Humans Can Discriminate More than 1 Trillion Olfactory Stimuli

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March 27, 2014

BBC news coverage

- We thought nose can detect about 10,000 different odours.
- But no! It can do a trillion!
  (probably an underestimate, they say)
- Human nose outperforms the eye and the ear in terms of the number of stimuli it can distinguish between.

How to estimate the number of discriminable stimuli?

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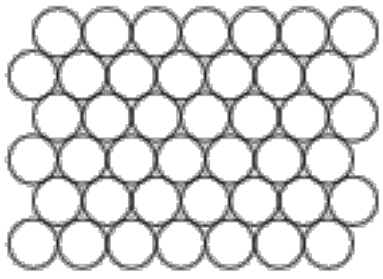
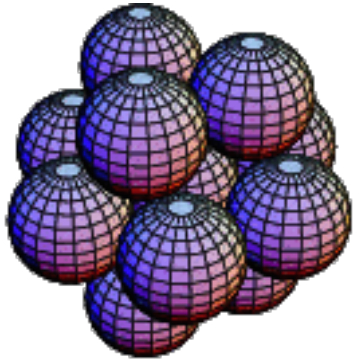
Sphere packing





Outline

A tale of ten thousand odours

"Humans are able to discriminate about 10^4 odours."

A tale of ten thousand odours

Crocker-Henderson smell classification (1927):

4 odour qualities	$\times$	9-point scale	$= 6561$
fragrant		0–8	
acid			
burnt			
caprilic ("goatiness")			

A tale of ten thousand odours

$$6561 \sim 10{,}000$$

Other classifications

Hans Henning "smell prism":

Flowery
Foul
Fruity
Spicy
Burnt
Resinous

r^6

$(2^6 = 64;\ 10^6)$

Zwaardemaker (1895)

Ethereal
Aromatic
Fragrant
Ambrosiac
Alliaceous
Empyreumatic
Hiccine
Foul
Nauseous

$r^9 \quad (512;\ 10^9)$

Other classifications

Non-negative matrix factorisation (Castor et al., 2013):

Fragrant
Woody/resinous
Fruity (non-citrus)
Chemical
Minty/peppermint
Sweet
Popcorn
Lemon
Pungent
Decayed

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$r^{10} \quad (1024; 10^{10})$

Outline

Bushdid and all approach

- Take 128 molecules
  (well spaced in perceptual and physicochemical space)
- Mix them (10, 20, 30)
- Give 3 vials at different dilutions.
  Find odd-one-out.

- Can't test all-against-all, so do math

Sphere packing

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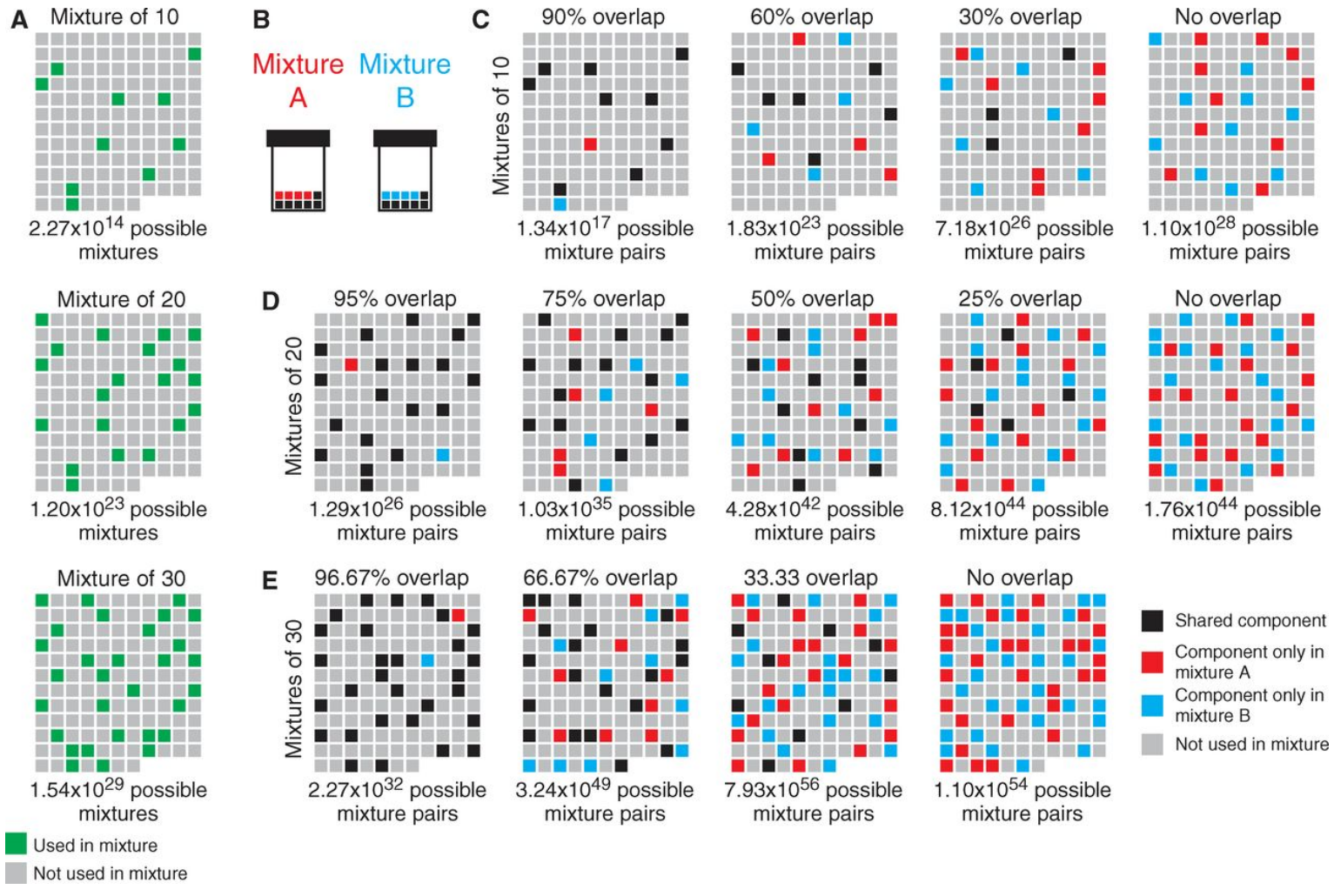
A
Mixture of 10
2.27x10^14 possible mixtures
Mixture of 20
1.20x10^23 possible mixtures
Mixture of 30
1.54x10^29 possible mixtures
Used in mixture
Not used in mixture
B
Mixture A
Mixture B
C
90% overlap
60% overlap
30% overlap
No overlap
Mixtures of 10
1.34x10^17 possible mixture pairs
1.83x10^23 possible mixture pairs
7.18x10^26 possible mixture pairs
1.10x10^28 possible mixture pairs
D
95% overlap
75% overlap
50% overlap
25% overlap
No overlap
Mixtures of 20
1.29x10^26 possible mixture pairs
1.03x10^35 possible mixture pairs
4.28x10^42 possible mixture pairs
8.12x10^44 possible mixture pairs
1.76x10^44 possible mixture pairs
E
96.67% overlap
66.67% overlap
33.33 overlap
No overlap
Mixtures of 30
2.27x10^32 possible mixture pairs
3.24x10^49 possible mixture pairs
7.93x10^56 possible mixture pairs
1.10x10^54 possible mixture pairs
Shared component
Component only in mixture A
Component only in mixture B
Not used in mixture

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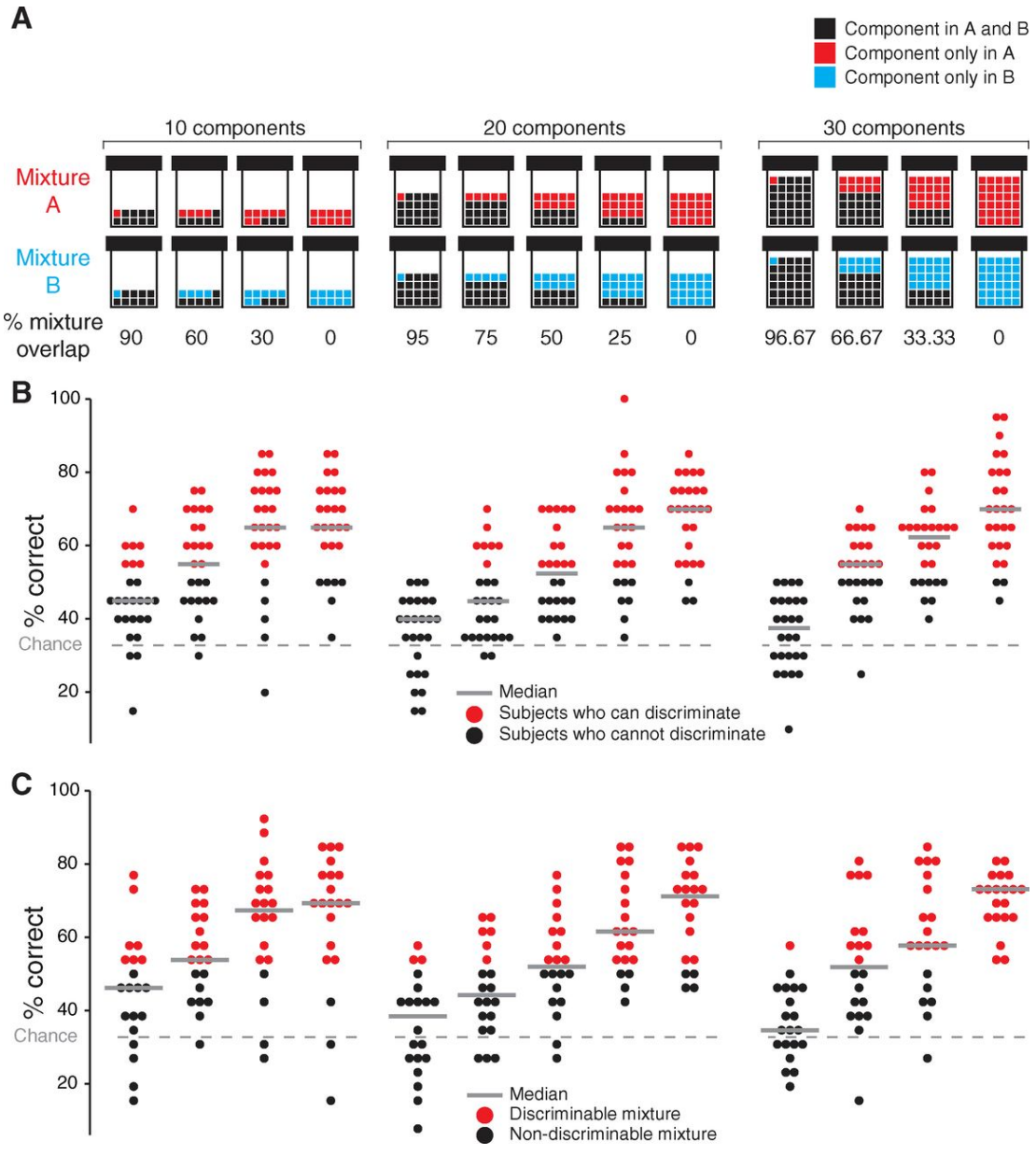
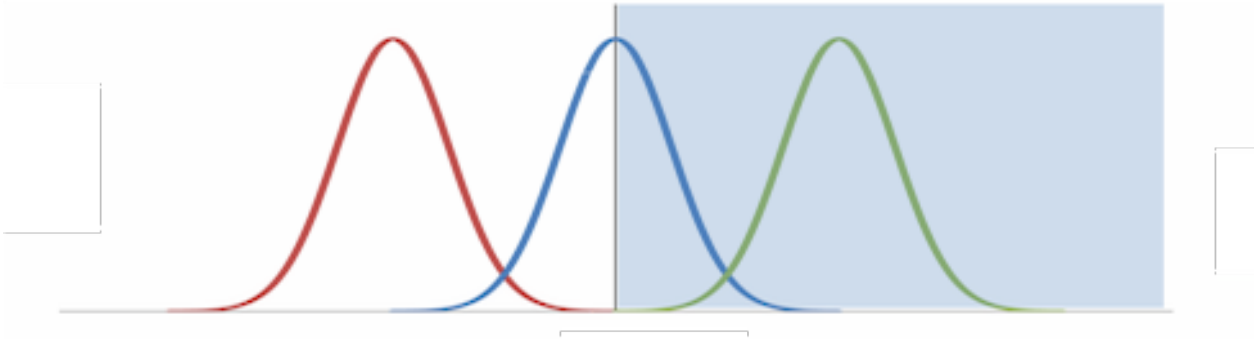
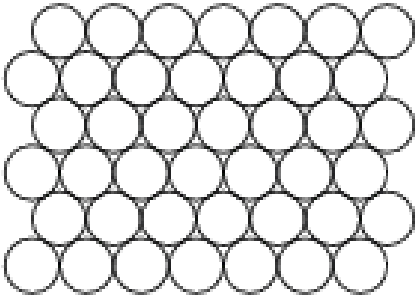
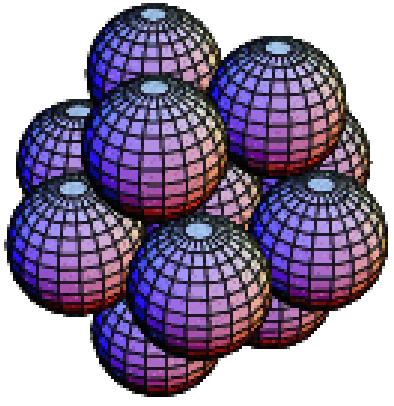

A
Component in A and B
Component only in A
Component only in B
10 components
20 components
30 components
Mixture A
Mixture B
% mixture overlap
90
60
30
0
95
75
50
25
0
96.67
66.67
33.33
0
B
% correct
100
80
60
40
20
Chance
Median
Subjects who can discriminate
Subjects who cannot discriminate
C
% correct
100
80
60
40
20
Chance
Median
Discriminable mixture
Non-discriminable mixture

Outline

Sphere packing







Sphere packing

Assumption:
all that matters is the overlap between the mixtures.

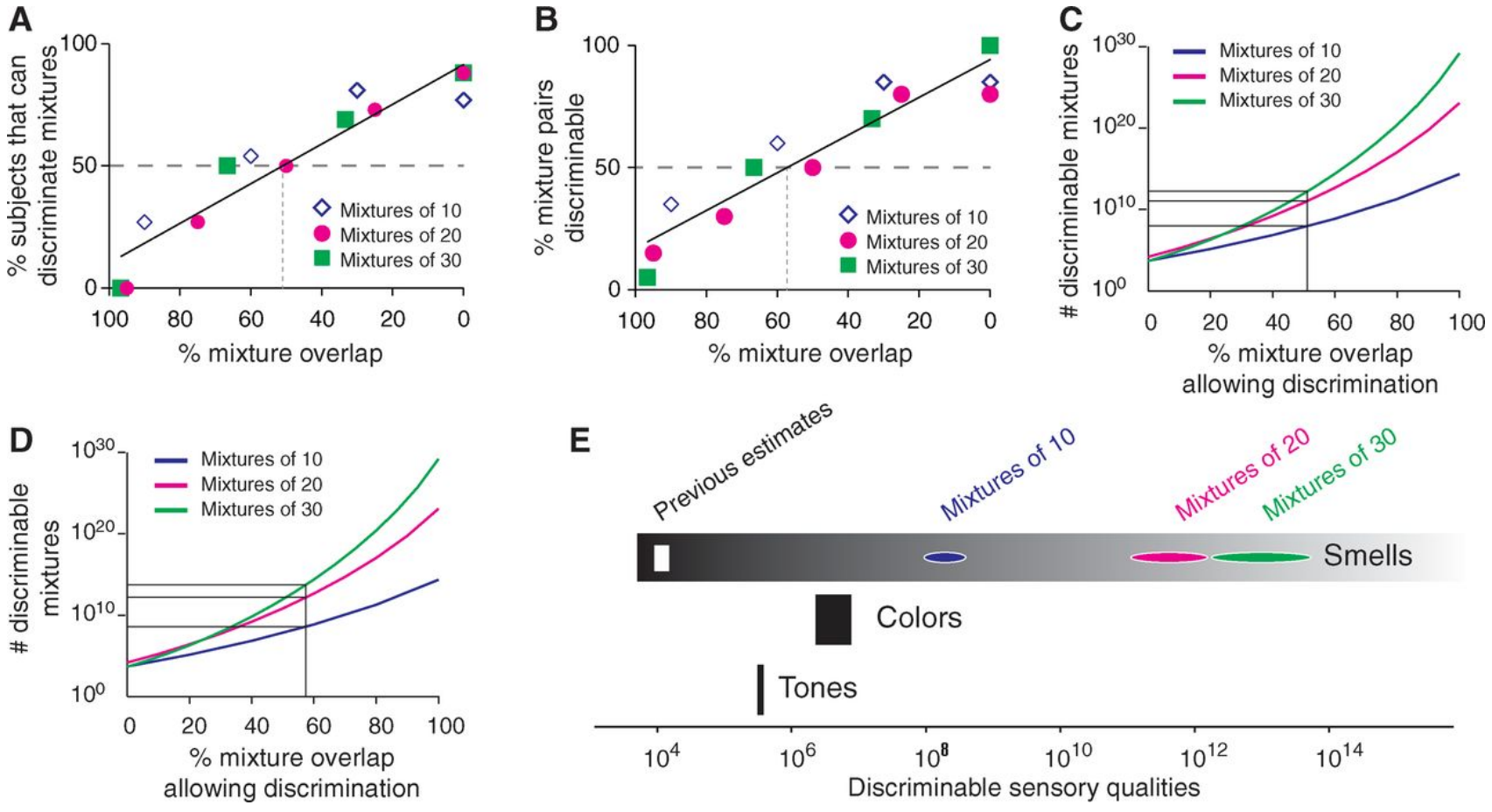
Resolution:
D — difference linen (highest number of components differing in the "same" percept)

Number of all mixtures: $V = \binom{128}{N}$

Number in a ball of radius R: $v = \sum_{n=0}^{R} \binom{N}{n} \binom{128 - N}{n}$

$R = D/2$

Number of stimuli : V/v


A
% subjects that can discriminate mixtures
100
50
0
100 80 60 40 20 0
% mixture overlap
Mixtures of 10
Mixtures of 20
Mixtures of 30
B
% mixture pairs discriminable
100
50
0
100 80 60 40 20 0
% mixture overlap
Mixtures of 10
Mixtures of 20
Mixtures of 30
C
discriminable mixtures
10^{30}
10^{20}
10^{10}
10^{0}
0 20 40 60 80 100
% mixture overlap
allowing discrimination
Mixtures of 10
Mixtures of 20
Mixtures of 30
D
discriminable mixtures
10^{30}
10^{20}
10^{10}
10^{0}
0 20 40 60 80 100
% mixture overlap
allowing discrimination
Mixtures of 10
Mixtures of 20
Mixtures of 30
E
Previous estimates
Mixtures of 10
Mixtures of 20
Mixtures of 30
Smells
Colors
Tones
10^{4} 10^{6} 10^{8} 10^{10} 10^{12} 10^{14}
Discriminable sensory qualities

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But...

$$V_n(R) = \frac{\pi^{n/2}}{\Gamma(\frac{n}{2}+1)} R^n$$

$$V_{2k}(R) = \frac{\pi^k}{k!} R^{2k}$$

so it's taking little space in a cube R^{2k}...

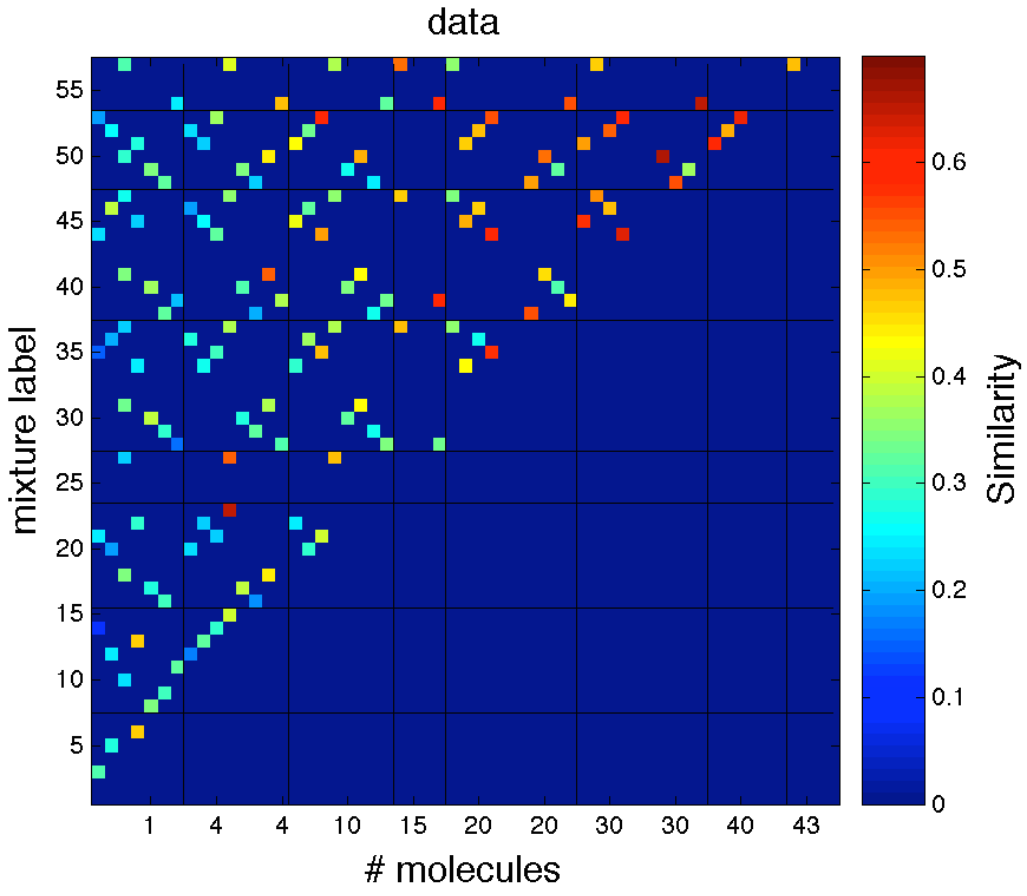
Take-home message

- We have a new urban legend: 10,000 replaced by

  1000,000,000,000

  - Forgot to mention (in the main text), it's an "upper bound"...
  - And if we take more molecules, we get even more!
- Comparison with other senses truly unfair...
- Some math to be done again.

Better estimate of similarity?



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Estimates of dimensionality

Input:

- perceptual features (Dravniek's atlas, 146 verbal descriptors)
- physicochemical features (now up to 1600)

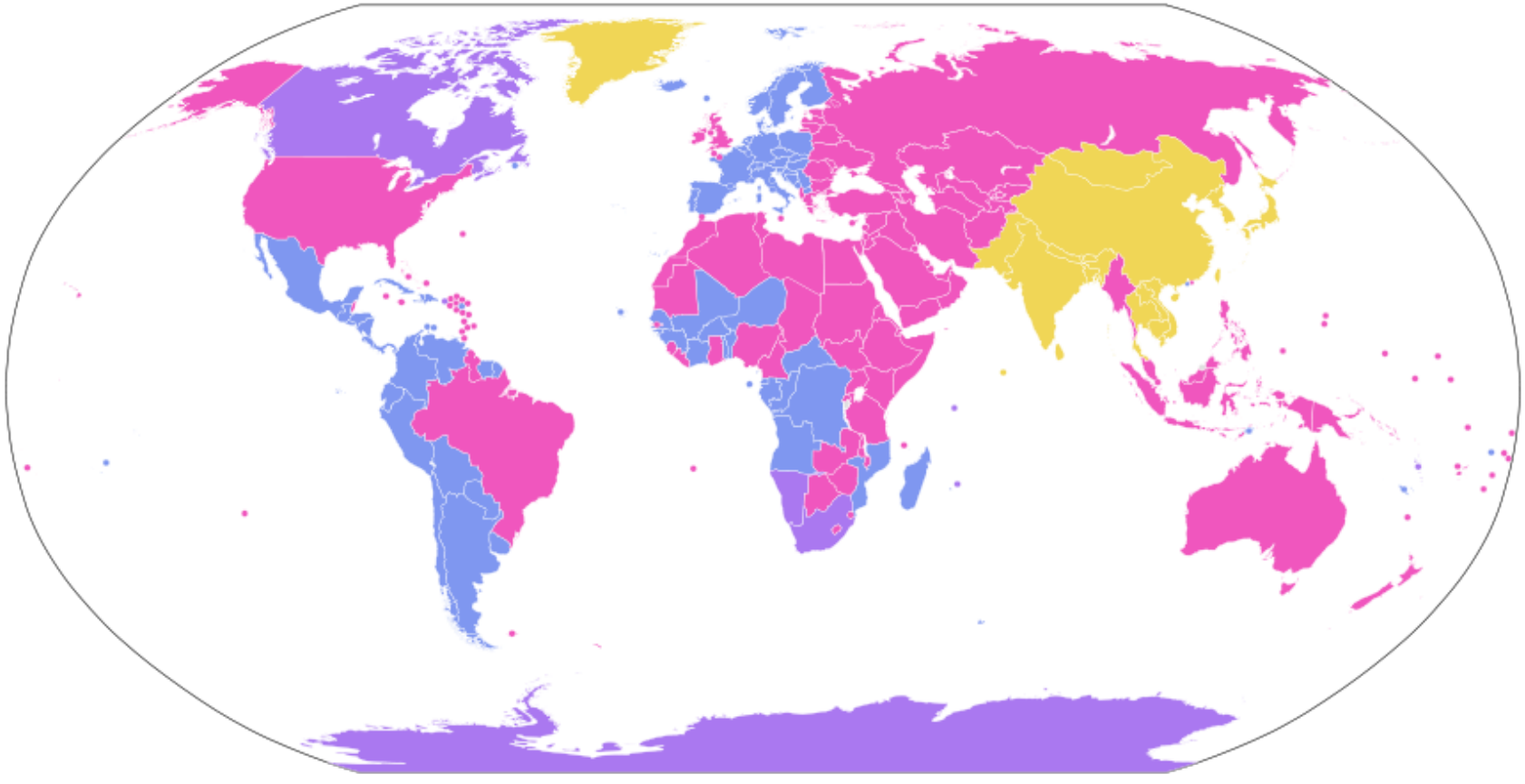
Method:

- Statistical dimensionality reduction

[Koulakov AA, Enikolopov AG, Rinberg D (2009) The structure of human olfactory space. arXiv.

Madany Mamlouk A, Chee-Ruiter C, Hofmann UG, Bower JM (2003) Quantifying olfactory perception: mapping olfactory perception space by using multidimensional scaling and self-organizing maps. Neurocomputing.]
Non-negative matrix factorisation (Castor et al., 2013)

Thank you!



Trillion $= 10^{12}$

Trillion $= 10^{18}$

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