# Noisy population dynamics lead to efficiently compressed semantic systems

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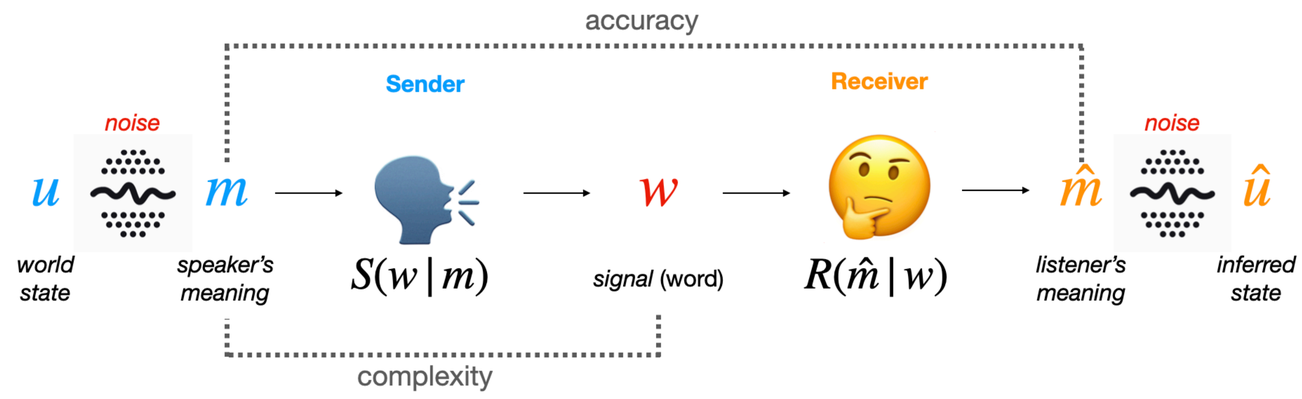
## How do efficient vocabularies evolve?

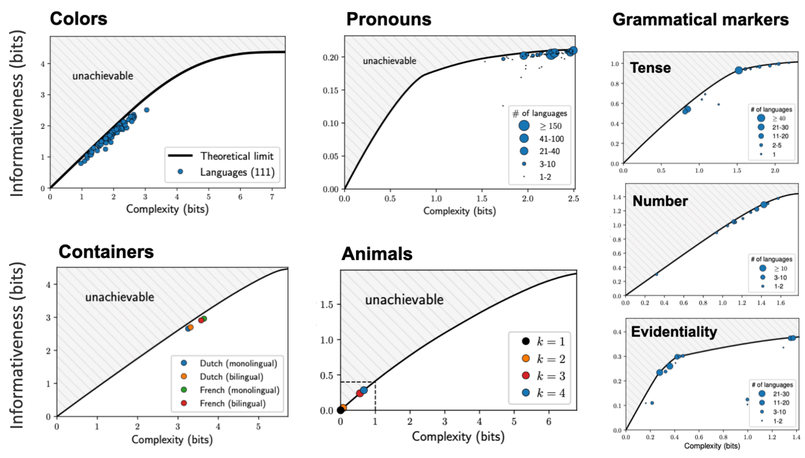
Human vocabularies optimally balance communicative and cognitive cost [2-5]




What agent-based dynamics might drive efficient trade-offs?

### The Information Bottleneck

- IB principle shown to shape semantic systems [1-5]




- characterizes systems' optimal, fixed point behavior

IB objective

$$\min_{S(w|m)} I(M;W) - \beta I(W;U)$$

### The Replicator Dynamics

- foundational model in evolutionary game theory [6]
- a **noisy discrete-time** replicator dynamic [7,8]:

Sender update

$$S^{(t+1)}(w \mid u) \propto \sum_m p(m \mid u) \cdot S^{(t)}(w \mid m) \cdot f_S(w, m)$$

Receiver update

$$R^{(t+1)}(\hat{u} \mid w) \propto \sum_{\hat{m}} p(\hat{m} \mid \hat{u}) \cdot R^{(t)}(\hat{m} \mid w) \cdot f_R(w, \hat{m})$$

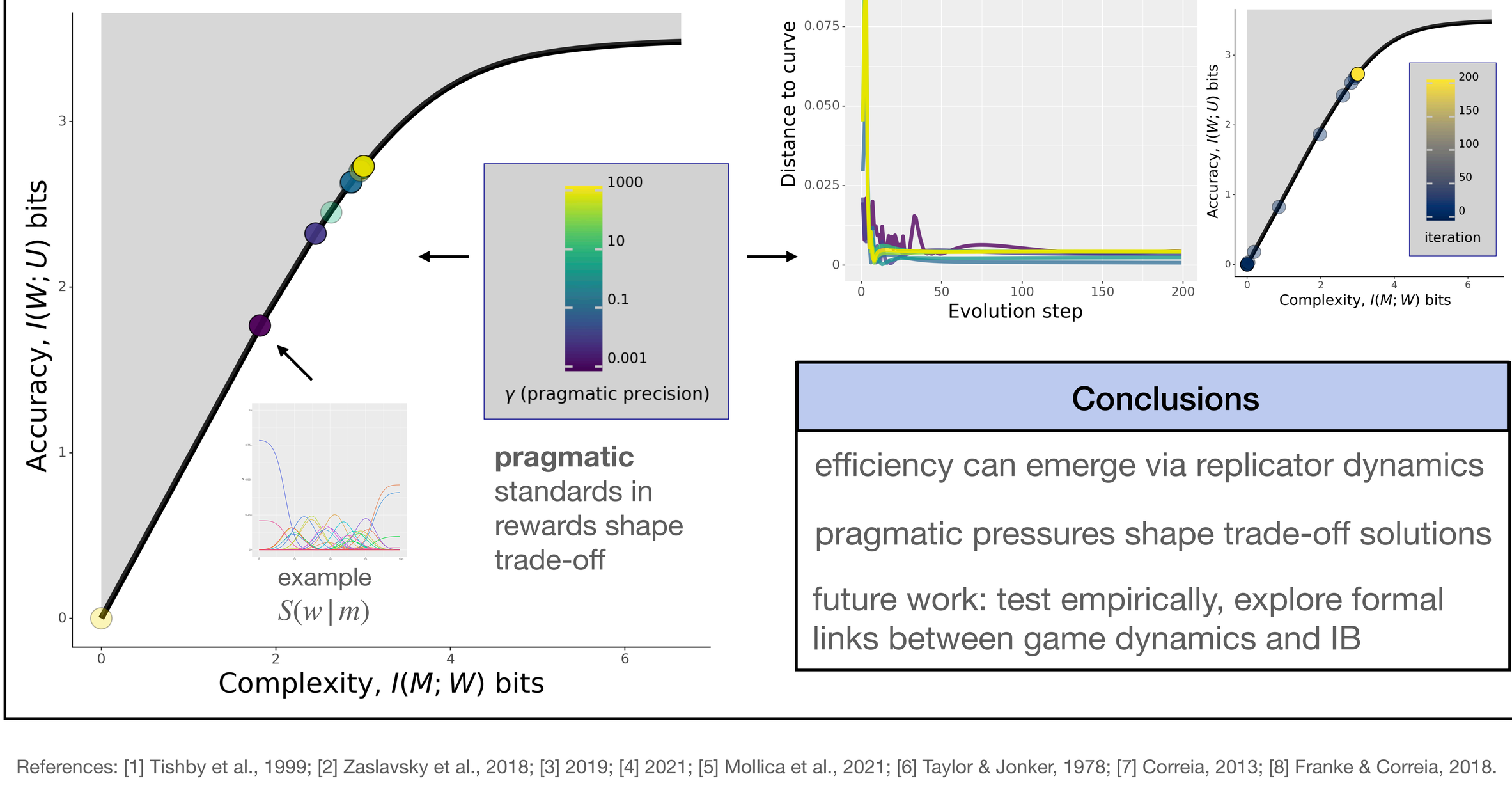
Fitness functions

$$f_R(w, \hat{m}) = \sum_m P(m) \cdot S^{(t)}(w \mid m) \cdot \mathrm{sim}_\gamma(m, \hat{m}) \qquad f_R(w, m) = \sum_{\hat{m}} R^{(t)}(\hat{m} \mid w) \cdot \mathrm{sim}_\gamma(m, \hat{m})$$

## The replicator dynamics leads to near-optimal compression

Numerical simulations with 100 integer-valued states, discrete words

systems tend to evolve towards bound




### Conclusions

efficiency can emerge via replicator dynamics

pragmatic pressures shape trade-off solutions

future work: test empirically, explore formal links between game dynamics and IB

References: [1] Tishby et al., 1999; [2] Zaslavsky et al., 2018; [3] 2019; [4] 2021; [5] Mollica et al., 2021; [6] Taylor & Jonker, 1978; [7] Correia, 2013; [8] Franke & Correia, 2018.