Informatics 1 Cognitive Science

Lecture 12: Categories

Frank Keller

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School of Informatics
University of Edinburgh
keller@inf.ed.ac.uk

Slide credits: Frank Mollica, Chris Lucas, Mirella Lapata

Overview

Concepts and Categories

Classical Theory of Categorization

Similarity-based Theories of Categorization

Problems for Similarity-based Theories

Recap: From Words to Categories

In the last lectures, we discussed words:

- How to find word boundaries in the speech stream and infer a lexicon (using probabilities and MDL).
- How to learn which objects words refer to (using inductive biases).
- How to compute context vectors that capture of the meaning of words (using neural network).

In this lecture:

- We will look at categories. These are more abstract than words.
- They include object classes (dog), abstractions (prime number), or complicated concepts (democracy).
- We acquire categories as part of cognitive development; but how do we work out if something belongs to a particular category?

Concepts and Categories

Concepts and Categories

We will focus on **concepts** as mental representations of classes of objects or events. They determine how things are related or categorized – concepts and categories go hand in hand.

1. What are the functions of concepts?
2. How do people categorize things?
3. How do we represent concepts?

Functions of Concepts (Rosch, 1978)

Concepts:

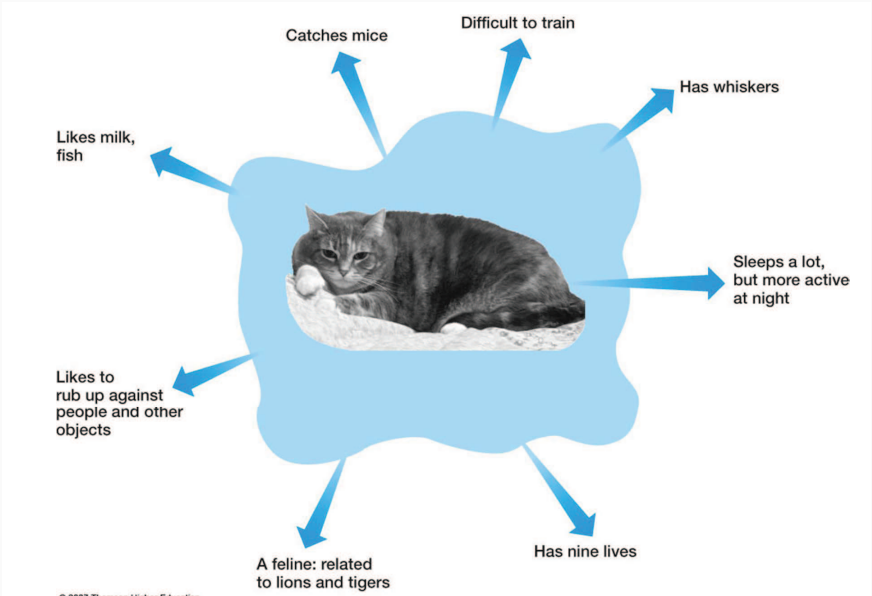
- improve cognitive economy: By dividing the world into classes of things, we decrease the amount of information we need to learn, perceive, remember, and recognize.
- help us make useful predictions and generalizations.
- help us communicate.

Cognitive economy

"... what one wishes to gain from one's categories is a great deal of information about the environment while conserving finite resources as much as possible."[1]

[1] Rosch, E., & Lloyd, B. B. (Eds.). (1978). Cognition and categorization.

Knowing the Category Provides a Lot of Information



Knowing the Category Provides a Lot of Information

If we've encountered 20 cats, it's more economical to remember "cat" features and the occasional exception, than to track all of their features separately.

Classical Theory of Categorization

Theories of categorization

Classical (or definitional) theory

Originated with Aristotle. Categories are represented as list of features which are both necessary and jointly sufficient. Category membership is determined by checking if an item possesses all requisite features.

Classical theory

tea cup	
1.	*concrete object*
2.	*concave*
3.	*can hold liquids*
4.	*has a handle*
5.	*can be used to drink hot liquids*

Classical theory

Time for a short quiz on Wooclap!

https://app.wooclap.com/KLPYYB

Classical theory

Implications:

- All members of a category are equally good
- Category boundaries are clear and inflexible

Pros:

- Intuitive, economical
- Definitions are easy to communicate
- Easy to check category membership against definition

Cons:

- It's hard to find satisfactory definitions
- Borderline/debatable cases
- Typicality Effects

Finding good definitions

- What is art?
- What is a game?
- What is a teacup?

Finding good definitions

tea cup
1. *concrete object*
2. *concave*
3. *can hold liquids*
4. *has a handle*
5. *can be used to drink hot liquids*

Properties 4 and 5 are debatable (Chinese tea cups). If you drop 4 and 5, then there are many objects (bowls) that satisfy 1–3.

Borderline cases and inconsistency

Category membership isn't always clear cut.

- Is an olive a fruit?
- Is a poet an animal?
- Is a candlestick furniture?

Not just that people have *different* clear-cut categories: There is within-subjects inconsistency.[2]

[2] McCloskey, M. E., & Glucksberg, S. (1978). Natural categories: Well defined or fuzzy sets? *Memory & Cognition*, 6(4), 462-472.

Typicality Effects

The classical theory predicts that typical and atypical category examples should be equally easy to judge as members.

Typical

- is robin a bird?
- is dog a mammal?
- is diamond a precious stone?

Atypical

- is ostrich a bird?
- is a whale a mammal?
- is turquoise a precious stone?

Slower verification times for atypical items.

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Is this a *chair*?

Is this a *cat*?

Is this a *dog*?

Classical theory

Tweaks to classical theory can explain some of these phenomena, but the original version has largely been abandoned.

Similarity-based Theories of Categorization

Similarity-based theories

Another view: Concepts built on similarity, not definitions.

- Wittgenstein: concepts are structured based on family resemblance.
- Take a composite photo of all family members.
- Only the common features are retained.
- Photo looks like everyone in family, but isn't any one person.

Prototype Theory

Categories are organized around a category prototype. A prototype is a summary representation, such as an average family member. Potential members of the category are identified by how closely they resemble the prototype.

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- Categories under prototype view are fuzzy
- Organized around typical properties or correlated attributes
- Category membership is similarity-based

Fuzzy Boundaries

Is this a cup or a bowl?

Fuzzy Boundaries

Is this a cup or a bowl?

- It can be both!
- It is perhaps more prototypical of a bowl.
- Fuzzy boundary means membership can be graded (0.75 bowl vs. 0.25 cup).

Similarity-based theories

Prototype theories:

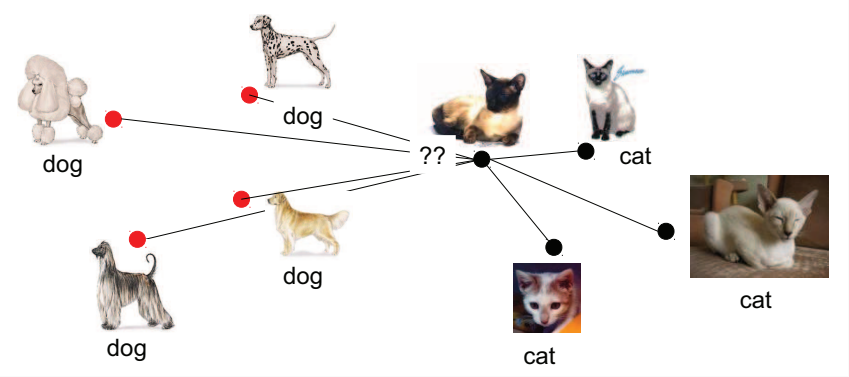
- Can explain typicality effects and borderline cases.
- Economical – one prototype per category.

However, it faces some problems:

- Sometimes averages or summaries are ill-defined (or just bad).
- Imposes strong restrictions on what kinds of categories are learnable.

Exemplar Theory

A category is represented by list previously encountered exemplars. New exemplars are compared to known exemplars — most similar item will influence classification the most.



Exemplar Theory

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1. Retrieve memories of specific cats we have encountered.
2. Retrieve memories of relevant non-cats e.g., memory of a dog; memory of a stuffed animal; memory of a raccoon.
3. Compute total similarity of current instance to memories of positive and negative exemplars (exemplars of cats/non-cats).
4. Decide that exemplar is a cat if it is more similar to the memories of cats than to memories of relevant non-cats.

Similarity-based theories

Exemplar Theory

A category is represented by list previously encountered exemplars. New exemplars are compared to known exemplars — most similar item will influence classification the most.

How do we define similarity?

We can encode our exemplars as vectors and use the cosine to compute similarity between the vectors (see last lecture)!

Exemplar Theory

Time for a short quiz on Wooclap!

https://app.wooclap.com/KLPYYB

Prototype vs Exemplar Theory

In both theories, category membership is based on similarity or resemblance.

Prototype theory:

- category structure is based on prototypes;
- categorization based on similarity to prototype of category.

Exemplar theory:

- categorization based on total similarity of object to exemplars of the category versus total similarity of object to non-exemplars of the category;
- assumes only that we can retrieve memories of specific instances of a category;
- no abstraction of prototypes.

Maybe both theories are true but for different situations – there are theories that incorporate both exemplars and prototypes.

Problems for Similarity-based Theories

Problems for similarity-based approaches

How do we know which properties to compare?
(Murphy and Medin, 1985).

- Both plums and lawnmowers weigh less than a ton
- They are both found on earth
- They are both bigger than a grain of sand.

Problems for similarity-based approaches

Options can change the implicit similarity function:

- 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]

(Tversky, 1977)

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Similarity is subject to framing effects. This is one of the cognitive biases we'll discuss in the next two lectures.

Problems for similarity-based approaches

Typicality isn't just a matter of (simple) similarity.

(https://www.boredpanda.com/useless-object-design-the-unusable-katerina-kamprani/)

For artifacts, being a **functional** example is important.

Problems for similarity-based approaches

Compositionality: Similarity-based approaches don't give a good account of how categories should compose.

Pet fish: Just add or average the properties of a typical pet, and a typical fish?

Summary

Categorization is one of the classical problems in the field of cognitive science, one with a history dating back to Aristotle.

- Ability to generalize from experience underlies a variety of common mental tasks.
- Perception, learning, and the use of language.
- Classical, prototype and exemplar theory.
- Prototypes as summaries, family resemblance.