Concepts and Categories II

Informatics 1 CG: Lecture 16

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Concepts and Categories

Note:

We're focusing on concepts that are **mental representations of classes of objects or events.**

You might have concepts of "skipping", "justice" or "wanderlust", but the category "things we're talking about today" does not include them.

Today

(1) Revisit theories of categorisation and

(2) Connections to inductive bias and generalisation

The uses of categorisation

What are categories good for?

1. Efficient representation
2. Communication
3. **Generalisation**

Theories of categorisation

- Definitional (or "classical") theory
- Similarity-based approaches
  - Prototype theory
  - Exemplar theory
- Theory theory

Definitional (or "classical") theory

Categories have necessary and sufficient features, e.g.,

"bachelor" ←→ unmarried & adult & male

Definitional (or "classical") theory

Pros:

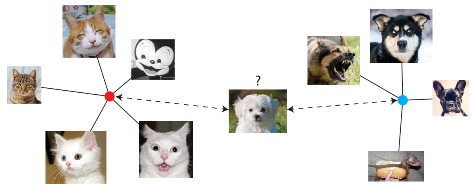
- Intuitive; economical; easy to communicate.

Cons:

- Good definitions are hard to find
  - Is the pope a bachelor?
  - What about an unmarried person in a single-partner long-term relationship?
  - What's "male"? "Adult"?
- Can't explain typicality effects or fuzzy boundaries
- Where do definitions come from?

Similarity-based theories: **Prototype theory**

Membership is based on similarity to a category prototype – a summary representation, usually taken to be an average.



Similarity-based theories: **Prototype theory**

Pros:

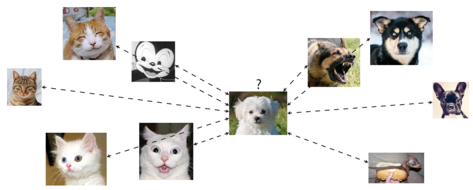
- Economical representation.

Cons:

- Has trouble capturing complex category structure.

Similarity-based theories: **Exemplar theory**

Membership is based on similarity to known category members.



Similarity-based theories: **Exemplar theory**

Pros:

- Flexible representation; can represent categories that don't have a single mode and complex category boundaries

Cons:

- Not economical

Similarity-based theories: **Hybrids**

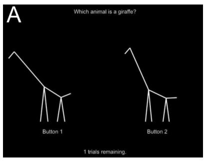
Can we combine the advantages of prototype and exemplar theories?

Idea: lexical concepts can correspond to many clusters of entities, e.g.,:

- fluffy white cats,
- tabby cats,
- that one green cat

Similarity-based theories: **Hybrids**

We can express both exemplar and prototype theories this way, and treat categorisation as a problem of **density estimation.**
Can we use this to understand human categories and concepts in detail?



(Figure 2 from Sanborn et al., 2007)

Similarity-based theories: **Hybrids**

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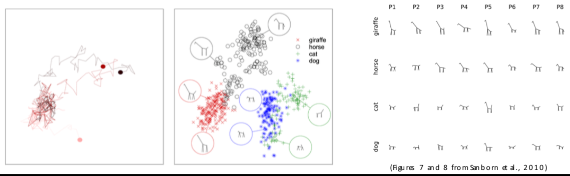


(Figures 7 and 8 from Sanborn et al., 2010)

Similarity-based theories

Challenges to all similarity-based theories:

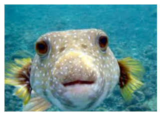
- Where do features come from?

Similarity-based theories

Challenges to all similarity-based theories:

- Compositionality



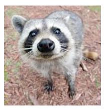


Similarity-based theories

- Is Sweden, Poland, or Hungary most similar to Austria?
  → Sweden (49%) > Hungary (36%)
- Is Sweden, Norway, or Hungary most similar to Austria?
  → Hungary (60%) > Sweden (14%) [Geography]

Similarity-based theories

- Discourse context

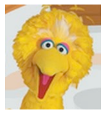
- Within-individual variability

Similarity-based theories

- Variance effects:


Theory theory

- Category membership depends on causal and explanatory features.
- Causal features are more important than surface features, e.g.,
  - Function > appearance (for adults, at least)
  - Cat DNA > Catlike appearance
- Does everything have one natural category?
  Can we think of category labels as features?



Categories and generalisation

A typical generalisation problem involves:

- A new case and some data about it,
- Previously-observed cases,
- Some background and contextual information,

We want to draw conclusions about the new case.

Categories and generalisation

We might want to know different things:

- Is it edible?
- Will it try to eat us?
- What's its display resolution?
- How should we label it?

Category-based induction

Example:

If pelicans have a choroid membrane in their eyes and
albatrosses have a choroid membrane in their eyes, do
all birds have a choroid membrane in their eyes?

(Osherson et al., 1990)

Category-based induction

Phenomena:
- Premise typicality
- Premise diversity
- Conclusion specificity
- Premise monotonicity*
- Inclusion fallacy

(Osherson et al., 1990)

Category-based induction

Phenomena:

- Premise typicality

Robins have <feature>
Birds have <feature>
>
Penguins have <feature>
Birds have <feature>

(Osherson et al., 1990)

Category-based induction

Phenomena:

- Premise diversity

Hippos have <feature>
Hamsters have <feature>
Mammals have <feature>
>
Hippos have <feature>
Rhinos have <feature>
Mammals have <feature>

(Osherson et al., 1990)

Category-based induction

Phenomena:

- Conclusion specificity

Bluejays have <feature>
Falcons have <feature>
Birds have <feature>
>
Bluejays have <feature>
Falcons have <feature>
Animals have <feature>

(Osherson et al., 1990)

Category-based induction

Phenomena:

- Premise monotonicity*

Hawks have <feature>
Sparrows have <feature>
Eagles have <feature>
Birds have <feature>
>
Sparrows have <feature>
Eagles have <feature>
Birds have <feature>

(Osherson et al., 1990)

Category-based induction

Phenomena:

- Premise monotonicity*

Sparrows have <feature>
Eagles have <feature>
Birds have <feature>
>
Sparrows have <feature>
Eagles have <feature>
Rabbits have <feature>
Birds have <feature>

(Osherson et al., 1990)

Category-based induction

Phenomena:

- Inclusion fallacy

Robins have <feature>
Birds have <feature>
>
Robins have <feature>
Ostriches have <feature>

(Osherson et al., 1990)

Theories

Similarity-based accounts of category-based induction:

- Tversky's contrast model (1977):
  - Feature overlap determines salient features.
- Osherson et al. (1990):
  - Weighted combination of similarity and coverage
  - Assumes stable, hierarchical categories
- Connectionist (neural network) model (Sloman, 1993):
  - Proportion of shared features between premises and conclusion
  - Estimated with neural network

(and others)

Theory theory strikes again!

Causal knowledge drives category-based induction.

Examples:

- If <X> eats <Y>, they're more likely to share a disease.
- If <X> is taxonomically related to <Y>, they're more likely to share bone types.
- If <X> is the same weight as <Y>, they're likely to need similar amounts of sodium in their diet.

How can we use and combine these kinds of knowledge?

For one proposal, see [1].

[1] (Kemp & Tenenbaum, 2009: "Structured Statistical Models of Inductive Reasoning")

Summary

Similarity is at the heart of prototype and exemplar theories, but it's a complex concept in its own right.

- Context matters! (What's being compared, goals, ...)
- Category variability
- Trade-off between expressiveness and economy; hybrid models can help

Categories help us generalise

- Category-based induction:
  features of some categories or exemplars → inferences about others

"Theory theory" issues and questions remain