Clusters, Symbols and Cortical Topography

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agenda…

①	**motivation**	symbols with similarity
②	**model**	self-organizing maps (SOMs)
③	**demo task**	object categorization
④	**wrap-up**	discussion

issue 1: sensory transduction

- the environment and the human sensory systems that capture it, are analog…
- Soar operates on discrete symbols

Q: what might be learned from how the brain transduces information via senses?

issue 2: symbols with similarity

(b32 ^shape round ^color red)

- symbols “red” and “pink” have no inherent similarity
- “red and round” ⇨ “apple”
  “pink and round” ⇨ ???
- similarity not currently possible in Soar, but well-established in human cognition

Q: what might be learned from how similarity is achieved in the brain?

red apple

pink apple

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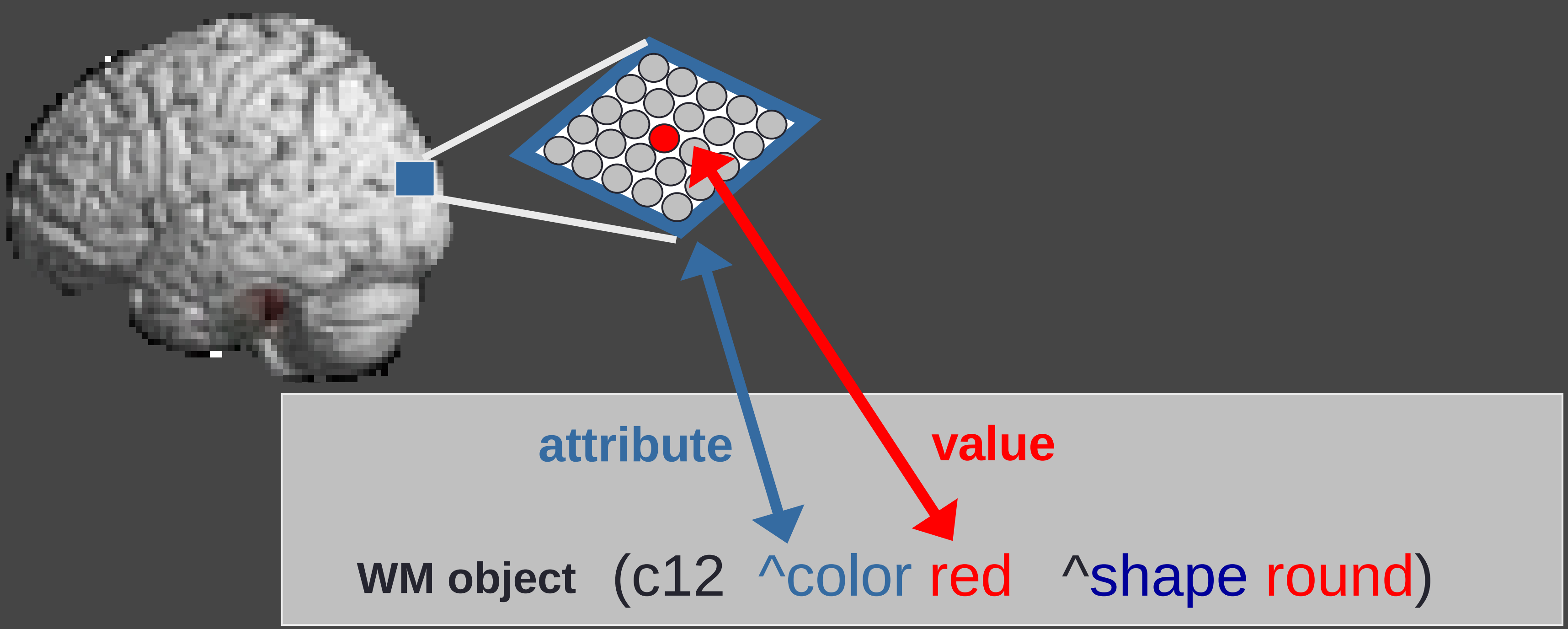
possible mapping between cortex and *Soar*

attributes

- cortical areas (*maps*) correspond to attributes

values

- most active representation in a cortical area (*winning cell)* corresponds to attribute-value



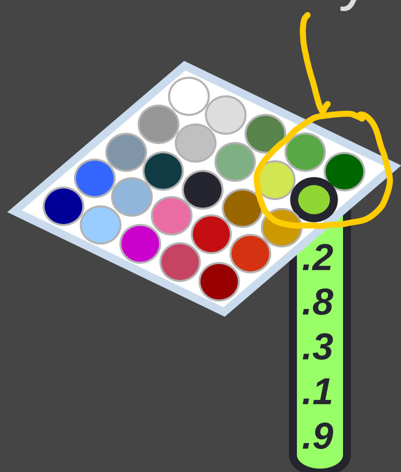
overview: self-organizing maps (SOM)

general features of SOMs

- based on properties of cortical representations
- competitive learning algorithm (unsupervised)
- cells in a map represented by “codebook vector”
- learning by moving a cell’s vector closer to an input

unique feature of SOMs

- similarity via 2D location in cortical area

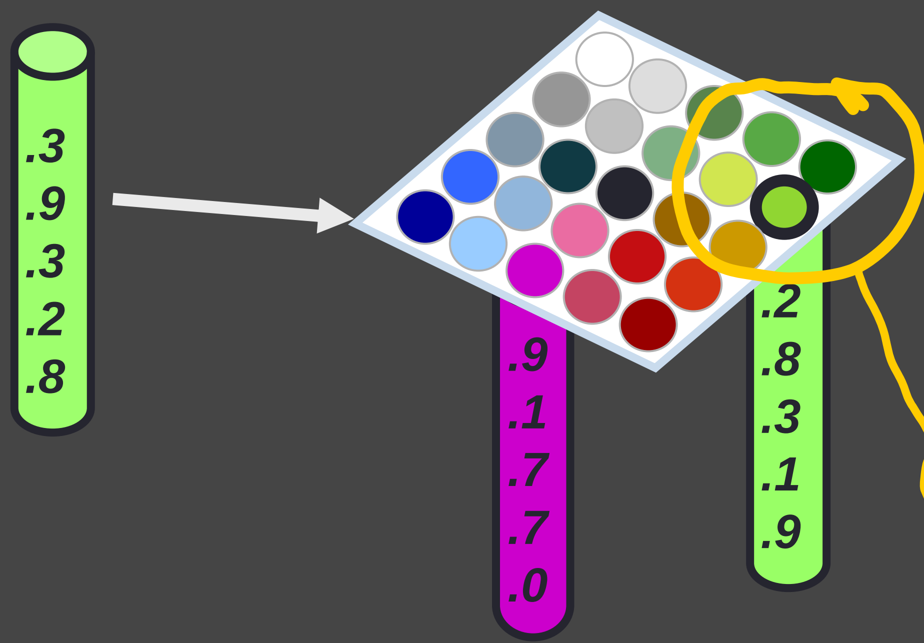


cortical map (SOM)

SOM learning algorithm (in a nutshell)

sensory stimulus

cortical map color attribute



winning cell
"yellow green"

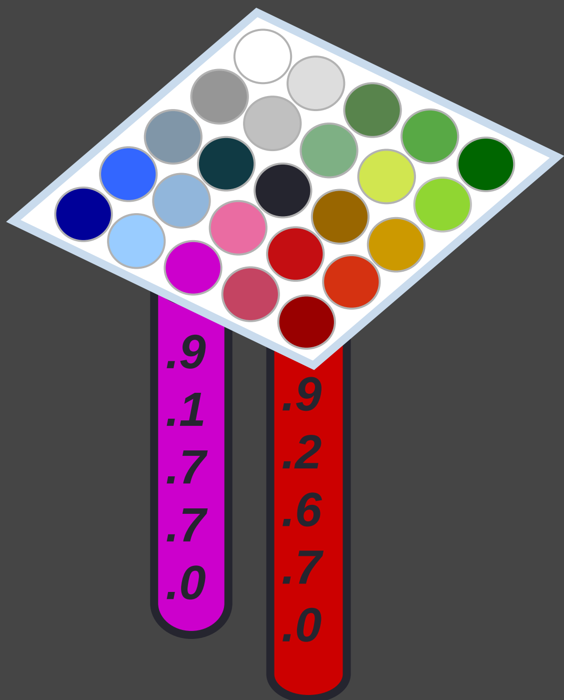
1. winning cell is value for the attribute
2. winner's codebook vector moved closer to input vector
3. neighbors' codebook vectors moved closer to input vector (by less)

→ with experience, regions of similarity develop.

→ nearby cells code for similar stimuli

SOMs can produce symbols with similarity

cortical map
color attribute



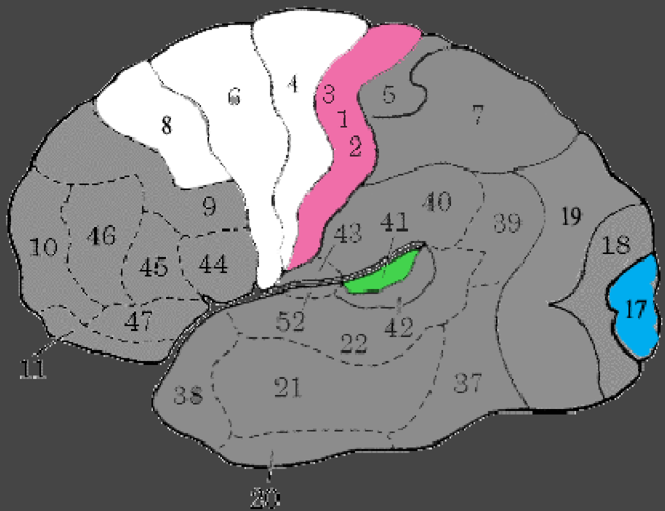
red apple

pink apple

- generate unique symbols for “red” and “pink”
- **and** “red” and “pink” are similar (spatially proximal)

once have symbols, how preserve similarity?

- **situation:** SOMs can do sensory transduction, i.e. converting continuous valued inputs to symbols, with similarity.
- **complication**: most cortical areas are **<u>not</u>** directly connected to sensory inputs, but to other cortical areas.



Direct Connections to Sensation

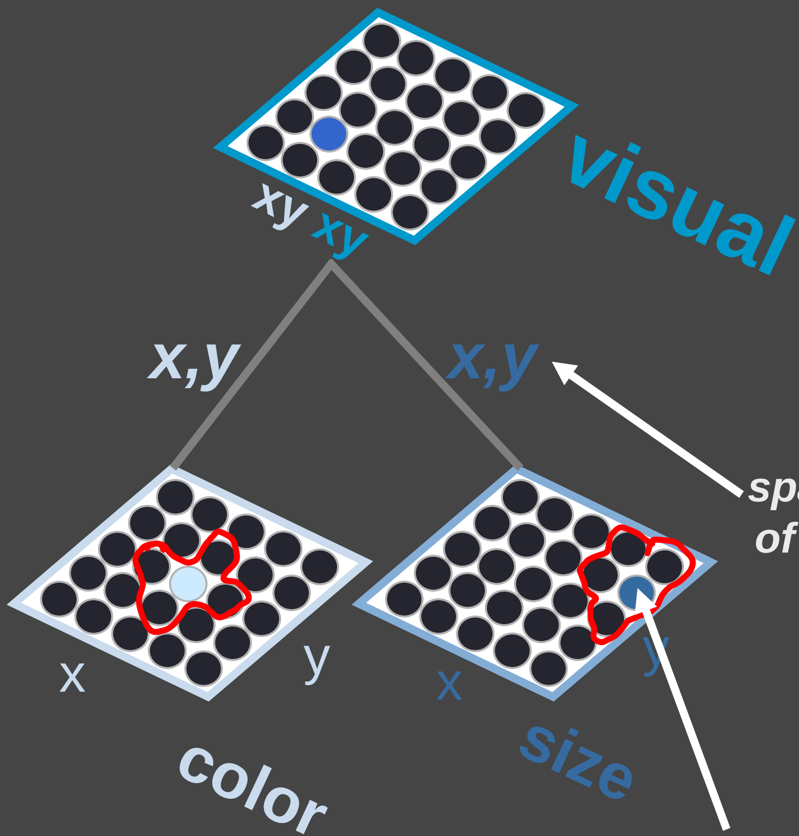
- Primary Visual
- Primary Auditory
- Primary Somatosensory

CorticoCortical Connections

- Uni-, multi-modal association

Q: can extend SOMs to higher-order maps that receive symbolic inputs from other maps…while preserving similarity relations?

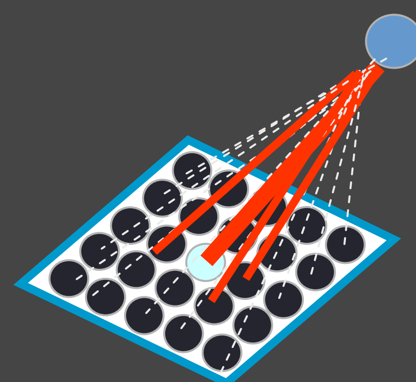
idea: encoding via 2D “cortical coordinates”

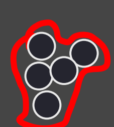


- x,y coordinate is a computational abstraction of the ***pattern*** of synaptic strength between a cell and all cells in an afferent map
- temporal coincidence of firing strengthens connections, “*fire together, wire together*”

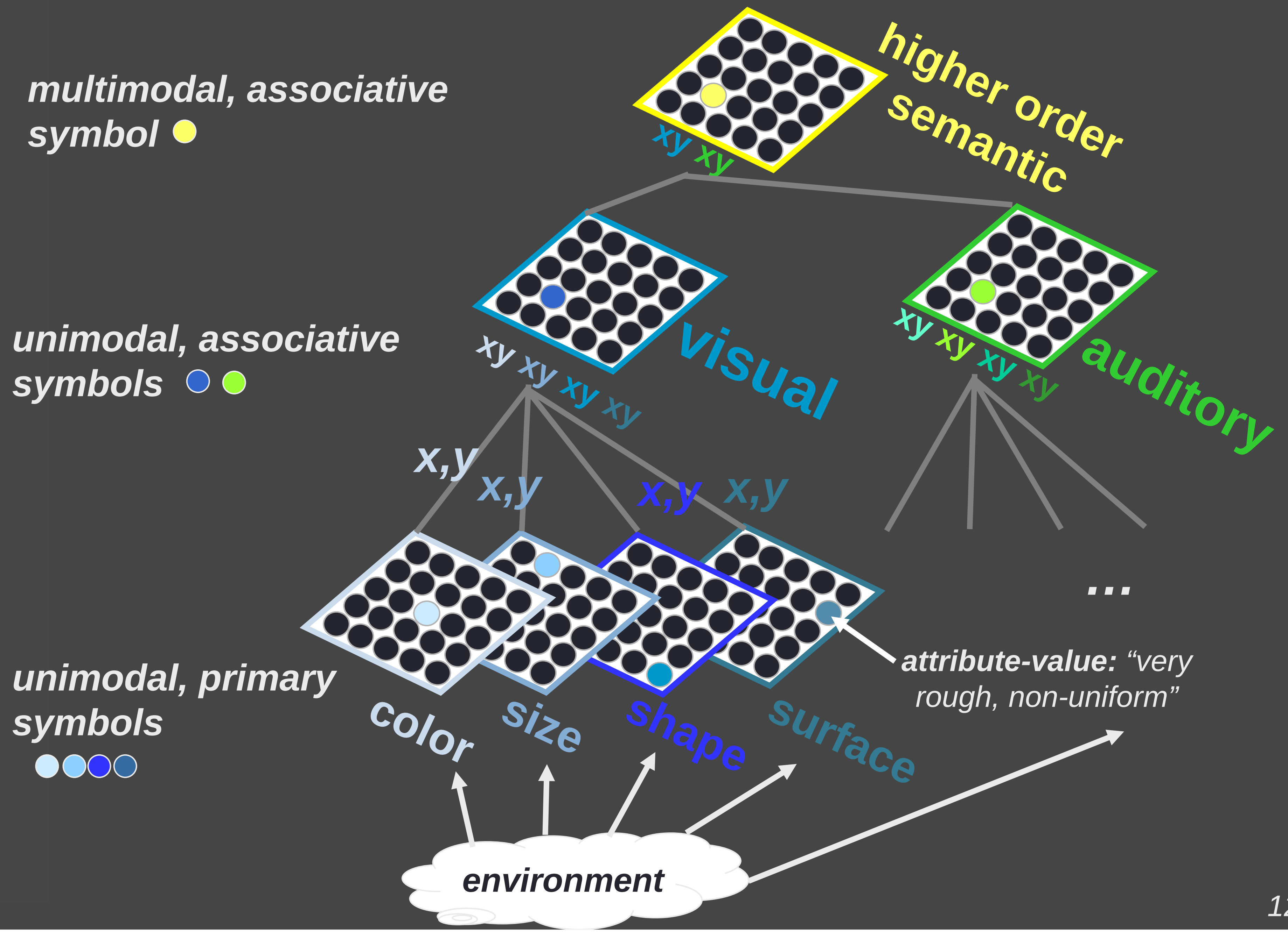
spatial location of winning cell

attribute-value
“large, vertically oriented”




cell’s receptive field in an afferent map

spatial location: common language of higher level networks



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③ **demo task** object categorization

④ **wrap-up** discussion

example task: object categorization

super category
category
class

- **Living**
  - **Plants**
    - Trees
    - Bushes
  - **Animals**
    - Dogs
    - Cats
- **NonLiving**
  - **Vehicles**
    - Cars
    - Bikes
  - **Furniture**
    - Tables
    - Chairs

- **96 exemplars, 12 per class**

  e.g. 12 trees: 3 colors x 4 sizes

- **naturally overlapping attribute-values**

  e.g. size: small dog ~ size large cat

  surface: car ~ table

stimulus attributes (assumed continuous valued)

Visual Perception

color	(hue, saturation, brightness)	[0..1]
size	($size_x$, $size_y$ $size_z$)	[feet]
shape	(roundness, complexity)	[0..1]
surface	(smoothness, uniformity)	[0..1]

Auditory Perception

sound	(loudness, char. freq)	[0..1,Hz]

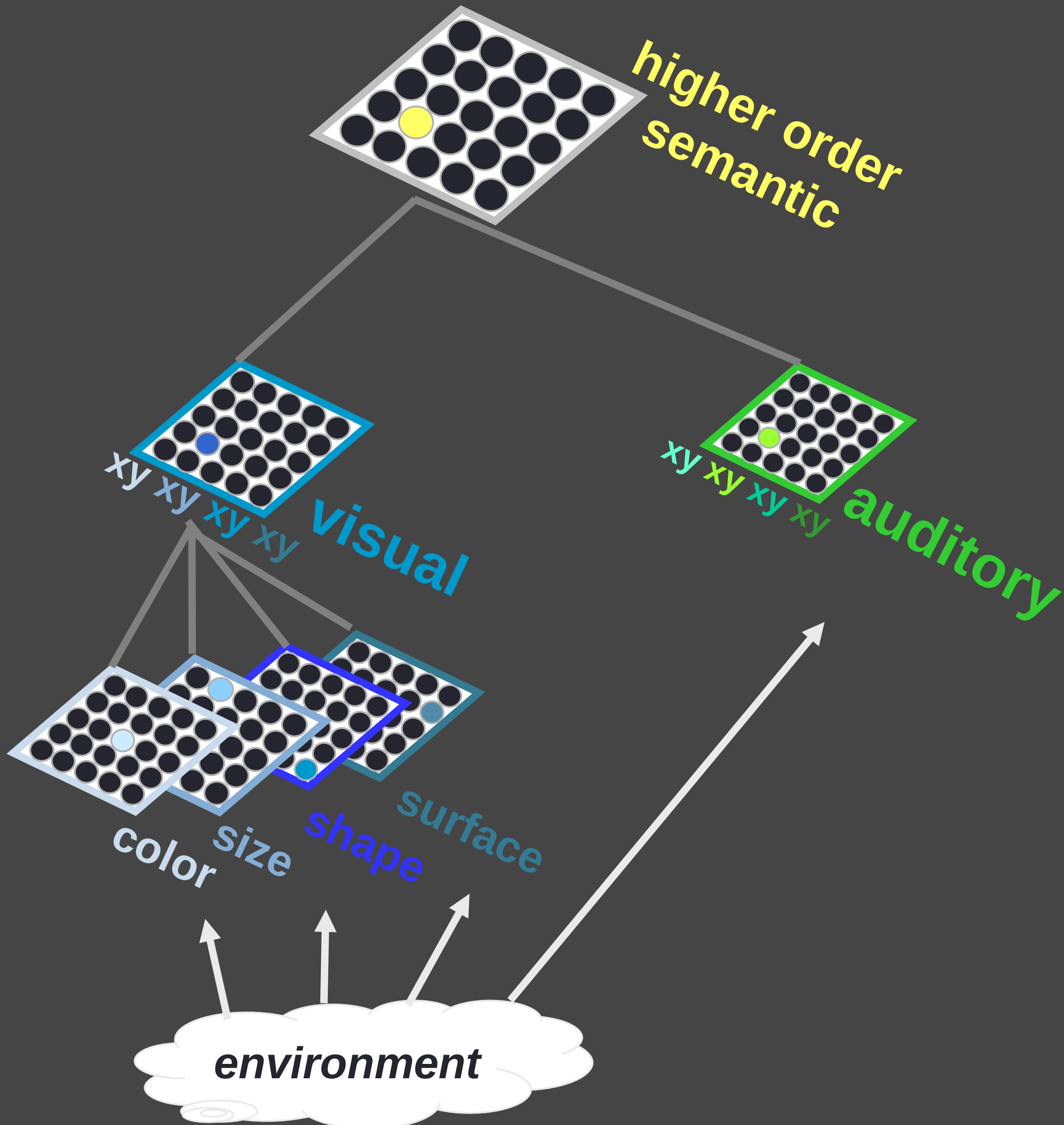
attribute coding – independently motivated

examples:

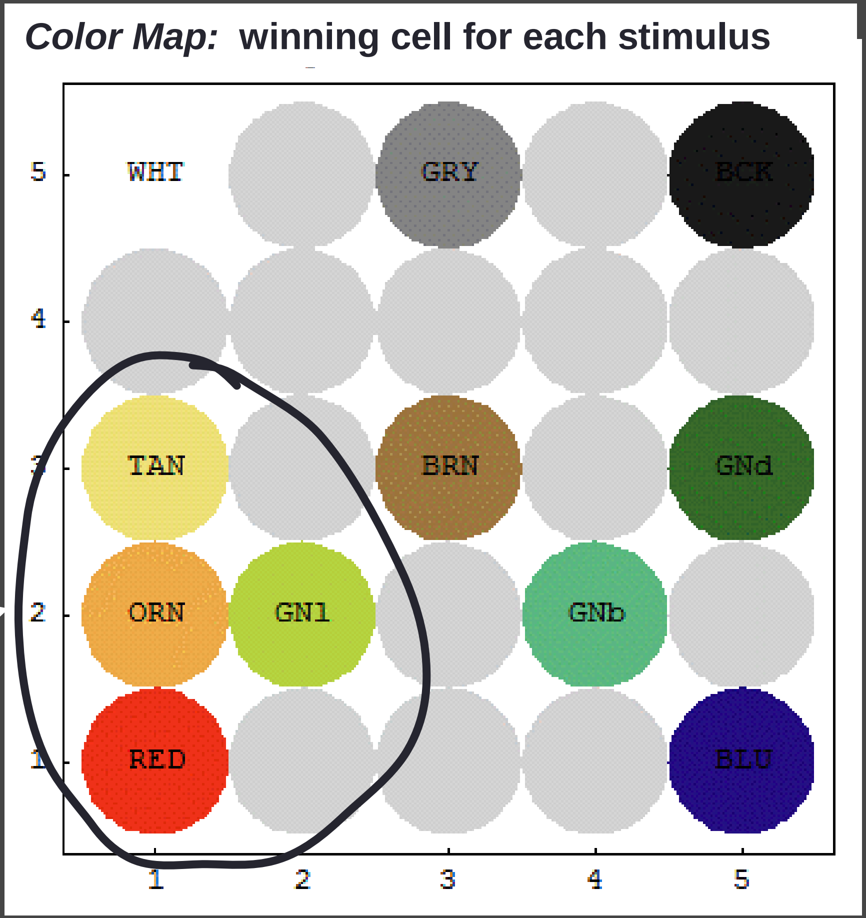
dog shape: (***roundness***: 0.85, ***complexity***: 0.15)

dog colors: (***H/S/B:*** (0.1,0.6,0.6), (0,0,0.1) , (0,0,1), (0,0,0.5))

model architecture



transduction example: color (h,s,b) to 2D-SOM



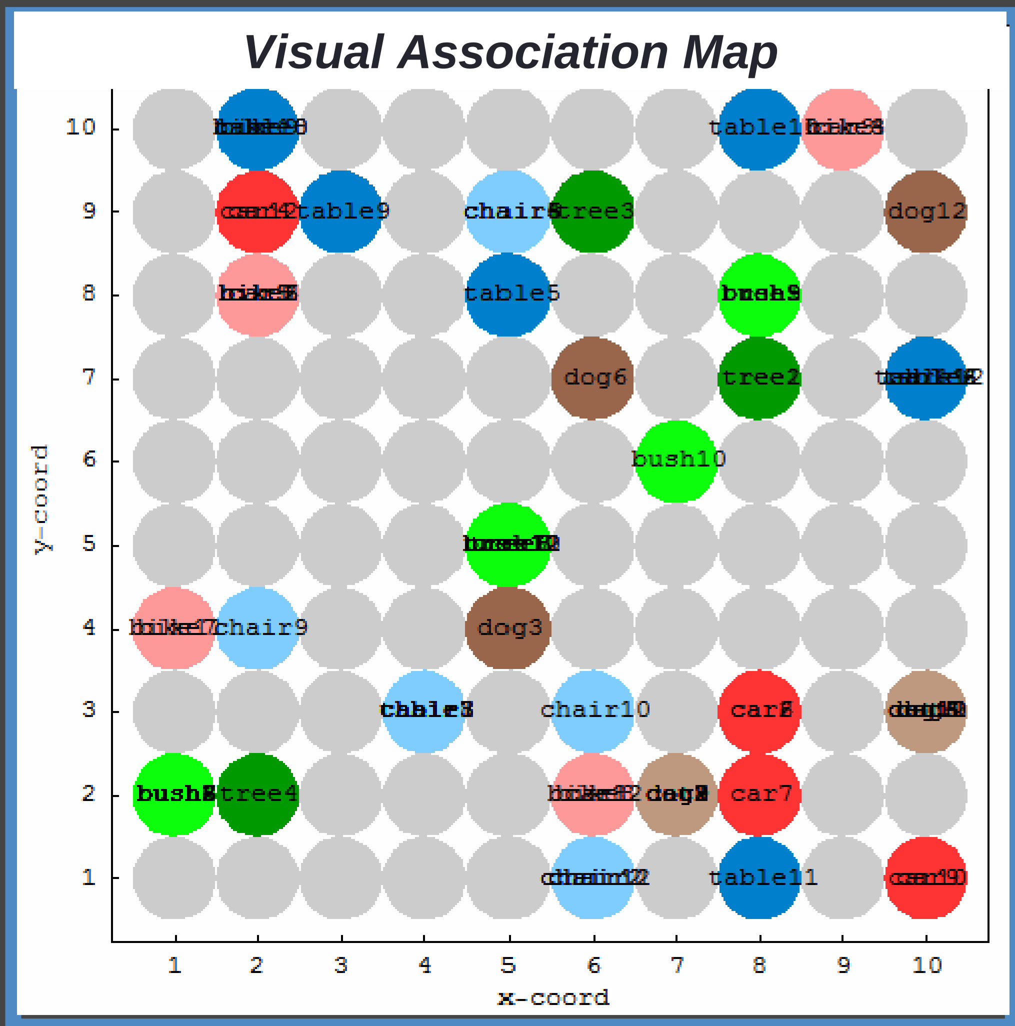
similar colors are neighbors

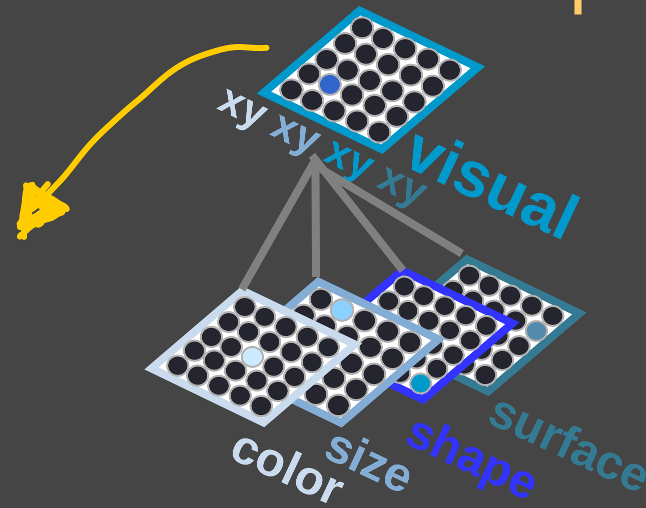
- *25 cells (5x5 map)*
- *After training*

- winning cells serve as symbols for each color stimulus
- similarity encoded by spatial location (closer, more similar)

higher order example: visual association map

- initial map: random codevectors
- no pattern to winning cells

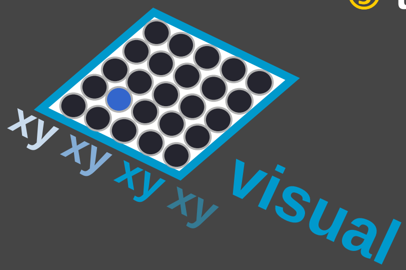


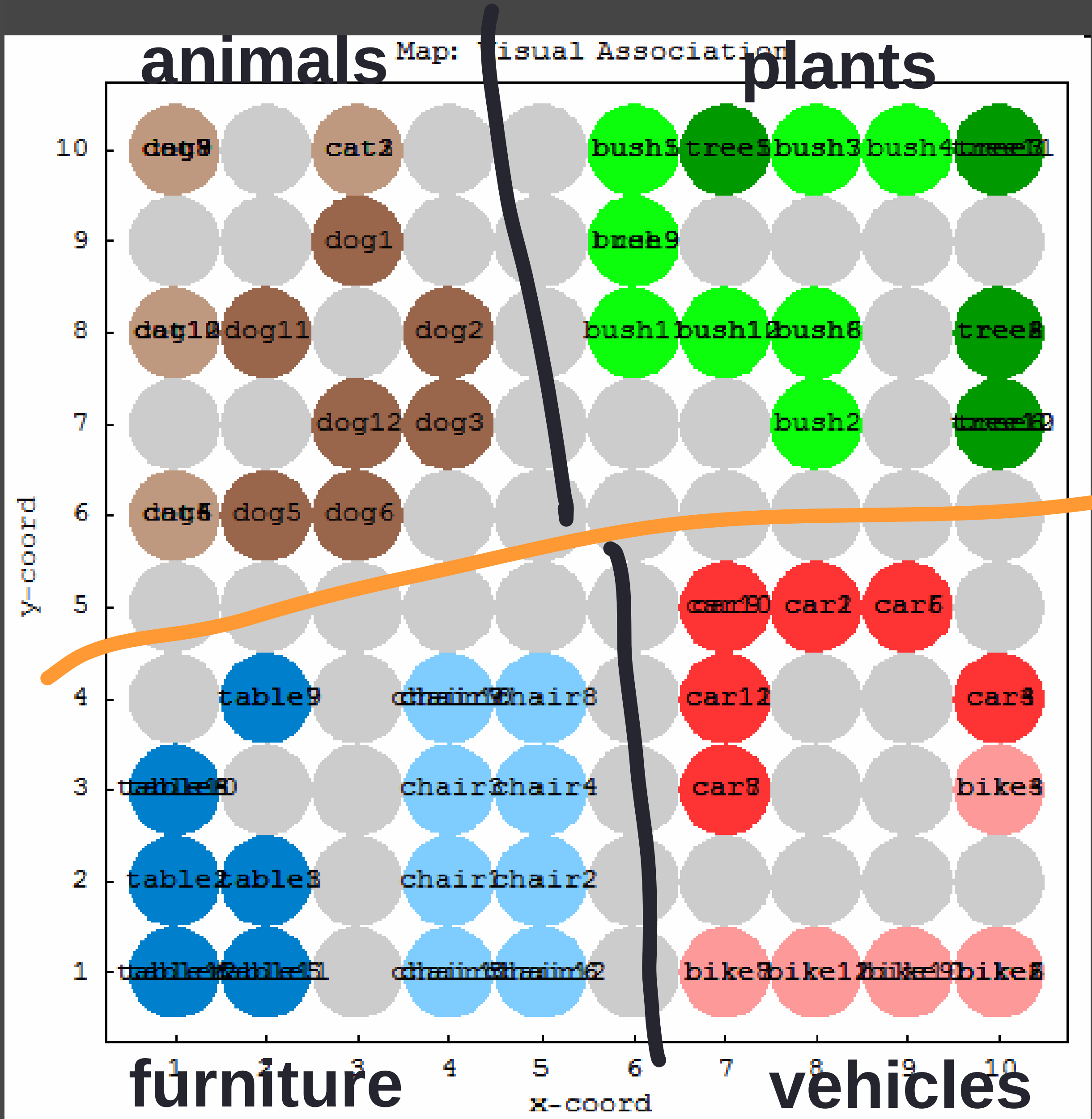


- Trees
- Bushes
- Dogs
- Cats
- Cars
- Bikes
- Tables
- Chairs

results: visual map learning

③ task





living

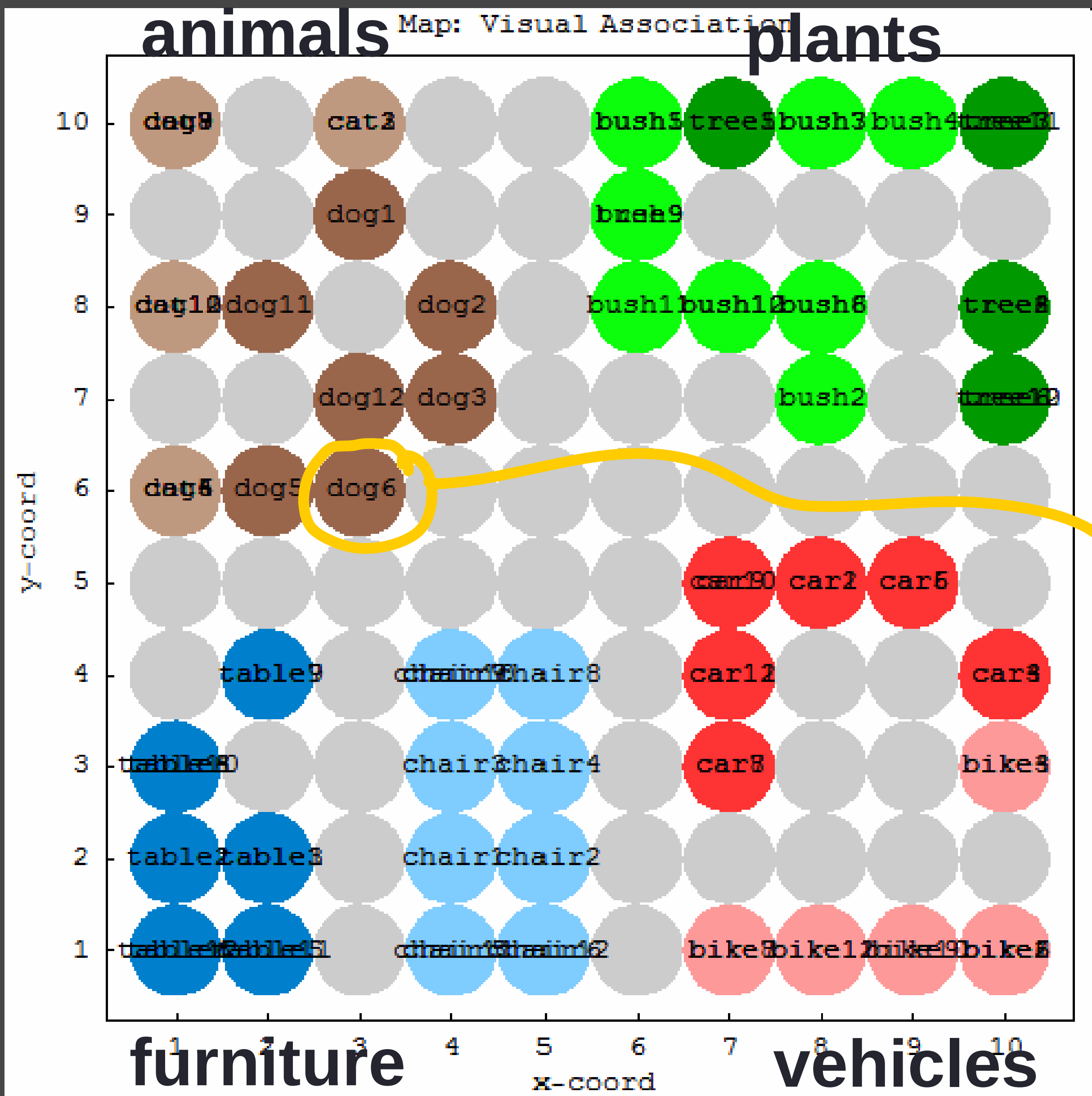
nonliving

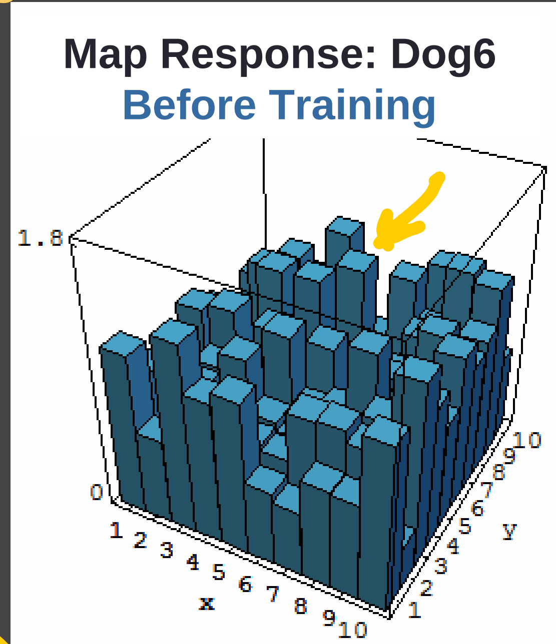
Learned:

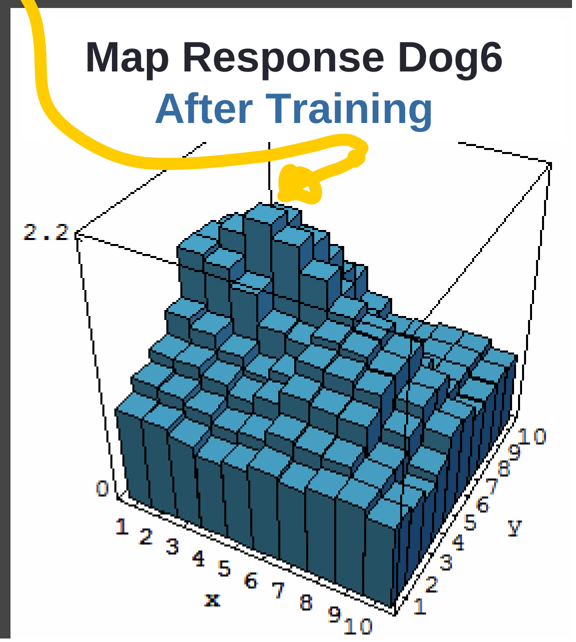
- super-category
- category
- most classes
- some exemplars

winning cells, within topography

③ task







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^nuggets golden

- **clustering & similarity** via neurally-inspired competitive learning

- **sensory transduction** creates symbols

- **semantic networks** at increasing levels of abstraction via cortical coordinates

^nuggets coal

- **top-down effects:** require additional extensions of SOM model (in progress)
- **attentional modulation:** allow relative weighting of attributes based on goals, context (in progress)
- **practical considerations:** viability of semantic network in Soar based on SOMs? training? exploitation of knowledge?

END

similarity: well established in human cognition

- **behavioral performance**
  - generalization, learning transfer
  - acoustic confusion in working memory tasks
  - similarity errors in speech production
- **electrophysiological recordings**
  - receptive fields: neurons tend have graded responses to similar stimuli

Q: what might be learned from how information is represented in the brain?

topography: important principle in the brain

- **sensory cortex has topographic organization**
  - neurons are *spatially* organized based on sensation; neighboring neurons encode similar information
  - **visual**: *retinotopic* (based on retina, visual field)
  - **auditory**: *tonotopic* (based on auditory nerve, frequency)
  - **somatosensory**: *somatotopic* (based on the human body)
- **sensory-based topography gives way to topography at a higher level of abstraction**
  - example: nearby cells in late-stage visual cortex (TE) of monkeys show graded response to similar *visual objects*

SOMs can produce symbols with similarity

transduce continuous sensory inputs
<u>and</u> provide similarity via topography

- cell in one cortical … tends to be excited by nearby cells fr… ceives inputs
- apple tends t… “red + round” and “pink + round”