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Discretisation and Continuity

Simulating the Emergence of Symbols in Communication Games

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https://robert-lieck.github.io/emergence-of-symbols

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme under grant agreement No 760081 – PMSB.

Questions

Our guiding questions are:

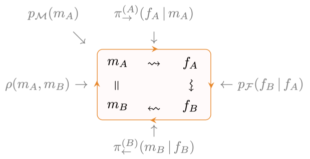
- ***Why*** *are continuous meanings not always communicated using continuous forms?*
- ***What*** *is causing discretisation in regions with continuous meanings?*
- ***How*** *can we describe symbols with discrete and continuous properties in a unified way?*

Previous research

- used mainly discrete **form** and **meaning** spaces (ours are **fully continuous**)
- did not explain the **emergence of discrete symbols** (we observe discretisation emerge and identify **two causes**)
- did not describe symbols with **both discrete and continuous** properties (we provide mathematical definitions) and/or
- did not investigate the effect of **different topologies** of the **form** and **meaning** space (we use several non-trivial topologies).

Reinforcement Learning

We simulate communication games, in which two agents *A* and *B* repeatedly engage in communication by exchanging forms $f\in\mathcal{F}$ to communicate meanings $m\in\mathcal{M}$. The form and meaning space ($\mathcal{F}$ and $\mathcal{M}$) are **fully continuous**; meanings are distributed as $p_{\mathcal{M}}(m)$; forms are transmitted through a noisy channel $p_{\mathcal{F}}(f'\,|\,f)$. The agents only receive a **reward feedback** $\rho(m, m')$ about the quality of their communication. They improve their sender and receiver policies $\pi_{\rightarrow}(f\,|\,m)$ and $\pi_{\leftarrow}(m\,|\,f)$ by estimating and maximising the expected reward $r(f, m)$.



Exploratory policies:

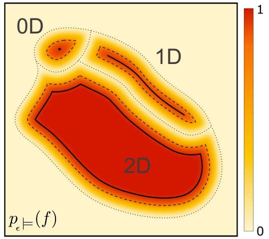
$$\pi_{\rightarrow}(f\,|\,m) = \frac{r(f,m)}{\int_{\mathcal{F}} r(f',m)\,df'}$$

$$\pi_{\leftarrow}(m\,|\,f) = \frac{r(f,m)}{\int_{\mathcal{M}} r(f,m')\,dm'}$$

Discrete Symbols in Continuous Spaces

Discrete symbols are embedded in continuous form-meaning space:

> *A symbol is a* ***connected region*** *in form space, in which all forms can be* ***effectively used in communication*** *and that is* ***separated*** *from other symbols.*



- f is near-optimal for some meaning m ($f_\epsilon\models m$):

$$\frac{1}{|\mathcal{F}|}\int_{\mathcal{F}} [\![r(f',m) > r(f,m)]\!]\,df' \le \epsilon$$

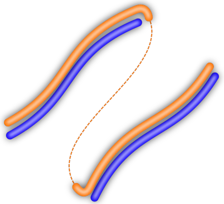
- these meanings are likely to occur:

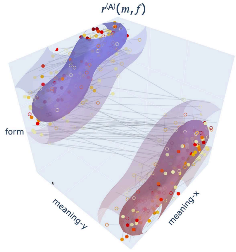
$$p_{\epsilon\models}(f) = \int [\![f_\epsilon\models m]\!]\, p_{\mathcal{M}}(m)\,dm$$

Results

Cause 0): Modal Worlds

If the **meaning** space has multiple distinct modes (blue lines), the continuous **form** space has to be cut (dashed line) and contains **separate symbols**, each having additional internal **continuous dimensions**.

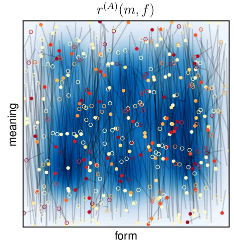


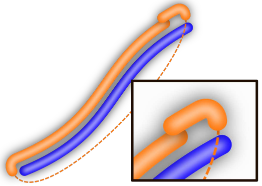


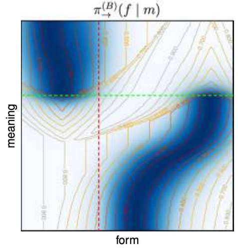
Cause 1): Sub-Optimal Solutions & Local Optima

If the **form** and **meaning** space have the same topology (here 1D), a continuous mapping is possible.

But the optimal solution is not guaranteed to be found. Especially, **premature convergence** under **low transmission noise** is likely to produce fragmented sub-optimal solutions.

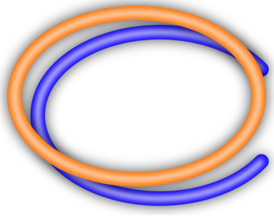


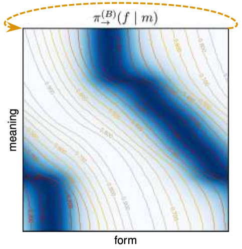




Cause 2): Topological Mismatch

If the **form** and **meaning** space have **incompatible topologies** (here, a circle and a line), a continuous mapping is impossible. This is highly plausible be the case in complex real-world scenarios.





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