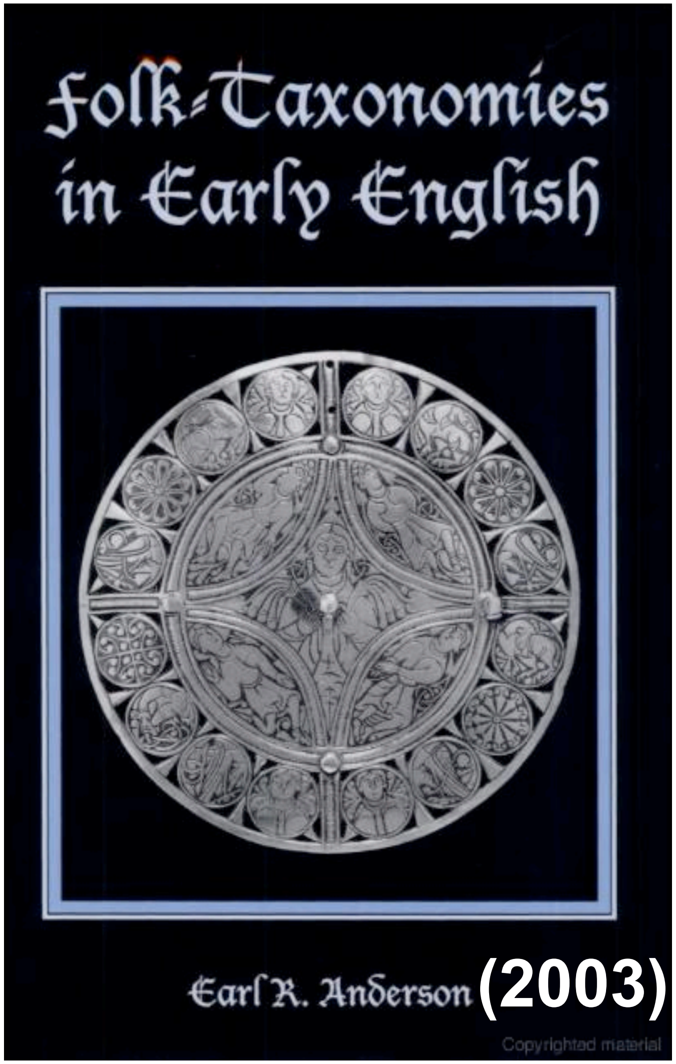


(2) A universal need to communicate about color when it serves a purpose

- Identifying nonpoisonous food items.

http://www.mykoweb.com/

A universal need to communicate about color when it has social utility

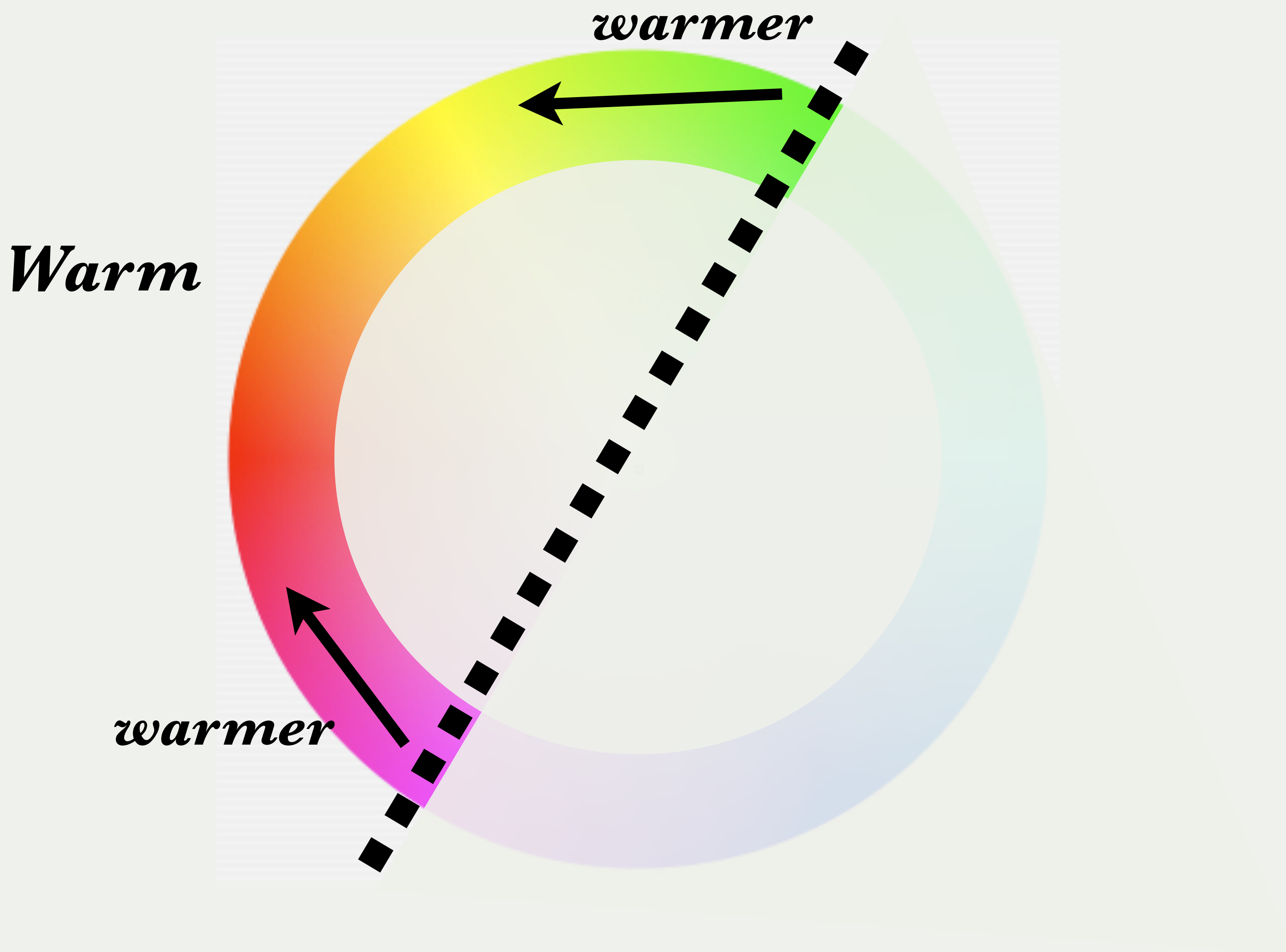


- Adopting categorical distinctions for utilitaritan reasons.
  - Celts used woad in the 6th century.
  - Blue gets gentrified when introduced as Medieval European Christianity.
  - Subsequent lexicalization of blue in early English.

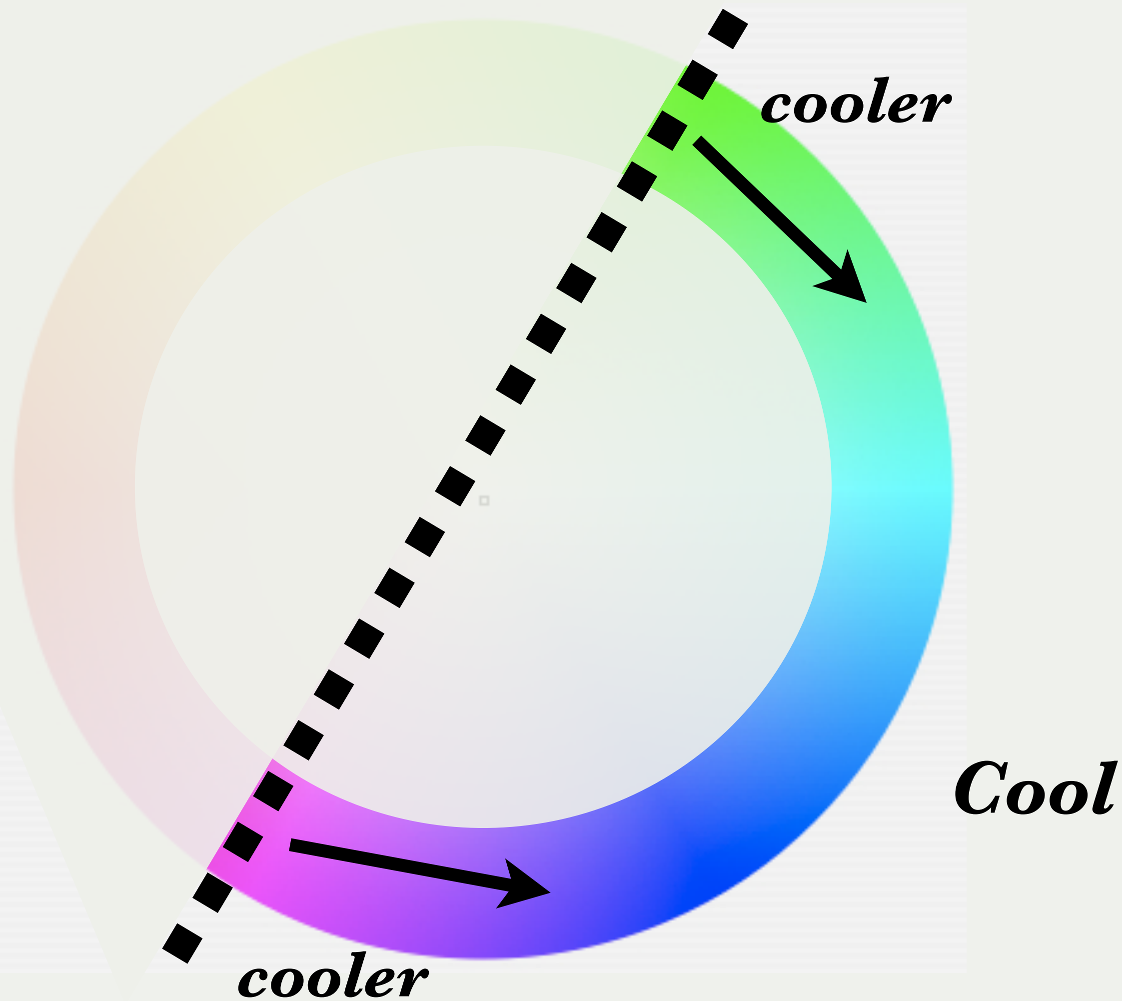
(3.) Different dimensional emphases in color naming across cultures.

Many Cultures make a Warm versus Cool color distinction:

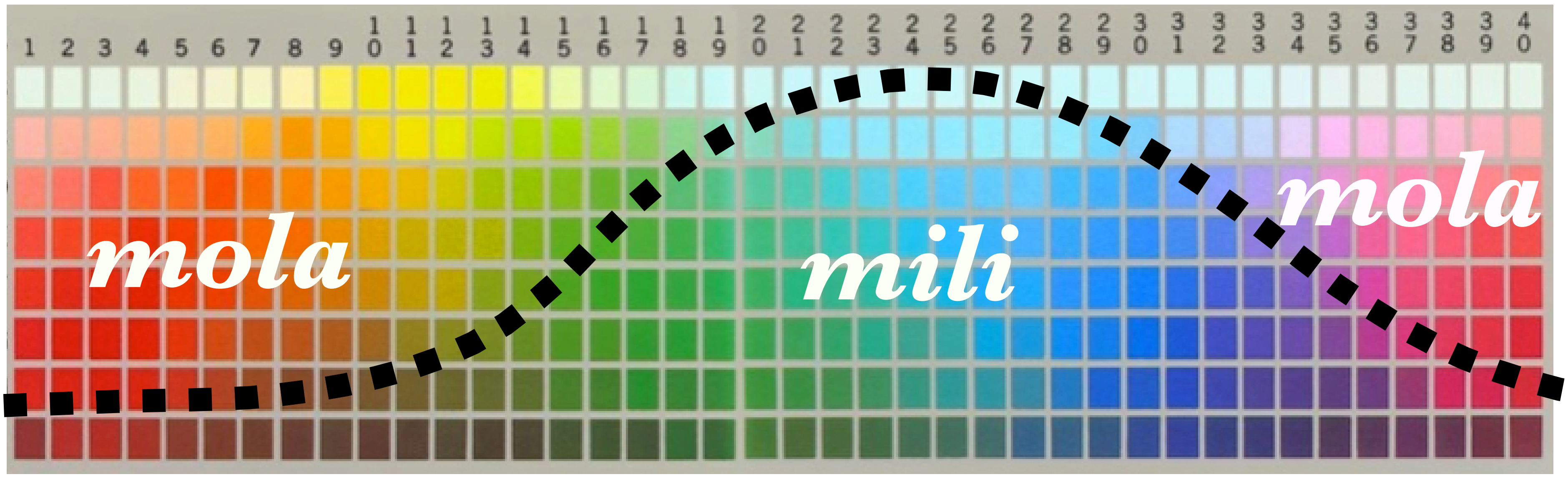
Many Cultures make a Warm versus Cool color distinction:



Many Cultures make a Warm versus Cool color distinction:



Dugum Dani (Papua, New Guinea) Color Categories:



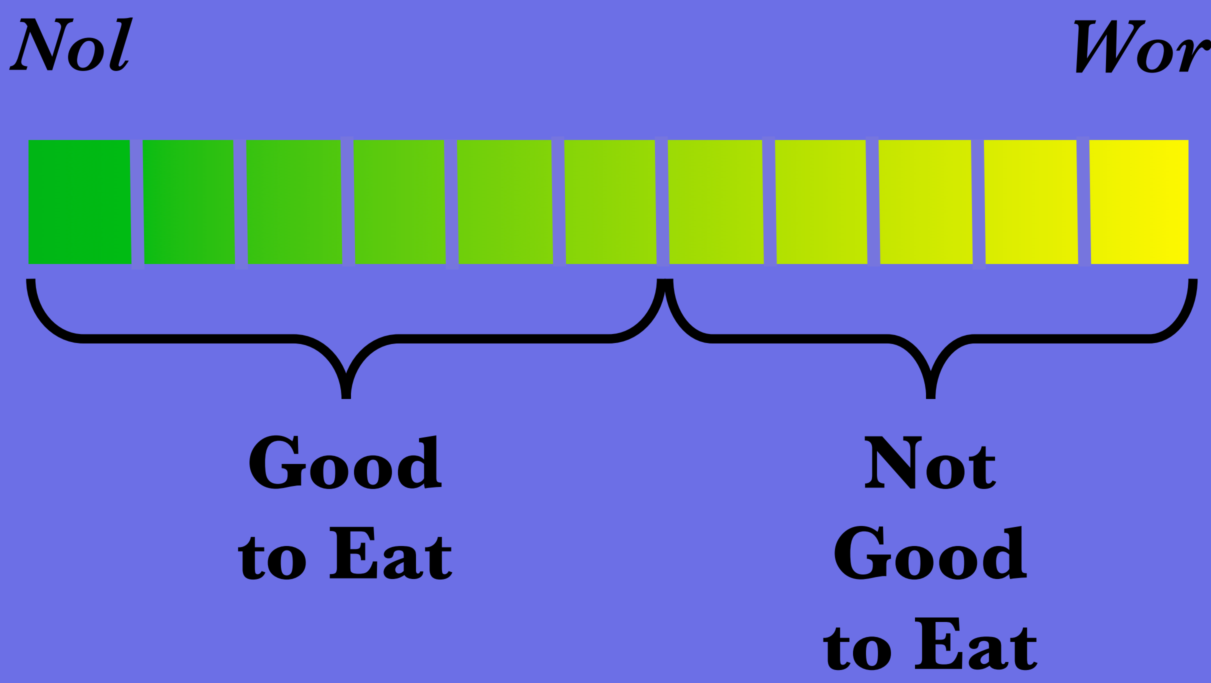
mola ~ warm colors
mili ~ cool colors

Kay, P. (1975). *Language in Society, 4*.

- Other Culturally-specific dimensions exist.
- e.g., Conklin's (1955) Hanunóo:

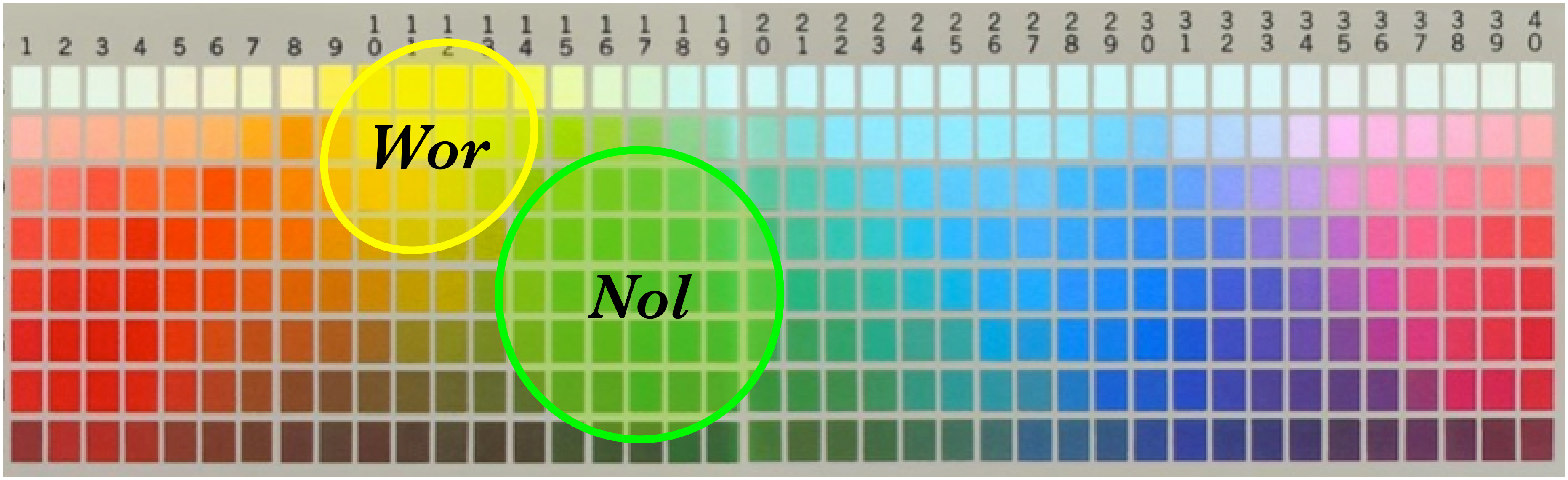
Light - Dark
Dessication - Freshness
Deep appearances - Pale appearances

Berimno's *Nol* and *Wor*
Pragmatically defined stimulus continuum:



Roberson, D. (2005). *Cross-Cultural Research*.

World Color Survey stimulus:



These may resemble "yellow" & "green" category glosses in the WCS model, but they arise for practical reasons rather than from perceptual processing constraints.

Roberson, D. (2005). *Cross-Cultural Research*:

- *Nol* and *Wor* are a pragmatic partition:

- " ... for Berinmo speakers, ... tulip leaves, a favorite vegetable, are bright green when freshly picked and good to eat, but quickly yellow if kept. Agreement over the color term boundary coincides with agreement over when they are no longer good to eat and is highly salient in a community that talks little about color."

Roberson, D. (2005). *Cross-Cultural Research*:

- *Nol* and *Wor* are a pragmatic partition:

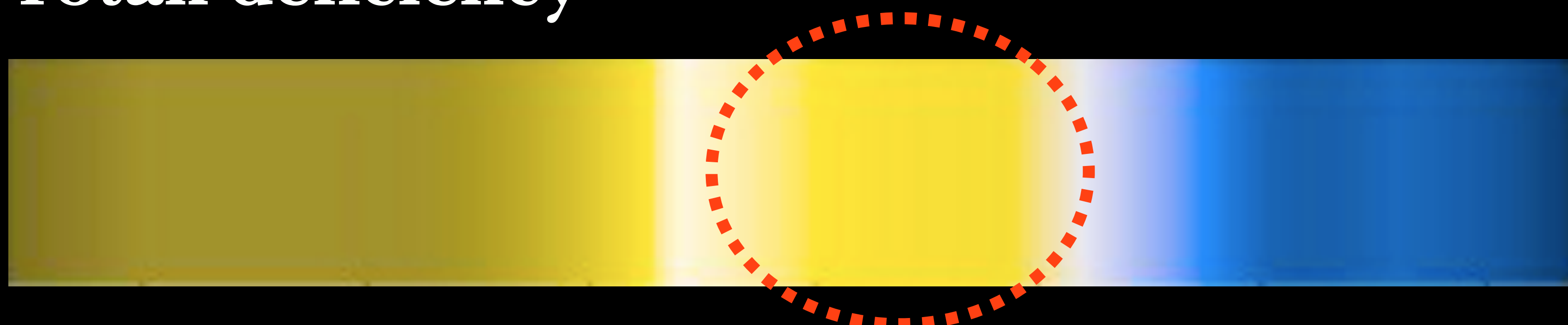
Trichromat

Protanope

Trichromats can easily use Nol & Wor, while some dichromats may not.

Normal Human Spectral Sensivity

Protan deficiency



(4.) Simulated Category Solutions compared with Empirical Category Solutions

Regier, Kay, & Khetarpal (2007). Color naming reflects optimal partitions of color space. *PNAS, 104(4)*.

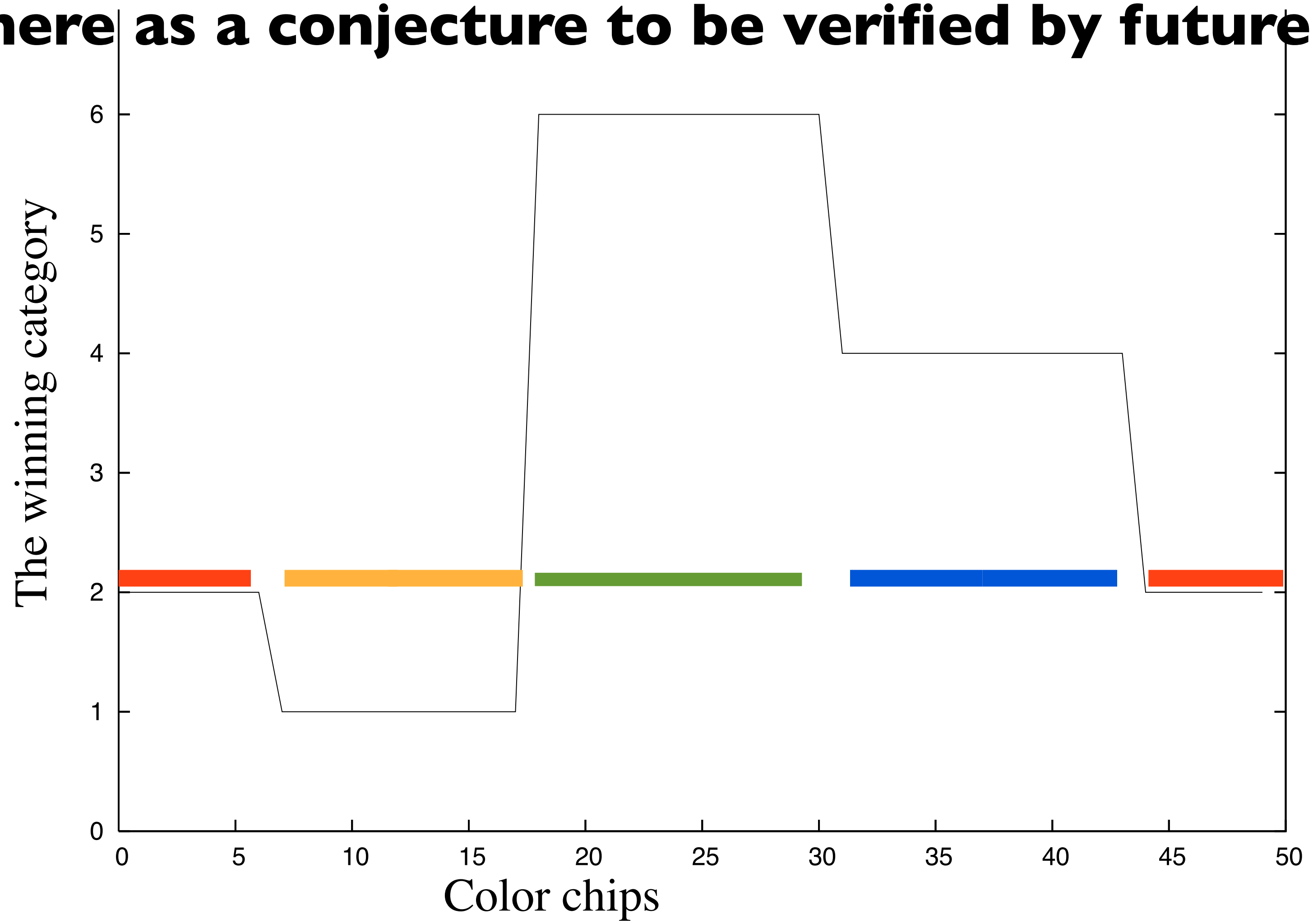
Regier, Kay & Khetarpal (2007)

- Compared to Regier et al (2007), we do not assume any perceptual model (*i.e., CIEL*a*b**). Komarova & Jameson (in-press). *Journal of Theoretical Biology.*

http://aris.ss.uci.edu/~kjameson/KomarovaJamesonJTBresubmit.pdf

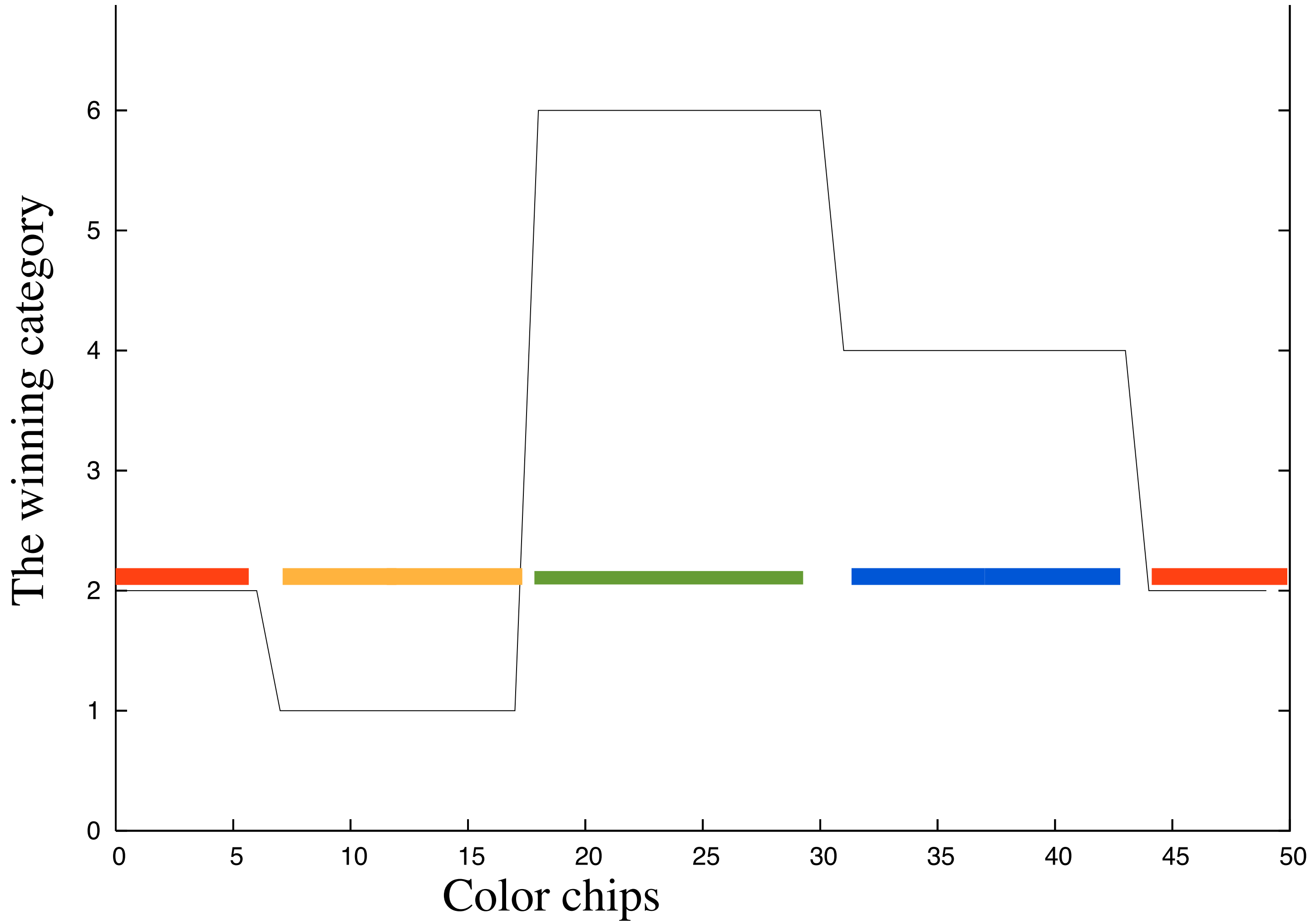
- So, what kind of categorization solutions are possible in the absence of such a observer model?

Note: The comparisons of Regier et al. (2007) and Komarova & Jameson (in-press) results are presented here as a conjecture to be verified by future research.



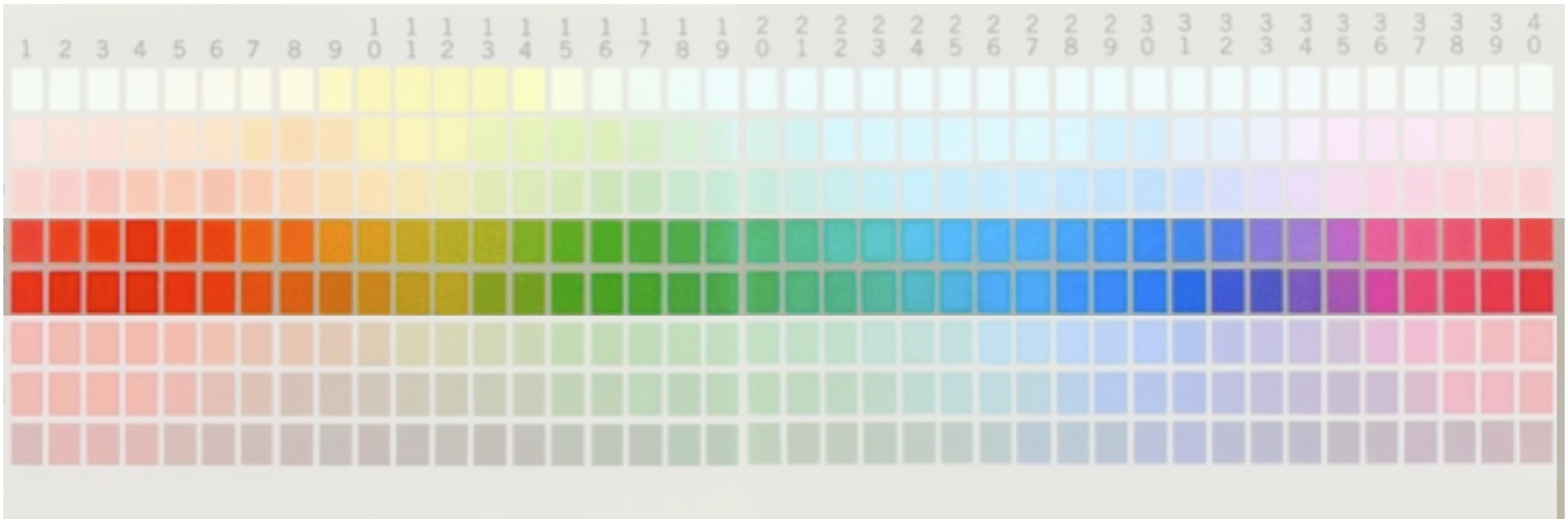
Heterogeneous population; 4-category solution. Parameters are m = 6, L = 12, Ksim = 6, N = 10, Nd = 1, (line model), n = 50, the number of rounds is 10^7.

... yet, the color line segments here show denotative ranges of our category solution.

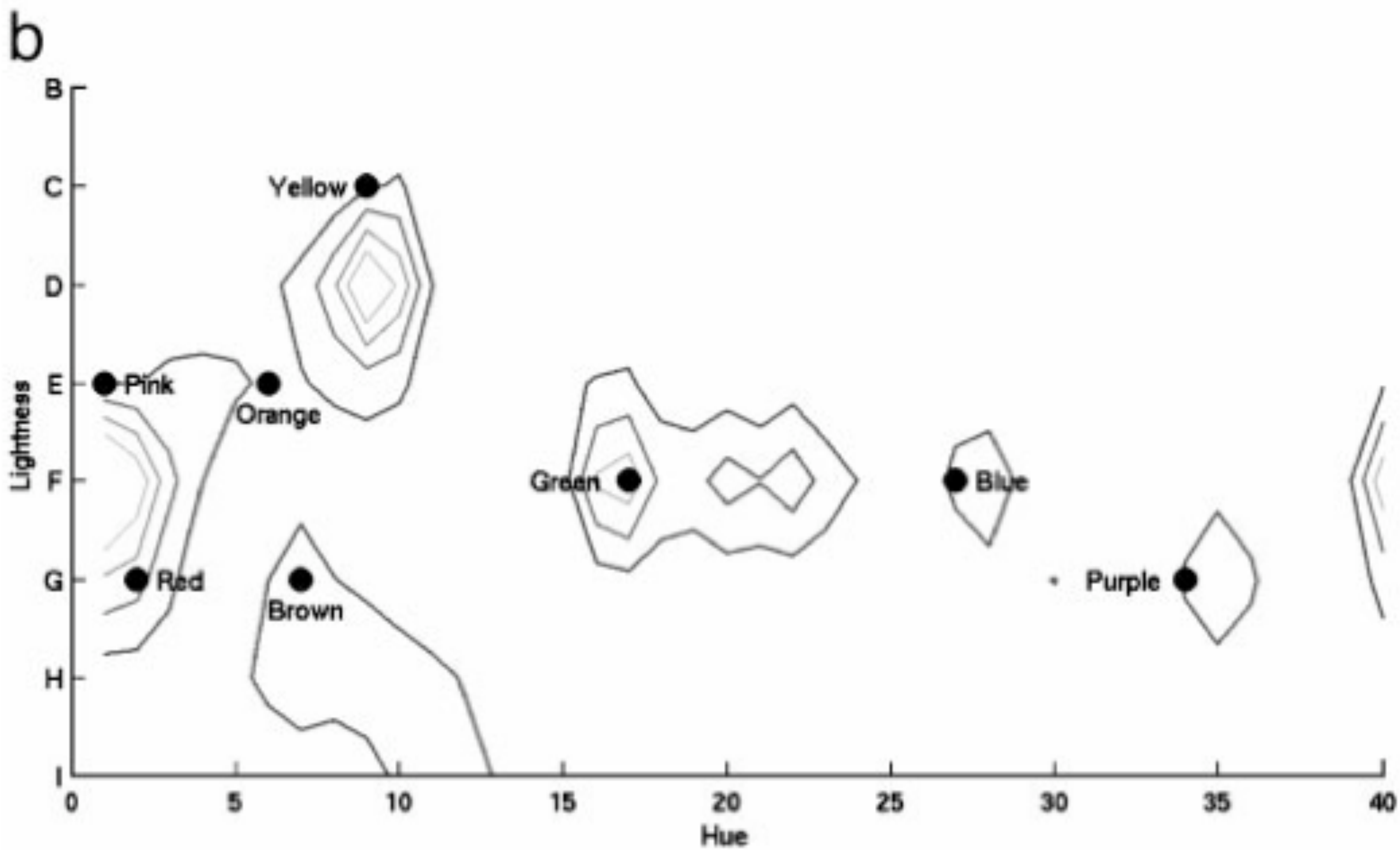


Heterogeneous population; 4-category solution. Parameters are m = 6, L = 12, Ksim = 6, N = 10, Nd = 1, (line model), n = 50, the number of rounds is 10^7.

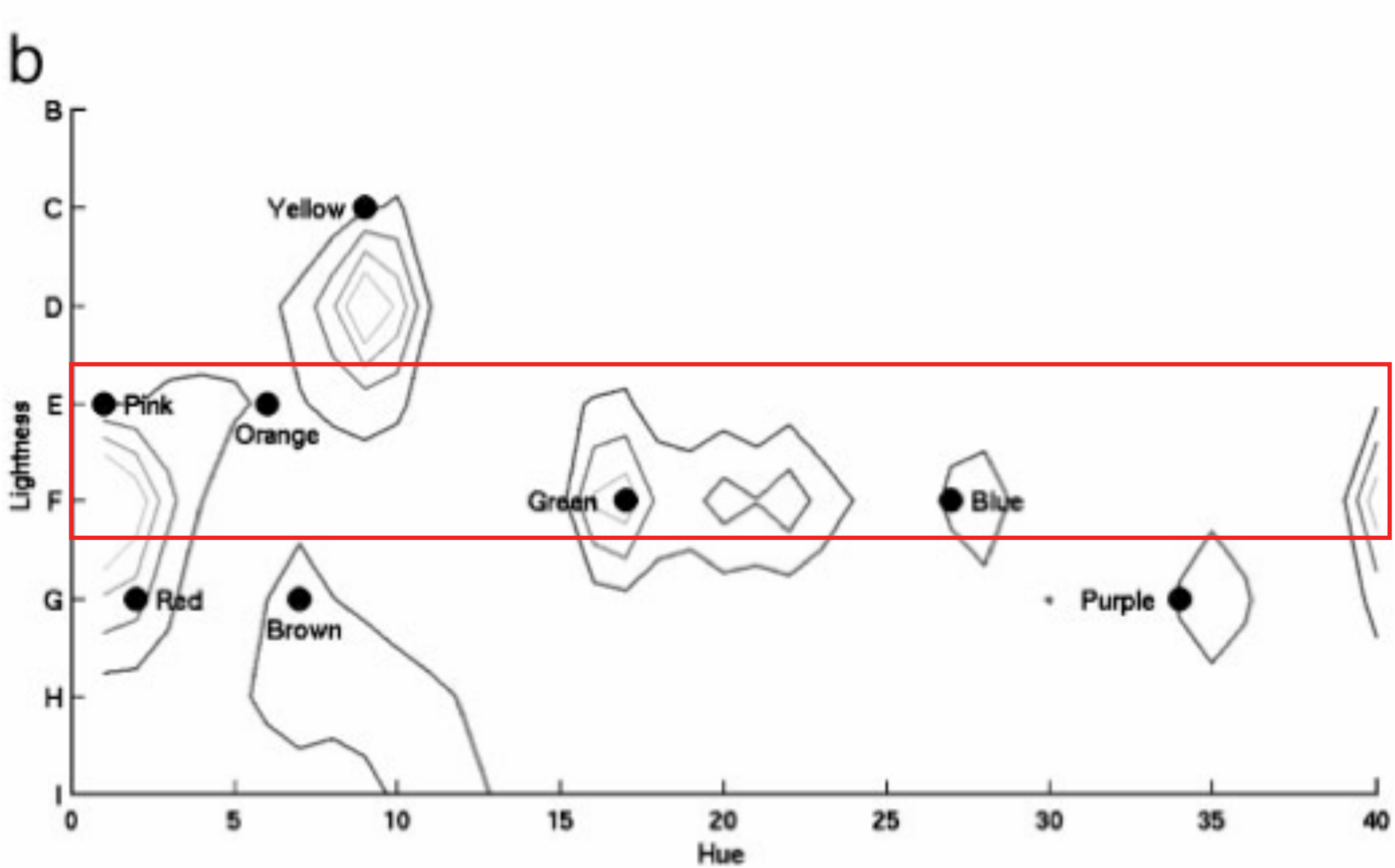
The World Color Survey stimulus:



World Color Survey categories (Kay & Regier 2003, *PNAS*):

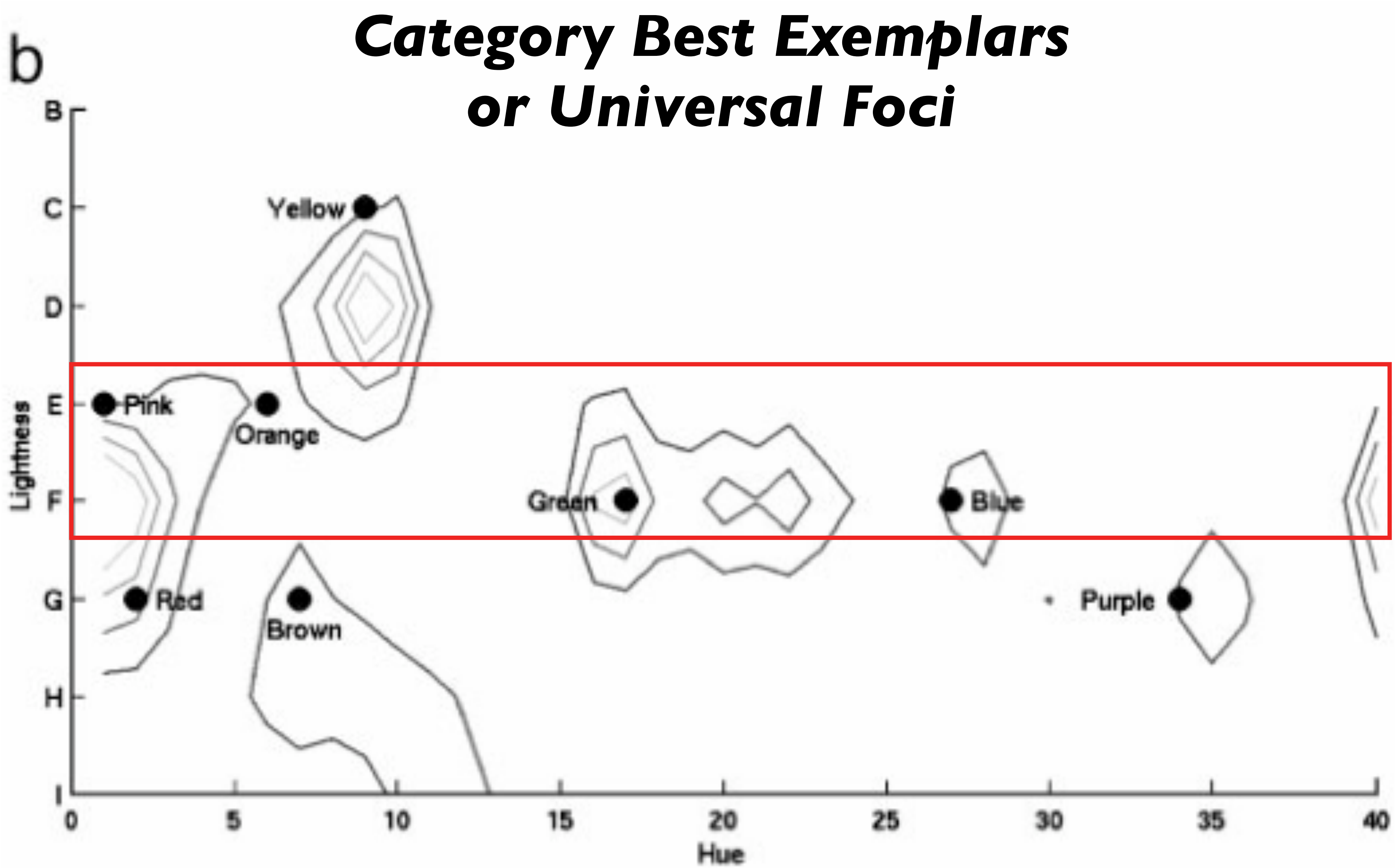


World Color Survey categories (Kay & Regier 2003, *PNAS*):

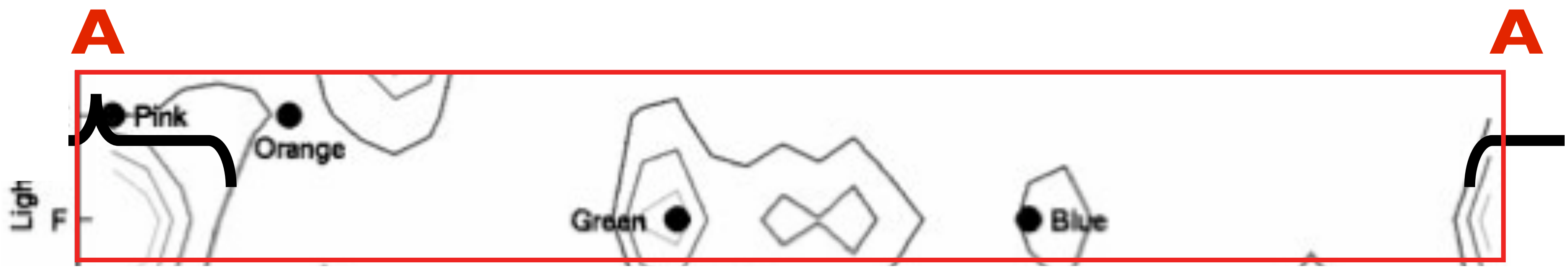


World Color Survey categories (Kay & Regier 2003, *PNAS*):

Category Best Exemplars or Universal Foci



Category Best Exemplars
or Universal Foci (Kay & Regier 2003, *PNAS*):



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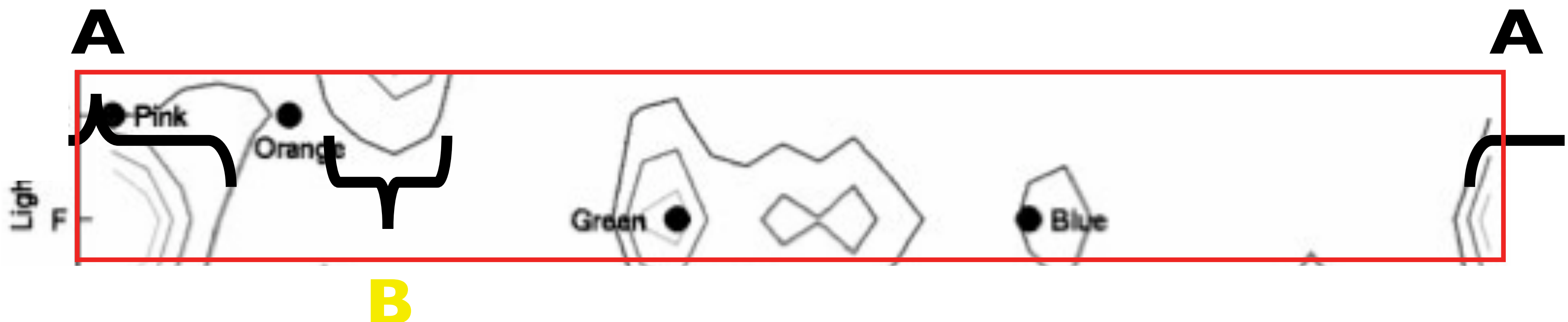

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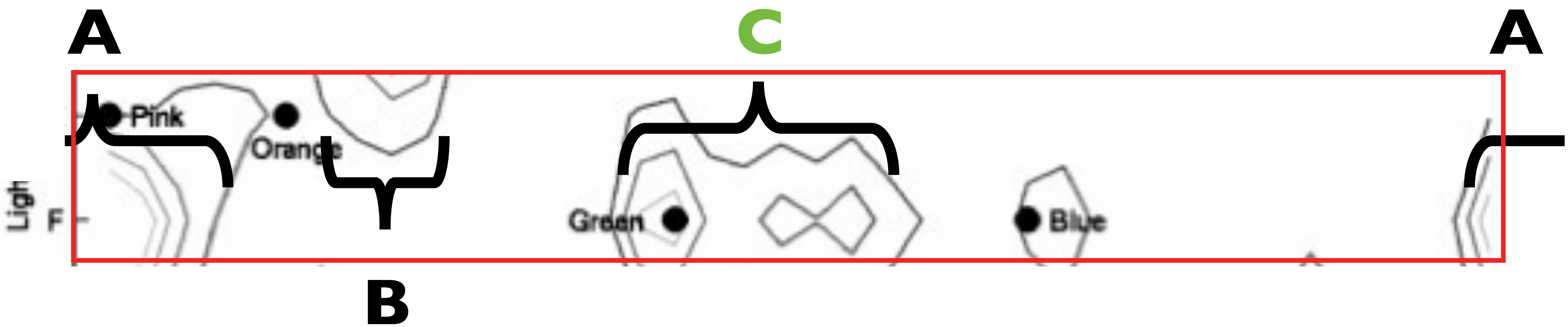

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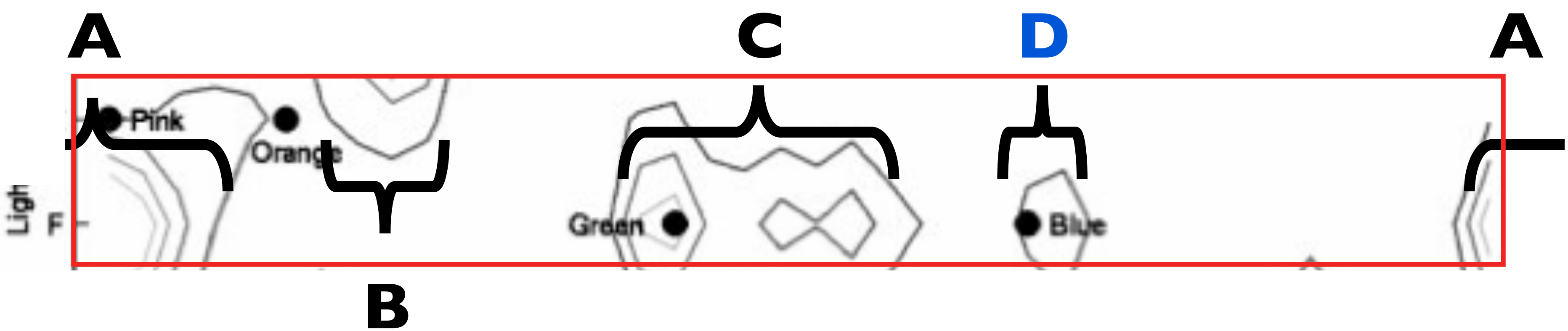

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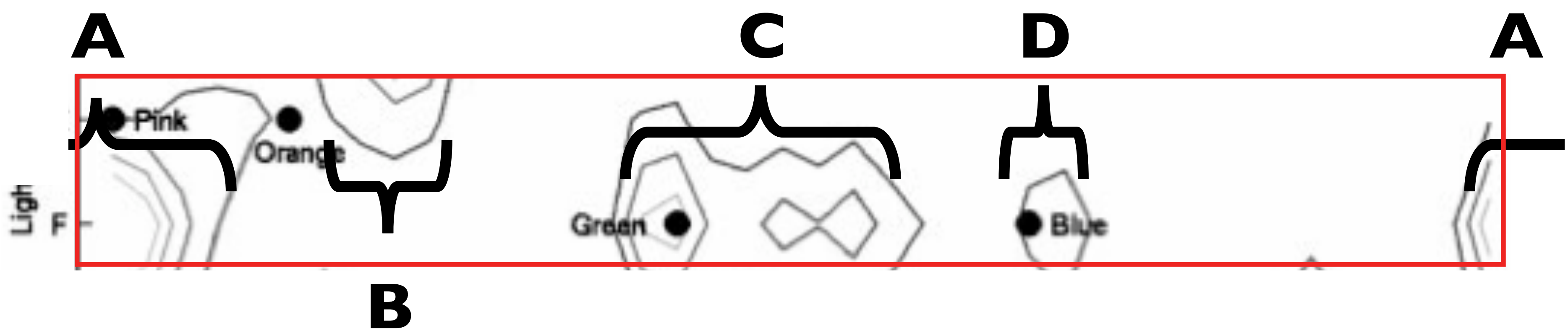
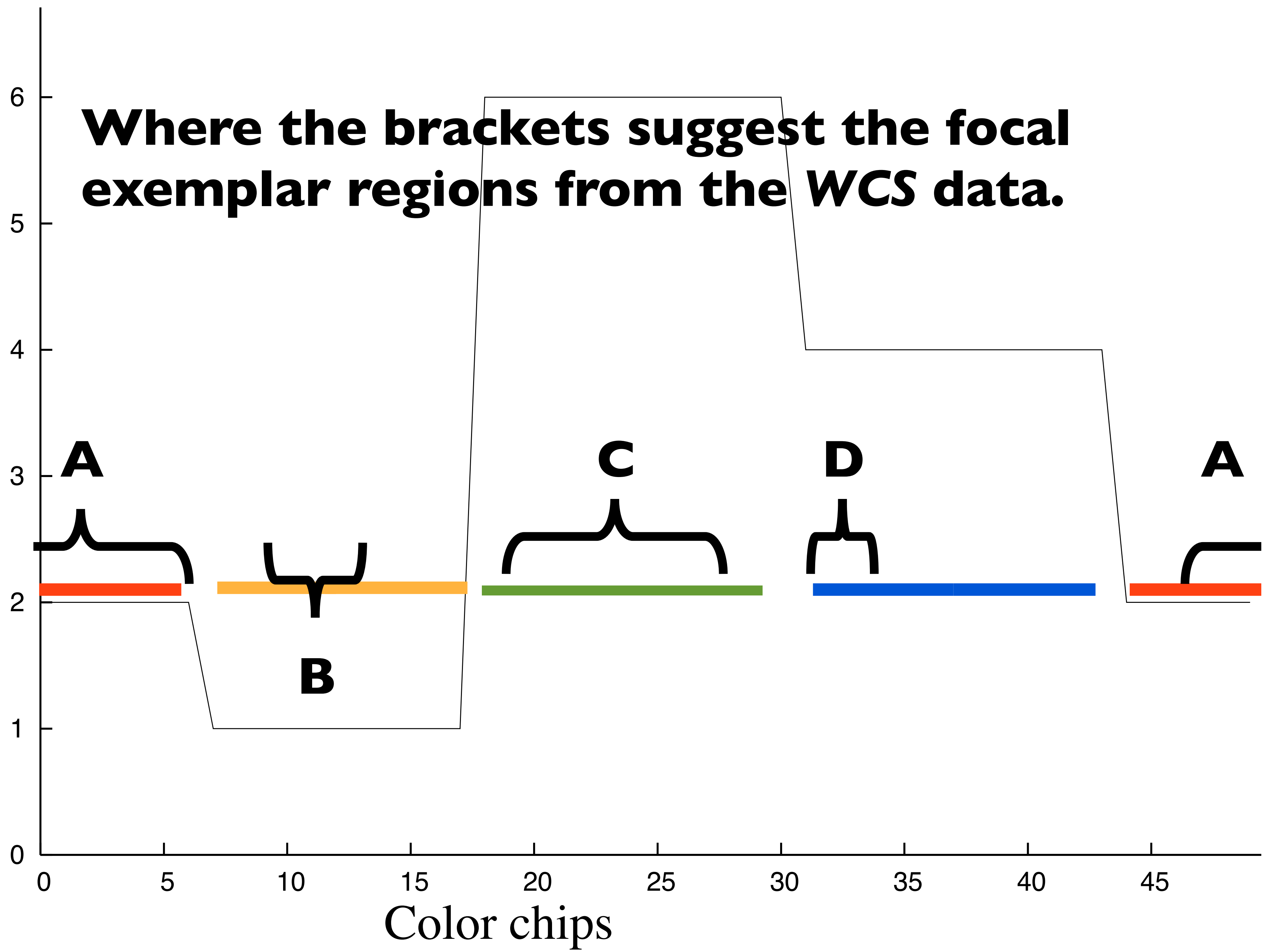
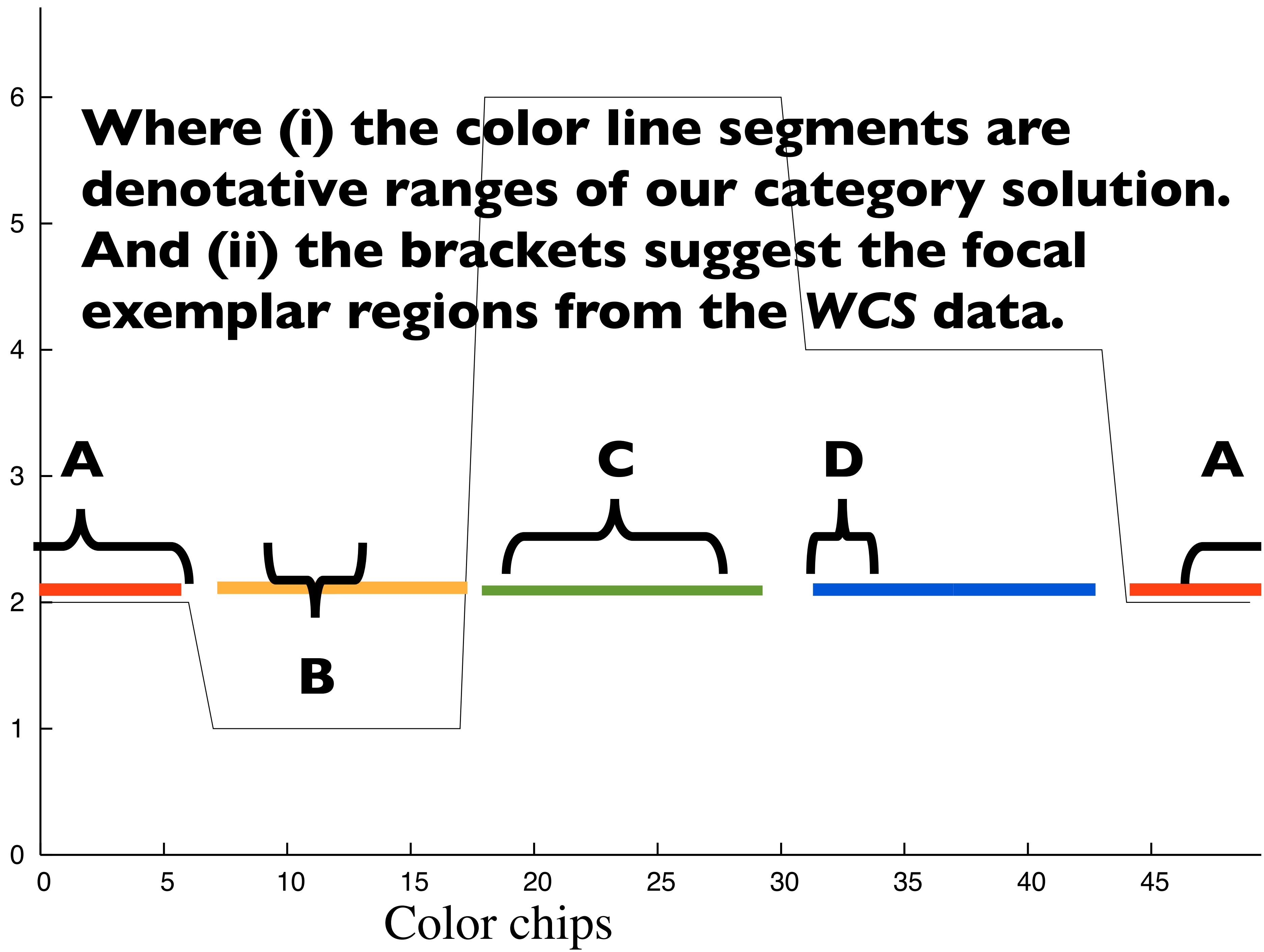
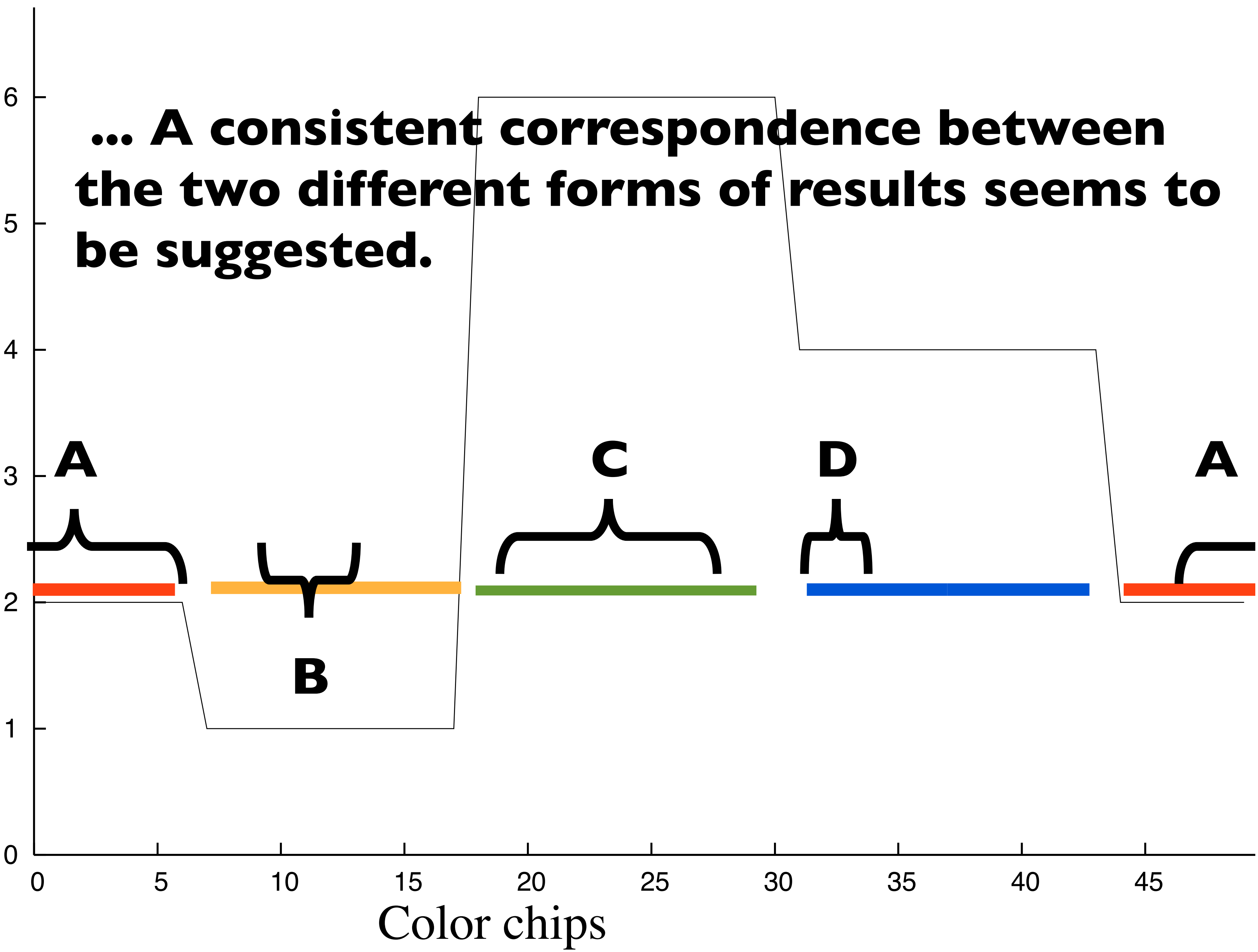




Where the brackets suggest the focal exemplar regions from the *WCS* data.
A
B
C
D
A
0
1
2
3
4
5
6
0
5
10
15
20
25
30
35
40
45
Color chips



Where (i) the color line segments are denotative ranges of our category solution. And (ii) the brackets suggest the focal exemplar regions from the *WCS* data.
A
B
C
D
A
0
1
2
3
4
5
6
0
5
10
15
20
25
30
35
40
45
Color chips


... A consistent correspondence between the two different forms of results seems to be suggested.
A
B
C
D
A
0
1
2
3
4
5
6
0
5
10
15
20
25
30
35
40
45
Color chips

Concluding

Results shown today:

- Color categorization solutions are obtained assuming very little about the phenomenon at levels of observer features, environmental stimulus, and socio-pragmatic influences on color signaling systems.
- Individual agent and Population solutions obtained resemble realistic solutions.
- Agent color perception heterogeneity and color environmment heterogeneity both influence population solutions obtained, and systematically interact when implemented simultaneously.

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- Individual agent and Population solutions obtained resemble realistic solutions.
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What's ahead:

• Diachronic studies of color category evolutionary dynamics are possible with these techniques.
• Extensions using realistic models of population interaction and discrimination is on-going.
• Extension to the full dimensions of color appearance space is in progress.
• Simulations based on the empirical literature are in progress for comparison with relevant empirical results.

Thankyou for listening!

http://aris.ss.uci.edu/~kjameson/kjameson.html