

COSMO, a Bayesian computational model of speech communication: Assessing the role of sensory vs. motor knowledge in speech perception

Marie-Lou Barnaud, Julien Diard, Pierre Bessiere, Jean-Luc Schwartz

▶ **To cite this version:**

Marie-Lou Barnaud, Julien Diard, Pierre Bessiere, Jean-Luc Schwartz. COSMO, a Bayesian computational model of speech communication: Assessing the role of sensory vs. motor knowledge in speech perception. ICDL-EpiRob 2015 - 5th International Conference on Development and Learning and on Epigenetic Robotics, Aug 2015, Providence, RI, United States. hal-02004350

HAL Id: hal-02004350
https://hal.science/hal-02004350

Submitted on 1 Feb 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Modeling the concurrent development of speech perception and production in a Bayesian framework

Marie-Lou Barnaud[1], Julien Diard[2], Pierre Bessière[3], Jean-Luc Schwartz[1]

[1] *GIPSA-Lab, UMR 5216 - CNRS & Université Grenoble Alpes, France*
[2] *LPNC, UMR 5105 - CNRS & Université Grenoble Alpes, France*
[3] *ISIR, UPMC, UMR 7222 - CNRS & Universités Paris Sorbonne, France*

Introduction

It is widely accepted that both **auditory** and **motor representations** intervene in the perceptual processing of speech units. However, the question of the functional role of each of these systems remains seldom addressed and poorly understood.

This is where computational models can play a crucial role. We developed **COSMO**, a Bayesian model comparing **sensory** and **motor** processes in the form of probability distributions which enable both theoretical developments and quantitative simulations.

The three trends about the invariants of speech perception

Auditory theories: the invariants are acoustic properties.

Motor theories: the invariants are the intended phonetic gestures of the speaker.

Perceptuo-motor theories: the invariants are perceptuo-motor units characterized by both their articulatory coherence and their perceptual value.

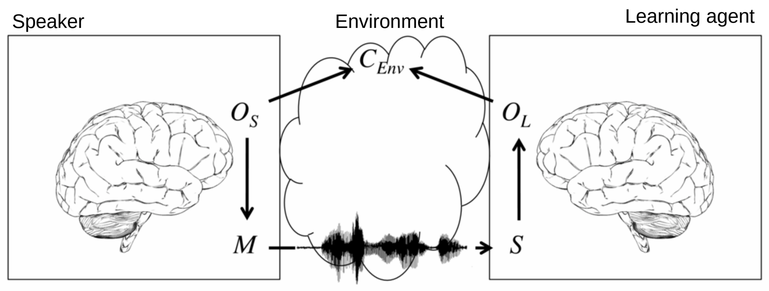
Context and Bayesian model

Issues

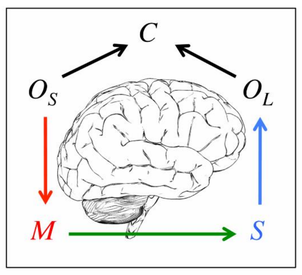
Question of interest: Why perceptuo-motor units ?

Hypothesis: The **auditory** and the **motor** systems would be complementary.

COSMO: from a model of communication…



COSMO: … to a model of communicating agent (the internalization hypothesis)



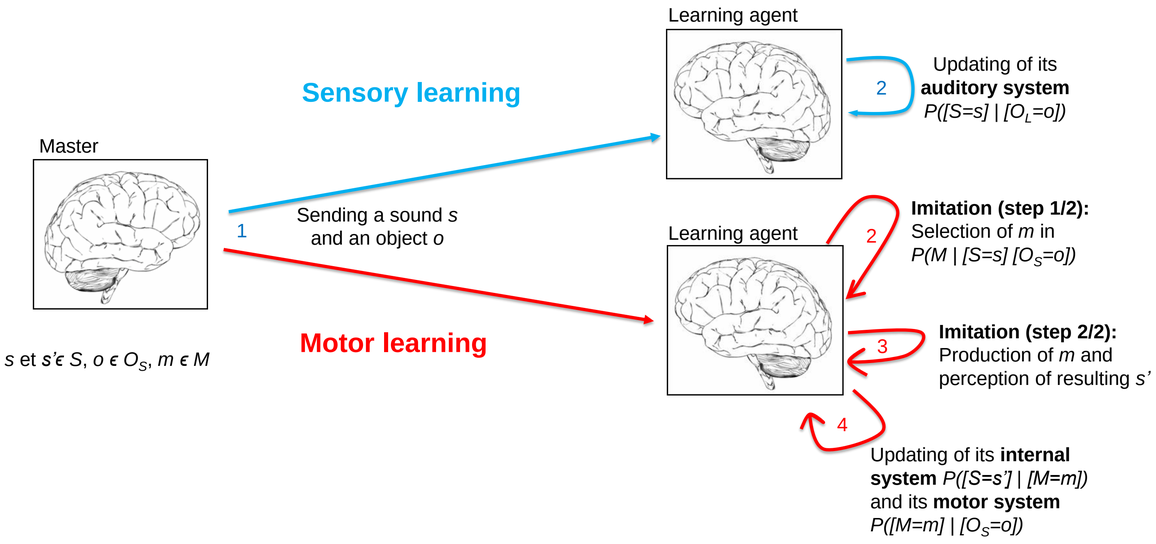
$$P(C\ O_S\ S\ M\ O_L) = P(O_S) \times P(M \mid O_S) \times P(S \mid M) \times P(O_L \mid S) \times P(C \mid O_S\ O_L)$$

Sensori-motor system

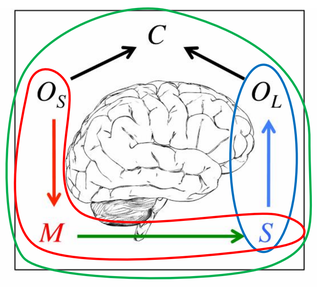
Prior on the objects | Motor system | Auditory system | Validation system

Model learning and simulation of perception processes

Model learning

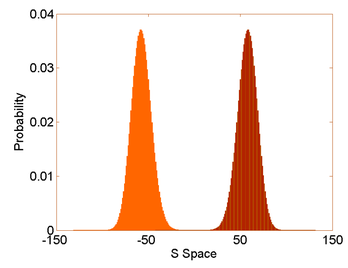


Simulation of perception processes



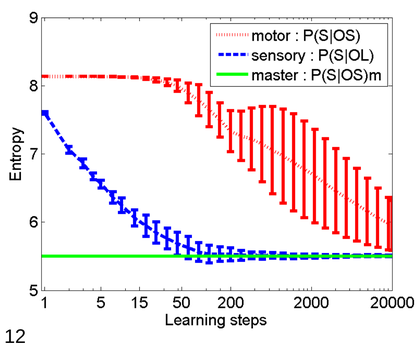
Comparison of three perception processes:
- Sensory system $P(O_L \mid S)$
- Motor system $P(O_S \mid S)$
- Perceptuo-motor system $P(O_L\ O_S \mid S\ [C=1])$

In 1D simulations:
- 2 objects O_1 and O_2
- Spaces S and M in one dimension
- $P(M \mid O_S)$, $P(S \mid M)$ and $P(O_L \mid S)$ gaussians



Results

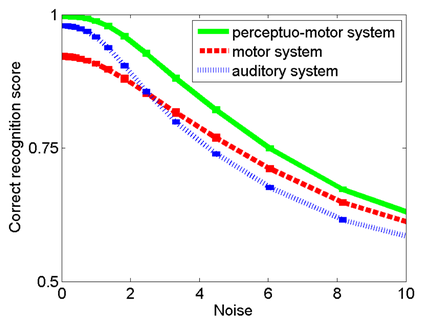
Learning pace: Comparison of the entropy of the sensory and motor learning



The entropy of the **sensory model** converges quickly to a level close to the entropy of the stimuli produced by the **master** (in less than 200 learning steps), while the entropy of the **motor model** converges more slowly (in more than 20,000 learning steps).

N = 12

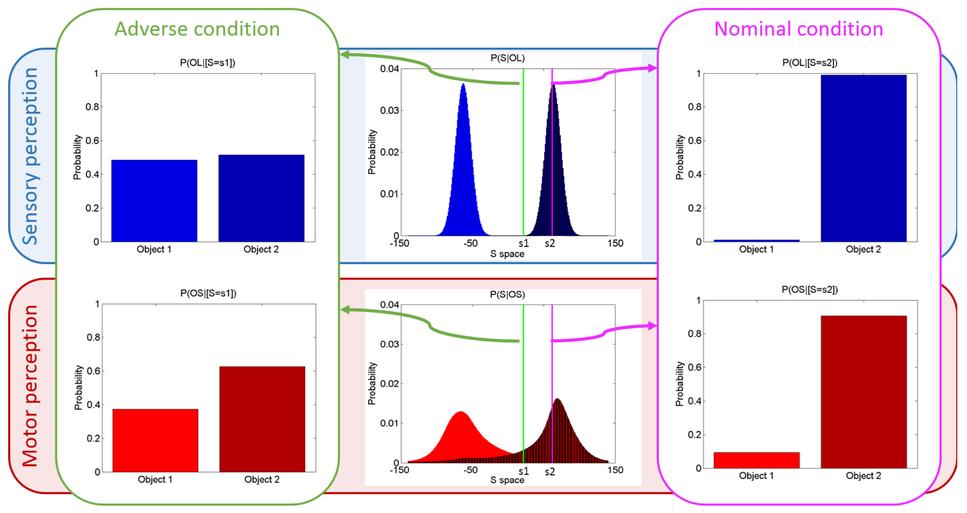
Evaluation of perception: Comparison of recognition rates of the three perception processes in noisy conditions



The **sensory system** provides good recognition scores without noise, with a quick degradation of performance when noise is added. The **motor system** is better than the sensory model in noise, though still being poorer without noise. The **perceptuo-motor system** performs better than both isolated systems in all conditions.

N = 12, learning step = 2,000

Discussion



Learning step = 1,000

The **sensory model** is of lower variance than the **motor model** and yields a less uncertain categorization probability distribution than the motor categorization process. By contrast, the **motor model** is of larger variance than the **sensory model** and generalizes better.

Consequently, in **nominal condition**, both systems are able to categorize the stimulus but the **sensory system** is better than the **motor system**. In **adverse condition**, the **sensory system** performs a random categorization whereas the **motor system** succeeds to correctly categorize.

Conclusion and perspectives

Conclusion

We have compared and illustrated in detail the behavior and the performance of the learned **sensory** and **motor** models. We have shown that the **sensory model** directly *exploits* the associations between objects and stimuli to learn the sensory classifier in a quick and efficient way. In contrast, the **motor model** needs to build both motor repertoires and an internal model of the sensory-motor mapping. In order to do so the Learning Agent *explores* its motor space. As a result, the **motor model** is less efficient for the processing of stimuli typical of the learning set ("nominal conditions") but more robust to degradations and adverse conditions. The **motor model** has some generalization capacities thanks to its exploration phase, when the **sensory model**, in some sense, overlearned. This is what we summarize as **the "sensory narrow-band vs. motor wide-band"** property.

Perspectives

- We have already extended COSMO to more complex configurations in multi-dimensional spaces involving synthetic plosive-vowel sequences.
- We are currently exploring further the learning algorithm and its ability to produce "idiosyncrasies" which are variations in learned motor and sensory strategies in the learning agent.

The research leading to these results has received funding from the European Research Council under the European Community's Seventh Framework Programme (FP7/2007- 2013 Grant Agreement no. 339152, "Speech Unit(e)s", PI: Jean-Luc-Schwartz).