# *Guess What You Don't Know*
## *Towards an Evolutionary Epistemology of Ontology Learning*

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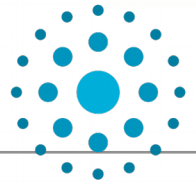


# *Agenda*

- Ontology Learning and KB Enrichment as KDD
- How does our knowledge grow?
- How do we test axioms/rules?
- How do we generate axioms/rules?

# *Ontology Learning & KB Enrichment*

- In the context of the semantic Web
- A special case of Knowledge Discovery from Data
  - The data are in the form of RDF triples
  - Knowledge is expressed in the form of OWL axioms/SWRL rules
- This is a form of inductive reasoning
  - From instances (RDF triples) to generalizations (axioms/rules)
  - Need a principled approach to it: look at epistemology
- Issues:
  - How do we generate hypotheses?
  - How do we test a hypothesis?

# Question I
# How does Knowledge Grow?

# *Evolutionary Epistemology*

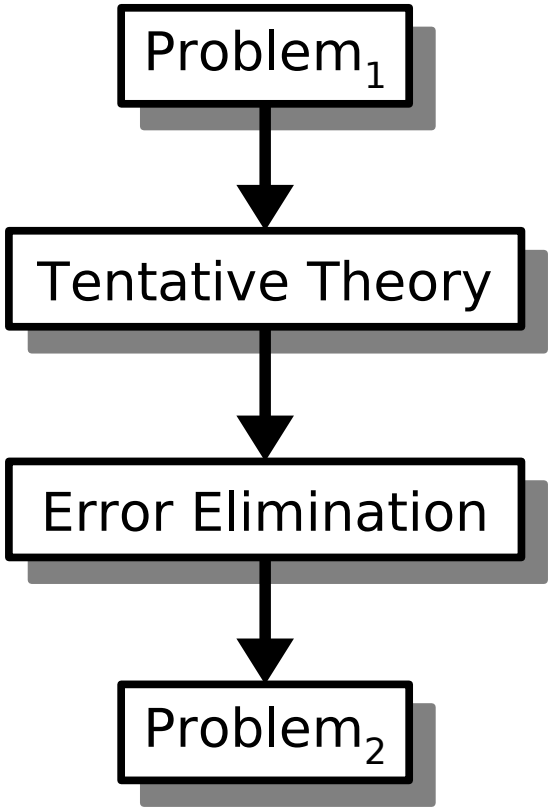
- A “naturalistic” approach to epistemology
- Based on the work of Karl Popper, Donald Campbell, Konrad Lorenz, Stephen Toulmin, and Michael Bradie
- Importance of natural selection in two primary roles
  - Generator and maintainer of the reliability of our senses and cognitive mechanisms, as well as of the “fit” between those mechanisms and the world
  - Enabler of the growth of human knowledge
- A descriptive approach!

# *A Tale of Three Worlds*

# *How Does Our Knowledge Grow?*

- The problem of induction
  - Are inductive inferences justified?
  - Under what conditions?
- Popper's "solution":
  - Inductive inferences are *never* justified
  - The way new hypotheses are come up with has nothing to do with logic (creative intuition?)
  - We can (and should) test hypotheses
  - No hypothesis can ever be accepted as "true" → Conjectures
  - However, we must reject hypotheses that do not stand to the test
- This has become known as "falsification"

# *Process*



# *The Natural Selection of Hypotheses*

“ [T]he **growth** of our **knowledge** is the result of a **process** closely resembling what Darwin called **‘natural selection’** […]: our knowledge consists, at every moment, of those hypotheses which have shown their (comparative) **fitness** by **surviving** so far in their struggle for existence; a competitive struggle which eliminates those hypotheses that are unfit”.

– Karl Popper. *Objective Knowledge: An evolutionary approach,* 1972*.*

# *Criticisms of Falsification*

- Popper's solution has been criticized by some philosophers of Science
  - Kuhn argues against a simplistic use of falsification
    - Paradigm shift
    - Incommensurability of theories
  - Fayerabend attacks the prescriptive aspect of Popper's idea
    - Scientists should be free to follow whatever method they want
    - Dialectics and sociology are critical factors
- To say that Popper has been *discredited* is an exaggeration
- We all agree that there is more to "Science" than falsification
- After all, we are just interested in ontology learning

# *Other Issues*

- (Darwinian) Evolution requires
  - Inheritance of traits (transmission)
  - A mechanism to produce variation
  - Selection (survival of the fittest)
- That our capability of knowing is the result of evolution is almost obvious (for us, today, at least...)
- That the growth of knowledge is evolutionary too should be argued for, e.g.
  - Evolution of biological substrate → evolution of brain → evolution of the mind → evolution of (Kantian) categories → evolution of knowledge... (?)
- More pragmatically: **if we can make it work, it might be true!**

# Question II
# How do We Test Hypotheses?

# *Axiom Testing*

$\phi$
Axiom
(hypothesis)

**?**

$e$
Assertions
(evidence)


**Extended hypothetico-deductivism**

$e$ confirms $\phi$ $\iff$ $\phi \models e$

$e$ disconfirms $\phi$ $\iff$ $e \models \neg\phi$

# *Probability of an Axiom*

Estimate $\Pr(\phi \text{ is true} \mid \text{evidence})$ "confidence"

= Confirmations / Support ?

Bayes Rule:

$$\Pr(\phi \mid e) = \frac{\Pr(e \mid \phi)\Pr(\phi)}{\Pr(e \mid \phi)\Pr(\phi) + \Pr(e \mid \neg\phi)\Pr(\neg\phi)}$$

Are we sure we can compute $\Pr(e \mid \phi)$ ??

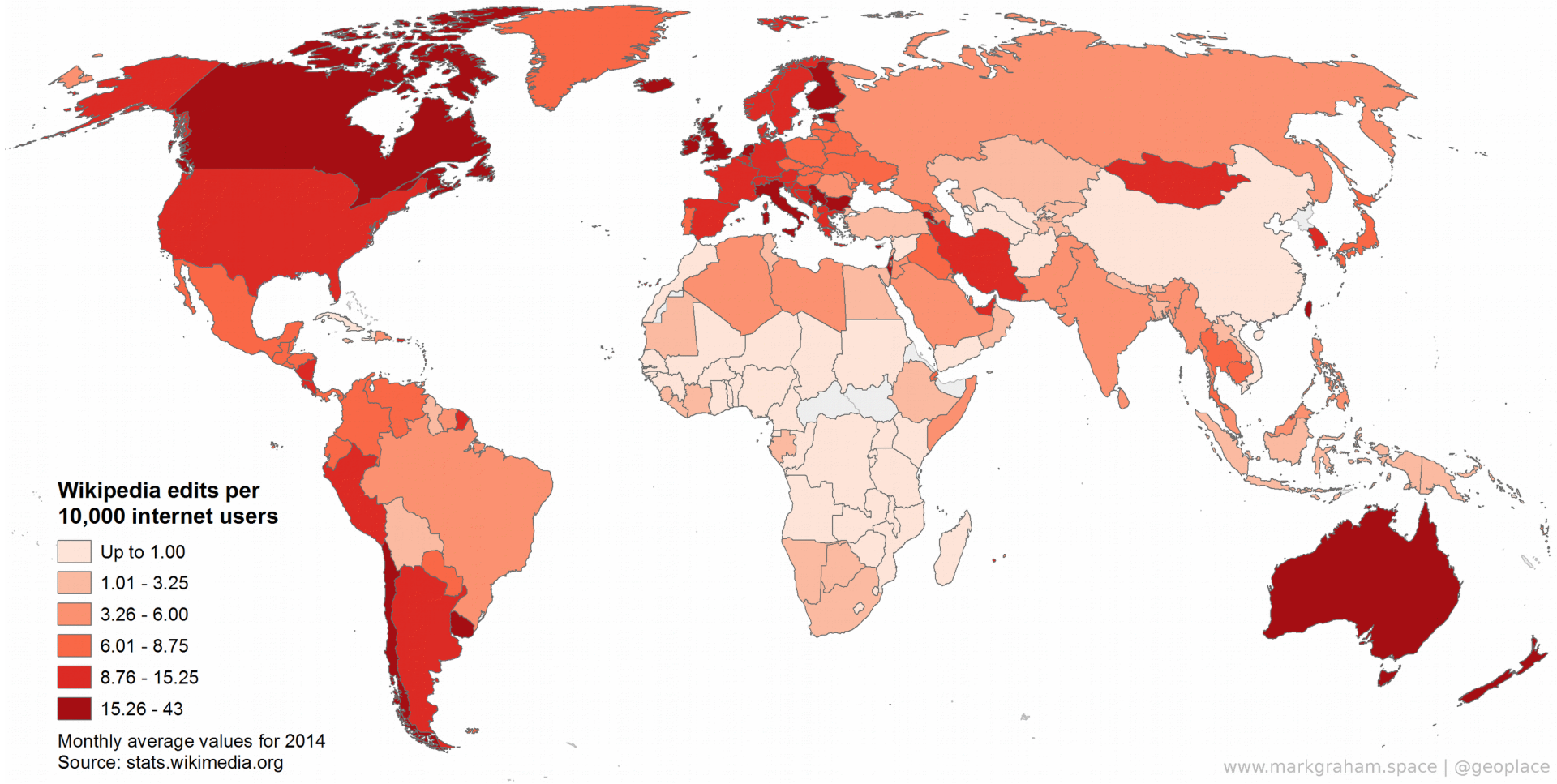
# *Basic-Level Categories*

# *Basic-Level Primacy*

Basic-level categories are functionally and epistemologically primary wrt:

- Gestalt perception
- Image formation
- Motor movement
- Knowledge organization
- Ease of cognitive processing (learning, recognition, memory, …)
- Ease of linguistic expression

# *Cultural Bias*



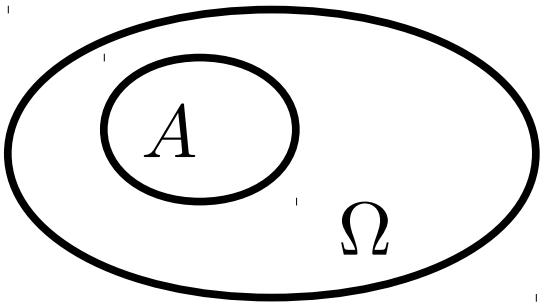
# *Possibility Theory*

Possibility Distribution:

$$\pi : \Omega \rightarrow [0, 1]$$

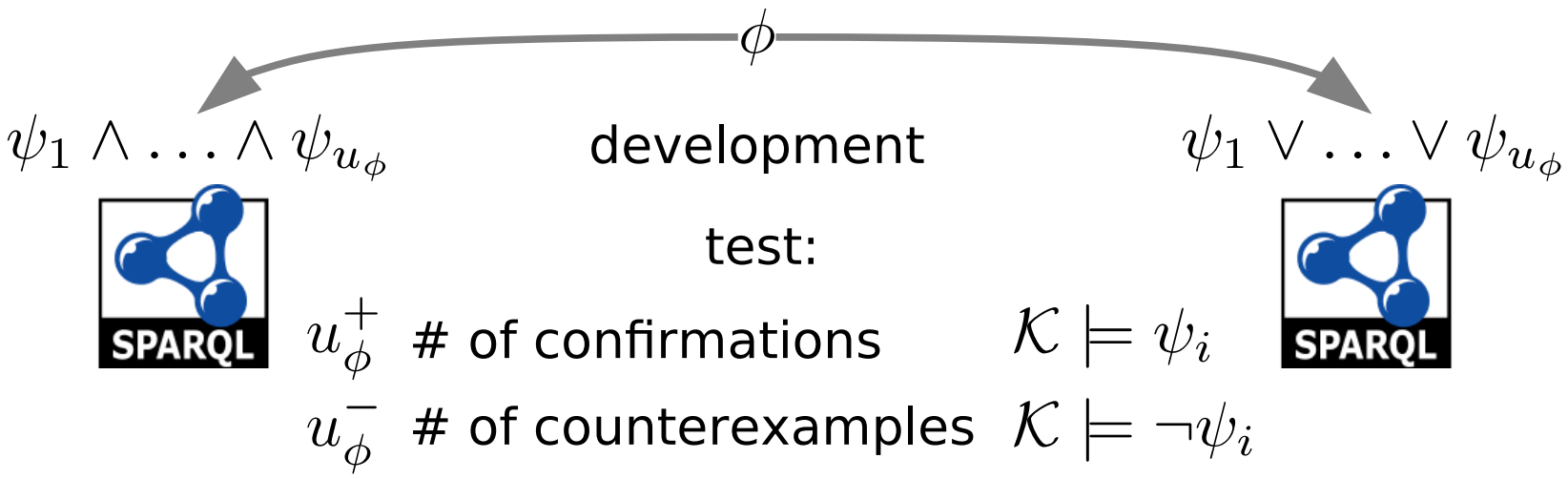
Possibility and Necessity Measures:

$$\begin{aligned} \Pi(A) &= \max_{\omega \in A} \pi(\omega); \\ N(A) &= 1 - \Pi(\bar{A}) = \min_{\omega \in \bar{A}} \{1 - \pi(\omega)\}. \end{aligned}$$




$$N(A) \leq \Pi(A)$$
$$N(A) > 0 \Rightarrow \Pi(A) = 1$$
$$\Pi(A) < 1 \Rightarrow N(A) = 0$$

# *Possibilistic Axiom Scoring*




$$\Pi(\phi) = 1 - \sqrt{1 - \left(\frac{u_\phi - u_\phi^-}{u_\phi}\right)^2};$$

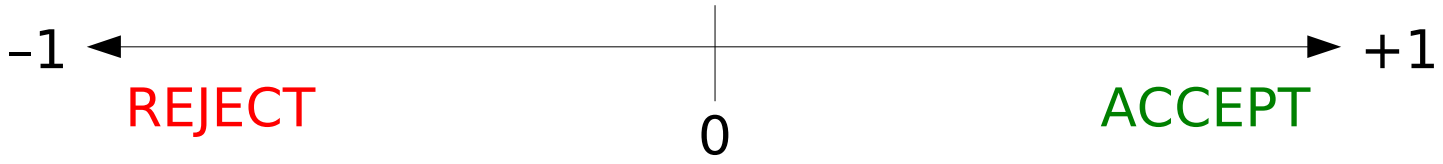
$$N(\phi) = \begin{cases} \sqrt{1 - \left(\frac{u_\phi - u_\phi^+}{u_\phi}\right)^2}, & \text{if } u_\phi^- = 0, \\ 0, & \text{if } u_\phi^- > 0; \end{cases}$$

$$\Pi(\phi) = \begin{cases} 1 - \sqrt{1 - \left(\frac{u_\phi - u_\phi^-}{u_\phi}\right)^2}, & \text{if } u_\phi^+ = 0, \\ 1, & \text{if } u_\phi^+ > 0; \end{cases}$$

$$N(\phi) = \sqrt{1 - \left(\frac{u_\phi - u_\phi^+}{u_\phi}\right)^2};$$

# *Acceptance/Rejection Index*

$$\mathrm{ARI}(\phi) = N(\phi) - N(\neg\phi) = N(\phi) + \Pi(\phi) - 1$$

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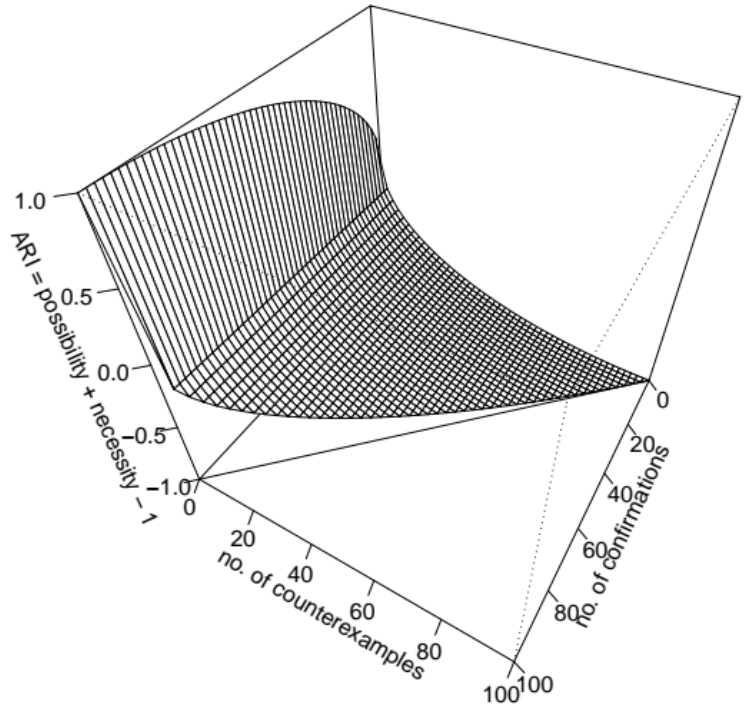
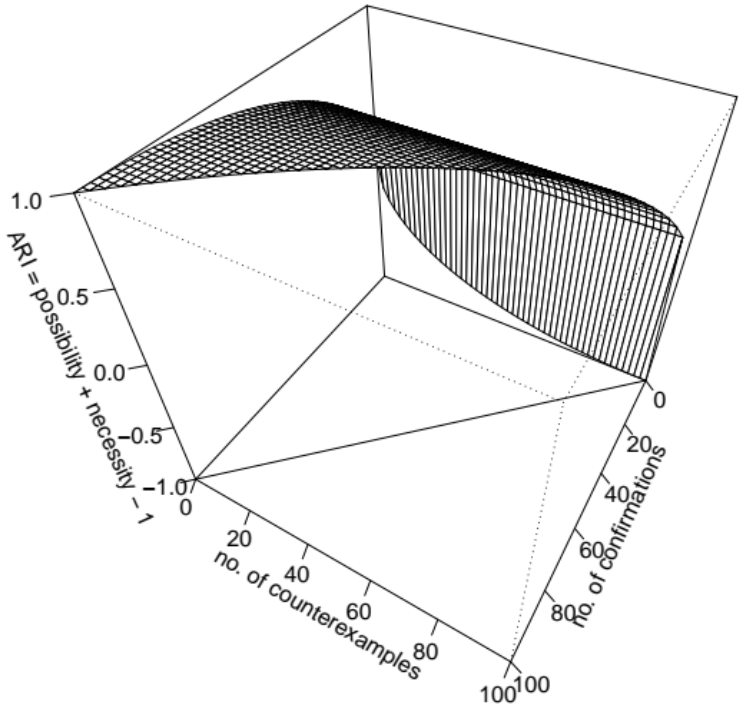
$\psi_1 \wedge \ldots \wedge \psi_{u_\phi}$




$\psi_1 \vee \ldots \vee \psi_{u_\phi}$



# Question III
# How do We Generate Hypotheses?

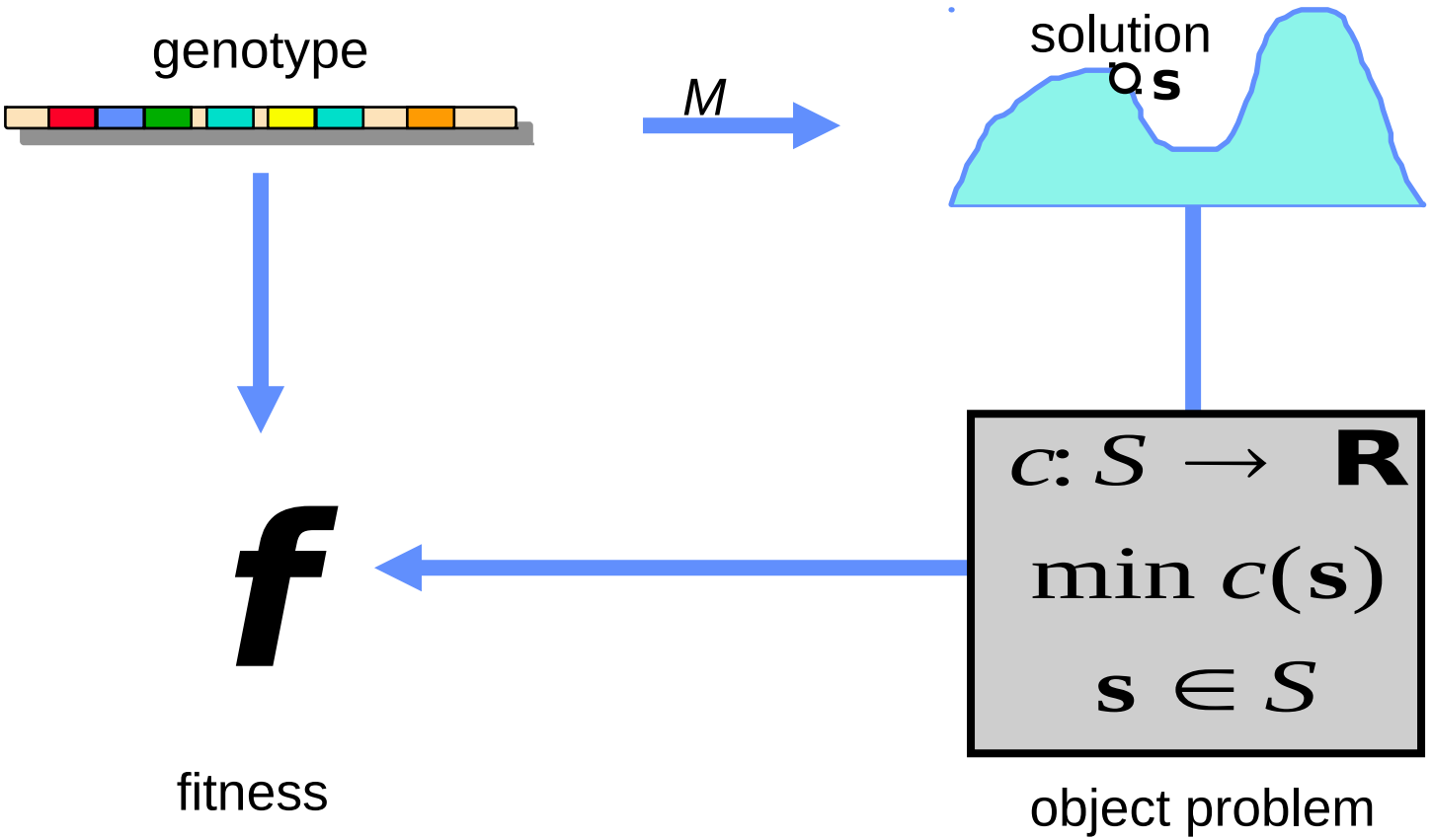
# *Evolutionary Algorithms*

- Search/Learning/Optimization
- Mimic Natural Evolution
- Distinctive features
  - operate on appropriate encoding of solutions
  - population search
  - no regularity conditions required
  - probabilistic transitions

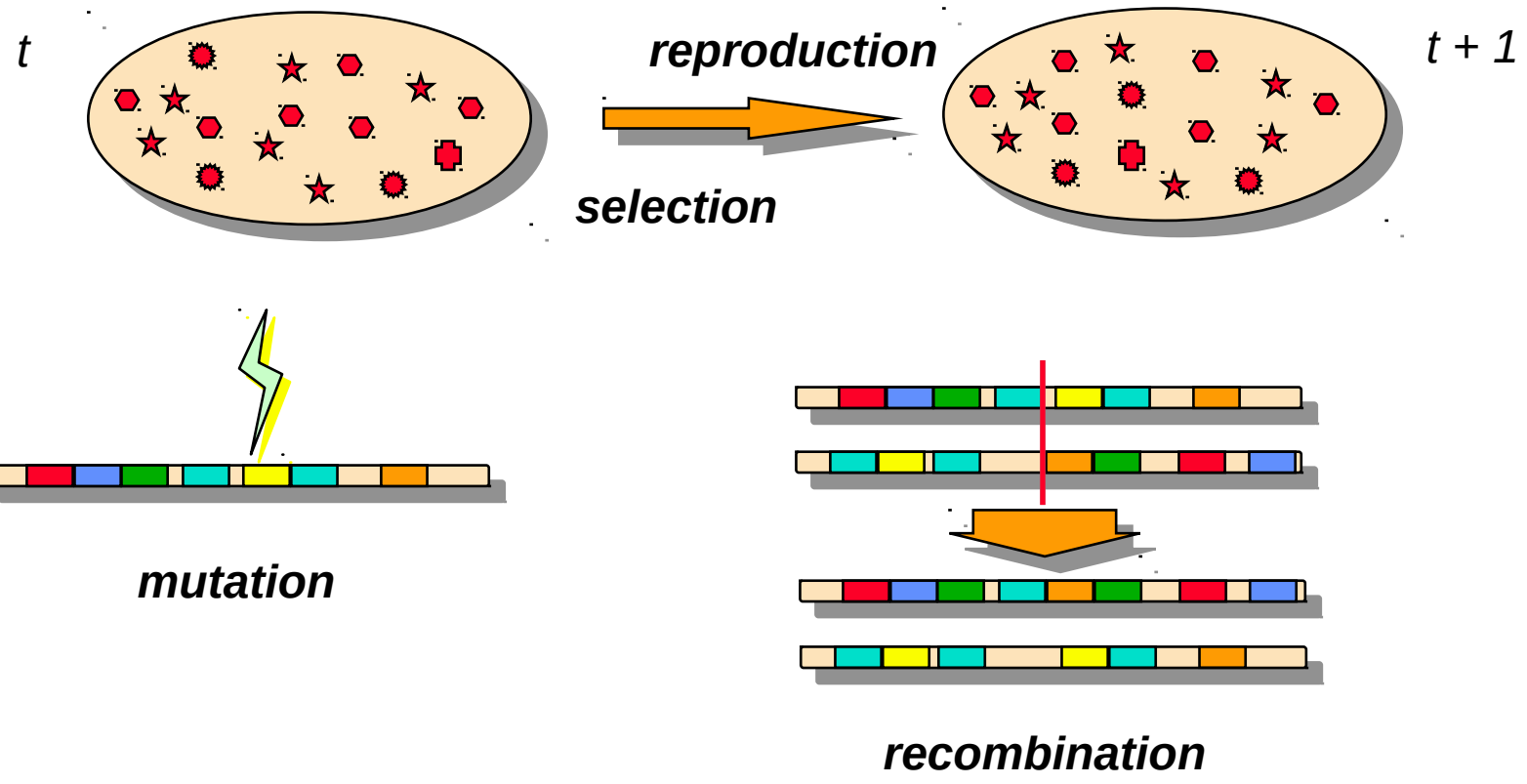
# *The Metaphor*

| EVOLUTION | PROBLEM SOLVING |
|---|---|
| Environment | Object problem |
| Individual | Candidate solution |
| Fitness | Quality |

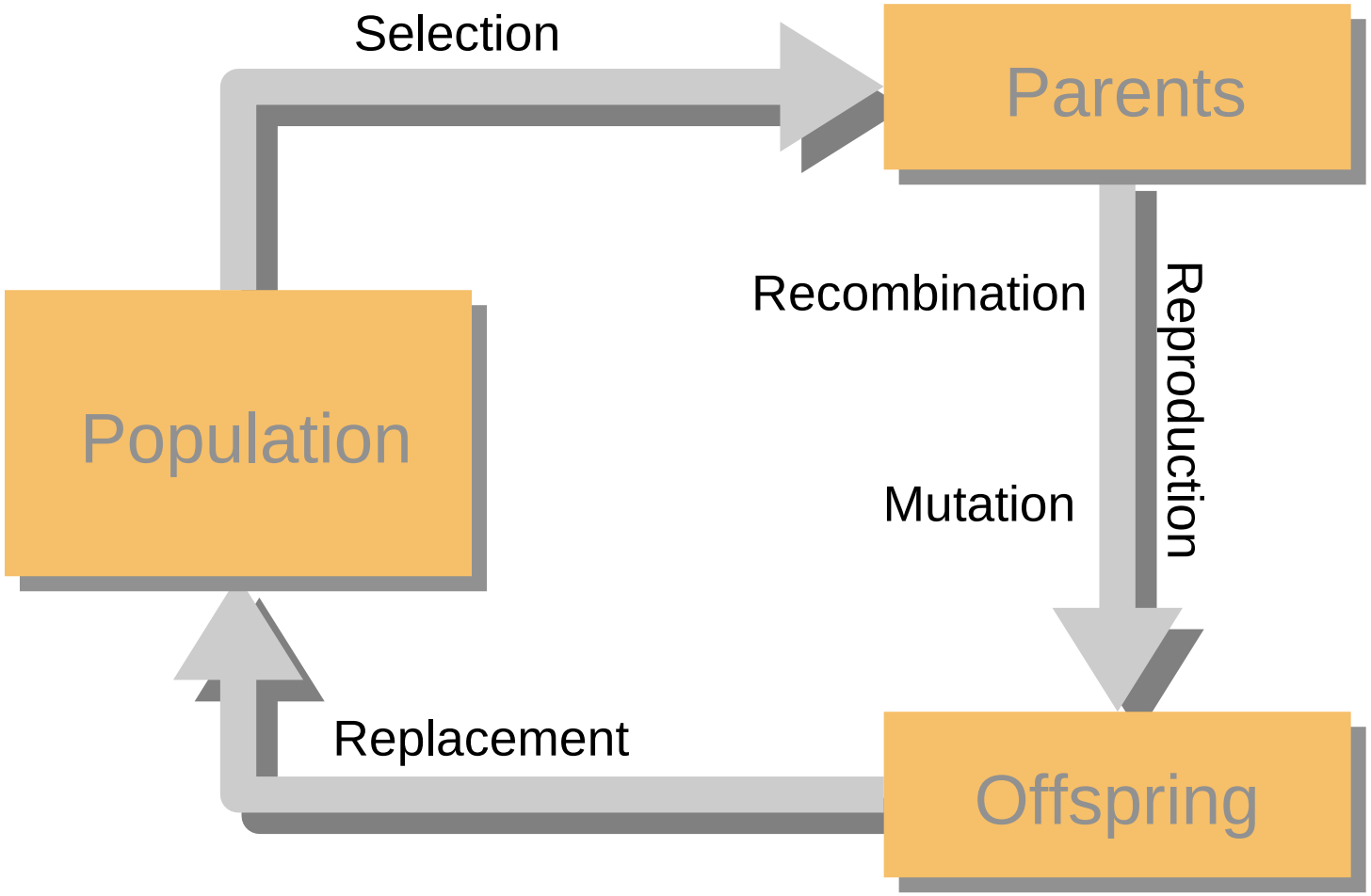
# *Object problem and Fitness*



# *The Ingredients*



# *The Evolutionary Cycle*



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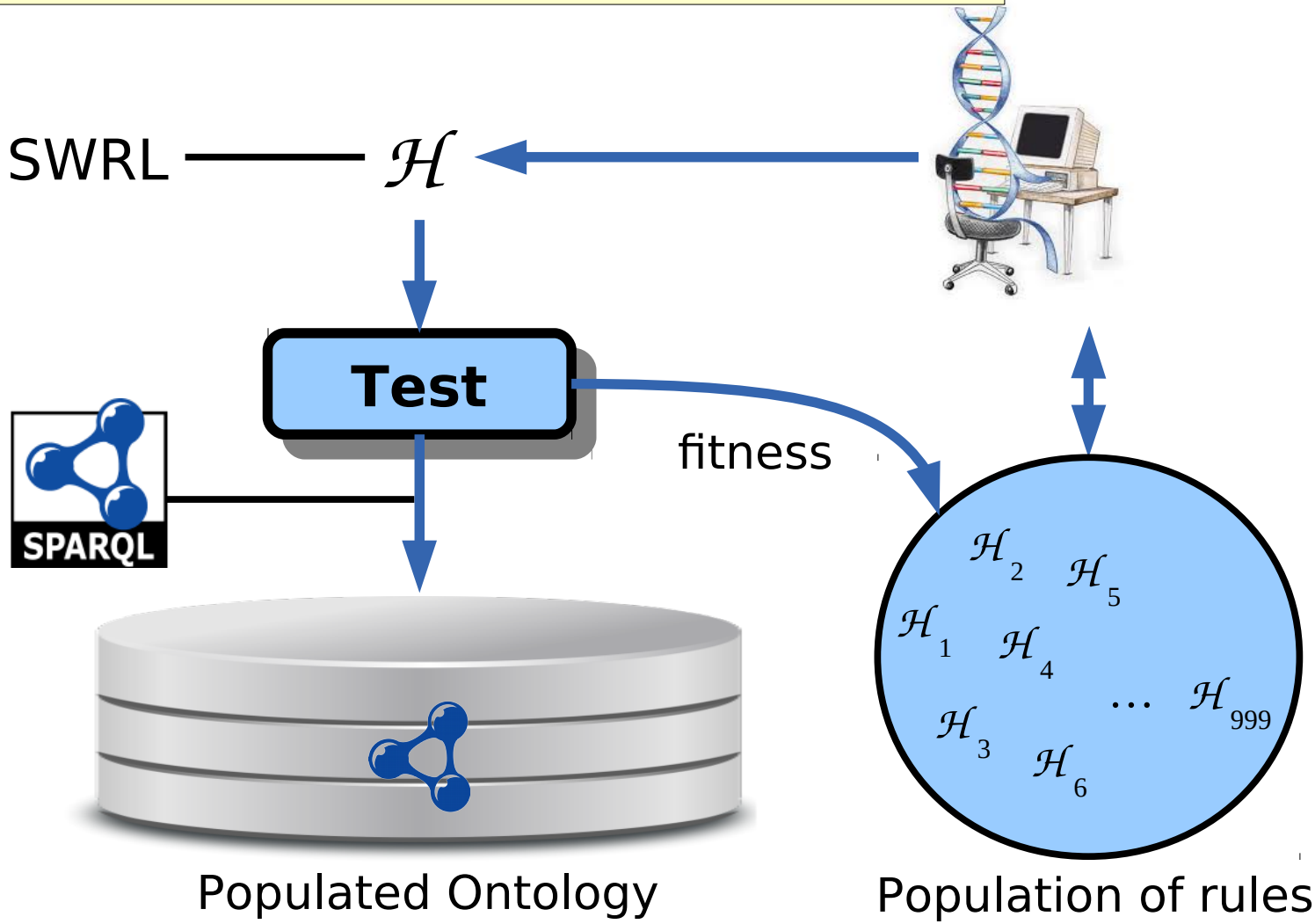
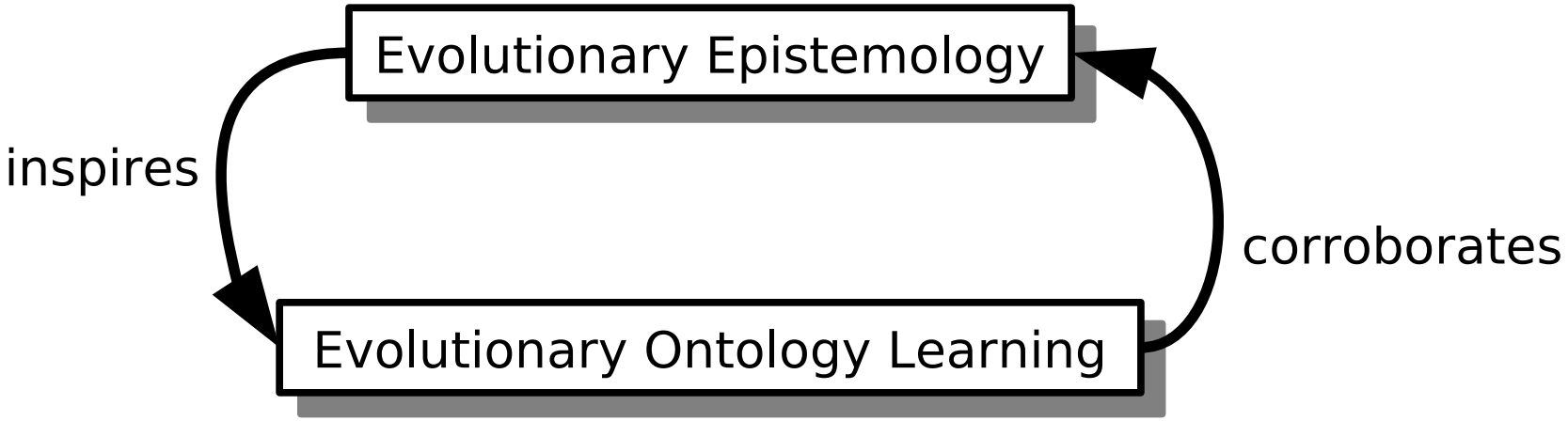


# *Conclusion*


Evolutionary Epistemology
inspires
corroborates
Evolutionary Ontology Learning

# *This was Joint Work with...*

Catherine Faron

Claudia d’Amato

Fabien Gandon

Tran Duc Minh