CATEGORIZATION IN SCIENCE AND IN COGNITIVE SCIENCE

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How do people categorize an object or a phenomenon, which they have never faced before?

Two rival theories in contemporary cognitive science give different answers to this question:

- categorization is ***similarity-based***
- categorization is ***rule-based***

Because it has been collected enough evidence both for and against similarity-based and rule-based categorization, most cognitive scientists today assume that each of these mechanisms takes place under certain conditions.

What determines which mechanism will be switched on?

Recent experimental findings [*Kloos & Sloutsky*, 2007] reveal that it is the structure of the category, which points at the particular mechanism:

- ***Dense categories*** invoke similarity-based categorization;
- ***Sparse categories*** call for rule-based categorization

IN THIS TALK:

- A brief outline of the distinction between dense and sparse categories;
- What this distinction might reveal about the categorization in science;
- A case study: the categorization of the cathode rays

Statistical density as a measurable characteristic of category structure

Heidi Kloos, Vladimir Sloutsky (2007) What’s behind different kinds of kinds: effects of statistical density on learning and representation of categories. *Journal of Experimental Psychology: General.*

*(*in press, a draft available on *http://cogdev.cog.ohio-state.edu/html/publications.html)*

Statistical density is «the ratio of category-relevant (in-category) invariance to the total (between-categories) variance» (p.4)

Statistical density: a formal account

$D = 1 - H_{within}/H_{between}$

where

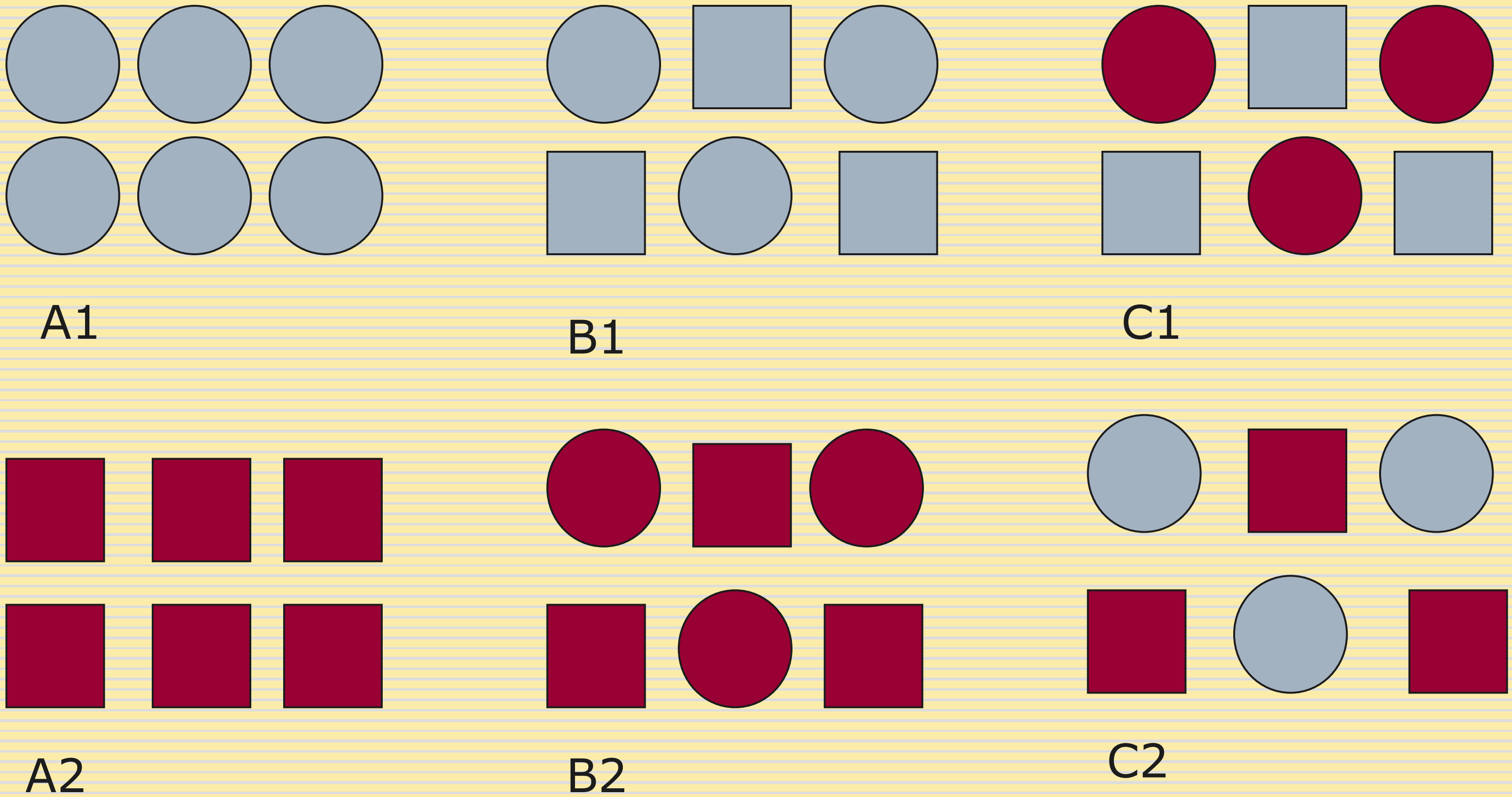
D – statistical density

H_{within} – the entropy observed within the target category

$H_{between}$ – the entropy observed between target and contrasting categories

H is calculated using the classical formula of Shannon [Shannon, 1948]

Dense and sparse categories: EXAMPLE



Dense and sparse categories: important differences

- dense categories could be learned without supervision, sparse categories cannot;
- categorization in respect to dense categories is similarity-based, while in respect to sparse categories it is rule-based.

- all natural kinds are dense categories (but not all dense categories are natural kinds);
- most scientific concepts (for example, the concept of accelerated motion) are sparse categories

What about categorization in science?

- There are two kinds of scientific concepts: concepts referring to sparse categories (accelerated motion) and concepts referring to dense categories (electrons, chemical elements, biological species).
- If scientists behave as “normal epistemic subjects”, they should follow different categorization strategies in respect to dense and sparse categories;
- QUESTION: Does the use of different categorization strategies lead to the use of different justification (confirmation) strategies?

EXAMPLE 1

Let’s assume that ***X*** is an object manifesting a property ***y***, which is not possessed by any of the members of the category ***A***.

- If ***A*** is a dense category, ***X*** will be viewed as highly dissimilar to its members because of ***y***; therefore, ***y*** will be counted as a decisive evidence for that ***X*** is not ***A***.
- If ***A*** is a sparse category, however, the same evidence ***y*** will not be taken seriously enough because sparse categories allow greater variability of the properties of their members.

EXAMPLE 2
THE CATHODE RAYS STORY

1. The beginning

The cathode rays (CR) were discovered in 1857 by *Julius Plücker* in Bonn, who noticed that during electrical discharge in a vacuum-tube a part of the glass wall near the cathode become phosphorescent. He also found that:

E1 - CR are deflected by magnetic force;

E2 - particles of the platinum cathode can be found on the wall of the tube near the cathode.

Ten years later Plücker's student *Johann Hittorf* discovered that:

E3 - CR follow straight lines, and

E4 - CR cast shadows;

2. The formation of two rival hypotheses

- 1871 - the British electrical engineer *Cromwell Fleetwood Varley* launched the hypothesis that the CR are "***attenuated particles of matter, projected from the negative pole by electricity***".

- 1876 - *Eugen Goldstein* in Germany introduced a different hypothesis: the cathode rays are "***electromagnetic waves similar to light***".

3. Attempts to prove the rival hypotheses

- 1879 - *William Crookes* reported the results of experiments, which seemed to him to provide definitive proof of the corpuscular nature of cathode rays. These included observations of:

  E5 - sharply defined shadow of a metal Maltese Cross on the wall of the glass tube behind the cross;

  E6 - the movement of a tiny paddle wheel put in the beam of the cathode rays.

- 1884 - *Heinrih Hertz* seemed to show that

  E7 - an electric field had no effect on the cathode rays.

4. The 90's: the crucial decade for the debate about CR

- 1892 - Hertz discovered another wave phenomenon:
  E8: CR penetrate thin metallic leaves and "issue from them in a state of diffusion, like light passing through a turbid medium, e.g. opal glass".
- 1894 - J.J. Thomson measured the speed of CR and showed that
  E9: the speed of CR is much smaller than the speed of light.
  The same year Ph. Lenard discovered that
  E10: CR can past through the highest vacuum.
- 1897 - Walter Kaufmann in Germany and J.J. Thomson in England succeeded ***to measure the ratio e/m*** for the alleged particles constituting the cathode rays(E11).
- 1902 - Lenard observed that
  E12: two beams of CR do not interfere

At the beginning of 20th century most physicists become convinced that CR are not waves (although they strongly disagreed about what kind of particles are CR: material corpuscles, quanta of pure electricity, or states in the electromagnetic field).

QUESTION: Having in mind the ambiguous evidence, what brought scientists to the consensus that CR are not waves?

Many historians of science claim that the crucial evidence against the wave nature of CR has come in 1894 when Thomson discovered that the speed of CR is much lower than the speed of light

- [Sarton, 1937]: " The Herzian or Lenardian conception of cathodic rays as aetherial waves became untenable when J. J. Thomson measured their speed by means of rotating mirror and found that it was variable but always materially smaller than the speed of light"
- [Gribbin, 2002]: "Evidence that cathode rays could not simply be a form of electromagnetic radiation came in 1894, when J. J. Thomson, in England, showed that they move much more slowly than light (remember, Maxwell's equation tell us that all electromagnetic radiation moves at the speed of light)".
- [Errede, 2005]: "1894: J. J. Thomson measures the speed of cathode rays and shows that they travel much more slowly than the speed of light. The aether model of cathode rays begins to die".

However, in the late 19th century, the physicists did not see in the speed of CR a crucial argument against their wave nature: neither Thomson himself nor his main opponent Lenard mentioned that.

In the introduction of his 1897 paper J. J. Thomson wrote the following:

"It would seem at first sight that it ought not be difficult to discriminate between views so different, yet experience shows that this is not the case…"

The main advantage of electrified-particle theory over the wave-aetherial theory he saw in that

"it is definite and its consequences can be predicted; with the aetherial theory it is impossible to predict what will happen under any given circumstances, as on this theory we are dealing with hitherto unobserved phenomena in the aether…"

Lenard gave up the wave conception of CR in 1902 when discovered that two beams of CR do not interfere

IS THE CONSENSUS ABOUT THE NON-WAVE NATURE OF CR AN OCCASIONAL ACHIEVEMENT?

It looks like that: the different scientists came to the non-wave conclusion following different reasons.

But if one takes seriously the fact that in the particle-wave controversy two categories of a different type have been opposed, he/she can see that the win of the particle conceptions has not been occasional.

CR

are

waves

CR penetrate thin metallic leaves and issue from them in a state of diffusion

the speed of CR is much smaller than the speed of light.

CR can past through the highest vacuum.

the ratio e/m is measurable

two beams of CR do not interfere

CR

are

particles

THE EXPLANATION

- The dense categories (the members of which demonstrate less variability) are more sensitive to anomalies than the sparse categories (which allow bigger variations). In respect to dense categories any anomaly seems crucial and undermines any positive evidence.
- The situation with the sparse categories is just the opposite: any indirect positive evidence (even if it is based on “confirmation bias”) undermines the multiple anomalies.

The follow-up of the cathode rays story

- 1905 – Einstein discovered that light also consists of quanta
- 1924 – Luis de Broglie inferred theoretically the wave properties of the electron.
- 1927 – C. Davisson and L. Germer reported that the specific reflection and refraction phenomena, which have been observed when a homogeneous beam of electrons is scattered by a crystal of nickel could be explained in terms of wave mechanics.
- 1927 – G. P. Thomson succeeded to obtain a picture of diffracted electrons, which confirmed the prediction of de Broglie.
- 1937 – Davisson and G. Thomson shared the Nobel prize for the experimental proof of the wave properties of the electron.

CONCLUSIONS

- A significant part of scientific hypotheses are categorization statements (***X*** is ***A***);
- Categorization statements that refer to dense categories are more sensitive to negative evidence (i.e. to falsification) than categorization statements that refer to sparse categories;
- It is worthy to notice that the density of categories is a measurable factor. Therefore, the historical explanations, which use it are much less speculative than those referring to the alleged influence of the social environment.

Thank you!